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INVESTIGATION OF MINE HOIST WITH MULTI-LAYERED COILING OF HOISTING ROPE

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ABSTRACT
Pros and cons are shown for the mine hoist systems with multilayer coiling of a rope using annular and spiral grooves of a cylinder roll. Main parameters are set for hoist machine and conditions of resonance of hoisting rope by its multilayer coiling according to a scheme with annular grooves.

INTRODUCTION

Exhausting of technical resource for safe and effective work of a great part of the mining hoist systems is one of the main factors for non-profitability of underground mining of minerals in Bulgaria. That is why reasoning and selection of effective decisions for updating and reconstruction of MHS in mining seems to be a task of the day. The decision for updating and reconstruction of MHS at "Capitalna" shaft, Gorubso – Madan by supplying of a new cylinder roll with a multilayer coiling of the hoist rope was proved (Karcelin, 1998).

In the Republic of Bulgaria vertical MHS with a multi-layer coiling of the rope have not been. In the valid rules for occupational safety (Guidelines for Safety…, 1969) too limited position is allotted to this matter. These circumstances set the task for preliminary research of a series of questions from the theory of MHS with a multi-layered coiling of a hoisting rope aiming an application of results to design of final development decisions. Some of these results are shown in the present article.

1. Main point of the multi-layered coiling of a hoist rope.

Decisions with a multi-layered coiling of a hoist rope may also be applied for increasing the height of uplift under definite conditions. There are two different kinds of two-way multi-layered coiling: with stating of the hoist rope from the first layer in a spiral groove and with stating of the hoist rope in a annular groove.

In the second case (fig.1) many annular grooves, situated one by the other are formed on the roll surface, instead of a spiral grooves. However, there is a smooth stripe on the roll, without rims on it, and displaced at an angle β from roll axis.

The multi-layered coiling with a first spiral situated layer has the following advantages:

- simple and technologically accessible working out of the spiral groove by metal-sawing machines in manufacturing conditions;
- easily appliable for transition from one-layer to two-layer coiling in the process of penetrating in depth of the shaft.

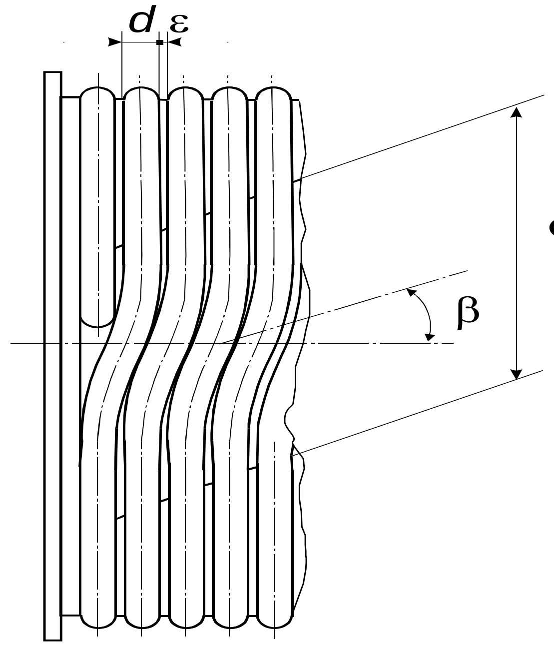

Figure 1.

Disadvantages:

- wedging of rope by the passing from layer to layer between roll rim and the last coil of previous layer;
- the odd layer is located on a spiral groove and the even layer performs a double shifting by transition from coil to coil on every revolution of the roll and consequent dynamic efforts in the rope;

- the compulsory working out of a filling wedge with a complex configuration and its situating in the transition from layer to layer (fig. 2).

The multilayer coiling with positioning of first layer in annular grooves has the following advantages:

- the rope performs a single shifting from coil to coil for every revolution of the roll ;
- the wedging of rope between roll rim and the last coil is almost totally missing.

Disadvantages:

- difficult manufacture of annular grooves with presence of a smooth shifting part;
- appropriate scheme for new machines for manufacture.

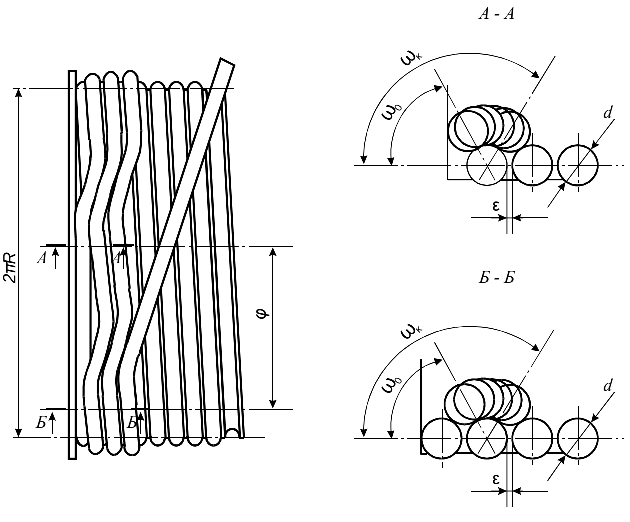

Figure 2.

2. Selection of rational parameters of the hoist machine by the multilayer coiling of hoisting rope according to the scheme with annular grooves.

The angle of slope β (fig.1) of the roll smooth part towards the roll axis and the length of smooth part φ, rad is specified by the expressions (Dimashko etc. 1969):

$$tg\beta = \frac{1}{2\left(1+\frac{\varepsilon}{d}\right)}\sqrt{\frac{D}{d}}\ F(\beta) \qquad (1)$$

$$\varphi = 2\sqrt{\frac{d}{D}}\ F(\varphi) \qquad (2)$$

$$F(\beta) = \int_{\frac{\Pi}{2}-\arcsin\frac{\varepsilon}{2d}}^{\frac{\Pi}{2}+\arcsin\frac{\varepsilon}{2d}} \frac{dx}{\phi(x)} \qquad (3)$$

$$F(\varphi) = \int_{\arccos\frac{d+\varepsilon}{2d}}^{\frac{\Pi}{2}} \frac{dx}{\phi(x)} \qquad (4)$$

$$[\phi(x)]^2 = \frac{\sin x - 2f\cos x}{1+4f^2} - \frac{1}{2} + \exp\left[2f\left(\arccos\frac{d+\varepsilon}{2d} - x\right)\right] \times$$

$$\times \left[\frac{1}{2} - \frac{\sqrt{4d^2-(d+\varepsilon)^2} + 2f(d+\varepsilon)}{2d(1+4f^2)}\right] \qquad (5)$$

d - is the rope diameter;

D – roll diameter;

ε - distance between the coils;

f – coefficient of friction “Rope to rope” depending on lubrication (0,1 - 0,14);

However, complex analytic expressions for values of F(β) and F(φ) involve determination by the diagram in fig. 3. (Dimashko etc., 1969). That enables β and φ to be set.

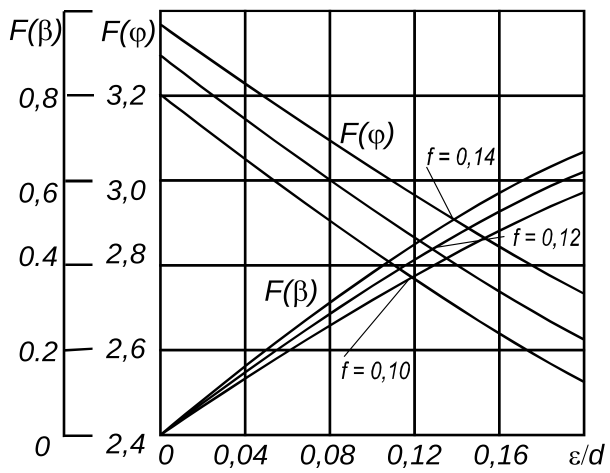

Figure 3.

The parallel coiling of rope to the rim and in the layers happens according to the scheme in fig.4. As roll width B and rope diameter d are preset, the only values that may be changed are ε and n – number of the coils in the first layer that must be integers, specified by the following expressions for the satisfying the given scheme for coiling of hoist rope

$$n = \frac{2B-d-\varepsilon}{2(d+\varepsilon)} \qquad (6)$$

$$\varepsilon = \frac{2B-d(2n+1)}{2n-1} \qquad (7)$$

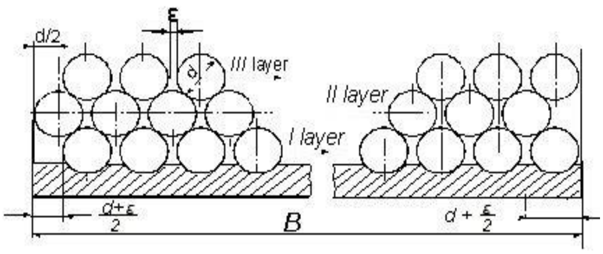

Figure 4.

The rational values of deviation angles providing the parallel coiling are attached in table.1.

Table 1

D/d	60	70	80	100	120	140
$\alpha \geq$	1° 30′	1° 20′	1° 15′	1° 00′	0° 50′	0° 40′

The angle of deviation must be within: $1^0 \leq \alpha \leq 1{,}30^0$ (Guidelines for Safety…, 1969)

That calculation enables the parameters of the multi-layered coiling with annular grooves to be specified accurately enough.

3. Conditions for arising of resonance in rope string.

It was mentioned above that in the scheme of multilayer coiling with a spirally positioned first layer the rope performs a double shift on every revolution of the roll at every even layer. This means that every revolution of the roll brings to two impact pulses.

For certain conditions, frequency of those impact pulses may coincide with frequency of own transverse vibration of a part of the rope, situated between the roll and the guiding wheels.

This effect is called resonance and may cause strong transverse motions of rope string, resulting in rope springing out from rims of guiding wheel, which is already an accident.

Frequency of the forced oscillation caused by impact-pulses in the transition of rope from coil to coil is as follows (Dimashko etc., 1969).

$$P_n = \frac{2\pi}{\varphi} n \text{ , cycles/min.} \qquad (8)$$

n – number of revolutions of the roll per minute;

φ - the angle between the double impact pulse, set on the basis of the expression (Dimashko etc., 1969) (fig.2);

$$\tau_2 = \tau\left[1 - \frac{d}{2(d+\varepsilon)}\left(\sqrt{3}.\sin\omega_0 - \cos\omega_0\right)\right] \text{, s} \qquad (9)$$

τ_2 is a time interval between first impact pulse and second impact pulse;

τ -time interval corresponding to one revolution of the roll;

ω_0 – angle of passage (coordinating angle), fig. 2.

The angle ω_0 is specified according to the diagram in fig.5 (Dimashko etc., 1969) depending on angle of deviation.

The natural frequency of the transverse vibrations is set according to the expression (Alexeev, 1975):

$$P_c = \frac{\varepsilon_0}{L}\sqrt{\frac{Qg}{q}} = 94\frac{\varepsilon_0}{L}\sqrt{\frac{Q}{q}} \text{ , cycles/min} \qquad (10)$$

L is the distance between vertical axes of body for coiling and guiding wheels;

Q – final load including the weight of rope;

ε_0 – dimension of the resonance - 1,2,3…;

q – linear weight of rope;

α - angle of deviation.

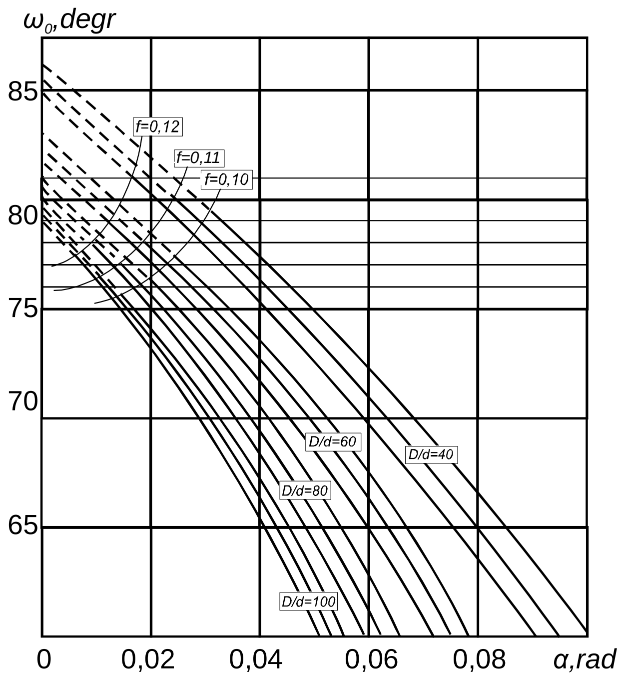

Figure 5.

To avoid the resonance the following condition must be satisfied:

$$P_n \neq P_c \qquad (11)$$

The parameters Q, L, α, q, D/d of the hoist machine may cbe changed to fulfil this condition:

CONCLUSION

The above results are applied to development of design decisions for updating and reconstruction of MHS at Capitalna shaft Capitalna, Gorubso, Madan.

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ASCERTAINING THE METHODOLOGY FOR APRON FEEDERS CALCULATION

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ABSTRACT
Aim of the present paper is the systematization and the unification of the formulae for calculation, the ascertaning of the values of the coefficients for the calculation, the proposition of new formulae for the determination of some of the apron feeders parameters, and to calculate specific apron feeders.
The calculations prove the correctness of the described methodology. The results for the calculated motor power are close to the values of the installed motor power of the apron feeders, although they are manufactured by different companies.

INTRODUCTION

Apron feeders (AF) are widely used in the mining industry for the transportation of heavy and lumpy materials. They are designed for the most hard conditions of exploatation to feed the crushers at quarry and storage bins. They have capacities up to 6000 t/h and are able to transport materials with maximum lump size up to 2000 mm (Das and Sahn, Maton).

The calculation of the AF is similar to that of the apron conveyors, but there are some peculiarities. The large size of material lumps is the cause for the increase of the width of the aprons and the height of the skirts. The presence of fixed skirts cause additional resistances due to skirt friction. The presence of receiving hopper causes additional resistance due to the pressure of the material in it. The hard conditions of exploatation and the great starting resistances are the cause for the introduction of a coefficient of reserve of motor power.

BACKGROUND

The basic formulae for the AF calculation are given in most of the references (Bandov, 1973; Vasiliev, 1991; Deevski 1982, Kuzmanov, 1989; Das and Sahn, Maton). Each company manufacturing AF has it's own methodology for calculation. In the companies prospects, diagrams for the AF selection are usually given (Smidth). A complete methodology for calculation, however, is not given.

For example in (Kuzmanov, 1989) the formulae for the determinaton of the additional resistances are missing. In (Deevski, 1982) there is a formula for the calculation of the resistance from the material pressure, but formula for the resistance from the skirt friction is missing. Data for the values of some of the coefficients is missing, as for example the coefficient of skirt friction (given only in (Vasiliev, 1991)). Formulae for the determination of some of the parameters, as the height of the skirts and the dimensions of the hopper opening, are not given too. Some of the formulae must be taken from the methodology for the calculation of apron conveyors, for example the formulae for the resistances in the chain sprockets given in (Deevski, 1982) and (Kuzmanov, 1989) and the the formula for the calculation of the skirt friction resistance, given in (Kuzmanov, 1973). The values of some of the coefficients must be taken from other chapters of the books and the manuals, as for example the coefficient of internal friction of the material.

Aim of the present paper is the sistematization and the unification of the formulae for calculation, the ascertaning of the values of the coefficients for the calculation, the proposition of new formulae for the determination of some of the AF parameters, and to calculate specific AF.

DETERMINATION OF THE WIDHT OF THE APRONS, THE HEIGHT OF THE SKIRTS AND THE APRON SPEED

As the transported material is lumpy, it's maximum lump size will determine the apron width B [m]. For the determination of B, the known formula [3,5]: $B = 0{,}0017.a_{max} + 0{,}2$ is used, and then the next standart width is assumed. The companies manufacturing AF usually give in tables the apron width B in accordance to a_{max} (Smidth) (Table 1). If the input a_{max} is not in the table, B is chosen for the nearest greater a_{max}.

Table.1

a_{max} [mm]	315	400	500	650	800	1000	1250	1600
B [m]	0,8	1	1,25	1,4	1,6	1,8	2	2,5
h [m]	0,5	0,6	0,8	1	1,1	1,2	1,3	1,8

Formula for the determination of the height of the skirts h for the AF is not given in the references. In (Kuzmanov, 1989) is given h for apron conveyors (h = 150-300 mm), but in AF h is much greater. From table 1 it is seen, that h can be determined approximately by the formula:

$$h = 0{,}65.B\text{, m} \qquad (1)$$

When the parameters B and h are determined, the apron speed *v* is determined by the known formula for the capacity (Bandov, 1973; Deevski, 1982; Kuzmanov, 1989):

$$v = \frac{Q_h}{3600.B.h.\rho.\psi.c}\text{, m/s} \qquad (2)$$

where:

Q_h [t/h] – capacity of the AF;

ρ [t/m^3] – density of the transported material;

ψ = 0,75 – extraction efficiency factor;

$c = \frac{100-\beta}{100}$ - inclination factor (β [°] – angle of inclination).

The coefficient c must be taken into account, because the AF feeding the cushers are inclined (usually β = 15 ÷ 25°) (Das and Sahn; Maton; The PHB Weserhutte ….). The reason for the inclination is the facilitation of truck discharge and the protection of the crusher from the material direct fall into it.

The apron speed is limited to 0,25 m/s (Das and Sahn), and in some cases – to 0,4 m/s (Deevski, 1982). The reasons for the limitation are the great dynamic loads in the track chains and the high abrasion wear of the aprons. If the calculated speed is greater than the limited, the skirt height *h* must be increased. The contemporary drives of the AF allow variation of the speed in the work diapason v = 0,03-0,16 m/s (Das and Sahn, Smidth, The PHB Weserhutte …) for different capacities. This is realized with the use of variable speed DC, AC and hydraulic motors.

There are AF, which are used to feed the belt conveyor after the crusher (Kuzmanov, 1973; The PHB Weserhutte …). They transport material with small lump size and with angle of inclination - 0°. For them the apron width B must be determined by the formula (2), and the coefficient c=1.

DETERMINATION OF THE TRACK RESISTANCES AND THE MOTOR POWER

The track resistances are classified in three groups (Bandov, 1973; Vasiliev, 1991; Maton): resistance from the apron movement and the lift of the material W_1, resistance from the skirt friction of the material W_2 and resistance from the internal friction of the material, as a result of the material's pressure in the hopper – W_3. The resistance W_1 [N] is a sum of the resistances in the loaded strand W_{ls}, in the bottom strand W_{bs}, in the drive chain sprockets W_{dcs} and in the return chain sprockets W_{rcs}. They are determined by the known formulae (Vasiliev, 1991; Deevski, 1982; Kuzmanov, 1989):

$$\begin{aligned} W_1 &= W_{ls} + W_{bs} + W_{dcs} + W_{rcs} \\ W_{ls} &= L.(q_o + q_m).(w_o.\cos\beta + \sin\beta) \\ W_{bs} &= L.q_o.(w_o.\cos\beta - \sin\beta) \\ W_{rcs} &= k_1.S_2 \\ W_{dcs} &= k_2.(S_1 + S_4) \end{aligned} \qquad (3)$$

where:

L [m] – feeder length;

$q_o = (A + 60.B).g$ [N/m] – linear weight of the aprons;

A = 150 – coefficient for heavy duty work (Vasiliev, 1991; Kuzmanov, 1989);

$q_m = \frac{Q_h.g}{3{,}6.v}$ [N/m] – linear weight of the material;

w_o = 0,03 ÷ 0,04 – apron movement loss factor;

S_1, S_2, S_3 и S_4 [N] – tensile forces in the chains;

$S_2 = S_{min}$ = 3000 N;

$S_3 = S_2 + k_1.S_2$;

$S_4 = S_3 + W_{ls}$;

$S_1 = S_2 - W_{bs}$;

k_1 = 0,07 – traction loss factor in the drive chain sprockets;

$к_2$ = 0,05 – traction loss factor in the return chain sprockets.

The resistance W_2 is determined by the formula (Kuzmanov, 1973):

$$W_2 = \frac{k_m.\rho.g.L.h^2.f.1000}{\cos^2\beta}\text{ [N]} \qquad (4)$$

where:

$k_m = \frac{1-\sin(\varphi_o)}{1+\sin(\varphi_o)}$ - coefficient of paticles mobility;

$\varphi_o = \text{arctg}(\mu_o)$ [°] – angle of the intenal friction of the material;

μ_o – coefficient of the internal friction of the material (μ_o = 0,7÷0,75 for ore and μ_o = 0,5 ÷ 0,1 for coal (Kuzmanov, 1989);

f - coefficient of skirt friction of the material (f = 0,7 for ore, f = 0,56 for rock and f = 0,5 ÷0,9 for coal [2]);

The resistance W_3 is determined by the formula (Deevski, 1982):

$$W_3 = P.\mu_o\text{ [N]} \qquad (5)$$

where:

$P = \frac{F_o.R_x.\rho.g.1000}{k_п.\mu_o}$ [N] – force from the material pressure in the hopper;

$F_o = C.D.10^{-6}$ [m^2] –effective section of the hopper opening;

$R_x = \frac{(C-a_{max}).(D-a_{max})}{2.(C+D-2.a_{max}).1000}$ [m] – hydraulic radius of the hopper opening;

C, D [mm] – dimensions of the hopper opening.

Folmulae for the determination of the dimensions C and D are not given in the literature. But from the data for the manufactured AF, the following formulae can be written:

$$C = (B - 0{,}05).1000 \text{ [mm]}$$

$$D = n.C \text{ [mm]} \quad (6)$$

where:

n = 1,2 ÷ 1,5 – ratio of the hopper opening dimensions.

From the three resistances the corresponding powers N_1, N_2, N_3 and the total motor power N are determined:

$$N_1 = \frac{W_1, v}{1000.\eta}$$

$$N_2 = \frac{W_2, v}{1000.\eta}$$

$$N_3 = \frac{W_3, v}{1000.\eta} \text{ [kW]} \quad (7)$$

$$N = N_1 + N_2 + N_3 \text{ [kW]} \quad (8)$$

where:

η = 0,8 - drive efficiency (Kuzmanov, 1989).

CHECK OF THE PROPOSED FORMULAE FOR THE CALCULATION OF SPECIFIC AF

With data from (Deevski, 1982; Das and Sahn; Maton; Smidth; The PHB Weserhutte), calculations for AF are made. The results are given in Table 2. For the calculations, the coefficients are assumed: μ_o = 0,7, f = 0,7, w_o = 0,03 and n=1,2

Table.2

№	1	2	3	4	5	6
a_{max} [mm]	500	700	1200	1500	1500	1500
B [m]	1,2	1,5	2	2,4	2,4	2,6
Q_h [t/h]	780	800	450	2700	6000	1500
v [m/s]	0,4	0,13	0,055	0,12	0,32	0,04
β [°]	25	22	23	26	22	15
h [m]	0,6	1	1,4	1,8	1,8	2,2
ρ [t/m^3]	1,4	1,9	1,4	2,6	2	2,8
L [m]	7	3,8	10,2	23,6	21	15
N_1 [kW]	10	5	7	108	184	24
N_2 [kW]	4	2	4	68	117	20
N_3 [kW]	7	6	4	24	50	12
N [kW]	21	13	15	200	351	56
N_i [kW]	30	29	17	180	530	65
k_p	1,4	2,2	1,4		1,4	1,2
reference	(Deevski, 1982)	(Das and Sahn)	(Smidth)	(The PHB Weser-hutte..)	(Maton)	(Maton)

The power of the installed motor N_i is greater than the calculated power N by formula (8) (Table 2). The ratio $k_r = \frac{N_i}{N}$ is the coefficient of reserve, which is in the range 1,2 - 2,2 (only for the forth AF, N > N_i). The three calculated motor powers (formulae (7)) are related as: $N_1 > N_2 > N_3$. Only for the short AF (the first and the second from Table 2), $N_3 > N_2$.

INFLUENCE OF THE APRON SPEED AND THE VALUES OF SOME OF THE COEFFICIENTS ON THE MOTOR POPWER

The calculations how, that with he increse of the apron speed v (at constant apron width B and decrease of the skirt height h), the necessary motor power N is almost not changed. For the sixth Af from Table 2, when the speed is increaed two tmes (from 0,04 to 0,08 m/s) and the skirt height is dereased two times (from 2,2 to 1,1 m), for the total power N is obtained N=58 kW (N_1 = 23 kW, N_2 = 25 kW and N_3 = 10 kW), or the increase is only 2 kW.

The influence of the coefficients μ_o, f, n and w_o for the same AF is shown in Tables 3-6. From Tables 4,5 and 6 it is seen, that when f, n and w_o are increased – N is increased, and from Table 3 - when μ_o is increased – N is decreased. The variation of the power N however is small, when different coefficients are used.

Table.3

μ_o	0,6	0,7	0,8
N [kW]	58	56	55

Table.4

f	0,6	0,7	0,8	0,9
N [kW]	53	56	58	62

Table.5

n	1,2	1,3	1,5
N [kW]	56	58	62

Table.6

w_o	0,03	0,04
N [kW]	56	57

CONCLUSIONS

The calculations prove the correctness of the described methodology. The results for the calculated motor power are close to the values of the installed motor power of the AF, although they are manufactured by different companies.

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METHOD FOR DIMENSIONING OF HIGH POWER CENTRIFUGAL BALL CLUTCHES

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ABSTRACT
The report suggests a method for determining the main parameters of centrifugal ball clutches for power higher than 500 kW. It employs other authors' developments aiming the minimization of mass and cost for equal initial parameters. The main geometric dimensions, contacts and masses of clutch and balls are determined. The methd is designed for dimensioning of high power clutches.

There are different methods (Mateev, 1984; Tasev, 1990) for dimensioning the centrifugal ball clutches (CBC). The initial moment of rotation (M_c) for nominal frequency of the motor ($\omega_н$) is most often considered the main parameter. Mass and cost prove to be very important for centrifugal ball clutches of high power (more than 500 кW) and comparatively lower frequency of rotation. The suggested method is established for constructing of centrifugal ball clutches of minimum mass and cost. The dependencies for lightening of centrifugal ball clutches are applied for the purpose (Tasev, 1990).

Quantity of ball filling is decisive for cost and mass of the centrifugal ball clutches. Ball filling quantity of the centrifugal ball clutch changes depending on filling of individuial chambers with balls. After rotation of the Centrigual Ball Clutch, the balls line up in a special order and form a later of radius R_1 concentric to the friction surface. Furthermore, the more filled chambers are, the lower R_1 is. In the CBC (Mateev, 1984) quantity of ball filling is shown by the coefficient $K_2 = \frac{R_1}{R_a}$, where R_a is the radius of active friction surface. The author (Tasev, 1990) derived the following dependence or the coefficient K_2, which determines the filling of CBC:

$$K_2^3 + 3.K_2.\left(\frac{\psi_c}{\psi_n} + 1\right) - 4 = 0 \qquad (1)$$

where:

$K_2 = \frac{R_1}{R_a}$ is a coefficient;

R_1 – radius of free surface of the ball filling, m;

R_a – active radius of friction, m;

Ψ_c – density of CBC, which depend on its construction (Tasev, 1990);

Ψ_n – density of ball filling $\Psi_n \approx 0,55$ (Тасев, 1990).

For different constructions of CBC the coefficient Ψ_c changes from 0,6 to 1,2. Significant number of CBC, developed by the author, reveal that for high power cluctches the coefficient is Ψ_c=0,8÷1. For those values of Ψ_c the coefficient K_2 gets values of 0,46÷0,52.

Mass of filling m_n is determined by the dependence:

$$m_n = \pi.\rho.\psi_n.l_a.R_a^2.\left[\left(1 - K_2^2\right) - K_1.\left(1 - K_2\right)\right], kg \qquad (2)$$

where:

ρ – is density of steel, kg/m³;

l_a – active wide of the mantle, m;

$K_1 = \frac{a_л}{R_a}$;

$a_л$ – thickness of shovel, m.

After determination of coefficient K_2 and mass of filling, the basic geometric dimensions, active radius R_a and active width l_a, in particular, are to be determined.

One exact determination of both values is impossible as the initial moment of rotation (M_c) depends on both. The following coefficient is employed for that reason:

$$K_5 = \frac{l_a}{R_a} \qquad (3)$$

Tasev (1990) performed a very detailed analysis on the effect of basic geometrical dimensions, in particular R_a и l_a, on the mass of CBC for equal initial parametrs. It was proved that with the increase R_a, under equal other conditions, the mass

m_c decreases significantly. Due to constructive and technical features this could not be unlimited.

For CBC of high power K_5=0,4 through 0,8, and the first values refer to CBC of lower frequency of rotation, and second value to higher frequencies.

The active radius R_a of CBC for the minimum mass of the CBC (G_c) is determined by the expression:

$$R_a = \sqrt[5]{\frac{3.M_c}{2.\pi.\rho.\psi_n.f.\omega_n^2.K_5.\left(1-K_2^3\right)}} \text{, m} \qquad (4)$$

where:

f is the coefficient of friction $\approx$ 0,04.

After determination of R_a the approximate value of active width is determined l:

$$l \approx K_5.R_a\text{, m} \qquad (5)$$

Number of ball lines for balls of radius r_c are determined:

$$n_p = \frac{1{,}1.l}{\sqrt{3}.r_c}\text{,} \qquad (6)$$

r_c is the radius of balls, m,

and n_p is approximated upward to an integer.

Final width of mantle l_a is:

$$l_a = \sqrt{3}.r_c.\left(n_p - 1\right) + 2.r_c\text{, m} \qquad (7)$$

Initial moment of rotation M_c, that is able to rotate the CBC is calculated for the determined active width of the mantle:

$$M_c = 6.\omega_n^2.f.\rho.\psi_n.l_a.R_a^4.\left\{ \frac{\pi}{9}.\left(1-K_2^3\right) - \frac{K_1}{2}.\left(1-K_2^2\right) + \frac{R_a}{l\sqrt{6}}.\left[\frac{\pi}{45}.\left(2-5.K_2^3+3.K_2^5\right) - \frac{K_1}{2}.\left(1-2.K_2^2+K_2^4\right)\right] \right\}\text{, Nm} \qquad (8)$$

is calculated for the determined active width of the mantle:
where:

$$K_1 = \frac{a_п}{R_a} \approx 0{,}05\,.$$

In case the calculated M_c differs more than 10% of the given one, K_2 has to be changed and calculation has to start again.

Contact tensions p_o in the zone of friction between balls and inner cylindrical surfacesв are calculated.

$$p_o = \frac{1{,}5}{\pi.n_a.n_b}.\sqrt[3]{\left(\frac{E'.R_a.\omega}{3}\right)^2.\rho.\psi_n.\left(1-K_2^3\right)}\text{, Pa} \qquad (9)$$

where:

n_a and n_b are parameters of the contact, determined by Hord;

E' – reduced modulus of elasticity, Pa.

Contact pressure may not be higher than 0,5 GPa. When higher values are obtained extension of width of mantle is needed, and reduction of active radius, respcetively.

Another more reasonable option for reducing contact tension is the change of parameters of contact, i.e. changing the sizes of grooves (its radius $r_ж$ and depth $h_ж$), hich was discussed in detail by Tasev (1989).

Change of groove radius $r_ж$, as it has to be similar to radius of ball r_c, brings to change of n_a and n_b. Latter being identified from specialized tables for calculating the contact tension according to the formulas of Hertz. For the needs of CBC the author (Tasev, 1989) suggests the following formula, which determines precisely the tension in the contact zone:

$$p_o = 175.10^8.(\beta-1)^{0{,}185}.(\omega_n.R_a)^{0{,}67}.\left(1-K_2^3\right)\text{, Pa} \qquad 10)$$

where:

$\beta = \frac{r_ж}{r_c} = 1{,}05 \div 1{,}005$ is the coefficient, depending on precision of groove performance. Lower values correspond to more precise performance.

Distance between separate grooves $a_ж$ and depth of groove $h_ж$ are calculated by the following formulas:

$$a_ж = \sqrt{3}.r_c\text{, m,} \qquad (11)$$

$$h_ж = 1{,}2.r_c.\left[1 - \omega_n.\frac{0{,}005.\left(\omega_n.R_a\right)^{2/3}}{(\beta-1)^{0{,}38}}\right]\text{, m}$$

After obtaining acceptable contact tensions $p_o \leq$ 0,5GPa quantity of ball filling in one chamber ma be determined $Q_{кам}$:

$$Q_{кам} = \frac{\pi}{6}.\rho.\psi_c.l_a.R_a.\left[\left(1-K_2^2\right) - K_1.\left(1-K_2\right)\right]\text{, kg,} \qquad (12)$$

For the entire clutch quantity of balls is:

$$Q_{пълнеж} = 6.Q_{кам}$$

Expected mass of the clutch without balls is:

$$G_c = \pi.\rho.\psi_c.R_a^2 l_a\text{, kg} \qquad (13)$$

Total mass of the clutch is:

$$G_{ЦСС} = G_c + G_п\text{, kg.}$$

Thus the dimensioning of centrifugal ball clutch is performed.

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OPERATIVE THERMAL PROTECTION OF CENTRIFUGAL BALL CLUTCHES

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ABSTARCT
The report discusses different opportunities for performing an operative thermal protection for centrifugal ball clutches. Indirect schemes with analogous thermal and electric models are described in details. Dependencies for dimensioning of respective models are derived with the aim of applying them tas operative protection for centrifugal ball clutches.

Protection of cenrifugal ball clutches /CBC/ from unwanted overheating, resulting from irregular operation of or overloading of machine involves the application of protection, which will provide switching off the machine before reaching dangerously high temperatures.

TYPES OF OPERATING THERMA PROTECTIONS

Knowing the temperature in the clutch in each moment is needed for the operative protection. Depending on how this is realized protections may be of two types – of direct temperature registration and indirect temperature registration. In the first ones temperature control is realized by a thermal sensor, assembled steadily to the mantle, in a point where the highest heating is expected. Taking away of the obtained signal is realized by contact rings, brushes and brush-holders, assembled to the inlet shaft. Obtained signal is amplified appropriately, an reaching a certain temperature value it excludes engine supply. Applying this principle of action the protection provides a very reliable and effective control on clutch temperature, and possible error is reduced only to the error of temperature registration of the assembled sensor. The basic disadvantage is heavy constructive decision, involving the assembly of rings and brush-holders. To a certain extent, this makes maintenance and safety of protection more difficult. For that reason this type of protection has not been practically applied yet.

The same principle employs a protection, which observes temperature in the mantle from a ceratin distance. It is realized by a special thermal sensor (pyrometer), which allows determination of temperature by the radiation obtained while the clutch is heated. Advantage of this solution is that construction of the clutch does not change and taking away of the signal is realized by an easy and safe approach. Comparatively higher inaccuracy of measurement and effect of sensor contamination on its registrations may be mentioned as a disadvantage. This may bring to irregular and not in-time work of the protection.

Operative thermal protections with an indirect action are based on a dependence of temperature change with time, which is known in advance. The most simple protection of that type is realized by a time-relay, which is adjusted for a time of switching off, a little bit higher than the time needed for the realization of a normal start. A special sensor controls putting of the machine into motion. If this does not happen for the time provided, the relay starts and gives signal for switching the engine off. Protection of that kind is effective only for a single unsuccessful start, but it may not react to overheating caused as a result of too many switches for a certain period of time.

Another form for realization of a thermal protection of indirect action is modelling of the process of heating and cooling. This may be .realized by a thermal or electric model. Principle of both approaches is the same and consists in the following:

When the engine is switched on, models are supplied proportionally to the thermal flow released in the clutch. Special sensors provide information about speed of rotation, when engine and machine are rotated. Depending on differences in speed, intensity of heating changes in the same way as thermal flow in the clutch changes for the same period of time. When speed of working machine reaches speed of the engine, voltage in sensors equalizes and supply to models interrupts. From this moment on modeling of cooling process is performed. In case of good dimensioning, values of temperature, respectively voltage in respective models may precisely follow the temperature changes in the ball clutch.

INDIRECT OPERATIVE PROTECTION WITH A THERMAL MODEL

Dimensioning of the thermal model is performed as follows. Its mass is to refer to mass of clutch and moment of rotation in it as follows:

$$\frac{\sum_1^i m_i.c_i}{M_c.(\omega_1-\omega_2)} = \frac{\sum_1^n m_n.c_n}{P_H} \qquad (1)$$

where:

m_i is the mass of respective eleemnt of CBC, kg;

c_i – specific heat consumption of respective element of CBC, J/kg.K°;

M_C – moment, developed by CBC, Nm;

ω_1 – angular speed of engine, rad/s;

ω_2 – angular speed of machine, rad/s;

m_n – mass of respective element of the model, kg;

c_n – specific heat consumption of respective element of the model, J/kg.K°;

P_H – power released in the heater, W.

Power, P_H, heating the model is determined depending on the heat, released in CBC:

$$P_H = M_c.(\omega_1-\omega_2).\frac{\sum_1^i m_i.c_i}{\sum_1^n m_n.c_n}, \text{W} \qquad (2)$$

In case of certain ratio of masses and heat power, the power released in the heater is to be of a respective value. Observing the following equation is needed for realizing one and the same conditions of cooling (Chichinidze, 1970):

$$\frac{W_c.e^{-K_C.t_{OX}}}{\sum_1^i m_i.c_i} = \frac{W_M.e^{-K_M.t_{OX}}}{\sum_1^n m_n.c_n}, \qquad (3)$$

where:

W_C is the whole quantity of heat, released in CBC, J;

W_M – whole quantity of heat, released in the model, J;

K_C and K_M – coefficient of cooling, for CBC and model, respectively, 1/s;

t_{OX} – time of cooling, s.

As above mentioned ratio of masses towards ratio of powers is a constant value. In this case, the observatiopn of the above equation for one and the same period of cooling needs: $K_C = K_M$.

$$K_C = \frac{\alpha_C.S_C}{\sum_1^i m_i.c_i} = \frac{\alpha_M.S_M}{\sum_1^n m_n.c_n} = K_M, \text{ 1/s} \qquad (4)$$

where:

α_C is the coefficient of heat release of the CBC, W/m^{2}K°;

S_C – surface of CBC, m^2;

α_M – coefficient of heat release of the model, W/m^{2}K°;

S_M – surface of the model, m^2.

The coolong surface of the model for realizing the same conditions of coolong, as in the clutch, is to be:

$$S_M = \frac{\alpha_C.S_C}{\alpha_M}.\frac{\sum_1^i m_i.c_i}{\sum_1^n m_n.c_n}, \text{ m}^2 \qquad (5)$$

If the above conditions are observed, it may be considered that heating and cooling of clutch and model are performed in one and the same way and the average volumetric temperature in each moment will be equal.

Temperature in the mantle differs from the average volumetric temperature with 5÷25 °C. Sensor assembled on the model is adjusted to switch off when temperature of 110°C is reached with the aim of providing its safe work.

Accurate and precise adjustement is performed at the place of work of the ball clutcher for a give quantity of filling and lubrication in it. Creating different modes of operation for the clutch, temperatures in it and in the model are measured simultaneously, and supplying voltage is selected in such a way that obtained temperatures differ with a minimum. The principal scheme employed by the protection is shown in fig.1.

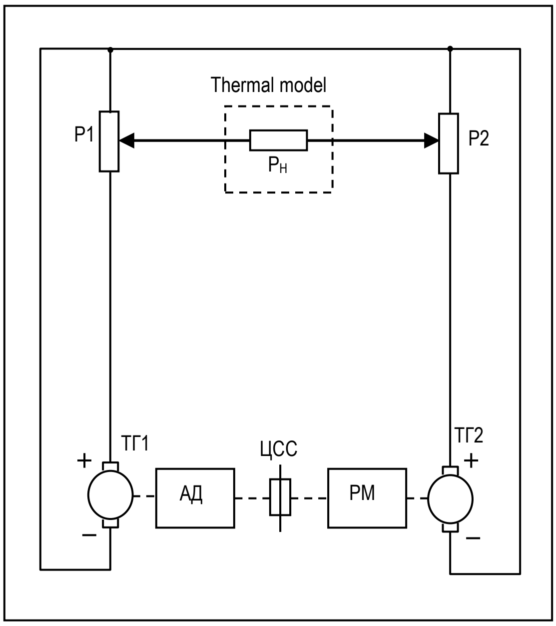

Figure 1.

OPERATIVE THERMAL PROTECTION WITH AN ELECTRIC MODEL

Constructing a protection based on electric model is reasoned by the electrothermal analogy – equal occurring and description of thermal and electric processes. Basic dependencies and correspondence in mathematical description of phenomena are cited in specialized references (Kuzmin, 1974).

The principal scheme is shown in fig. 2. Supply of current, proportional to thermal flow in the clutch is realized by the transistor T1, and by means of tachiogenerators, connected to engine and machine, the value of current changes analogically to thermal flow in the CBC.

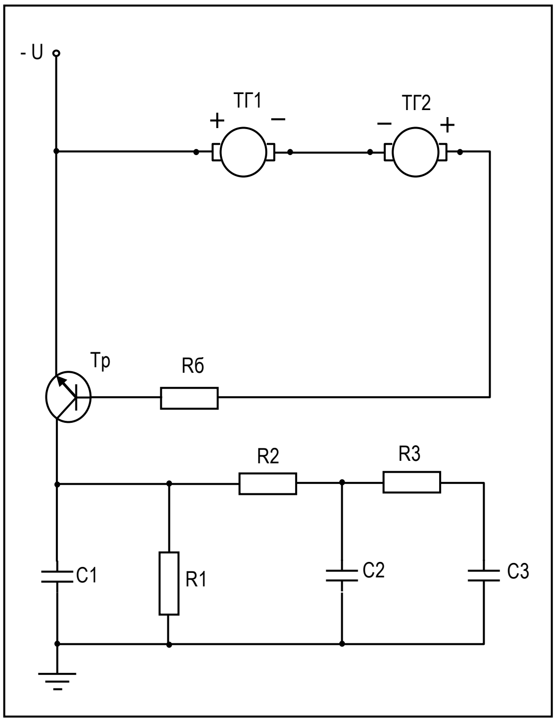

Figure 2.

Modeling of the heating of clutch is reduced to several RC – groups, having the following designation:
- the condenser C1 corresponds to the thermal capacity of the mantle;
- resistance R1 corresponds to disseminated heat by the clutch in the surrounding room;
- condensers C2, C3 and C4 correspond to thermal capacities of ball filling and the other elements of the clutch;
- resistences R2 and R3 are proportional to respective conductivities.

Dimensioning of separate elements is carried out in the following consecution:
- current I through transistor to be proportional to thermal flow through the mantle and ball filling (Kuzmin, 1974).

$$I = K_I.\frac{Q_C}{S_C} = \frac{M_C.(\omega_1-\omega_2)}{S_C}\text{, A} \qquad (6)$$

- voltage U on condenser C1 is to correspond to the temperature T in the mantle:

$$U = K_U.T\ ;\quad K_U = \frac{U}{T} \qquad (7)$$

- values of condensers, C_i corresponding to thermal capacities of respective details are calculated according to selected scales of current and voltage:

$$C_i = \frac{K_I}{K_U}.\frac{1}{\sum_1^i m_i.c_i}\text{, F} \qquad (8)$$

- resistance R1, corresponding to disseminated heat is determined:

$$R_1 = K_U.\frac{U}{S_i.\alpha_i}\text{, }\Omega \qquad (9)$$

where:

S_i is the respective surface, m^2;

α_i – respective heat conductivity, $W/m^2{}^\circ K$.

- resitances, coreesponding to respective heat conductivities are determiend:

$$R_i = K_U.\frac{U}{S_i.\alpha_i}\text{, }\Omega \qquad (10)$$

where:

S_i is the respective surface, m^2;

α_i – respective heat conductivity, $W/m^2{}^\circ K$.

Detailed development of an operative protection of that type was performed (Tasev, 1974) for a ball clutch ЦПСС 9, and the same is implemented and tested in practice

Protections, based on electrical modeling and thermal processes are very fleible, and practically one and the same protection may be applied to all types of clutches.

CONCLUSION

Indirect schemes always represent a certain element of insecurity. This may be caused by inaccurate adjustment, incorrect indications of the tachiogenerator and most often to possible change of clutch characteristics, due to change of filling and/or frictional parameters. For that reason their use in explosive atmosphere has to be combined with an accidental heat protection, which has to work n case of possible lack of in-time action of the operative protection.

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WORK VOLUME EVALUATION OF ROTARY ROLLER PNEUMATIC MOTORS

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SUMMARY
Analytical expressions applied for rotary roller pneumatic motors are presented in the paper. They refer to cameras' momentum values, the work volume of one camera, and the work volume of whole motor. These expressions can be used for theoretical work, power, rolling momentum and compressed air discharge evaluation at design and technological stage of such motors.

Main problem in dimensioning of rotary roller pneumatic motors (RRPM) is evaluation of work volume of motor and consequently its theoretical work, power and rotating momentum.

Method for RRPM work volume evaluation and more specifically its' cameras in regard of their whirling angle has not been recognized yet. Methods for dimensioning of rotational plate motors (Zeleneckii, Rjapov, Mikerov, 1976; Zinevich, Jarmolenko, Kapita, 1975; Makagon, 1971) are utilised for RRPM, imposing some errors due to neglecting the rollers volume which reduce the volume of camera.

Work volume of RRPM is defined under the following expression (also used for rotational plate motors) (Zinevich, Jarmolenko, Kapita, 1975):

$$V = V_p.z,\ m^3, \qquad (1)$$

where:
V is work volume of motor, m^3;
V_p – work volume of one camera, m^3;
z – work cameras number, equal to number of rollers.

Camera volume is the space enclosed by two neighbor rollers, rotor surface and side disks.

$$V_p = V_{max} - V_{min},\ m^3, \qquad (2)$$

where:
V_{max} is maximal work volume of camera, m^3;
V_{min} – is minimal work volume of camera, m^3.

As figure 1 shows maximal work volume V_{max} is achieved for rotor rotation angle $\varphi = \pi$, while the minimal V_{min} – when $\varphi = 0$.

Camera work volume evaluation is reduced to evaluation of camera cross section area depending on rotor rotation angle φ. This area is hatched zone named as **ampc** on figure 1.

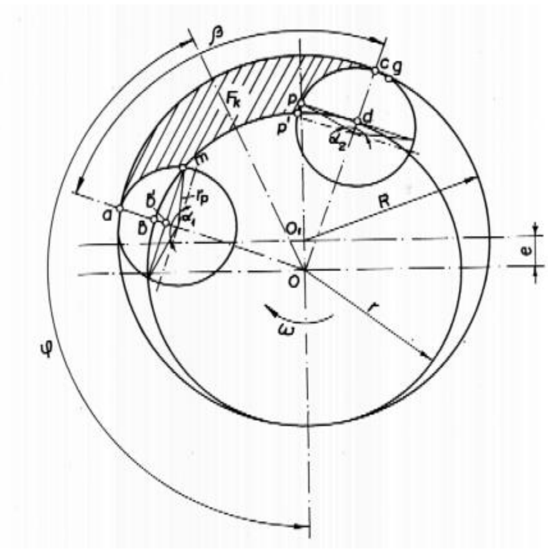

Figure 1. Cross section F_k of work camera

If we assume the following:

- Touch point of cross section of cylinders' circumference g coincides with point c at any moment of rotor rotation;
- This point is cross point of roller circumference and rotor radius extension

momentum value of camera work volume can be written as:

$$V_k = F_k.b,\ m^3, \qquad (3)$$

where:
V_k is momentum value of camera work volume, m^3;
F_k – camera area, equal to cross section of **ampc**, m^2;

b – rotor length (cylinder and roller), m.

Camera area is evaluated under formula (fig. 1)

$$F_k = F_{abdc} - F_{abm} - F_{pdc},\ m^2, \quad (4)$$

where F_{abdc} is camera cross section including rollers' area. It is evaluated under well-known formula for camera cross section of rotation plate motors, neglecting plates width (Zinevich, Jarmolenko, Kapita, 1975).

$$F_{abdc} = \frac{\beta}{2}\left(R^2 - r^2\right) - 2eR\cos\varphi.\sin\frac{\beta}{2} + \frac{e^2}{2}\cos 2\varphi.\sin\beta,\ m^2, \quad (5)$$

where:

β is angle between rollers, rad;
R – cylinder radius, m;
r – rotor radius, m;
e - eccentricity between axes O and O_1 of rotor and cylinder, m.

F_{abm} and F_{pdc} are half of areas of two neighbor rollers, located over the rotor, m^2.

Rollers areas over the rotor are set to be areas of segments of cross sections of rollers. Then camera area should be reduced with bb'm from left segment area and will increase with pp'd, which is not included into the right segment. These areas are almost equal and their influence on camera area can be neglected.

By applying well-known formula for segment area (Bronstein Semendjaev; 1986) F_{abm} and F_{pdc} can be written as:

$$F_{abm} = \frac{r_p^2}{4}\left(\alpha_1 - \sin\alpha_1\right),\ m^2; \qquad F_{pdc} = \frac{r_p^2}{4}\left(\alpha_2 - \sin\alpha_2\right),\ m^2; \quad (6)$$

where:

r_p is rollers' radius, m;
α_1 and α_2 – are angles, defining correspondingly left and right segment from both sides of camera, rad.

Angles α_1 and α_2 are divided into halves by segment Oa and Oc, located compared to line crossing the camera at it half correspondingly to angles $-\frac{\beta}{2}$ and $+\frac{\beta}{2}$ (fig. 2). Half of the camera is evaluated by rotor rotation angle φ.

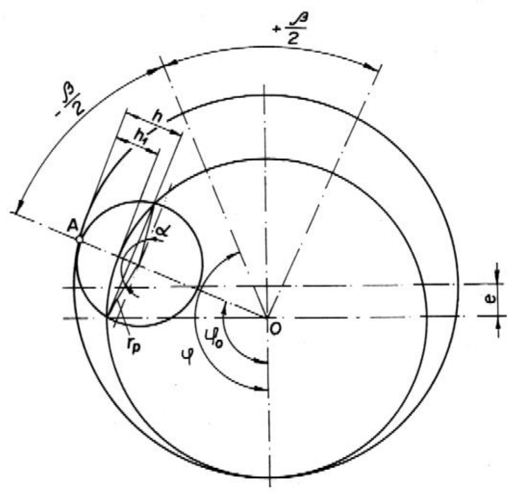

Figure 2. Work camera location in accordance with rotor rotation angle φ

Expressions (5) and (6) are substituted into (4) and camera area is:

$$F_k = \frac{\beta}{2}\left(R^2 - r^2\right) - 2eR\cos\varphi.\sin\frac{\beta}{2} + \frac{e^2}{2}\cos 2\varphi.\sin\beta - \frac{r_p^2}{4}\left[\left(\alpha_1 - \sin\alpha_1\right) + \left(\alpha_2 - \sin\alpha_2\right)\right],\ m^2. \quad (7)$$

In order to estimate changes in area F_k depending on rotation angle φ, angles α_1 and α_2 should be written with this angle.

Evaluation of α in accordance with rotation angle φ (fig. 2), we assumed that difference between height of segment h and height of sticking up part of roller over the rotor h_1 is very little and can be neglected ($h=h_1$).

Changes in height h in accordance with rotation angle together with rotor height is evaluated under the formula (Zinevich, Jarmolenko, Kapita, 1975) (fig. 2)

$$h = e\left(1 - \cos\varphi_0\right),\ m, \quad (8)$$

Where φ_0 is roller rotation angle together with rotor, rad.

Height h, set to be also the segment height, can be evaluated also under the following expression (Bronstein Semendjaev; 1986) (fig. 2)

$$h = r_p\left(1 - \cos\frac{\alpha}{2}\right),\ m. \quad (9)$$

Equalizing right parts of (8) and (9) for α we received:

$$\alpha = 2\arccos\left[1 - \frac{e\left(1 - \cos\varphi_0\right)}{r_p}\right],\ rad. \quad (10)$$

Bearing in mind that segments rollers angles α_1 and α_2 are shifted towards camera half at angel $\frac{\beta}{2}$ and putting that information into expression for φ_0, we can obtain

$$\alpha_1 = 2\arccos\left\{1-\frac{e\left[1-\cos\left(\varphi+\frac{\beta}{2}\right)\right]}{r_p}\right\}, \text{ rad};$$

$$\alpha_2 = 2\arccos\left\{1-\frac{e\left[1-\cos\left(\varphi-\frac{\beta}{2}\right)\right]}{r_p}\right\}, \text{ rad}. \quad (11)$$

Camera momentum area is evaluated when angles α_1 and α_2 from (11) are substituted into (7) under taking into account camera (rotor) rotation angle φ.

Areas F_{max} and F_{min} of the camera are obtained under rotation angles correspondingly: $\varphi = \pi$ и $\varphi = 0$. For that figures camera is symmetrically located towards vertical axes of motor and areas F_{abm} and F_{pdc} are equal. For this two cases in formula (7) is assumed that $\alpha_1 = \alpha_2 = \alpha$.

Maximal and minimal camera area is obtained correspondingly:

$$F_{max} = \frac{\beta}{2}\left(R^2-r^2\right)+2eR\sin\frac{\beta}{2}+\frac{e^2}{2}\sin\beta - \frac{r_p^2}{4}\left\{2\arccos\left[1-\frac{e\left(1+\cos\frac{\beta}{2}\right)}{r_p}\right] - \sin\left[2\arccos\left(1-\frac{e\left(1+\cos\frac{\beta}{2}\right)}{r_p}\right)\right]\right\}, m^2; \quad (12)$$

$$F_{min} = \frac{\beta}{2}\left(R^2-r^2\right)-2eR\sin\frac{\beta}{2}+\frac{e^2}{2}\sin\beta - \frac{r_p^2}{4}\left\{2\arccos\left[1-\frac{e\left(1-\cos\frac{\beta}{2}\right)}{r_p}\right] - \sin\left[2\arccos\left(1-\frac{e\left(1-\cos\frac{\beta}{2}\right)}{r_p}\right)\right]\right\}, m^2. \quad (13)$$

We put the expressions

$$\frac{r_p^2}{4}\left\{2\arccos\left[1-\frac{e\left(1+\cos\frac{\beta}{2}\right)}{r_p}\right] - \sin\left[2\arccos\left(1-\frac{e\left(1+\cos\frac{\beta}{2}\right)}{r_p}\right)\right]\right\} = A;$$

$$\frac{r_p^2}{4}\left\{2\arccos\left[1-\frac{e\left(1-\cos\frac{\beta}{2}\right)}{r_p}\right] - \sin\left[2\arccos\left(1-\frac{e\left(1-\cos\frac{\beta}{2}\right)}{r_p}\right)\right]\right\} = Б$$

After setting up the above written expressions into (12) and (13) and their substitution into (2), taking into account camera length b, expression for one camera work volume for RRPM is developed

$$V_p = b.\left[\frac{\beta}{2}\left(R^2-r^2\right)+2eR\sin\frac{\beta}{2}+\frac{e^2}{2}\sin\beta - A\right] - b.\left[\frac{\beta}{2}\left(R^2-r^2\right)-2eR\sin\frac{\beta}{2}+\frac{e^2}{2}\sin\beta - Б\right], m^3;$$

or

$$V_p = b.\left(4eR\sin\frac{\beta}{2} - A + Б\right), m^3 \quad (14)$$

Motor work volume is evaluated under formula (1) which is substituted into (14)

$$V_{дв} = V_p.z = zb.\left(4eR\sin\frac{\beta}{2} - A + Б\right), m^3. \quad (15)$$

CONCLUSIONS

1. Analytical expression (7) for moment values evaluation of rotational rollers motors camera areas in accordance with rotor rotation angle is worked out.
2. Also formulas for one camera work volume (14) and work volume of whole motor (15) are worked out. Their application in design process can help in evaluation theoretical work, compressed air discharge, power and rotating moment of rotation rollers pneumatic motors.

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COMPUTER DESIGN OF MINE PNEUMATIC NETWORKS

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SUMMARY
More precise method for mine pneumatic networks (MPN) design, served as verbal algorithm for creation a program in MATLAB environment is developed. Among great number of variants of main MPN properties an optimal one in regard of capital and operational costs can be defined by applying the method. Computer program can give information about main MNP properties in mine development process and also in its life cycle stages. Main MPN parameters' optimization at the design stage increase its operational effectiveness.

The following main requirements for Mine Pneumatic Networks (MPN) should be taken into account at design stage:

- To supply needed compressed air amounts to consumptions with predefined pressure and with minimal losses;
- Minimal capital costs;
- Minimal operational costs;
- Parallel to mine development to expand pneumatic system without its' economic parameters reduction.

Minimal capital costs can be achieved by usage of as little as possible pipeline diameter while minimal operational costs (minimal pressure loss) are less if tubes are greater. Talking about the same pipeline we have two opposite requirements which lead to great differences and discrepancies in MPN design.

Variations in consumers' number, in compressed air amounts supply, total distribution network length expansion and complication in its structure accompany each mine development. In the contrary to this reality, at design stage such networks are assumed to be stationary in time, with maximal consumers, compressed air amounts and pipelines' length. Such network design is not rational, exact compressed air amounts for different sections are not known, as well as total costs for different stages of its development and operation. These design MPN methods (Garbus, 1961; Smorodni, 1980; Цейтлин, Мурзин, 1985; Jankov, 1980) apply empirical formulae, family of curves and narrow diapasons of compressed air velocity variations.

The method developed and presented in this paper tries to overcome the above written problems by taking into account the most favorable compressed air velocity in pipeline under optimal capital and operational costs. At each stage of network development information for its main parameters can be obtained. The method developed serve as a basic algorithm for computer program in MATLAB environment. Data input is performed in matrix way in accordance with pneumatic network topology.

The essence of method comprises of calculation of inside pipeline diameters starting from the most distant section towards compressor station. It is assumed that pressure is equal elsewhere to the greatest nominal consumption pressure. Compressed air discharge at each supply point is evaluated, i.e. at the compressed station exit. This is performed by application of known analytical methods (Degtjarev, 1987; Smorodni, 1980; Цейтлин, Мурзин, 1985). Then calculation of inside diameters and pressure losses for each network section takes place.

Pneumatic network dimensioning is done at two basic stages. The first one is to calculate great number of variants for the highway pipeline and to choose the optimal (with minimal total capital and operational costs keeping velocity into desired limits). The second one includes calculation of subsidiary branches' diameters and total economic parameters.

Highway sections' inside diameters are calculated under the expression for air discharge of compressible fluid through a given surface:

$$F.u = V_y \frac{\rho_0}{\rho_{cp}}, \qquad (1)$$

where:

F is pipeline cross section area for dimensioning part, m^2;
u – compressed air velocity in pipeline, m/s;
V_y – air discharge through section, m^3/s;
ρ_0 – atmospheric air density, kg/m^3. For normal conditions it is set to be ρ_0 = 1,2 kg/m^3 (Smorodni 1980).
ρ_{cp} – compressed air average density in the section, kg/m^3.

The most favorable values for air velocity in mine pneumatic networks design methods (Цейтлин, Мурзин, 1985; Jankov, 1980) are in the range 6 - 10 m/s. Long term research

(Smorodni, 1980) in Leningrad mine institute show that it can be broaden to 4 - 12 m/s.

Compressed air average density in sections is calculated under expression:

$$\rho_{cp} = \frac{p_{cp}}{R.T_{cp}},\ kg/m^3, \qquad (2)$$

where:

p_{cp} is average pressure in pipeline, equals to mean arithmetic value between pressure at the two sides of pipeline section, Pa;

R – gas constant. Equals to 287 J/kgK;

T_{cp} – average temperature of compressed air in pipeline, K.

Writing expression for cross section area by inside diameter of section pipeline D_y and substituting values for ρ_0, u, R and ρ_{cp} in (2) the following formula for inside diameter is obtained:

$$D_y = \sqrt{\frac{438{,}5V_yT_{cp}}{(4 \div 12)p_{cp}}},\ m. \qquad (3)$$

Pressure losses in pipeline are calculated under Darsy-Weisbah formula (Цейтлин, Мурзин, 1985):

$$\Delta p_y = \frac{5{,}62.M_y^2.T_{cp}.L_y}{D_{cp}^{5{,}3}.p_{cp}},\ Pa, \qquad (4)$$

where:

M_y is mass discharge of compressed air through pipeline section, kg/s.

$$M_y = \rho_0.V_y,\ kg/s, \qquad (5)$$

L_y – section length, m.

$$L_y = 1{,}15\ell,\ m, \qquad (6)$$

ℓ - design length of section, m.

The length ℓ of each section increases with 15 % in order to compensate pipeline inclination and length losses due to assembling work.

Data consisting of V_y, M_y, Δp, p_{cp} and D_y for each variant for highway pipeline of pneumatic network is obtained. They are utilized to calculate total volumetric flow rate $V_{пм}$ through pneumatic network and pressure loss at compressor station exits $p_{кс}$.

Arbitrary great number of variants for highway pipeline can be generated. Taking 0,1 m/s step for calculation of reasonable velocity range 81 variants of pipelines for particular pneumatic farm are obtained. All variants are dimensioned for normal work of pneumatic consumption, but not all of them are economically enough in regard of total capital and operational costs.

Optimal variant for which pneumatic network will show favorable values of D_y and Δp is defined via comparison of values of diameters and pressure losses for equal velocities of compressed air. Program output can be either numerical or graphical. For each variant average diameter D_{cp} and total pressure loss $\sum\Delta p$ are calculated. Diagrams of D_{cp} = f(u) and $\sum\Delta p$ = f(u), shown on figure 1, can be built upon these parameters.

Table 1 shows main input and output data in cost optimization of highway pipeline procedures.

Table 1

Sec tion №	V_y, m^3/s	M_y, kg/s	Δp_y, MPa	p_{cp}, MPa	D_y, m	D_cp, m $\sum\Delta p$, Mpa $p_{кс}$, MPa
вариант № .... ; =						

Cross section point of curves D_{cp} and $\sum\Delta p$ define optimal values of average diameter, pressure losses and compressed air velocity, i.e. optimal variant for highway pipeline, namely D_{cp_0}, $\sum\Delta p_0$ and u_0. This variant is obtained for exactly defined air velocity while using for this process inside diameters and total losses. In order to obtain standard inside pipeline diameters under optimal losses pre-calculation of highway pipeline is required for optimal air velocity ($u=u_0$).

Main pneumatic network parameters' optimization is performed only for dimensioned highway pipeline because during its construction main part of capital costs are spent, the whole amount of compressed air passes through and great pressure losses are counted there.

The second stage of mine pneumatic network design is inside diameter of subsidiary network evaluation under known pressure losses. This is done by formula (4) which is solved for inside diameter D_y. All data is given in table view for sections of subsidiary branches.

Computer program gives information for all pneumatic network pipelines' diameters, volumetric yield of compressed air for any section, parts of network and for the whole network. It can calculate costs and diameters when number of consumers and length change.

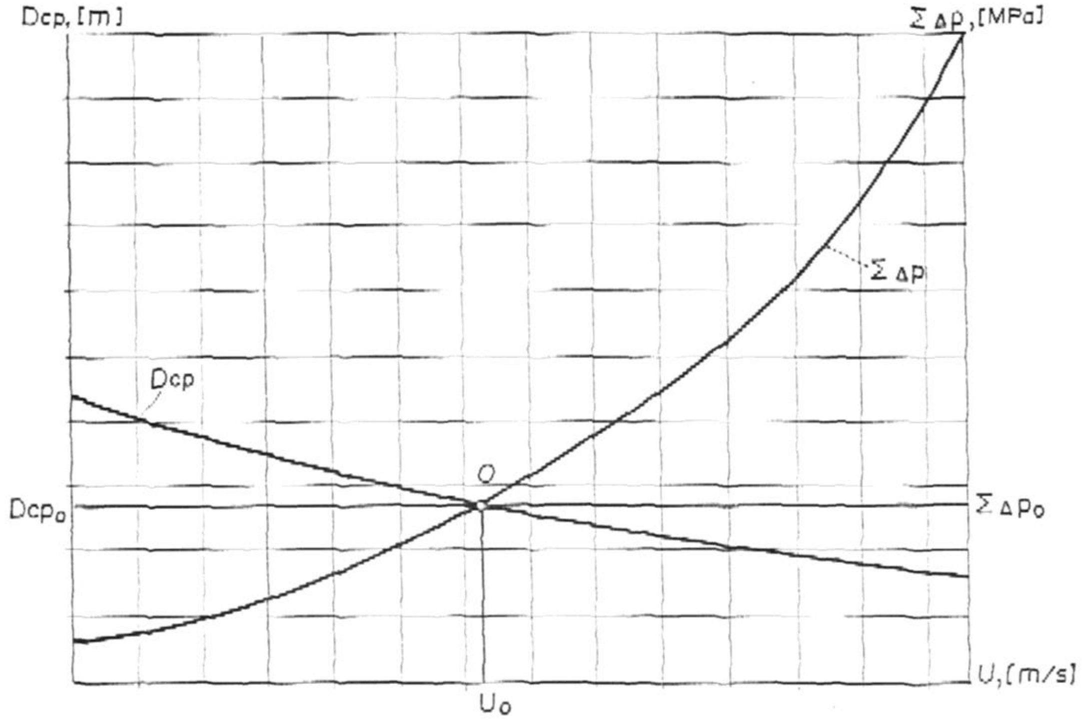

Figure 1.

CONCLUSION

1. Developed more precise method for mine pneumatic networks design served as verbal algorithm for computer program in MATLAB environment creation. It includes expansion of appropriate velocity range.
2. Method enables to choose optimal variant among great number of variants for main parameters of highway pipeline. Optimization is performed in regard of capital and operational costs.
3. Computer program cane give information about main pneumatic network parameters not only for static situation but in dynamic environment for variations in consumption number, length and stages of its construction during mine life cycle.
4. Computer program application decreases design time and increases its effectiveness.

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FRICTION, DEFORMATONS AND TENSIONS IN THE SHAFTS OF MILLS WITH PLANETARY MECHANISMS

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ABSTRACT
In the shafts of the grinding rolls of mills with vertical housing and activation by a planetary mechanism, additional loads are generated, resulting from the shafts' elastic deformations, caused by the friction unavoidable in such constructive designs.
In the work, by the use of modern methods, the deformations and the additional tensions generated in the course of exploitation of mills of this type, are discussed.
KEY WORDS: Grinding, planetary mechanisms, torsion shafts, friction, deformations, tensions.

The need of finely ground mineral and energy raw materials resulted in the design of a number of new grinding machines. The possible structure of such a mill is illustrated by the machine ЦРМ ВМГИ-70-А (Centrifuge-roll mill), designed at the Higher Institute of Mining and Geology "St. Ivan Rilski" (Obreshkov ,1968*)*.

ЦРМ ВМГИ-70-А has a vertical housing (Fig. 1); its operation is based on the centrifuge principle. Thus, it is downloaded gravitationally, all equations for calculation of its basic parameters being valid, such as: holding and rolling angle, free way, idle time, impact number, etc. (Вучев, 1973). As can be seen from Fig. 1, the mill consists of a central bearing knot, a housing, grinding rolls, devices for feeding in of raw materials and carrying away of the final product. Its activation is unique. It is effected by a planetary reductor at the planetary wheels, on which torsion shafts are fixed, and on the shafts, the grinding rolls are irreversibly fixed. In this way, each roll is activated by the common reductor.

Upon elaboration of the mill's prototype, it was tested (Койчев, 1975) with grinding in semi-industrial modes. These studies revealed that the mill could grind different raw materials manifesting good technical-economic parameters. The dolomite thus ground meets absolutely the requirements of road construction.

However, the strength of some of the machine's elements and its overall reliability do not meet the requirements for such machines. Yet in the end of the first 8 hours of test operation, one of the transition torsion shafts got broken at the place of the fixed connection between the grinding roll and the shaft. Upon fixing the broken shaft and increasing the shaft's diameter by 10 mm, the machine operated for 10 hours and then another shaft broke.

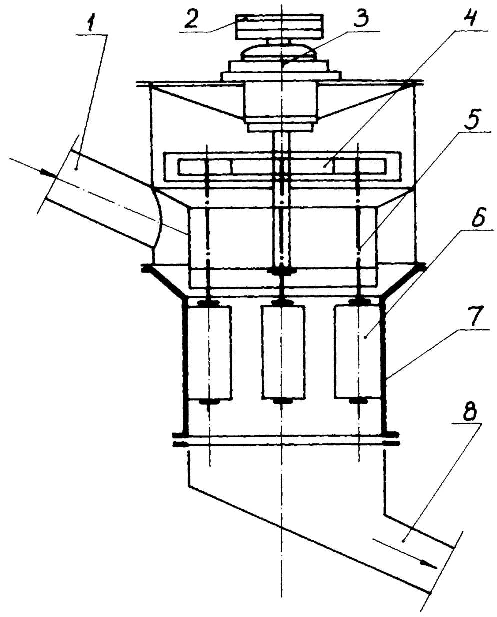

Figure 1.
1. power supply 2. activation 3. central bearing knot 4. planetary reductor 5. torsion shafts 6. grinding rolls 7. corpse 8. downloading

It is obvious that these breakings are caused by the speeded up fatigue of the shafts' material. In this case, there is considerable friction between the grinding roll, the corpse, and the ground material. It results in the shaft's lower part being greatly delayed (by about 30 mm with overall shaft length of 1080 mm) and bending in the tangential direction. Apart from this, the irregular load, and the deviations in the shafts axes-aligned directions also assist to the shafts' quick breaking.

To study the aforementioned shaft deformations and tensions, certain tests were carried out, using modern equipment and software. To model shaft geometry, the solid body modelling program SolidWorks 98+ was used, and to test strength – the program COSMOS/Works 4.0. The options of the program for the geometry's automatic shading and determination of the needed network density were used.

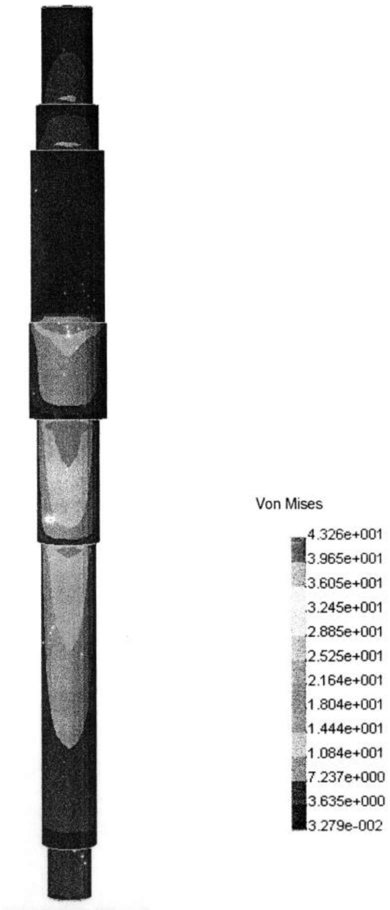

Figure 2.

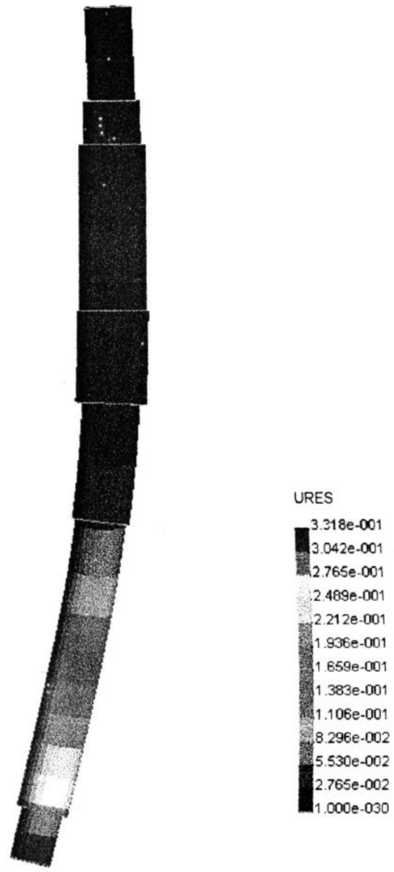

Figure 3.

As a conclusion it can be said that:

1. The centrifuge mills with planetary reductors grind well non-metalliferrous minerals, coal, and other softer materials.
2. Their hitherto available structure results in significant friction between the rolls, the milled material, and the corpse. It causes the shafts to bend in the tangential direction.
3. The irregular feeding of the milled material and some inaccuracies in their make-up increase the load and, hence, the probability for quick shaft breaking.
4. Precise studies by modern equipment and software can assist to these machines' improvement.

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SOME PECULIARITIES OF THE CHOICE OF BEARING UNIT OF CENTRIFUGE-ROLL MILLS

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ABSTRACT
In the introduction of controlled increased sliding in vertical-roll mills, the grinding effect, and respectively the fine-class yield, are increased but the wearing out of the working organs and the specific energy consumption are also increased.
In the paper, a solution is discussed where the increased sliding is achieved by inclining at a definite angle β of the grinding-rolls' axis as to the housing's vertical axis. In doing so, besides certain changes of the major parameters of the process, the requirements to the main bearing fixing are also changed. Axis-aligned forces are generated which must be accounted for in the design of the bearing knot. These forces are analyzed and the means are outlined for the choice and compliance with the requirements of the rolling bearing.
KEY WORDS: mills, vertical rotor, increased loading, sliding bearings, bearing knot.

Increased sliding with mineral raw material mills results in an increase of the yield of the final product's fine classes. It can be applied whenever the need of finer classes is greater. Whereas, it should be minded that, in this case, energy consumption is increased as well as the wearing out of the machine's working organs. Prior to such sliding's introduction, all these factors should be assessed and the optimal regime should be chosen. With centrifuge-roll mills, it can be established by inclination of the grinding rolls' axes with respect to the mill's vertical axis at a definite angle β (Fig. 1). Thereby, apart from the increased sliding, which increases proportionally with increasing of the inclination angle β, an additional load is created along the mill's axis. This load depends on the inclination angle β and the overall resistance with mill working. It can be determined by the equation:

$$P_\beta = P_c \sin\beta, \text{ N}$$

where:
P_c is the resistance with mill working.

This resistance can be determined by the use of the relevant equations provided in technical literature (Hoeffle, 1985). The force P_β puts some additional load on the mill's rotor and bearings. It can be applied in both directions, depending on whether the roll is inclined to the left or to the right, and also on the direction of the rotor's rotation.

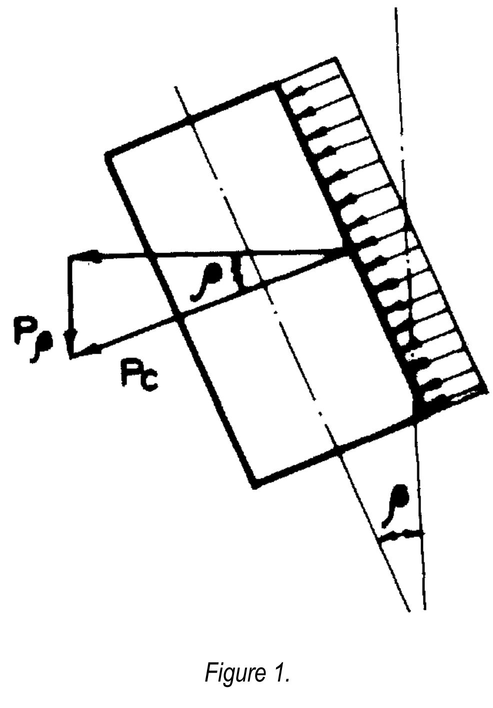

Figure 1.

In Fig. 2, a solution for such a bearing knot is shown. The design was performed by the program Solid Works 98+. In the design process, the loads P_β were taken into account, resulting from the rolls' inclination.

As can be seen in the Figure, two self-adjusting radial bearings and one single-operating ball-bearing have been used. With this configuration of the bearing knot, the self-adjusting bearings lose their self-adjusting ability. In this case, they were chosen because of their great loadability. Other structural designs are also possible. Since the bearing knot is intended for a mill, operating in strongly dusted environment, double protection is provided on both its sides.

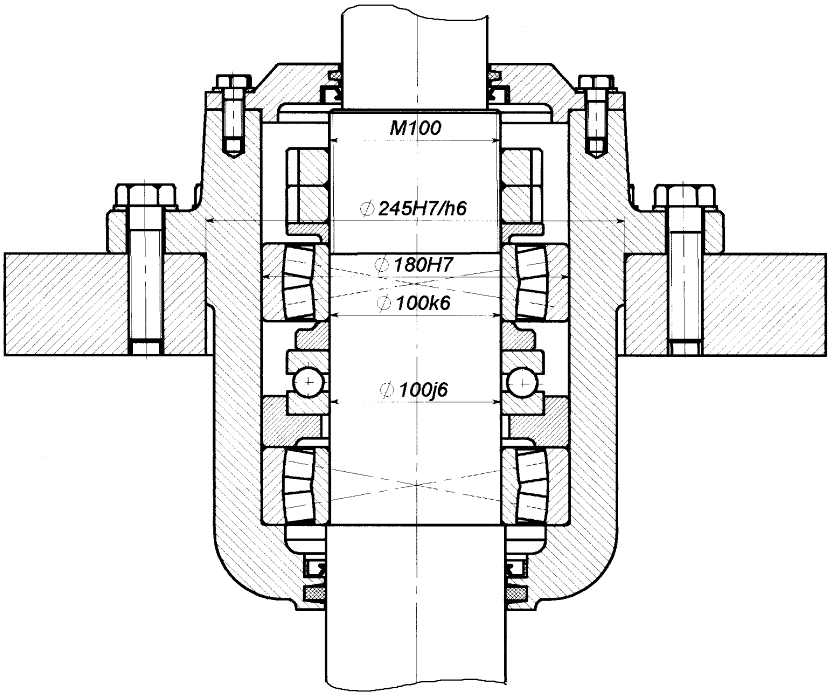

Figure 2.

With a view to the rotor bearing group's normal work, the inclination angle β is delimited in both directions for the following reasons:

1. With inclination to the left, as in Fig. 1, the additional load P_β will be directed downwards, increasing the axial load, resulting from the rotor's weight P_G. Whereas the overall load $P_a = P_G + P_\beta$ will also load the rotor bearings and angle β shall have to be restricted within an acceptable size for the bearing group.
2. With inclination to the right, the force P_β will be directed in the opposite, upward, direction, decreasing the bearings overall load $P_a = P_G - P_\beta$. This can be allowed only as much as a lifting force P_β, lesser than the rotor's weight P_G by the force P_{amin} is achieved. This force is needed to provide for the normal operation of the axial bearing. With further reduction of the force P_{amin}, the normal conditions for the balls' rolling are disturbed by the forces generated by their mass. The force P_{amin} can be determined by the equation:

$$P_{amin} = M (n_{max} /1000)^2$$

where:

M is a constant, provided in technical literature for rolling bearings (FAG Catalogue 1973).

As a conclusion, it can be said:

1. With centrifuge roll mills with inclined rolls, an additional loading of the rotor's bearing knot is created.
2. The additional loading of the mill rotor's bearing knot can be directed downwards or upwards with the reverse motion. It depends on the inclination angle and can be determined using the machine's geometry and parameters.

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A BOUNDARY ANALYSIS OF ROUND PLATES BY SHEAR FORCE CALCULATION

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ABSTRACT
A method is proposed which allows to solve Von Mise's nonlinear plasticity equation. An algorithm is suggested for solving a nonlinear differential equation on the basis of the balance equations which are suitable for defining some dimension less variables of Von Mise's plasticity conditions.
A software product has been developed with tabular and graphic appendices referring to accepted boundary conditions for propped and jammed plate.
The results can be used as a basis for certain studies on support elements in the mining industry.

INTRODUCTION

Boundary analysis of round ideally plastic plates is done by many authors (Brotchine, 1960; Guerlement, Lamblin, 1972; Mohaghegh, Coon, 1973; Sawczuk, Jaeder, 1963). One of the first published papers in this scientific area is (Sawczuk, Duszek, 1963). The criterium of maximal tangental stresses is used in it. In (Mohaghegh, Coon, 1973) are given the conditions for plasticity of a material, which follows Mise's criterium in intergral-parametric form, but the question about bending element and shearing stresses is not solved. In (Brotchine, 1960; Shapiro, 1961) a generalisation of previous results as a high non-linear equation of a surface and some particular cases are solved by using suitable linearisation of this equation.

In this article a method, systemizing all previous results and permitting to obtain solvation of non-linear Von Mise's equation is proposed.

EQUILIBRIUM EQUATION

On fig.1 cylindrical coordinates r, Q, z and positive directions of forces and moments are given.

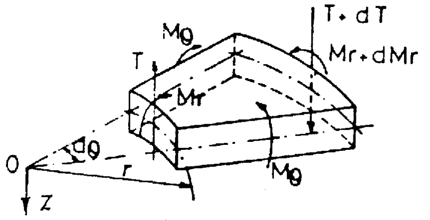

Figure 1.

The equilibrium equation could be written in the form:

$$\frac{d}{dr}\left(r.M_r\right) = M_\theta + r.T \tag{1}$$

It is suitable non-dimension variables x; m; n; t and the dimensional q and p to be defined:

$$x = \frac{r}{R};\ m = \frac{M_r}{M_o};\ n = \frac{M_\theta}{M_o};\ q = \frac{T_e}{M_o};\quad t = \frac{r}{2R};\quad p = \frac{P}{2\pi M_o} \tag{2}$$

where Mo, e, R are plastic moment, thicness and radius of the plate.

$$\frac{dm}{dx} = \frac{1}{x}\left(n - m\right) + \frac{TR}{M} \tag{3}$$

CONDITIONS FOR PLASTICITY EXISTENSE

1. Independent action of bending moment and shearing force

On (Shapiro, 1961) is assumed that stresses, caused by shearing force could be discussed independently from those of bending moment. The condition for plasticity existence in this case is given by the equations

$$F_1(T) = 0; \qquad F_2\left(M_r, M_\theta\right) = 0 \tag{4}$$

The arbitrary surface of the deformed plate could be assumed as small flat surfaces for which the equations (5) are valid:

$$F_1 = T \pm T_o = 0;$$
$$F_2 = \max\{|M_r|, |M_\theta|, |M_r - M_\theta|\} - M_o = 0 \qquad (5)$$

where T_o is shearing force for one unit length and is solved using the relation

$$T_o = E.\tau_o, \qquad (6)$$

where τ_o is tangential stress limit of plastic yield in pure shearing (fig.2).

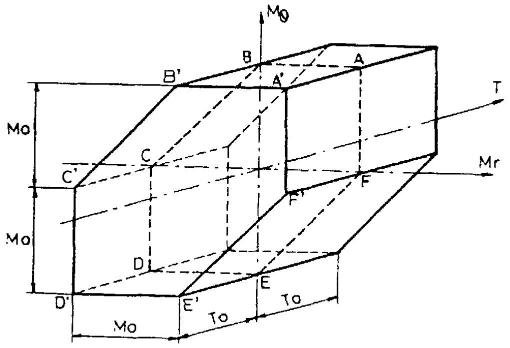

Figure 2.

2. Mutual action of shearing force and bending moment

2.1. Von Mise's plasticity conditions. Plasticity condition is written in the form (Brotchine, 1960; Sawczuk, Jaeder, 1963).

$$M_r^2 - M_r M_\theta + M_o^2 + \frac{3}{4}\left(\frac{TE}{2}\right)^2 - M_o^2 = 0 \qquad (7)$$

and presents an ellipsoid in coordinate system Mr Ma T. Family of sections of ellipsoid with a plain perpendicular to the axis t (t could be determined from the equation t = T/To) are presented on fig.3.

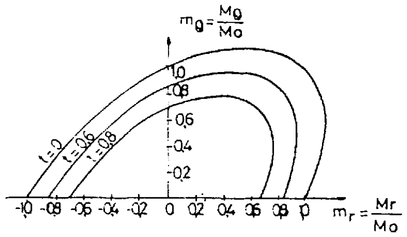

Figure 3.

Fig. 4 is a section of (7) with the plane o, t, n. Taking into account of non-dimensional variables (2), the equation (7) could be written in the form which could be taken as a square equation towards n.

$$f = m^2 - mn + n^2 + \frac{3}{16}q^2 - 1 = 0 \qquad (8)$$

There fore:

$$n = \frac{1}{2}\left[m \pm \sqrt{4 - 3m^2 - \frac{3}{4}q^2}\right] \qquad (9)$$

It is evident that

$$n = \frac{1}{2}\left[m + \sqrt{4 - 3m^2 - \frac{3}{4}q^2}\right] n \geq \frac{m}{2} \qquad (9a)$$

$$n = \frac{1}{2}\left[m - \sqrt{4 - 3m^2 - \frac{3}{4}q^2}\right] n \leq \frac{m}{2} \qquad (9b)$$

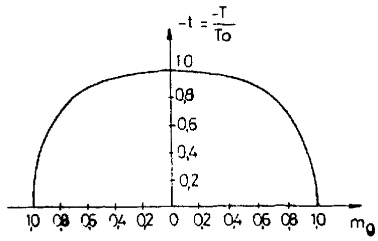

Figure 4.

2.2. Maximum of m. The m extremums are searched in plasticity conditions, static limits for the plate discussed to be defined.

For the purpose derivatives of (8) must be computed:

$$\frac{df}{dm} = 0, \quad \frac{df}{dn} = 0, \qquad (8a)$$

from where the relations are defined

$$2n - m = 0, \quad 2m - n = 0 \qquad (8b)$$

and the first one of them corresponds to m_{max}. From (8) could be found

$$m = \pm\sqrt{\frac{4}{3} - \frac{q^2}{4}} \qquad (10)$$

METHOD PROPOSED

The elimination of n from (3) and (9) leads to a differential equation:

$$\frac{dm}{dn} = \frac{1}{2x}\left[-m \pm \sqrt{4 - 3m^2 - \frac{3}{4}q^2}\right] + \frac{TR}{M_o}, \qquad (11)$$

Which is dependent of searched load parameters by q and T.

The algorithm proposed is as follows:

1. Equation (11) is integrated numerically into the interval (x_i, m_i), (x_r, m_{r1}). The result from the decision is saved in mr1, and x_r is between $x_i + x_f$.
2. Using the same method (11) is integrated for the second time, but in the interval (x_f, m_f) ÷ (x_r, m_{r2}) and m_{r2} is the solvation obtained.

3. Under the conditions $m_{r2} \geq \leq m_{r1}$ load parameters are corrected and then procedure 1° is repeated.
4. The procedure is stopped when the difference between m_{r1} and m_{r2} is negligably small, what could be put as an allowed punctuality of the solvation.

A software product is elaborated by following the algorithm above.

APPLICATIONS

1. Propped plate (fig.5a)
Boundary conditions

$$x_i = \frac{A}{R},\ m_i = \sqrt{\frac{4}{3} - \frac{P^2 t^2}{(A/R)^2}},\ x_f = 1,\ m_f = 0$$

Results obtained are given in tables 1, 2, 3, 4 and as graphs (fig. 5b).

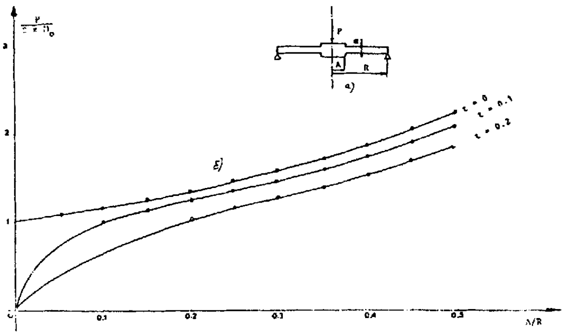

Figure 5

2. Fixed plate (fig.6a)
Boundary conditions

$$x_i = \frac{A}{R},\ m_i = \sqrt{\frac{4}{3} - \frac{P^2 t^2}{(A/R)^2}},\ x_f = 1,\ m_f = -\sqrt{\frac{4}{3} - P^2 t^2}$$

Table 1 t=0.05

A/R	$\frac{P_1}{2\pi M_o}$ without shearing force	$\frac{P_2}{2\pi M_o}$ with shearing force	$\Delta = \frac{P_1 - P_2}{P_2}$ %
0.1	1.193510	1.156638	3.19
0.15	1.276320	1.249567	2.14
0.20	1.365865	1.342972	1.70
0.25	1.465136	1.443725	1.48
0.30	1.577100	1.555844	1.37
0.35	1.705235	1.683139	1.31
0.40	1.853964	1.830071	1.31
0.45	2.029181	2.002376	1.33
0.50	2.239053	2.207852	1.41

Table 2 t=0.1

A/R	$\frac{P_1}{2\pi M_o}$ without shearing force	$\frac{P_2}{2\pi M_o}$ with shearing force	$\Delta = \frac{P_1 - P_2}{P_2}$ %
0.1	1.193510	1.037124	15.07
0.15	1.276320	1.171673	8.93
0.20	1.365865	1.277697	6.90
0.25	1.465136	1.383078	5.93
0.30	1.577100	1.495829	5.43
0.35	1.705235	1.620916	5.20
0.40	1.853964	1.762994	5.15
0.45	2.029181	1.927436	5.27
0.50	2.239053	2.121118	5.56

Table 3 t=0.15

A/R	$\frac{P_1}{2\pi M_o}$ without shearing force	$\frac{P_2}{2\pi M_o}$ with shearing force	$\Delta = \frac{P_1 - P_2}{P_2}$ %
0.1	1.193510	-	-
0.15	1.276320	1.046800	21.92
0.20	1.365865	1.178598	15.89
0.25	1.465136	1.292342	13.37
0.30	1.577100	1.406607	12.12
0.35	1.705235	1.528858	11.53
0.40	1.853964	1.664303	11.39
0.45	2.029181	1.817979	11.61
0.50	2.239053	1.995693	12.19

Table 4 t=0.20

A/R	$\frac{P_1}{2\pi M_o}$ without shearing force	$\frac{P_2}{2\pi M_o}$ with shearing force	$\Delta = \frac{P_1 - P_2}{P_2}$ %
0.1	1.193510	-	-
0.15	1.276320	-	-
0.20	1.365865	1.055572	29.39
0.25	1.465136	1.182634	23.88
0.30	1.577100	1.299774	21.33
0.35	1.705235	1.419349	20.14
0.40	1.853964	1.547722	19.78
0.45	2.029181	1.689841	20.08
0.50	2.239053	1.85063	20.99

Tables 5, 6, 7 contain results from numerical integration and fig.6b illustrates the calculations.

Table 5 t=0.05

A/R	$\frac{P_1}{2\pi M_o}$ without shearing force	$\frac{P_2}{2\pi M_o}$ with shearing force	$\Delta = \frac{P_1 - P_2}{P_2}$ %
0.1	1.897169	1.749513	8.44
0.15	2.097663	1.994682	5.16
0.20	2.304407	2.216200	3.98
0.25	2.526285	2.442476	3.43
0.30	2.770641	2.685430	3.17
0.35	3.045226	2.954035	3.09
0.40	3.359381	3.257489	3.13
0.45	3.725231	3.606797	3.28
0.50	4.159343	4.016234	3.56

Table 6 t=0.1

A/R	$\frac{P_1}{2\pi M_o}$ without shearing force	$\frac{P_2}{2\pi M_o}$ with shearing force	$\Delta = \frac{P_1 - P_2}{P_2}$ %
0.1	1.897169	-	-
0.15	2.0976668	1.672251	25.44
0.20	2.304407	1.964258	17.32
0.25	2.526285	2.210647	14.28
0.30	2.770641	2.453915	12.91
0.35	3.045226	2.709750	12.38
0.40	3.359381	2.988364	12.42
0.45	3.725231	3.298988	12.92
0.50	4.159343	3.651618	13.90

Table 7 t=0.15

A/R	$\frac{P_1}{2\pi M_o}$ without shearing force	$\frac{P_2}{2\pi M_o}$ with shearing force	$\Delta = \frac{P_1 - P_2}{P_2}$ %
0	1.230570	-	-
0.1	1.897169	-	-
0.15	1.976668	-	-
0.20	2.304407	-	-
0.25	2.526285	1.865976	35.39
0.30	2.770641	2.125957	30.32
0.35	3.045226	2.374025	28.27
0.40	3.359381	2.628064	27.83
0.45	3.725231	2.897946	28.55
0.50	4.159343	3.191302	30.33

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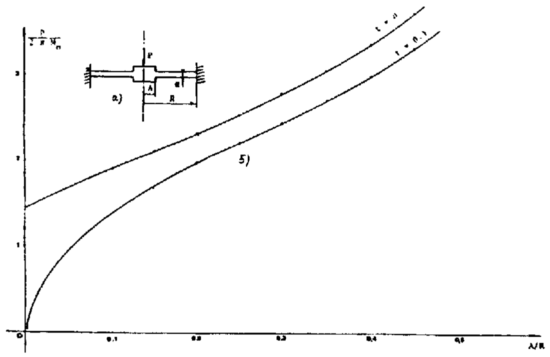

Figure 6.

CONCLUSION

Taking into account the computations made the following conclusions could be made:

a) For a propped plate the classic theory gives enough good results if

$$\frac{3R}{20} \le e \le \frac{R}{5}$$

b) For a fixed plate classic theory is suitable if

$$\frac{3R}{20} \le e \le \frac{R}{10}$$

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IMPACT OF THE BALL-CRUSHER GRINDING BALL LOAD AND THE NUMBER OF REVOLUTIONS ON THE SELECTIVE GRINDING IN THE PROCESS OF DRESSING OF CHROMITE-BEARING SOILS OF THE VURINOS OTHOLITE COMPLEX, WEST MACEDONIA - GREECE

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ABSTRACT
The weathering of ultrabasic rocks such as peridotites and dunites as well as the serpentines originating from them has led to a downward enrichment of valuable metals into the Vurinos complex. Nickel and cobalt could be absolutely enriched in certain zones where a weathered laterithic layer is observed while the iron and chrome spinel show a relative enrichment. As the mineralogical study made by X-ray and microscopic analyses as well as by microsounding showed that the more important products of the weathering are composed by ferro-hydroxy limonite and heavy minerals such as chromite and magnetite. The chromite grains are coalesced with the hard limonite aggregates in the soils. Thus they should be preliminary concentrated to have a possibility for their separation. For the purpose the samples are grinded selectively in a ball-crusher. After numerous of tests the following optimal grinding parameters are obtained: grinding ball load of the ball-crusher - 40 volume % and revolutions as of 30 % n_{krit}. The good grinding results are achieved in conditions of grinding ball load of steel balls with diameters 16, 12, 10, 8 и 3 mm respectively. The optimum grinding span is 15 min and in this case a content of 38 % Cr_2O_3 in a class of grading > 100 µm. The chrome loss is 13% in the class of grading <20 µm
Key wards: selective fine grinding, ball-crusher revolutions, chromite.

INTRODUCTION

Geological frame

The Vurinos massif is located in the Northern Greece province of Western Macadonia. It is of the type of "Super-Spreading Zone" (SSZ) otolith (Beccaluva et al., 1984, Pearce et al. 1984). There are number of these otolith which content chromite ore concentrations and thus they represent a scientific interest. That is way the SSZ otolith in that area could be considered as belonging to the world chromite reserves. For the reason the last fact let us have an opinion that the Vurinos massif material is very appropriate for investigations in respect of variability of the oregenetic, magnetic and tectonic processes. The Vurinos massif is considered as composed of three parts: Northern, Southern and Western Vurinos. The massif represents a fully separated ore body. The 12 km long otolith Vurinos vein is composed of a tectonic area which is probably of upper mantle material (shifted up during the time of a new crust formation) and a magmatic area formed by magma intrusion during processes of cumulative crystallization differentiation. Some of the chromite deposits are located in the dunites of the magmatic section.

The Vurinos massif situated on an area of 400 km^2 is separated from the big pindos and the ophiolites by mezzo-folded sediments (Smith, 1979). Ophiolitic rocks are represented in the mean zone of those sediments for which the same obduction direction. Therefore they are considered as co-oceanic (Smith & Moores, 1974; Smith, 1979). In the end, Vurinos has obducted during the Late Jurassic and Early Cretaceous through metamorphosed Lower Jurassic carbonates and Tertiary depositions along the West periphery of the Pelagonian (Moores, 1969). Smith (1979), Nazlor & Harlie (1976) и Rassios et al. (1983) point out that in that direction the obduction has been reoriented to the SSW direction.

Serpentinization and weathering processes of the Vurinos Otholites are investigated by Savvidis (1996), Savvidis & Hovorka (1996) и Savvidis et al. (1997, 2001a, 2001b, 2001c) и Hovorka et al. (1997).

EXPERIMENT FORMULATION

Selective fine grinding

A big amount of the material which is free of slime composed of limonite aggregates. They content also heavy materials such as magnetite and chromite. For achieving a high chromite recovery it should be outcropped. For the reason it was necessary the limonite aggregates to be selectively fine grinded.

As it was shown by the microscopic investigations of Hovorka et al. (1996) the chromite grains are very often aggregate with oxidized iron in such a way that it is impossible to obtain a valuable chromite concentrate by using of density separation which is usually applied for dressing of the primary ores. The Cr_2O_3 content in the concentrates of the laterite chromite ores which are recovered in a washed ore mass amounts of about 41 % at ratio of Cr - Fe equal to 1,4. The Cr_2O_3 content of the concentrate recovered from the primary chrome ores located in the same area and which Cr - Fe ratio were higher than that of the chrome spinels, amounts of about 50 % in conditions of the ratio 2,3 (Oh, 1984; Korn, 1970). A high quality dressing of the latherite chrome ores by using of the ore dressing methods is possible only in that case when a preliminary separation of the accreted grains has taken place. As the zones accreted with the chromite have a high content of FeO and substantially lower hardness than the chromite it is possible to obtain a better chromite product by using of selective fine grinding.

After considering of an investigation conception it was choosen the method of J. S. Oh (1985).

Grinding parameters influence

The ball-crusher was selected on the base of the more specific properties of the materials to be undergone to a selective fine grinding. Experiments related to the change of the different grinding parameters were performed aiming an optimization of the grinding conditions.

Ball-crusher parameters:

External diameter:	189 mm
Internal diameter:	175 mm
Ball-crusher length:	269 mm
Ball-crusher volume:	6470 ml

A smooth revetment ball-crush was chosen on the base of the theoretical and the reference data.

Diameter, mm	Weight ratio,%
16	30
12	23
10	19
8	16
6	12

Influence of the number of the revolutions and ball load of the ball-crusher

The chromite shows a brittle behavior during its processing so it is necessary to avoid the blow activity of the balls in the ball-crusher. For the reason the ball-crusher revolutions and the grade of its filling with grinding bodies should be determined very well. The optimal ranges of the revolutions and the grade of grinding ball filling were determined on the base of the results obtained by the performed tests. These values are as follow: the number of the revolutions are in a range between 20 and 40 % of n_{crit} and the degree of ball-crusher filling with ball load varying between 30 и 50 %. Different grinding time intervals ranging between 5 and 20 min were chosen to be possible a clarifying of the grinding kinetics. The result of the grinding allowed the bolting of the result product by screens of 100, 63 и 20 μm respectively and the four classes obtained were undergone to chemical analyses. The results are shown on a table. It was turned out that the number of the revolutions exert stronger influence on the results than the grade of the ball-crusher filing with grinding bodies. The last one proves the fact that the material fine grinding is relatively slightly influenced by the different forces of blow which depends on the grade of the filling mentioned above.

An increased chromite enrichment at number of revolutions as of 30 % of n_{crit} as well as a slight decrease of the Cr_2O_3 recovery were established for the solids of grinding size higher than 100 μm. It was established also that in the case of a higher number of revolutions - 40 % of n_{crit} the quality of the enrichment process become less and in the same time the recovery process was accelerated. It showed that at this number of the revolutions the selective action of the grinding balls was significantly decreased.

The results obtained by using of the finest class < 20 μm compared to the results related to the class > 100 μm were as follow: the content and the recovery of the Cr_2O_3 was increased rapidly at number of the revolutions as of 30 % n_{crit} . It was established that for obtaining of a better result of the grinding the grinding time should not to be more than 15 min. The grinding results obtained for a grinding time of 15 min are presented in the Figures 1 - 4.

As it is shown in the Figure 1 the grade of ball-crusher filling with grinding bodies exert a monotonic influence on the Cr_2O_3 content in the class > 100 μm when the number of the revolutions is 20 % of $n_{крит}$.

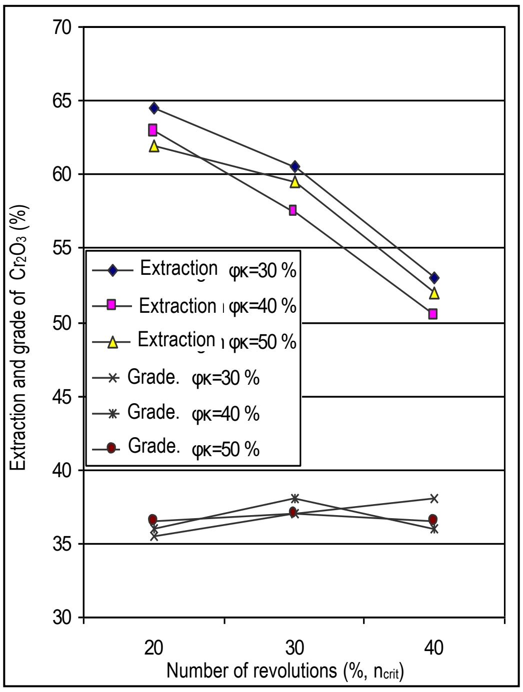

Figure 1. Results for the grinding of the class >10^{-4}mm depending on the number of the revolutions n_{crit} the ball-crusher grinding ball load. Grinding span - 15 min

When the ball-crusher filling with grinding bodies is increased the Cr_2O_3 content was increased from 35,5 to 36,3 %.

However, that result could be not established at a higher number of the revolutions. The highest Cr_2O_3 content – 37,2 % was established at number of revolutions 30 % of n_{crit} and filling grade of 40 %.

The grinding results was carried out further by using of microscope. There was not at all limonite aggregates. Nevertheless, the vein minerals such as quartz, piroxene and so on wich are still presented in the material should be separated.

The grinding results obtained at number of revolutions of 40 % of n_{crit} showed a highly undesired fine grinding of the chromite. As the best conditions for the fine grinding of the class of grinding size > 100 μm were established: number of the revolutions - 30 % of n_{crit} and grade of ball-crusher filling with grinding balls - 40 %.

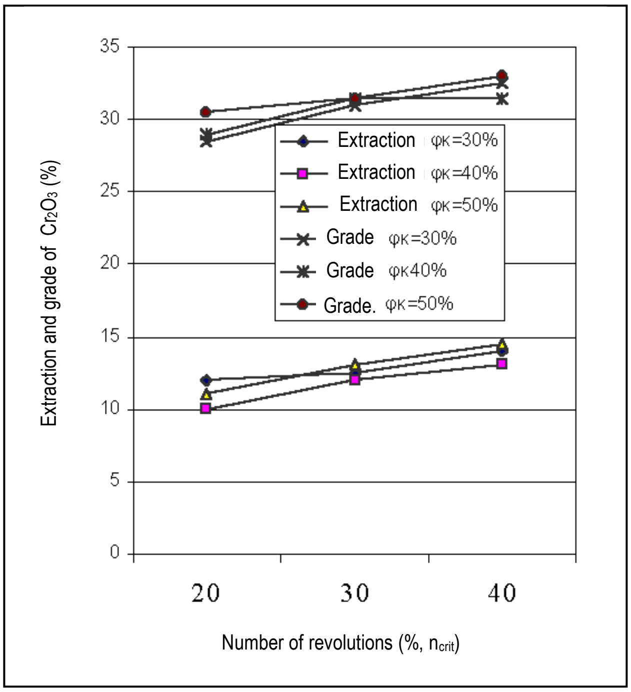

Figure 2. Results for the grinding of the class 100 -63 mm depending on the number of the revolutions n_{crit} the ball-crusher grinding ball load. Grinding span - 15 min

It could be seen from the Figure 2 that the desired dressing of the limonite aggregates in the medium class could be not achieved yet. The Cr_2O_3 content was still in the interval 29,1 - 32,5 %. The last fact could be explained as follow: the light limonite aggregates are so mobile in these conditions that they pass easy among the grinding balls and in that way they are not influenced by the last ones. In the limonite aggregates of the class of size > 100 μm as by-elements are most often observed fine heavy minerals and silicate minerals. Those inhomogeneous aggregates have a less hardness compared with the homogeneous aggregates which are composed only of agglomerated limonite and in that way they are being quite easily fine grinded in the ball-crusher. A high percent of limonite aggregates are presented in the class of the grinding size of 100 - 63 μm - about 70 % while heavy and silica minerals are not presented. Those aggregates are very stabile in respect to the crushing activity of the balls and that is why they are slightly fine grinded in these conditions.

The last grinding size class ore grinded during time of 15 min was bolted by screen of 80 μm. It turned out that the limonite aggregates are presented mainly in the class of grinding size of 80 - 63 μm.

The results of the grinding of the grinding class of size 63 - 20 μm are shown on the Figure 3. The Cr_2O_3. content increased contemporary with the increase of the number of the revolutions. The highest content of Cr_2O_3 was achieved at number of revolutions as of 40 % of n_{crit} and 50 % of the ball-crusher filling with the grinding bodies. That value amounts of 21,3 % in conditions of recovery of 18,8 %. The content obtained shows that a big part of that class is still assembled by limonite aggregates.

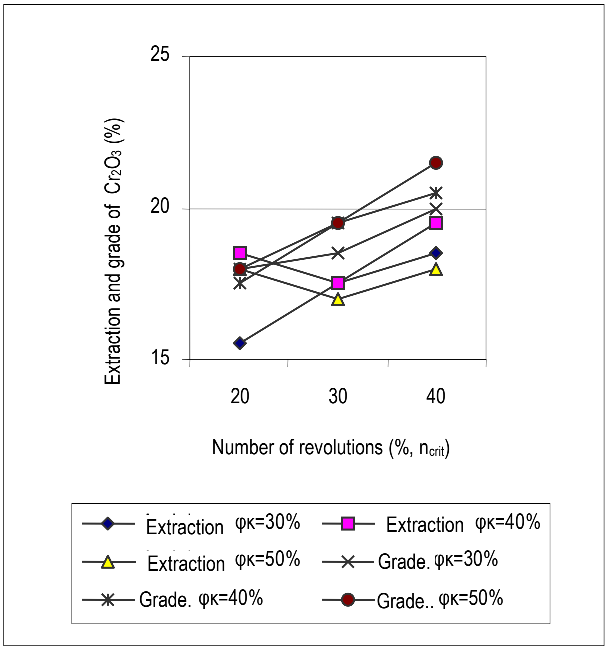

Figure 3. Results for the fine grinding experiments of the class 63 – 20 mm depending on the number of the revolutions n_{crit} the ball-crusher grinding ball load.

The finely grinded chromite is a premise for an increase of the Cr_2O_3 content and its recovery for the class of grinding size less than 20 μт. According to the curves shown in the Figure 4 it could be established that the Cr_2O_3 recovery depends more on the revolutions than on the grade of the ball-crusher filling with balls. A higher increase is observed when the number of the revolutions is 40 % of n_{crit}.

DISCUSSION OF THE RESULTS

After numerous of tests the optimal parameters of the grinding in respect to the grade of ball-crusher filling with balls as well as the number of the revolutions of the last one were found. As the most advantageous conditions among the all grinding conditions mentioned above were established the following ones: ball-crusher revolutions 30 % n_{crit} and the grade of ball-crusher grinding ball load as of 40 % because they could provide the best enrichment of the chromite high classes of grading.

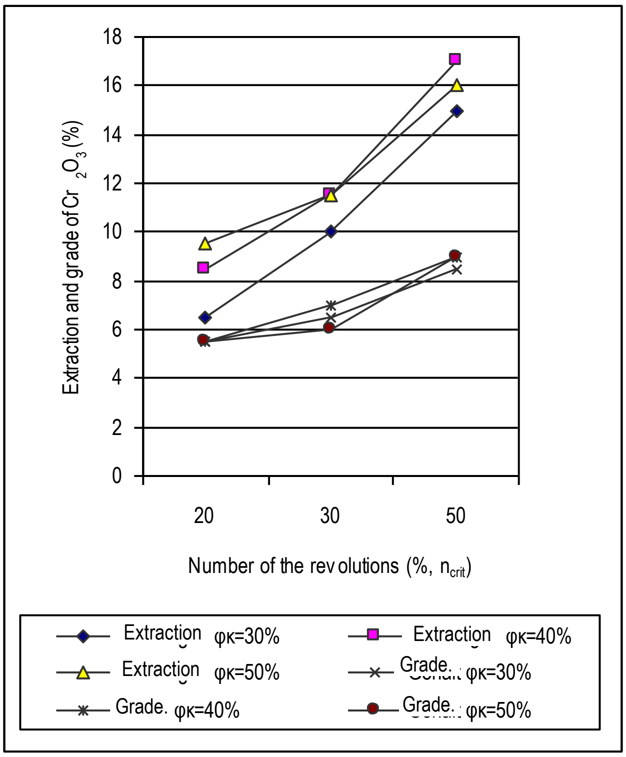

Figure 4. Results for the grinding of the class 63 - 20 mm depending on the number of the revolutions n_{crit} and the ball load of the ball-crusher; Grinding span - 15 min

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RESEARCH OF THE PROCESS OF REFINEMENT AT CENTRIFUGAL ROLLER MILL WITH MEANS OF DIMENSIONAL ANALYSIS

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SUMMARY
The results of laboratory examinations with centrifugal roller mills (CRM) are analyzed and on the basis of the accumulated experience conclusion are made for introduction of this kind of mills in production. In this paper the based model of process of grinding (refinement) with CRM is constructed and conclusions with means of dimensional analysis are made.
An example is presented of construction of a mill with ruling skidding of the grinding rollers, which corresponds to the boundary parameters of the model.
The deduced dependencies would be used to take optimal decisions at designing.
Key words: dimensional analysis, centrifugal roller grinding mills, optimum projection, optimum experiment, similitude, physical modeling

INTRODUCTION

Centrifugal roller mills (CRM) are machines for grinding. They use centrifugal forces created by relatively fast motion of grinding rollers. In comparison with rod and ball mills the use of fast CRM is characterized with:
- Smaller capacity and weight of mills;
- Better productivity;
- Smaller power consumption;
- Smaller wearing out of working parts;
- Higher universal for grinding of materials with different qualities.

More considerable problems in the process of maintenance of CRM:
- Fast and non regular outwearing on the grinding rollers;
- Decreasing the pressure of rollers on the materials with increasing of wearing on grinding rollers.

In the paper by Chalashkanov (1979) a profound analysis of the process of grinding is made on the base of theory of similarity and big number of experiments with laboratory CRM. There is a tendency of being slow of the advance of theory in comparison with the applicatin of CRM. D. Obreshcov and collective (Obreshcov D., 1965, Obreshcov D. et all., 1973) have made an attempt to accept centrifugal roller mills in manufacture. Base work was made on the tendency of increasing wearing resistance of the rollers. The process of wearing is described with a complicated system of differential equations, use of which meets some difficulties. This process of research is realized with big number of experiments with laboratory CRM. In the paper by Chalashkanov (1979) preferences to empirical research of the process of grinding are given.

THE PURPOSE

To apply a well-founded model of the process of a refinement is offered in this paper, created on the base of great number of experiments and conclusions by Chalashkanov (1979) and methods of dimensional analysis by Dimitrov (1998, 1999).

To apply a method for full use of the information about the working process of CRM, thus to realize rational simulation.

SCHEMATIC MODEL OF GRINDING WITH CRM

The process is characterized with two elements which are in dynamic condition:
- Rollers;
- Material of grinding.

The material and the rollers influence each other and as a result occurs destruction, fast fragmentation of a material and gradually wearing of the rollers.

The motion of the material from upward to down is under the action of the weight and at the same time it scrolled by the rotor.

The rotary motion of the rollers exists as a result of motion of the rotor in relation to the drum and at the same time they are skidding. The movement of each roller can be presented as a sum of free rotation without skidding at the given moments, alternatively replaced from a status of the block of a roller.

In definite conditions the status of process can be near to one of combinations (I.A, II.A), (I.A, II.B), (I.B, II.A) and (I.B, II.B) (Fig.1). During the usual work of CRM the dynamic process with dynamic elements (rollers and grinding material) is functioned. Their movement can be described as a superposition. The wearing can be represented as a process that is compounded of I.A and I.B, and process of a refinement - IIA and IIB.

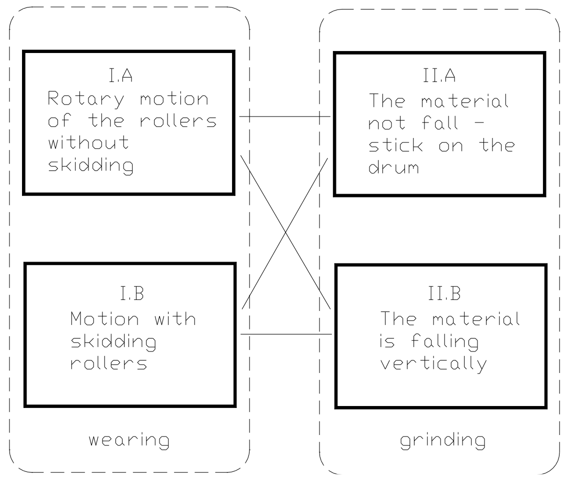

Figure 1. Schematic model of grinding with CRM

In addition, giving the wear process of rollers, it is necessary to think that at their cylindrical form and free movement, owing to free motion on the grinding material is realizing pushing away from a drum and after that strong impact on him at borders. This dynamic process is named an intersection of rollers. In result of that the wear process in borders of roller is fast.

SIMULATION OF WEARING PROCESS OF THE ROLLERS

By Chalashkanov (1979) and other authors the wearing process of the rollers of CRM depend on:
- Physicochemical properties of the grinding material;
- Type of working surfaces of the grinding mill;
- Thermal properties and temperature of the working parts;
- Geometrical measures, speed of motion and time for work.

d_p, h_p - Diameter and height of one roller,m:

a_p - Number of rollers on a level;

$k_{ет}$ - Number of levels;

D_k, H_k - Diameter and height of the barrel of the grinding mill, m;

w - Angular velocity of the rotor, s^{-1};

t - Duration of work.

For counting the wearing is introduced value J - speed of wear, that expresses the capacity of separated material from each roller for a unit time m^3/s .

- Rules defining speed of the wear process of the rollers (in short wear) J:
- The wear depends on right direction from pressing force P of each roller on the barrel;
- It depends on general working surface and continuity T_a of work before amortization of rollers;
- On frequency of effects by grinding material on a unit area from surface of the rollers;
- The wear is bigger in borders of the rollers because of specific way of motion (crossing of axis) of the rollers.

For full description of a process it is not enough to be expressed analytical dependence between its parameters. It is necessary to clarify and involvement of each of the parameters as physical quantity, expressed from physical dependence and dependence that is deriving from the subject of the task (we'll call it subject dependence) (Dimitrov, 1998). Under physical dependence we understand the presentation of the formulas of the parameter's dimension by some grounded physical quantities. This dependence is manifested as the grounded tendency and it is possible to separate it from randomness and manifestation of an empirical dependence. The subject dependence is link between the physical quantities, which appears from the subject of the task - concrete application in certain practical area. This type of dependence adds to the information from physical and empirical dependence.

From point of view of possibilities to apply the dimensional analysis by Dimitrov (1998) a process is named simple if it is described by analytical dependence, represented with exponent monomial and complex process when it is described with sum of exponent monomials. For the application, which we make, we admit that the processes are represented as a superposition of simple processes.

According to the perceived from us model of a refinement (fig.1), the process of wear is superposition of the free rotation of the rollers without skidding and work with the block of rollers.

For description of the process we use dimensional analysis. In original consideration, we divide decisive parameters of the processes on compulsory and which possibly participate.

The system of physical quantities include:
- $P = F_u$ - Normal pressuring force of each of rollers;
- $\dfrac{G_p}{g}$ - Average mass of rollers;
- $S = \pi d_p h_p a_p k_{ет}$ - working area under influence in moment t of work;

In each simple process takes part some of physical quantities:

t - Time for work $t \in (0.T_a)$, where T_a mean time for amortization of the rollers under certain conditions. The roller is amortized at reaching average size $d_a = 50mm$.

$v = \omega D_k$ - Linear speed of rotor in relation to barrel.

When working with the block of the rollers, the wear depend in right direction by:

h_p - Height of the roller – describes influence of crossing of axis of the rollers on wearing.

We use also specific for a dimensional analysis a method for choice of basic parameters of dimension, which give dependence between some of parameters of the process:

$$[P]=\frac{L_1M}{T^2},\quad \left[\frac{G_p}{g}\right]=M,\quad [S]=L_2^2,$$

$$[v]=\frac{L_2}{T} \text{ and } [t]=T .$$

At rotation without skidding $[J_1]=\frac{L_1L_2^2}{T}$,while at work with block of rollers $[J_2]=\frac{L_1L_2^2}{T}$ or $[J_2]=\frac{L_1L_2L_3}{T}$ depending on if h_p takes part.

In dependence of which of the quantities t or v takes part in system of physical quantities, are received two types generalized schemes sch.1 (fig.2) and sch.2 (fig.3)

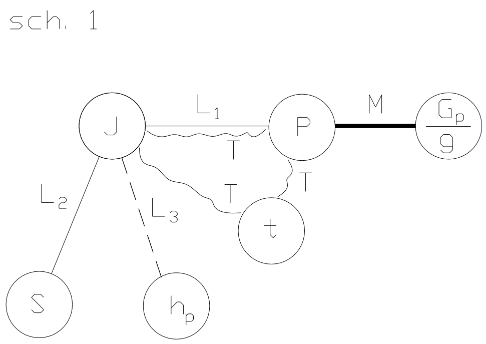

Figure 2. Scheme of the dimensions – sch. 1

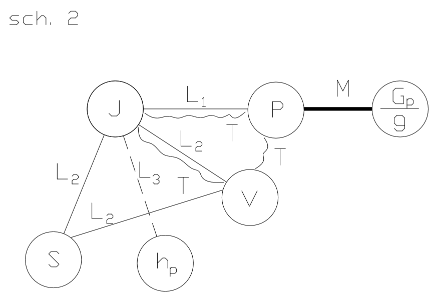

Figure 3. Scheme of the dimensions – sch. 2

Schematic the generalized equivalencies are:
A. At the rotation without skidding

$$[J_1]=[P]^{x_1}\left[\frac{G_p}{g}\right]^{x_2}[S]^{x_3}[z]^{x_4} \tag{1}$$ and

B. Work with the block of rollers

$$[J_2]=[P]^{x_1}\left[\frac{G_p}{g}\right]^{x_2}[S]^{x_3}[z]^{x_4}[h_p]^{x_5}, \tag{2}$$

where with z is denoted one of the quantities t or v .

Therefore are received 2 x 2 = 4 variants for the process. The structural formulas for the simple processes A. and B. are given in table 1.

Table 1: Structural formulas of the simple processes

A. sch.1:	B. sch.1:
$J_1=C_1\frac{gP}{G_p}S\cdot t$	$J_2=C_2\frac{gP}{G_p}S^{\frac{1}{2}}\cdot th_p$
A. сх.2:	Б. сх.2:
$J_1=C_1\frac{gP}{G_p}\cdot\frac{S^{\frac{3}{2}}}{v}$	$J_2=C_2\frac{gP}{G_p}\cdot\frac{Sh_p}{v}$

The choice of the appropriate variant is realized by experimental way. Also there are the following considerations for choice of variants A. sch.1 and B. sch.2 - the working surface S is proportional to the number of effects of the particles of a grinding material on unity of this area - proportional on the speed of wearing.

Therefore the structural formula of the wearing is:

$$J=C_1\frac{gP}{G_p}S\cdot t+C_2\frac{gP}{G_p}\cdot\frac{Sh_p}{v} \tag{3}$$

From $P=F_ц=\frac{G_p}{g}\cdot\frac{D_к-\tilde{d}_p}{2}\cdot\frac{v^2}{D_к^2}$, $v=D_к\cdot\omega$ and $\tilde{d}_p=L(t)$, $t\in(0,T_a)$ is receive

$$J=\frac{\pi}{2}\frac{h_p}{D_к}\omega a_p k_{ет}\left(C_1D_к\,\omega+C_2h_p\right)x$$
$$x\,[D_к-L(t)]L(t) \tag{4}$$

Let $\Delta V=\pi\left[\left(\frac{d_p}{2}\right)^2-\left(\frac{\tilde{d}_p}{2}\right)^2\right]h_pa_pk_{ет}$ is average volume of a material, detached from the work parts of the rollers for the period t . Here d_p is the initial diameter, and $\tilde{d}_p=L(t)$ is the average diameter of rollers in moment $t.L(T_a)=d_a=50$ mm.

Then $J=\frac{\partial\Delta V}{\partial t}=-\frac{\pi}{2}L(t)L'(t)h_pa_pk_{ет}$ and after replacement in the structural equation is received

$$\ln\frac{D_k-L(t)}{D_k-d_p}=C_1\frac{\omega^2t^2}{2}+C_2\frac{\omega th_p}{D_k} \tag{5|}$$

For defining of constants C_1 and C_2 is used data which refers to the grinding of dolomite. The data is divided into experimental and test parts (table. 2).

Table 2: Data for calculate of wearing

T_a	h_p	d_p	ω	D_k	d_a
Experimental data					
1260	150	70	100	250	50
1400	120	70	80	250	50
2120	90	90	60	250	50
2480	90	90	80	250	50
1920	45	90	100	250	50
2220	45	90	80	250	50
2010	45	90	80	250	50
2480	45	70	100	250	50
Test data					
2010	90	70	80	250	50
2640	90	90	60	250	50
2460	45	70	80	250	50
1720	90	90	100	250	50

The experimental data is used for calculation of C_1 and C_2 by method of the least squares, and test data – for defining of errors.

The values $C_1 = 3.4 \cdot 10^{-11}$ and $C_2 = 1.4 \cdot 10^{-5}$ received. The mean relative error for test data is 4%.

DEFINITION OF THE USEFUL POWER OF MILL

For deducing the formula for the power, the scheme on fig.1 can baused and a system of parameters, including grounded quantities for wearing J and efficiency of the mill Q. Because the useful work for grinding is related to the work wearing of the rollers, power also can be represented as a superposition $N = N_1 + N_2$ of power N_1 at free rolling of the rollers and power N_2 at working with the block of rollers. The corresponding simple processes have schemes of dimensions, which are obtained from the properties given with the respective schemes of wearing with addition of new parameters (fig.4 and fig.5).

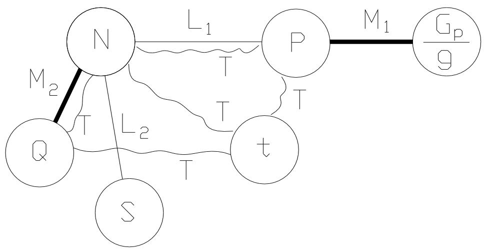

Figure 4. Scheme for determination of power corresponding to sch. 1

We add the data from table 3 to that from table 2, including: the power N, efficiency Q and working surface S at mean diameter $d_{cp} = \dfrac{d_p + d_a}{2}$ of a roller.

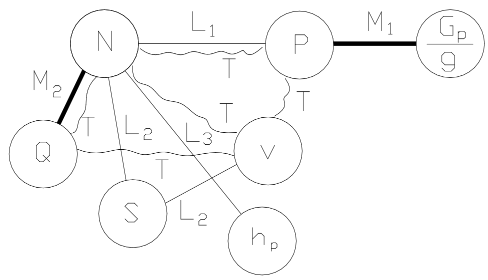

Figure 5. Scheme for determination of power corresponding to sch. 2

Table 3: Data for calculating of power

N	Q	S	d_{cp}
Experimental data			
7	0.1	200000	60
4	0.1	100000	60
2	0.1	79168	70
4	0.1	78168	70
4	0.1	59376	70
2.5	0.1	29688	70
3	0.1	39584	70
2	0.1	25447	60
Test data			
4	0.1	59375	70
2	0.1	76341	90
2.5	0.1	29688	70
8	0.1	300000	90

The structural formula is

$$N = C_1 \frac{gPQS^{1/2}}{G_p} + C_2 \frac{gPQS}{G_p h_p} \qquad (6)$$

From the experimental data are received $C_1 = 1.8 \cdot 10^{-7}$ and $C_2 = 2.2 \cdot 10^{-9}$ and the mean relative error for the test data is 10 % .

CENTRIFUGAL ROLLER MILL WITH SKIDDING ROLLERS

The different boundary states included in schematic model (fig.1) are simple processes, which in actual applications do not meet separately. In the most often met construction of a centrifugal grinding mill the motion of the rollers is provoked from the motion of the rotor in relation to the barrel. At which the process of grinding has weakly manifested skidding - status I.B. In some cases for more efficient grinding of material is necessary to combine pressure with rubbing. Fig.6 represents CRM working in this way.

The principle of work of the grinding mill is given as follows: Material is fed throush the hole 1 by gravitation. It is distributed uniformly on the barrel of the mill by blades 2 and is grinded with rollers 3, pressed on the barrel 4, under the action of a centrifugal force, which is provoked from rollers rolling on the internal cylindrical surface of the barrel. The rollers have bearings to slippers 5 (on which they have axial motion), so they gain two independent motions. The rollers roll around their axis by the electric motor through reducer 6 with the universal coupling 7. On the other hand the barrel of the reducer 6 receives compulsory rotary motion from reducer 8. As a result of superposing from these two motions, the roller affects pressing and rubbing on a particle from the grinding material. By this method is received considerably refine product in comparison with the mills with cleanly rotary motion of rollers.

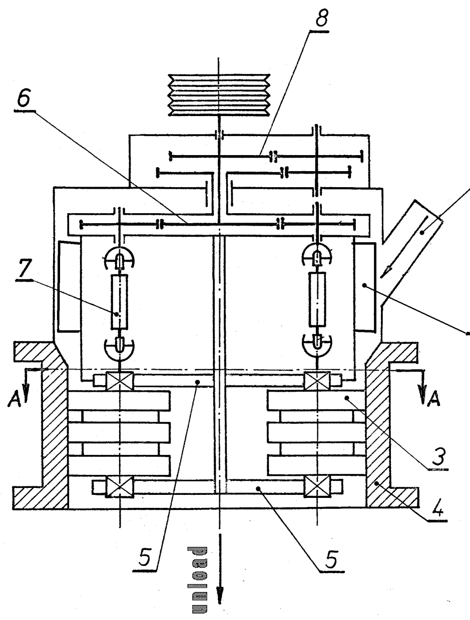

Figure 6. CRM with control on the skidding of the rollers

The mill is intended for high quality and dry refinement of ore and nonmetal minerals. It is possible to be used for experimental research of the schematic model on fig. 1.

CONCLUSION

The offered schematic model gives a possibility for applying of dimensional experiment by deducing of dependencies between the parameters.

The given example of CRM with control on the skidding of the rollers and received results for the error (4% and 10%) prove the correctness of the schematic model (fig.1).

The construction on fig.6 confirms the equality of the states I.A and I.B of the process of grinding, that is not manifested at the customary constructions of CRM.

The considered here common model of the grinding process and offered method of experimental research will found application at theoretical explanation of processes, which accompany with a grinding and in a practical construction of effective CRM

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CHEMICAL METHODS FOR PROCESSING PLANTS MACHINES SLAG CLEANING

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ABSTRACT
Paper deals with slag formation in compressors and applicable measures to prevent it. Mechanical and chemical depositions cleaning are discussed and evaluated. Technology for its elimination under application of chemical agents is presented in details. In conclusion regulations for safety operations with acids and alkali has been formulated.

SLAG PROBLEM IN SOME PROCESSING PLANTS' MACHINES

Compressed air for some subsidiary technological procedures in ore processing plants is required. For that reason compressors for low pressure are used. Processes with great amount of heat liberation take place in such machines and need for cooling arose consequently. Cooling is a process of heat transfer from hot walls and maintaining the temperature in special limits. More often water is applied as cooling liquid and as a result on pipelines and machines walls hard depositions are accumulated which cause difficulties in normal cooling process. It can be worsen so severe that the temperature of exit compressed air can reach 190-200°C (in comparison with maximal admissible – 170°C). This circumstance could be precondition for explosion if hot residue particles from vacuum valves burn oil deposits. This could become accidental situation with high-risk degree for workers and equipment.

In the processing plant "Elatzite – med" JsC, village of Mirkovo near Sofia are used traditional piston compressors as well as special compressors for air conditioning system, which role is to maintain constant temperature for computer remote control center. From there technological parameters and processes are controlled remotely. Both types of compressors operate in continuous regime that make the problem discussed in this paper immediate and topical.

Information about slag

Many soluble types of brine make slag depending on their type. For instance calcium bicarbonate $Ca(HCO_3)_2$ make soft depositions, while calcium sulfate $CaSO_4$ – hard one.

Main reason for slag formation is separation of less soluble brines from their saturated solutions in case of temperature increase. Little increase in water temperature is enough to evaporate little amounts water and saturated solutions in regard to calcium and magnesium bicarbonates - $Mg(HCO_3)_2$, due to their little solubility.

According to its chemical composition slag could be classified as:

- Carbonates consisting more than 50 % $CaCO_3$;
- Gypsum – up to 50 % $CaSO_4$;
- Silicates – over 25 % SiO_2;
- Mixed – consisting calcium and magnesium carbonates and silicates.

Water ability to form slag is called water hardness and is due to soluble in it brines of calcium and magnesium.

It is well known that slag heat transfer coefficient is several times less compared with steel and cast iron - material of cooling walls. By that reason even in presence of thin deposition layer cooling efficiency decrease rapidly.

PRETPEATMENT OF WATER FOR SLAG FORMATION PREVENTION

Several methods for water treatments are known, based mainly on reagents adding into it. These reagents hamper crystallization processes or change concentration of soluble elements. Such treatment is reasonable only if the water is turnover and the process is linked with cooling towers construction. Recent practice in processing plants show that pretreatment of water is not profitable and that is why industrial water is used there.

METHODS FOR SLAG ELIMINATION FROM MACHINES, COOLERS AND PIPELINES

Accumulated depositions on cooling systems' walls can be eliminated either in mechanical or in chemical way.

Mechanical way

This method requires disassembling operations in order to ensure access to the accumulated slag. Mechanical removal means to scrape off the residue with steal scrapers and wire brushes at reachable places. In practice such surfaces are very limited in number. That is why mechanical way is not applicable for full cleaning especially at hard to reach places. There exist another problem – a risk to damage the metal in thin walls installations.

Chemical way

Slag is eliminated by solving with appropriate reagents such as hydrochloric acid, chom acid, alkaline, natrium fosphatus etc.

Acids are applied to carbonate depositions, while the alkaline – for sulfate or silicate ones. The action of such chemicals transforms the slag into slurry by its shagging. Reagents effect is achieved by circulation of the chosen solvent or by its presence for certain time inside the equipment. Special supplements called inhibitors are added in order to prevent metal walls from corrosion. These are substances able to slow down or prevent metals from corrosion in aggressive acid environment.

SLAG ELIMINATION FROM COMPRESSOR WITH HYDROCHLORIC ACID

Conditions forcing cleaning

In the process of compressor operation when:

- Water is sufficient and its outlet temperature is 30-35°C;
- Compressed air outlet temperature precedes the norms (170° C) with 8-10°C

these are serious indirect arguments for bad cooling due to slag accumulation. Cleaning is requirement. Its postponing will lead to further depositions formation and even more difficult removal afterwards.

Technological operations required by chemical cleaning of slag are discussed below.

Cooling system disassembling

Compressor is normally cooled at the following places: cylinder water mantel from I-st degree, intermediate cooler between II degree and cylinder water mantel II degree and I. More often low-pressure compressors (mainly such types are used in processing plants) are linked in one cooling system, where water is supplied. That is why disassembling of pipelines, joining these areas, need to be done as first operation. Then the coolers and cylinder mantels covers are removed. Outside inspection of these spaces is performed and washing with water through hose with pressure 0,1-0,2 MPa in order to wash out mechanical and oils depositions, sands etc.

Taking samples for depositions tests

Samples from cleaned water mantel (cooled space) mechanical depositions are taken in order to test its composition. This is required only at first cleaning of equipment. Such sampling is not obligatory in further cleaning if water composition has not been change and no reason for slag structure changing exists.

Depositions analysis predefines reagent usage. Our research shows that slag is mainly with carbonate composition, which lead to hydrochloric acid (HCl) application for its cleaning.

Technical means for cleaning

Equipment needed for this action are: containers for solutions, electrical pump, hoses and tabs, as shown on fig. 1.

Container 1 serves as place to make the solution. Ordinary 200 l barrel with removed upper cover can be used.

Container 2 is similar to 1, but at its lower part tab 3 for slurry discharge and tab 4 (link between barrel and pump) are mounted.

Pump 5 is normal centrifugal pump and there is not need to be acid-proof. Its motor is one phase electrical unit.

Hoses 6 and 8 are with diameter $1\frac{1}{2}''$ or $2''$.

Preparation of solutions

If the reagent has been already chosen (in our case hydrochloric acid, it is needed to define its concentration. References show that carbonate slag are removed by application of 2 to 12% hydrochloric acid water solutions. Hydrochloric acid concentration depends on metal wall depth of cooling space and on depositions depth. Design requirements for water mantels depth are serious (over 10 mm) and by that reason solutions with great concentration can be applied (10÷12 %). When cleaning of intermediate cooler, built from sheaf of pipes with wall depth of 2 - 2,5 mm, hydrochloric acid concentration should be less - 4 - 5 %.

Optimal concentration depends also on slag depth. Depositions with great depth should be treated with less concentration but with great time duration. Higher concentration of acid lead to strong chemical reaction, to big particles elimination which hamper circulation of cleaning liquid. Pipes from intermediate cooler are very narrow, which predefines thicker slag layer and consequently application of solution with less concentration.

Hydrochloric acid is produced with 37% concentration. In order to count how much acid with appropriate concentration should be ordered simple calculations should be done. For example 100 l water solution with 5% hydrochloric acid concentration should be made by adding 13,5 l hydrochloric acid (37%) into 86,5 l water.

Acid is added to water gradually under constant mixing

Different inhibitors are added to thus prepared solution. Composition and quantity of these substances are chosen under technical and economical reasons. When cleaning procedure is performed for installations with thick walls higher concentrations should be used and vice versa. Our research shows that application of inhibitor Urothropine is very appropriaate in dosage of 10 g per 1 l solution for cylinder mantel cleaning and 25 g per 1 l for intermediate cooler.
Solution amounts depend on cooling space volume need to be cleaned.

Cleaning technology

It is recommended that slag cleaning should start from that cooling space where lowest concentration is required, in our case intermediate cooler. The purpose of this is in case some amount hydrochloric acid remains unused to be applied for next objects.

Slag cleaning can be performed in two ways:

- Filling of whole cooling space with solution and its remaining there for 10-12 hours;
- Solution is constantly added into the space by pumping (circulation way of cleaning).

Advantages of the second method (circulation) are out of any doubts and such technology is strongly recommended.

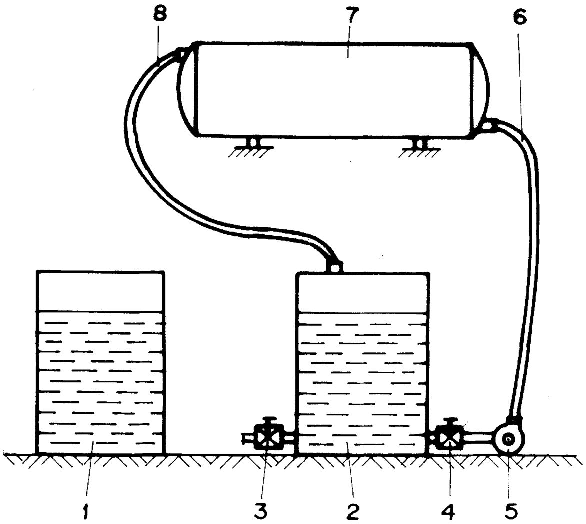

Figure 1.

Depositions cleaning itself is shown on figure 1 on the example of intermediate cooler. Into reservoir 2 needed solution (120-150 l) are added and by pump 5, hose 6, cooler 7 and hose 8 continuous solution circulation is achieved, which consequently lead to slag cleaning. Regularly solution status is tested. If the solution forms foam the process is in normal condition. In case foam forming stops it can mean one of the following:

- Slag is eliminated and the cleaning is over;
- Hydrochloric acid is spent out, but still there is slag remaining on the walls.

Testing of cleaning process is performed in the following way. 40-50 ml from cleaning liquid are pour in a glass and several drops of 10 % argenium nitrate solution are added. If white depositions appear it is certainly that hydrochloric acid has not been spent off completely and slag has been cleaned. The absence of white deposition shows that the acid has been spent off and cleaning should continue with new amounts of solution.

Duration of cleaning operation depends on several factors and normally prolong 3-4 hours.

Washing of cooling space

On end of cleaning process solution is collected into the vessel. If whole hydrochloric acid has been utilized the solution is drained into wastewater canals. If some acid has not been used the solution is further applied for preparation of other cleaning solutions.

The vessel is cleaned with flowing water, which with slurry drains out through tab 3. After washing the vessel is filled with technical water and by pump for 15-20 min washing of cooler is in progress. On the end of washing procedure some sodium alkaline or caustic lime solution is added so that neutralize acid remains on walls.

Slag cleaning from cylinder water mantels and from water transporting pipelines, water reservoirs etc. is performed in similar way

LABOR SAFETY IN SLAG CLEANING CHEMICAL TECHNOLOGIES

Great amounts of acids and alkaline are used in such technologies that impose serious requirements for safety operations. Some specific rules are:

- Acids concentrates are transferred from one vessel to another through siphons with rubber pump and tab placed on the vessel. Pouring out of acid should be done regularly and only $\frac{3}{4}$ of vessel volume is filled;
- Dilution of concentrated acid is performed by adding the acid into water;
- Plastic gloves with long cuffs and safety glasses should be ware always for acids are highly mordant;
- Acid solutions are drained only after their dilution.

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DIAGNOSTICS OF ROLLING BEARINGS OF MACHINES FOR EXTRACTION AND PROCESSION OF ROCK MATERIALS

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RESUME
The article deals with the matter of rolling bearings wearing effect, expressed by increase of their radial clearance, on the dynamic characteristics of diamond discs of disc and cutting machines for processing of lining materials of rock origin. A method is proposed for establishing the size of the radial clearance by means of non-dismantling control of vibrations.

The main problem in the maintenance of machines for extraction and processing of lining materials of rock origin is how to control the condition of the separate units and architectonic components during the period of operation. This control is directly relating to the quality of the products and is implemented by means of labor and time consuming mounting and dismounting operations.

The methods of technical diagnostics, in particular the non-dismantling control of vibrations, are a means of making the maintenance of machines in this industry more precise and up-to-date. The machines themselves react to defects and wearing of their components and units, bad assembly, etc. by changing the conduct of their vibrations. The implementation of the non-dismantling control of vibrations requires normalizing of the vibration indicators (by frequency and amplitude) beforehand appropriate to the design characteristics of the particular machine.

In the particular case is treated the matter of the rolling bearings wearing effect (increase of the radial clearance) on the vibration characteristics of the diamond disc of disc and cutting machines. As it is known, the radial clearance in bearings is established by dynamic eccentricity, which is equivalent to unbalance [1,2]. If we assume that the disc is perfectly balanced, then the radial clearance in the bearing preconditions the shift of its geometric center from the theoretical rotation axis (Fig.1).

The following assumption were made in research of this problem: the shaft is non-deforming, its mass is insignificantly small as compared with the disc, the bearing shields are perfectly hard in radial direction and play the function of vibro-acoustic bridges, the damping in the system is ignored. The shaft and the disc are coaxial and rotate at one and the same angular speed. The shift of the geometrical center of the disc from the theoretical rotation axis in result of the radial clearance in the bearing creates a centrifugal force, which could be presented by means a vertical component F and moment M [4] (Fig.1).

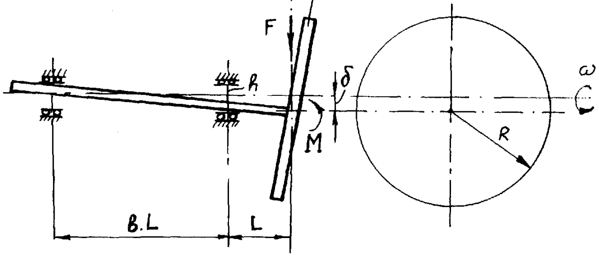

Figure 1.

$$\begin{cases} F = m\omega^2\delta \\ M = I_g\omega^2\theta \end{cases} \quad (1)$$

where:

- m - mass of the disc;
- ω - angular speed;
- $I_g = m\dfrac{R^2}{4}$ - radius of the disc inertia towards its diameter
- δ and θ - parameters, which determine the shift of the geometrical center of the disc towards the rotation axis.

Using the method of the influence factors and the Maxwell's theorem of reciprocity, δ and θ are as follows:

$$\begin{cases} \delta = F.\delta_F + M\delta_M \\ \theta = F.\theta_F + M\theta_M \end{cases} \quad (2)$$

where: $\delta_F, \delta_M, \theta_F, \theta_M$ are influence factors reflecting the linear and the angular shift of the shaft axis from the theoretical rotation axis as follows:

$$\delta_F = \left(\frac{L^3}{3EI}\right)(1+b)$$

Shift of the shaft axis caused by a force unit applied.

$$\delta_M = \left(\frac{L^2}{6EI}\right)(3+2b)$$

Shift of the shaft axis caused by a momentum unit applied.

$$\theta_F = \left(\frac{L^2}{6EI}\right)(3+2b)$$

Angle of shaft inclination caused by a force unit applied $(\delta_M = \theta_F)$

$$\theta_M = \left(\frac{L}{3EI}\right)(3+b)$$

Angle of shaft inclination caused by a momentum unit applied.

After substitution of the influence factors and transformation of equations (2), for the frequency equation of the system is obtained:

$$\begin{vmatrix} \left(1-m\omega^2\delta_F\right)\delta + \left(I_g\omega^2\delta_M\right)\theta = 0 \\ \left(m\omega^2\theta_F\right)\delta - \left(1+I_g\omega^2\theta_M\right)\theta = 0 \end{vmatrix} \tag{3}$$

From equations (3) can be established the frequency and the amplitude of the vibrations due to radial clearance in the system and its size. After simple geometrical transformations is obtained the size of the radial clearance h:

$$h \approx 2(\delta - tg\theta) \tag{4}$$

Formula (4) is an approximate solution of the radial clearance size because of the assumptions made to simplify the analysis. It can be used with sufficient practical precision only with respect to discs, which are designed in accordance with the diagram on Fig.1 and operate within the optimum range of cutting speeds.

The adopted approach to analyzing the frequency characteristics of the system as a function of the radial clearance well illustrates the necessity for setting standards of the vibration indicators appropriate to the structure of the particular machine and its specific features such as: balance quality, dynamic stresses, deformation and strength characteristics, stability, suspension type, pliability of the foundations, etc.

The technical implementation of the non-dismantling vibrations control provides an opportunity for early diagnostics of pending damages in the machines and timely repair works.

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ABOUT SOME TECHNOLOGICAL PERFORMANCES OF DIAMOND CIRCULAR BLADES FOR CUTTING ROCK MATERIALS

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ABSTRACT
Here is considered the market situation of diamond circular blades in our country and on the bases of the analyses is suggested to produce them only on the bases of the physical and mechanical characteristics of the rock materials. About the production of diamond circular blades is commented the case of using synthetic diamond produced according to the requirements of the standards of FEPA and USA. The indicators for production of circular diamond blades in conformity with the type of the rock materials are dealt with in detail.

THE PROBLEM OF CHOOSING CIRCULAR DIAMOND BLADES

It is well known that a big assortment of diamond circular blades for cutting different materials, produced by foreign and Bulgarian companies, has been offered recently at our market. In most cases the diamond circular blades, which companies offer are so-called diamond circular blades for common purposes: cutting concrete, asphalt, ceramics, terracotta and different types of rock materials. Obviously, these instruments cannot satisfy the specific technological requirements for rational sawing of different rock materials. Moreover, these saw blades are with various qualities prices, which in most cases are determined by the market situation and to less extend by the technical and technological parameters of the instruments. In such cases, it is not rational to use diamond circular blades, which are not consistent with exploitation conditions of work and especially with the type and physical and mechanical properties of the rock material. Under the conditions of market economy the high competition between companies, producing diamond circular blades, forces them to take commission for single pieces which are consistent with a particular user's requirements. In this way, in order to do one correct commission for making diamond circular blades, which satisfy the user's requirements to the highest degree, it is necessary to avail of definite information, which is scrutinized below.

The production of diamond circular blades is connected with two kinds of factors: limiting and eligible.

The limiting factors mainly are connected with the kind, physical and mechanical properties and granule composition of the diamond material, which the producers of diamond circular blades supply from producers of diamond materials.

The eligible factors are defined by the user depending on the physical and mechanical properties of the sawing rock materials and other operating conditions and requirements.

Limiting factors of the technological characteristics of circular diamond blades

Specification of circular diamond blades. This is one of the basic factors, which determine the working capacity and technical resource of circular diamond blades. At present circular diamond blades for sawing rock materials are made exclusively from synthetic diamond. This stuff is made with programmable physical and mechanical qualities and granule characteristics. These parameters are defined by the technological parameters of diamond synthesis.

The synthesis being a company secret, the factories produce synthetic diamond with different indexes, but their materials correspond to the requirements of ГОСТ or of FEPA and USA. The production of the main manufacturers of synthetic diamond in the world corresponds to standards of FEPA and USA, so here are scrutinized only these materials. The synthetic diamonds are manufactured with various properties grouped as follows: SDA, SDA85, SDA100 and SDA100S.

The synthetic diamond SDA is typical for its very good strength index and controlled granule characteristics. This material is suitable for making segments for circular diamond blades for sawing rock materials with medial hardness such as marble and limestone.

The material SDA85 is designed for diamond tools for sawing rock materials with a wide range of hardness. It is accepted that this kind of diamond is suitable for sawing different non-metal materials.

The synthetic diamond SDA100 is more wear-resistant than the above mentioned. This sort contains a higher rate of diamond grains with raised hardness and this circumstance makes it suitable for tools sawing very hard rock materials such as granite and quartz. The tools with diamond segments made of SDA100 require higher engine power than those made of SDA and SDA85.

The synthetic diamond SDA100S is of exceptionally high quality and has the highest price. It is used for special needs as making segments for saw mills, which can saw very hard rock materials, as well as for drill heads.

It is very difficult to determine which sort of diamonds is most suitable for sawing rock materials with circular diamond blades. The basic criterion is realization of lower prime cost for a single sawing surface, which is determined by experimental research.

Diamond material granule characteristics. It is well-known that the granule characteristics of ordinary grinder diamond tools are determined quantitatively by the standards of FEPA and the USA by the so-called 'mesh system', which is different from the metric system, used in some Eastern Europe countries, Russia and others. The producers of synthetic diamond of sorts SDA, SDA85, SDA100 and SDA100S supply material for sawing tools only by the USA standard ASTM with grain dimensions higher than 80 mesh i.e. fraction 60/80, 50/60, 40/50, 30/40 and 20/30 (the latter is with the biggest size). In this aspect the granule characteristics factor of diamond materials is limiting for the producers of circular diamond blades with which circumstance the consumer have to consider.

Circular diamond blade indexes determined by the type of rock material.

Diamond concentration. This is one of the most important indexes of circular diamond blades, which determines its sawing properties, output, technical resources and price.

The diamond concentration is called the percentage contents of diamond (by aggregation) in a unit of a diamond layer in the segment. This important index is determined by the USA standard accepted in 1922. For 100% concentration under condition it is accepted the contents of 7 ct (1 ct = 0,2 gr) diamond in a cubic inch. Transformed in metric system this measure is 0,88 g/mm^3. Providently the diamond compactness is 3,5 gr/cm^3, so the diamond content in 1cm^3 is:

$$Vg = 0{,}88/3{,}52 = 0{,}25 \text{ cm}^3$$

Consequently, independently of the type of connecting substance, for 100 % concentration, the diamond pieces take 25 % of the whole diamond layer.

The diamond tools for common purposes are made with concentration from 12,5 % to 200 %. The diamond concentration in circular diamond blades is defined over technical and economical consideration and it is normally between 25 % and 50 %.

When choosing diamond concentration, it have to pay attention to many factors, the most important of which is keeping the diamond grain in the bind substance as long as possible, under the condition that it retains its sawing characteristics. This formulation can be explained with the following special cases: circular diamond blades with maximal and minimal diamond concentration.

A circular diamond blade with high concentration has many diamond grains on the sawing surface and at sawing its percussion load is much lower in comparison with a circular diamond blade with low concentration. The probability of extracting grains in this situation is minimal. The result is that the sharp sawing edges get smooth, which decreases the productivity of the circular diamond blade.

A circular diamond blade with low concentration has a lower number of diamond grains on the surface of the segments, and the load upon the separate sawing grains is considerable. If it passes over the critical value, the grains will brake and extract from the connecting layer. The result is that the wearing out of the circular diamond blade increases and the sawing is not effective anymore.

Discussing the diamond concentration in circular diamond blades there must be taken into consideration the strength of tie, whose quantity is defined by the index strength of tie.

Strength of tie. The tie in diamond segments fixes the diamond grains and the aggregate substances in a sufficiently solid diamond layer. The segment ties in sawing rock materials are metal and consist of various compositions based on tin, copper, iron, cobalt and others. The basic parameter of metal ties, that determines its sawing ability and technical resource, is their strength which is defined with micro-strength measuring machine.

The problem of choosing compound elements and hardness of metal ties is rather complicated. It cannot have a simple solution because of the importance of the hardness and abrasive qualities of the rock material, which factors are independent from each other.

Basically, in practice the following rule is valid: in case of a hard metal tie, it achieve low productivity and high technical resource are achieved, and vice versa, in case of a soft tie – high productivity and low technical resource.

Extent of diamond grains. As it has been noted, rational size of diamond grains is limited and ranges from fractions 60/80 meshes to 20/30 meshes. The choice of diamond grains massiveness has to be based on the analysis of the factors loading up the working grains in sawing process. These are the peripheral speed of sawing and hardness of rock material. To choose diamond materials with the optimum granule characteristics the following rules have to be taken into consideration: Solid rock materials are sawn with circular diamond blades of low granule characteristics and small peripheral speed of sawing of 30 to 40 m/s, and converse, medial solid and soft rock materials are sawn with circular diamond blades with higher granule characteristics and higher peripheral speed from 45 to 55 m/s.

These are the basic factors, which determine the choice of circular diamond blades for sawing rock materials.

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TECHNOLOGY FOR WORKING GRANITE MATERIALS FOR SINGLE THICK PRODUCTS

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ABSTRACT
It has been scrutinized the technological scheme for working granite materials used in big stone working factories. This scheme is unsuitable for the small factories from the same branch. The suggested technological scheme completely satisfies the following requirements of the small factories: low prime cost of the ready production, maximum using of stuff and rapidly executing the certain order.

ANALYSES OF THE TECHNOLOGICAL SCHEMES FOR WORKING GRANITE MATERIALS

Common information

It is well - known that the production of different granite products is made by different operations, executed by different orders, which compose the integrated technological process. As a result of these technological and production operations, the product with the necessary mould, size and fracture (stage of area working) is made.

The term technological scheme for working rock materials means the succession of the main operations for getting ready production. The technological scheme of working depends on many factors like: the physical and mechanical features of the rock material, the mould and size of the block and the index of the ready product (mould, size and the quality of working area).

The optimal variant for the technological scheme for producing a given product, except for the above-mentioned factors, depends on the production and economic conditions such as: availability of suitable machines, charges of technological materials, economic and effective prime cost.

Extant technological schemes for working granite materials

In the accessible technical literature and especially in Marhov (1993), is considered a technological scheme for working granite materials, shown in fig. (1).

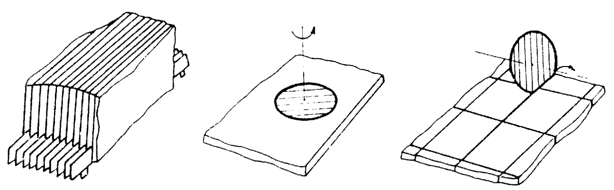

Figure 1.

In this technological variant, block sawing is made by saw mill, working with free abrasive (steel or cast iron shot), which are with high abilities up to 150 blades, allowing working blocks with length up to 4 m, width 3m and height 2 m. It is typical of these technological schemes that the slabs, obtained from block sawing, first are ground and polished and after that they are circumcised by length and width. This special feature is solely prompted by the circumstance, that for the granite materials, which are made of hard rock-forming minerals, with rigidness 6 and 7 by Moss's scale, much more pressure of the grinding instrument is necessary, than for other rock materials, like marble and limestone. In this case, when the granite slab is first circumcised to the necessary size and then it is ground, as a result of the big pressure and tangential strength of grinding instrument, the mineral grains near the edge of slab start to break off. This is so-called edge break off.

The technological scheme described in literature source \1\ is advisable only for sawing granite materials for manufacturing thin and medium slabs, in the condition of big serial production, which was the compulsory element for the so-called planned economy.

IMPROVED TECHNOLOGICAL SCHEME FOR WORKING THICK PRODUCTS FROM GRANITE MATERIALS

In the present conditions of market economy and high competition in the sphere of stone working industry, the small factories took the only available market niche, making non-standard products and finishing half ready products like - curb stones, memorials, monuments, pedestals, stairs and other. These conditions force the small factories to have fast retune of the technological processes, high flexibility of the technological scheme, low self cost of the production and high yield (maximum using of the stuff).

The limited investments and the specific working process in making thick granite products, reject the first section of the technological scheme working in the big companies - the saw mill. The enormous investment and inability to fulfil the product capacity of the saw-mill are the reasons for the removal of the latter from the production nomenclature of small factories.

As the first section in the technological scheme in the small factories, a wire sawing machine with free abrasive, or a disk cutter with a disk diameter 2500 mm - 3000 mm can be used.

The disk cutter also requires high investments, has compound structure and its height of sawing is limited to 1200mm. A big priority of these machines is the high speed of sawing and comparatively flat sawing surface, which is connected with consumption of expensive diamond segments and high power capacity. The slot made of diamond circular blade reaches 14 - 15 mm, which leads to consumption of stuff.

Wire sawing machines, working with free abrasive, do not require high investment. They have the ability to saw blocks with big sizes, as the limits in height of sawing surface are 1800 mm - 2000 mm,which completely satisfy the needs of small factories. The expensive consumption is prerequisite for limited usage of these machines. Lately in the practice has been enforced the using of waste products like substitutes of silicon carbide (the main free abrasive used for sawing granite materials). These substitutes vastly decrease the prime cost of ready product. Due to the fact that the slot made by the wire reaches 5 - 6 mm and the power capacity of the machine is low, the using of wire sawing machines with free abrasive is most suitable for the needs of small factories.

The above economical and technological conditions apply using of automatic grinding machines with a single executive body and a manual grinding machine. The line grinding machines have limit in height of working surface - 200 mm, high investment, expensive maintenance and high power capacity, which do not agree with the given conditions. This leads to rejection of these machines from the technological schemes used in the small factories.

Technological scheme used in the small factories working thick granite materials

The suggested below technological scheme has been applied for the last 10 years with the creation of the small private factories.

This scheme fig. (2) consists of the following operations: /1/ block sawing, 2 circumcising the slab, 3 grinding and polishing, 4 secondary circumcising and 5 taking chamfer and polishing the forehead.

The special feature in this scheme is that the circumcising goes before the process of grinding. It is applied because of the fact that the unduly part (waste) of the slab range from 10 % to 50 %. In this case grinding the whole slab is connected with the increase of the production cost-grinding abrasive and electric power. According to this the technological time, for making a given product, increase.

At the next operation grinding and polishing there is a risk braking off the slab edges. The break off is caused from the diamond, grinding head, which is made by a few segments. Its small size lead to increasing the pressure over a unit of grinding surface. This increases the probability of breaking off grains of the minerals. For evasion of this harmful effect, toward the first circumcising it have to be left larger size for next correct the right size by second circumcision. By the given technological parameters, breaking off edges can be smooth out, by taking a chamfer.

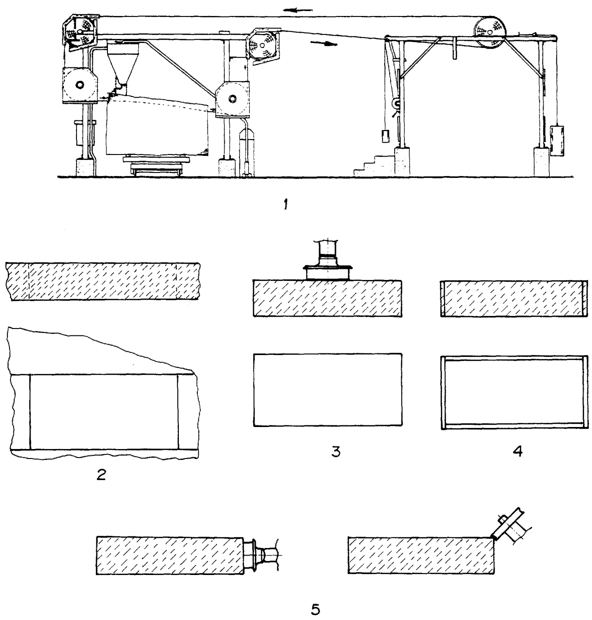

Figure 2.

These are the main reasons for choosing this technological.

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A METHOD FOR DETERMINING THE INSULATION PARAMETERS OF THREE-PHASE NETWORKS WITH VOLTAGE UP TO 1000 V WITH INSULATED STAR CENTRE OF THE TRANSFORMATOR

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ABSTRACT
A method is proposed for determining the insulation parameters by connecting an additional conductance to one of the phases and measuring the voltage of the other two phases. The method proposed has the following advantages: it is easily realizable, and it is based only on the voltage measurement, whereas the necessary accuracy and safety of the measuring are achieved.

In order to ensure the necessary electrical safety conditions, it is very important to know the insulation parameters (with respect to the ground) of networks for voltage up to 1000 V, with insulated star centre of the transformator. Different methods are known for these parameters determination. Measurement of running-light current and short-circuit current is the most often used method (Sichev, Zapenko 1979). The necessity to measure short-circuit current that aggravates the electrical safety during the measurement can be outlined as disadvantage of this method. Use of phase-sensitive equipment represents other measuring method (Zapenko, 1972) Disadvantage of this method is the necessity to measure the current phase in addition to the measurement of the current size. This complicates the measurement process and decreases its accuracy. A graphical-analytical method exists also (Sichev ,Zapenko, 1979). Its disadvantage is the necessity to carry out heavy calculations.

A method is proposed here for determining the insulation parameters by connecting an additional conductance to one of the phases and measuring the voltage of the other two phases. The method proposed has the following advantages: it is easily realizable, and it is based only on the voltage measurement, whereas the necessary accuracy and safety of the measuring are achieved. The method is elucidated and realized by the scheme shown in Fig. 1, where: $U_{\phi A}$, $U_{\phi B}$, $U_{\phi C}$ are the complex phase voltages of the source and these voltages form asymmetric three-phase system; U_A, U_B, U_C – complex voltages (with respect to the ground) of the individual phases of the network; U_N - complex biased voltage of the grounded neutral;

r_A, r_B, r_C – active insulation resistance between the ground and phases;

C_A, C_B, C_C – conductors capacity (with respect to the ground);

R_D – additional resistance that is connected during the measurements.

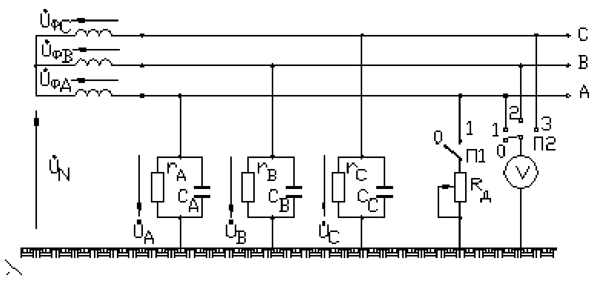

Figure 1

A diagram shown in Fig. 2 can represent each state of the network described above, at predetermined directions of the voltage vectors. In order to determine the coordinates (x, y) of the point N it is necessary at first to find the analytical expression for determining U_A, U_B and U_C voltages using the data read in the voltmeter. To solve the tack, equations are worked out for circumferences with centers in points A, B and C and radiuses U_A, U_B and U_C.

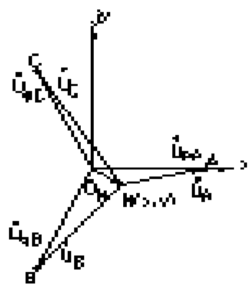

Figure 2

To solve the tack, equations are worked out for circumferences with centers in points A, B and C and radiuses U_A, U_B and U_C.

Coordinates of points A, B and C are determined in the following way:

$$A(\frac{U_Л}{\sqrt{3}},0),\ B(-\frac{U_Л}{2\sqrt{3}},-\frac{U_Л}{2}\ \text{и}\ C(-\frac{U_Л}{2\sqrt{3}},\frac{U_Л}{2})$$

The equation of a circumference with a radius R is represented in the following way:

$(x – a)^2 + (y – в)^2 = R^2$.

Consequently:

$$(x-\frac{U_Л}{\sqrt{3}})^2+y^2=U_A^2;$$

$$(x+\frac{U_Л}{2\sqrt{3}})^2+(y+\frac{U_Л}{2})^2=U_B^2;$$

$$(x+\frac{U_Л}{2\sqrt{2}})^2+(y-\frac{U_Л}{2})^2=U_C^2\cdot$$

After finding the quadrate, it is obtained:

$$x^2+y^2-\frac{2U_Л}{\sqrt{3}}.x+\frac{U_Л^2}{3}=U_Л^2; \qquad (1)$$

$$x^2+y^2+\frac{U_Л}{\sqrt{3}}.x+U_Л.y+\frac{U_Л^2}{3}=U_B^{2;} \qquad (2)$$

$$x^2+y^2+\frac{U_Л}{\sqrt{3}}.x-U_Л.y+\frac{U_Л^2}{3}=U_C^2\cdot \qquad (3)$$

Coordinates of U_N are determined using the equations of circumferences with a center in point B and radius U_B and with a center in point C and radius U_C. Using equation (2) and (3), it is obtained:

$$x^2+y^2+U_Ф.x+U_Л.y+U_Ф^2=U_B^2 \qquad (4)$$

$$x^2+y^2+U_Ф.x+U_Л.y+U_{\hat{o}}^2=U_C^2 \qquad (5)$$

After processing equation (4) and (5), it is obtained:

$$y=\frac{U_B^2-U_C^2}{2U_Л}=\frac{U_B^2-U_C^2}{2\sqrt{3}.U_ф}, \qquad (6)$$

$$x=\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}.U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2}-\frac{U_Ф}{2}, \qquad (7)$$

where $U_Ф$ is the phase voltage.

Then:

$$U_N=\left[\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2}-\frac{U_Ф}{2}\right]+j(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф})\cdot \qquad (8)$$

Knowing that:

$U_A = U_{ФA} - U_N = U_Ф – U_N$,

$$U_B = a^2 . U_A = (-\frac{1}{2}-j\frac{\sqrt{3}}{2}).U_Ф - U_N, \qquad (9)$$

$$U_C = aU_A = (-\frac{1}{2}+j\frac{\sqrt{3}}{2}).U_Ф - U_N$$

and laying out

$$U_i=a_i+jd_i, \qquad (10)$$

where i = A,B, C, it is obtained:

$$U_A=\frac{3}{2}U_Ф-\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2}+j(\frac{U_C^2-U_B^2}{2\sqrt{3}U_Ф}), \qquad (11)$$

$$U_B=\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2}+j(-\frac{\sqrt{3}}{2}U_Ф+\frac{\sqrt{3}}{2}U_Ф+\frac{U_C^2-U_B^2}{2\sqrt{3}U_Ф}), \qquad (12)$$

$$U_C=\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2}+j(\frac{\sqrt{3}}{2}U_Ф+\frac{U_C^2}{2\sqrt{3}U_Ф}) \qquad (13)$$

It is laid out in equations (11), (12), and (13)

$$\left.\begin{aligned} a_A&=\frac{3}{2}U_Ф-\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2};\\ d_A&=\frac{U_C^2-U_B^2}{2\sqrt{3}U_Ф};\end{aligned}\right\} \qquad (14)$$

$$\left.\begin{aligned} a_B&=-\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2};\\ d_B&=\frac{U_C^2-U_B^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф;\end{aligned}\right\} \qquad (15)$$

$$\left.\begin{aligned} a_C&=-\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2};\\ d_C&=\frac{U_C^2-U_B^2}{2\sqrt{3}U_Ф}+\frac{\sqrt{3}}{2}U_Ф.\end{aligned}\right\} \qquad (16)$$

By use of the equation of a circumference with center in point A and radius U_A, it is obtained:

$$(x-U_A)^2+y^2=U_A^2. \qquad (17)$$

Taking into consideration (6) and (7), it is found:

$$U_A = \sqrt{\frac{1}{2}\left[U_B^2 + U_C^2 + 3U_\Phi^2 - \sqrt{9U_\Phi^2(2U_B^2 + 2U_C^2 - 3U_\Phi^2) - 3(U_B^2 - U_C^2)^2}\right]} \quad (18)$$

As it can be seen from equation (18), the measurement of only two voltages U_B and U_C is enough, because the U_A voltage can be found analytically.

It is important to note that the system of equations describing the circumferences has two solutions symmetric with respect to the straight line connecting centers of those circumferences. Calculations presented are for solution situated to the right of the line BC.

The electric circuit shown in Fig. 1 can be described by two complex independent equations, in conformity with the first law of Kirchhoff.

$U_A.Y_A + U_BY_B + U_CY_C = 0$

$U_A'Y_A + U_B'Y_B + U_C'Y_C = -U_A'Y_d$ (19)

The first equation of the system (19) reflects the initial state of the circuit (the switch П1is in position 0). The second equation reflects the state when to one of the phases (phase A) is connected and additional resistance r_d (the switch П1 is in position 1).

The system (19) of complex equations is transformed into a system of algebraic equations, while equation (10) is taken into account, as it follows:

$$\left.\begin{aligned}&(a_A + jd_A)Y_A + (a_B + jd_B)Y_B + (a_C + jd_C)Y_C = 0;\\&(a_A' + jd_A')Y_A + (a_B' jd_B')Y_B + (a_C' + jd_C')Y_C = -(a_A' + jd_A')\frac{1}{r_d}.\end{aligned}\right\}$$

Taking into consideration that:

$Y_A = g_A + jb_A,\ Y_B = g_в + jb_B$ и $Y_C = g_C + jb_C$,

it is obtained:

$$\left.\begin{aligned}&a_Ag_A + a_Bg_B + a_Cg_C - d_Ab_A - d_Bb_B - d_Cb_C = 0;\\&d_Ag_A + d_Bg_B + d_Cg_C + a_Ab_A + a_Bb_B + a_Cb_C = 0;\\&a_A'g_A + a_B'g_B + a_C'g_C - d_A'b_A - d_B'b_B - d_C'b_C = -\frac{a_A'}{r_д}\\&d_A'g_A + d_B'g_B + d_C'g_C + a_A'b_A + a_B'b_B + a_C'b_C = -\frac{d_A'}{r_д}\end{aligned}\right\} \quad (20)$$

It is known that the network with a voltage up to 1000V is characterized with insignificant asymmetry of the capacitive conductance of the phase insulation with respect to the ground. That is why it is considered in practice that $C_A=C_B=C_C$. At the same time, the asymmetry of the active conductance of the phase insulation with respect to the ground is well pronounced and can vary in broad range.

For the conditions pointed out, the system (20) of equations can be represented in the following form:

$$\left.\begin{aligned}&a_Ag_A + a_Bg_B + a_Cg_C - (d_A + d_B + d_C)b = 0;\\&d_Ag_A + d_Bg_B + d_Cg_C + (a_A + a_B + a_C)b = 0;\\&a_A'g_A + a_B'g_B + a_C'g_C - (d_A' + d_B' + d_C')b = -\frac{a_A'}{r_д}\\&d_A'g_A + d_B'g_B + d_C'g_C + (a_A' + a_B' + a_C')b = -\frac{d_A'}{r_д}\end{aligned}\right\} \quad (21)$$

From the system (21) of equations it can be found:

$r_A = 1/g_A$, $r_B = 1/g_B$, $r_C = 1/g_C$ и $C = b/\omega$ (22)

In this way, the insulation parameters can be determined by measuring with a voltmeter the *voltages* U_B, U_C, U_B' *u* U_C', These voltages are introduced as coefficients in specially created program for a calculator able to be programmed.

Having in mind the above mentioned, the following conclusions could be drawn:

1. A method is proposed for determining the insulation parameters by connecting an additional conductance to one of the phases and measuring only four voltages.
2. The method proposed does not require a measurement of the current of directly grounded connection. This ensures electrical safety conditions of measurement.
3. Investigation of the accuracy of the method proposed in dependence of the change of the linear voltage, size of the additional resistance connected, and of the voltmeter internal resistance can be pointed out as future tack.

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ON THE NECESSITY OF DEVELOPING AND IMPLEMENTING A CONTROLLABLE ELECTRIC DRIVE FOR MINE CHAIN CONVEYORS IN UNDERGROUND COAL MINES

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ABSTRACT
Because of some advantages of mine chain conveyors in comparison with other transportation equipment they imposed themselves as ones of the basic mine machines taking part in the technological sequence of underground coal mining. Besides those advantages which ensure a wide range of applications for the chain conveyors, they are also characterized by a number of essential drawbacks requiring new, up-to-date solutions.
An analysis of problems accompanying the utilization of chain conveyors is carried out in the present report, and the main trends and possible technical solutions for their modernization are discussed.
A special place is dedicated to the considerable impact exerted by the driving system on the qualities of chain conveyors.
The report conclusions generalize the importance of the task of developing and implementing a controllable electric drive of mine chain conveyors in underground coal mines.
Key words: mine chain conveyors, controllable electric drive, reliability, safety.

The mine chain conveyors (MCC) are used for coal transportation from mining faces in flat or steep seams and nowadays they are ones of the most widely applied machines in underground coal mining. The advantages of mine chain conveyors are connected with the high mechanical strength of their traction member (steel chain) and sections, small size, relatively simple and easy assembling and disassembling, possibility of applying them in other operations (as a carrier of a cutter plough, as a track for relocating a coal getter, etc.), operational reliability at various slopes, possibility of mechanized movement. All these advantages determine the wide range of applications and future perspectives for MCC in coal transportation as well as in underground mine construction.

The basic driving mechanism of all types of modern MCC designs is the electric drive consisting of the following main components: an electric motor; a reducer; a hydraulic turbo-coupler connecting the electric motor to the reducer, and a switching device for which mine magnetic starters are mostly used.

Squirrel-cage induction motors are most frequently used in the electric driving of MCC. The induction motor features a number of advantages in comparison to the d.c. electric motors. These advantages are mainly expressed by the lack of a brush assembly, relatively simple design, higher reliability, lower-value (for the same power) size and weight data, etc.

The insufficient controllability of squirrel-cage induction motors is the main reason not only for quickly exhausting the performance resource of the MCC drive itself, but also for the low efficiency of its automation scheme.

Improving the driving system will not be possible without thorough and all-embracing studies of the performance regimes of MCC. These studies are oriented towards two principal directions: investigating the transient (starting, hard braking) and steady-state operating modes.

Controlling the travelling speed of traction member at a high rate of conveyor productivity (up to 1000 t/hour) allows to attain a considerable increase in its performance resource.

The operational processes of mine chain conveyors are accompanied by the occurrence of extreme mechanical loads causing failures of individual assemblies and components in the transmission and traction member. In this connection developing efficient technical means and methods for MCC protection against overloading will result in a large-scale economical and social effect. The main reason for the occurrence of dynamic overloadings is related to the abrupt increase in resisting forces acting upon the conveyor's traction member, which leads to its instantaneous shut-down.

It should be also taken into account that dynamic overloadings are directly proportional to the braking interval and the value of the system's inertia moment.

It is well known that the electric braking of squirrel-cage induction motor leads to transferring energy into the armature, and the value of that energy is equal to the kinetic energy stored at the initial instant of braking. This fact permits to make the conclusion that using electric braking in the driving system of a chain conveyor in the case of blocking up of its traction member will allow a considerable reduction of the quantity of kinetic energy consumed in the deformation of design components, and in such a way the dynamic forces emerging in the transmission and traction member will be reduced as well.

That is why, in developing a controllable system for MCC's electric drive, it should be required that the system shall ensure a possibility of constraining the dynamic forces by using an electric braking process. Such a solution will considerably simplify the mechanical part of the electric drive (there will be no need of including a protective coupler any more) by introducing a slightly more complex electric circuit at the expense of using thyristor switching devices for the control of squirrel-cage induction motors.

CONCLUSIONS

1. Developing and implementing a controllable electric drive to improve the technical and operational parameters of mine chain conveyors is an important task of considerable economical and social effect.
2. According to the initial estimations, developing a controllable system for the electric drive of squirrel-cage induction motor using thyristor switching devices is the most optimal solution that requires additional investigation and advantage evidences in comparison with other possible solutions.
3. The system of controllable electric drive for MCC should meet the requirement for realizing a regime of electric braking for the driving squirrel-cage induction motor.

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MATHEMATICAL MODELS FOR INVESTIGATING MINE POWER SYSTEMS

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ABSTRACT
This report presents Markovian models of various complexity and capabilities intended for the investigation of mine power systems.
Keywords: Markovian models, power supply, reliability, safety.

INTRODUCTION

Creating absolutely reliable and safe technical systems is an unrealizable task. However, creating technical systems with a pre-set level of reliability and safety is a real and important task. Especially critical is the problem of developing mathematical models adequate to a corresponding technical system, based on which it would be possible to substantiate theoretically and select the most correct path of realizing a system with pre-set indices of reliability and safety.

This task is of special critical importance for mine power systems in connection with the necessity of quantitatively defining the risks in utilizing the electrical power in underground coal mines.

Markovian models of various complexity presented in this report are used for a mine power supply system. Their capabilities of analyzing and estimating the impact of individual parameters on general indices of the reliability and safety system are shown.

TWO-STATE MODEL OF THE MINE POWER SYSTEM

The mine power system (MPS) can be in one of two states: safe or dangerous [Makarov, 1990, 1996]. The term "safe state" shall be understood as such a state of MPS at which all requirements of the effective normative and technical documents are being met [Regulations-1967; Regulations-1992]. If the system is in a state at which just one of those requirements is not met, it should be considered "dangerous".

The first state (the safe one) will be denoted by 0 (zero), and the second (dangerous) state by 1 (one).

To formalize the MPS functioning process the following assumptions are made.

The probability of occurrence of one or another number of events during an arbitrary time interval Δt, in result of which MPS is transferred from one state into another, does not depend on what number of events have occurred for other time intervals not crossing that in question, i. e. it does not depend on the state of MPS in previous time instants, and this is a characteristic trait of Markovian processes.

The probability that for a given time interval Δt MPS will make two or more transitions is assumed to be an infinitesimal of order higher than that of the probability MPS will make one transition for the same time interval. The probability of occurrence of one or another number of events for a time segment of length τ, depends on the segment length only.

Based on the properties indicated above the flow of events that turns over the system from one state into another will be a Poisson's flow, and the process taking place in a system of discrete states and being continuous in time will be a Markovian process.

For a Markovian process of MPS functioning it is assumed that the occurring failures follow an exponential distribution law. The time for restoring the operable (safe) state of MPS are assumed to have an exponential law of distribution, which is confirmed by multiple investigations.

To determine the probabilities of safe and dangerous MPS states ($P_0(t)$ and $P_1(t)$, respectively) in an arbitrary instant of time t the following set of differential equations is composed. It describes the stochastic states of a discrete system of two states, in which a Markovian process, being continuous in time, takes place.

$$\left.\begin{aligned}\frac{aP_0(t)}{at} &= -\lambda_{01}P_0(t)+\lambda_{10}P_1(t)\\ \frac{aP_1(t)}{at} &= -\lambda_{10}P_1(t)+\lambda_{01}P_0(t)\end{aligned}\right| \qquad (1)$$

For every instant of time *t* the condition

$$P_0(t)+P_1(t)=1 \qquad (2)$$

is valid.

Set (1) under initial conditions $P_0(0) = 1$ and $P_1(0) = 0$, and if condition (2) is met, will have the following solution

$$P_0(t)=\frac{\lambda_{10}}{\lambda_{10}+\lambda_{01}}\left[1+\frac{\lambda_{01}}{\lambda_{10}}\ell^{-(\lambda_{01}+\lambda_{10})t}\right] \qquad (3)$$

$$P_1(t)=\frac{\lambda_{01}}{\lambda_{01}+\lambda_{10}}\left[1-\ell^{-(\lambda_{01}+\lambda_{10})t}\right]$$

(4)

In such a way the assumption for a Markovian character of the MPS functioning process enables the relatively simple way of obtaining relationships between the probability for a safe state *P0(t)* of MPS and its reliability parameters (a flow parameter of dangerous failures λ_{01} and restoration intensity λ_{10}), which allows to perform, as a first approximation, an analysis of the most effective paths to system safety improvement.

The advisability of the assumption for Markovian processes taking places in MPS functioning is confirmed by the following two circumstances. In the first place, these are the results from multiple investigations confirming the exponential distribution law for the operational period between failures and the time for MPS restoration, which is a necessary and sufficient condition for the existence of homogeneous (Poisson's) flows, and hence of a Markovian process having discrete final number of states and being continuous in time [Makarov, 1990].

In the second place, for most of the problems of applied nature the replacement of non-Poisson's flows of events by Poisson's flows of the same intensity leads to obtaining solutions which differ relatively little from the actual ones. Moreover, the error obtained is in principle within the accuracy limits of the initial data which also are most often known rather approximately. [Ovcharov,1969]

It is proposed to analyze expression (3) with the purpose of finding relationships between the probability for a safe state of MPS and the coefficient of danger K_0 as well as of clarifying the duration of time interval t_c after which a stationary value of $P_0(t)$, not depending on time, is established. In essence, this stationary value of $[P_0(\infty) = K_S]$ is that constant stationary probability with which MPS will be in a safe state at every instant of time *t* after t_c.

The condition of stationarity of $P_0(t)$ allows to simplify considerably the solution of differential equations which describe the stochastic states by replacing them with algebraic equations. This is important for the further analytical investigations regarding the safety of MRS in cases where the number of states considered is higher than two.

Equation (3) can be written in the following form:

$$P_0(t)=\frac{1}{1+K_0}\left[1+K_0\ell^{-(\lambda_{01}+\lambda_{10})t}\right] \qquad (5)$$

where K_0 is called coefficient of danger, T_0 average operational period to a dangerous failure, T_y average period for which the system is in a dangerous state (average duration of the dangerous state), λ_{01} parameter of dangerous failures, λ_{10} intensity of restoring the safe state (intensity of eliminating the dangerous failures).

The coefficient of danger K_0 is determined by the expression

$$K_0=\frac{T_y}{T_0}=\frac{\lambda_{01}}{\lambda_{10}}$$

(6)

The following important conclusions can be derived from the relationships obtained:

1. The duration of time interval t_c within which a stationary probability value for system's safe operation is established, i. e. $P_0(t) = P_0(\infty)$ for MPS, is not great and in fact it is of the order of 12 hours. Taking into account the actual resource, this allows to eliminate the transition process in analyzing the state of MPS, i. e. to consider the system state after the time $t > t_c$.

In a stationary process

$$P_0(t)=P_0(\infty)=K_S=\frac{1}{1+K_0} \qquad (7)$$

2. With the increase of the value of coefficient K_0 the probability of a safe state is abruptly diminished. That is why it is possible to attain a high level of safety not only at the expense of increasing the safety by realizing a longer operational period to a dangerous failure T_a and by decreasing the time for eliminating a dangerous failure T_y, but also at the expense of fulfilling the conditions

$$K_0=\frac{T_y}{T_0}=\frac{\lambda_{01}}{\lambda_{10}}<<1$$

(8)

Even for a low initial reliability.

3. To obtain a small value of the coefficient of danger K_0 in accordance with condition (6) it is possible to apply two approaches: by increasing T_0 or by diminishing T_y. The world experience gained in this field shows that it is connected with

considerably lower costs, and is also relatively simpler and more effective to use for a second time, by considerably increasing the maintainability of the electric equipment in MPS as well as by automatic turning on of the section (ATS), when a new element is virtually immediately put into operation instead of the failed system element, by the telemechanical control of high-voltage explosion-proof switchgears, by the use of built-in or mobile diagnostic devices, by applying search algorithms for dangerous failures, etc.

To the presentation made so far it should be also added the requirement for a certain correspondence between the values of T_0 and T_y: the smaller T_0, the greater T_y should be, or in other words: the worse the failure-free operation, the better the maintainability should be.

4. For a pre-set level of safety it is possible to define normative requirements for the reliability of MPS. For this purpose, by using equation (5) with taking into account the dependence of the coefficient of danger in accordance with (6), and pre-setting the necessary level of safety, the requirements for both indices T_0 and T_y being in strict correspondence to each other shall be simultaneously determined. In such a way multiple couples of the values of T_0 and T_y are obtained, which allows to find the most effective solution for attaining the pre-set level of safety: either at the expense of improving the safety, or at the expense of improving the maintainability.

THREE-STATE MODEL APPLICABLE TO A MINE CABLE NETWORK

To ensure a safe and failure-free electric power supply to the underground mines very severe requirements are defined for the mine cable network. Such cable parameters as the insulation and shield resistances as well as the value of transitional resistances in places of connecting the cable to electric power consumers and electric control apparatuses. The value of insulation resistance not only effects an essential influence on the risks of human-injuring accidents caused by electric current, but also on the possibility of fire occurrence.

In principle the values of parameters indicated are subject to normalization. If these values do meet the determinate norms the cable will be in a safe state. If not, it will be in a dangerous state.

Thus, from the viewpoint of the requirements for a safe and reliable functionality the following three states are characteristic for the cables:

I). A safe operable state, where the cable meets all requirements of the normative and technical documentation (NTD) regarding the values of parameters given above and is capable to provide electric power to consumers in the underground mine (state 1).

II). A dangerous operable state, where the values of one or several of the parameters given above do not meet the requirements defined by NTD, but the cable is in position to provide electric power to consumers (state 2).

III). A safe inoperable state, where the cable is turned off (state 3).

In such a way, in contrast to MPS, the mine cables can be in one of the three states (for them the dangerous inoperable state is excluded).

The flow of events that transfers the cables from the 1st state into the 3rd one is a flow of dangerous partial failures at which the cable's technological function is not disturbed, but the parameters influencing the safety do not meet the admissible norms. The intensity of this flow of events is equal to $\lambda_{12} = T_1^{-1}$, where T_1 is the average operational period of a partial dangerous failure.

Mine cables can pass from the 2nd state into the 1st one primarily through the 3rd state (upon switching off the cable and eliminating the causes for a partial failure). However, sometimes they can go into state 1 with increasing the insulation resistance as a result of cable drying by the heat generated by the working current (the intensity of this transition is denoted by λ_{21}).

The flow of events in resulting of which the cable performs a transition between the 2nd and 3rd states with intensity λ_{23} is the flow for switching off the cable by the automatic protection or operational personnel when partial dangerous failures occur. The intensity of this transition is equal to $\lambda_{23} = T_2^{-1}$, where T_2 is the average period from the occurrence of a partial dangerous failure to the instant of switching off the cable. It is assumed that the partial dangerous failure will be eliminated in state 3. For this reason the transition from the 3rd state into the 2nd one is impossible. From the 3rd state only a transition to the 1st state is possible with intensity $\lambda_{31} = T_3^{-1}$, where T_3 is the average period of eliminating complete and partial cable failures.

The transition between the 1st and 3rd states results from the occurrence of complete failures connected with disturbing the technological function of the mine cable (supplying power to underground consumers), which leads to actuating the corresponding protection devices and switching off the cable. The intensity of this transition is equal to $\lambda_{13} = T_4^{-1}$, where T_4 is the average operational period at a complete failure.

Such a system of three states is described by the following set of differential equations

$$\left| \begin{aligned} \frac{aP_1}{at} &= -(\lambda_{13} + \lambda_{12})P_1(t) + \lambda_{21}P_2(t) + \lambda_{31}P_3(t) \\ \frac{aP_2}{at} &= -(\lambda_{23} + \lambda_{21})P_2(t) + \lambda_{12}P_1(t) \\ \frac{aP_3}{at} &= \lambda_{13}P_1(t) + \lambda_{23}P_2(t) - \lambda_{31}P_3(t) \end{aligned} \right. \qquad (9)$$

The following normalized condition corresponds to equation set (9):

$$P_1(t) + P_2(t) + P_3(t) = 1 \qquad (10)$$

The initial conditions have the following appearance:

$$P_1(0)=1, \quad P_2(0)=P_3(0)=0 \tag{11}$$

In a stationary process the set of equations (9) will be in the following form:

$$\begin{cases} -(\lambda_{13}+\lambda_{12})P_1+\lambda_{21}P_2+\lambda_{31}P_3=0 \\ -(\lambda_{23}+\lambda_{21})P_2+\lambda_{12}P_1=0 \\ \lambda_{13}P_1+\lambda_{23}P_2-\lambda_{31}P_3=0 \\ P_1+P_2+P_3=1 \end{cases} \tag{12}$$

The probability for the cable to be in state 2 (dangerous operable state) is determined according to the following expression:

$$P_2=\frac{\lambda_{31}\lambda_{12}}{(\lambda_{13}+\lambda_{31})(\lambda_{23}+\lambda_{21})+(\lambda_{23}+\lambda_{31})\lambda_{12}} \tag{13}$$

Analyzing expression (13) in accordance with the numerical values of quantities shows that the probability of dangerous state most essentially depends on ratio $\lambda_{12}/\lambda_{23}$.

In such a way, to improve the degree of safe operation of mine cables requires, on one hand, an improvement in the failure-free work of cables at the expense of decreasing the parameter of partial dangerous failure flow, and on the other hand, a decrease in the period from the time of partial dangerous failure occurrence to the time of switching of the cable, e. g. by the automatic protection not allowing the operation of a cable of low insulation resistance.

The relationship (13) allows to establish a normative safety level for mine cables in respect to partial dangerous failures depending on the effectiveness of technical means for detecting those failures at a pre-set safety level.

CONCLUSION

Using Markovian processes of MPS functioning for two, three, or more states, it is possible to obtain, in a relatively simple manner, relationships between the safe state probability and the reliability parameters as well as to perform an analysis of the most effective ways of safety improvement. Eliminating the transition process of MPS functioning makes the analysis much simpler.

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AUTOMATIC CONTROL OF PUMPS FOR WATER PUMPING DRAINAGE ON THE BASIS OF TIMER 555

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ABSTRACT
A simple and reliable control scheme of two pumps for water pumping drainage on the basis of timer 555 has been suggested in the paper. High reliability, simple construction and low price make the scheme applicable instead of specialized computer system.

INTRODUCTION

The scheme of water pumping drainage in a mine depends on the shaft depth, the number of levels, water inflow etc. The simplest scheme is that with one water pumping drainage equipment.

Main, additional and transferring water pumping drainage equipment which pump out water from the water - collectors are localized in special chambers usualli above water level. Chamber under water level are also being used in order to make automatization easier, to supply constant flow ower pumps and to increase the efficiency.

Automatic mine water pumping drainage system according to (Melkumov, 1973; Volotkovski, 1983) shuld supply the folluing:
- automatic control - starting the pumps with preliminarily owerflouing and stopping depending on water level in the water-collector;
- manual control;
- serial pump operation and distaht control;
- switching on additional pumps at increase of water level;
- automatic surtching on reserve pump;
- automatic switching out of pump at productivity lost;
- Blockages at switching on at unowerflounpump;
- hidrolic defence;
- signalling pumps operation and alarm switching out.

The equipement in our mines is mainly Russian:
- AB - 5, AB - 7 - equipement for sectional waterr pumping drainage;
- ABH - 1M - equipement for automatic control of three pumps;
- UAB - universal equipement for automatic control of 16 pumps;
- VAV - equipement for control of 9 pumps with high ang low voltage motors.

The element basis of the mentioned equipement comprises relays, motor relays, and manual switches with mechanical contacts. Modern technical solutions are realized by microprocessor command-controllers and noncontact operational mechanisms.

We suggest an example of a scheme for automatic control of two pumps for water pumping drainage on the basis of Timer 555. It can demonstrate the realizing possibilities of comparatively simple schemes for automatic pump control by the same Timer.

CONTROL SCHEME SYNTHESIS

The aim is to realize a control scheme for two pumps which do not need overflowing. Such are the submerged pumps and pumps set in chambers under water level in the water-collector.

As block scheme in Fig.1 shows pump 1 is the basic one and it is switched on at water level 1 by trigger "level 1". The block "debit control" checks up in time T from switching on pump 1 by a debit transducer. If its debit is normal pump 1 continues operating. At some defect in pump 1 its debit decreases, the block "debit control" switches it out and switches on pump 2. In case of increased water flow in the water-collector the operation of one pump is insufficient and at water increase above level 2, pump 2 is being switched on operating together with pump 1.

Scheme in Fig 2 has been synthesized on the basis of this block scheme. Four Timers LM555 have been used. Integral scheme LM555 consists of precise input divider, two comparators, RS trigger, output amplifier and charged transistor. Through outer RC group integral scheme LM555 usually operates as a timer of single impulses or as a generator. IC can be applied also as a trigger with two level switch on and switch off.

Electrode transducers at three levels have been put into the water-collector connected respectively to the inputs of triggers I and II. When the transducer is wet its potential is high as it is connected by a resistance to the supply pole. When the transducer is in water, through water resistance it is connected to earth and its potential is low.

Trigger I is switched on at water level reaching water-collector to level H1. Its output 3 reaches high potential and brings to operation relay P1 the last switching on pump 1. Water is being pumped out and at down level Ho the transducer Ho remains wet, trigger I is switched out and the pump is also switched out by relay P1.

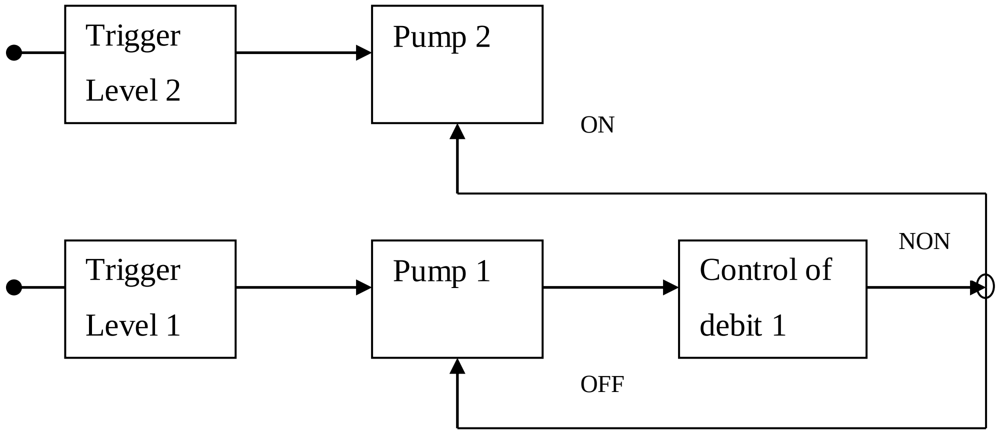

Figure 1.

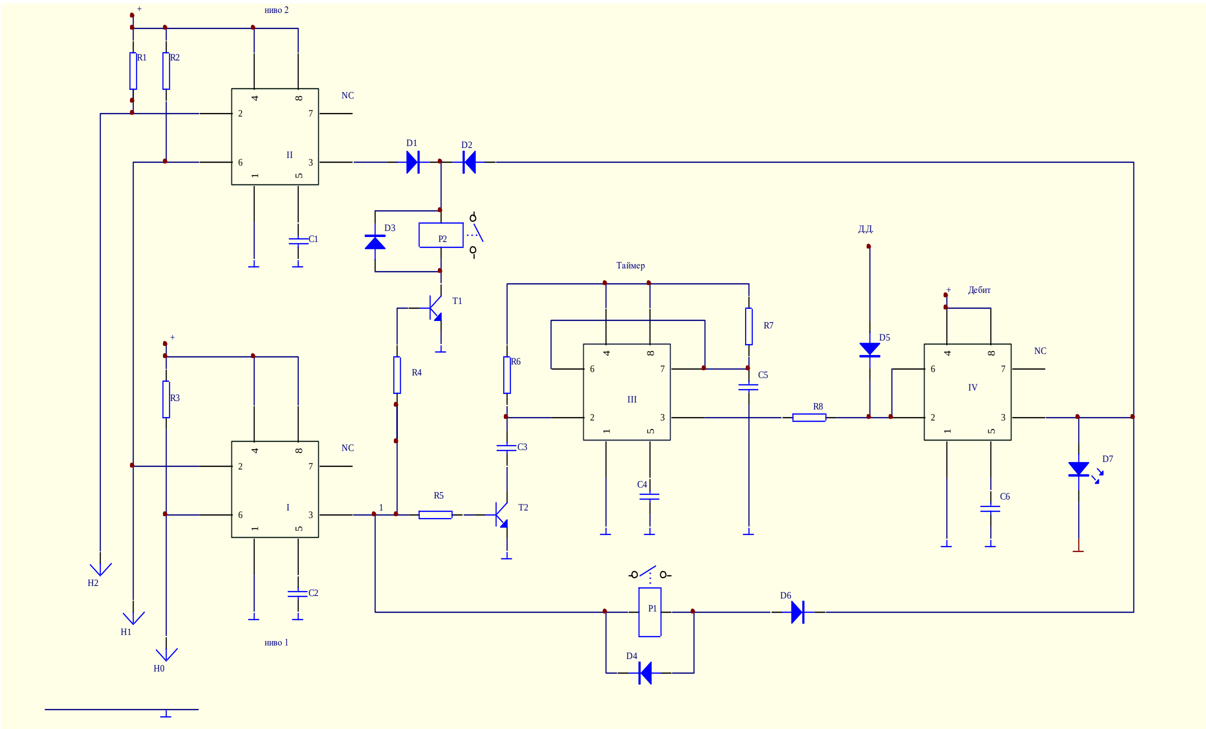

Figure 2.

In case water flow in water-collector is bigger than pump 1 debit, water reaches level H2 and by the trigger for level II voltage supply is provided for relay P2. Transistor T1 is opened at this moment, relay P2 goes into operation and switches on pump 2 starting to work together with pump 1.

Three operational regimes are possible:

1. Only one working pump;
2. Two pump working together at water level increase;
3. Only pump 2 working at pump 1 alarm regime.

Alarm regime of pump 1 is established by debit control device realized by timer (IC III) and trigger (IC IV). Timer keeps relay P1 switched on 10sek. In this interval the debit transducer D.T. should signalize for normal debit. If the debit is not normal low potential is supplied to the input of IC IV while the output (p.2) gets high potential. As relay P1 is between p.1 and p.2 they also have a hidh potential at alarm regime and the relay is switched off. At the same time IC IV output supplies relay P2 through diode D2. There is high potential on transistor T1 base and it

switches on relay P2 which gets into operation pump 2 as a reserve one.
In this way relay P2 is switched on in case at least one condition is being full filled:

- water level is above H1 and pump 1 has no normal debit
- water level is above H2

In the first case the second pump is switched on as a reserved and in the second case as an additional one at increased water flow in the water-collector.

CALCULATION AND REGULATION

Level triggers

Such volumes for resistances R1, R2 and R3 should be chosen that when electrode transducers H1,H2 and H0 are put into water their potential will be lower than 1/3 U_C .This is the real supporting level for input comparator to start working (leg 2 of IC) under which the trigger is switched on.

The resistances R1,R2 and R3 should be higher than 60k as water resistance between the submerged transducer and earth does not exceed 20kΩ. We have chosen the value 100kΩ. Each condensator C1 and C2 is 10nF. When water level exceeds H1, trigger I is switched on (high potential p.1) and when it falls under H0 the trigger is switched off. Respectively, when the water level is above H2 trigger II is switched on and when it is under H1 the trigger is switched off.

Timer

Timer III is being put into water together with trigger I through the group R5,R6,C3,T2. The volumes of the elements are: R5=10kΩ, R6=27kΩ,C3=100nF. The length of positive impulse is defined by the expression :T=1,1.R7.C5. At R7=100kΩ,C5=100μF the impulse length is 10sek. It is enough to get into operation pump 1 and to reach its normal debit.

Debit trigger

At trigger IV input two signals reach - from the timer and from the debit transducer D.T. At normal work there should be low potential at the output(p.2) and high potential at the input in the first 10sek. The high input trigger potential is received from the timer and later from D.T. If the transducer does not give a high potential in the first10sek., the trigger is switched over (high potentialp.2) relay P1 is switched off, relay P2 is switched on and light diode D7 lights up. That is an indication for alarm in pump 1. Resistance R8 volume is 10kΩ. It limits the current from D.T. to timer output when it is switched off.

CONCLUSION

The suggested scheme for automatic regulation has been realized under laboratory conditions with two integral schemes LM556 (two timers 555 in one corp.) Voltage supply is +12V/-12V. Water resistance and transducer debit signal are simulated so that all states and scheme function could be checked up.

The main scheme advantages are:

1. Low price - The price of all elements with the supply does not exceed 20lv.
2. High reliability and maintenance ability- the number of electronic components is small. Integral schemes are assembled on sockets and can be changed rapidly and easily at any defect.
3. Possibility of widening - The scheme is constructed on a block principle and can be easily widened for regulation of a greater number of pumps. On these basis control and regulation schemes can be synthesized. Some other operational parameters can be also controlled by pressure, temperature etc. transducers.
4. Intrinsically safety - The scheme is intrinsically safe at using intrinsically safe supplying source and relays with hermetized contacts.

Due to these advantages the suggested scheme and other based on timer 555 can find an application for regulation of one or two pumps in cases where the use of specialized controllers is too expensive.

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CAD AND CIM SYSTEMS: STATE OF THE ART AND DEVELOPMENT TRENDS

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ABSTRACT
The paper considers the present state of Computer Aided Design (CAD) and Computer Integrated Manufacturing (CIM) systems. A thorough analysis of these systems is presented utilizing a large number of information sources. Some new concepts, approaches and methods are proposed based on system theory and artificial intelligence.
Key words: information models anf flows (in CAD and CIM), system analyses

INTRODUCTION

At first place in the series of processes in the computer integrated manufacturing (CIM) stands the Computer Aided Design (CAD). This is a definitely new technology that started in the second half of the twentieth century as a subsidiary tool in engineering. Series of not linked to each other projects (1956-59), that started in MIT (Massachusetts Institute of Technology), with the name APR-Project (Automatic Programmed Tools) aimed at acting as a tool in geometric representation of machine details in their manufacturing by digital controlled machines (NC-Machines). In 1962 the first interactive computer graphic systems ICG (Interactive Computer Graphic – System) for 2D objects were invented and only one year later T.E.Johnson expanded the potentialities of the SKETCHPAD system for 3D objects. Using this system the perspective representation (3D representation of the objects on the plane became possible).

The first CAD-systems were too expensive and were applied only in automobile and aircraft engineering enterprises. Nowadays these systems are applied as a main tool in all fields of industry. They are the main factor for the increase of the productivity, flexibility and quality (Autodesk 91, Haasis 1992a; Held 1990).

Peculiarities of the present CAD/CIM systems

A. ***Information providing of projecting and production.*** The providing of information is an important factor in projecting and production. Inadequate prognoses of the potential customers' desired demands of the main technical parameters and quality indicators of the industrial products, quality/price proportion and so on are the main reason for the disintegration of many companies and industrial trusts.

The information flows in the user-based CAD/CIM systems provide the realization of all basic productions procedures.

- development and design (planing, conception, projecting, technology);
- preparation of the manufacture (workplans, NC-programming);
- manufacture and installation (technology, materials, tools, continuous lines, installation lines).

B. Computer-based geometrical modeling. Applied are:

- 2D-linear and 3D-linear models, based on the following main elements: points, lines, and circular forms;
- 3D-plane models that include not only the elements in the 2D and 3D-linear models but also surfaces;
- 3D-spatial models that include not only the elements from the two previous models but also spatial elements.

C. Computer-based manufacturing model. Most often the model has a modular structure from the following pieces: module Design, module Planning, module Manufacture, module Installation, module Prime cost, module quality control, module sale. These modules consist of submodules that include in details series of procedures referred to the technology, the quality of the materials, data for the utilized tools, grade of accuracy, order of manipulations etc. (parameter modules).

D. Program interface: Data about the models and their modules in a CAD/CIM system are stored as a code by a database. These data's format depends on the used architecture and the applied software. For speeding up the data exchange between a multitude of a CAD/CIM system's databases two-way channels (connections) are applied.

General rating of the present state of CAD/CIM systems

The progress in the considered field (computer-based projecting and manufacturing) is impressive and meets appliance in all leading companies. The same is the situation with the potentialities for flexibility of the products' production range. But in the available literary sources some important elements of the present projecting conceptions are still missing.

1. Questions referred to the development of variants of a certain project or construction are not regarded.
2. It is not clear how far a considered construction meets with the theoretic potentialities for optimum. Probably these questions are worked out beforehand and out of the available CAD/CIM system.

CAD/CIM Strategies

The design of CIM system may be started from the top. This can readily be done when a new plant is designed.

The advantages are as follows:

1 The information flow through the control modules from the top to the bottom will be defined in a concise and logical manner and the task of the modules can be outlined in a true hierarchical fashion.
2. All hardware and software modules can be provided with compatible data formulas, communication protocols, and interfaces.
3. Standardization of hardware and software modules is simplifies.
4. The modules can easily be interfaced in a hierarchical fashion and the interface to the lower tier is tested with a simulator.

The disadvantages of this approach are:

1. Often, modules are purchased from an outside vendor or developed in another plant and they are not compatible with the system being built.
2. When the system needs to be changed at a future date, a completely different control strategy may be followed, which, when implemented, requires a major revision of the existing architecture.

The bottom up approach has the following advantages:

1. Many control modules can be started in parallel and operated individually.
2. Modules from outside vendors are often easier to implement.
3. The implementation has less overhead than usually associated with most standards.

The disadvantages are:

1. The interfacing of applications on a control tier or between control tiers might be extremely difficult because no attempt was made to define interfaces, data formats, and communication protocols.
2. Computing and communication equipment used may not be compatible.
3. Programming of the computer system, in particular where hierarchical levels are tied together, may become very difficult because no considerations were given to the use of common languages and programming tools.

Usually, in a practical application, neither strategy is being followed. The systems grow together from the top and the bottom. The whole matter gets further complicated when a CIM system is approached with either a pure CAM, PP&C, CAD/CAM, or CIM strategy in mind (Nuber et al. 1989).

- CAM strategy: The computer is introduced by the manufacturing engineer. He tries to automate manufacturing process warehouse operations, material movement systems, and quality control standards. The installation of CNC and FMS systems without interface to design is another example.
- PP&C strategy: This approach is done from an organizational point of view. The main goals are to obtain improved schedules, to shorten set-up and lead times, to improve lot-sizing and timephasing, and to reduce the in-shop time of the workpieces.
- CAD/CAM strategy: With this approach, a so called vertical integration is taken to merge CAD, CAM, and CAQ. An attempt is made to reduce the duplication of processing and storing data. Usually, the integration process is done via design where all pertinent product data are used for all succeeding manufacturing planning and control operations.
- CIM strategy: This strategy usually builds on one of the before mentioned strategies. It is a consequent integration of existing computer controlled operation. There are two strategies possible. First, one starts with a centralized database and an existing application and integrates new applications in a well defined fashion. Second, one starts with a computer network and tries to coordinate the access to all pertinent data of all manufacturing modules, so that data can be used for common control purposes.

Development trends of CAD/CIM systems

One of the greatest challenges of CIM will be the integration of CAD, CAP, PP&C, and CAM. An open system architecture (OSA) for computer Integration will have to be provided to make common CIM modules, and computing equipment and peripherals available to the manufacturing community. There are several ongoing activities to define product, manufacturing and operational models which are the backbone of any standardization effort. These efforts try to tackle a broad spectrum of technique and components and adress a diversity of users. The results are often difficult to anderstand for an average manufacturing engineer because the models are usually very abstract and use an unfamiliar terminology. Efforts are underway whereby an attempt is made to design specification aids for CIM objects which combine the best features of the natural, formal, and grapfical representation methods.

One problem with the design of CIM modules is the software. There are many programming and system design languages being used and still under development. There is no direction to be seen where these developments will lead au to. The explicit languages are often too cumbersome to apply. Even simple applications are usually very complex when they are described completely. The implicit or task-oriended language may look to the user an answer to his problem.

Another tool to be mentioned in connection with software aids is the simulation. Simulation systems which we will allow the emulation of a factory from a global view down to the microscopic view should be available to lay-out new manufacturing systems, to plan manufacturing runs or to experiment with manufacturing alternatives. Certainly, there are many modular simulation products available. However, they are usually for special purposes or only represent a limited view of a manufacturing operation. A tool box for simulation aids must include models of all manufacturing processes and configurations means to set up the desired manufacturing environment.

Another promising development that appears on the horizon is the artificial intelligence (A.I.). The tools so far available for manufacturing really do not deserve to be named artificially intelligent. Expert systems are presently the most useful tools from A.I., which may be applied to planning and controlling of manufacturing systems. Until today, the possibilities of A.I. in manufacturing have been overestimated, and very few good applications do exist. However, the potential of A.I. is very great and it is necessary to develop methods which can be used for solving manufacturing problems particularly for operations planning. It is believed that with A.I. methods, it will be possible to take many routine jobs out of the responsibility of the manager so that he can devote his creative ability to solving complex problems. An hitherto not well understood problem is the merging of A.I. solutions with conventional ones. Very seldom, A.I. techniques will be used in their pure form. They have to be integrated into other technical systems and applications.

The management of an organization must have an integrated view of CIM in mind when a factory is automated. CIM is not something that can be bought of the shelf, it has to be engineered and configured to an application and the organization has to grow with this new technology.

In our opinion it is desirous for the intellectual potentialities of the new generation CAD/CIM systems to be expanded.

1. Possibilities for a rational generating of variants for the project.
2. Possibilities for a multicriterial choice of the optimal variant.
3. Possibilities for a more accurate analysis of the particular character of the environment where the projected object works – conditions of certainty, conditions of stochastic environment (risk).
4. Development of universal models of the product, the manufacturing system and the manufacturing operation.
5. Development of standards for the communication within a manufacturing system.
6. Development of modeling and animation systems for manufacturing processes.
7. Development of more powerful computers.
8. Investigation of new management strategies for CAD/CIM systems.
9. Development of new curricula for the manufacturing engineers.
10. Exploitation of the A.I. potential for manufacturing

CONCLUSION

The new generation CAD/CIM systems should be based widely on the system theory methods, the methods of the multicriterial optimization and the artificial intelligence.

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METHODS FOR DECISION - MAKING AND RISK ASSESSMENT IN THE DESIGN OF TECHNOLOGICAL EQUIPMENT

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ABSTRACT
Designing is a sequence of procedures of decision – making in the condition of indefiniteness (probability, fuzz, or their combination). For the designer parameters of selection depend on parameters of the medium and this brings to accepting risk. Principles, criteria and methods for decision – making in the different conditions of indefiniteness in the design of technological equipment are thoroughly considered.
Key words: Optimization, risk, indefiniteness, fuzz, probability.

INTRODUCTION

Main procedures in executing design works are assigning tasks, selecting criteria for optimal decisions, generating of variants and the decision – making. According to the conditions of work of the object of design two approaches for choosing of the optimal decision are possible:

- When the factors of the medium are stochastic and their probable characteristics are known, the choice is in the conditions of risk.
- When the factors of the medium are characterized with indefiniteness, contingent on the lack of reliable enough methods or technical means for measuring, confusing factors with unstable statistic characteristics, the choice is in the conditions of indefiniteness. The designer should decide very precisely in which one from the two categories are the factors of the medium in order to find a reasonable method for choosing the optimal variant.

A. Decision – making in conditions of risk.

A multiplicity of the criteria for optimality (productivity, exploitation outcome, reliability etc.), that are functions of many variable factors (argument) is formed. The numerical value of a criterion depends on two groups of factors. The first one depends on the human (the person, who makes the decision) and its bears the nomination elements of the decision. Most often the elements of the decision have strictly defined (determined) importance for the value of the criterion. These factors are the choice of determined technical parameters (for example the choice of the number of the transmissions, the choice of the transmission ratios of the transmissions and others in constructing a reduction gear). The second group of factors characterizes the conditions, in which the object of design functions (for example work rate, average ambient temperature in which the considered as an example reduction gear works). The person who makes the decisions cannot influence the values of these factors that represent casual processes, but it is necessary that this person have information about their probable distribution. Unless the person has this information, the decision is made in conditions of indefiniteness.

The decision – making in the conditions of risk means that the designer is forced to accept the expected value of the probable characteristics of the casual factors of the medium. Afterwards it is possible to turn out that the chosen by the designer values are not the real ones, in which the object of the designing functions. In this consists the choice, called choice in conditions of risk.

According to the general theory of the statistic decisions, various principles for decision – making exist. Principle for decision – making means the mathematical definition and the character of the criteria for decision – making. Two types of criteria exist:

- Criteria, which characterize the gain from the made choice of decision and the higher the value of the considered criterion, the better the decision (problem about the maximization of the criterion);
- Criteria, characterizing the expenses for the realization of the made decision. There is an evident necessity to achieve the lowest possible value (problem about the minimization of the criterion).

The next important point is the choosing of strategy, related to the behaviour of the medium. Several types of strategies for the choice exist:

- Principle of maxmin (minimax). It is also known as the principle of Valud. For criteria from the first type (gain) the optimal strategy is the strategy, in which the minimal gain is maximized. For criteria from the second type (expenses) the optimal strategy is the one, in which the maximal expenses are minimized.

The strategy of maxmin (minimax) is based on the supposition that the casual medium will realize the worst possible conditions (approach, based on an extreme pessimism). The indifferent in nature behaviour of the medium is changed with the behaviour of an ill-intentioned adversary. This strategy is reasonable when the designer wants to warrant maximally his or her decision.

More often it is reasonable to apply an intermediate strategy between the extreme pessimism and the unreasonable optimism. A weight coefficient α, $0<\alpha<1$ for correction the strategy of maxmin (minimax), is initiated.

The Bernoulli's strategy of the insufficient reason is expressed in the supposition that all the factors of the medium are equally possible, e. g. dominating casual factors are lacking. Despite the fact that it is based on an ungrounded supposition, this strategy has its advantage – it is not based on extreme, but on average conditions.

B. Decision – making in conditions of indefiniteness.

This choice is based on a system of presumptive knowledge of the subject about the behaviour of the factors of the medium. In its nature the decision is subjective and thus the responsibility of the designer (the subject) increases. The methods of the fuzzy multitudes from the scientific direction artificial intellect are applied as a formal apparatus. Fuzzy relations about the quality values of the factors of the medium and of the purpose function (the criterion for optimality) are initiated more concretely. A fuzzy relation is characterized with a function of property, which is a subjective measure for the grade of execution (truthfulness) of the ratio factor – criteria. By the Belman-Zade's composition rule the fuzzy ratio is applied for calculating the value of the criterion for the values of the factors of the medium.

C. Decision – making in conditions of risk and indefiniteness.

Most often in the complicated objects and systems, characterized with substantial quantitative and qualitative particularities, the factors (arguments) of the choice of the designer are determined qualitative parameters (quantities) and the factors of the medium are casual or are evaluated by qualitative (linguistic) values.

As a result of the joint action of these two different factors the solution (the criterion) is many-valued, e. g. there are fuzzy (inaccurately determined) values. These values may be interpreted as qualitative (linguistic), logic or interval. A suitable apparatus for formal description of the criterion for optimality of the design decision is the many-valued logic probabilities and the many-valued logic fuzzy functions, respectively. They are based on the many--valued logic (κ – symbol logic), $\kappa \geq 3$, generalization of the two – symbols logic. The Algebra, formed by the k – elementary multitude, along with all the operations in it, is called Algebra of the k – symbols logic. The operations (n – dimension operations) in the k – elementary multitude are called k – symbol logic functions with n variables.

Two circumstances are worth for paying attention to:

1. Many properties and results that are valid in the two symbol logic remain the same in the k – symbol logic systems;
2. In the k – symbol logic systems there are some particularities that differ in principle from the particularities of the two – symbol logic.
3. In spite of the numerous researches and interpretations, there are not any set generally accepted definitions for the nature of the logic values, accepted in the respective logic system.

Like all functions, the functions of the k – symbol logic f (x_1, ... x_i ..., x_n), where x_i, $i = 1 \div n$, where each x_i possesses κ logic true values, can be represented in tables or analytically. Let P_κ be the multitude of all the functions of a given k – symbol logic system. The number of the sets (α_1,...., α_n) of the values of the variables x_i equals κ^n. This yields that the number of all the functions of the multitude P_κ, dependent on n variables x_1, ..., x_n, equals k^{k^n}. It is clear that in the multitude P_κ when $\kappa \geq 3$ the difficulties increase greatly in comparison with the two-symbol logic as a possibility for an effective use of the table representation of the functions, as well as the possibilities for reviewing all the functions of n variables.

This often causes the representation of the functions P_κ, $\kappa \geq 3$, by means of algorithm for calculating the functions. Besides that, like in P_2, the concept for substantial and unsubstantial variables is initiated, as well as the concept equality of functions. Thus it is possible to observe the functions P_κ with accuracy within fictitious (unsubstantial) changes.

"Elementary functions" are also initiated:

1. $\overline{x} = x + 1$ (mod k). Here $\overline{x}$ is a generalization of negation (cyclic change of values).
2. Nx = κ – 1 – x, often symbolized by ~x is another generalization of the negation of the value (negation of Lukashevitz).
3. min (x_1, x_2) – generalization of conjunction.
4. $x_1.x_2$ (mod k) – second generalization of conjunction.
5. max (x_1, x_2) – generalization of disjunction.
6. $x_1 + x_2$ (mod k).

The applied list of elementary functions reveals that functions of the algebra of the logic have several analogs in the k – symbol logic ($\kappa \geq 3$), each analog generalizing respective property of the function. The main properties of the elementary functions are the properties associating, commutation, distribution, rules for simplifying etc.

The briefly observed many0valued logic functions are used for description of non-linear chance dependencies when these dependencies are in the conditions of definiteness. When there are logic factors (variables x_i), that determine a multitude of possible values of the functions P_κ, the many-valied possible logic functions are initiated, respectively fuzzy logic functions are initiated, when some of the factors x_i determine indefiniteness.

The many-valued logic probable function y= f (x_1, x_2, W_1, W_2), where x_1 and x_2 are quantitative factors (parameters) of the designer's choice and W_1 и W_2 are qualitative parameters of the medium, is presented as an example in Table 1. When there are m logic (qualitative) values of the function y ($y = y_s$, s = 1, 2, …, 5), e. g. m = 5, and when the factors x_1, x_2, W_1, W_2 – have three values x_{11}, x_{12}, x_{13}; x_{21}, x_{22}, x_{23}; W_{11}, W_{12}, W_{13}; W_{21}, W_{22}, W_{23}, e.g. к = 3, n = 4, the number of the different possible sets of the factors x_1, x_2, W_1, W_2 is $L = k^n = 3^4 = 81$. For each set of factors there are possible m = 5 logic (qualitative) values of the function y, and the total number of the values of the function y is $m.k^n = 5.3^4 = 405$. Each one of these values is characterized with defined probability $p\{y\}$, when the factors of the medium W_1 and W_2 are casual quantities or respectively with definite grade of property $\mu\{y\}$, when W_1 and W_2 are characterized with indefiniteness.

Table 1. y = f (x_1, x_2, W_1, W_2)

Set	№	1	2	3	4			81
x_1		x_{11}	x_{12}	x_{12}	…	…	…	x_{13}
x_2		x_{21}	x_{21}	x_{22}	…	…	…	x_{23}
W_1		W_{11}	W_{11}	W_{12}	…	…	…	W_{13}
W_2		W_{21}	W_{21}	W_{22}	…	…	…	W_{23}
y	y_1	p_{11}	p_{12}	p_{13}				p_{181}
	y_2	p_{21}	p_{22}	p_{23}				p_{281}
	y_3	p_{31}	p_{32}	p_{33}				p_{381}
	y_4	p_{41}	p_{42}	p_{43}				p_{481}
	y_5	p_{51}	p_{52}	p_{53}				p_{581}

The probability p_{NS}, respectively the grade of property μ_{NS}, where N is the number of the set, S is the number of the logic value of y, is within $0 \le p_{NS} \langle 1$ ($0 \le \mu_{NS} \langle 1$). The sum of the probabilities is $\sum_{s=1}^{5} p_{NS} = 1$ for each N = 1, 2, 3, ... , 81. This does not concern $\sum_{s=1}^{5} \mu_{NS}$ in the case of fuzzy values.

D. Dialog systems for decision – making.

Dialog is understood as iterative process of decision – making, which is based on a direct and sufficiently fast exchange of information between two subjects and on constant change of the roles (informer – informed subject). Unless this change of the roles exist, the process is unilateral and is characteristic for traditional information systems. In the examined case the concept dialog concerns also the contact between the user and the computer.

The main advantages of the dialog systems are:

- a possibility for applying knowledge of higher grade (semantic networks, dispersed data etc.);
- a possibility for detailed observation of the process of decision–making (a more thorough mechanism for explanation);
- a possibility for applying methods for non-monotonous logic conclusions.

In their nature these are possibilities for the application of new generation systems of artificial intelligence.

The dialog systems for decision–making are subject – oriented, which is a characteristic for contemporary artificial intelligence systems and are an actual task of the CAD/CIM systems.

CONCLUSION

According to the theory of the statistic decisions the problem for decision–making in the conditions of risk and indefiniteness is systematized. Development of the theory by a new formal apparatus – the many-valued logic - is suggested.

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APPLICATION OF THE ARTIFICIAL INTELLIGENCE METHODS IN CAD/CAM/CIM SYSTEMS

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ABSTRACT
Recent CAD/CAM/CIM systems have reached a very high level of development and application based mainly on the development of the computer technique and the applied mathematics tendencies and information technologies. The reference review showed that the application of the scientific tendency artificial intelligence is still insufficient. In the process of work it is attempted to synchronize the potential of its wide application in the considered system class.
Key words: Projecting stage, choice of decisions, optimization in conditions of risk and indetermination.

INTRODUCTION

Design is a series of procedures, in which an analysis of designed object and conditions of environment, development of variants and choice of optimal decisions, according to the assignment of design are made. It is not needed to prove the creative character of design and necessity of extended application of artificial intelligence systems.

Intelligence is the ability of a human, in the considered case the designer, to find successful decisions in the presence of incomplete or insufficiently accurate a priori information. Artificial intelligence is a computer program, in which the intelligence of prominent specialists in certain field is synthesized and set up.

The power and potential of Artificial Intelligence (A.I.) tools for planning and controlling of manufacturing processes has been proven by many research projects and demonstrations. The most important A.I. techniques are quantitative reasoning and simulation, and the use of deep models. Typical applications are for design, manufacturing planning, machine diagnosis, machine lay-out, system configuration, task-oriented programming, man/machine communication, vision, sensor data interpretation ect. At the present time, however, it is not known how many of these systems are practicable and are being used. A conservative estimate is that the results of only 5% of all research endeavors have found their place in the factory. This may be a very discouraging reality; but there are numerous reasons for this problem, including:

- The tools for building expert systems are not sufficiently developed and are difficult to apply.
- Good expert systems usually contain several thousand rules and are huge software systems which are difficult to use on conventional computer systems.

STRUCTURE OF AN EXPERT SYSTEM

The builder of an expert system must have a model of the system for which a solution is to be sought. The model describes the properties and behavior of the system. Usually, an attempt is made to keep the model simple and to only include the important features of a process.

Numerous programs and programming packages have been developed to solve manufacturing problems. The heart of a program consists of the algorithm and data. The execution of a program is done in a concise manner laid down by the rules of the algorithm, which may include branching and looping.

The basic difference between the program and the expert system is the way knowledge is presented and processed. The expert system consists of a knowledge database containing explicit knowledge of a human expert in a specialized, domain, and a reasoning or inference engine which can access the knowledge base to derive at a decision for a described problem. The description of the problem and the context are entered by the user or by the system. An Expert system consists of the following seven components:

- *User or tutor Interface.* There are two groups of persons who must have access to the expert system. First, the tutor who set up the system and who prepares the knowledge to be entered into the database. The tutor will also maintain the expert system. Second, the user who tries to find a solution to a problem. He must be able to describe the context of his problem to the system.
- *Knowledge Acquisition Module.* This module processes the data entered by the expert and transforms it into a data presentation understood by the system.
- *Language Interface Module.* There are various ways of communicating with the system; it can be done by natural, graphical or problem oriented language. The level of abstraction of the user language will be much higher than

that of the tutor language. The language used must be understood by the interface, and a special expert system may be needed to extract from the user input the semantics which describes the problem uniquely.

- *Manufacturing Knowledge Module.* This module can be understood as a world model of the domain for which the expert system was developed. It is like a huge database which contains all factual knowledge and rules needed for the operation of the expert system.
- *Context or Workspace Module.* There are two ways of operating this module. First, the user enters into the system the description of his problem. Second, the system constructs the description itself by interrogating the user in a question and answer session. For this operation, there must be a description of the problem available to the system.
- *Interference Engine.* Essentially, this module is the knowledge processor which looks at the problem description and tries to find a solution with the help of both the factual and meta-knowledge. First, all rules of the factual knowledge are investigated by the reasoner, and, with the Help of the pattern matcher, the ones to be used are selected. Thus, a set of candidate rules are obtained. Second, one of the rules is selected and applied to the problem description by the processor.
- *Explain.* The user can communicate with the explainer to obtain a report about the operation of the expert system. He can find out how a solution was derived and which individual steps were taken. If the user desires, he can obtain intermediate data and information on how the knowledge was used.

ARTIFICIAL INTELLIGENCE APPLICATION IN MANUFACTURING

It is known that the control systems for the enterprise has to be designed in a hierarchical manner. On each level expert systems can be used to perform and to diagnose the current status of the next lower level, the planning task on that level.

- *Design*. When a product is being developed, the design process passes through the definition stage of the functions, definition stage of the physical principle, design stage of the shape, and the detailing stage. The expert system will be of help where the designer is concerned with details, such as finding available similar designs, standard components, tolerances, alternative solutions, reduce significantly trial and error searches, etc. There are three types of designs which lead to the conception of a new product. They are the new design, variant design, and modified design. It will be extremely difficult to produce a new design with the help of an expert system. There is no way of finding with this tool a solution to a problem for which no prior knowledge is stored. The variant design is based on existing functional and physical principles of a similar product. Dimensions and other physical parameters, however may be different. Here, expert systems will be of help to propose to the designer a solution based on a variant. The modified design usually has only a few alterations of an existing product. The design of the product determines, to a great extent, its manufacturing process. Expert systems can be of assistance to consult the designer about the manufacturability of the product.
- *Process planning.* When the design of the product is completed, process planning gets into action (Majumdar et al. 1989). There are two different methods used for process planning: they are the generative and variant methods. With the generative method, the part surface to be created has to be related to a manufacturing method. With variant process planning, the manufacturing process of a part variant must be known and stored in the computer as a nonparameterized variant. The designer queries a variant catalog in the computer and searches for the variant which is similar to the part to be made. This method has the disadvantage that a variant must be available for every part to be manufactured. Expert systems will mainly be of help for the first four phases of process planning:

1. *Selection of blanks or stock* (selection of material, determination of the type of blanks or stock, Calculation of the machining allowance).
2. *Selection of processes and machining sequences* (surface features, dimensions and tolerances, surface treatment and finish, piece rate, required work space for the tool, cutting direction, necessary tool changes, etc).
3. *Machine tool selection* (size of part, surface finish, machining sequences, process variants, required accuracy, piece rate, machine tools, etc).
4. *Selection of fixtures.*

- *Manufacturing Scheduling.* The information going into scheduling are the type and number of parts to be manufactured, the process plans, the bill of materials, order delivery dates, available machine tools, other resources, factory monitoring data on resource utilization, etc.

The two artificial intelligence tools most suitable for scheduling are the generate and test, and the constraint *propagation* methods.

- *Quality control.* Quality control is an important function of the manufacturing process. A quality control operation is done in several phases: First, a test plan is drafted. Second, the test system is configured and programmed for the individual products to be tested. Third, the measurements are performed and the data are recorded. Fourth, the data are evaluated and test protocols are prepared.

There are two areas where expert systems may be of considerable help to improve a quality control operation: test planning, and data evaluation and interpretation

- *Diagnosis.* Expert systems for diagnosis are the most advanced A.I. tools used in manufacturing. They play an important role in supervising complex production equipment and locating problems as soon as they arise. Presently available diagnosis systems can be defined by three categories: Statistic diagnosis systems, heuristic diagnosis systems and diagnosis models.
- *Implicit Programming of Robots and other Manufacturing Equipment*.

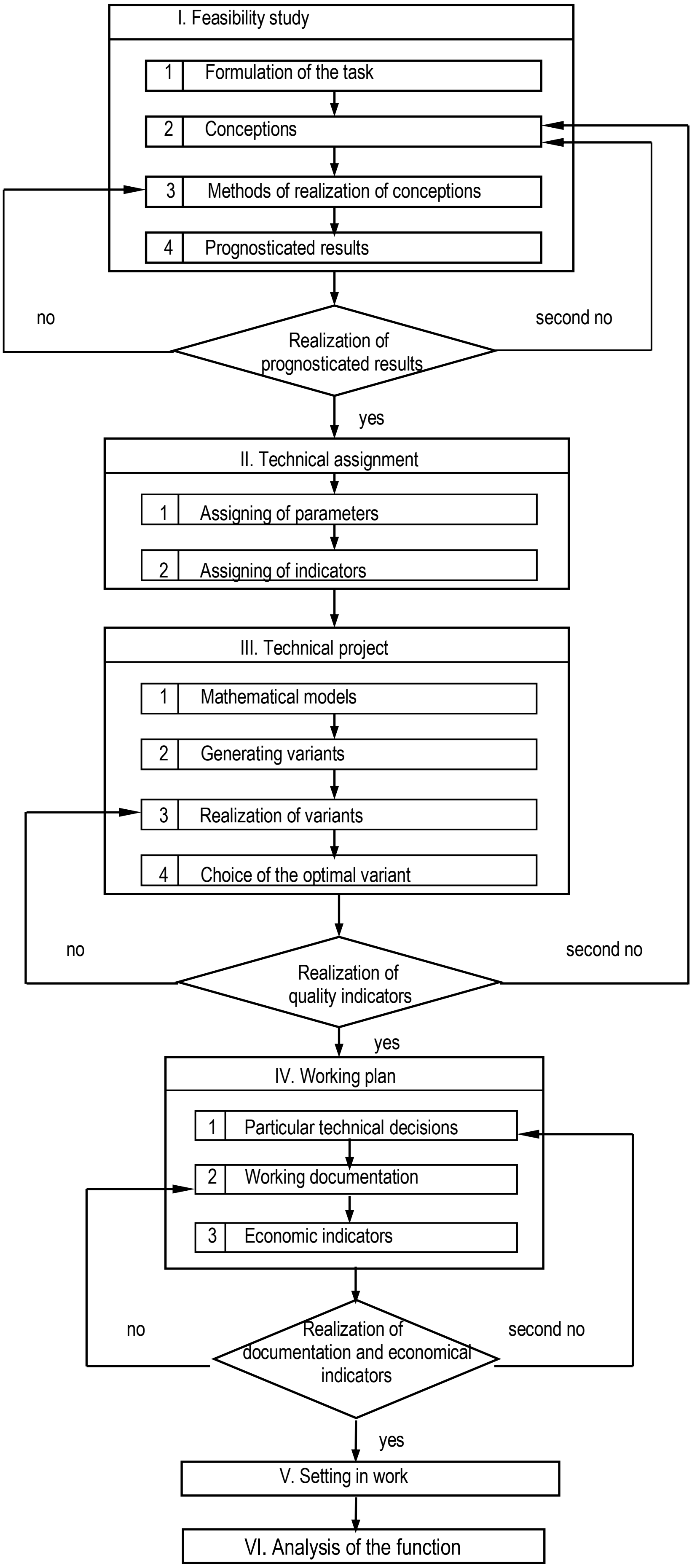
I. Feasibility study
1 Formulation of the task
2 Conceptions
3 Methods of realization of conceptions
4 Prognosticated results
no
second no
Realization of prognosticated results
yes
II. Technical assignment
1 Assigning of parameters
2 Assigning of indicators
III. Technical project
1 Mathematical models
2 Generating variants
3 Realization of variants
4 Choice of the optimal variant
no
second no
Realization of quality indicators
yes
IV. Working plan
1 Particular technical decisions
2 Working documentation
3 Economic indicators
no
second no
Realization of documentation and economical indicators
yes
V. Setting in work
VI. Analysis of the function

Figure 1.

Application of systems in the stage of feasibility study

Considering the tasks performed on that stage, development of systems is advisable the for a better-grounded choice of conceptions and principles by the realization of the projected decisions, choice of the alternative variants of the final purposes and tasks for providing the maximum values of the quality/cost criteria. A better-grounded realization of the task for the feasibility study of the developed projects has a direct dependence on the appraisal for potential application of the offered decisions in the considered stage. It is useful to develop an expert system with an extended database regarded to the projected object, the possible conceptions and the methods for their realization.

Application of systems in the stage of technical project

Here the possibilities for application are extremely extended and various. The development of a wider spectrum of variants of the design decisions with more detailed setting of the peculiarities and the parameters of ambient factors are of great significance. The most important application of the systems of artificial intelligence is in the reasoned choice of optimal variants in conditions of indetermination.

Recent computers have practically unlimited potential for formalizing of the factors (parameters) of the choice, the factors of the unspecified environment and appraisal of the optimality criteria values. It is considered here that the criteria for optimality are considerably different from criteria by the optimization in conditions of determination (determinism) and risk (stochastic conditions). In particular, the criterion for optimization under conditions of indetermination has not an only value but a multitude of values in a defined interval with a defined stage of attachment. This means that an application of a multi-digit function is reached.

Important peculiarity of the present requirements to design decisions is the presence of a multitude of criteria for optimality (task for multicriteriality of design decisions). Under conditions of indetermination (multidesignation of the particular criterion) the task for a vector optimization acquires extreme complexity not only in qualitative (semantic) sense, but also simply in quantity (combinatorial explosion). In these conditions setting the level of compromises (the level of Pareto) is practically impossible with the known conventional methods of the multi-criteria optimization theory. Assuming the possibility for applying of non-monotonous logical deductions, the application of systems of artificial intelligence is practically the only way for finding the optimal multi-criteria decisions in conditions of indetermination.

Processes in the development of design decisions

The basic conceptions of the system approach in design are:

1. Principle for coordination of the projecting works and decisions between the separate groups of designers-specialists in the relevant scientific-technical directions (technical engineers, mathematicians, mechanics, electrical engineers, etc.).

2. Principle of the iterative approach by solving problems, arisen during the realization of the projecting work. Iterative approach means that after performing of a certain number of procedures and analyses of the results, if needed, the performed procedures are repeated in order to improve and reach optimal, in the assigned purpose (assigned criteria), projecting decisions. The main requirement is the performed iterative procedures to be ensured in respect to identity the required optimal decision. It is desirable that the number of the iterative procedures is as least as possible. If a good identity is missing the iterative procedures must include some of the previous stages in order to correct already accepted decisions.

Generalized algorithm for iterative procedures in the development of design decisions

One of the many possible iterative procedures is shown through a diagram (fig.1.).

Iterative procedures are referred to every single stage of projecting, so that with an increase of the serial number of the iteration, procedures that precede the respected stage are included. For example in the stage feasibility study the non-realization of the prognosticated results leads to iteration that is addressed to procedure № 3 "Methods of realization of conceptions", this means searching for new approaches for their realization and reaching to the desired prognosticated results. If a new non-realization of the prognosticated results, "second no", is reached it is needed the new iteration to be addressed to the procedure № 2 "Conceptions". This means that based on the "Formulation of the task" (procedure № 1) a new conception search must be made. In case of a new non-realization "second no" appears as a third iteration, by which new conceptions are searched for, until the formulation of the task is satisfied by the prognosticated results.

In the stage "Technical assignment" iterations are impossible, since the assigned parameters and quality indicators must be maintained.

In the stage "Technical project" the non-realization of the quality indicators leads to iteration to the same stage but by a second non-realization the next iteration requires a return to the first stage "Feasibility study".

The iterations in stage "Working project" are performed in a similar way. A return to a previous stage is not provided, because the realization of the quality indicators in the stage "Technical project" means that new particular technical decisions inside the stage "Working project" must be searched.

CONCLUSION

Significant potentialities of the artificial intelligence methods to different stages of design are presented. These potentialities considerably increase the efficiency of the computer systems for design (CAD/CAM/CIM).

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GENERATING ACCURATE PLANS OF THIRD-DEGREE MODELS WITH IMPROVED FACTOR OF MULTICOLINEARITY

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ABSTRACT
Known plans of experiment for assessing third-degree models exhibit well expressed multicolinearity, i. e. a linear relationship between the columns of the information matrix. Their implementation impairs the processing of experimental data, and in many cases leads to obtaining biased estimates for the coefficients.
Algorithms and programmes that minimize two indirect criteria, namely the sum of extradiagonal elements of the covariance matrix, or the maximal one of those elements, are proposed for finding plans of a low factor of multicolinearity. Using these algorithms and programmes, plans of experiment for cubic regressions with two, three, or four factors have been generated. In all cases the value of the maximum variance inflation factor of experiment plans obtained has been improved up to two or three times.
Keywords: optimal planning of experiment, multicolinearity, cubic regression.

PROBLEMS OF OPTIMAL EXPERIMENT PLANNING FOR CUBIC REGRESSION

Besides a complete polynomial of second degree the polynomial models of third degree with *m* controlling factors also involve a term in one of the following forms or a combination of several such terms.

$$A = b_0 + \sum_{i=1}^{m} b_i x_i + \sum_{i=1}^{m-1}\sum_{j=i+1}^{m} b_{ij} x_i x_j + \sum_{i=1}^{m} b_{ii} x_i^2 \qquad (1)$$

$$B = \sum_{i=1}^{m-2}\sum_{j=i+1}^{m-1}\sum_{l=j+1}^{m} b_{ijl} x_i x_j x_l \qquad (2)$$

$$C = \sum_{i=1}^{m-1}\sum_{j=i+1}^{m} b_{ijj} x_i x_j^2 + \sum_{i=1}^{m-1}\sum_{j=i+1}^{m} b_{iij} x_i^2 x_j \qquad (3)$$

$$D = \sum_{i=1}^{m} b_{iii} x_i^3 \qquad (4)$$

There exist many approaches to searching optimal plans for models of that type (Vuchkov, Krug et al., 1971; Vuchkov, Iontchev et al., 1978; Merzhanova and Nikitina, 1979; Iontchev, 1991). Criteria for *D*- or *G*-optimality are mostly used in those approaches, and the plans obtained have very good values of D_{eef} or G_{eef}. However, their applications are connected with problems emerging in the statistical processing of experimental data. This is due to the violation of one of the pre-requisites of using the method of least squares for assessing the coefficients in regression models, namely the requirement for lack of multicolinearity (i. e. no linear relationship between the columns of extended matrix *F* of the experiment plan should be present).

Several criteria calculated from the elements of matrix $\overset{o}{G} = \overset{o}{F}{}^{T} \overset{o}{F}$ have been proposed for the assessment of multicolinearity. A survey of those criteria has been compiled by Mitkov and Minkov (1993). $\overset{o}{F}$ designates the standardized matrix of the experiment plan, the elements of which are determined in accordance with the relationship:

$$\overset{o}{f}_{ji-1} = \frac{f_{ji} - \bar{f}_i}{\sqrt{\sum_{j=1}^{N}\left(f_{ji} - \bar{f}_i\right)^2}}\ ,\ \mathrm{i} = 2, \mathrm{k}\ ;\ \mathrm{j} = 1, \mathrm{N} \qquad (5)$$

where *k* is the number of coefficients in the regression model being assessed, *N* the number of trials in the experiment plan, and $\bar{f}_i$ the arithmetic mean of the i^{th} column of *F*.

The most frequently used criterion for multicolinearity is the variance inflation factor or VIF. It is a vector consisting of the diagonal elements of standardized covariance matrix $\overset{o}{C} = \overset{o}{G}{}^{-1}$ It is assumed (Belsley, Kuh et al., 1980; Hocking, 1983) that a multicolinearity is present when the maximal element of VIF is greater than 3 to 5.

Table 1 shows data for the maximal VIF values of some known plans of experiment for models of complete third degree.

Table 1

Type of the experiment plan	Proposed by	m	N	Max VIF
1	2	3	4	5
Plan of 4 levels		2	16	12.69
Orthogonal non-compositional	Razdorskiy, Chaliy et al. (1973)	3	40	34.04
	Denisov and Popov (1976)	3	32	67.50
Discrete quasi-D-optimal	Vuchkov, Krug et al. (1971)	3	40	19.83
Non-saturated consecutive D-optimal	Vuchkov, Iontchev et al. (1978)	3	20	23.48

There is also an expressed multicolinearity in plans obtained for a non-complete third degree (Merzhanova and Nikitina, 1979; Iontchev and Stoianov, 1998).

Applying the method of least squares in the presence of multicolinearity leads to instability of coefficient estimates. In such a case it is recommended to process the experimental data by using the method of principal components, ridge regression analysis, regression analysis on characteristic roots, regression analysis with generalized reversal. A common disadvantage of the estimates obtained by these methods is their biasing which is the more considerable the stronger the mutual relationship between columns in matrix *F* is expressed.

Problems discussed above impose the development of algorithms and programmes for generating plans of experiment for cubic regression that have a low factor of multicolinearity. In such a way the needed pre-conditions will be created for finding more accurate estimates for coefficients in the equations being sought after.

INDIRECT CRITERIA FOR MULTICOLINEARITY

In the most general case, procedures of searching optimal experiment plans are reduced to improving iteratively a characteristic of an initial plan by consecutively eliminating and adding points to it.

For the assigned task of searching plans of a low multicolinearity factor it would be logical that the criterion of optimality be connected with minimization of the maximal VIF value. However, its direct application is limited by the large number of necessary computational operations. Every modification of the current plan (adding or eliminating a point) requires new standardization of *F*, forming and reversing matrix *G*. Although there are recurrent relationships for the first two operations, reversing the matrix implies considerable computational losses.

To synthesize algorithms of satisfactory speed of performance it is convenient to use parameters connected with the non-standardized covariance matrix *C*. Re-calculating its elements, when there is a change in the number of trials in the plan, can be easily realized by using the relationships proposed by Galil and Kiefer (1980). Substituting an indirect criterion for the basic one will be possible if only there is a correlation between them. To verify this hypothesis for various types of experiment plans for a sample of volume 10 the following has been found:

- the estimates for correlation coefficient $\hat{r}_1$ between maxVIF and the sum of absolute values of the extradiagonal elements in *C*;
- the estimates for correlation coefficient $\hat{r}_2$ between maxVIF and the extradiagonal element of maximal absolute value in *C*;
- the estimates for correlation coefficient $\hat{r}_3$ between maxVIF and the extradiagonal element of maximal absolute value in *C*;
- the calculated values of Student's *t*-criterion $t_i\ , i = 1,...,3$.

Results for four of the variants examined are shown in Table 2. For the first three of them the model is in the form $\hat{y} = A + D$, and for the last one $\hat{y} = A + B + D$.

Table 2.

Characteristics	Variant			
	1	2	3	4
1	2	3	4	5
m	2	3	3	4
k	8	13	13	23
N	12	13	19	28
$\hat{r}_1$	0.896	0.945	0.898	0.786
$\hat{r}_2$	0.988	0.996	0.991	0.996
$\hat{r}_3$	0.980	0.996	0.980	0.985
t_1	8.555	8.190	5.769	3.594
t_2	26.799	33.767	20.660	29.694
t_3	21.104	30.318	14.120	16.293

At a significance level of 0.05 the tabular value of the *t*-criterion is 2.306. In all cases examined it is smaller than the calculated one. This allows to assume the hypothesis for the presence of a linear relationship between the investigated variables, and to build up algorithms using indirect criteria for multicolinearity. Here, it should be taken into account that it is not possible to realize "free of charge" decreasing of the multicolinearity, and the plans obtained will have reduced parameter values for D_{eef} .

ALGORITHMS FOR GENERATING PLANS WITH A LOW FACTOR OF MULTICOLINEARITY

Two indirect criteria for searching optimal plans ζ^* with a low factor of multicolinearity have been used: a minimum of the sum of the absolute values of extradiagonal elements in matrix *C*, and a minimum of the extradiagonal element of highest module value in the same matrix.

$$\sum_{i=1}^{k-1}\sum_{j=1}^{k-1}\left|c_{ij}\left(\zeta^*\right)\right| = \min_{\zeta}\sum_{i=1}^{k-1}\sum_{j=1}^{k-1}\left|c_{ij}\left(\zeta\right)\right| \qquad (6)$$

$$\max_{i,j}\left|c_{ij}\left(\zeta^*\right)\right| = \min_{\zeta}\max_{i,j}\left|c_{ij}\left(\zeta\right)\right| \qquad (7)$$

They have been selected based on the following considerations:
- finding a minimal value 0 for the first criterion leads to generating an orthogonal plan, which means non-correlation of the estimates for regression coefficients and easy processing of experimental data;
- the coefficient of correlation between the second criterion and the maximal VIF is of the highest value.

Algorithm MMC1

From a random initial plan of *N*-1 points that point shall be eliminated, which minimizes the criterion selected. A random point from the points of number *L* forming the set of candidates is added to the *N*-point plan obtained. If this leads to a decrease in the criterion value it is assumed that a point has been successfully replaced. This procedure is continued until unsuccessful replacements of number *L* are carried out.

Algorithm MMC2

It applies a criterion of optimality (6) and in a generalized form realizes the following sequence of operations:
1. An initial plan of *N*+1 points is generated, the points being randomly selected from the set of candidates.
2. Eliminating consecutively one point at a time from the initial plan leads to obtaining *N*+1 plans, each of them consisting of trials of number *N*.
3. Sums S_i, $i = 1, 2, ..., N+1$, of the absolute values of extradiagonal elements in the covariance matrices are computed for all plans obtained at step 2.
4. A k^{th} plan for which $S_k \leq S_i$, $i = 1, 2, ..., N+1$ is defined. It is assumed to be the best one for the time being, and the value of S_k is assigned to the minimal sum of extradiagonal elements S_{min}.
5. A check for depleting the set of candidates is performed. If consecutive unsuccessful attempts for adding all candidate points have been made, then the best plan obtained so far is assumed to be the one that has been sought after. Otherwise, the programme goes to step 6.
6. A random point from the set of candidates is added to the best plan found so far, and a plan of *N*+1 points is obtained.
7. Eliminating consecutively one point at a time from the plan formed at step 6 leads to obtaining *N*+1 plans, each of them consisting of trials of number *N*. The sum S_i, $i = 1, 2, ..., N+1$, of the absolute values of extradiagonal elements in the covariance matrix is computed for each of those plans.
8. A p^{th} plan, for which $S_p \leq S_i$, $i = 1, 2, ..., N+1$ is defined.
9. If $S_p < S_{min}$, then the p^{th} plan is assumed to be the best at that moment of the search procedure, the value of S_p is assigned to S_{min}, and the algorithm continues performing from step 6. If $S_p \geq S_{min}$, then the programme goes to step 5.

Algorithm MMC3 has a structure analogous to that of MMC2 but the optimality criterion it uses is (7).

The algorithms shown have been realized as programmes in FORTRAN 77. To increase the speed of performance the programming solutions are based on:
- using only the supradiagonal elements of the covariance matrix for the matrix is a symmetrical one, and
- applying a recurrent computation of the effectiveness criterion value.

ANALYSIS OF RESULTS

Accurate experiment plans for the cases shown in Table 3 have been searched for by using the algorithms represented for the two selected criteria.

Table 3.

№	Type of model	m	k	N	L
1	2	3	4	5	6
1	$\hat{y} = A + D$	2	8	12	441
2		3	13	13	9261
3		3	13	19	9261
4		4	19	24	6561
5	$\hat{y} = A + B + D$	3	14	15	9261
6		4	23	28	6561
7	$\hat{y} = A + C$	3	16	21	9261
8	$\hat{y} = A + B + C + D$	3	20	25	9261

The characteristics of plans generated with procedure FDOP proposed by Iontchev (1991) have been used as a basis for comparing the results obtained.

In algorithm MMC1 the decision for replacing a point is made from the value of characteristics calculated for a plan of N+1 points. It turns out this being an essential problem in searching as the minimal value of the criterion obtained on the basis of N+1 points does nor guarantee a minimum for the criterion obtained from a plan of N points. For the algorithm considered the number of replaced points is relatively small, a tendency towards involving points symmetric to those existing in the current plan is observed, and the resulting plan depends to a considerable degree upon the initial one. For these reasons, the use of algorithm MMC1 is inefficient, irrespective of the fact that it finds plans of reduced multicolinearity.

Data for the maximal VIF of the best plans obtained through procedures FDOP, MMC2, and MMC3 are given in Table 4.

Table 4.

№ of plan	MaxVIF for plans obtained through:		
	FDOP	MMC2	MMC3
1	2	3	4
1	11.1954	5.3504	4.7934
2	15.8430	8.0715	7.2006
3	15.1251	5.8280	6.6307
4	16.5743	7.8128	7.7146
5	22.1535	9.0887	6.1818
6	27.7123	9.9930	5.9266
7	10.0000	4.7857	4.2968
8	28.3218	15.8197	11.6665

Fig. 1 shows the averaged parameters for maxVIF. Data from 10 successive realizations have been used for each of the eight required experiment plans. Plots corresponding to results obtained through procedures FDOP, MMC2, and MMC3 are designated by 1, 2, and 3, respectively.

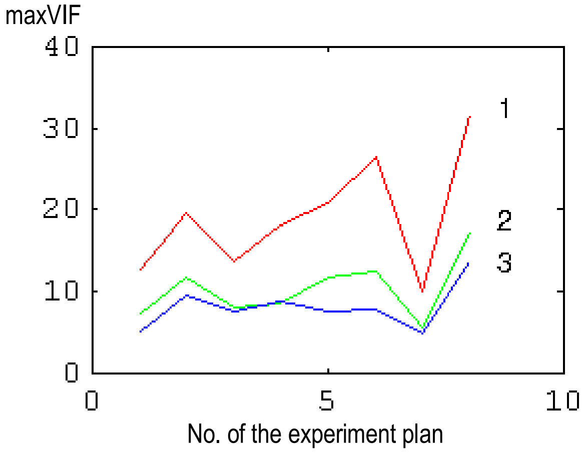

Figure 1. Variation of the mean value of the maximal variance inflation factor.

The number of iterations depends on the initial random plan. That is why the average number of iterations can be used for comparing the speeds of convergence of the algorithms proposed. Data for experiment plan No. 1 are shown in Table 5.

Table 5.

Parameters	Algorithms	
	MMC2	MMC3
1	2	3
Average number of iterations	1520	1560
Maximal number of iterations	2475	2430
Minimal number of iterations	724	805
Average number of successful iterations	42	48

Moreover, there is no much difference between the numbers of iterations needed for generating the rest of the plans when using algorithms MMC2 or MMC3. This allows to conclude that they are characterized by practically comparable speeds of convergence.

A simulation programme has been created in the MATLAB environment for the purpose of checking the properties of experiment plans generated. This programme is characterized by the following:

1. For all points of the plan examined it determines multiple times the value at the output of a plant described by a model of complete third deegree in the presence of a standard white noise. The real values of the coefficients are given in column 2 of Table 6. The ratio between the standard deviations of noise and the useful signal is 7 percent.
2. Using the method of least squares it determines the estimates of coefficients in the regression equation.
3. It calculates the variance of regression coefficients.

Results obtained for plan No. 8 are shown in Table 6.

It is obvious that for plans generated by using MMC2 and MMC3 the maximal value of coefficient variance has been reduced more than twice compared to that of the respective D-optimal plan.

The following conclusion can be deduced from the analysis of results obtained:

- using procedures MMC2 and MMC3 leads to obtaining plans of maximum value for the variance inflation factor being 2 to 3 times lower than that of respective D-optimal plans, which determines a considerable decrease in the variance of coefficient estimates for the regression equation;
- using criterion (7) generally leads to finding plans with lower values of maxVIF.

Table 6.

Symbolic designations and real values of coefficients		Coefficient variance when using:		
		FDOP	MMC2	MMC3
1	2	3	4	5
b0	3.0	0.2868	0.2299	0.1680
b1	-2.0	0.8462	0.4314	1.0682
b2	4.0	3.3604	0.8103	0.5105
b3	6.0	1.2387	0.6983	0.5164
b12	-4.0	0.0809	0.3071	0.1047
b13	2.5	0.1053	0.2905	0.1391
b23	-3.7	0.1293	0.1322	0.1446
b123	9.0	0.1043	0.0619	0.4879
b11	-12.0	0.2012	0.3108	0.2235
b22	-4.0	0.0724	0.2730	0.0892
b33	-3.0	0.1825	0.2694	0.4403
b111	-1.5	0.4016	0.3748	1.0697
b222	2.0	3.3216	1.3945	0.4629
b333	6.0	1.4865	0.3574	0.5643
b112	4.0	0.8494	0.4110	0.9025
b113	-3.0	0.5768	0.5376	0.9957
b221	6.5	0.7121	0.6688	0.3853
b223	4.4	0.2715	0.9387	0.3070
b331	-2.6	0.3759	1.3532	0.9951
b332	3.3	0.2184	1.0997	0.4293

At the same time it should be remembered that reducing the multicolinearity leads to lower D-effectiveness of the plans as well. Fig. 2 shows the averaged values of D_{eef} for the eight experiment plans obtained through MMC2 (plot 1) or MMC3 (plot 2).

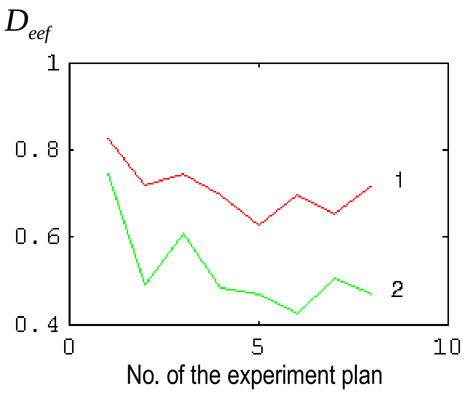

Figure 2. Variation of the mean value of D_{eef}.

Investigating the algorithms MMC2 and MMC3 and their respective programming implementations has shown that they can be used for generating plans for cubic regression, while the experimenter will have to choose the criterion to be used depending on the requirements for proximity of the plan obtained to the D-optimal one.

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RECOGNOTION OF SYMMETRICAL SHAPES IN SCANNED MECHANICAL DRAWINGS

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SUMMARY

The scanned mechanical drawings have some defects. Defects connected with the infringement of geometrical form received from scanning are discussed in this paper.

Basic methods for establishing of symmetry relation between vector segments are discussed. Here is offered a decision of automated determination of symmetry and appropriate centerline in mechanical drawings.

Key words: Symmetry detection, deskewing, centerline, symmetry axes, recognition,mechanical drawing

INTRODUCTION

The qualitative transformation from raster to vector format meets definite difficulties. They follow from ambiguity of possible ways for replacement of raster representation by vector depending on context. The using of heuristics methods is necessary.

There are many program products, which transform from raster to vector format without reading of context. As examples are - GTX RasterCAD and VP HybridCAD . Graphical determined relations between graphical objects are presenting with axes line in mechanical drawings, that are represented as symmetric location and common axis. The symmetric form of some graphical objects is representing. Axis lines uses as basis for reinstatement of regular geometric form of objects in scanned image of GTX RasterCAD and VP HybridCAD.

The scanned image of mechanical drawing contains defects, which can and not exercise influence on the quality of visual perception, but are obstacle to necessary processing. The defects show as small disturbances , expressed in lack of single pixels, or of not large groups of pixels, or in surplus of that. There are distinguishing the follow fundamental types of defects: isolated spots of excess of pixels; isolated white spots of missing pixels; tearing to pixels; false end points in contour of lines; missing end points; disturbances along the length of line. That defects are showing in redundant or in missing pixels and in bending of the form of the objects. Because of that the recognition of the axis line meets some difficulties. If we add to that and the fact that the axes draw up by not clearly-distinguished sequence of lines and points that simultaneously are intersected from another projection elements then the recognition of them becomes impossible without determination of respectively symmetric relation.

THE PURPOSE

To be systematized the ways for determination of symmetric axis between symmetric elements of raster images.

To be offered a method for detecting of symmetry relation in raster image of mechanical drawing .

METHODS FOR DETERMINATION AXIS LINE

The papers of Blum (1978), Brooks (1978) and Brady (1984) are initiator workings out for representation the form of raster-depicted objects in computer as symmetry toward axis. For the purposes of this material is necessary to consider the problem for symmetry axis determination of the multitude M that consists from projection objects at mechanical drawings. Two alternative methods will be formulated – *method of raster elements for recognition of axis line and method for straight lines for recognition of the axis line.*

Method of raster elements for recognition of axis line

- Essence of the method

In this case the multitude M consists from raster elements, that are given with their coordinates $M = \{x_i, y_i\}$ (Fig. 1). More common variant of this method is considered from Friedberg (1986) for determination the axis lines in axonometric projection of mechanical product. For the purposes of recognition of the objects in orthogonal projection is enough to consider the special case of this method.

Let the multitude $M = M_1 + M_2$, where M_1 and M_2 are its two symmetric parts. Let, a chosen point U from axial line is called *point of support*. The centre of gravity M is selected for the point of support $U = (a, b)$, where

$a = \frac{\sum x_i}{n}$, $b = \frac{\sum y_i}{n}$ and n is the number of elements of M.

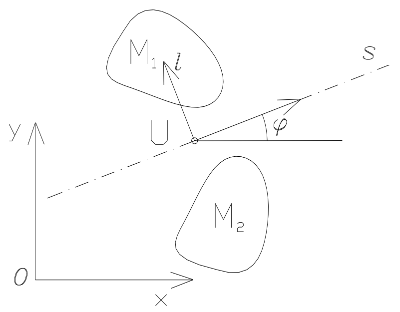


Figure 1: Symmetrical multitudes of raster elements M_1 and M_2, point of support and axial line

Let, $\Lambda = m_{11}x^2 + 2m_{12}xy + m_{22}y^2$ is a quadratic form, where $m_{11} = \sum (x_i - a)^2$, $m_{12} = \sum (x_i - a)(y_i - b)$ and $m_{22} = \sum (y_i - b)^2$. Let, s is the axial line and it conclude angle $\varphi = (\vec{Ox}, s)$ with abscissa $\vec{Ox}$.

As a result of the transformation $Oxy \to Us\ell$, that consists from a translation and a rotation with angle φ, the quadratic form transforms in $\Lambda' = n_{11}s^2 + 2n_{12}s\ell + n_{22}\ell^2$. Between the coefficients of the linear forms the relation is performed:

$$T\begin{pmatrix} m_{11} & m_{12} \\ m_{12} & m_{22} \end{pmatrix}T' = \begin{pmatrix} n_{11} & n_{12} \\ n_{12} & n_{22} \end{pmatrix},$$ where

$$T = \begin{pmatrix} \cos\varphi & \sin\varphi \\ -\sin\varphi & \cos\varphi \end{pmatrix}.$$

From this equation follows:

$$n_{12} = \frac{1}{2}(-m_{11}\sin 2\varphi + 2m_{12}\cos 2\varphi + m_{22}\sin 2\varphi) \qquad (1)$$

Because of the symmetry for every element of M_1 with coordinates $(s_i, \ell_i), \ell_i > 0$, there is a element of M_2, such that its coordinates are $(s_i, -\ell_i)$.

Then

$$n_{12} = \sum s_i \ell_i = 0 \qquad (2)$$

and from (1) follows

$$2m_{12}\cos 2\varphi = (m_{11} - m_{22})\sin 2\varphi \; . \qquad (3)$$

If $m_{12} \neq 0$, then

$$\varphi = \frac{1}{2}\text{arccotg}\,\frac{m_{11} - m_{22}}{2m_{12}}. \qquad (4)$$

From the received result can make the following conclusions:

- With $m_{12} \neq 0$ or $m_{12} = 0$ and $m_{11} \neq m_{22}$ from equation (4) two values follow for the symmetry angle φ and $\varphi + \frac{\pi}{2}$ toward $\vec{Ox}$;
- With $m_{12} = 0$ and $m_{11} = m_{22}$ the equation (3) is with innumerable many decisions. In this case, if M is a circle, than they are innumerable many axial lines and if it is a regular polygon – there are determined number of axes of symmetry.
- Determination of the symmetry relation

The practical application of attribute (2) is - if M is symmetric, then by them can be determined direction of the axis of symmetry. Because of the eventual defects of the image and its raster presenting m_{11}, m_{12} and m_{22} are considered as accidental variables. As far as the mathematical expectation for m_{12} is nearly zero, it influences considerably the precision of receiving of φ - i.e. the formula will give more inaccurate results, if φ is nearly zero, $\frac{\pi}{2}$ or π. This special feature of the method ought to take into account at program realization, that does not represent the special difficulty.

Obviously, for every multitude M can received two values for φ and if $m_{12} = 0$ and $m_{11} = m_{22}$, then other point of support ought be chosen and then $m_{11} \neq m_{22}$ and equation (3) will have only two decisions.

After determination of the axis s is verifying for every element of M_1 whether exists a symmetrical element in M_2 and if this elements, for which are no suitable, are no more from determinate with appropriate parameter part of M_1, then we consider M_1 and M_2 as symmetric.

The application of the method is implemented, as in the parameters of the axial line – point of support and direction, a narrow *area* S from the drawing is defined in which is viewed for the raster image of the axis line with some of the methods for line recognition.

Method of the lines for the recognition of the axis line

- Essence of the method

The representation of the segments in (θ, R) *space* is used, as in this way facilitates the recognition of axis line. This transformation applies in the method of Hough (Gotchev G., 1998).

Let the multitude M consists from segments. The center of gravity of M is chosen for point of support U and uses rectangular coordinate system Uxy .(fig.2). For determination of angle $\varphi = \angle(\vec{Ux}, s)$, between axis $\vec{Ux}$ and axis line s are represented lines, that consist of segments of M in space (θ, R) .

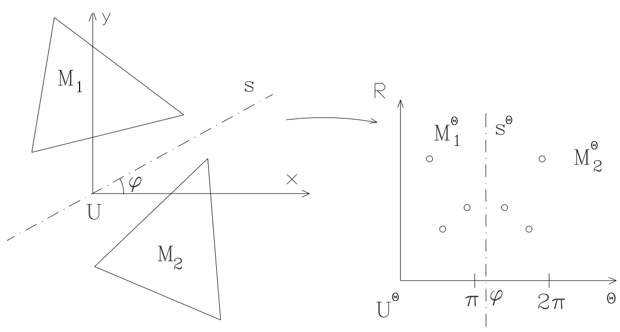


Figure 2: Symmetrical multitudes M_1 and M_2, with them images in (θ, R) space

As a result of the transformation, the segments of M represents in the symmetric multitude M^θ from the points of (θ, R) , with vertical direction of the axial lines s^θ . The point of support of axis line in (θ, R) is determined as point of support of multitude M^θ . After axis building s^θ , its moving toward π is the angle $\varphi = \angle(\vec{Ux}, s)$

- Determination of the symmetry relation

To be M symmetric multitude, M^θ must be symmetric. In additional must to verify that respective segments in M are symmetric about s

- Application of the method

Because of the specific path is to information's transformation at passing to (θ, R) space , this method can be used for determination of the axis line and in the case, when the multitude of segments M_1 is symmetric to sub-multitude $\overline{M}_2$ of the multitude of segments M_2 (fig. 3).

In such submission of the task is impossible to determination the point of support, at first. The task has decision through search in $\overline{M}_2$ to detection of symmetry. Using the (θ, R) space can decrease the operations significantly. Is a possibly to select and origin of system Uxy in a point that is near to point of support. This can made, for example, as with appropriate weights, calculate the coordinates of point near to the point of support $M_1 \cup \overline{M}_2$. For the of choice of U , the projections on a coordinate axis $\vec{U^\theta \theta}$ of points of M_1^θ and $\overline{M}_2^\theta$ are symmetrical. By viewing in $\vec{U^\theta \theta}$, is receiving the subset $\overline{M}_2$ and is checking are symmetric to M_1 . The process stops, when finds the multitude $\overline{M}_2$.

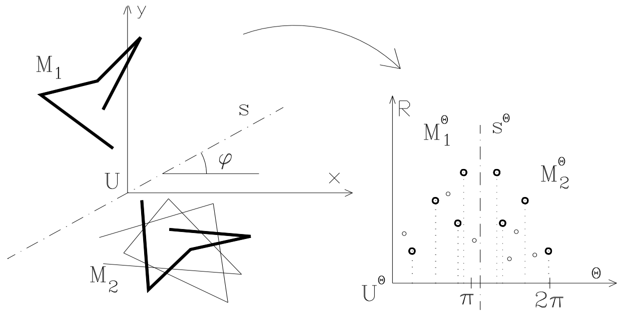


Figure 3: Representation in (θ, R) space were M_1 is symmetrical sub-multitude of M_2

Determination of the axial line at symmetrical arcs of circle

- Essence of the method

As a result of recognition of the lines, that represent the projection elements in mechanical drawing, are received vector-described segments and arcs of circles. If in M are arcs of circles with symmetric parts, then they are with equal radiuses. A point of support is the center of the segment, which connected centers of these two arcs. On the fig.4 is illustrated the case, when an arc of circle k_1 is symmetrical to a part of arc of circle k_2 . If the centers of arcs are $O_1 \neq O_2$, then the axial line s is the axial line of the segment O_1O_2 .

- Determination of the symmetry relation

The criterion for symmetry of two arcs of circle k_1 and k_2 is the equality of their radiuses. In the case, when two arcs have equal radiuses, with some approximation, then defines the middle point U between the centers of arcs and the symmetric axis s . If the sufficient part of the symmetric image of one arc towards s coincides with another, then the arcs are symmetrical. When the centers of arcs O_1 and O_2 coincide, then two arcs are symmetrical as the axial lines have any direction for s , with that the symmetrical image of one arc covers sufficient part of another arc.

DETERMINATION OF THE SYMMETRY RELATION

Realization on recognition of a fragment of the drawing

Here the surveyed methods are using for determination of symmetry between the multitude M_1 and subset $\overline{M}_2 \subset M_2$, in the cases of segments and arcs of circles, for the recognition of the symmetry relation between the vectorized segments of a mechanical drawing.

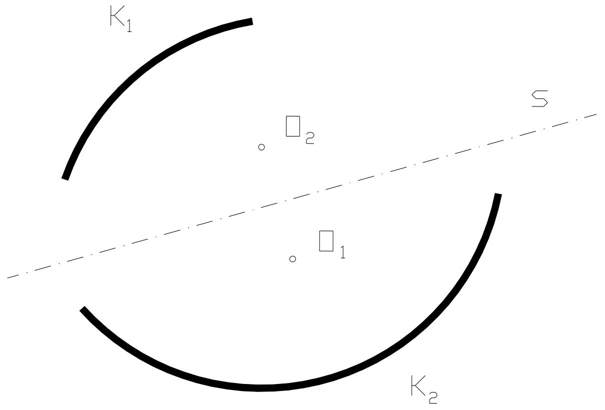


Figure 4: Determination of the axial line at symmetrical parts from circle

After receiving the vectorzation description of the *segments of lines and circles* (we here name as a *segments*), the recognition of the scanned image of the mechanical drawing follows with determination of the symmetry relations between segments and parts of segments. This can be realized full-automatically, as looking for every segment a segment with part that is symmetric to the first. If has such, then in the obtained narrow area S is required the axis line. Independently of defects owing to the raster representation and other difficulties in recognition, the determination of the axis line realizes with representing in (θ, R)-space as in Dimitrov (2001).

The presence in area S of a axis line is a necessary condition for the presence of symmetry relation between segments. All segments with one and same axis line are described in one symmetrical multitude - symmetry relation is registered.

The determination of symmetrical sets of segments can be performed with intervention of the operator. He points one or some segments and procedure for searching for symmetrical subset of symmetrical arcs of circles or symmetrical segments. In this aspect the realization has considerable advantages before to abilities that offered VP HybridCAD.

Complete decision

For the processing of real examples of scanned mechanical drawings it is necessary to applied a method for the effective recognition of the objects and symmetrical shapes. For the purpose, here will formulate such a method based on heuristic considerations – *the model of the visual perception*. The perception is a process of comparison of the images for the object with the ideas for it. The key feature of models is research perception as *interaction between processes.* The perception is adaptive and at the presence of errors in the object's images, they overcomes if possibly use additional properties for confirmation of the notions. The notion includes different elements about conservatism, that are related with *basic principles for depicting on the drawing (BP)*; *Experience from by hand execution and reading (EH)* and *dynamic variable experience (DVE)* – a result of consisted processes of perception of the concrete image (fig.5).

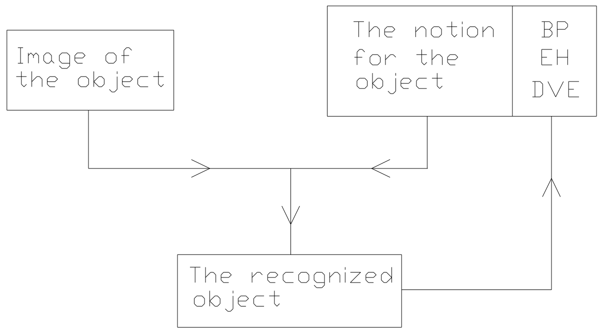


Figure 5: Figure 4: Determination of the axial line at symmetrical parts from circle

The perception process conditionally divides on procedures and in this way it can be reproduced through programs, in dependence of the elements of the notion (BP, EH or DVE). In every given moment the notion have reference to concrete area of the image. The objects of perceiving are changing dynamically, as that can interpret with moving area on the drawing – a *creeping window*. In every concrete position the creeping window consists perceived objects and only a part of attributes of the system are active (BP, EH and DVE), as only attributes of DVE are dynamic.

This dynamic model is used for recognition, as for every attribute of the system (BP, EH and DVE) is creating a procedure, that works in dependence of the position of the creeping window and the state of DVE. With so defined model receives effective structure of methods for recognition of raster image.

On the stage of recognition of vector segments through this method is solved the question for overcoming of the defect dismemberment of the segments and the places of cutting with another lines. This receives with a constant velocity of moving of the creeping window and these two problems for fusion of different parts of the recognized segment are decided with their faster appearance in comparison with the appearance of the parts of another segments.

Within the boundaries of given position of the creeping window is realizing and recognition of symmetric shapes, as for the multitude M_1 from segments in the creeping window determines appropriate symmetric multitude $\overline{\mathrm{M}_2} \subset \mathrm{M}_2$.

The model is supplemented with the division of the methods for recognition to methods for separation as the separation of symbol information from projection elements and to methods for recognition – recognition of lines, symbols and marks etc. (Dimitrov, 2001).

EXAMPLES AND CONCLUSIONS

With the axes lines in mechanical drawings is denoting a particular symmetry between the elements of the drawing:

- A linear symmetry between the parts of objects of the drawing.
- A symmetry with horizontal and vertical axes in simplified cases in depicting of the apertures and cylindrical bodies.

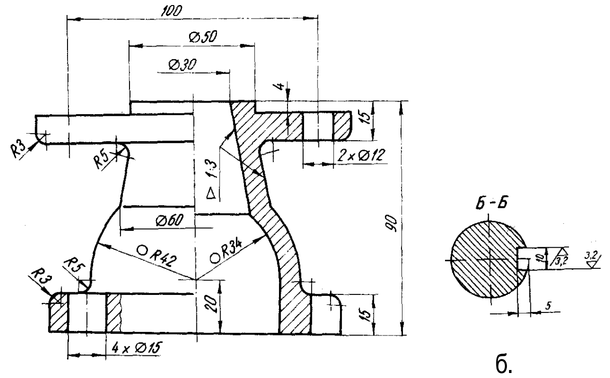
The offered method for definition symmetrical units in a mechanical drawing is implemented with the programmed procedures used immediately of graphics possibility of the display. Before the applying of the method a procedure of separation the projection elements from characters and symbolic set was used. The creeping window is realized with shape of rectangular. At given its position are used simultaneously different stages of the treatment of the image. The operator points on set of projection elements Γ_r and after looking for in the set of segments, their symmetrical are determining and the position of axis line is specifying. There is provided a parameter that gives limit of precision of the symmetrical accordance. If the program not recognized the symmetry, then a greater value is giving to the parameter.

After recognition of the axis line, a procedure for determination of all symmetric segments about axis line is implementing. After which, it can correct its position and shape – with this realizes an exact presentation of the symmetric shape.

On the fig 6 are presented two images, that were processed. On processing with VP HybridCAD it turn out that the automatic operation for correcting on the shape and the positioning on the drawing Deskew is performed successfully for the image on the fig. 6^{a} and can not work for the image $6^{б}$.

The symmetry in image on fig. 6^{a} is discern by offered here method. Here for Γ_r is point segments from contour. The image on fig. $6^{б}$ is with two axes lines, which are not recognized, directly because of overlapping with hatch lines. From imaging in (θ, R) space the hatch lines are separating. After that it is received, that the outline is an arc of a circle. In this case the axial lines can be two – horizontal and vertical. At the image is discerned the presence of two lines with this directions.

The offered method reconstructs the exact geometric shape of the symmetric elements of a mechanical drawing. It is realizing with minimum intervention of the operator or fully automatically, if it is performs by tracing in the set of all segments. The method supports and the recognition of axial lines in all cases of their using.



а. б.

Figure 6: Experimental examples

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AUTOMATIC RECONSTRUCTION FROM SCANNED IMAGE OF MECHANICAL DRAWING IN AXONOMETRY

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SUMMARY
Because of ambiguity presentation, the qualitative transformation from raster to vector format meets definite difficulties. In the well-known commercial program products for vectoring of technical images are used only some semantically characteristics of the mechanical drawings. This is realized thoroughly only in the reconstruction of the symmetrical forms of the image.
Here is discussed a method for machine recognition of segments (segments of lines and arcs of circles) and basic constructive elements (features) in scanned image of a mechanical detail in axonometry. Here are enunciated conditions for reconstruction of the image that are suitable for computing realization.
Key words: recognition, vectorization of mechanical drawing, reconstruction, raster image,

INTRODUCTION

The scanned image of mechanical drawing is a rasterized copy, what contains additionally deviation from original, by reason of mistakes of the copying system. The raster formats of the images are not suitable for the used methods for treatment and graphical work with the copies of the mechanical drawings. It is necessary a special transformation of the image, that is connected with recognition of drawings elements and in a result of this, receiving a definite semantic way of preserving and presenting of the graphical information.

There exist many publications that contain methods and algorithms for recognition for decides definite tasks but they are not adapted for mechanical drawings. The realization of a qualitative transformation from raster to vector format of an image meets with some difficulties. From one side this follows from dissimilarity of the ways for replacement of raster presentation with vector, but from another side from unsolved questions that are connected with context dependent of the elements of the image.

There are established many methods and algorithms for recognition. Each one of these algorithms performs a part of the processing and they follow to be combined for a full decision.

The image of a mechanical detail in axonometry is two - dimensional, but it is easily perceived as three - dimensional. The establishment of the exact shape and position of one object and building the it's orthogonal projection on given it's image in axonometry and some necessary data is called reconstruction. The necessary data and restrictions for of the discussed objects are the conditions for reconstruction.

For the effective recognition of segments and arcs of circles in the image and for maximal approach to two - dimensional vector presentation is necessary to perform and reconstruction that includes:

- Determination of the technological features, that are basic geometrical bodies, constituting the object and concomitant with them simple geometrical figures;
- Building the orthogonal projection with additional denotations for the technological indications of the object;
- Semantically recognition of segments and arcs of circles in the context of the definite technological features.

THE PURPOSE

To present a method for recognition of a lines and arcs in axonometric drawing of detail. It automatic reconstruction on properties restrictions on complexity of detail.

RECOGNITION OF A LINE IN SCANNED IMAGE OF THE ORTHOGONAL PROJECTION OF MECHANICAL DRAWING

The lines are basic graphical elements in mechanical drawing, depicted in orthogonal projection. Vertical and horizontal lines predominate. Most of the lines are segments and arcs of circle. The lines are denoted in an exactly determined way in dependence of their aspect (BDS - ISO 128) and have standard:

- Shape: segment of line, arc of circle, continuous line with great bends and continuous wave line;
- Kind: continuous line, broken line, broken line with dot and broken line with two dots;
- Thickness and minimum elongation between parallel lines - according to standard requirements;
- Requirements for the way of realization.

The transformation from raster to vector format with the programs used for processing of scanned images of mechanical drawings meets with definite difficulties. A basis problem at vectorization is that the segments was not usual identified as one segment. It is relying for the thickness of the line and some mistakes was obtained in a case of not well - shown difference in thickness of different lines. There is not mechanism for context recognition and depends on operator's intervention to correct mistakes.

Processing of raster presented line

The basis characteristic of a raster represented line, is that it has definite thickness. For good visual perception it is necessary enough large dividing ability, so the width of the line to put in several pixels.

There exists a criterion for optimum choice of the dividing ability, that is called condition for compatibility (Pavlidis - 1988), so that raster representation to contain main topological characteristics of the curve. This criterion is arise out of heuristic considerations - is considered that if raster represented curve is well visual perceived, than it have all its characteristics. The aspiration for decreasing of the raster net is connected with this, that the number of raster elements is athwart dependent of the number of necessary operations for processing of line's image - i.e. the complexity of the image in this presentation depends from it. The decreasing of the number of pixels of the line or the presentation in another way by similar basis elements in preservation of the necessary characteristics for the transformation increases the informative character of the raster image.

The choice of the proper method for recognition of segment and arc of circle

Method for recognition depend of way for realization of the lines, the standard properties of raster depicted lines, the predominant defects in the raster image and presence the intersection of lines. It is a proper method, which interpret drawing of the lines by hands as consecutive plotting small segments with definite length d_e.

We call *basic vector* a segment of line with length d_e and characteristic: the length d_e to be sufficient, as that in presenting of a arc of circle is possibly the least radius on the drawing with sequence of segments with length d_e, the mistake must not exceed in advance definite value.

After applying of the standard method for contouring the received chain code is replaced by sequence of basic vectors, whose direction depended from direction of transition on the contour.

The presentation of the contour with segments with length d_e has the priority, because it overcomes defects as:

- Some alternating of missing or redundant pixels on the contour;
- Missing small groups or single pixels inside for the line;
- Defects only on one boundary of sectional area of the line;
- Redundant circumstantially presentation of the contour, which delay performance.

Every segment (part of the segment or arc of circle) presented with pair Γ_1 and Γ_2 multitudes of basic vectors approximating the contour (fig.1,fig.2). $\Gamma_r \subset \Gamma_1 \bigcup \Gamma_2$ is determined (defined) as a sequence of basic vectors with sufficient number, so it be able to determine the curvature of the segment and thence whether it is segment of straight line or arc of circle. The segment describes in vector format as an area – segment of straight line or arc of circle. There is applied the method of Hough (Гочев Г., 1998).

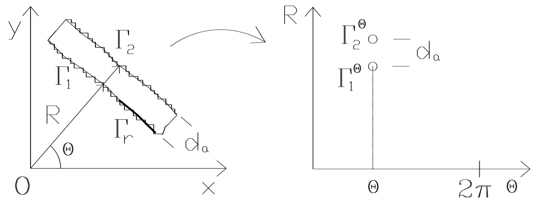

Figure 1: Representation of segment of line in (θ, R) space

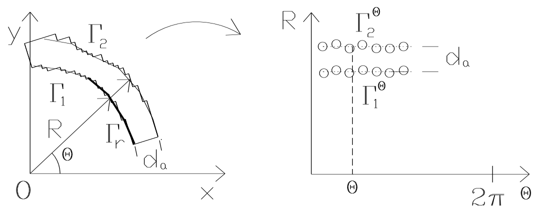

Figure 2: Representation of segment of a circle in (θ, R) space

RECOGNITION OF ARC OF CIRCLE IN SCANNED IMAGE OF MECHANICAL DRAWING IN AXONOMETRY

In the common case the circle depicts as ellipse. The recognition of the arc of ellipse most generally can become with interpolation of the pixels of the line with describing ellipse with parameters. With means of geometry the problem realizes more rational.

The determination of the conjugate radiuses of segment of ellipse and its complements to ellipse

After presentation of the segment of ellipse with basic vectors on Γ_r determines that the segment is not a part of straight line. Here uses the middle line of the segment between Γ_1 and Γ_2. When the arc is less of ½ part of ellipse here can applied the method illustrated on figure 3. The arc splits into three equal parts and on each 2/3 part construct (draw up) diameter and tangent line. Here uses that the conjugate diameter is parallel to the tangent line. The center of ellipse determines according two diameters. For addition of the segment to ellipse uses that each chord parallel to one diameter halves (divides into halves) from its conjugate diameter.

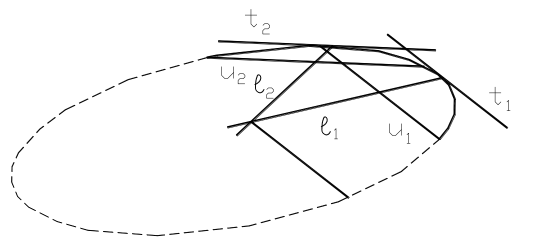

Figure 3: Building of the center of the ellipse and its conjugate radiuses by given segment of it

Reconstruction of circle, that is depicted in axonometry

The transformation of the ellipse into circle can become in different ways depending on the chosen affinity transformation. The problem has standard decision, when the circle lines in the coordinate plane. On the figure 4 is illustrated a transformation of arc of ellipse from plane Oxy into circle at oblique axonometry with scale units e'_x, e'_y, e'_z. The received circle is similar to the actual with the coefficient of similarity $k = \frac{e}{e_x}$. This transformation applies on the basic vectors and receives Γ_1 and Γ_2 for circle. It is named the method of Hough.

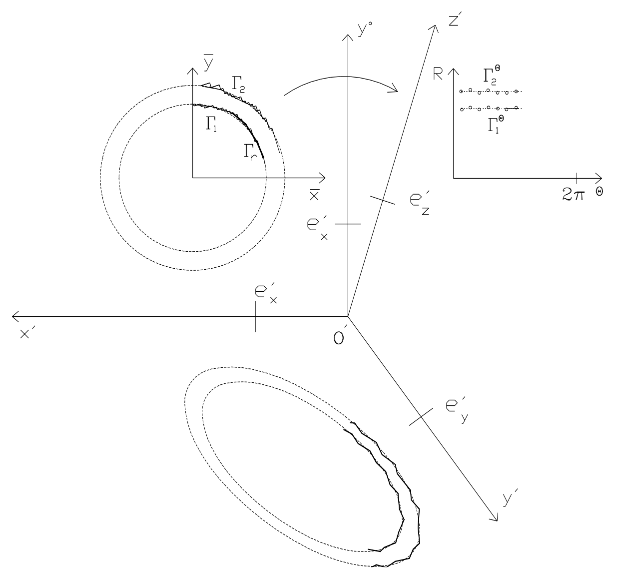

Figure 4:Reconstruction of arc of circle incumbent in co – ordinate plane

RECONSTRUCTION FROM SCANNED IMAGE OF MECHANICAL DETAIL IN ACSONOMETRY

We shall understand under reconstruction of scanned image in axonometry, the detecting of relation of the space coordinates and sizes of the segments of lines and of circles, representing the edges of the detail. The finite result will serves us for exactly depiction of the object in orthogonal projection or in axonometry.

By more complete decision of the problem for recognition from scanned image is necessary to use symbols for size. Here we will to restrict only to geometrical receiving of the sizes, what is sufficient to the purposes of representation.

Basic conditions for reconstruction

For the reconstruction of most simple body of right rectangular prism and right circular cylinder with base in Oxy is sufficient to give:

- The beginning of the frame of reference and sizes of three segments of lines, with directions that are parallel to the co-ordinates. They can be points of the foundation and edges of the represented body (fig.5);
- The edges of the base of the body must be denoted.

On such given conditions the lines of bodies fig.5 can easily to be recognized and described with theirs spatial dimensions. Here is used that:

- The parallel and identical segments have equal lengths;
- The sides,which are figures of a plane and have two contours of segments, which are parallel to co-ordinate plane, are parallel to this plane and have one fixed co-ordinate for all their points;
- The foundation of the cylinder is received in the way for reconstruction of a circle in a co-ordinate plane that is up considered;
- The identical ellipses are the images of equal circles from parallel planes.

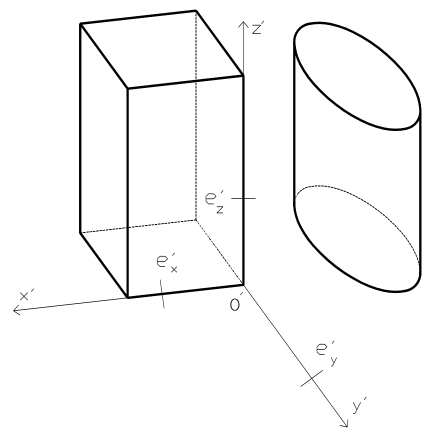

Figure 5: A prism and circular cylinder with given basic conditions for reconstruction

Additional conditions for reconstruction

We consider the question for reconstruction of a body, constructive presented as intersection, union and difference of right rectangular prisms and right circular cylinders. Such a form is most frequently meets in details in mechanical drawings. Usually in representation in axonometry the bigger part of the sides of the body are parallel to the co-ordinate planes and the body is lays with its base on the Oxy.

In the given basic conditions for reconstruction it is necessary, begin with lower point of the body can traced on of all its edges and it are determining co-ordinates of the end points of the edges. The tracing can perform at the same time with marking the sides of the body with filling on side determine the edges that restricted it. Here uses that the edges lay on planes, which are parallel to the co-ordinate plane and it are determining the co-ordinates of its ending points.

The surfaces are three types:
Type 1 - planar figure, that is parallel to the co-ordinate plane;
Type 2 - planar figure or cylindrical surfaces, that is parallel only to one co-ordinate axis;
Type 3 - planar figure, that is not parallel to co-ordinate axis or not planar figure.

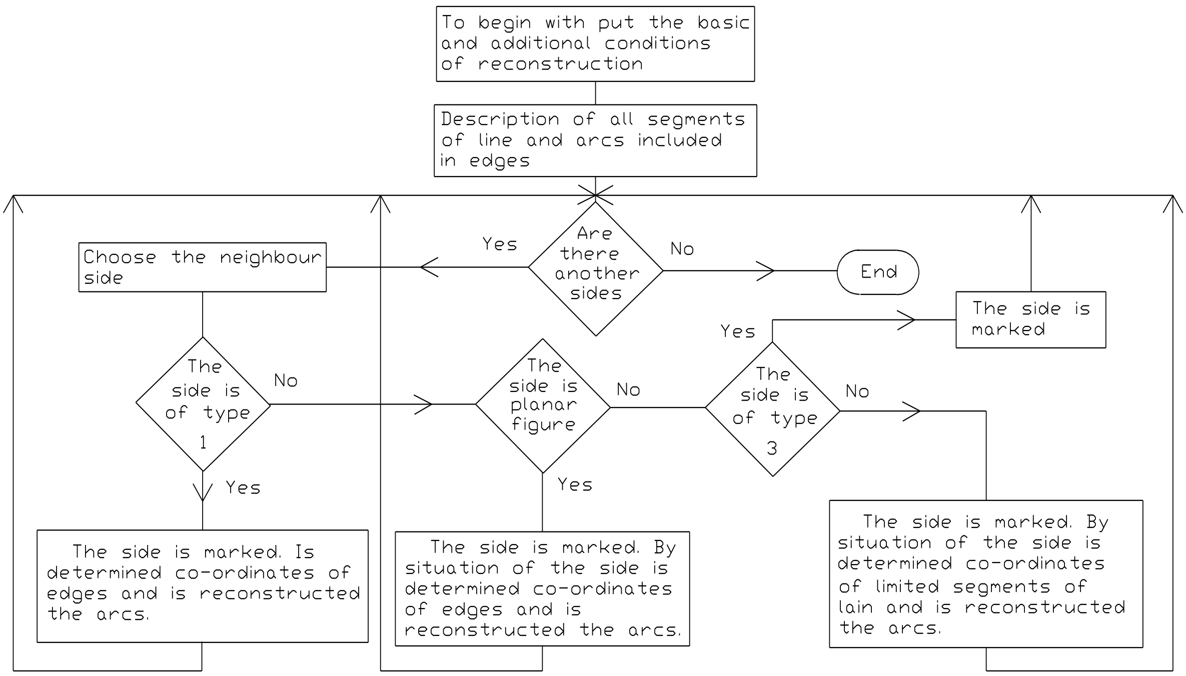

Figure 6: Logical scheme of the method of reconstruction on detail from scanning image of acxonomery

Additional conditions consists in leading from the operator the sides from type 3 and they are not participate in algorithm, represented on fig.6 for building the co-ordinates of the edges finite points.

Hidden information

The axonometric image is visual (clear), but it may not contains all graphical information. The detail that is depicted on fig.7 has hidden the sides and parts, which are not depicted. This information may be supplemented only if are given orthogonal projections of the object and eventually the necessary aspects and sections.

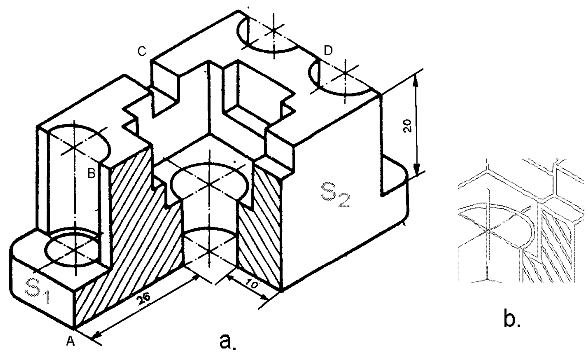

Figure 7: a. – scanned image a detail from mechanical drawing in axonometry; b. – a fragment from image after the tracing the contour of the edges

THE REALIZATION OF THE METHOD

For experimental realization is used a scanned from paper copy of mechanical drawing of a detail (fig.7) with dividing ability 300 dpi. The basic operations are executed in memory of a context unit for visualization with 256 colors.

The following algorithms are realized:
- Contouring;
- Describing of the contour with basic vectors;
- Recognition of segment of line and arc of circle;
- Separating (allocating) and recognition of the hatch – lines;
- Separating of size (dimension) lines and the symbols;
- Reconstruction of the axonometric image of circle from co-ordinate plane;

Here is introduced a parameter for length of basic vector, standard thickness of the lines and admissible curvature (torsion) of the segments. The hatched part determines from the thickness of the lines.

On figure 7 a. the surfaces from type 3 are denoted with s1 and s2. The beginning of the frame of reference is in point A . The points B, C and D are chosen for control of the calculations. The results are given in table 1.

Table1: Co-ordinates of the points A, B, C, and D are obtained at implementation of a method

	x	y	z
A	0.00	0.00	0.00
B	8.02	2.23	27.15
C	34.40	17.05	27.15
D	54.84	-2.45	27.15

On fig.7 b. is depicted a fragment from the image after contouring. From it immediately are observing important characteristics, that are using for recognition of the lines:

- Less thickness of the lines;
- Clearly expressed curvature of the arcs from edges;
- The ability for overcoming defects, as the received contour is approximating
- Very well expressed coherence of the inside contour with all edges restricting one side.

The discussed approach for recognition of an axonometric mechanical drawing of a detail contains the basic necessary context-dependent processing. Here is offered a rational method for recognition of the objects in (θ, R) space and reconstruction of the information for the basic figures of the image.

The enunciated problem for reconstruction of scanned copy of axonometrical image and the chosen approach can be used for automatically obtaining of the basic constructive features of a detail and creating a system for recognition with optimum using of the semantic of the object.

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ON THE EQUIVALENCE OF DIFFERENTIAL SYSTEMS ARISING IN ELECTROMAGNETIC TWO-BODY PROBLEM

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SUMMARY
The equivalence of two systems of equations of motion arising in electromagnetic two-body problem is obtained.

In the present note we consider two systems of equations of motion arising in electromagnetic two-body problem (Synge, 1940; Synge, 1960) and formulated in (Angelov, 2002).

First we recall some denotations and results from (Angelov, 2002; Angelov, 2000) conserning

J. L. Synge’s equations of motion
As in (Synge, 1940) we denote by

$$x^{(p)} = (x_1^{(p)}(t), x_2^{(p)}(t), x_3^{(p)}(t), x_4^{(p)}(t) = ict)$$

$(p = 1,2,\ i^2 = -1)$ the space-time coordinates of the moving particles, by m_p - their proper massses, by e_p - their charges, c - the speed of the light. The coordinates of the velocity vectors are

$$u^{(p)} = (u_1^{(p)}(t), u_2^{(p)}(t), u_3^{(p)}(t)) \quad (p = 1,2) .$$

The coordinates of the unit tangent vectors to the world-lines are

$$\lambda_\alpha^{(p)} = \frac{\gamma_p u_\alpha^{(p)}(t)}{c} = \frac{u_\alpha^{(p)}(t)}{\Delta_p} \ (\alpha = 1,2,3),\ \lambda_4^{(p)} = i\gamma_p = \frac{ic}{\Delta_p} ,$$

where

$$\gamma_p = \left(1 - \frac{1}{c^2}\sum_{\alpha=1}^{3}[u_\alpha^{(p)}(t)]^2\right)^{-\frac{1}{2}},\ \Delta_p = \left(c^2 - \sum_{\alpha=1}^{3}[u_\alpha^{(p)}(t)]^2\right)^{\frac{1}{2}} .$$

It follows $\gamma_p = c / \Delta_p$.

By $<.,.>_4$ we denote the scalar product in the Minkowski space, while by $<.,.>$ - the scalar product in 3-dimensional Euclidean subspace. Synge’s equations of motion modeling the interaction of two moving charged particles are the following:

$$m_p \frac{d\lambda_r^{(p)}}{ds_p} = \frac{e_p}{c^2} F_{rn}^{(p)} \lambda_n^{(p)} \ \ (r = 1,2,3,4) \qquad (1)$$

where the elements of proper time are

$$ds_p = \frac{c}{\gamma_p} dt = \Delta_p dt \ (p = 1,2) .$$

Recall that in (1) there is a summation in $n\ (n = 1,2,3)$.

The elements $F_{rn}^{(p)}$ of the electromagnetic tensors are derived by the retarded Lienard-Wiecherd potentials

$$A_r^{(p)} = -\frac{e_p \lambda_r^{(p)}}{\left\langle \lambda^{(p)}, \xi^{(pq)} \right\rangle_4} \ \ (r = 1,2,3,4) \text{ , that is}$$

$$F_{rn}^{(p)} = \frac{\partial A_n^{(p)}}{\partial x_r^{(p)}} - \frac{\partial A_r^{(p)}}{\partial x_n^{(p)}} \quad \xi^{(pq)} .$$

By $\xi^{(pq)}$ we denote the isotropic vectors (cf. Synge, 1940; 1960) drawn into the past:

$$\xi^{(pq)} = (x_1^{(p)}(t) - x_1^{(q)}(t - \tau_{pq}(t)),$$
$$x_2^{(p)}(t) - x_2^{(q)}(t - \tau_{pq}(t)), x_3^{(p)}(t) - x_3^{(q)}(t - \tau_{pq}(t)), ic\tau_{pq}(t))$$

where $\left\langle \xi^{(p,q)}, \xi^{(p,q)} \right\rangle_4 = 0$ or

$$\tau_{pq}(t) = \frac{1}{c}\left(\sum_{\beta=1}^{3} [x_\beta^{(p)}(t) - x_\beta^{(q)}(t - \tau_{pq}(t))]^2 \right)^{\frac{1}{2}} \qquad (*)$$

$((pq) = (12), (21))$.

Calculating $F_{rn}^{(p)}$ as in (Angelov, 1990) we write equations from (2) in the form:

$$\frac{d\lambda_\alpha^{(p)}}{ds_p} = \frac{Q_p}{c^2}\left\{ \frac{\xi_\alpha^{(pq)}\left\langle \lambda^{(p)}, \lambda^{(q)} \right\rangle_4 - \lambda_\alpha^{(q)}\left\langle \lambda^{(p)}, \xi^{(pq)} \right\rangle_4}{\left\langle \lambda^{(q)}, \xi^{(pq)} \right\rangle_4^3} \left[1 + \left\langle \xi^{(pq)}, \frac{d\lambda^{(q)}}{ds_q} \right\rangle_4 \right] + \frac{1}{\left\langle \lambda^{(q)}, \xi^{(pq)} \right\rangle_4^2} \left[\left\langle \lambda^{(p)}, \xi^{(pq)} \right\rangle_4 \frac{d\lambda^{(q)}}{ds_q} - \left\langle \xi^{(pq)}, \frac{d\lambda^{(q)}}{ds_q} \right\rangle_4 \xi_\alpha^{(pq)} \right] \right\} \quad (\alpha = 1,2,3) \qquad (2.\alpha)$$

$$\frac{d\lambda_4^{(p)}}{ds_p} = \frac{Q_p}{c^2}\left\{ \frac{\xi_4^{(pq)}\left\langle \lambda^{(p)}, \lambda^{(q)} \right\rangle_4 - \lambda_4^{(q)}\left\langle \lambda^{(p)}, \xi^{(pq)} \right\rangle_4}{\left\langle \lambda^{(q)}, \xi^{(pq)} \right\rangle_4^3} \left[1 + \left\langle \xi^{(pq)}, \frac{d\lambda^{(q)}}{ds_q} \right\rangle_4 \right] + \frac{1}{\left\langle \lambda^{(q)}, \xi^{(pq)} \right\rangle_4^2} \left[\left\langle \lambda^{(p)}, \xi^{(pq)} \right\rangle_4 \frac{d\lambda^{(q)}}{ds_q} - \left\langle \xi^{(pq)}, \frac{d\lambda^{(q)}}{ds_q} \right\rangle_4 \xi_4^{(pq)} \right] \right\} \qquad (2.4)$$

where $Q_p = \frac{e_1.e_2}{m_p}$, $(p = 1,2)$. Further on we denote $u^{(q)} \equiv u^{(q)}(t - \tau_{pq})$,

$$\lambda^{(q)} = (\gamma_{pq} u_1^{(q)} / c, \gamma_{pq} u_2^{(q)} / c, \gamma_{pq} u_3^{(q)} / c, i\gamma_{pq}) = = (u_1^{(q)} / \Delta_{pq}, u_2^{(q)} / \Delta_{pq}, u_3^{(q)} / \Delta_{pq}, ic / \Delta_{pq}),$$

where $\gamma_{pq} = \left(1 - \frac{1}{c^2} \sum_{\alpha=1}^{3} [u_\alpha^{(q)}(t - \tau_{pq}(t))]^2 \right)^{-\frac{1}{2}}$,

$\Delta_{pq} = \left(c^2 - \sum_{\alpha=1}^{3} [u_\alpha^{(q)}(t - \tau_{pq}(t))]^2 \right)^{\frac{1}{2}}$ and

$$\frac{d\lambda_\alpha^{(p)}}{ds_p} = \frac{d\left(\frac{\gamma_p}{c} u_\alpha^{(p)} \right)}{\frac{c}{\gamma_p} dt} = \frac{d\left(\frac{u_\alpha^{(p)}}{\Delta_p dt} \right)}{\Delta_p dt} = = \frac{1}{\Delta_p^2} \dot{u}_\alpha^{(p)} + \frac{u_\alpha^{(p)}}{\Delta_p^4} \left\langle u^{(p)}, \dot{u}^{(p)} \right\rangle \quad (\alpha = 1,2,3)$$

$$\frac{d\lambda_4^{(p)}}{ds_p} = \frac{d(i\gamma_p)}{\frac{c}{\gamma_p} dt} = \frac{icd\left(\frac{1}{\Delta_p} \right)}{\Delta_p dt} = \frac{ic}{\Delta_p^4} \left\langle u^{(p)}, \dot{u}^{(p)} \right\rangle,$$

where the dot means a differentiation in *t*.

Proceeding as in (Angelov, 2000) and proving that 4-th and 8-th equations are a consequence of the rest ones we obtain a system of 6 equations. Now we are able to formulate the initial value problem for the above equations in the following way: to find unknown velocities $u_\alpha^{(p)}(t)$ $(p = 1,2; \alpha = 1,2,3)$, for $t \geq 0$ satisfying equations $(3_{1\alpha})$, $(3_{2\alpha})$ of motion (written in details below):

$$\frac{1}{\Delta_1} \dot{u}_\alpha^{(1)} + \frac{u_\alpha^{(1)}}{\Delta_1^3} \left\langle u^{(1)}, \dot{u}^{(1)} \right\rangle = = \frac{Q_1}{c^2} \left\{ \frac{\left[c^2 - \left\langle u^{(1)}, u^{(2)} \right\rangle \right] \xi_\alpha^{(12)} - \left[c^2 \tau_{12} - \left\langle u^{(1)}, \xi^{(12)} \right\rangle \right] u_\alpha^{(2)}}{\left[c^2 \tau_{12} - \left\langle u^{(1)}, \xi^{(12)} \right\rangle \right]^3} \times \frac{\Delta_{12}^4 + D_{12} \Delta_{12}^2 \left\langle \xi^{(12)}, \dot{u}^{(2)} \right\rangle + \left(\left\langle \xi^{(12)}, u^{(2)} \right\rangle - c^2 \tau_{12} \right) \left\langle u^{(2)}, \dot{u}^{(2)} \right\rangle}{\Delta_{12}^2} + \right.$$
$$+ D_{12} \frac{\left(\left\langle u^{(1`)}, \xi^{(12)} \right\rangle - c^2 \tau_{12} \right) \dot{u}_\alpha^{(2)} - \left\langle u^{(1)}, \dot{u}^{(2)} \right\rangle \xi_\alpha^{12}}{\left[ c^2 \tau_{12} - \left\langle u^{(2`)}, \xi^{(12)} \right\rangle \right]^2} + \qquad (3_{1\alpha})$$
$$+ \frac{D_{12}}{\Delta_{12}^2} \cdot \frac{\left(\left\langle u^{(1`)}, \xi^{(12)} \right\rangle - c^2 \tau_{12} \right) u_\alpha^{(2)} \left\langle u^{(2)}, \dot{u}^{(2)} \right\rangle}{\left[ c^2 \tau_{12} - \left\langle u^{(2`)}, \xi^{(12)} \right\rangle \right]^2} +$$
$$\left. + \frac{D_{12}}{\Delta_{12}^2} \cdot \frac{\left(c^2 - \left\langle u^{(1`)}, u^{(2)} \right\rangle \right) \xi_\alpha^{(12)} \left\langle u^{(2)}, \dot{u}^{(2)} \right\rangle}{\left[ c^2 \tau_{12} - \left\langle u^{(2`)}, \xi^{(12)} \right\rangle \right]^2} \right\}.$$

$$\frac{1}{\Delta_2}\dot{u}_\alpha^{(2)} + \frac{u_\alpha^{(2)}}{\Delta_1^3}\left\langle u^{(2)}, \dot{u}^{(2)}\right\rangle =$$

$$= \frac{Q_1}{c^2}\left\{\frac{\left[c^2 - \left\langle u^{(1)}, u^{(2)}\right\rangle\right]\xi_\alpha^{(21)} - \left[c^2\tau_{12} - \left\langle u^{(1)}, \xi^{(21)}\right\rangle\right]u_\alpha^{(1)}}{\left[c^2\tau_{12} - \left\langle u^{(1)}, \xi^{(12)}\right\rangle\right]^3}\times\right.$$

$$\times\frac{\Delta_{21}^4 + D_{21}\Delta_{21}^2\left\langle \xi^{(21)}, \dot{u}^{(1)}\right\rangle + \left(\left\langle \xi^{(21)}, u^{(1)}\right\rangle - c^2\tau_{21}\right)\left\langle u^{(1)}, \dot{u}^{(1)}\right\rangle}{\Delta_{21}^2} +$$

$$+ D_{21}\frac{\left(\left\langle u^{(2`)}, \xi^{(21)}\right\rangle - c^2\tau_{21}\right)\dot{u}_\alpha^{(1)} - \left\langle u^{(2)}, \dot{u}^{(1)}\right\rangle \xi_\alpha^{21}}{\left[c^2\tau_{21} - \left\langle u^{(1`)}, \xi^{(21)}\right\rangle\right]^2} +$$

$$+ \frac{D_{21}}{\Delta_{21}^2}\cdot\frac{\left(\left\langle u^{(2`)}, \xi^{(21)}\right\rangle - c^2\tau_{21}\right)u_\alpha^{(1)}\left\langle u^{(1)}, \dot{u}^{(1)}\right\rangle}{\left[c^2\tau_{21} - \left\langle u^{(1`)}, \xi^{(21)}\right\rangle\right]^2} + \qquad (3_{2\alpha})$$

$$\left. + \frac{D_{21}}{\Delta_{21}^2}\cdot\frac{\left(c^2 - \left\langle u^{(2`)}, u^{(1)}\right\rangle\right)\xi_\alpha^{(21)}\left\langle u^{(1)}, \dot{u}^{(1)}\right\rangle}{\left[c^2\tau_{21} - \left\langle u^{(1`)}, \xi^{(21)}\right\rangle\right]^2}\right\}.$$

Recall that in the above equations $(3_{1\alpha})$

$$u^{(1)} = u^{(1)}(t),\; u^{(2)} = u^{(2)}(t - \tau_{12})$$

while in $(3_{2\alpha})$

$$u^{(2)} = u^{(2)}(t),\; u^{(1)} = u^{(1)}(t - \tau_{21}) .$$

We note that the delay functions $\tau_{pq}(t)$ satisfy functional equations (*) for $t \in (-\infty, \infty)$. For $t \le 0$ $u_\alpha^{(p)}(t)$ are prescribed functions: $u_\alpha^{(p)}(t) = \bar{u}_\alpha^{(p)}(t),\, t \le 0$, where $\bar{u}_\alpha^{(p)}(t) = \frac{d\bar{x}_\alpha^{(p)}(t)}{dt},\, t \le 0$.

This means that for prescribed trajectories $(\bar{x}_1^{(1)}(t), \bar{x}_2^{(1)}(t), \bar{x}_3^{(1)}(t)), (\bar{x}_1^{(2)}(t), \bar{x}_2^{(2)}(t), \bar{x}_3^{(2)}(t))$ for $t \le 0$ one has to find trajectories, satisfying the above system of equations for $t > 0$.

(We recal $x_\alpha^{(p)}(t) = x_{\alpha 0}^{(p)} + \int_0^t u_\alpha^{(p)}(s)ds$, where $x_{\alpha 0}^{(p)}$ are the coordinates of the initial positions.)

Kepler problem in polar coordinates

In what follows we consider plane motion in Ox_2x_3 coordinate plane for above equations. We suppose that the first particle P_1 is fixed at the origin $O(0,0,0)$, that is,

$$P_1 : \left| \begin{array}{l} x_1^{(1)}(t) = 0 \\ x_2^{(1)}(t) = 0, \quad t \in (-\infty, \infty) . \\ x_3^{(1)}(t) = 0 \end{array}\right.$$

It follows by necessity $\left| \begin{array}{l} \bar{x}_1^{(1)}(t) = 0 \\ \bar{x}_2^{(1)}(t) = 0 . \\ \bar{x}_3^{(1)}(t) = 0 \end{array}\right.$

Passing to the polar coordinates we can put

$$P_1 : \left| \begin{array}{l} x_1^{(2)}(t) = 0 \\ x_2^{(2)}(t) = \rho(t)\cos\varphi(t) \\ x_3^{(2)}(t) = \rho(t)\sin\varphi(t) \end{array}\right. \quad \text{, where } \rho(t) > 0 .$$

After transformations made in (Angelov, 2000) we obtain the following second order system:

$$\ddot{\rho}(t) = \rho(t)\dot{\varphi}^2(t) + \frac{Q_2}{c^3}\cdot\frac{\left[c^2 - \dot{\rho}^2(t)\right]\sqrt{c^2 - \dot{\rho}^2(t) - \rho^2(t)\dot{\varphi}^2(t)}}{\rho^2(t)}$$

$$\ddot{\varphi}(t) = -\frac{2\dot{\rho}(t)\dot{\varphi}(t)}{\rho(t)}\cdot\left[1 + \frac{Q_2\sqrt{c^2 - \dot{\rho}^2(t) - \rho^2(t)\dot{\varphi}^2(t)}}{2c^3\rho(t)}\right] \qquad (4)$$

for $t > 0$ and initial conditions

$$\rho(0) = \rho_0,\, \dot{\rho}(0) = \dot{\rho}_0,\, \varphi(0) = \varphi_0,\, \dot{\varphi}(0) = \dot{\varphi}_0 .$$

On the other hand beginning with the original form of Synge equations (Angelov, 2002) we obtain for Kepler problem the following equations of motion:

$$\frac{d(\gamma_2 u_\alpha^{(2)})}{dt} = \frac{Q_2\xi_\alpha^{(21)}}{\rho^3} \quad (\alpha = 1,2,3) . \qquad (5_\alpha)$$

But $\xi^{(21)} = (0, \rho(t)\cos\varphi(t), \rho(t)\sin\varphi(t))$. Then integrating (5_α) from 0 to *t* we have

$$\gamma_2(t)u_\alpha^{(2)}(t) - \gamma_2^0 u_\alpha^{(2)}(0) = Q_2\int_0^t \frac{\xi_\alpha^{(21)}(s)}{\rho^3(s)}ds \text{ or}$$

$$\left| \begin{array}{l} \dot{\rho}(t)\cos\varphi(t) - \rho(t)\dot{\varphi}(t)\sin\varphi(t) = \frac{1}{\gamma_2(t)}\left[Q_2\int_0^t \frac{\cos\varphi(s)}{\rho^2(s)}ds + C_2\right] \\ \dot{\rho}(t)\sin\varphi(t) + \rho(t)\dot{\varphi}(t)\cos\varphi(t) = \frac{1}{\gamma_2(t)}\left[Q_2\int_0^t \frac{\sin\varphi(s)}{\rho^2(s)}ds + C_3\right] \end{array}\right. \qquad (6)$$

where $C_2 = \gamma_2^0\left(\dot{\rho}_0\cos\varphi_0 - \rho_0\dot{\varphi}_0\sin\varphi_0\right)$,
$C_3 = \gamma_2^0\left(\dot{\rho}_0\sin\varphi_0 + \rho_0\dot{\varphi}_0\cos\varphi_0\right)$,
$\gamma_2^0 = \frac{1}{\sqrt{1 - \frac{1}{c^2}(\dot{\rho}_0^2 + \rho_0^2\dot{\varphi}_0^2)}}$.

The systems (6) and (5_α) are equivalent.

Indeed, the right-hand side of (5_α) is the vector-function $\vec{F}(t)=\left(\frac{\cos\varphi(t)}{\rho^2(t)},\frac{\sin\varphi(t)}{\rho^2(t)}\right)$ and $\left|\vec{F}(t)-\vec{F}(t_0)\right|^2=$

$$=\frac{1}{\rho^4(t)}+\frac{1}{\rho^4(t_0)}-\frac{2\cos(\varphi(t)-\varphi(t_0))}{\rho^2(t)\rho^2(t_0)}\underset{t\to t_0}{\to}0,$$

that is, $\vec{F}(t)$ is continuous vector-function – the necessary and sufficiently condition for equivalence of (6) and (5_α).

On the other hand $\dot\gamma_2=\frac{d}{dt}\left(\frac{c}{\Delta_2}\right)=\frac{c}{\Delta_2^3}\langle u,\dot u\rangle$,

$$\frac{d}{dt}\left(\gamma_2u_\alpha^{(2)}\right)=\dot\gamma_2u_\alpha^{(2)}+\gamma_2\dot u_\alpha^{(2)},\ (\alpha=2,3)$$

Then from (5_α) we obtain the system (with $u\equiv u^{(2)}$):

$$\left|\begin{array}{l}\frac{c}{\Delta_2^3}\langle u,\dot u\rangle u_2+\frac{c}{\Delta_2}\dot u_2=\frac{Q_2\cos\varphi}{\rho^2}\\ \frac{c}{\Delta_2^3}\langle u,\dot u\rangle u_3+\frac{c}{\Delta_2}\dot u_3=\frac{Q_2\sin\varphi}{\rho^2}.\end{array}\right. \qquad (7)$$

Multiplying the first equations of (7) by u_2, the second - by u_3 and summing we obtain:

$$\frac{c}{\Delta_2^3}\langle u,\dot u\rangle\left(\langle u,u\rangle+\Delta_2^2\right)=\frac{Q_2}{\rho^2}\quad(u_2\cos\varphi+u_3\sin\varphi),$$

that is $\frac{c}{\Delta_2^3}\langle u,\dot u\rangle=\frac{Q_2\dot\rho}{c^2\rho^2}$.

Thus we have $\dot\gamma_2=\frac{Q_2\dot\rho}{c^2\rho^2}$.

Multiplying the first equations of (7) by $\cos\varphi$, the second – by $\sin\varphi$ and summing, and next multiplying the first equations of (7) by $-\sin\varphi$, the second - by $\cos\varphi$ and summing, we obtain the system

$$\left|\begin{array}{l}\dot\gamma_2\dot\rho+\gamma_2(\ddot\rho-\rho\dot\varphi^2)=\frac{Q_2}{\rho^2}\\ \dot\gamma_2\rho\dot\varphi+\gamma_2(2\dot\rho\dot\varphi+\rho\ddot\varphi)=0\end{array}\right.,$$

or ($\dot\gamma_2=\frac{Q_2\dot\rho}{c^2\rho^2}$)

$$\left|\begin{array}{l}\gamma_2(\ddot\rho-\rho\dot\varphi^2)=\frac{Q_2}{c^2\rho^2}(c^2-\dot\rho^2)\\ \gamma_2(\rho\ddot\varphi+2\dot\rho\dot\varphi)=-\frac{Q_2}{c^2\rho}\dot\rho\dot\varphi\end{array}\right. \qquad (8)$$

The final system (8) is equivalent to the system (4), since $\gamma_2=\frac{c}{\Delta_2}=\frac{c}{\sqrt{c^2-\dot\rho^2-\rho^2\dot\varphi^2}}$.

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ON *j*-LIPSCHITZIAN MAPPINGS IN PSEUDOMETRICALLY CONVEX UNIFORM SPACES

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SUMMARY
Conditions guaranteeing global *j*-Lipschitzicity of mappings defined in complete pseudometrically convex uniform spaces are given. Such mappings arise in many applications mentioned in the references.

Let $(X, \mathbf{A})$ be a complete T_2-separated uniform space whose uniformity is generated by a saturated family of pseudometrics $\mathbf{A} = \{d_a(x,y): a \in A\}$, where A is an index set. Basic notions concerning the uniform spaces can be found in (Weil, 1938; Kelley, 1959; Isbell, 1964; Page, 1978). A uniform space $(X, \mathbf{A})$ is said to be pseudometrically convex if for every $x, y \in X$ there is $z \in X (z \neq x \neq y)$ such that

$$d_a(x,y) = d_a(x,z) + d_a(z,y)$$

for every $a \in A$ provided $d_a(x,y) > 0$ (cf. Angelov et al., 1997). The metrical segment between *x* and *y* with respect to the pseudometric $d_a(.,.)$ we denote by $[x,y]_a$, $a \in A$ and

$$(x,y)_a = [x,y]_a \setminus \{x,y\}.$$

Let $j: A \to A$ be a map of the index set into itself whose iterates are defined inductively as follows

$$j^0(a) = a, j^k(a) = j(j^{k-1}(a)) \ \ (k \in N).$$

Further on by $(X, \mathbf{A})$ and $(Y, \mathbf{A})$ we mean uniform spaces whose index sets for their families of pseudometrics coincide, i.e. we have

$$(X, \{d_a(x,y): a \in A\}), (Y, \{d_a(x,y): a \in A\}).$$

Let $\{M_a\}_{a \in A}$ be a family of positive constants where A is the same index set. A mapping $T: X \to Y$ is called *j*-Lipschitzian if for every $x, y \in X$ is satisfied

$$d_a(Tx, Ty) \leq M_a d_{j(a)}(x,y) \text{ for } a \in A.$$

The main goal of the present note is to formulate local conditions which imply the *j*-Lipschitzian character of mappings defined in complete pseudometrically convex uniform spaces. Such mappings are generated by functional differential equations treated in (Angelov, 1987; 1989, 2000).

Prior to formulate the main result we present an example of pseudometrically convex uniform space. Consider the set $C(R^1)$ of all continuous functions $f: R^1 \to R^1$. Let us fix an arbitrary function $\mathrm{b}(.) \in C(R^1)$ and assume that $\mathrm{b}(t)$ is unbounded and positive on R^1. Define the set $C_{\mathrm{b}}(R^1) = \{f \in C(R^1): |f(t)| \leq b(t)\}$. It is easy to see that the sum of two functions from $C_{\mathrm{b}}(R^1)$ does not belong to $C_b(R^1)$ in general case. This means $C_{\mathrm{b}}(R^1)$ is neither a Banach space nor linear topological space. Denote by A the family of all compact intervals $a = [p,q] \subset R^1$ and introduce a family of pseudometrics $\mathbf{A} = \{d_a(f,g): a \in A\}$ on $C_{\mathrm{b}}(R^1)$ where

$$d_a(f,g) = \| f - g \|_a, \| f \|_a = \sup\{|f(t)|: t \in a\}.$$

For every $f, g \in C_b(R^1)$ with $f \neq g$ we define the functions $h_\lambda = (1-\lambda) f(t) + \lambda g(t)$, where the parameter $\lambda \in [0,1]$. For each fixed $a \in A$ we have

$$d_a(f, h_\lambda) = \| f - (1-\lambda) f - \lambda g \|_a = \lambda d_a(f,g)$$

$$d_a(g, h_\lambda) = \| g - (1-\lambda) f - \lambda g \|_a = (1-\lambda) d_a(f,g).$$

Obviously $d_a(f,g)=d_a(f,h_\lambda)+d_a(h_\lambda,g)$. So by $[f,g]_a$ we denote the closed metrical segment $[f,g]_a=\{h_\lambda:\lambda\in[0,1]\}$, while by $(f,g)_a=\{h_\lambda:\lambda\in(0,1)\}$. It is easy to verify that $d_a(f,g)>0$ implies $d_a(f,h_\lambda)>0$ and $d_a(g,h_\lambda)>0$ for $\lambda\in(0,1)$ and vice versa.

The mapping $T:X\to Y$ is said to be almost directionally *j*-Lipschitzian on X if for each $x,y\in X$ with $x\neq y$ the following inequality holds:

$$\inf\left[\frac{d_a(Tx,Tz)}{d_{j(a)}(x,z)}:z\in(x,y)_{j(a)}\right]\le M_a \qquad (1)$$

for $d_{j(a)}(x,y)>0$ and $d_a(Tx,Ty)=0$ for $d_{j(a)}(x,y)=0$.

The above definition extends the corresponding notion in metric spaces (cf. Kirk et al., 1977).

For $d_{j(a)}(x,y)=0$ there is no metrical segment between x and y with respect to $j(a)$.

Recall that a mapping $T:X\to Y$ is closed if for $\{x_n\}\subset X$ the conditions $\lim_n x_n=x$ and $\lim_n T(x_n)=y$ imply $x\in X$ and $Tx=y$.

THEOREM. Let $(X,\mathbf{A})$ and $(Y,\mathbf{A})$ be complete T_2-separated uniform spaces with $(X,\mathbf{A})$ being pseudometrically convex. Let $T:(X,\mathbf{A})\to(Y,\mathbf{A})$ be almost directionally *j*-Lipschitzian mapping with a family of positive constants $\{M_a\}_{a\in A}$. If T is closed, then T is *j*-Lipschitzian mapping on the whole $(X,\mathbf{A})$.

Proof: Let x and y be two distinct elements of X, i.e. $x\neq y$. Let us choose a new family of positive constants $\{M'_a\}_{a\in A}$ such that $M'_a>M_a$ for every fixed $a\in A$. By Ω we denote the countable ordinals and fixed $\gamma\in\Omega$ (cf. Ch.XV, Angelov, 1987). For all $\alpha\in\Omega$ less than γ define the set $\{x_\alpha\}$ so that

(γ1) $x_0=x$;

(γ2) if $x_\alpha=y$ for some α and $\alpha\le\eta<\gamma$, then $x_\eta=y$;

(γ3) if $\alpha<\beta<\eta<\gamma$ and $x_\eta\neq y$, then $x_\beta\in(x_\alpha,x_\eta)_{j(a)}$ for those $a\in A$ for which $d_{j(a)}(x_\alpha,x_\eta)>0$;

(γ4) If $\beta<\eta<\gamma$ and $x_\eta\neq y$, then $x_\eta\in(x_\beta,y)_{j(a)}$;

(γ5) T is *j*-Lipschitzian with a family $\{M'_a\}_{a\in A}$ on the set $\{x_\eta:\eta<\gamma\}$.

If γ has a predecessor $\mu\in\Omega$, that is, $\gamma=\mu+1$, then we put $x_\gamma=y$.

If $x_\mu\neq y$ and $d_{j(a)}(x_\mu,y)>0$ in view of the definition (1) we choose $x_\gamma\in(x_\mu,y)_{j(a)}$ so that

$$d_a(Tx_\gamma,Tx_\mu)\le M'_a d_{j(a)}(x_\gamma,x_\mu)$$

(recall that $d_{j(a)}(x_\mu,y)>0$ implies $d_{j(a)}(x_\mu,x_\gamma)>0$).

In what follows we show that (γ1)- (γ3) hold for $\eta=\gamma$. If $\alpha<\mu$, then (γ4) implies

$$\begin{aligned}
d_{j(a)}(x_\alpha,x_\gamma)&\le d_{j(a)}(x_\alpha,x_\mu)+d_{j(a)}(x_\mu,x_\gamma)=\\
&=d_{j(a)}(x_\alpha,y)-d_{j(a)}(x_\mu,y)+d_{j(a)}(x_\mu,y)-d_{j(a)}(x_\gamma,y)=\\
&=d_{j(a)}(x_\alpha,y)-d_{j(a)}(x_\gamma,y)\le d_{j(a)}(x_\alpha,x_\gamma),
\end{aligned}$$

that is, $d_{j(a)}(x_\alpha,x_\gamma)=d_{j(a)}(x_\alpha,x_\mu)+d_{j(a)}(x_\mu,x_\gamma)$ or $x_\mu\in(x_\alpha,x_\gamma)_{j(a)}$. If $\alpha<\beta<\mu<\gamma$, then (γ3) implies

$$\begin{aligned}
d_{j(a)}(x_\alpha,x_\gamma)&=d_{j(a)}(x_\alpha,x_\mu)+d_{j(a)}(x_\mu,x_\gamma)=\\
&=d_{j(a)}(x_\alpha,x_\beta)+d_{j(a)}(x_\beta,x_\mu)+d_{j(a)}(x_\mu,x_\gamma)\ge\\
&\ge d_{j(a)}(x_\alpha,x_\beta)+d_{j(a)}(x_\beta,x_\gamma)\ge d_{j(a)}(x_\alpha,x_\gamma),
\end{aligned}$$

that is $d_{j(a)}(x_\alpha,x_\gamma)=d_{j(a)}(x_\alpha,x_\beta)+d_{j(a)}(x_\beta,x_\gamma)$ which means $x_\beta\in(x_\alpha,x_\gamma)_{j(a)}$. So (γ3) is thus proved for $\eta=\gamma$.

For $\beta<\gamma$ we have

$$\begin{aligned}
d_{j(a)}(x_\beta,y)&=d_{j(a)}(x_\beta,x_\mu)+d_{j(a)}(x_\mu,y)=\\
&=d_{j(a)}(x_\beta,x_\mu)+d_{j(a)}(x_\mu,x_\gamma)+d_{j(a)}(x_\gamma,y).\\
&=d_{j(a)}(x_\beta,x_\gamma)+d_{j(a)}(x_\gamma,y)
\end{aligned}$$

Therefore (γ4) holds for $\eta=\gamma$.

We have to show that (γ5) holds for $\eta=\gamma$.

Suppose $\beta<\gamma$. As we have already shown $x_\beta\in(x_\alpha,x_\gamma)_{j(a)}$ and

$$\begin{aligned}
&d_a(Tx_\beta,Tx_\gamma)\le d_a(Tx_\beta,Tx_\mu)+d_a(Tx_\mu,Tx_\gamma)\le\\
&\le M'_a d_{j(a)}(x_\beta,x_\mu)+M'_a d_{j(a)}(x_\mu,x_\gamma)=M'_a d_{j(a)}(x_\beta,x_\gamma)
\end{aligned}$$

which proves (γ5).

If $\gamma\in\Omega$ is a limit ordinal, then we can choose a increasing sequence of ordinals $\{\gamma_n\}_{n=1}^\infty$, $\gamma_n\in\Omega$ such that $\lim_n\gamma_n=\gamma$. In view of (γ1) and (γ3)

$$d_{j(a)}(x_0,x_{\gamma_{n+1}})=d_{j(a)}(x_0,x_{\gamma_n})+d_{j(a)}(x_{\gamma_n},x_{\gamma_{n+1}})$$

which implies $d_{j(a)}(x_0,x_{\gamma_{n+1}})\ge d_{j(a)}(x_0,x_{\gamma_n})$, that is, the sequence $\{d_{j(a)}(x_0, x_{\gamma_n})\}_{n=1}^{\infty}$ is non-decreasing. Since (γ4) implies

$$d_{j(a)}(x_0, y) = d_{j(a)}(x_0, x_{\gamma_n}) + d_{j(a)}(x_{\gamma_n}, y),$$
$$d_{j(a)}(x_0, x_{\gamma_n}) = d_{j(a)}(x_0, y) - d_{j(a)}(x_{\gamma_n}, y)$$
$$\text{or } d_{j(a)}(x, x_{\gamma_n}) \le d_{j(a)}(x, y)$$

which implies the convergence of the sequence $\{d_{j(a)}(x_0, x_{\gamma_n}\}_{n=1}^{\infty}$. If we put $x_{\gamma_0} = x$ then

$$d_{j(a)}(x, x_{\gamma_n}) = \sum_{k=0}^{n-1} d_{j(a)}(x_{\gamma_k}, x_{\gamma_{k+1}}),$$

which implies

$$\sum_{k=0}^{\infty} d_{j(a)}(x_{\gamma_k}, x_{\gamma_{k+1}}) \le d_{j(a)}(x, y) < \infty .$$

This means that $\{x_{\gamma_n}\}_{n=0}^{\infty}$ is a Cauchy sequence in $(X, \mathbf{A})$. The completeness of X implies an existence of an element $z \in X$ such that $\lim_n x_{\gamma_n} = z$. We can define $x_\gamma = z$.

If for any $\alpha < \gamma$ we have $x_\alpha = y$, then $\{x_{\gamma_n}\}$ is eventually the constant sequence {*y*}. In this case (γ2) - (γ5) are satisfied for $\eta = \gamma$.

Since $\gamma_n < \gamma$ then (γ5) implies

$$d_a(Tx_{\gamma_n}, Tx_{\gamma_m}) \le M'_a d_{j(a)}(x_{\gamma_n}, x_{\gamma_m})$$

for all m and n. We can assume without loss of generality that $d_{j(a)}(x_m, x_n) > 0$. Otherwise we remove the elements for which $d_{j(a)}(x_m, x_n) = 0$ and renumber the rest ones. Consequently $\{Tx_{\gamma_n}\}_n$ is a Cauchy sequence in Y. But Y is a complete uniform space and T has a closed graph. Then $\lim_n Tx_{\gamma_n} = Tx_\gamma$. Let $\alpha < \beta < \gamma$ and let n be chosen sufficiently large such that $\gamma_n \ge \beta$. In view of (γ3) we have

$$d_{j(a)}(x_\alpha, x_{\gamma_n}) = d_{j(a)}(x_\alpha, x_\beta) + d_{j(a)}(x_\beta, x_{\gamma_n}).$$

Passing to the limit $n \to \infty$ in the last equality we obtain

$$d_{j(a)}(x_\alpha, x_\gamma) = d_{j(a)}(x_\alpha, x_\beta) + d_{j(a)}(x_\beta, x_\gamma),$$

that is, $x_\beta \in (x_\alpha, x_\gamma)_{j(a)}$. Also (γ4) implies

$$d_{j(a)}(x_\beta, y) = d_{j(a)}(x_\beta, x_{\gamma_n}) + d_{j(a)}(x_{\gamma_n}, y)$$

and after $n \to \infty$ we obtain $x_\gamma \in (x_\beta, y)_{j(a)}$. Consequently (γ3) and (γ4) are satisfied for $\eta = \gamma$. Condition (γ5) implies

$$d_a(Tx_\beta, Tx_{\gamma_n}) \le M'_a d_{j(a)}(x_\beta, x_{\gamma_n})$$

(provided $d_{j(a)}(x_\beta, x_{\gamma_n}) > 0$) hence by $n \to \infty$

$$d_a(Tx_\beta, Tx_\gamma) \le M'_a d_{j(a)}(x_\beta, x_\gamma).$$

Finally we obtained a set $\{x_\gamma : \gamma \in \Omega\}$ in X so that (γ1) - (γ5) are satisfied. If $x_\gamma \ne y$ for all $\gamma \in \Omega$ then (γ3) implies that the set $Z = \{d_{j(a)}(x, x_\gamma) : \gamma \in \Omega\}$ is a discrete set of real numbers. In view of Theorem 2, Ch. XV, (Sierpinski, 1965) Z is non-denumerable set. The obtained contradiction implies that for some $\gamma \in \Omega$, $x_\gamma = y$ and then (γ5) implies

$$d_a(Tx, Ty) \le M'_a d_{j(a)}(x, y).$$

The last inequality is valid for arbitrary $M'_a > M_a$ and consequently

$$d_a(Tx, Ty) \le M_a d_{j(a)}(x, y).$$

Theorem is thus proved.

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ASSESSMENT FF LOSSES IN POWER ELECTRONIC STRUCTURES IN KEY MODE

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SUMMARY
Theoretical investigation of the possibility of maximum losses while switching a //// electronic structure (transistor, IGBT, etc.) in key mode operation. The settings are; switch process duration and maximum possible change rate of element conductivity. The presumption is that because of noise and other deviations from normal mode, the form of signal, which governs the power element, can be changed according to an arbitrary rule. Determined are the most unfavorable rule to change conductivity and the value of its losses.

We know (S. Tabakov, Research work for academic degree) that a significant part of losses in electronic converters are to be found in switching electronic elements. The way to determine these losses is treated by a great number of publications (S. Tabakov, хабилитационен труд, Tz. Grigorova, Paper On дисертация, Giteva etc., Annual Of IZM). In all cases it is presumed that the rule of changing the governor signal upon the time is known and that it is near to the optimum in order to minimize losses on switching (conducting and blocking). There are a number of formulas to determine losses according to the electric parameters of the power mode and governing impulse.

The losses at blocking the power elements are significant for the converter efficiency as well as for its reliable operation, since a power transistor or OGBT is damaged irreversibly even at a lower excess of admissible losses. On the other hand, it is possible that at a given moment, due to some external influence, the governing impulse form is changed considerably to separate the maximum capacity of the power element while switching. We presume a given duration of ΔT of the process and we are looking for the most unfavorable switching rule. We have to take into consideration that it is a physical fact that each switch element, regardless of its kind, has some maximum conductivity change rate upon the time. $G^I_{MOT}\left[\frac{\Omega^{-1}}{s}\right]$>0 for conducting and $G^I_{M3}\left[\frac{\Omega^{-1}}{s}\right]<0$ for blocking.

Because of the complexity of this phenomenon we can admit with first approximation that this maximum rate is a constant for the whole range of change G.

When load is purely active and the presence of паразитен inductivity is not taken into consideration, the capacity of switching element is also not taken into consideration.

The replacing diagram is shown on Figure 1.

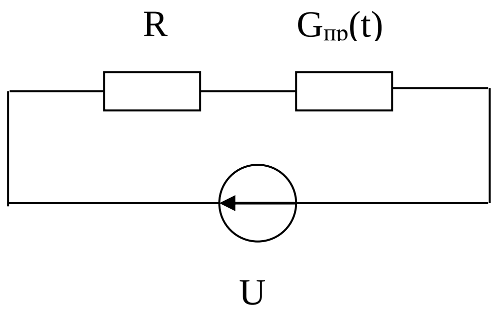

Figure 1.

The task for the conductivity case is determined as follows:
We search the kind of function $G_{ПР}=G_{ПР}(t)$ in the interval from:

$t=0$ *to* $t=\Delta T_{OГ}>0$, *whereas* $G_{ПР}(\Delta T)=G_{ПРMAX}$,

$\frac{dG_{ПР}}{dt}\le G^I_{MOT}$ for $0\le t\le \Delta T_{OT}$,

whereas the value is

$$\Delta W=\int_0^{\Delta T_{OT}} U^2\frac{G_{ПР}(t)}{(RG_{ПР}(t)+1)^2}dt=Max .$$

The variation analysis, according to the restrictions is quite large. As a result we get the following solution. For:

$0\le t\le t_1; G_{ПР}(t)=\frac{t}{Rt_1};$

for $t_1\le t\le t_2; G_{ПР}(t)=\frac{1}{R};$

for $t_2\le t\le \Delta T_{OT}; G_{ПР}(t)=G_{ПРМ}-$

$-\Delta T_{OT}G^I_{MOT}$, *where*

$$t_1 = \frac{1}{RG^I_{MOT}}; t_2 = \Delta T_{OT} - \frac{G_{\Pi PM} - \frac{1}{R}}{G^I_{MOT}}.$$

The graph is shown on Figure 2.

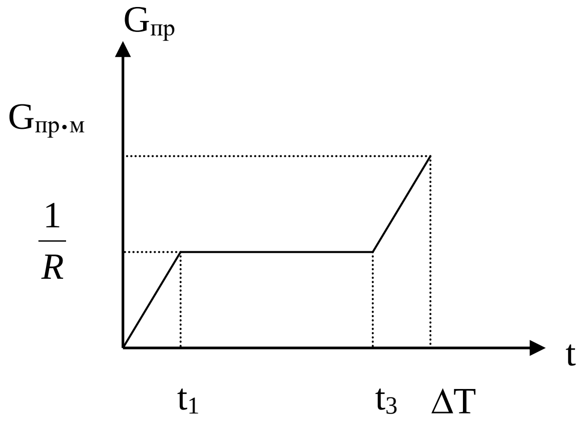

Figure 2.

The rule for change of the value $G_{\Pi P}$ upon the time shows that the maximum energy emitted by the element during one conducting state is determined by the formula:

$$\Delta W_{OT} = \frac{U^2}{4R}\left(\Delta T_{OT} - \frac{G_{\Pi PM}}{G^I{}_{MOT}}\right) +$$
$$+ \frac{U^2}{R^2 G^I_{MOT}}\left[\ln\frac{RG_{\Pi PM}+1}{2} + \frac{1}{RG_{\Pi PM}+1} - 0{,}31\right] =$$
$$= \frac{U^2}{4R}\left(\Delta T_{OT} - \frac{G_{\Pi PM}}{G^I_{MOT}}\right) +$$
$$+ \frac{U^2}{R^2 G^I_{MOT}}\left[\ln\left(RG_{\Pi PM}+1\right) + \frac{1}{RG_{\Pi PM}+1} - 1\right]$$

For all real cases $RG_{\Pi PM} >> 1$, or the conductivity of the transistor in complete conducting state is much greater than the conductivity of the purely active load. If the time for blocking the transistor ΔT is much greater than the relation $G_{\Pi PM} / G^I_{MOT}$, we can use the simplified formula with a small positive error:

$$\Delta W = \frac{U^2}{4R}\Delta T.$$

When the switching element is blocked, we do the same investigation. It is obvious that the maximum energy at a single blocking is emitted when the conductivity of the key element is changed according to the graph from Figure 3.

For the total energy emitted by the element we get the equation:

$$\Delta W_3 = \frac{U^2}{4R}\left[\Delta T_3 - \frac{G_{\Pi PM}}{G^I_{M3}}\right] +$$
$$+ \frac{U^2}{R^2 G^I_{M3}}\left[\ln\frac{RG_{\Pi PM}+1}{2} + \frac{1}{RG_{\Pi PM}+1} - 0{,}31\right] =$$
$$= \frac{U^2}{4R}\left[\Delta T_3 - \frac{G_{\Pi PM}}{G^I_{M3}}\right] +$$
$$+ \frac{U^2}{R^2 G^I_{M3}}\left[\ln\left(RG_{\Pi PM}+1\right) + \frac{1}{RG_{\Pi PM}+1} - 1\right].$$

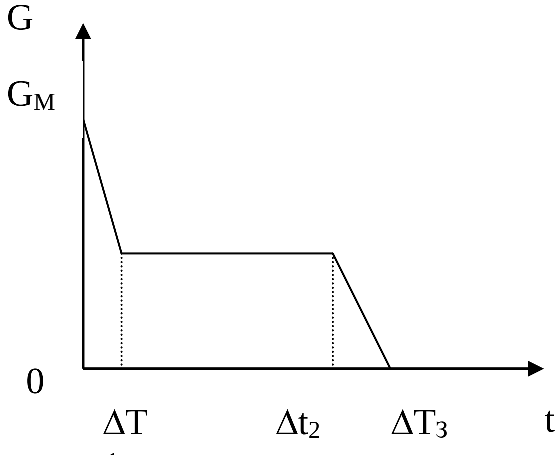

Figure 3.

To have a better idea of the dimension of the upper limit of losses, we will determine the losses at two more probable hypotheses for the blocking process. The first one admits that during blocking with duration ΔT, the voltage at the ends of the switching element grows according to a linear rule:

$u = U\frac{t}{\Delta T_3}$, where U is the constant voltage of the power supply source. When the load is purely active, the current during blocking is changed according to the rule:

$$i = \frac{U}{R}\left(1 - \frac{t}{\Delta T}\right)$$

Losses are;

$$\Delta W_3 = \frac{U^2}{6R}\Delta T_3.$$

The result is for example by 30% less than the determined upper limit.

According to the second hypothesis, we admit that during time ΔT, the switching element conductance is lowered from its maximum value to zero, according to a linear rule. In this case we have:

$$\Delta W_3 = \frac{U^2 \Delta T}{R^2 G_M}\left(\ln\left(RG_M + 1\right) + \frac{1}{RG_M + 1} - 1 \right)$$

Because of $RG_M >> 1$, during the second assumption, we have losses several times less than during the first one.

CONCLUSION

The results enable us to assess with a certain positive error the cases when there is no exact data about the processes. To determine the upper limit, it is sufficient to know the nominal voltage, nominal current and time for full conducting and blocking. They can be determined by an oscillogram of the work current.

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