EQUIPMENT FOR THE CLASSIFICATION AND CRUSHING SECTION IN FERTILIZER PRODUCTION

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ABSTRACT. The paper includes an analysis of the most common grain-size raw material preparation schemes applicable in the mineral processing. Factors influencing the optimal management of the crushing process are clarified and authors' and other installations to regulate this process are presented. Based on this, a variant for equipment for the crushing and sieving sections, tested in practice, is presented.

Keywords: sieving, crushing, fertilizer production

ОБОРУДВАНЕ ЗА ВЪЗЛИТЕ ЗА КЛАСИФИЦИРАНЕ И РАЗДРОБЯВАНЕ ПРИ ПРОИЗВОДСТВОТО НА ТОРОВЕ
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РЕЗЮМЕ. В статията е направен анализ на най-често срещаните схеми за зърнометрична подготовка на суровини, приложими при обработката на минерални суровини. Изяснени са влияещите фактори за оптимално управление на процеса на раздробяване и са представени авторски и други инсталации за регулиране на този процес. На тази основа е разработен вариант на апаратурно оборудване на възлите за раздробяване и пресяване, който е проверен в практиката.

Ключови думи: пресяване, раздробяване, производство на торове

Nowadays, the granulation methods, used at modern large-scale fertilizer production plants, cannot guarantee the obtaining of a product with narrow particle size distribution range, conforming to strict requirements of standards. Thus, any fertilizer production incorporates the classification and crushing section. In spite of that this section is often considered as a mechanical unit, the operation of granulation unit and product qualitative parameters depend significantly on it [1, 2]. Not only particle size distribution depends on it, but, also physical and chemical properties of fertilizers, primarily, caking and dust formation. The more fines in commercial product, the higher value of these parameters. In paper [3], it is specified that caking of DAP granules with size less than 2 mm is higher by 1.8-4.4 times than caking of granules with size of 2-5 mm.

In the fertilizer industry, the following granulation processes are the most prevailing:

1. Process with ammonizer-granulator (AG) and drying drum (DD). In this process, after the granulation and drying, the material is classified into three fractions in four or six double-sieve screens (1st stage of classification). Further, fines and oversized fraction (after crushing) are returned to recycle, and product fraction is additionally classified in single or two double-sieve screens (control classification). The part of product fraction, conforming to load, is discharged as a final product, another part is fed to recycle. Usually, these processes have larger recycle ratio – from 2.5-3.0 and more. Accordingly, the classification unit shall be suitable for such amount of material:

$M = (1 + P) \times B$, where

M – amount of material, which should be classified, t/h;
P – recycle ratio (ratio of recycled material flow and final product);
B – final product yield (determined by load), t/h.

2. Process with drum granulator-dryer (DGD) or spherodizer. In these units, slurry is sprayed onto granules curtain, formed by special lifting flight. The DGD unit and spherodizer are different, DGD has a screw for moving of internal recycle. Usually, the processes with DGD have lower external recycle ratio (not more than 3). Thus, in these processes, the material

is classified in less number of screens – usually, in two screens at one stage (without control classification), but there are some exclusions.

3. Process with granulation tower. This is the process with the lowest recycle ratio. Here, the recycled material is determined by removal of off-spec fractions (fines and oversize fraction) only, i.e. granulation uniformity. Therefore, lower classification capacity is required.

The most typical classification processes were shown, actually, the processes are more various. For example, for the production of flexible products like urea-based NPK, some companies like Jacobs propose the removal of fine fraction from the material after drying in single-sieve screens (hot screens), further oversieved product is cooled and classified again in double-sieve screens (cold screens) [4]. At WMC Fertilizers factory (Australia), at DAP production plant (capacity 123-145 t/h), the three stage material classification after DD is used: at first, in three double-sieve screens, then in four single-sieve screens, further, after cooling, in two control double-sieve screens.

In paper [5], the screening process is proposed, in which the material from DD is divided into two flows: one is classified in standard way, and second flow is classified firstly in single-sieve screens with particle size limit of 4 mm; oversieved product is fed for crushing and to recycle, and undersieved product is fed partially to recycle and partially into single-sieve screen and final product. Advantages: recycle is not classified by lower size limit, the upper limit is artificially understated; simultaneously, the recycled material particle size becomes lower. Jacobs proposes the different ways of development of classification systems for optimization of fertilizer quality [6].

The authors of paper [7] propose the perspective process of classification and crushing, which helps to regulate the granulation process for changing of granules size. In this process, material after DGD or drying drum (DD) is fed by elevator onto two vibrating distributors, which help to distribute the material uniformly onto vibrating screens meshes, on which it is classified into fractions. Fine fraction from lower sieves is fed to recycle directly – product fraction is divided into two parts by gates with remote control: one part is fed to final product conveyer and further, it is fed for cooling etc., another part is fed to recycle.
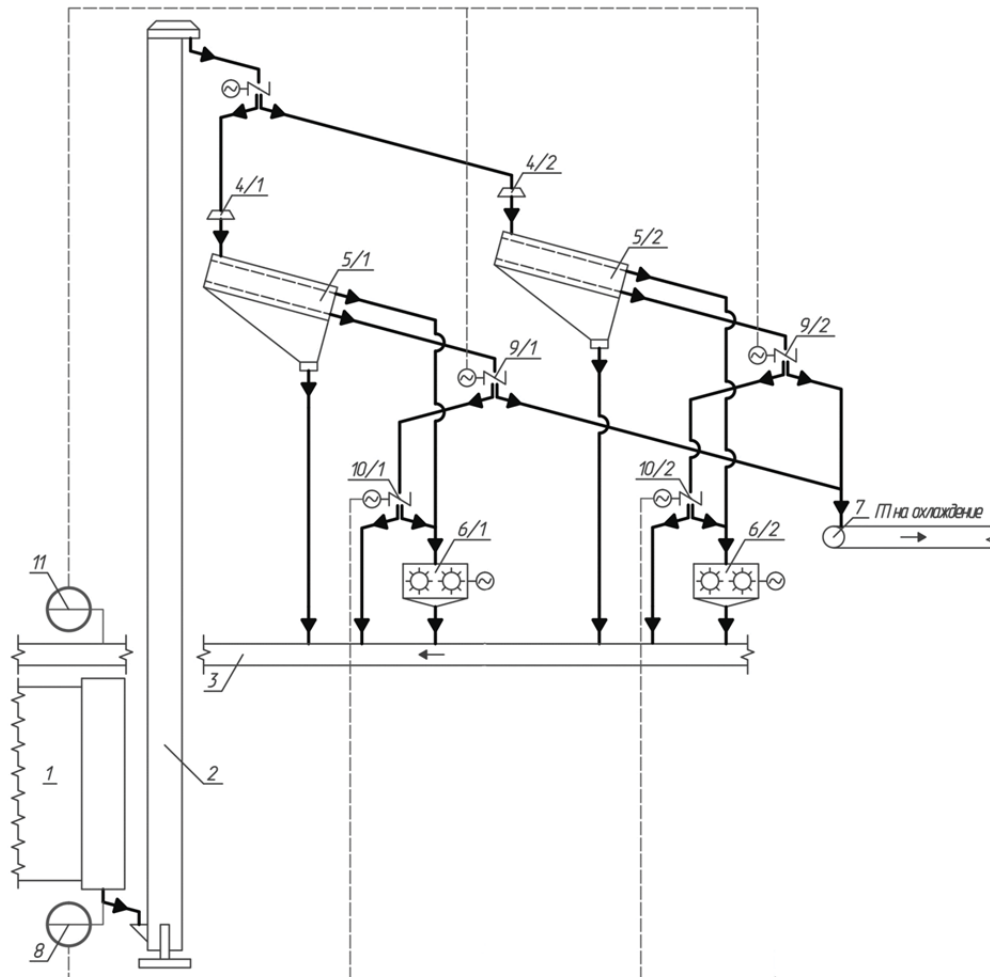

Fig. 1 – Principal diagram of classification and crushing unit, allowing to regulate the granulation process
1 – DGD; **2** – elevator; **3** – recycled material belt conveyor; **4/1**, **4/2** – vibrating distributor; **5/1**, **5/2** – vibrating screen; **6/1**, **6/2** – chain crusher; **7** – final product belt conveyor; **8** – particle size automatic analyzer; **9/1**, **9/2**, **10/1**, **10/2** – gate with remote control; **11** – recycled material scales.

The part of product fraction, fed to recycle, is divided in two flows by gates with remote control, one flow is fed directly to recycled material conveyor, and second flow is crushed in chain crushers before being fed to recycle also. The oversize fraction from upper sieves of screens is also fed to these chain crushers, after crushing it is fed to recycle. The rotary speed of chain crushers rotors (i.e. crushing intensity) and amount of product fraction, fed for crushing, is automatically controlled by frequency regulators and regulated gates, depending on values of automatic particle size analyzer and based on tendency of oversizing or fining of fraction. (Fig.1).

Such classification and crushing process allow to regulate and stabilize the particle size of fertilizers without interference in general process parameters. But, for implementation of such flexible process, it is needed to have the certain crushing capacity reserve, i.e. it is necessary to implement the above-proposed method: 1 screen – 1 crusher.

The general equipment of classification and crushing section is screens and crushers. More often, the inertial screens are used in fertilizer industry. They differ by number of sieves, methods of their tension, fixing, cleaning, sealing design of device for material distribution, sieve width etc. The significant improvement of screen operation is achieved at usage of material vibrating distributors.

Screens are selected on the basis of following requirements:

1   Provision of required capacity;
2   Provision of required quality of classification;
3   Operation reliability;
4   Easy to maintain;
5   Tightness.

In accordance with these parameters, the screens should be selected. Screen reliability is related to its long-term operation without repair. Easiness of maintenance – firstly, it is the accessibility of sieves for cleaning and replacing. Tightness – the screens should not form dust.

It is impossible to calculate precisely the performance of inertial screens, this value is a test value. It is proportional to sieve width, material layer height and its motion rate. It is considered that the layer height, equal to two or three fraction sizes, is the most preferable for classification. Vibration frequency of inclined screen [5]:

$$f = 44 \sqrt{\frac{l}{a}}, \text{ where:} \tag{1}$$

l – opening size;
a – vibration amplitude.

Roughly, the screen performance may be determined by the following methodology [10]:

at sieve vibration per minute n, the motion rate of particle on sieve will be:

$$v = \frac{a \times \tan \alpha \times n}{60} \text{ (м/с), where:} \tag{2}$$

a – amplitude;
α – sieve inclination angle.

At sieve length L (m), the retention time on it will be:

$$\tau = \frac{L}{v} \text{ (с)} \tag{3}$$

At known classification time, it is possible to calculate the sieve length L at given capacity Q (kg/s):

$$Q = B \times h \times v \times \rho_{\text{н}}, \text{ where:} \tag{4}$$

B – sieve width, m;
h – material layer height, m;
$\rho_{\text{н}}$ – material bulk density, kg/m³.

Using the value v, the following will be obtained:

$$Q = \frac{B \times h \times a \times \tan \alpha \times n \times \rho_{\text{н}}}{60} \tag{5}$$

Screen specific capacity q (kg/(m²×s)):

$$q = \frac{Q}{S} = \frac{h \times \rho_{\text{н}}}{\tau} \tag{6}$$

This formula shows that, under this methodology, screen capacity is not connected with classification quality, the general parameter for calculation – classification time – may be determined from experiment only.

Specific load also depends on required efficiency of segregation. As a result of processing of experimental data, the following relation has been obtained [4]:

$$q = q_0^{1-n \times \eta}, \text{ where:} \tag{7}$$

q_0 – specific load, at which the efficiency is 0, depending on design, operation mode of screen and size of material;
n – empiric coefficient, depending on flowing and adhesive properties of product;
η – total screening efficiency.

$$\eta = \frac{(\beta - \alpha) \times (\alpha - \theta)}{\alpha \times (1 - \alpha) \times (\beta - \theta)}, \text{ where:} \tag{8}$$

α, β and θ – content of any fraction in initial, undersieved and oversieved product, respectively. Classification efficiency decreases with increasing of specific load onto sieve.

For optimal classification process, the correct selection of amplitude and frequency of screen vibration is needed. In vibrating screens, the effect of vibrational motions of sieve surfaces is used for material distribution on sieve, its transferring and loosening of caked material.

There is a certain relation between amplitude, vibration frequency and granule size (fraction size). The higher the fraction size is, the higher amplitude and lower frequency are. And vice-versa, the lower the fraction size is, the lower amplitude and higher frequency are. The relation of sieve vibration amplitude and fraction size is shown on Figure 2.

On the figure it is seen that the relative low vibration amplitude is applied for screens with direct excitation, the fraction size of 5 mm is located at the extreme bound of their operation.

As written above, the most preferable height of a layer on sieve is the height, equal to two-three fraction sizes [8]. But, this requires a certain screen vibration amplitude.
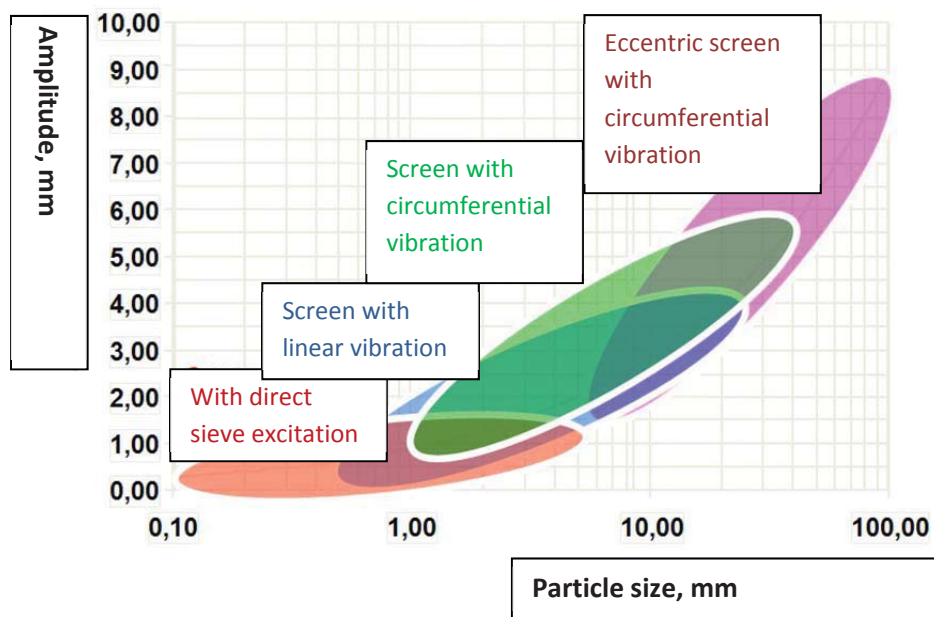
Fig. 2 – Diagram of relation of amplitude and fraction size

At high temperatures, the intensive tossing, loosening of material layer occur, the large lumps of caked and adhered material are broken. At the same time, at overrated amplitudes, fine granules fly over the mesh and don't pass through the sieve. At low amplitude, the screen capacity decreases because of insufficient shaking of material. Also, the possibility of fouling of sieve meshes increases because the particles, stuck in mesh, don't get the sufficient acceleration for fly out from mesh. It is experimentally determined that screen operates effectively, and at this the self-cleaning from hard-to-remove particles at height of material tossing [8, 10, 11]:

$$h \geq 0,4 \times l, \text{ where:} \tag{9}$$

h – material tossing height;
l – sixe of sieve mesh.

Also, it should be considered that at constant amplitude, the frequency cannot be increased infinitely, because, in this case, this will result in screen wearing and decreasing of its life-time. If the frequency is underrated, the screen capacity will decrease.

Now, if we, with taking into account the above-mentioned, again look at Figure 1, we will understand that screens with direct sieve excitation are not suitable for fertilizer classification at fraction size of 5 mm, because they have insufficient amplitude. Also, it is seen that the most optimal parameters for required product conform to the screens with circumferential vibration. They are suitable for increasing of capacity of existing and revamp requiring plants, and have the good capacity reserve.

It is experimentally determined that for the screens of this type, the specific capacity of classification at 5-mm fraction size is 12-15 t/(m²×h); at 2-mm fraction size – 3,0-4,5 t/(m²×h).

The following may be said about certain models of screens, used in fertilizer industry. Within the course of about ten years, within a special program, proposed to us by the German company MavegIndustrieausrüstungen GmbH (MAVEG), our specialists had visited plants and studied the experience of leading fertilizers producers in Germany, Poland, Spain, Bulgaria, Morocco, Turkey, Jordan, Australia etc. The meetings and consultations with leading developers of fertilizers production technologies, like INCRO and Jacobs, were carried out.

On the basis of this work results, the following conclusions can be made.

According to our data, screens with direct sieve excitation (direct transferring of vibration onto classifying surface) are reliable enough, they have high overhaul run, they doesn't require the monolithic platforms from reinforced concrete for their installation (because the vibration doesn't transfer onto steel construction structures). However, they have certain disadvantages. The access to lower sieves for repair and maintenance is difficult. Also, the large screen inclination angle decreases the classification quality. In our opinion, screens with direct vibration transfer onto sieve surface are better for classification of finer products (for example, feed phosphates) than granulated fertilizers (see Figure 2).

This type of screens has no sufficient reserve of capacity. At relatively not high loads, screen with direct sieves excitation may be able to solve its tasks in full manner; but, at load increasing, the dramatic decreasing of capacity by target product and decreasing of classification quality may happen.

From our point of view, other types of sieves are less suitable for fertilizer production.

In our opinion, units with vibration at horizontal plane are not effective and inefficient and not suitable for fertilizers production. They are rather for flour-grinding industry.

Also, there is a doubt about the effectiveness of screens with top axial arrangement of vibrating motors, because the vibration from them transferred to sieve center with the help of special closure dams (Figure 3).
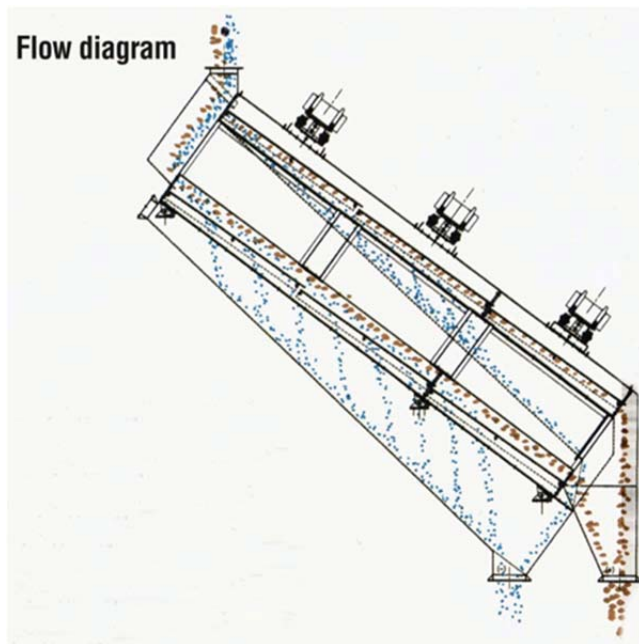

Fig. 3 – Screen with top arrangement of vibrators

As a result, the sieve central part has the high vibration amplitude, which decreases practically down to «0» at edges of sieve surface, this leads to non-uniformity of fertilizer distribution along sieve width and decreases dramatically the capacity and effectiveness of classification, and therefore, this leads to faster wearing of sieve itself. Producers of such screens try to compensate this disadvantage by increasing of screens size, but, this also creates the problems with their arrangement, layout and creates the additional loads on construction structures. Although these screens are quite cheap, we can't recommend them as equipment for classification and crushing sections of fertilizer production plant.

The most suitable screens for fertilizers production are vibrating screens with circumferential vibrations, because they have the optimal parameters, particularly, sufficient amplitude (see Figure 2). In spite of this type of vibrating screens requiring platforms from reinforced concrete for suppression of vibration or special additional frames for vibration suppression at installation, these units have high capacity and effectiveness. As we mentioned above, on the basis of our operational data, the specific capacity of this type of vibrating screens (at presence of high effectiveness of classification and provision of qualitative particle size distribution of commercial product) is 12-15 t/(m²×h) at 5-mm fraction size, at 2-mm fraction size – 3,0-4,5 t/(m²×h).

Theoretic calculations and studying of equipment operation experience at similar plants, impressive reference list – more than 110 units of installed similar equipment in more than 40 countries around the world, give us the right to recommend the equipment of Haver Niagara GmbH company for these specified purposes.

The familiarization with Haver Niagara GmbH screens at foreign and Russian fertilizer production plants convinced us in their high reliability and efficiency, even at operation in severe conditions, during long period of time (more than 20 years).

At revamp of phosphorous-containing fertilizers production plant at one of the largest factory for production of this product, JSC NIUIF specialists in the factory and MAVEG engineering company specialists made a selection of vibrating screens for replacement of existed old-fashioned screens GIL-52. The Haver Niagara screens with the size of sieving surface of 2000x6000 mm (Figure 4), selected by us, were supplied to the factory by MAVEG company, which is an authorized representative of Haver Niagara GmbH. After replacement of screens, the classification capacity increased significantly (up to values 0.949 at 2 mm interface and up to 0.933 at 5 mm interface, at DAP production), and also, this allowed (with other measures) to increase significantly the capacity of process lines [2, 13, 14]. This equipment proved its value, and it has already been used for 5 years. The single disadvantage of these screens is their insufficient tightness due to presence of soft inserts, which requires the periodic replacement due to their breakages during operation.
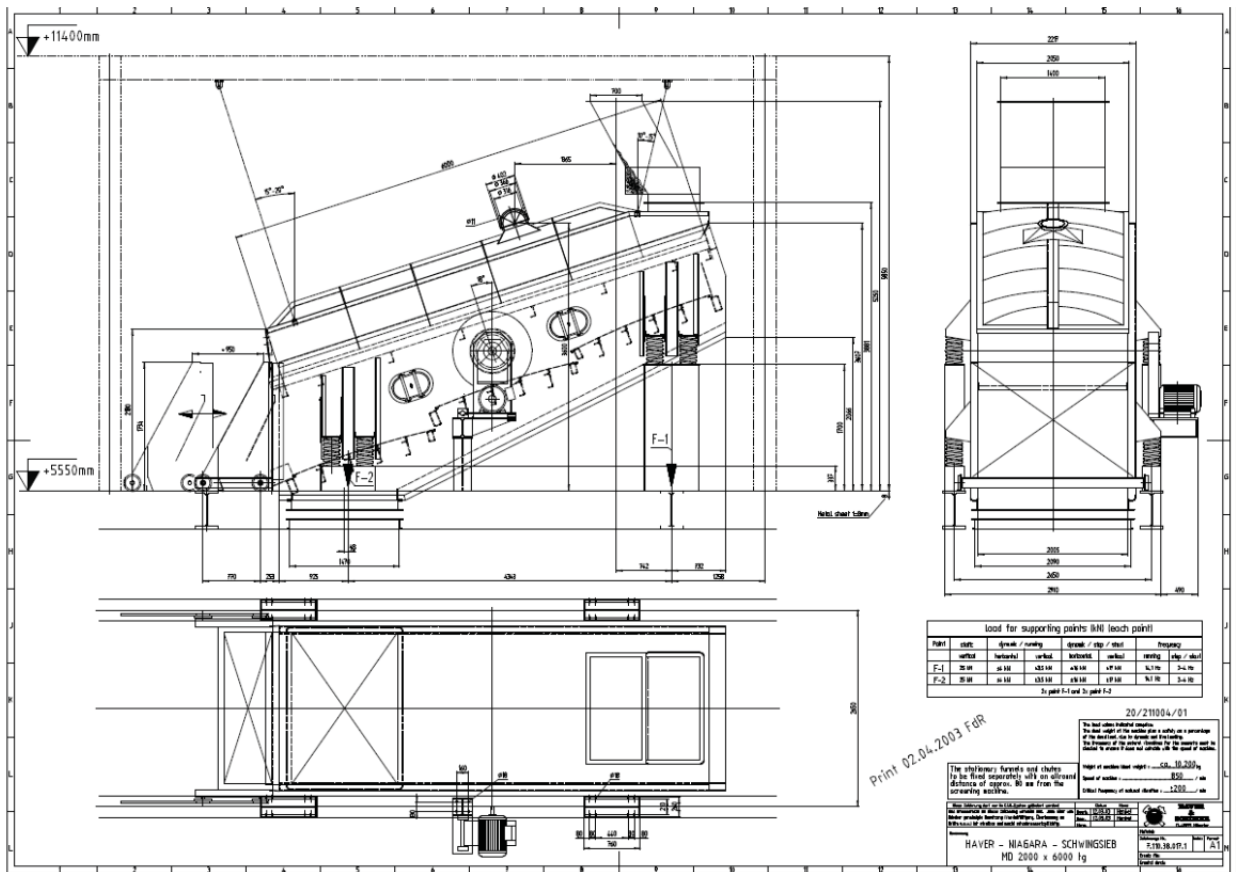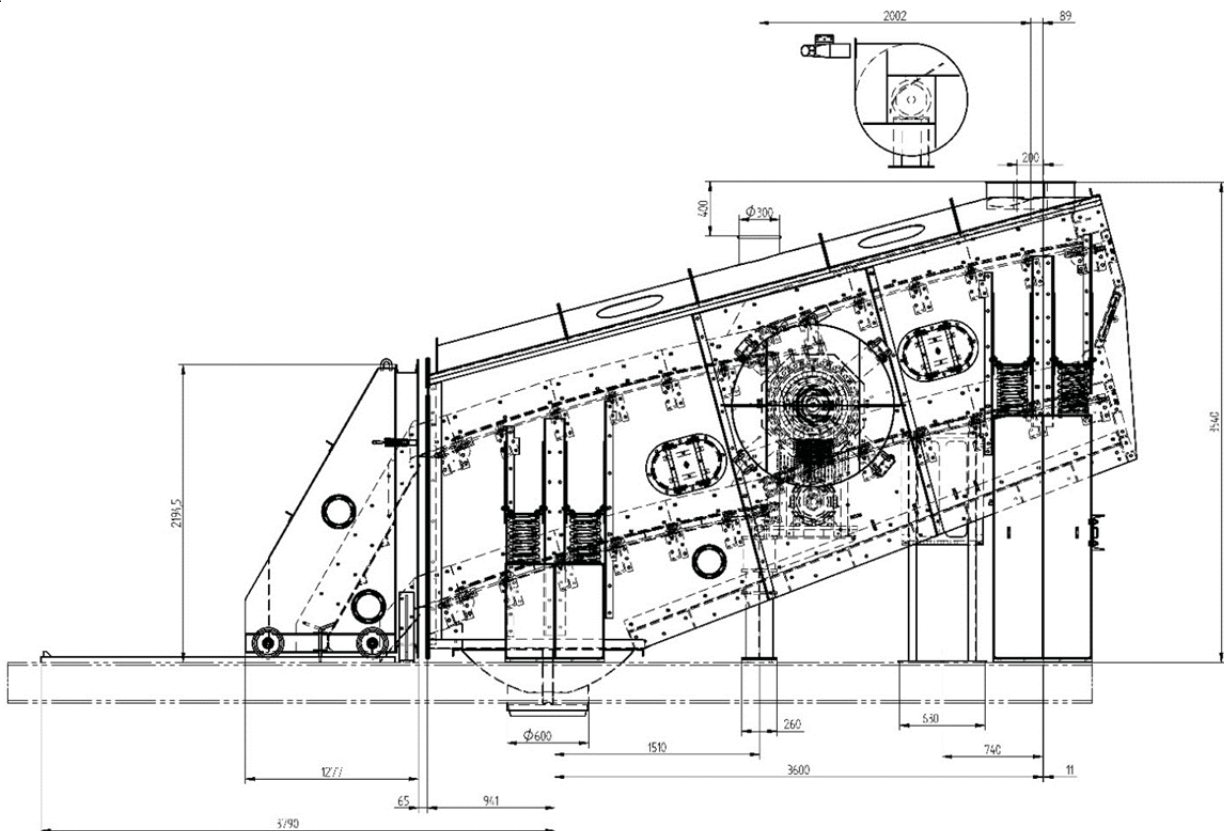
Fig. 4 – Haver Niagara 2000×6000 screen

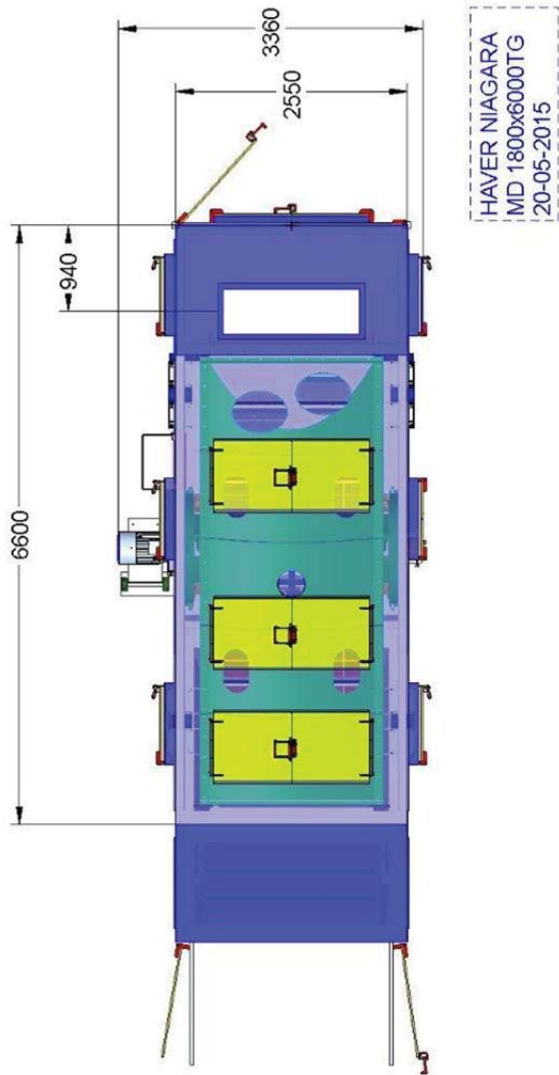Fig. 5 – Haver Niagara 1800×5000 screen

Fig. 6 – Haver Niagara 1800×6000 screen

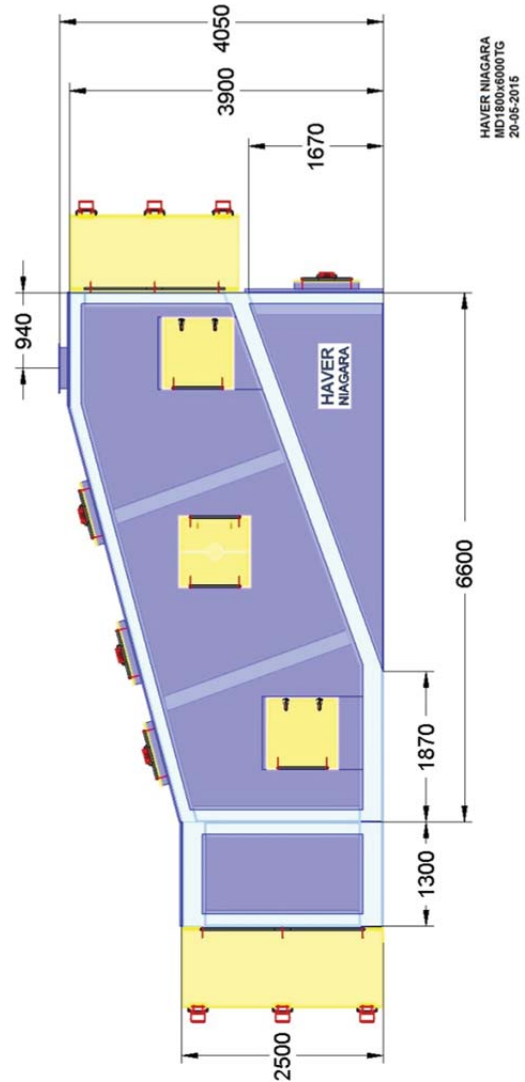**Fig. 7 – Fully closed modification of Haver Niagara 1800×6000 screen (top view)**

Fig. 8 – Fully closed modification of Haver Niagara 1800×6000 screen (side view)

In our point of view, the vibrating screens Haver Niagara 1800×6000 mm, proposed by MAVEG, as screens at first classification stage, and screens 1800×5000 mm for control classification, have the following advantages:

–   They provide the required classification quality, including at higher capacities;

–   They are reliable in operation – for several years, such units have operated successfully at fertilizer production plants in Balakovo and Kingisepp, and also at many other plants;

–   They are easy to maintain;

–   They are tight.

The important, and most critical criterion, for the selection of equipment for revamp of existing plant were the capabilities of MAVEG engineering company and the manufacturer, Haver Niagara GmbH, for adaptation of the new equipment with significantly higher capacity to certain conditions at the Customer's plant, designed earlier under the parameters of previously used equipment with less capacity.

The capabilities of the mentioned companies allowed to convert the serial equipment into equipment of individual design with taking into account all features of the Customer's production areas, this allowed to reduce significantly the possible costs for capital construction.

It is necessary to point out that it is rationally to install the modern vibrating screens only with proper vibrating distributors (vibrating feeders). This gives the following advantages:

–   The screen sieves surface is used more fully, the material is distributed more uniformly along mesh width, as a result of this, the capacity and effectiveness of segregation onto fractions increase;

–   As a result of more uniform product distribution along the whole width of the sieve, the wearing of its surface is more uniform; therefore, the life time increases;

–   The impact load onto screen (firstly, onto vibrating frame) decreases, as a result of this, its life time increases, and idles decrease.

Also, the necessity of usage of vibrating feeders before screens is proved by the specialists from fertilizer production processes developing companies, such as Jacobs Engineering and INCRO [12].

We analyzed the operation of vibrating feeders of different companies. It was determined that many of them are plugged periodically by lumps of adhered product during operation, this happened due to their design features. This leads to failures in feeder and screen operation, non-uniform distribution of material onto sieves, and further, to decreasing of capacity and effectiveness of classification. This issue may be solved by installation of additional device for lumps removal from vibrating feeders, as was done at one of the foreign plants (Figure 9).

Fig. 9 – Device for lumps removal from vibrating feeder

But, it is more rational to equip the screens with vibrating feeders of Haver Niagara company, which do not have these disadvantages due to their original and reliable design (Figures 10 and 11).

Practical usage of vibrating feeders shows that, for provision of stable operation of classification unit, it is needed to provide some reserve of vibrating distributors capacity: for a screen with classification capacity of 150 t/h at 5-mm fraction size, the vibrating distributor shall have capacity of 200 t/h, for a vibrating screen with capacity of 100 t/h – 150 t/h.

Particular attention shall be paid to crushing equipment at classification unit arrangement. The detailed study of usage of different equipment for these purposes at many plants around the world allowed us to give preference to the proposed by MAVEG chain crushers with capacity of 50 t/h, made by Sulta company, with taking into account the solved tasks on increasing of production capacities (Figure 12). Some years ago, together with the specialists from a large plant and MAVEG company, which is the authorized representative of Sulta company, we selected this equipment for phosphorous-containing fertilizer production plant. Since then, more than 5 years have been passed, and they have been operating at all process lines. The main advantages of equipment of this type are:

– operational reliability;
– efficiency;
– easiness in maintenance and repair;
– this type of crushers gives the highest yield of grain fraction from 0.5 up to 2,0 mm (it is the germs for granules formation) and less dust fraction at crushing;
– with the frequency regulators, it is easy and convenient to change intensity and thinness of crushing;

– at shut-down, the crushers are not overfilled by product, therefore, they doesn't require the by-pass chutes and dampers.

During the selection of equipment, we had familiarized ourselves with the operation of chain and chain-hammer crushers at foreign facilities (in Lithuania, Turkey, Jordan, Morocco, Spain etc.), and the best references were obtained from everywhere. Also, the preference to chain crushers, as more reliable in operation and having higher capacity, is given by lead developers of fertilizer production plants, such as Jacobs Engineering [12] and INCRO.

Below, the Sulta comparative data on particle size distribution of product, obtained after crushing in chain and chain-hammer crushers, is specified. The company provides the possible content of fractions, critical for production, more than 3 mm and less than 1 and 3 mm (Table 1).

For fertilizer production, Sulta company recommends the use of chain crushers, for feed phosphates – chain-hammer crushers.

During crushing of fertilizer large-size fraction, it is rational to obtain «grains» – particles of size from 0,5 up to 2,0 mm, which are the "germs" of granules at granulation process in AG or DGD. Finer, dusty fraction is of significantly less interest for granules obtaining, the most part of it flows to the gas scrubbing system, increasing the density of absorbing liquid and mole ratio NH_4/H_3PO_4 in it, complicating water balance; this results in decreasing the capacity of the process line and worsening of the gas scrubbing.
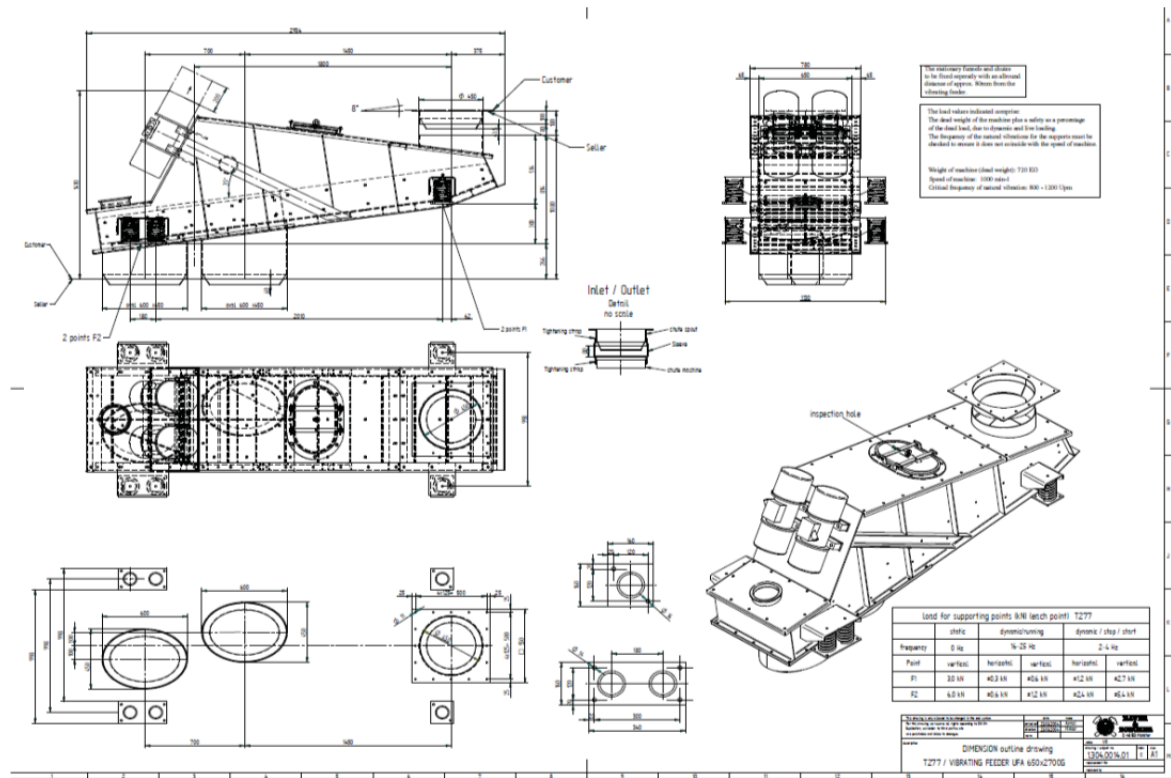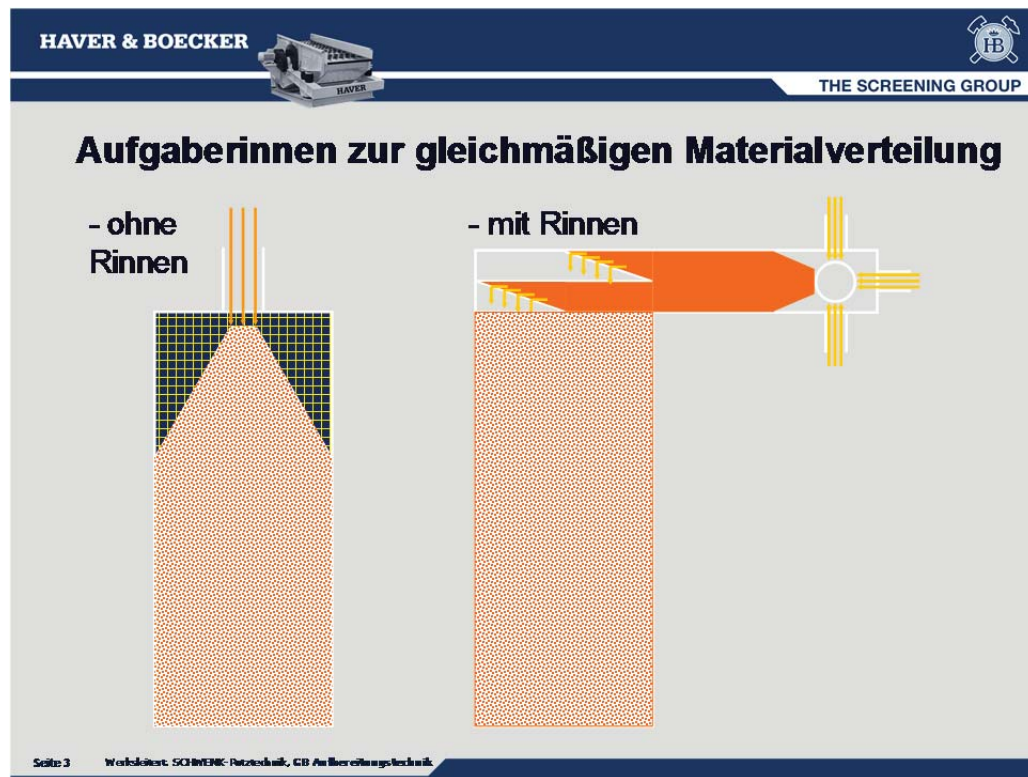
Fig. 10 – Vibrating distributor «Haver&Boecker»

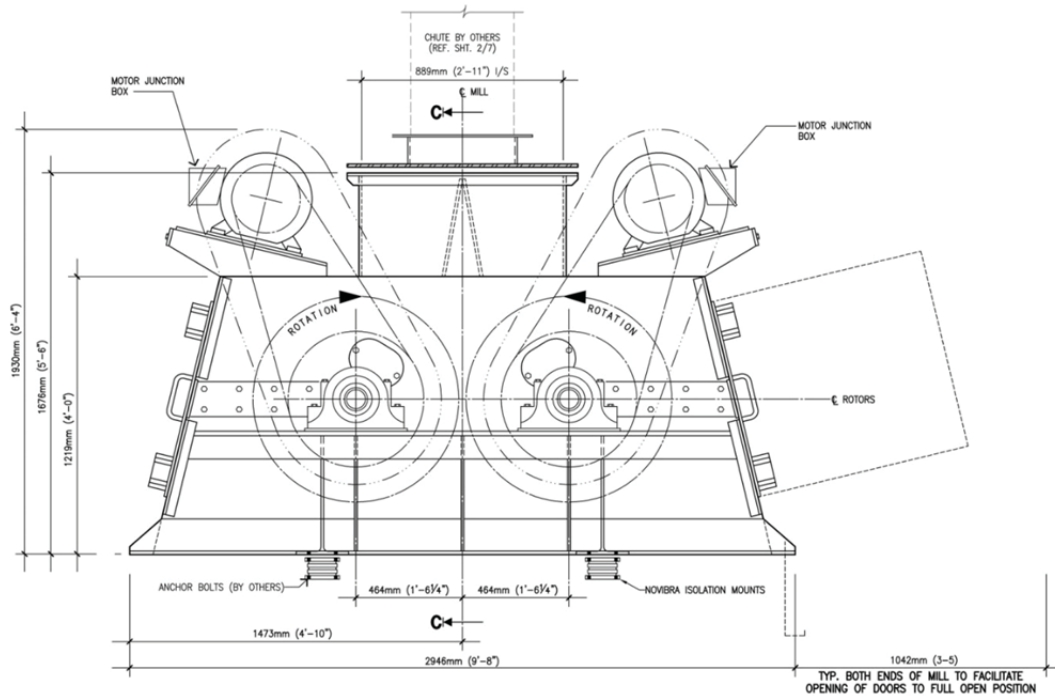Fig. 11 – Diagram of flows in feeder «Haver&Boecker»

Fig. 12 – Sulta chain crusher with capacity of 50 t/h

Table 1.
Characteristics of chain and chain-hammer crushers of Sulta company

Item No.	Parameter	Crusher MODEL 604-W36-C			
		Chain		Chain-hammer	
1	Particle size distribution of loaded product, %				
	>20 mm (max.)	10		10	
	>10 mm (max.)	20		20	
	>4 mm	100		100	
2	Particle size distribution of unloaded product, %	MAP/DAP	NPK	MAP/DAP	NPK
	>3 mm	20-35	30-45	15-30	25-40
	<3 mm	80-65	70-75	85-70	75-60
	<1 mm (max.)	10	5	12	8
3	Design capacity, t/h	50		50	

Examination, made after phosphorous-containing fertilizer production plant revamp at one of the largest facilities in Russia [2, 13, 14], showed that particle size distribution values at crushers outlets were close to the shown in Table 1. The content of fractions less than 0.5 mm and less than 1.0 mm decreased more than 2 times as a result of usage of the mentioned crushers. Other types of crushers give worse results.

After crushing, the hammer crushers give the significant amount of fine fraction (dust) and non-crushed product lumps, passed through the crusher.

Three-roll crushers also form mush dust at crushing; and in case of using of more flexible products, they may even form the plates ("cakes") of pressed fertilizers.

The examination also proved the possibility of crushing process regulation with frequency regulators: at changing the rotating speed, the intensity and thinness of crushing change.

We can conclude that our proposed option of equipment for classification and crushing sections at fertilizer production plants has been proved in practice and is worth serious attention.

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