50 years University of Mining and Geology "St. Ivan Rilski"
Annual, vol. 46, part III, Mechanization, Electrification and Automation in Mines, Sofia, 2003, pp.21-23

OPTIMIZING THE SELECTION OF A HOIST ROPE IN THE DESIGN AND OPERATION OF SHAFT HOISTS

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ABSTRACT
This paper deals with the selection of an optimal hoist rope design with preserving the hoist parameters in terms of geometry, need for changing the effective load or lift height in the design process, deepening the vertical shaft or reconstructing the shaft hoist by replacing the hoist vessel. Variants and recommendations are proposed for the selection of each parameter in compliance with the Labor Safety Regulations and underground mine design norms.

INTRODUCTION

Hoist shafts are used for vertical haulage of minerals and ores, waste rock, elements of mining and transport mechanization, ancillary, i.e. blasting and support materials, cables, pipes, etc. They are also used for man riding in two directions for the shift personnel, mine construction, erection and repair workers. In the design process it is normal to preset the lift height – H, annual mine output, shaft hoist function, mineral type, extraction levels, configuration of the surface technological complex.

The sequence of calculating and selecting each hoist device is as follows:
- selecting the hoist vessel (HV) according to the hourly output;
- selecting the hoist rope;
- designing the shaft reinforcement;
- calculating the shaft frame;
- selecting the hoist (HM) – a rope winding device – by diameter and width;
- calculating the hoist kinematics and dynamics;
- selecting the electric drive, brake system and protection equipment.

The aim of this paper is: A) to check the bearing capacity of various hoist rope designs and propose an optimal variant for a constant rope diameter d_r = const that also determines a constant diameter of the hoist D_{HM}= const and a possibility for variable hoist vessels - Q_P = var - to have variable effective load; B) or for Q_P = const , variable lift height H = var, i.e. to check the maximum capacities of the hoist ropes in shaft hoist design as well as their strength reserve when changes are required during operation.

STUDY PARAMETERS

The main performance characteristics that have an effect on the hoist rope design are as follows:
- hoist type and location of hoist drum mounting – on the surface or a friction sheave – on the surface or in the hoist frame;
- shaft hoist function – materials (skip) or materials and men (non-tipping skip);
- lift height and number of levels;
- HV guiding – rigid or flexible;
- conditions in vertical shaft – presence of dampness; air flow direction;
- maximum rate of motion; acceleration and delay rates; type of rope vibrations at starting and stopping;
- ratio of HV effective to dead weight;
- shaft hoist output – hourly, daily;
- allowable rope tensile force;
- ratio of hoist diameter, leading and angle sheaves to d_r; lining of leading sheaves,
- friction sheaves or drum;
- contact stress in the rope cross-section.

Two variants are considered focusing on the most important parameters listed above.
A) Design: the lift height is preset H = const; the maximum effective load is sought $Q_{P\,max}$ for d_r = const and D_{HM}= const - various hoist rope designs are considered – with variable linear weights (p = var) and a braking force (S_{bf} = var) that provide higher strength within the allowable working diameter of the hoist.
B) Operation: the effective load is known Q_{HM} = const and the lift height can vary H = var – deepening of the shaft. H_{max} is sought for preserved rope diameter d_r = const and hoist parameters D_{HM} = const. We check the various rope designs – p = var whose tensile strength increases within certain limits. According to the safety requirements for rope bending [1], [2], the hoist diameter should be D_{min}=79.d_r and the standard D_{max} is given in the manufacturing plant catalogues, most of which contain data on the maximum d_r of the respective hoist according to its design, type of lining, etc.

The study made is limited for depths of $H \leq 500$ m as are most vertical shafts in Bulgaria for hoists with a constant winding radius – drums with one-layer winding and friction sheaves – one- or multi-rope. The results can be applied for all shafts hoists operating in Bulgaria. An object of a further separate study can be the capacities of hoist ropes in vertical shafts of great depths (up to 1000 m for Bulgaria). We consider a shaft hoist only for load – mineral, especially ore for the more complicated case as compared with coal. We work with high density ρ = 1.8 – 1.9 t/m^3. The hoist vessels as effective and dead weight are larger than those used for men and materials (non-tipping skips) so that the conditions observed for them and the hoist rope selection will be valid with a high reserve factor for the others as well.

Two sets of calculations are made – of the lift height H = 400 m and H = 500 m. The complete height for which the rope is dimensioned is: where we assume

$$H_0 = H + h' + h'', m \quad (1)$$

h' – the height from elevation 0'00 to the axis of the leading sheaves;
h" - maximum value of sagging in the presence of a lower balance rope with linear weight (q = p).

The hoist ropes are selected by linear weight "p" according to the following formula [3],

$$p = \frac{Q_0}{\frac{\sigma_0}{k_s.\gamma_0} - H_0}, N/m \quad (2),$$

where: $Q_o = Q_P + Q_D$, N, (Q_D – dead load of HV);
σ_o = 1770 kN/mm^2 – as assume;
k_S= 6, 5 factor of safety (for a hoist only for materials);
γ_o = 100 N/m^3.

Given the requirement for a constant rope diameter, its linear weight will depend only on its design – number of wires with variable diameters and total number of wires; number and shape of strands, type of core. From practice we know that for such heights and one-rope hoisting, we can expect a hoist with $D_{HM} \geq$ 3.5m thus presupposing ropes with $d_r \geq$ 40 mm. In order to increase the capacities of the rope in terms of designs and forces, we select d_r = 45 mm thus determining a standard drum diameter of 4 m [1].

We can calculate the drum width by the formula below [3] and check whether it is sufficient for the respective lift heights H = 400m; H = 500 m

$$B_{HM} = \left(\frac{H + l_t}{\pi . D_{HM}} + z_{fr} + z_l \right).(d_r + \varepsilon), m \quad (3),$$

where:
l_t = 30m;
$Z_{fr} + Z_l$ = 6 windings;
ε = 3 mm.

For standard two-drum hoists with D_{HM} = 4 m the maximum width is B_{HM} = 2,3 m, which is sufficient for H = 500 m. From formula (2) we express the finite suspended load Q_s:

$$Q_0 = p.\left(\frac{\sigma_0}{k_s.\gamma_0} - H_0 \right), N \quad (4)$$

On the other hand, the maximum static force by which we select the rope is:

$$F_{st} = Q_0 + p.H_o = \frac{Q_{bf}}{k_s}, N \quad (5),$$

where Q_{bf} is the ultimate breaking force for the selected strength σ_o and was selected from a catalogue [2].

The sequence of calculations is given below and the results obtained are presented in Table 1.

1.We select 4 different designs of one-layer ropes with d_r = 45 mm from [1]: graph 2, Table 1.
2.We calculate the maximum load they can carry by formula (Fst) – in graph 5 from Table 1 and we subtract the natural weight of the rope $p.H_O$ – graph 6 for H = 400 m and graph 7 for H = 500 m.
3.The results obtained are plotted in graphs 8 and 9, respectively.
4. From reference data [3] for standard hoists in the mining industry we search and check for ones having maximum efefctive load Q_P = V.ρ depending on Q_O and Q_D – graphs 10 and 11.

SUMMARY AND ANALYSIS OF RESULTS

For hoists with diameter D_{HM} = 4m and a rope with $d_в$ = 45mm when lifting only materials (minerals and ores), the possibilities for maximum weight Q_P are as follows:

a) for H = 400 m and ore with ρ = 1.8 t/m^3 a standard tipping skip with a capacity of V = 7.5m^3 and a hoist rope with triangualr strands – design 1 from Table 1 can be used. For coal, due to its lower density ρ =0.9 t/m^3, the capacity can be increased up to 11 m^3 for a single rope skip for Q_D = 87.3kN. We have reserve both from the density and the rope designs.

b) for H = 500 m and ore with ρ = 1.9 t/m^3 we can use a similar skip but with a capacity of V = 5 m^3 and all proposed rope designs so as to be able to select a lighter one – e.g. the fourth one with p = 68.86N/m since the allowable working static force F_{st} is much lower than the bearing capacity of the given ropes. For coal it is again possible to have V = 11m^3 even for the lightest rope design.

B) For the conditions listed above and selected hoist vessels: V = 7.5m^3, ρ = 1.8 t/m^3 tipping ore vessel; lift height H = 400 m and a rope with d_r = 45mm and p = 80,05N/m with a 6 x 27 design, triangular strands and the similar skip for H = 500m and V = 5m^3 at ρ = 1.9 t/m^3 we check its capacities for taking an additional load from its natural weight in deepening the vertical shaft.

From formula (1) we determine inversely:

$$H_{max} = H_{0max} - (h' + h'') = H_{0max} - 40, m,$$

where:

$$H_{0max} = \frac{(F_{st} - Q_0)}{p}, m \quad (6)$$

Table 1

	Rope constructions	p, N/m	Q_{bf}, kN	F_{st}, kN	p.H_o, N 400 m	p.H_o, N 500m	$Q_{0\,pos}$, kN 400m	$Q_{0\,pos}$, kN 500m	Q_P+Q_D, kN 400m	Q_P+Q_D, kN 500m
1	2	3	4	5	6	7	8	9	10	11
1	Δ - fascicles, 6x27	80,05	1520	233,85	35,22	43,22	198,63	190,63	132+63,76	93,2+54,94
2	O - fascicles, 6x36	72,98	1410	216,9	32,11	39,41	184,79	177,49	88,3+54,94	88,3+54,94
3	O - fascicles, 6x29	71,5	1380	212,3	31,46	38,61	180,84	173,69	88,3+54,94	88,3+54,94
4	O - fascicles, 6x19	68,86	1330	204,6	30,3	37,18	174,3	167,42	93,2+54,94 88,3+54,94	93,2+54,94 88,3+54,94

From Table 1 for the selected vessels we check the rope reserve. Besides the largest HV (H_{res} = 35m only), for all others we obtain sufficient reserve of length from 530 m (for rope 1 and H = 500 m) to 225 m (for rope 4 and H = 500), which may be considered double reserve. This is so because of the lack of standard HV with intermediate capacities or different designs. For the separate mines, depending on the mining technology, this can allow for entering in depth of 1 to 4 more levels.

In the coal skips the reserve rope lengths are shorter due to the more appropriately selected capacities. For example, for rope 1 and H = 500 m, the reserve length for a skip with V = 11m^3 will be 77 m.

From the calculations made for the selected hoist rope designs within the limits of d_r = 45mm with preserving the hoist diameter D_{HM} = 4 m we can draw the following conclusions:

- The steel rope with triangular strands (1) gives the greatest possibilities in terms of tensile strength, which for variant (A) means maximum effective load Q_P – for the standard ore hoists used in Bulgaria – up to 7,5 m^3 capacity, and generally up to 8-9 m^3 depending on the vessel design and its dead weight; and for variant (B) – maximum lift height up to two additional extraction levels of 100 m each or four levels of 50 m each depending on the mining technology;
- The breaking force reserve for the same rope in operation can be used also for increasing the output for preserved height – or replacing the hoist vessel with one with a higher effective load; basically, it is important to preserve the other expensive hoist devices, mostly the shaft reinforcement; normally there should not be any problem because the standard skips are designed in such a way that every following size type increases its capacity at the expense of a change only in height.
- The study carried out can be a basis for creating a complete future methodology for selection of hoist ropes that can include all hoists with D_{HM} = 2 - 6m manufactured in Bulgaria as well as all possible depths, below 400 m down to 1000 m. Other rope designs can also be included – with a different number of strands and more than one layer.

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