UDC 622.67:621.31

RESEARCH OF THE AREA OF POSSIBLE SHIFT LOADED SKIP BARYCENTRE OF ELECTROMAGNETIC LIFTING INSTALLATION

Aikeyeva A.A.[1], Zhautikov B.A.[2], Zhautikov F.B.[1], Mukhtarova P.A.[1]

[1]EA Buketov Karaganda State University, Str. University, 28, 100028, Karaganda, Kazakhstan, aikeeva@mail.ru
[2]Kh Dosmukhamedov Atyrau State University, Str. Students, 212, 060011, Atyrau,Kazakhstan, bakhyt.zhautikov@atgu.kz

The application of existing outdated, inefficient mine winders has increased the cost of minerals several times. The solution to this problem is the creation of an electromagnetic lift installation. With this setup transportation of much greater weight is possible, spending less energy resources in comparison with existing technologies. According to the objectives of creation the electromagnetic lifting installation it is necessary to carry out the analysis and reveal the most loaded periods of work of skips of mine and career electromagnetic lifting installations. While determining the constructive parameters of skips it is necessary to consider the local external forces created by reactions of electromagnetic forces of electromagnets of the directing devices.

Keywords: mining, machine, electromagnets, lifting, installation, transportation, electromagnetic forces.

Reactions of electromagnetic forces of electromagnets depend on what distance from the axis of the vessel there is a center of its masses. Therefore while projection of a lifting vessel it is necessary to provide conditions providing its center of mass to be as closer as possible to the axis of symmetry. But actually, it is very difficult to provide such a condition because of the unequality of loading and other factors having casual character. Besides, it is necessary to consider dynamic processes while change of traveling speed of the vessel and condition of its entrance to the field of electromagnets of the directing devices.

Theoretical researches for analytical definition of the area of possible shift of loaded lifting vessel barycentre from the vertical axis of symmetry taking into account inequality filling of the load by calculation of the maximal size of shift of the barycentre of the skip were conducted [1]. Researches are conducted for determination of the maximal values of reaction of electromagnetic forces of electromagnets of the directing devices to the vertical wall of the moving ahead skip.

The bulk load is filled up inequally because technologically the tray of the feed bin settles down on the one hand a skip. The surface of the bulk load in a body of a skip will be slanted from the tray of the feed bin. The rake angle is equal to the angle of repose of rock mass (coal, ore or rock). We consider a geometric solid in the form of the slanted cylinder. At worst the surface of rock mass represents the plane. If it is not carried out, the barycentre of the loaded lifting vessel will be displaced from the vertical axis of symmetry to a lesser extent. Therefore we will determine the size of the maximal shift of the barycentre of the skip. Besides, design feature of lifting vessels mine electromagnetic lifting installations such as conicity of the bottom which provides the complete unloading of the skip is considered. The slope angle forming the cone is accepted equal to the angle of repose angle of rock mass (α).

Theoretical researches for determination the maximal size of shift of the loaded lifting vessel barycentre from the vertical axis of symmetry taking into account the inequal load filling are given below. In such a way it is possible to define the area of possible shift of the barycentre of the loaded lifting vessel. The calculated scheme of the skip is performed according to Figure 1.

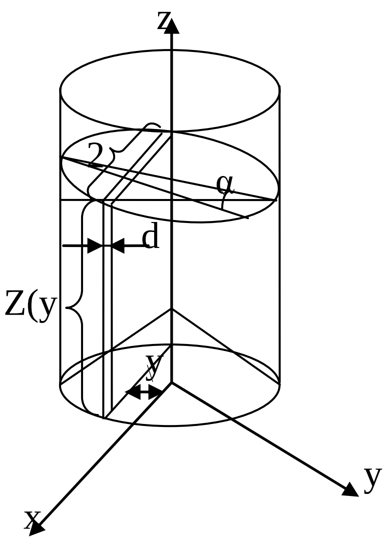


Fig.1.Calculated scheme for definition of the barycentre of the skip mine electromagnetic lifting installation

Section of the top slanted part of the bulk load in the skip according to figure 2 is shown.

We are set by orthogonal system of coordinates. As origin of coordinates we take a cross point for a long axis of symmetry of the skip of the lower cut of the vessel. We perform integration on coordinate axis *x*.

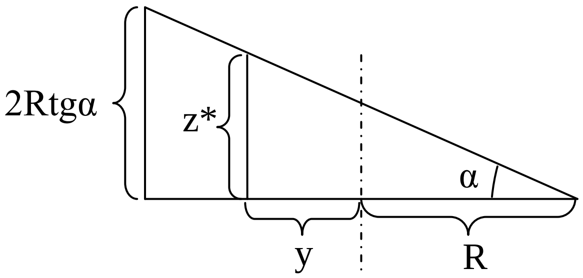


Fig.2. Section of the top slanted part of the bulk load in the skip

Let's calculate the moments of inertia *I* of the loaded lifting vessel components: the skip taking into account conicity of the bottom, two parts of the bulk load – the correct cylinder and the top load filling (the slanted cylinder) due to nonuniformity.

$$dI = \rho y dS dy = \rho z(y) 2xy dy \ , \tag{1}$$

$$\frac{z^*}{2Rtg\alpha} = \frac{R-y}{2R} \Rightarrow z^* = (R-y)tg\alpha \, , \tag{2}$$

where ρ – density of the bulk load, kg/m^3;

dI – change of the moment of inertia, kg/m^2;

dS – sectional area, m^2;

R - radius of the skip, m;

α - slope angle

$$z(y) = h_r - 2Rtg\alpha + (R-y)tg\alpha = h_r - (R+y)tg\alpha \, , \tag{3}$$

$$x = \pm\sqrt{R^2 - y^2}\,, \tag{4}$$

$$2x = 2\sqrt{R^2 - y^2}\,, \tag{5}$$

$$dI = \rho\left[h_r - (R+y)tg\alpha\right] - 2\sqrt{R^2 - y^2}\,ydy \tag{6}$$

where h_r – height of the skip, m; y_c – shift of the barycentre from a long axis of the symmetry of the skip, m.

$$\begin{aligned}
I &= 2\rho\int_{-R}^{R}\left[h_r - (R-y)tg\alpha\right]\sqrt{R^2 - y^2}\,ydy = \\
&= 2\rho h_r\int_{-R}^{R}\sqrt{R^2 - y^2}\,ydy - 2\rho\int_{-R}^{R}(R-y)tg\alpha\sqrt{R^2 - y^2}\,ydy = \\
&= 2\rho Rtg\alpha\int_{-R}^{R}\sqrt{R^2 - y^2}\,ydy - 2\rho tg\alpha\int_{-R}^{R}\sqrt{R^2 - y^2}\,y^2dy = \\
&= \left|\begin{array}{l} y = R\sin t \\ dy = R\cos tdt \\ \sqrt{R^2 - y^2} = \sqrt{R^2 - R^2\sin^2 t} = R\cos t \end{array}\right| = -2\rho\ tg\alpha\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}R\cos t\ R^2\sin^2 t\ R\cos tdt = \\
&= \\
&= -2\rho tg\alpha R^4\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\sin^2 t\ \cos^2 tdt = -\frac{\rho tg\alpha R^4}{2}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\sin^2 2tdt = \\
&= -\frac{\rho tg\alpha R^4}{4}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}(1 - \cos 4t)dt = -\frac{\rho tg\alpha R^4}{4}\left(t - \frac{\sin 4t}{4}\right)\Bigg|_{-\frac{\pi}{2}}^{\frac{\pi}{2}} = -\frac{\pi\rho tg\alpha R^4}{4}
\end{aligned} \tag{7}$$

Without the cone-shaped bottom of the skip the ordinate of the bary of the loaded skip is equal:

$$y_c = \frac{I}{M} = \frac{-\dfrac{\pi\rho tg\alpha R^4}{2}}{\pi\rho R^2\left(h_r - Rtg\alpha\right)} = -\frac{R^2 tg\alpha}{4\left(h_r - Rtg\alpha\right)}\,. \tag{8}$$

Taking into consideration such factors as conicity of the bottom and weight of the empty skip we can consider position of three bodies with three different masses and barycentres according to figures 3, 4.

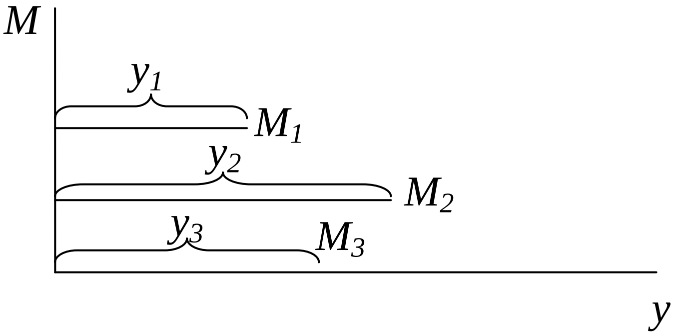


Fig.3.Schedule of the arrangement of barycentres of components of the loaded skip

Then the common barycentre of the cumulative body can be found as follows.

On the basis of the schedule in Figure 3 we will calculate the barycentre ordinate of the nonuniformly loaded skip.

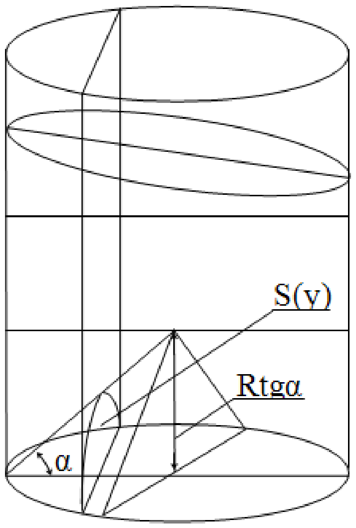


Fig.4. The calculated scheme for definition of shift of the barycenter weights of the loaded skip taking into account conicity of the bottom

$$y_{c_{общ}} = \frac{y_{c_1}M_1 + y_{c_2}M_2 - y_{c_3}M_3}{M_1 + M_2 - M_3}, \tag{9}$$

where M_1 – the mass ofload, kg;

M_2 – the mass of an empty skip, kg. $M_2=M_c$;

M_3 – the mass of load which could be situated in a cylindrical skip on the conic bottom, kg.

y_{c_1} - the calculated ordinate of the barycentre of the bulk load, m;

y_{c_2} - ordinate of the barycentre of the empty skip, m;

y_{c_3} - ordinate of the barycentre of load of conic form which could be situated on the site of the conic bottom, m;

y_{c_2} и y_{c_3} are also equal to zero (for symmetry reasons).

The mass of the load is determined by the formula:

$$M_3 = \rho \frac{1}{3} \pi R^2 R tg\alpha = \frac{\rho \pi R^3 tg\alpha}{3}. \qquad (10)$$

Then

$$y_{c_{общ}} = \frac{-\dfrac{\pi \rho tg\alpha R^4}{4}}{\pi \rho R^2 (h_r - Rtg\alpha) + M_c - \dfrac{\pi \rho R^3 tg\alpha}{3}} = \frac{-\pi \rho tg\alpha R^4}{4\left[\pi \rho R^2 (h_r - Rtg\alpha) + M_c - \dfrac{\pi \rho R^3 tg\alpha}{3}\right]}. \qquad (11)$$

where ρ_c - the surface density of material of a vessel, kg/m^3.

In this way it is so possible to calculate values of the maximal shift of a barycentre of a loaded skip by the formula (11) according to figure 3.7.

$$x^2 + y^2 = \pm z^2. \qquad (12)$$

Knowing the maximal shift of the barycentre it is possible to define the maximal value of reaction of electromagnets of the directing devices to a vertical wall of a skip.

After carrying out analytical researches of barycenter shift value of a loaded skip mass of mine electromagnetic lifting installation for check the reliability of the received theoretical calculations, control calculation of shift of the center of mass of a loaded skip was carried out by method of a simulation modeling.

For simplification the calculations the wall thickness of a skip was accepted equal 5 mm, other input data are based on [2]. To estimate the shift of the center of mass of the loaded vessel, we use a licensed system of the automated projection COMPASS 3D V7 [3,4,5].

The main problem solved by system the COMPASS 3D V7 is modeling operation of products for the purpose of essential reduction of the period of projection and their fastest start in production. In system the COMPASS 3D V7 measurement of various geometrical characteristics, and also calculation of mass-inertial characteristics of model is possible (the volume, weight, coordinate of the center of mass, axial and centrifugal moments of inertia, the direction of principal axes of inertia).

In calculations values of density of materials of details are used. For example as material of the vessel we use Steel of 10 (State standart Specification 1050-88) from the library of the materials COMPASS 3D V7 with density ρ = 7,82 t/m^3. As material of load we use mineral coal with bulk density ρ = 1 t/m^3.

According to the COMPASS program 3D V7 the three-dimensional model of a skip vessel, loaded with coal with nonuniform loading (angle of repose $\alpha = 40^0$) is developed according to Figure 5.

Beforehand the geometrical sizes of a skip, mechanical density of material of the skip, bulk load, load angle of repose were set. For the purpose of achievement of the complete unloading of a lifting vessel, the conicity angle of the bottom of a skip is accepted equal to the angle of repose of the bulk load taking into account fineness and other factors, for example humidity.

Unlike the model assembly of a skip given on Figure 5, the model assembly according to Figure 6 considers conicity of the bottom of the vessel.

According to Figures 5, 6 on the basis of three-dimensional model assembly of the skip of mine electromagnetic lifting installation loaded with coal, in the COMPASS program 3D V the calculation of masso-centering characteristics of a vessel mis performed.

Fig.5.Three-dimensional model assembly of a skip of mine electromagnetic lifting installation, loaded with coal

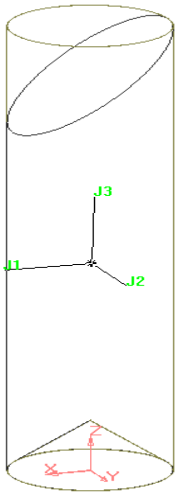
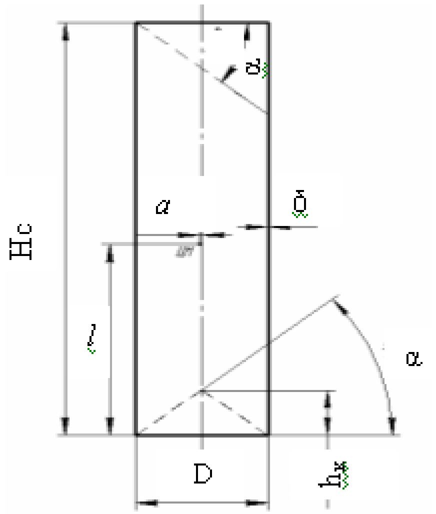


Fig.6.Model assembly of the mine skip loaded coal taking into account conicity of the bottom of the vessel and nonuniform loading of loose load

For each type of the bulk load (coal, ore, rock) it is necessary to accept the value of conicity angle of the bottom, and respectively the skip design for different loads will be different.

Geometrical characteristics of skip vessel section of mine electromagnetic lifting installation correspond to Figure 7.



H_c – skip height; D – diameter of a skip; $h_к$ – skip bottom cone height; a, l – shift of the center of mass; α – angles of repose and a skip bottom cone; δ – wall thickness of a skip

Fig.7. Longitudinal section of a skip

The analysis of results of calculation of mass-center characteristics of a skip, showed that the maximal value of shift of the center of mass of a vessel taking into account nonuniformity of loading in theoretical calculation and the experimtnt studies by methods of simulation modeling are almost identical (the error makes 1,3%).

Calculations for other numerical values of diameter, height, conicity angle of the bottom of a skip of mine electromagnetic lifting installation are perfprmed. Comparison of theoretical and experiment studies, values of shift of the center of mass of a loaded skip, is shown on schedules of dependence of size of shift of the center of mass of a skip taking into account nonuniformity of loading from the size of diameter of a skip. Analytical dependences rather fully define shift of the center of mass of a loaded skip depending on nonuniformity of loading of rock mass. As it was stated above, for simplification of calculations wall thickness of a skip was accepted equal to 5 mm, i.e. the schedule according to figure 8 cannot be accepted as a type sized number of skips.

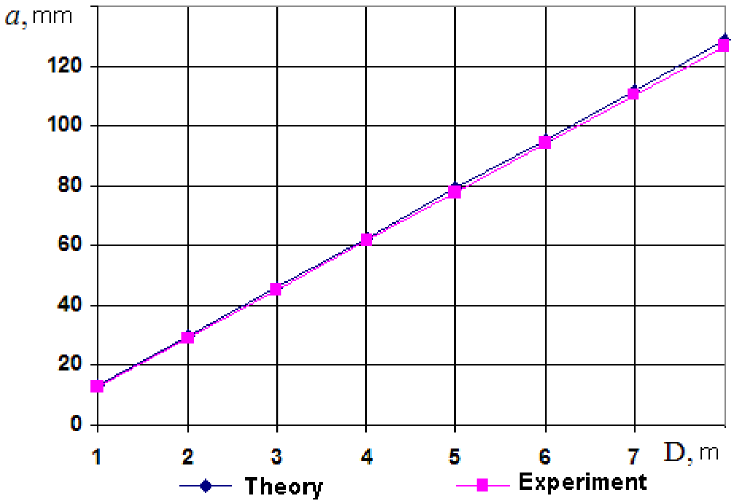


Fig.8. The comparative schedule of shift of the center of mass of a loaded skip taking into account nonuniformity of loading of loose load

It is revealed that, setting the coefficient of container it is impossible to determine the size of wall thickness of a skip as with increase in mass of a skip shift of its center of mass decreases. Respectively the size of the loads operating of skip walls from electromagnets of the directing devices also decrease. We define wall thickness of a skip proceeding from an assessment of the yield values of the loadings operating on a skip during various periods of its work. Results of theoretical and experimental studies according to Figure 8 are given in tables 1, 2.

Table 1 – Calculation of a mine lifting vessel, loaded with coal

Name of parameter	Designation of parameter	Value of parameter							
Диаметр скипа Diameter of a skip	D_c, m	1	2	3	4	5	6	7	8
Hydraulic radius	$R_г$, m	0,25	0,5	0,75	1	1,25	1,5	1,75	2
Height of a mine skip	$h_ш$, m	3,75	7,5	11,25	15	18,75	22,5	26,25	30
Load volume	V_{max}, m^3	2,78	22,45	76,02	180,52	352,94	610,31	969,63	1447,92
Load volume *	$V_α$, m^3	2,46	19,85	67,21	159,58	312	539,49	857,09	1279,84
Sectional area	S_C, m^2	0,785	3,14	7,06	12,56	19,62	28,36	38,46	50,24
The mass of a skip for steel of 5 mm	M_c, т	0,51	2,06	4,64	8,26	12,91	18,59	25,31	33,07
The mass of load, for coal, ρ = 1 t/m^3	$M_п$, т	2,78	22,45	76,02	180,52	352,94	610,31	969,63	1447,92
The mass of load, for coal, ρ = 1 t/m3 *	$M_{пα}$, т	2,46	19,85	67,21	159,58	312	539,49	857,09	1279,84
Shift of the center of mass of a skip (theory)	a, mm	13,66	29,81	46,14	62,53	78,93	95,35	111,77	128,19
Shift of the center of mass of a skip (experiment)	a, mm	13,18	29,17	45,33	61,54	77,77	94	110,25	126,5

Table 2 – Calculation of a mine lifting vessel, loaded with ore

Name of parameter	Designation of parameter	Value of parameter							
Диаметр скипа Diameter of a skip	$D_с$, m	1	2	3	4	5	6	7	8
Hydraulic radius	$R_г$, m	0,25	0,5	0,75	1	1,25	1,5	1,75	2
Height of a mine skip	$h_ш$, m	3,75	7,5	11,25	15	18,75	22,5	26,25	30
Load volume	V_{max}, m^3	2,78	22,45	76,02	180,52	352,94	610,31	969,63	1447,92
Load volume *	$V_α$, m^3	2,46	19,85	67,21	159,58	312	539,49	857,09	1279,84
Sectional area	S_C, m^2	0,785	3,14	7,06	12,56	19,62	28,36	38,46	50,24
The mass of a skip for steel of 5 mm	$M_с$, т	0,51	2,06	4,64	8,26	12,91	18,59	25,31	33,07
The mass of load, for coal, ρ = 1 t/m^3	$M_п$, т	5.56	44.9	152.04	361.04	705.88	1220.62	1939.26	2895,84
The mass of load, for coal, ρ = 1 t/m3 *	$M_{пα}$, т	4,92	39,7	134,42	319,16	624	1078,98	1714,18	2559,68
Shift of the center of mass of a skip (theory)	a, mm	14,92	31,27	47,68	64,1	80,52	96,96	113,39	129,82
Shift of the center of mass of a skip (experiment)	a, mm	14,43	30,61	46,84	63,09	79,34	95,59	111,85	128,11

Thus, the area of the maximal shift of the loaded skip barycentre taking into account the conicity of the bottom is received analytically and confirmed with methods of simulation modeling. It allows to determine the value of reaction of electromagnetic forces of electromagnets of electromagnetic lifting installation.

This article is written on the basis of results of the researches which are carried out within grant financing of the Ministry of Education and Science of the RK on a subpriority of "Technology of mineral development", on the subject "Justification and Development of Energy Saving Technology of Dredging of Mined Mass by Creation of Electromagnetic Lifting Installation".

REFERENCES

1. Lizin V.G., Pyatkin V.A. *Projection of thin-walled designs.* Moscow, Mechanical engineering, 1976, 408p.
2. Bratchenko B. F. *Stationary installations of mines*. Moscow, Nedra, 1977, 440 p.
3. Potemkin A.E. *Solid-state model operation in KOMPAS-3D system: scientific publication*. St. Petersburg, 2004, 502 p.
4. Kudryavtsev E.M. *KOMPAS-3d V6. Bases of work in system: scientific publication*. Moscow, 2004, 527 p.
5. Kudryavtsev E.M. *KOMPAS-3d V7. The fullest manual: scientific publication*.Moscow, 2006, 662 p.

Article accepted for publication 24.10.2014