ELECTRICITY EFFICIENCY OF A SEMI-AUTOGENOUS MILL INVESTIGATION

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ABSTRACT This paper discusses a semi-autogenous ore grinder. A software product is considered, which makes it possible to study data by using the polynomial model for interpolation. The input-output data related to the grinding process are collected, processed and analyzed. The purpose is to find the relationship between the power of the electric motor and the amount of ore at different openings of the grids of the unloading cover of the mill and to find the optimal mode of operation of the mill.

Keywords: Electricity efficiency, Semi-autogenous mills

ИЗСЛЕДВАНЕ НА ЕЛЕКТРОЕНЕРГИЙНАТА ЕФЕКТИВНОСТ НА ПОЛУАВТОГЕННА МЕЛНИЦА

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РЕЗЮМЕ. В тази статия е разгледана полу-автогенна мелница за смилане на руда. Разгледан е софтуерен продукт, който дава възможност,за изследване на данни, чрез използването полиномния модел за интерполация. Събрани, обработени и анализирани са входно-изходните данни, свързани с процеса на смилане. Целта е да се намери връзка между мощността на електродвигателя и количеството руда при различни отвори на решетките на разтоварващият капак на мелницата и да се намери оптималният режим на работа на мелницата.

Ключови думи: електроенергийна ефективност, полуавтогенни мелници, решетки

Introduction

In modern production conditions in the mining industry, in addition to ball mills, as the most used method for changing the particle size, grinding or mixing materials, semi-autogenous mills are widely used. Semi-autogenous mills grind the ore by rotating the drum of the mill, which raises the ore to a certain height. Lifters located in the inner surface of the mill help to lift. After lifting the material (ore), it goes into the mode of free flight, beginning to fall below its own weight. When falling, the material is crushed by parts grind. Semi-autogenous machines and the grinding medium, which is most often in a spherical shape (balls), which help grind (Tsvetkov, 1988, Minin, 2012).

Semi-autogenous grinding extends to many applications due to the range of available mill sizes. They can do the same job of reducing ore size as rod and ball mills in two or three stages of crushing and sieving. Semi-autogenous mills are also the optimal solution for wet grinding, as crushing and sieving can in some cases be difficult at other mills, if not impossible (Timm, 2011).

This article collects, processes and analyzes input-output data related to the grinding process, as well as the operation of the electric motor crushing mill. The aim is to study the ratio of energy consumption to process values in unloading lining of the mill with hole sizes of 23 mm and unloading lining with hole sizes of 25 mm. For this purpose, measurements performed on a mill type SAG 8.5 x 5.3 m are used (Minin, 2014).

Description of the software

MatLab is a dialog program system for conducting scientific and technical calculations. It integrates the possibilities for analytical transformations, numerical calculations and graphical presentation of the obtained results. It is oriented to work with data arrays - vectors, matrices, multidimensional arrays, arrays of cells and arrays of records. Hence the name MatLab - Matrix LABoratory. This allows a single operator to perform simultaneous actions on all elements of the array, without the need to organize loops. The system has built-in functions that solve basic problems in linear algebra, numerical analysis, experimental data processing, two-dimensional and three-dimensional graphics, animation and more. The most used areas of application of MatLab are:

- Mathematical and computer calculations;
- Development of algorithms;
- Computational computer experiments;
- Simulation modulation;
- Computer data analysis;
- Research and visualization of data;
- Scientific and engineering graphics;

Development of applications including graphical user interface. As a tool for computer modeling, which provides research in virtually all known fields of science and technology.

Another feature of the software that is used is the input of data from Excel, which are downloaded from the monitoring and data collection system PI.

Principles of the grinding process

The grinding process in semi-autogenous mills can be considered as a process of increasing the total particle area of the digestible material. This is done by reducing the particle size due to the collision with the grinding bodies and the subsequent crushing and grinding of the material. The kinetic energy of the grinding medium depends on the rotation speed of the mill and the mass of the grinding bodies, and in terms of rotation speed three main modes of operation are possible: cascade, waterfall, centrifugation. The effective operation of drum mills depends on the nature of the movement of the digestion medium.

Cascading: The charge is lifted to then roll to the toe of the charge. This occurs at lower speeds and results in mainly attrition and abrasion grinding regimes. When the mill operates in cascade mode, productivity is low, so this mode is rarely used.

Cataracting: The charge is lifted and thrown to the toe of the charge. This occurs at higher speeds and results in predominantly impact breakage. Grinding is done mainly by impact and partly by grinding. This is the most common mode in practice.

In practice, the charge motion is a combination of cascading and cataracting to achieve all three principle types of grinding. For variable speed drive mills, the shell speed can be adjusted to promote effective impact breakage at the toe of the charge. The optimum speed for a given mill load allows for direct contact between the cataracting charge and toe of the charge. If the speed is too low, cataracting conditions may not be created. If the speed is too high, the cataracting grinding media may impinge directly onto the liners, potentially cracking balls and seriously damaging liners.

For grate discharge mills, the total charge level can be variable as compared to the constantly full nature of overflow mills. As such, measurement of the total charge is important and is achieved via the installation of load cells under one of the trun-nions.

As for mill speed, the total charge level must be optimized to promote effective impact breakage at the toe of the charge. Underloaded or overloaded mills behave similarly to mills op-erating at too fast or too slow shell speeds, respectively. Correct total charge conditions also expose sufficient grate area for slurry to be effectively pumped from the mill.

When the angular velocity of the mill becomes so high that it exceeds the critical one

and for the innermost layer of balls, the entire ball filling is distributed evenly over

the periphery of the drum and begins to move with it. This mode is called flywheel mode.

The semi-autogenous mills are unloaded through grids (fig. 1) with a certain size X and the ratio of the diameter and their length is medium to high. The grain size of the source material, the circulating load and the amount of feed ore to the mill depend on the grids.

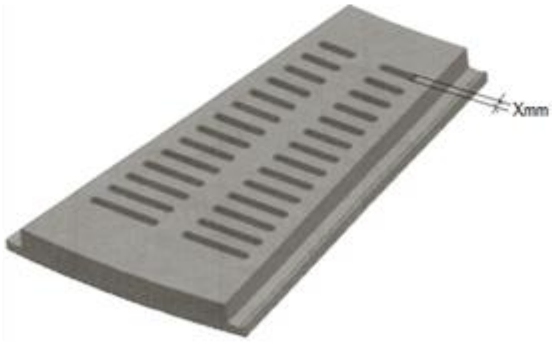

Fig. 1. Unloading grid

Conducting the Experiment and Collecting Data

The data required for the present study were obtained from a monitoring and data collection system PI. They cover the period from 11.12.2019 to 24.07.2020. The measured parameters are shown schematically in (fig. 2).

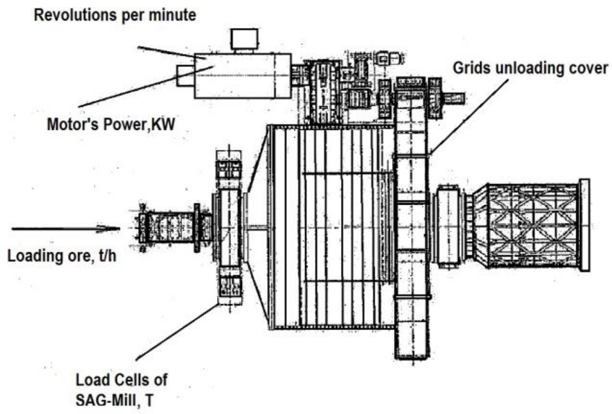

Fig. 2. Scheme of a semi-autogenous mill

Results of measurements of the main parameters influencing the value of motor power

The obtained results from the measurements are averaged over one hour and are shown in (table 1), covering every day of the period - installation of a new lining of the cylinder and grids with holes' s size X = 23 mm on 11.12.2019 - until the change of grids on 29.03. 2020 and (table 2), from the period-work with grids on the unloading cover with the size of the holes X = 25 mm and installation of a new lining of the cylinder on 03.05.2020 to 24.07.2020

The first column of the table shows the day of the measurement; the second column is hour. The third column records the average hourly values of the motor power. The following columns record the average hourly values of the motor speed, the load cell of the mill and the amount of incoming ore.

Table.1. *Measured during the operation of a semi-autogenous mill, I at dimensions X = 23mm for opening the grids of unloading cover.*

Date	Time	Motor's stator	Revolution, (min-1)	Load Cells SAG Mill, (t)	Ore feed in SAG Mill ,(t)
12/11/2019	12:15:00 PM	4981.32854	1093.75948	75.8351524	0.05425353
12/14/2019	4:15:00 AM	1998.87227	372.499721	87.5192693	0.05425353
12/14/2019	5:15:00 AM	3755.25383	887.858583	88.3816083	0.05425353
12/14/2019	6:15:00 AM	4735.74578	995.390315	90.9309222	0.05425353
12/14/2019	7:15:00 AM	4641.80828	1000.36478	89.4022953	0.05425353
12/14/2019	8:15:00 AM	4235.3366	976.168898	88.5727039	0.05425353
12/14/2019	9:15:00 AM	4216.77156	962.011046	91.8758733	0.05425353
12/14/2019	10:15:00 AM	4691.09768	1000.00631	94.3464637	0.05425353
12/14/2019	11:15:00 AM	4679.81729	999.348534	93.5625713	0.05425353
12/14/2019	12:15:00 PM	4825.44993	999.608526	93.8173708	0.05425353
12/14/2019	1:15:00 PM	4612.44206	999.73862	94.7911541	0.05425353
12/14/2019	2:15:00 PM	4603.39886	1000.11188	93.6777951	0.05425353
12/14/2019	3:15:00 PM	4542.51509	1000.11331	92.6615897	0.05425353
12/14/2019	4:15:00 PM	4554.02466	999.517553	92.2629581	0.05425353
12/14/2019	5:15:00 PM	4518.17907	999.322721	93.2684463	0.05425353
12/14/2019	6:15:00 PM	4665.01727	999.387167	95.7261337	0.05425353
12/14/2019	7:15:00 PM	4378.21014	999.13111	93.9649615	0.05425353
12/14/2019	8:15:00 PM	4345.21203	999.302426	92.9054474	0.05425353
12/14/2019	9:15:00 PM	4315.38887	999.286543	91.8464863	0.05425353
12/14/2019	10:15:00 PM	4330.90401	999.366353	91.9721745	0.05425353
12/14/2019	11:15:00 PM	4431.30586	999.602915	92.8343761	0.05425353
12/15/2019	12:15:00 AM	4447.29388	999.35169	92.4329555	0.05425353
12/15/2019	1:15:00 AM	4424.84194	999.689235	92.7187536	0.05425353
12/15/2019	2:15:00 AM	4488.91668	999.226784	93.377018	0.05425353
12/15/2019	3:15:00 AM	4509.39188	999.706925	92.7109154	0.05425353
12/15/2019	4:15:00 AM	4540.50769	999.520069	93.2415222	0.05425353
12/15/2019	5:15:00 AM	4652.13123	998.751599	94.3883338	0.05425353
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3/28/2020	3:15:00 PM	5035.82424	998.944933	83.718898	196.939333
3/28/2020	4:15:00 PM	4919.11997	998.670465	82.4335167	172.773774
3/28/2020	5:15:00 PM	4680.99048	987.72397	81.8188468	198.093953
3/28/2020	6:15:00 PM	4961.0612	974.15606	82.5039658	268.95435
3/28/2020	7:15:00 PM	5353.24226	999.102381	84.285327	233.253157
3/28/2020	8:15:00 PM	5284.3748	999.022975	83.7101525	250.713953
3/28/2020	9:15:00 PM	5343.40655	999.142292	83.9420467	240.252062
3/28/2020	10:15:00 PM	5304.588	999.016433	83.7130983	242.376537
3/28/2020	11:15:00 PM	5348.77576	998.741871	84.0893812	249.344618
3/29/2020	12:15:00 AM	4921.26015	986.373423	81.9527649	202.947724
3/29/2020	1:15:00 AM	4982.30901	992.034893	82.3423554	228.95965
3/29/2020	2:15:00 AM	5050.50219	998.97055	82.3614841	224.122808
3/29/2020	4:15:00 AM	4962.97676	995.364841	82.150314	225.189842
3/29/2020	5:15:00 AM	5119.51982	995.24346	82.7308403	195.355891
3/29/2020	6:15:00 AM	5148.65635	999.035425	83.0627596	189.746784
3/29/2020	7:15:00 AM	5185.45685	998.743416	82.9676871	251.319545
3/29/2020	8:15:00 AM	5068.1658	998.709547	84.020514	250.068831
3/29/2020	9:15:00 AM	5041.66659	998.627479	82.642305	261.765735
3/29/2020	10:15:00 AM	5311.47087	998.90686	83.5996484	259.473669
3/29/2020	11:15:00 AM	5307.27039	999.090831	84.595343	241.529223
3/29/2020	12:15:00 PM	5046.00434	998.840892	82.6369958	262.829804
3/29/2020	1:15:00 PM	4792.59863	998.731102	81.7334712	275.322305
3/29/2020	2:15:00 PM	5228.71355	998.853542	83.1570415	265.628276
3/29/2020	3:15:00 PM	5268.26931	998.848989	83.4777883	258.565337
3/29/2020	4:15:00 PM	5098.43237	999.011702	82.6326041	258.457278
3/29/2020	5:15:00 PM	5340.48781	998.964607	83.8909183	263.679383
3/29/2020	6:15:00 PM	5459.16937	998.84746	85.0418499	249.635751
3/29/2020	7:15:00 PM	4980.80273	998.471833	82.0938328	245.013521
3/29/2020	8:15:00 PM	4860.52185	992.692473	81.2301569	234.980913
3/29/2020	9:15:00 PM	4986.39967	998.809272	81.8433984	240.244693

Table 2. *Measured during the operation of a semi-autogenous mill, I at dimensions X = 25mm for opening the grids of unloading cover.*

Data	Time	Motor's stator	Revolution, (min-1)	Load Cells SAG Mill, (t)	Ore feed in SAG Mill, (t)
4/10/2020	12:15:00 AM	5221.36535	1013.42233	82.0606701	177.260677
4/10/2020	1:15:00 AM	4916.69084	1010.32498	81.861611	182.219455
4/10/2020	2:15:00 AM	3950.32581	904.661892	78.8836192	219.56048
4/10/2020	3:15:00 AM	4943.91229	943.113882	84.5226746	240.473118
4/10/2020	4:15:00 AM	5255.97613	1013.73626	84.3407097	257.069658
4/10/2020	5:15:00 AM	5245.60167	1013.59319	83.8106956	268.728345
4/10/2020	6:15:00 AM	5101.36191	1013.71432	83.5491268	268.733561
4/10/2020	7:15:00 AM	3634.40281	762.8746	82.1471584	167.100927
4/12/2020	1:15:00 AM	624.313166	155.091078	79.9593529	35.276039
4/12/2020	2:15:00 AM	4038.31401	872.822353	81.2865226	291.510145
4/12/2020	3:15:00 AM	4818.67484	936.911757	83.1277503	251.635697
4/12/2020	4:15:00 AM	4548.96129	943.443172	81.2448139	271.107035
4/12/2020	5:15:00 AM	3986.05351	877.853505	80.8766088	276.167817
4/12/2020	6:15:00 AM	4371.63583	889.826995	83.1351383	257.613452
4/12/2020	7:15:00 AM	4976.75723	961.729795	82.8479638	259.273603
4/12/2020	8:15:00 AM	5058.53372	976.812153	82.0548901	235.733872
4/12/2020	9:15:00 AM	4956.73066	969.854999	81.2685204	173.008275
4/12/2020	10:15:00 AM	4672.43039	923.28552	81.7390312	158.360012
4/12/2020	11:15:00 AM	5110.31161	953.67778	83.1368479	156.316223
4/12/2020	12:15:00 PM	5403.5203	1007.71582	82.6006832	155.760099
4/12/2020	1:15:00 PM	5464.68382	1013.35359	82.4304799	154.278832
4/12/2020	2:15:00 PM	5323.45532	1009.98868	81.8300113	223.998773
4/12/2020	3:15:00 PM	5024.5378	975.383811	81.2393829	234.569044
4/12/2020	4:15:00 PM	5064.49905	962.744157	82.2983138	231.692266
4/12/2020	5:15:00 PM	5062.7518	979.586337	82.1648445	234.557167
4/12/2020	6:15:00 PM	4953.57394	968.444647	81.5620241	190.606345
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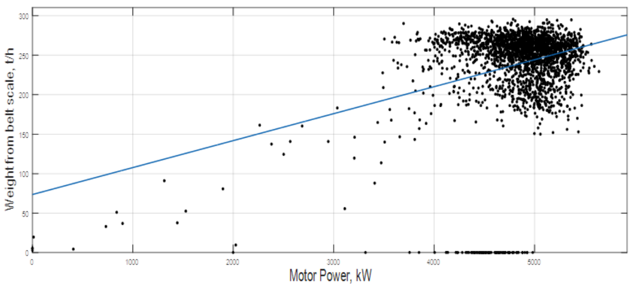
...					
7/23/2020	4:15:00 PM	4849.91774	928.19952	86.7339391	293.382214
7/23/2020	5:15:00 PM	4955.10159	965.352225	85.0732896	286.835014
7/23/2020	6:15:00 PM	4538.92611	940.853808	84.1431337	291.720608
7/23/2020	7:15:00 PM	3947.90157	889.007109	82.425296	216.470838
7/23/2020	8:15:00 PM	3822.95279	867.947049	81.6385381	298.305039
7/23/2020	9:15:00 PM	4431.27777	891.520427	85.4415935	291.392028
7/23/2020	10:15:00 PM	4574.42136	915.388489	85.1744899	292.375529
7/23/2020	11:15:00 PM	4651.62195	925.250635	85.133078	290.902096
7/24/2020	12:15:00 AM	4325.32688	894.772105	84.3612661	282.452611
7/24/2020	1:15:00 AM	4948.63187	938.617017	86.5583461	295.006411
7/24/2020	2:15:00 AM	4993.84176	975.285173	84.6544527	290.232079
7/24/2020	3:15:00 AM	4697.8022	941.525234	84.4780017	293.217976
7/24/2020	4:15:00 AM	4675.11886	931.8373	85.1847261	292.256413
7/24/2020	5:15:00 AM	5009.81323	956.592376	85.8235175	290.841973
7/24/2020	6:15:00 AM	5315.00258	996.966546	86.3018428	293.393837
7/24/2020	7:15:00 AM	5102.79698	997.490243	85.3109624	290.862992
7/24/2020	8:15:00 AM	5068.68374	982.917879	84.8697449	289.177754
7/24/2020	9:15:00 AM	4500.45274	965.371888	83.2967888	274.738602
7/24/2020	10:15:00 AM	3641.27444	869.07113	81.8928033	290.24497
7/24/2020	11:15:00 AM	4335.56098	875.884505	85.3955506	290.292388
7/24/2020	12:15:00 PM	5020.15294	949.141082	86.3285851	275.56469
7/24/2020	1:15:00 PM	5151.76474	982.88658	85.191256	290.623709
7/24/2020	2:15:00 PM	5045.71506	982.377445	84.7333025	291.471446
7/24/2020	3:15:00 PM	4993.96264	969.27835	84.7718216	294.313256
7/24/2020	4:15:00 PM	4847.64222	952.177783	84.7385717	291.052048
7/24/2020	5:15:00 PM	4695.63518	940.824656	84.7167837	294.353312
7/24/2020	6:15:00 PM	3957.49302	900.1514	83.2809808	242.001773
7/24/2020	7:15:00 PM	3830.83256	867.379109	81.8436054	199.762501
7/24/2020	8:15:00 PM	4023.194	867.250112	83.1192581	161.674442
7/24/2020	9:15:00 PM	4161.72057	867.219406	83.8872701	169.285251
7/24/2020	10:15:00 PM	4865.56104	916.593997	86.7520972	249.781302

Analysis of the obtained results

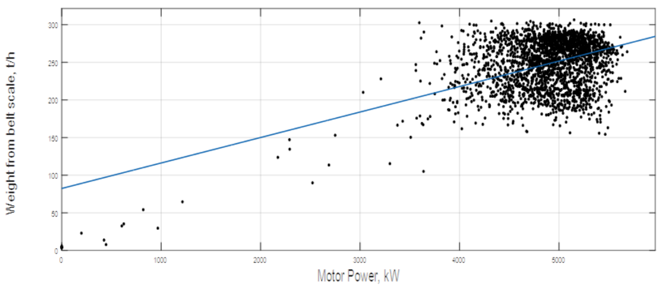
The analysis of the obtained results allows research, using the polynomial model for interpolation and quantitative measurement of dependence through the correlation coefficients and determination of the measured power of the electric motor to the productivity of the mill by the amount of incoming ore per unit time, motor speed, mill load cell during mill operation with two different sizes of gratings on the unloading cover.

After processing the input - output data from the software shown in (fig. 3a and b) there is a lower consumption for processing the amount of incoming ore per unit time when operating the mill with gratings with holes 25mm, but the total amount of energy consumed with gratings with holes 25mm is higher comparing the two reported periods, as the amount of processed ore is bigger. The correlation coefficient r of both scatter plots is 0.3 ÷ 0.5, which makes the relationship moderate.



R-square: 0.09502

a) relationship on the sizes of holes of the gratings 23 mm

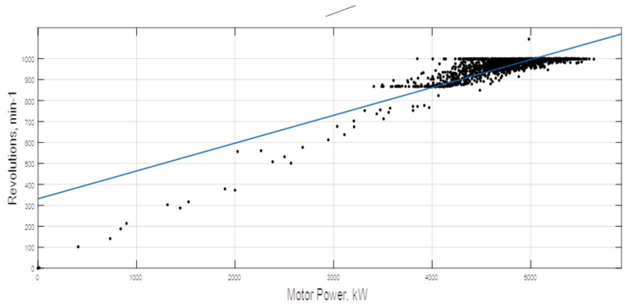


R-square: 0.2533

b) relationship on the sizes of the holes of the gratings 25 mm

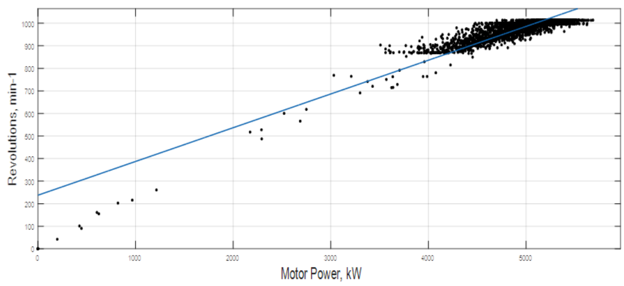
Fig. 3. Relationships between the measured power of the electric motor and the amount of ore entering the mill per unit time

On (fig. 4a and b) show the relationships between the motor power and the motor speed. The same energy consumption is observed at the same motor revolutions at the different holes of the grids. This is due to the automatic control of the motor speed by the load cell of the mill. The correlation coefficient r in both graphs is 0.7 ÷ 0.9, which makes the relationship strong.



R-square: 0.754

a) relationship on the sizes of holes of the gratings 23 mm

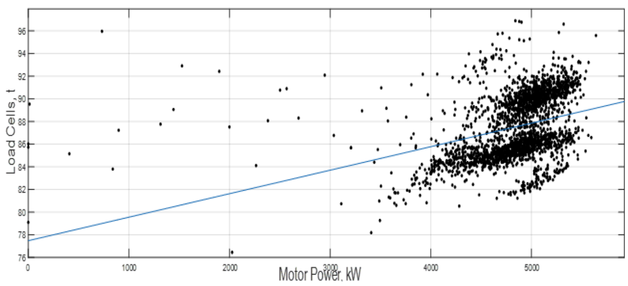


R-square: 0.843

a) relationship on the sizes of holes of the gratings 23 mm

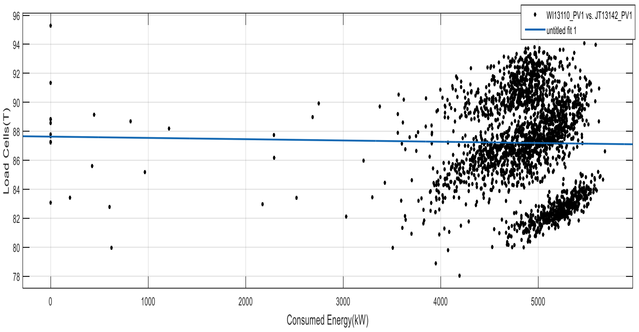
Fig. 4. Relationships between measured power and motor speed

From the scatter plots shown in (Fig. 5b), it can be seen that no correlation between the motor power and the load cell during the operation of the mill with unloading grids 25 mm. The correlation between the motor power of an ore mill with 23 mm unloading grids is positive. As the load cell increases, the energy consumed increases. The most optimal weight of the load cell is 92-94 t. The correlation coefficient of the scatter plots (Fig. 5a) is r = 0.34, which makes the relationship weak.



R-square: 0.1205

a) relationship on the sizes of holes of the gratings 23 mm

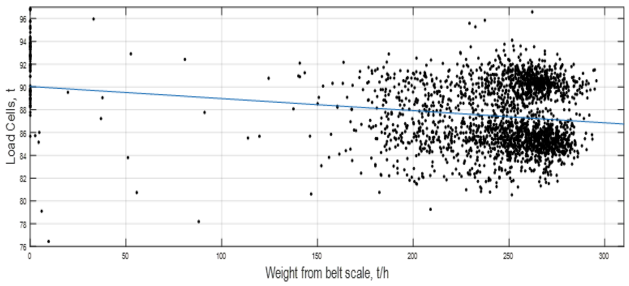


R-square: 0.0002272

b) relationship on the sizes of the holes of the gratings 25 mm

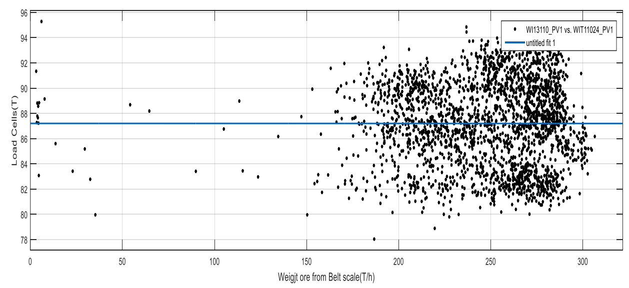
Fig. 5. Relationship between the measured power of the electric motor and the load cell of the mill

The relationship between the measurement results (Fig. 6a) is very weak. The relationship with the dimensions of the openings of the gratings 23 mm (Fig. 6b), r = -2.53e-04, which makes it negative and with very weak dependence. The reason is the large openings in the gratings of the unloading cover of the mill, which leads to a reduction in the time of passage of the ore in the mill.



R-square: 0.03895

a) relationship on the sizes of holes of the gratings 23 mm



R-square: 6.419e-08

b) dependence on the sizes of the holes of the gratings 25 mm

Fig. 6. Relationships between the measured amount of ore entering the mill and load cell of the mill

Conclusion

In conclusion, the following conclusions can be drawn:

1. The power of the electric motor to the feed ore to the mill has 25 mm larger grid holes than the 23 mm grid sizes. This is due to the faster passage of the ore through the unloading cover, which allows higher processing.
2. With larger openings of the grids there is no relationship between the power of the electric motor and the load cell of the mill. With the grids with openings 23 mm we see a very weak connection, but still allows to use a correlation relationship.
3. No relationship is observed between the incoming ore in and the load cell of the mill in both types of grids.
4. The most cost-effective operation of the mill in terms of energy used in grinding the ore is setting a weight of more than 90 tons reported by the load cell of the mill. This is observed when operating the mill with both types of grids on the unloading cover

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