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NEW APPROACH TO INCREASING THE VERTICAL CONVEYANCE CAPACITY THROUGH TRANSPORT CYCLE MODIFICATION

NOWA METODA ZWIĘKSZENIA WYDAJNOŚCI PRACY URZĄDZEŃ TRANSPORTU PIONOWEGO POPRZEZ MODYFIKACJĘ CYKLU JAZDY URZĄDZENIA

Scientific research discussed in the present article is focused on the determination of the vertical conveyance capacity in the process of mining minerals, while applying a mathematical calculation and verification of the calculation results by simulation. Input parameters for the capacity calculation include the transport cycle time. The article presents the results of measuring a transport cycle during the operation and a calculation of the transport cycle while using known formulas. On the basis of the observed findings, two methods of increasing the hoisting machine capacity were proposed. The first method is increasing the velocity from the original value of 6 m.s^{-1} to the velocity of 7 m.s^{-1}. In this case, we achieved the daily capacity increase in 2-2.5%. The second method consisted in changing the hoisting machine acceleration and deceleration modes by which we achieved as much as 9% increase in the daily capacity. The article also describes a transport cycle simulation model, with its output being the number of work cycles parameter. The obtained parameter was used again in the capacity calculation. The simulation model was used in experiments for both, the current status as well as proposed solutions. The simulation model serves also for calculation verification.

Keywords: vertical conveyance, hoisting machine, capacity, transport cycle, travel diagram, simulation

Badania opisane w niniejszym artykule dotyczą określania i identyfikacji wydajności pracy instalacji transportu pionowego w ramach całościowego procesu wydobycia kopalin przy wykorzystaniu obliczeń matematycznych i weryfikacji wyników obliczeń poprzez symulacje. Wśród parametrów wejściowych wykorzystywanych do obliczeń wydajności pracy uwzględniono czas trwania cyklu jazdy urządzenia. W artykule przedstawiono wyniki pomiarów czasu cyklu jazdy dokonanych na urządzeniu rzeczywistym, zaś obliczenia dla cyklu jazdy wykonano w oparciu o ogólnie znane wzory. Na podstawie wyników pomiarów zaproponowano dwie metody zwiększania wydajności pracy urządzenia wyciągowego. Metoda pierwsza polega na zwiększaniu prędkości podnoszenia, z wartości początkowej 6 ms^{-1} do 7 ms^{-1}; w rezultacie

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uzyskując w skali dziennej wzrost wydajności o 2-2.5%. Druga metoda polegała na zmianie wartości przyspieszenia i opóźnienia (hamowania); uzyskany w ten sposób wzrost wydajności pracy urządzenia wynosi 9%. W pracy przedstawiono także model do symulacji cyklu jazdy urządzenia wyciągowego, parametrem wyjściowym modelu była liczba cykli jazdy. Otrzymaną wartość tego parametru wykorzystano następnie do obliczeń wydajności pracy urządzenia. Model symulacyjny następnie wykorzystano do przeprowadzenia eksperymentu uwzględniającego zarówno stan obecny urządzenia wyciągowego i jego wydajność, a także proponowane rozwiązania. Powyższy model symulacyjny wykorzystany został także do weryfikacji obliczeń.

Słowa kluczowe: urządzenie transportu pionowego, urządzenie wyciągowe, wydajność pracy, cykl jazdy, schemat procesu podnoszenia, symulacja

1. Introduction

Mining industry is still the only supplier of mineral resources, both metals, coal and other useful mineral substances. Vertical conveyance is used to remove excavated materials, deliver materials, machinery and equipment required for the mining process and related activities, as well as the transportation of persons. This mode of transport is most frequently carried out in underground mines in form of a hoisting machine. Hoisting installations in mines have been constructed and operated for many years, yet they still merit a rigorous research to identify all factors that would enable us to improve their performance parameters (Wolny & Badura, 2012). Operational life of a hoisting machine is a very important part of transport logistics in every mining company (Despodov & Panov, 2015). Hoisting machines can be categorised from several systemic perspectives. For the purpose of the present article, we present the categorisation by the maximum rated velocity (Marasová & Šaderová, 2017); the category of large hoisting machines with the rated velocity above 3 $m.s^{-1}$ and the category of small hoisting machines with the rated velocity below 3 $m.s^{-1}$. In terms of the conveyance method we distinguish between single-acting hoisting machines – only a single cage is suspended on the rope, and double-acting machines that use two cages in the operation; the latter are used much more frequently. Single-acting hoisting machines, as compared to double-acting hoisting machines, have only half the capacity of the latter. Issues regarding the hoisting machine capacity were dealt with already in 1949 by J.F. Reid in his article, discussing the improvements required to achieve the desired increase in the capacity of a particular hoisting machine (Reid, 1949).

Hoisting machines consist of several structural components, such as drums, sheaves, steel wire ropes, skips, and others that affect their capacity. When designing a hoisting machine, current global manufacturers of hoisting machines use new calculation methods and introduce new construction approaches – design. Designing mechanical parts of hoisting machines begins with proposing hoisting machine parameters (identification of an appropriate machine type, calculation of its basic parameters, mining capacity, transport velocity, required output, etc.). For this purpose, manufacturers use special computer software enabling creation of several optimisation alternatives. This is followed by the construction section – strength calculations made while applying the finite element method with graphical visualisation of results and preparation of technical documentation in AutoCAD and Inventor software (Zach, 2014).

Vertical conveyance issues are discussed in several publications and articles. Some of them include chapters focused on general characteristics of vertical conveyance. Number of publications deal with the issues of structural components, such as drums, friction pulleys (Wolny & Badura, 2012), sheaves (Grobler, 2005; Dumitrescu et al., 2015), brakes (Kowal et al., 2012; Ungureanu et al., 2017a) and drives (Tiley, 1993), cages (skips) and hoist steel wire ropes (Stanova et al., 2015; Šaderová, 1997). Some authors describe hoisting machines used in practice (Despodov et al., 2012; Johansson, 2005), some deal with safety issues (Hayes, 2011) and maintenance (Vayenas & Wu, 2011), others evaluate engagement of vertical conveyance in comparison with other available conveyance systems, e.g., conventional shaft hoisting and flexowell vertical belt applications (Gonen at al., 2012), vertical shaft and a ramp system (Elevli et al., 2002). Authors also present modernisation and reconstruction of existing hoisting machines (Despodov & Panov, 2015; Wang, 2014). Majority of articles are highly specialised, they deal with detailed problems of hoisting machines: a model of longitudinal vibrations of mine hoist, treated as a discrete-continuous system is formulated (Tejszerska, 1997), research focused on tribological aspects of hoisting machine brakes (Ungureanu & Ungureanu, 2017b), modelling and simulation of hoisting machine forces (Popescu, 2015), the selected aspects of the dynamic behaviour of mine hoists during the emergency braking phase (Wolny, 2017), Schubert`s paper describes factors that are recognised to have influence on rope life and suggests definition of new design criteria for friction winders in order to get viable solutions for high-capacity hoisting from deep mines similar to drum hoisting (Schubert, 2005), quality assessment (Marasová & Boroška, 2001), inspection and service life of hoist steel wire ropes (Peterka et al., 2014). The literature review above indicates that authors deal with specific problems related mainly to vertical conveyance system components. Capacity issues are discussed very rarely and only at the theoretical level, through conventional calculations and without the use of a particular simulation system. It is therefore reasonable to discuss these issues and develop them, while implying also clear scientific benefit.

Research discussed in this article is focused on the determination of vertical conveyance capacity while applying two approaches. The first one – a conventional one, is a calculation of capacity while using known mathematical formulas (Šaderová & Marasová, 2017). The second one – an experimental approach, identifies the capacity on the basis of simulation application, as the simulation has remarkable potential also in terms of further research in the given area (Straka, 2017).

The created simulation model has several functions. The first function mentioned above is that the output from the model (number of transport cycles) serves as the basis for the capacity determination. The second function is the verification – it serves for the verification of results obtained by calculation. A function of equal importance is a visual side of the entire model in a particular simulation system, enabling identification of potential deficiencies of the entire system.

The main emphasis of the research, within both, the first and the second approach, is put on the parameter "transport cycle time" which significantly affects the capacity. Transport cycle time depends on the velocity and the acceleration and deceleration methods.

On the basis of the results of calculations and simulation, it was proposed to increase vertical conveyance capacity by changing selected parameters (velocity, acceleration mode). Such design was carried out again by a conventional method and verified by simulation.

2. Methodology

The issues regarding increasing the vertical conveyance capacity were dealt with on the basis of the transport cycle time, while applying the procedure consisting of the several steps. The sequential steps are described in individual chapters. A formalised scheme of the work cycle is shown in Fig. 1 and will serve as the basis for the creation of a simulation model.

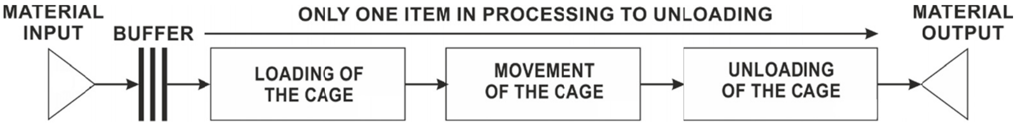


Fig. 1. Formalised work cycle scheme

2.1. Measuring of the transport cycle time

Measurement of the transport cycle during the operation was carried out while applying one of the time study methods, particularly the "Multiple Activity Chart". Multiple Activity Chart is the method of measuring working times of regularly repeated operations or sections thereof (actions). The purpose of such chart is to obtain the information on the average real consumption of time to perform each section of the operation. To achieve reliable data, the activity chart must be carried out repeatedly to exclude accidental circumstances. The Multiple Activity Chart is carried out in several stages: Preparation for monitoring and measurements, Observation, measurements, and recording of measured values and Processing and analysis of measured times. (Kováč & Szombathyová, 2010).

2.2. Calculation of the transport cycle time by calculation

Conveyance carried out using a hoisting machine is cyclical conveyance. The total time of the work cycle T_w is calculated in compliance with the travel diagram of the hoisting machine.

The travel diagram shows the course of the cage movement during the transport cycle T_t. A single work cycle consists of several time intervals (Šaderová & Marasová, 2017):

t_1 acceleration time (accelerated movement) in seconds (s),
t_2 uniform motion time (uniform movement) in seconds (s),
t_3 deceleration time (decelerated movement) in seconds (s),
t_4 cage loading and unloading times in seconds (s),
t_5 cage adjustment time (in multi-deck cages) in seconds (s),
t_6 down-times in seconds (s).

Transport cycle time or travel time is determined as the sum

$$T_t = t_1 + t_2 + t_3 \tag{1}$$

Total time of one work cycle is determined by formula

$$T_w = T_t + t_4 + t_5 + t_6 \tag{2}$$

Transport velocity cannot be chosen arbitrarily. A decisive parameter affecting the velocity in mining is the pit depth. Mining velocity should not exceed its maximum value determined by formula:

$$v_{\max} = 0{,}8\sqrt{D} \tag{3}$$

where D is the pit depth in metres.

Movement of cages in a pit are subjected to general kinematic relationships between the time, route, velocity, acceleration, or deceleration. In terms of acceleration, hoisting machines are divided into (Marasová & Šaderová, 2017):

(A) machines with constant acceleration – linear acceleration,
(B) machines with variable acceleration,
    a) parabolic acceleration,
    b) semiparabolic acceleration,
    c) cubic acceleration.

Acceleration with linear acceleration is characteristic with constant acceleration during the entire acceleration time. In the parabolic acceleration, acceleration falls down linearly from the initial value to the zero value at the end of the acceleration. In the semiparabolic acceleration, acceleration is constant in the first part of the acceleration and then linearly falls down to zero. In the cubic acceleration, acceleration parabolically falls down from the initial value to zero. Most frequently, the deceleration is linear or semiparabolic.

A shape of the travel diagram for certain transport track may be affected by the value of velocity v. The travel time with a constant velocity decreases with an increasing final hoisting velocity. Eventually, a travel section with uniform velocity disappears and we reach the marginal velocity v_m – onset of the travel diagram in a triangle. Marginal velocity for certain transport track (when $a = z$) is calculated while using formula

$$v_m = \sqrt{a \cdot D} \tag{4}$$

By increasing the mining velocity above (0.5 to 0.6) v_m, the total travel time will be reduced only a little. Therefore, the v_e value is introduced; it is referred to as the economical velocity

$$v_e = (0.5 \text{ to } 0.6)\, v_m \tag{5}$$

Velocity depends on the type of transported component. Highest velocities (10-20 m.s^{-1}) are reached in the conveyance of minerals, lower one are reached in the transportation of persons (3.5 to 12 m.s^{-1}), and the lowest one during pit inspections (0.5 to 1.0 m.s^{-1}).

2.3. Comparison of values obtained by calculation and by practical measurements

Values obtained by measurement and calculation should be compared while applying an appropriate method. Conclusions should be made from such comparison.

2.4. Calculation of vertical conveyance capacity while applying the mathematical approach

Capacity of a hoisting machine is the amount of transported minerals for certain time unit. Calculation of the hourly capacity of a hoisting machine Q_h [t/h] can be carried out while using the:

$$Q_h = \frac{3600}{T_w} M_u \tag{6}$$

where: M_u – mass of the useful load in tons, T_w – total time of the work cycle in seconds.

Real hourly capacity Q_R is calculated while using the formula

$$Q_R = \frac{Q_h}{k_i} \tag{7}$$

where k_i is the coefficient of transport irregularity (for skip equipments $k_i = 1.1$, for cage equipments $k_i = 1.15$).

Daily capacity Q_d [t.day^{-1}] is calculated while using the formula

$$Q_d = \frac{Q_R \cdot T_f}{60} \tag{8}$$

where T_f is the usable daily time fund in minutes.

2.5. Calculation of vertical conveyance capacity while applying the simulation approach

The first step is the creation of a work cycle simulation model while using a selected simulation system. The second step is to carry out experiments for the so-called current status, enabling the verification of whether the model is correctly constructed. The third step is a capacity calculation on the basis of the output parameter obtained from the simulation.

2.6. Proposed method of increasing the capacity by changing the transport cycle

On the basis of the results obtained by the capacity calculation and the verification thereof by simulation, we propose increasing the capacity while applying both approaches. Determination of the capacity increase may be carried out while applying several methods, e.g., by changing the transport cycle mode, increasing the travel velocity during the travel, increasing the useful load, reducing the manipulation times. The choice of an appropriate method depends on operating conditions and hoisting machine parameters, as well as parameters of a mining pit.

3. Results

The methodology described above was applied to the evaluation and proposal of increasing vertical conveyance capacity for a selected large hoisting machine. The hoisting machine is used for the transportation of crews and conveyance of material. Basic parameters required for the calculation of the transport cycle time are maximum nominal velocity $v = 6$ m.s^{-1}, acceleration (deceleration) $a = 0.7$-1.2 m.s^{-2} and transport depth $D = 281.2$ m. Hoisting machine acceleration and deceleration are with constant acceleration but under specific conditions. The acceleration and deceleration distances are determined, for safety reasons, as 30 m and the maximum allowed velocity along this distance is 1.5 m.s^{-1}.

3.1. Measuring the transport cycle during the operation

The measurements were carried out in the machine room where the hoisting machine is located, as well as the accessory thereto and the control centre – the room for a hoisting machine mechanic. Time intervals were recorded by a stop watch and a depth meter located on the mechanic's panel, showing a current position of the cage.

Measurements of the transport cycle were carried out during two working shifts. The measurements were carried out while the miners were working and while the materials were transported. The following measurements were carried out:

1) time charts of the transport cycle time T_t – acceleration, uniform movement, and deceleration altogether,
2) time charts of a specific acceleration of the cage $t_{1_{30}}$. This chart represented the acceleration interval on the 30-meter track when the maximum velocity of 1.5 m.s^{-1} was maintained,
3) time charts of uniform movement t_2 that included the acceleration up to the velocity of 6 m.s^{-1}, the movement time at such velocity, and subsequent velocity reduction down to 1.5 m.s^{-1} within the distance of 30 m before the stop,
4) time charts of a specific deceleration $t_{3_{30}}$ – the deceleration interval along the track of 30 m at the maximum velocity of 1.5 m.s^{-1}.

The obtained results were statistically processed, see Table 1. On the basis of the values in Table 1 we can state the following: average values obtained from time charts approach the median of values. The lowest dispersion of values was observed for measurements of specific deceleration.

TABLE 1

Results of measurements

Time charts	**Median**	**Modus**	**MAX**	**Dispersion**	**Standard deviation**	**Average value**
Transport cycle time T_t [s]	89	86	92	4.98	2.23	**88.53**
Specific acceleration time $t_{1_{30}}$ [s]	26	24	29	3.03	1.74	**25.8**
Uniform movement time t_2 [s]	35	35	37	2.56	1.6	**34.2**
Specific deceleration time $t_{3_{30}}$ [s]	29	28	31	1.12	1.06	**28.87**

3.2. Calculation of the transport cycle time for given conditions

For the basic parameters, calculations were made to determine individual transport cycle times (Šaderová, 2016). Calculation of the transport cycle was carried out for the two values of acceleration and deceleration. Alternative 1 – the calculation is carried out for $a = z = 0.7$ m.s^{-2}. Alternative 2 – the calculation is carried out for $a = z = 1.2$ m.s^{-2}. Results obtained by calculations are listed in Table 2.

TABLE 2

Calculated values

	$t_{1_{30}}$ [s]	t_2 [s]	$t_{3_{30}}$ [s]	T_t [s]
Alternative 1	21.07	44.90	21.07	87.04
Alternative 2	20.62	41.55	20.62	82.80

3.3. Comparison of values obtained by calculation and by practical measurements

Figure 2 presents the graphical comparison of calculated values and average values obtained by measurements and also the comparison of transport cycle times. Figure 2 indicates that the deceleration time and the acceleration time obtained by measurements were higher, as compared with the values obtained by calculation. By contrast, the uniform travel time was lower, as compared with the calculated values. The statement above applies also to the transport cycle time; the time measured during the operation is 2 seconds longer than the transport cycle time in Alternative 1, and 6 seconds longer than in Alternative 2. On the basis of the observations made during the operation we can state that the difference is caused mainly by the fact that the hoisting machine is controlled manually by a mechanic whose performance is influenced by various social, psychological, and physical external factors.

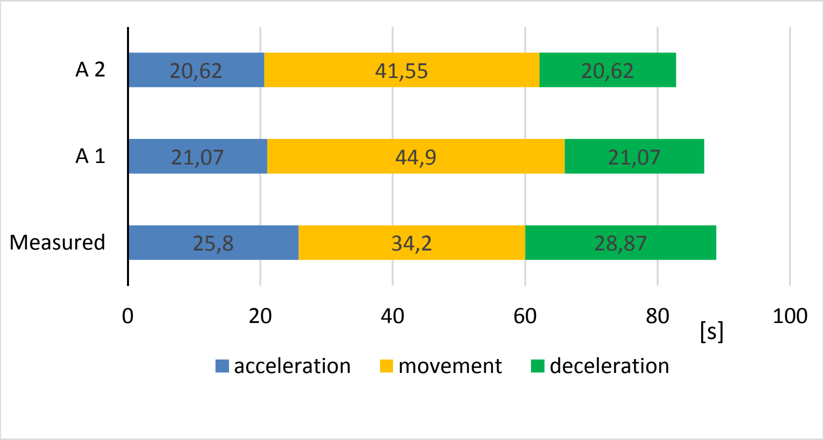


Fig. 2. Comparison of calculated and measured values

3.4. Calculation of vertical conveyance capacity while applying the mathematical approach

Values listed in Tables 2 were used as the basis for the calculation of hourly capacity of vertical conveyance while using the formula (6), calculation of the hoisting machine real capacity while using the formula (7), and daily capacity while using the formula (8), for the daily time fund T_f = 780 min (2 work shifts) and cage loading and unloading times, including down times

$t_4 + t_6 = 98$ s. Calculation of the capacity was carried out for $M_u = 1.6t$. The values used in the calculation and the values obtained by the calculation are listed in Table 3.

As indicated by Table 3, the daily capacity of the hoisting machine calculated on the basis of the measured values is 348 t.hour^{-1}, representing a decrease in 4 tons (1.2%), as compared with Alternative 1, and in 12 tons (3.37%), as compared with Alternative 2.

TABLE 3

Values used in the calculation and values obtained by the calculation

Parameter	T_t **[s]**	T_w **[s]**	Q_h **[t.h^{-1}]**	Q_R **[t.h^{-1}]**	Q_d **[t.day^{-1}]**
Measured time	89	187	30.8	26.8	348
Alternative 1	87.04	185.04	31.13	27.07	351.91
Alternative 2	82.8	180.8	31.85	27.7	360.1

3.5. Calculation of vertical conveyance capacity while applying the simulation approach

A simulation model was created in the ExtendSim simulation system, a product of ImagineThat, Inc. USA. The used simulation language belongs to modern simulation tools in which simulation models consist of blocks contained in its libraries. A simulation model is a model of a discrete simulation, created from the blocks of the “Discreet Event“ and “Plotter“ libraries (Straka, 2017). The block scheme of the model is shown in Fig. 3. The model created in EXTENDSim is presented in Fig. 4.

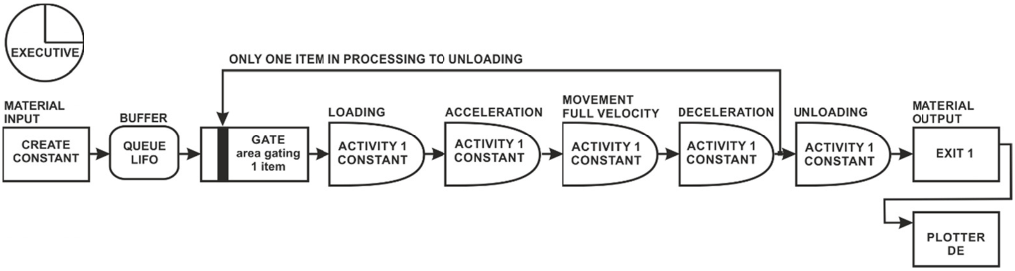


Fig. 3. The block scheme of the model

The block scheme of the simulation model consists of the following blocks:

- for generating inputs “*Create*“ (simulating arrival of the material that must be transported via vertical conveyance, a request), a single arriving item represents the capacity of the skip which weighs approximately 1,600 kg,
- for a queue of unprocessed requests “*Queue*“ (simulating a queue formed in front of the vertical conveyance loading site),
- for the simulation of operation equipment “*Activities*“ (first 4 blocks simulate time intervals, loading, acceleration, uniform travel, and braking, including the stop, block 5 simulates the unloading time interval),

- “*Gate*“ that provides that a request enters the process at the instance when a previous request completes block 4 “*Activity*“ (ensuring that loading as well as unloading are carried out within a single time interval); until the transfer process is completed, next item is not allowed to enter the system,
- for the request output “*Exit*“ (simulating a request exiting the vertical conveyance system),
- for the visualisation of results “*Plotter, DE*“.

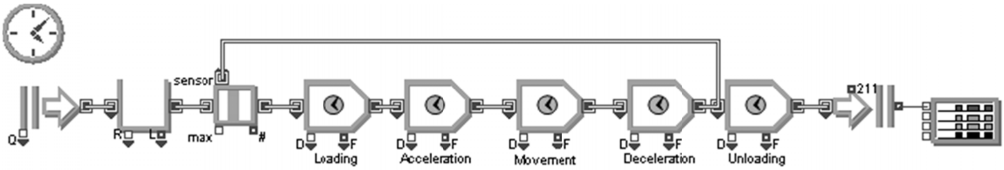


Fig. 4. Simulation of the hoisting machine transport cycle model

Simulation inputs include work cycle time intervals t_1 to t_6. Model output is the parameter – number of work cycles for the simulated time n_c. This parameter can be used for the calculation of daily capacity Q_d, while using the formula (9), obtained by editing formulas (6) to (8):

$$Q_d = \frac{n_c}{k_i} \cdot M_u \tag{9}$$

where n_c – number of work cycles obtained for the simulated time.

Experiments were carried out for Alternatives 1 and 2 mentioned above. The simulation time was set to 13 hours, corresponding to the T_f value. Simulation results:

- number of work cycles for the simulated time is 252 for Alternative 1, the given number corresponds to the daily capacity calculated while using the formula (9) 350.61 t.day^{-1},
- number of work cycles for the simulated time is 258 for Alternative 2, the given number corresponds to the daily capacity calculated while using the formula (9) 358.96 t.day^{-1}.

By comparing the daily capacity values obtained by simulation and calculation, we can state the following: The daily capacity calculated on the basis of the simulation is, as compared with the value calculated while using the formula (8), lower on average in 1.62 ton/day. This is caused by the fact that the simulation output is only the number of completed transport cycles in the simulated time. The transport cycle that was currently running at the time of simulation completion was not recorded. Unlike in the capacity calculation while using the formula (8), the calculation considered also unfinished transport cycles.

3.6. Proposed method of increasing the capacity by changing the transport cycle

Proposed increase in the hoisting machine capacity can be achieved by several methods. In this case we apply two approaches: velocity increase and acceleration mode change.

3.6.1. Proposed capacity increase by changing the velocity

For the depth $D = 281.2$ m

- the maximum velocity is calculated while using the formula (3) $v_{\max} = 13.41$ m.s^{-1},
- the marginal velocity calculated while using the formula (4) $v_m = 14.029\ m.s^{-1}$,
- corresponding economical velocity calculated while using the formula (5) is $v_e = 7.0\text{-}8.4$ m.s^{-1}.

The monitored hoisting machine works with the velocity of 6 m.s^{-1} which is below the limit of the calculated economical velocity while using the formula (5). Table 4 represents the comparison of calculated values for Alternatives 1 and 2 with an increase of the original velocity of 6.0 m.s^{-1} to the velocity of 7.0 m.s^{-1} which represents the lower limit of economical velocity. Table 4 indicates that the transport cycle time for both alternatives is reduced on average only in 5%.

The values listed in Table 4 were used as the basis for the capacity calculation while using formulas (6) to (8), calculation for $T_f = 780$ min, Table 5.

In Alternative 1, when the velocity was increased to 7 m.s^{-1}, the hourly, real, and daily capacities increased in 2%. For the daily capacity it represents an increase in 7.28 tons per day. In Alternative 2, when the velocity was increased to 7 m.s^{-1}, the hourly, real, and daily capacities increased in 2.5%. For the daily capacity it represents the increase in 8.97 tons per day.

TABLE 4

Comparison of calculated values

	Alternative 1 ($a = z = 0.7$)			**Alternative 2 ($a = z = 1.2$)**		
	Specific		**Linear**	**Specific**		**Linear**
	$v = 6$ m.s^{-1}	**$v = 7$ m.s^{-1}**	**$v = 6$ m.s^{-1}**	**$v = 6$ m.s^{-1}**	**$v = 7$ m.s^{-1}**	**$v = 6$ m.s^{-1}**
	[s]					
$t_{1_{30}}$	21.07	21.07	8.57	20.62	20.62	5.00
t_2	44.90	41.15	41.60	41.55	37.16	41.71
$t_{3_{30}}$	21.07	21.07	21.07	20.62	20.62	20.62
T_t	**87.04**	**83.29**	**71.24**	**82.8**	**78.4**	**67.33**

TABLE 5

Comparison of capacities

	Alternative 1 ($a = z = 0.7$)			**Alternative 2 ($a = z = 1.2$)**		
	Specific		**Linear**	**Specific**		**Linear**
	$v = 6$ m.s^{-1}	**$v = 7$ m.s^{-1}**	**$v = 6$ m.s^{-1}**	**$v = 6$ m.s^{-1}**	**$v = 7$ m.s^{-1}**	**$v = 6$ m.s^{-1}**
Q_h [t.h^{-1}]	31.13	31.77	34.03	31.85	32.65	34.83
Q_R [t.h^{-1}]	27.07	27.63	29.59	27.7	28.39	30.3
Q_d [t.day^{-1}]	351.91	359.19	384.74	360.1	369.07	393.84

3.6.2. Proposed method of capacity increase by changing the acceleration mode

If the velocity cannot be changed, it is possible to consider changing the hoisting machine acceleration mode. Particularly in this case it is a switch from the specific acceleration to the linear acceleration mode. Table 4 shows of calculated values for the linear acceleration, for both alternatives, too. Table 4 for Alternative 1 indicated that the travel time T_t has decreased from the original value of 87.04 s down to 71.24 s, representing a 18% decrease. For Alternative 2, Table 4 indicates that the travel time T_t has decreased from the original value of 82.8s down to 67.33s, representing a 19% decrease. Table 5 contains the calculated capacities after the acceleration mode change while applying formulas (6), (7), and (8) for T_f = 780 min, too. For Alternative 1, the daily capacity has increased in 32.83 tons, representing a 9 % increase. For Alternative 2, the daily capacity has increased in 33.74 tons, again representing a 9 % increase.

On the basis of Table 5 we can state that an increase in the daily capacity may be achieved by changing the acceleration mode, as compared to increasing the travel velocity. Daily capacity determined as stated above is not marginal; it may be increased for example by introducing the third work shift or by increasing the mass of useful load M_u (depending on the carrying capacity of the hoist wire rope).

3.6.2. Verification of proposals by applying the simulation

To verify the calculated capacity, for both proposed methods, a created simulation model was used. Table 6 summarises and compares the results obtained by the simulation for Experiment A – original state, Experiment B – increasing the capacity by changing the velocity, and Experiment C – increasing the capacity by changing the acceleration mode.

Fig. 5 represents the simulation result, increased number of work cycles for Alternative 1 and Alternative 2.

TABLE 6

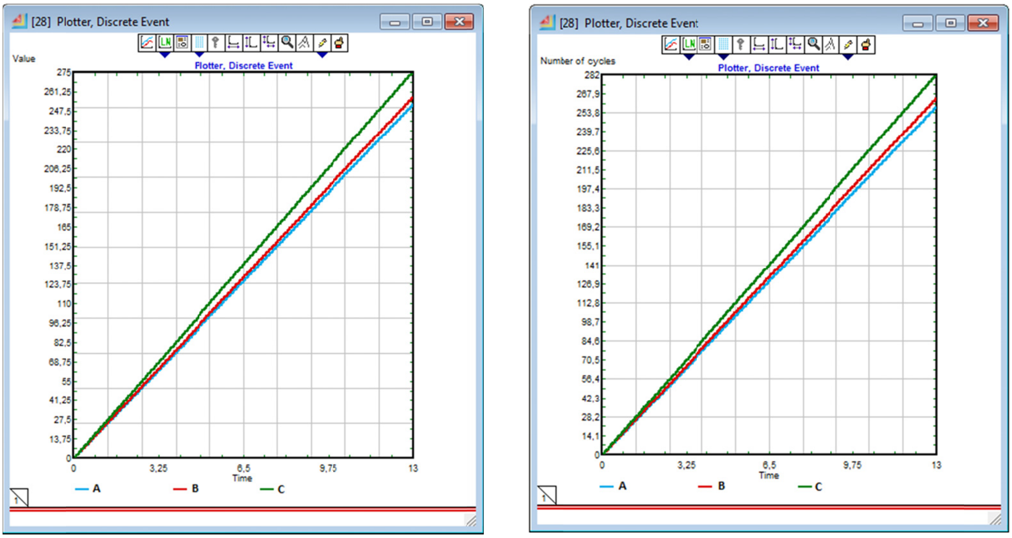
Simulation results and calculated daily capacity for Alternatives 1 and 2

Experiment	**Number of cycles**		
	Specific acceleration		**Linear acceleration**
	to the velocity of 6 m s^{-1}	**to the velocity of 7 m.s^{-1}**	**to the velocity of 6 m s^{-1}**
	A	**B**	**C**
Alternative 1	252	257	275
Alternative 2	258	264	282
Q_d [t.day^{-1}] while using the formula (9)			
Alternative 1	350.61	357.56	382.61
Alternative 2	358.96	367.30	392.35

4. Discussion

Calculation and simulation showed comparable results. We can state that the simulation model was created correctly. The above described method is applicable in practice as an auxiliary tool for capacity verification – evaluation of existing vertical conveyance systems that use hoisting machines during the operation. Other applications of the methodology include the application in the modernisation of older hoisting machines.

The above described model is not a final version, indeed; it can be further extended for more activities related to vertical conveyance on the surface as well as in the underground. It may be a part of the simulation model of the entire transport system in a mining company.



Alternative 1

Alternative 2

Fig. 5. Simulation results for Alternatives 1 and 2

5. Conclusion

The article presents the methodology aimed at increasing the vertical conveyance capacity while applying two procedures – calculation and simulation. The article presents two proposals. In the first proposal, i.e. to increase the transport velocity in 1 $m.s^{-1}$, the daily capacity increased in 2-2.5%, compared to the original capacity. In the second proposal, i.e. to switch from the specific to the linear acceleration mode, the capacity increased in 9%.

Decision-making on which one of the presented methods is more appropriate in an operation is affected by several other operational factors, e.g., hoisting machine parameters, whether it is possible to increase the existing velocity, technological conditions of the operation, working time, transport time, pit condition, operation safety, etc. It is necessary to realise that a vertical conveyance capacity value calculated as described above is applicable to double-action hoisting machines. In the case of single-acting hoisting machines, the capacity is half-the-value of the former.

An advantage of using the simulation is the result visualisation that provides a good image of the given situation. A disadvantage is the fact that inputs for the simulation model require quality and relevant data, either directly from the operation or from the technical documentation.

When implementing any system changes, such changes should be first verified by simulation and assess their acceptability. The system simulation may point out positive as well as negative changes following an intervention in the system.

To evaluate the current status and use such evaluation to solve a particular problem, other methods and operation indicators may be used as well, as they may serve as the basis for the final decision-making (Andrejiová et al., 2015). Ultimately, every decision must be well thought over and relevantly compared to the baseline.

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