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ANALYSIS OF TRANSPORT CYCLE OF MINING HOISTING MACHINE

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Abstract:
The paper presents the issue of transport cycle of mining hoisting machine. The first part of the topic is given in theory - cycle time, economical speed and driving diagram. The second part of paper analyses the transport cycle in a particular operation.
The paper shows a comparison of the calculated values based on the parameters of the hoisting machine to the measured values in service.

Key words: Transport cycles, hoisting machine

INTRODUCTION

Vertical transport is used for the removal of excavated materials, delivery of various materials, machinery and equipment required for the mining process and related activities, and for the transportation of persons. This mode of transport, in particular, the hoisting machinery, is most frequently used in underground mines. Operational life of a hoisting machine is a very important part of transport logistics in every mining company [1]. Hoisting machines consist of several structural components, such as drums, sheaves, steel wire ropes, skips, and others that affect their capacity. Vertical transport issues are discussed in several publications and articles. Some of them include chapters focused on general characteristics of vertical conveyance [2]. Number of publications deal with the issues of structural components, e.g. steel ropes [3], machine brakes [4], friction pulleys [5]. Some authors describe hoisting machines used in practice [6]. Majority of articles are highly specialised, they deal with detailed problems of hoisting machines, e.g. the dynamic behaviour of mine hoists during the emergency braking phase [7] the determination of mining equipment motion resistance [8].

The main focus of the paper is put on the "transport cycle time" parameter. Transport cycle time depends on velocity and acceleration and deceleration methods.

1 METHODOLOGY

The paper issues regarding of the transport cycle time, while applying the procedure consisting of the following steps - transport cycle calculation using the formulas, measuring the transport cycle time during the operation and comparison of the measured and the calculated values of the transport cycle time.

1st step: Transport 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 skip movement during the transport cycle T_t. A single work cycle consists of several time intervals, Figure 1:

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

Transport cycle time or travel time is determined as the sum

$$T_t = t_1 + t_2 + t_3 \qquad [s] \qquad (1)$$

Total time of one work cycle is determined by formula

$$T_w = T_t + t_4 + t_5 + t_6 \qquad [s] \qquad (2)$$

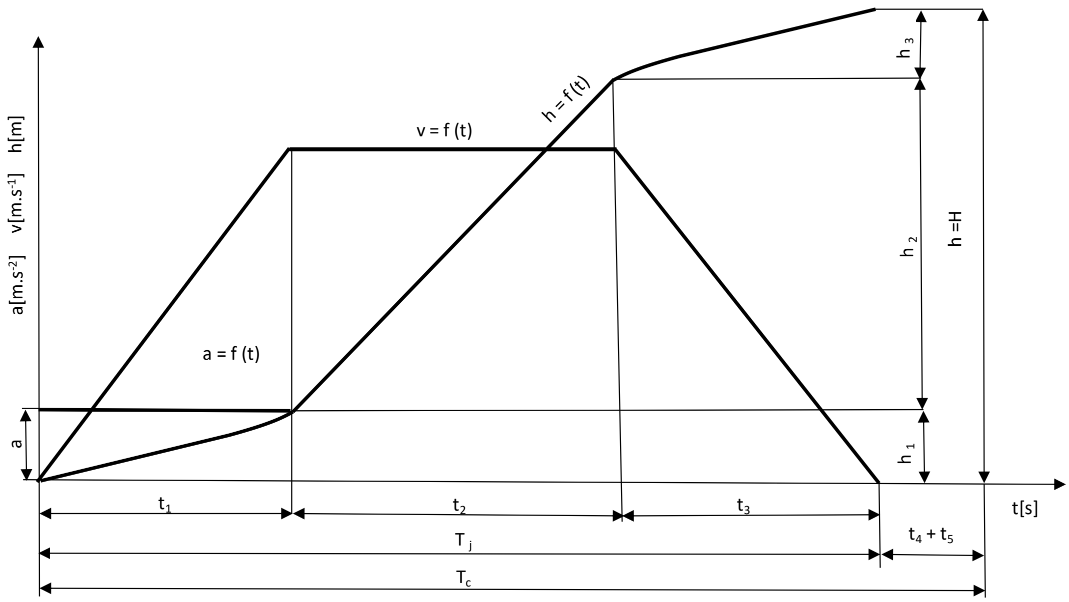

Fig. 1 *Travel diagram with linear acceleration and deceleration*

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 (Figure 2) into
(A) machines with constant acceleration - linear acceleration

(B) machines with variable acceleration
   a) parabolic acceleration
   b) semiparabolic acceleration
   c) cubic acceleration.

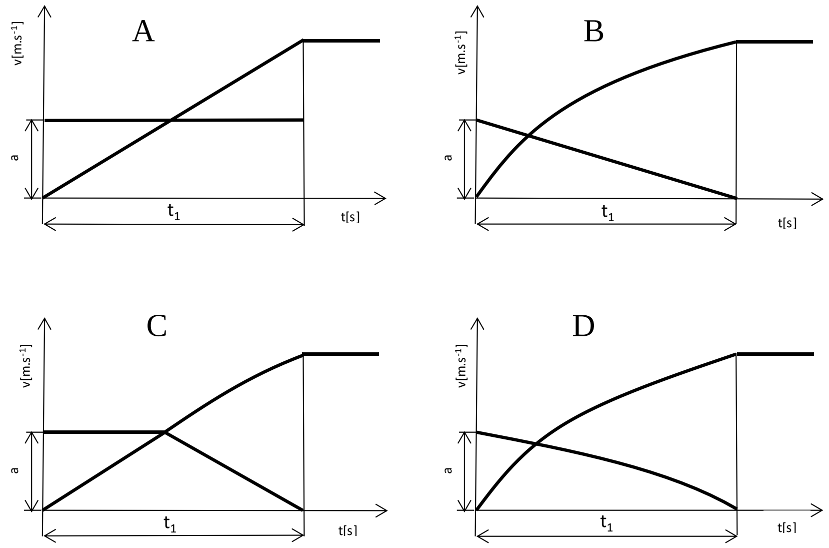

Fig. 2 *Acceleration types*
A - linear, B - parabolic, C - semiparabolic, D - cubic

2nd step: 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:

1. Preparation for monitoring and measurements – this stage is the first step, aimed at ensuring the smooth course of the activity chart. The first step requires choosing a correct workplace and a machine to be monitored; the choice depends on the purpose of the Multiple Activity Chart, chart duration determination. The chart duration (number of measurements) must ensure the required chart accuracy as well as cost-efficiency (the measurement should not last unnecessarily long).
2. Observation, measurements, and recording of measured values - observation and measurements in the Multiple Activity Chart represent recording the times of their duration while using a stop watch or any other recording devices. Observation should be carried out at times when the time consumption is average (i.e. not only in the beginning of a shift or during the highest output).
3. Processing and analysis of measured times – this is the last stage of the chart, the measured times and findings are processed and then used for the analysis. The most frequently used Multiple Activity Chart is the chronometry. It is used in cyclical works that are carried out repeatedly [9].

3rd step: Values obtained by measurement and calculation should be compared while applying an appropriate method. Conclusions should be made from such comparison.

2 RESULTS

For the parameters stated in publication [10], calculations were made to determine individual transport cycle times and transport tracks. As the hoisting machine acceleration and deceleration are with constant acceleration, but under specific conditions, calculations of partial transport cycle sections were carried out on the basis of the modified formula (1):

$$T_t = t_{1_{30}} + t_2 + t_{3_{30}} \tag{3}$$

1. Calculation of the time in the acceleration for the transport section of 30 m $t_{1_{30}}$

$$t_{1_{30}} = t_{1_0} + t_{1_{1,5}} \tag{4}$$

where t_{1_0} is the time of acceleration from 0 to the velocity of 1.5 m.s^{-1},
$t_{1_{1,5}}$ – time of travel at uniform velocity of 1.5 m.s^{-1}.

2. Calculation of travel time at uniform velocity of 6 m.s^{-1} t_2 is calculated in this case as follows:

$$t_2 = t_{2^1} + t_{2^2} + t_{2^3} \tag{5}$$

where t_{2^1} is the time of acceleration from the velocity of 1.5 m.s^{-1} to 6 m.s^{-1},
t_{2^2} - time of travel at the velocity of 6 m.s^{-1},
t_{2^3} - time of travel during which the velocity of 6 m.s^{-1} is reduced down to 1.5 m.s^{-1}.

3. Calculation of the retardation time for the transport section of 30 m $t_{3_{30}}$ *is calculated similarly to paragraph 1:*

$$t_{3_{30}} = t_{3_0} + t_{3_{1,5}} \tag{6}$$

where t_{3_0} is the time of travel within which the velocity of 1.5 m.s^{-1} is reduced down to 0,
$t_{3_{1,5}}$ – time of travel at uniform velocity of 1.5 m.s^{-1}.

Calculation of the transport cycle was carried out for the two values of acceleration and retardation. 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 1. Figure 3 shows the driving diagram for the calculated values (a = 0.7m.s^{-2}).

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, the scheme there of is in Figure 4. The basic technical device of the control centre is the control panel, used for the hoisting machine control.

Tab. 1 *Calculated values*

	Alternative 1		Alternative 2	
	$a = z = 0.7\ m.s^{-2}$		$a = z = 1.2\ m.s^{-2}$	
Time	**Calculated time [s]**	**Transport tracks h_i [m]**	**Calculated time [s]**	**Transport tracks h_i [m]**
t_{1_0}	2.14	1.6	1.25	0.94
$t_{1_{1,5}}$	18.93	28.4	19.37	29.06
t_{2^1}	6.43	14.47	3.75	8.44
t_{2^2}	32.04	192.26	34.05	204.32
t_{2^3}	6.43	14.47	3.75	8.44
$t_{3_{1,5}}$	18.93	28.4	19.37	29.06
t_{3_0}	2.14	1.6	1.25	0.94
	$\boldsymbol{T_t = 87.04}$	**H = 281.2**	$\boldsymbol{T_t = 82.8}$	**H= 281.2**

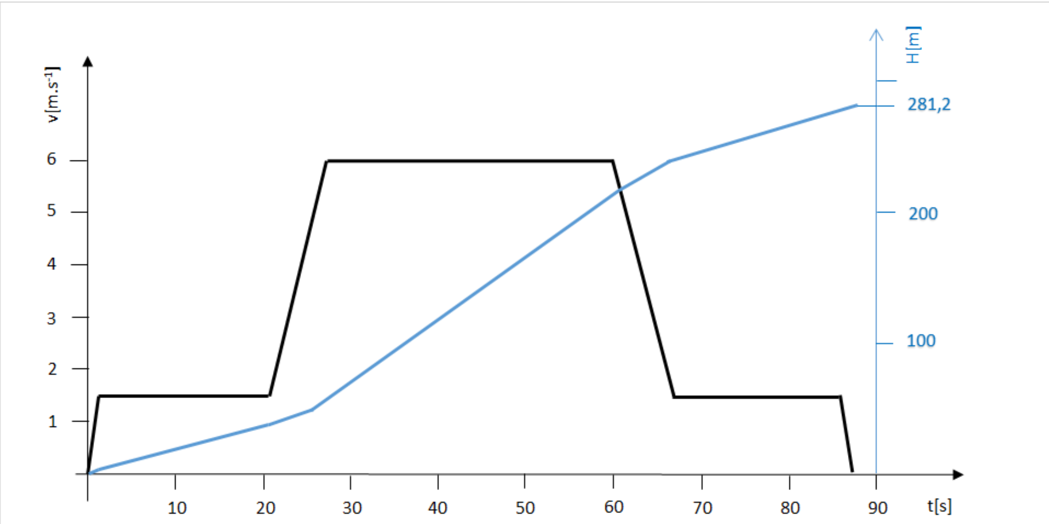

Fig. 3 *Driving diagram for a = 0.7m.s*$^{-2}$

The control panel comprises components used for measuring (depth meter, tachograph), control (travel brake), and communication. 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 and recorded in pre-arranged logs. 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 travel, and retardation altogether,
2) time charts of a specific acceleration of the skip $t_{1_{30}}$. 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 travel t_2 that included the acceleration up to the velocity of 6 m.s^{-1}, the travel time of travelling 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}.

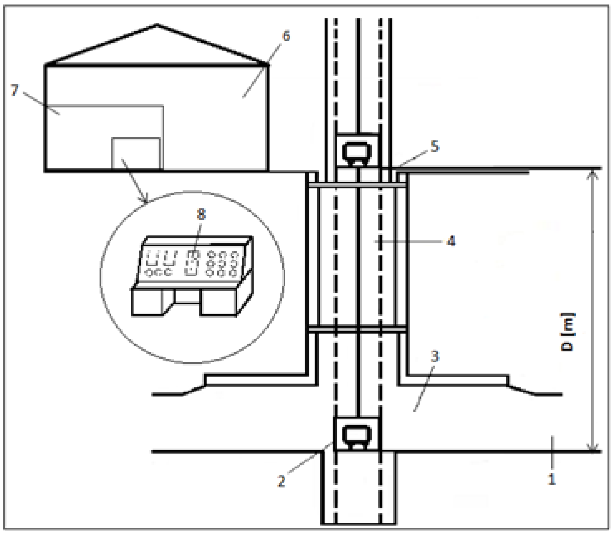

***Fig. 4** Simple scheme*

1 – mining level, 2 – skip, 3 – buffer, 4 – mining pit, 5 – exit level, 6 – machine room, 7 – control centre, 8 – control panel with a depth meter, D – transport depth (track)

Figure 5 presents the graphical comparison of calculated values and average values obtained by measurements of transport cycle times.

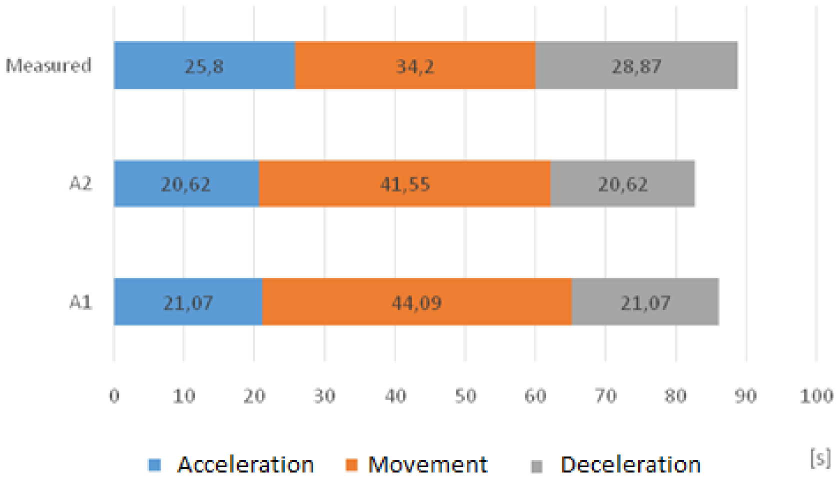

***Fig. 5** Comparison of calculated and measured values*

Figure 5 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 1.5 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.

3 Discussion

The transport cycle time affects the capacity of the hoisting equipment. One of the ways to increase the capacity of the towing equipment is a reducing of the transport cycle. The reducing of the transport cycle is possible in several ways, e.g. by increasing transport velocity and by changing the acceleration mode. Figure 6 shows velocity curves (travel diagrams) for Alternative 1 (**A** curve – current status - specific acceleration at v = 6 m.s^{-1}), **B** curve – specific acceleration at the velocity v = 7 m.s^{-1}, **C** curve – linear acceleration at v = 6 m.s^{-1}).
B: the transport cycle time is reduced only in 5 %. C: representing a 19% decrease.

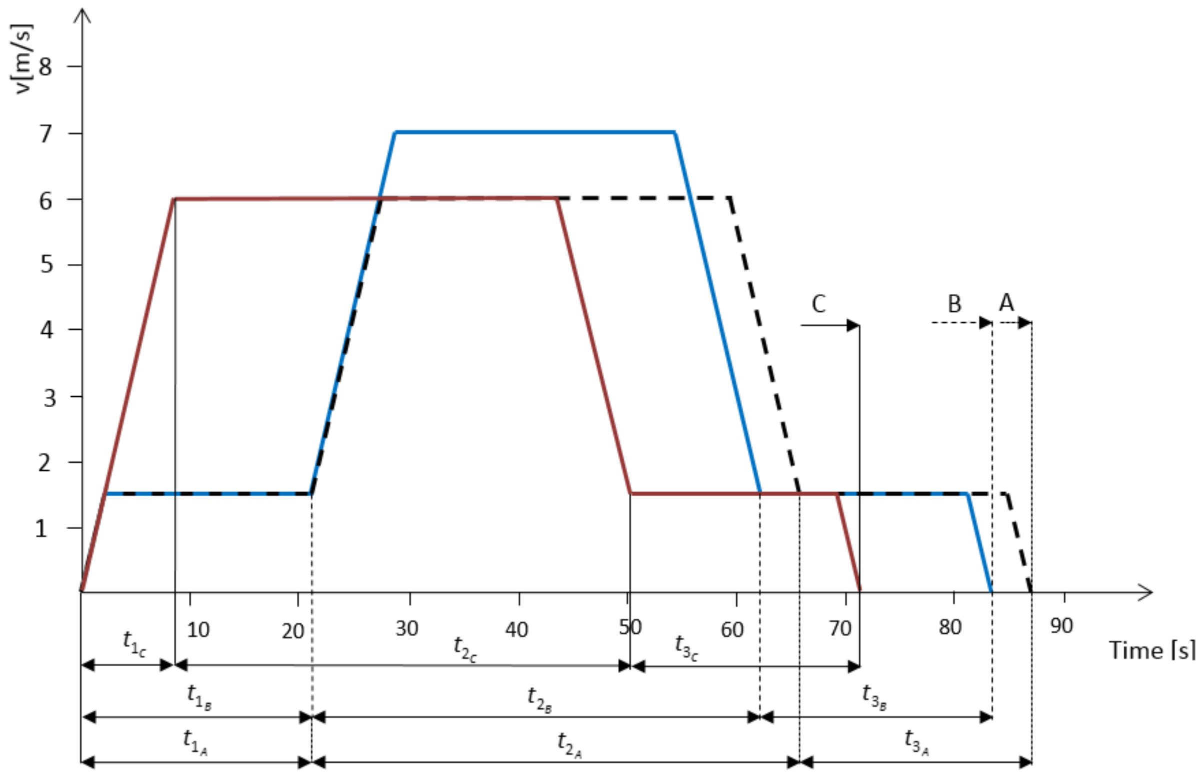

Fig. 6 *Driving diagram for Alternative 1:*
A- current state, B - increasing to the velocity, C - changing the acceleration mode

3 CONCLUSIONS

The paper deals with problem of the transport cycle time of hoisting equipment in mining industry. The results of a calculation of the transport cycle time, while using known formulas and measuring a transport cycle time during the operation, are presented in the paper. The comparison of the calculated and measured values showed the measured transport cycle time during the operation is several seconds longer. It is mainly caused by operational conditions.
This analysis is applicable in practice as an auxiliary tool for the planning of transport during the mining transport of raw materials.

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