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Excavation process control with using modern methods in the case of giant machines

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Abstract

For disintegration process control we need a quantity that respects objectively rock-disintegrating tool interaction with the elimination of human factor. From this, basic requirements for the evaluation quantity given below follow: is available in advance or at the moment of disintegration; minimises the influence of human factor on the resultant effect; evaluates objectively the disintegration process. A measure of efficiency of any disintegration process is the consumption of energy usually related to the unit volume of disintegrated rock; on the basis of analysis done theoretical and practical researches orientated towards the disintegration processes and the verification of objectivity when used in situ (in drilling and tunnelling), at present it is minimised specific volume energy that is the most objective evaluation quantity. This quantity has a general validity for dispersion processes, and thus its use even for the evaluation of diggability on the digging wheel of excavator has a rational basis. In connection with the GIS application for controlling the extracted quantity, an optimal tool is offered for the maximum efficiency of excavation process.

Introduction

As for production / excavation processes, the maximum efficiency and the minimum energy consumption are required. These requirements are naturally antagonistic, and both of them cannot be fulfilled. However, it is possible to minimise the specific energy consumption, and as far as excavation processes are concerned, it has been proved that such combination of parameters of disintegration exists at which the specific consumption is minimal.

Specific volume energy as criterion for diggability

Diggability expressed by specific volume energy

If we subject the methods used for the diggability determination, which concerns digging resistances as well, to the analysis of objectivity, we shall find that they do not take into account, to a more or less extent, the whole set of affecting factors, and thus their informative ability concerning the real disintegration process diminishes. What remains debatable is the quantification of evaluation quantity as well. The basic question is, for the benefit of which we are in need of absolute value of diggability. For disintegration process control we need a quantity that respects objectively rock-disintegrating tool interaction with the elimination of human factor. From this, basic requirements for the evaluation quantity follow:

- availability in advance or at the moment of disintegrating;
- the objective measurement of quantities and software processing.

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The wheel diggability will be defined as "the amount of energy needed for the disintegration of unit volume of rock per unit time and for breaking down other wheel resistances; mode parameters being regulated to ensure the minimisation of this specific energy" [1]. Diggability defined in this way is quantified in Jm^{-3}.

A general equation for specific volume energy is given as follows:

$$w = \frac{P}{V_{tj}} \tag{1}$$

where:

w – specific volume disintegration energy [Jm^{-3}];
P – power input to the disintegrating tool [W];
V_{tj} – the volume of rock taken by the wheel per unit time [m^3s^{-1}].

For digging by the excavator wheel, the volume of rock taken by the wheel per unit time will be as given below:

$$V_{tj} = s \cdot h \cdot v_o \tag{2}$$

where:

s – the depth of cut [m];
h – the height of cut [m];
v_o – the speed of slewing (of digging-wheel boom at max. radius) [ms^{-1}].

In the creation of cut, the outputs of wheel and slew mechanism participate, and thus we consider to be necessary to formulate a relation for diggability on the excavator wheel as follows:

$$w = \frac{P_k + P_o}{s \cdot h \cdot v_o} \tag{3}$$

where:

P_k – input power to wheel drives [W];
P_o – input power to the slew mechanism drive [W].

The relation given uniquely determines the quantities that must be measured in excavator operation to establish diggability values:

- input power to wheel drives [W];
- input power to the slew mechanism drive [W];
- the depth of cut in the horizontal plane [m];
- the height of cut in the vertical plane [m];
- the speed of slewing [ms^{-1}].

Specific volume energy from the point of view of digging resistances according to ČSN 27 7013

If we consider the case of wheel diggability analogously to digging resistance determination according to the norm ČSN 27 7013 *Stroje pro povrchovou těžbu* [2], neither power required for disintegrated rock uplift into the point of unloading, nor power corresponding to resistances at the idle run of wheel can be considered.

To determine the digging resistance defined by specific volume energy (henceforth referred to as a digging resistance), we deduct the values of lifting power and no-load power from the measured value of input power. The magnitude of lifting power is directly proportional to the theoretical extracted quantity, i.e. the size of chip taken by crowding, and does not depend on the power for disintegration.

We shall express the digging resistance by the following relation:

$$w_R = \frac{P_{K\,str} + P_o - P_{zdv} - P_0}{V_{tj}} \tag{4}$$

where:

w_R – the digging resistance expressed by specific volume energy [Jm^{-3}];
$P_{K\,str}$ – the instantaneous measured input power [W];
P_{zdv} – the lifting power [W];
P_0 – the no-load output power [W].

A relation for the digging resistance will have the following final form:

$$w_R = \frac{P_{K\,str} + P_o - P_{zdv} - P_0}{v_o \cdot s \cdot h} \tag{5}$$

The presented relation determines uniquely quantities that must be measured in excavator operation to establish the values of diggability according to the methodology presented.

Measurement and evaluation of digging resistances from the point of view of objectiveness

The application of specific volume energy as evaluation quantity of disintegration process on the excavator wheel is, from the point of view of latest knowledge of rock disintegration, more objective than *digging resistance* used so far. For this statement it is necessary to analyse the following problems:

Objectiveness of disintegrating force on the wheel

In addition to ineffective losses of the drive, which are expressed by efficiency (no-load power) and power output for acceleration and material lifting to the point of unloading, the installed input power must overcome the resistances that are a sum of forces acting on the wheel, i.e.:

- a sum of rock resistances to disintegration (disintegrating and frictional forces on the bucket cutting edges and teeth in engagement);

- resistances caused by the friction of disintegrated rock against to the bucket sides and between each other during the bucket filling;
- resistances caused by the friction of rock against the ring;
- forces for overcoming resistances caused by the friction of the buckets against the rock induced by a ratio between the speed of the wheel boom rotation to the wheel circumferential speed are not eliminated either.

Forces corresponding to the presented resistances are shown schematically in figure 1.

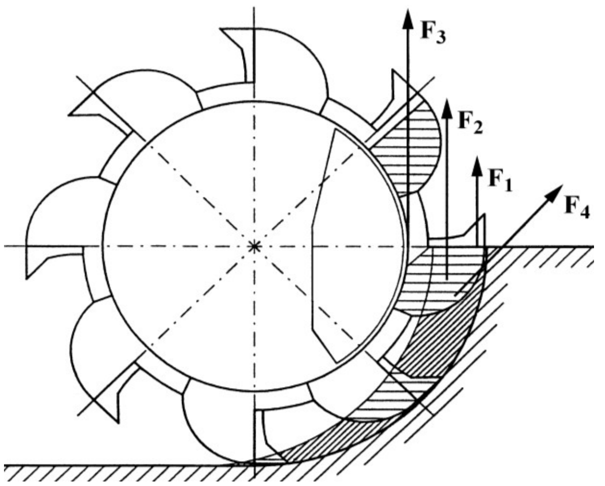

Fig. 1. Forces acting on the wheel

F_1 – the disintegrating and frictional forces on the bucket cutting edge; it acts on the radius given by the shape of cut – the point of application of the force changes during the superstructure slewing, the magnitude and direction change depending upon the position of the bucket;
F_2 – the force to lift the disintegrated material in the vertical direction – it grows towards the point of unloading, the point of application of the force changes with the position of the bucket;
F_3 – the force to overcome the friction of rock against the ring – variable with the position of the bucket;
F_4 – the force to overcome the friction of rock against the bucket sides – it occurs merely in certain modes of excavation – variable.

Thus it is evident that the forces corresponding to the presented resistances do not have the same point of application and the same direction; individual forces change in magnitude, in the point of application and in the direction during the wheel rotation.

The disintegrating ability of the wheel [2] is given by technical parameters of excavator and by the wheel structural design, and is defined by the following relation:

$$F_{KL} = \frac{P_{ck} \cdot \eta_c}{v_k} \tag{6}$$

where:
F_{KL} – the nominal circumferential digging force on the wheel [kN];
P_{ck} – the output rated of excavator motors of wheel drive [kW];
η_c – the overall efficiency of wheel drives [–];
v_k – the circumferential speed of wheel [ms^{-1}]

or decreased by the power required for rock lifting:

$$F_R = \frac{(P_{ck} - P_{zdv}) \cdot \eta_c}{v_k} \tag{7}$$

The force defined like that represents an imaginary force that is theoretically available on the wheel circumference. However, the resistances do not act there, and therefore the calculation of real forces is unreal.

Problems of in-process measurements

A methodology for the measurement of output and force parameters during excavation is determined in [2]; in practice, measurements are taken in the following way:

- the measurement is done merely in that part of the chip, where the depth of cut does not differ much from the maximal one; the maximum depth of setting being considered;
- the measurement of drive input power;
- the depth of cut is taken from the extension or advance;
- the width of cut is calculated from revolutions of slewing gear (for maximum value);
- the height of cut is estimated according to the number of buckets engaged, or by the measurement of pitch of the boom.

Followed by an evaluation of the measurement results, which requires a certain time. Final results are available no sooner than the place observed is already worked-out. Thus it can be stated that present in-process measurements are burdened with the inaccuracies, and that, there is a delay in providing the results.

Preliminary conclusion

If we want to evaluate briefly the existing and the newly proposed method of evaluation of excavation process we must pose the following two important questions on top of that:

Is it important to us to know digging resistances as force on the length of cutting edge?

Is not the reason for this only the fact that nobody has convinced us of advantages of another method yet?

In principle, for evaluation, we are in a need of a quantity that will be, at the present level of knowledge, the most objective, easy-to measure, that will express *rock – tool* interaction and will be available immediately.

It is a quantity of specific volume energy that fulfils these requirements. We recommend it in the form of equation [3]:

$$w = \frac{P_k + P_o}{s \cdot h \cdot v_o} \quad (8)$$

Application of GPS to the excavator wheel

A feasible possibility of using the quantity of specific volume energy is given by the following requirements:

- the minimisation of influence of human factor on the excavation process;
- the accurate setting of parameters of the cut excavated;
- the accurate driving into a new bench;
- the minimisation of the idle times;
- the maximisation of efficiency in a chip;
- a possibility of continuous observing the excavation process by the criterion of specific volume work.

This requires equipment capable to provide, at a given moment, required information and transfer it to the operator of the excavator to control effectively the excavation process. Simultaneously, it is necessary to take into account the requirement for the highest efficiency and the requirement for the minimisation of specific energy consumption. Progressive technologies cannot be spared here any more.

Into many technological processes, GPS systems enabling a high accuracy in machine control penetrate increasingly. That is why we considered a possibility of using a GPS system for the control of giant machines. In the course of our investigations we found that GPS application to the excavator had already been performed in Germany.

The advantages of GPS application to the excavator are as follows:

- the setting of required dimensions of cut with an accuracy in cm;
- the accurate driving into a new cut and a new bench without ineffective movements;
- the creation of a flat surface in the last bench with an accuracy in cm (lesser demands for additional improvement);
- a possibility of continuous observing the extracted quantity in a block;
- a possibility of continuous (or cyclic) observing the specific volume energy in individual cuts – analogy to digging resistances;
- a possibility of comparing the suitability of constructional design of the buckets in the given rock environment – by the continuous measurement of specific volume energy.

Conclusions

Defining the criterion of specific volume energy as evaluation quantity for digging resistances

Factors affecting the disintegration process are as follows: *rock*, *disintegrating tool*, *mode conditions of disintegration* (*choice of dimensions of cut*) and *other influences*. For the objective evaluation of disintegration process we would need such a quantity that takes into account all the factors. This is not practically possible, and thus we try to find such quantity that considers the maximal possible number of affecting factors.

The excavation process of wheel excavators is a subject, likewise any other process in the course of which a rock is being disintegrated, to common laws affecting the final effect. Thus, theoretical conclusions and practical results verified in the operation of drilling equipment and tunnelling machines, when by the regulation of mode parameters of disintegration considerable energy and thus also economic savings were achieved, can be applied. The basis of proposed solution is to find such parameters of the cut when the specific volume energy is minimal. However, this means a change in the view of evaluation quantity:

- present-day quantity
  digging resistance [kNm^{-1}];
- proposed quantity
  specific volume energy [Jm^{-3}].

The name of quantity is not decisive – it is definition and quantification that are decisive. The observation and evaluation of the new quantity bring the following advantages:

- it is available for the operator of excavator for the continuous control of excavation process (on the assumption that the dimensions of cut and input power to the wheel drives are measured and relevant software is solved);
- it reacts sensitively and immediately to the change in the rock environment (an increase in strength parameters of rocks excavated) and thus allows the correction of mode parameters of the excavation process;

- it shifts the influence of human factor on the excavation process to the side of quality – provides immediate and objective information;
- it makes it possible to describe the course of disintegration in the whole chip;
- it does not require any additional measurement in situ and any subsequent evaluation – it can be recorded and archived at any time;
- it will enable the processing of database of benches and sections from the point of view of diggability;
- its main importance will manifest itself in parts with the occurrence of solid layers, where it will make it possible to optimize the excavation process;
- it enables a simple comparison between individual types of disintegrating tools (bucket, wheel) from the point of view of energy demand;
- its use does not exclude the observation of excavation process by the existing methodology (measurement of digging resistances and digging forces) on the assumption of software equipment;
- in the upshot, it will positively influence the energy demand of excavation process.

Application of GPS to the excavator

The use of GPS system for excavator control is required for the good quality of excavation process and its effectiveness. With regard to the life of excavator, it is necessary to utilize, in spite of high purchase costs, the advantages provided by the new progressive technology. There is a need to emphasise the accuracy of setting the dimensions of a cut, which is carried out during periods of relative inactivity (dead centres) and is not thus endangered by the dynamics of excavation process.

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