

# Modernization of dump truck onboard system

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**Abstract.** The review of the only automated dispatch system for the career dump trucks, which is presented in the domestic market, was made. A method for upgrading the loading control system and technological weighing process of the career dump was proposed. The cargo weight during loading is determined by the gas pressure in the suspension cylinders at the time of the oscillation ending and at the start of the vibration smoothing process; the smoothing speed correction is performed. The error of the cargo weighting is 2.5-3%, and of the technological weighing process during driving - 1%, which corresponds to the error level of the steady-state weighting means.

## 1. Modern trends in the development of the mining industry

The main trend in the development of the mining industry for the foreseeable future is now regarded with an emphasis on the open cast mining of minerals, as it provides the best economic performance. It accounts for up to 73% of the total volume of the mining operations in the world (in the US - 83%, in CIS countries - about 70%) [1]. In Russia about 91% of the iron ore, more than 70% of the non-ferrous metals and 60% coal is mined using open cast. As the depth of pits increases, the proportion of the career transport costs comes to 55-60% of the total mineral mining cost, which represents a significant value and shows the necessity of perfection of the quarry vehicles use. Perfection of the quarry vehicles use consists in operation of the dump truck in optimal modes, which is a potential reserve for increasing the efficiency of any quarry or mine. The optimal modes are: loading of the dump trucks in each voyage in accordance with its nominal carrying capacity, the optimal speed mode of movement in the loaded state in accordance with the load weight and road conditions, minimal return flight time and minimal downtime. Implementation of these modes is impossible without using the career dump truck computerized automation equipment or onboard system for the load automatic control and technological accounting of transported rock mass [2].

## 2. Automated dispatching control system

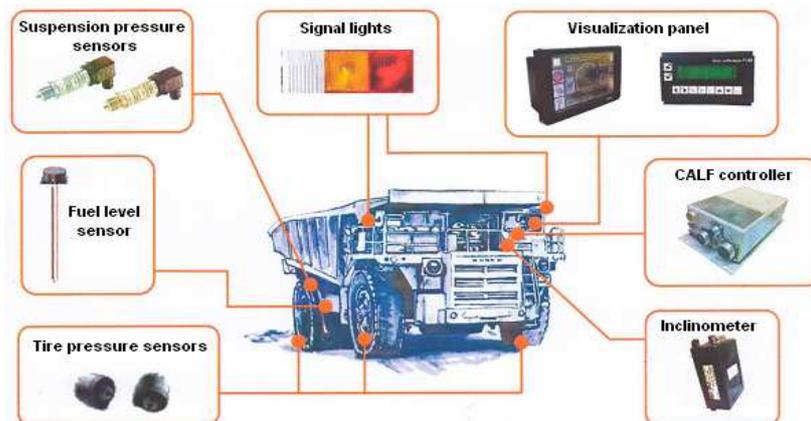
Currently in the domestic market there is the unique automated dispatching control system "Karier" developed by the "Vist group" company (Moscow) to perform the tasks mentioned above. System "Karier" uses satellite global positioning (GPS or GLONASS), which allows one to determine the exact coordinates of moving objects (trucks), their speed and route. "Karier" system as its component part includes the control system of loading and fuel (CALF), which is shown in Figure 1, indicating equipment and its installation places on the dump truck. CALF onboard system is installed on all serial



dump trucks of carrying capacity of 55-220 ton directly on the plant "BELAZ" at their release, since 2000. It allows one [3-5]:

- to measure the weight of the cargo, transported by dump trucks, by a gas pressure in the cylinders of its hydro-pneumatic suspension (pressure sensors in the suspension);
- to issue the excavator driver light signals (signal lights) on the load of dump truck up to a level close to its rated capacity;
- to control the longitudinal angle during loading of dump truck (inclinometer) to increase the accuracy of determining the mass of freight;
- to collect and store information (CALF controller) about the flights completed by loaded dump truck, the date and time of each load, fuel consumption (fuel level sensor), the mass of the load and volume of cargo, mileage, etc;
- to control information referred in the previous paragraph on the visualization panel.

CALF system is produced commercially for more than 15 years, it is equipped with dump trucks, running on almost all major mining companies. However, over the years the system has not been modernized, although it has some significant drawbacks. The main drawback of CALF – low weighing accuracy of the rock mass during its loading into the dump and subsequent technological weighing. The system is not designed for conducting of the accounting and settlement operations and is not certified as a weighing device; however, some companies use it for the internal production accounting.



**Figure 1.** Block diagram of CALF onboard system

Low weighing accuracy of the cargo is related to the fact that the suspension of dump truck is a non-linear system consisting of four hydro-pneumatic cylinders with the dry friction. Dry friction in each cylinder is the random value and can take values in a wide range from zero to five or more tons at different time points. The total error of the load control can be 8-10% of the maximum load of the body. The specified error value and values of dry friction forces in suspension cylinders were confirmed by the results of numerous research tests of load control systems analogous to CALF at different careers [6].

It is known that according to the rules of mining vehicles operation the overweight of dump trucks for 10% or more of their passport load capacity is prohibited. It is obvious that the CALF system with such weighing errors will not be able to ensure no overload.

From the literature it is known that the dump trucks are generally underloaded. This is indicated by data on the average values of load capacity utilization rate of different types of dump trucks in mining operations. These coefficients are in the range of 0,81 ...0,9 for dump trucks with carrying capacity of 120 ton as the most common in large open pits, which ranges from 10 to 20 tons of rock mass. The transport cycles with the specified underload are 65 - 70% of the executed laden flights.

Underloads are explained by the existing loading technology, instead of pouring a cargo from the bucket from a certain height, a bucket with a cargo is placed in the body, the bottom opens and during

its lifting the cargo is poured out. Although such loading is forbidden, but in practice it is used in all mining enterprises, as it ensures the minimum spillage of cargo.

### 3. A method of improving the load weighing accuracy

The only way to avoid the disadvantages of dump load control system is to increase its accuracy. [7] It is known that the vibration is one way to combat dry friction. Vibrations are present on a dump truck. They are created by the rotating masses of the power unit and represent a harmonic effect with a frequency determined by the number of engine idling. Vibration action causes the slow change in the gas pressure in the cylinders of the suspension after unloading an excavator bucket. A sliding process or a process of vibration smoothing occurs, during this process indications of cargo weight in a truck body on the instrument CALF are also slowly changes. These changes range from 0.5 to 6 tons or more, and the duration of the sliding process is between 25 and 45 seconds. A rate of the result change on the CALF screen from the vibration action is important in this sliding process. If to use speed as an additional parameter for the loading control and use its values for the correction of measurements results, it is possible to significantly improve the load control error.

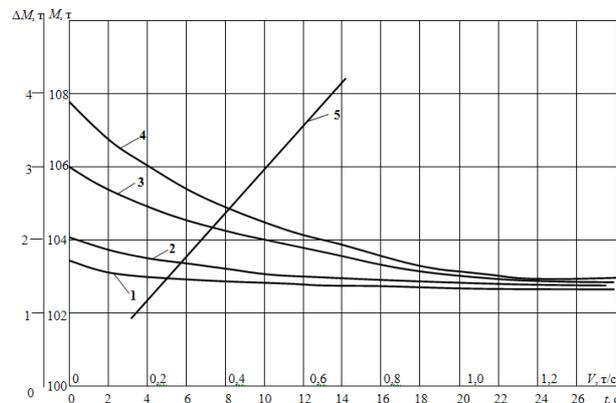
To confirm this, the experimental studies on loading of the dimensional cargo have been conducted on the 110 and 120-ton BelAZ dump trucks. It was found that at the end of the sliding process, when the forces of dry friction blocks suspension cylinders and the vibration action is terminated, the measured values of the onboard systems and the true weight of the load in the body differ by 2-3 tons. This corresponds the accuracy of dump loading control in the range of 2.5-3% of nameplate capacity.

Figure 2 shows the experimental characteristics of change of the cargo mass indications in the back of the dump truck BelAZ-75191 in time from the vibration action while loading the last dimensional cargo weighing 10.64 tones. After loading the total weight of the cargo in the body was 100.2 tons. Loading was carried out four times, from a very smooth installation of the cargo to rigid. The sliding process started with four different points from 103.4 tons to 107.7 tons, and lasted from 14 to 27 seconds (1-4 curves). Weighing error in the beginning of the sliding process ranged from 2.7% to 6.3% and was within 1.5% at the end of the process. Turning on of signal lights occurs at the moment corresponding to the beginning of the sliding process, i.e. with the high error. This is especially important before loading the last bucket. The excavator driver needs to know to what extent fills the bucket, to make full use of dump load, preventing its overload. If the signal lights would be turned on after the sliding process, i.e. in 30-45 seconds after unloading a bucket, then a load control loses all meaning, since it will affect the technology of excavation and loading and will not be accepted by excavator drivers.

The figure shows that in each of the four cases, the rate of the sliding process  $V$  is different, especially in the beginning. The greater the process speed, the greater the accuracy of the rock mass weighing. If this speed is measured and its correction value is added with the appropriate sign to the result of the measurement, it is possible to significantly reduce the error in weighing and not to affect the technology of excavating loading in any way.

Figure 2 also shows the dependence of the change in the correction value  $\Delta M$  on the speed of the vibration smoothing process  $V$  (curve 5), based on the averaged experimental data. In fact, this is linear relationship.

Based on the analysis of the results of experimental studies, a new way of loading control was proposed. Weight of cargo during loading is determined by the gas pressure in the cylinders of the suspension after the time of oscillations end and at the beginning of the vibration smoothing process. Then, in the first two seconds the speed of this process and its sign are determined. Correction  $\Delta M = F(V)$  is entered in the result of the measurement. The error of cargo weighing with a high degree of probability will be 2.5-3% of the maximum body load, instead of the 5% specified in the technical characteristics of the system CALF.



**Figure 2.** Experimental characteristics of change of cargo mass indications  $M$  in the body of dump truck BelAZ-75191 from time while loading dimensional cargo weighing 10.64 tons (curves 1÷4) and the change in the correction  $\Delta M$ , depending on the speed of the vibration smoothing  $V$  (curve 5).

Technical implementation of the proposed method of loading control in CALF system does not require any additional equipment. It is only necessary to expand the software functionality and introduce it into the CALF controller of on-board equipment.

The presence of the signal lights in CALF system provides an information link between the dump truck and an excavator. Turning on of signal lights informs the excavator driver about achieving of the optimum load, and he gives an audible signal to the driver to start the movement of loaded dump truck to the unloading place. According to the comments of excavator drivers, the signal lights are not always clearly visible, for example, in good sunny weather, which creates some inconvenience. The authors propose to transmit digital information about the cargo loaded weight on the display of the excavator driver. For this purpose, it is necessary to use a modem connection for mobile objects, working on MESH-technology. Such communication should only work during the loading of the dump truck, i.e. it should be turned on after unloading of the first bucket and turned off simultaneously with the sound signal at the end of load. During the rest of transport cycle, it does not work. For realization of such link the MESH-modem should be included in the CALF structure (see. Figure 1), which should be managed by onboard controller CALF. The same modem with digital display should be installed in the cabin of the excavator driver [9].

#### 4. A method of technological weighing during the dump truck movement

The internal technological accounting is used at mining enterprises for the real-time performance monitor of mining equipment and making operational decisions to improve the efficiency of work. By means of the onboard equipment sets installed on dump trucks, the "Karier" system continuously provides the control room and management personnel of the mining enterprise with information on the current status and technical condition of dump trucks which are situated in the working area; the number of completed laden flights; the mass of the cargo transported in each flight; time of loading, unloading and the run in the laden and unladen conditions; speed; the fuel consumption and others. On the basis of this information, removable reports on all dump trucks are compiled, according to which the mining company's performance indicators per a shift, day, month and pay for employed workers, including drivers of dump trucks, are calculated.

The weighing error of 2.5%, obtained during the loading control, does not fully satisfy the technological weighing, which is the main component of technological accounting. Technological weighing is carried out at open pits, usually on stationary truck scales with a stop of laden dump truck or during its movement at a speed of 5 ... 10 km/h. In the latter case, the maximum permissible error of weighing shall be established: for scales of 1 accuracy class - 0.5%, for 2 accuracy class - 1%. In addition, on-board systems of European manufacturers perform technological weighing with an

accuracy of up to 1%. Hence, in order to meet the standard and level CALF system must perform the weighing process with an error less than 1% [10, 11].

This can be achieved only by performing weighing while the vehicle is moving. Sprung mass of the dump truck together with the cargo under the influence of random disturbances from road profile oscillates around some mean value corresponding to the effect of gravity of cargo on suspension cylinders. The error from the action of dry friction forces will be minimized. Using the average value of the pressure, it is possible to calculate the mass of cargo  $M$  on the basis of the following expression:

$$M = \frac{1}{\tau} \int_0^{\tau} S_f [p_{fl}(t) + p_{fr}(t)] + S_r K [p_{rl}(t) + p_{rr}(t)] \cos \alpha(t) dt$$

where  $p_{fl}$ ,  $p_{fr}$ ,  $p_{rl}$ ,  $p_{rr}$  - the pressure of the gas-oil mixture in the front left, front right, rear left and rear right suspension cylinders respectively, Pa;  $S_f$  and  $S_r$  - rods square of front and rear cylinders,  $m^2$ ;  $K$  - a constructive factor taking into account the effect of rear suspension jet arms;  $\tau$  - the integration time, s;  $\alpha$  - the angle of the longitudinal tilt of the dump truck, calculated as an average over the time  $\tau$ .

The average pressure value is calculated by integrating the signals from the pressure sensors during a time interval, the duration of which is determined by the frequency of gas-oil mixture pressure oscillations in the cylinders of the suspension. It was established experimentally that the integration time must be at least 10÷15 s. During this time laden dump truck overcomes 50÷60 m of track at an average speed 20÷15 km/h.

The integration may be performed either in parallel channels from the four sensors simultaneously or by one channel after summation of signals from the sensors. The second version of integration has been implemented in the test samples of weighing devices designed by Mining University together with NPP "Agrotech" for BelAZ dump trucks with carrying capacity 75 tons or more. Weighing device consisted of a pressure sensor; inclinometer; summation and gain unit and an output measuring device.

Prototype tests were carried out on Tomusinskaya motor depot at Kemerovo Region, OAO "Apatit" and OAO "Karelsky Okatysh". During the tests at OAO "Karelsky Okatysh" the calibration of three weighing devices was performed and their metrological evaluation using control cargoes with a total weight of 121.9 tones. Weighing was carried out during the movement of dump trucks at career roads. Readings were taken during the motion on uphill, downhill and on flat areas. The commission that was conducted the test, included representatives of the metrological service of the enterprise. Weighing accuracy ranged from 0.47% to 1.01%, what corresponds to the error level of stationary means of moving objects weighing. This error completely satisfies the requirements of the technological weighing, which have been formulated earlier.

## 5. Conclusion

According to test results, it was concluded: technological weighing should be performed during motion of the laden dump truck on the horizontal sections of the career road or during the uphill motion. Weighing on the slopes is inadvisable to carry out, as the driver in this mode often uses brake, causing additional errors.

Organization of technological weighing in CALF system does not require any additional equipment. Only the corresponding software will be required, so that all elements of the system work according to a certain algorithm.

The system should operate automatically without external participation, including the driver of the dump truck. The exception is the system on and off modes that the driver performs. The on-board system operates according to the following algorithm.

After the start of dump truck movement to the loading place measuring of the empty dump truck (container) is carried out, which is performed at least three times. The controller calculates the mean value and stores the tare mass. During loading of first bucket the modem connection is turned on and the digital data transmission channel on loaded weight from the dump truck to an excavator is

organized. Communication is turned off after the load of last bucket at the time of alarm signal from an excavator, allowing laden truck to get started. With the beginning of movement the technological weighing mode is turned. In accordance with the signal from the inclinometer, weighing is permitted on horizontal sections or on elevations. Such measurements should be at least six. The controller calculates the average value and subtracts the tare weight, and then displays the result on the display and stores mass carried in flight. After the start of the empty dump truck movement, the tare weight measurement mode is switched on and the algorithm is repeated.

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