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KRZYSZTOF ĆWIERTNIA

A newly patented method for measuring the actual forces of hoist vessel impact on shaft reinforcement

Observations and conclusions regarding a new method of measuring shaft hoist vessel forces acting on the structure of shaft reinforcement are presented in the article. The idea behind this method is the direct absorption of the forces resulting from the impact of the measuring rollers (front and two side rollers) attached to the vessel by the guide and transferring them to the measuring elements, i.e. through a hydraulic actuator, pressure transducer and recorder. The recorder also receives a signal from an optical sensor, which determines the position of the vessel in the shaft. The method allows measuring the actual values of hoist vessel forces acting on shaft reinforcement, without any simplifications, theoretical assumptions and complicated mathematical functions.

Key words: *hoist vessel, shaft reinforcement, impact forces*

1. REFERENCE TO MINING REGULATIONS

The need to measure the impact of shaft host vessel forces on shaft reinforcement results from the requirements of the mining regulations [1] contained in Annex 4 to the *Regulation of the Minister of Energy of November 23, 2016, on the detailed requirements regarding the operation of underground mining plants:*

– "3.13. Rigid guidance of hoist vessels and shaft reinforcement.
– 3.13.7.6. On the dates specified by the maintenance manager, depending on local conditions in the mining plant, but not less frequently than every five years, control measurements and tests are carried out in the following scope:

1) reinforcement elements geometry referred to in point 3.13.6, straightness of vessel routing, lines of guides and angular guides as well as dimensions specified in § 545, § 546 and § 558 of the Regulation; the tests are conducted by the mine surveyor;
2) hoist vessel forces acting on shaft reinforcement, for lines of guides in the shaft, with the applied parameters of hoist vessel ride; the tests are conducted by an expert who prepares an opinion containing the measurement results together with their analysis and determines the conditions for the further operation of the shaft reinforcement elements".

2. CURRENT STATE OF TECHNOLOGY IN THE FIELD OF MEASUREMENTS OF THE ABOVE-MENTIONED IMPACT FORCES

In the first decade of the 21st century, devices utilizing strain gauges with direct readout of the values of hoist vessel forces acting on shaft reinforcement became available on the market; the devices were well suited for measuring static forces but did not meet the expectations regarding the measurements of dynamic (fast-changing) forces.

The currently used methods and measuring devices enable indirect measurement of hoist vessel forces acting on shaft reinforcement in mining plants. Some of them involve measuring the horizontal acceleration of hoist vessel displacement carried out by means of acceleration transducers [2]. The essence and most uncertain element of these methods is determination of the hoist vessel mass impacting the shaft reinforcement by means of mathematical functions containing theoretical and barely verifiable assumptions and coefficients. Other methods are based on laser distance measurement or other parameters, which are then converted into the values of "theoretical" impact forces.

OPA Bytom Sp. z o.o. has developed a new method of measuring actual hoist vessel forces acting on shaft reinforcement [3], involving the direct measurement of a physical quantity (pressure), which after conversion according to the formula:

$$F = p \cdot S,$$

where:

- F – force,
- p – pressure,
- S – piston surface in the cylinder,

is directly proportional to the value of the existing impact force and is calculated without taking into account any theoretical assumptions and coefficients.

3. DESCRIPTION OF THE MEASURING DEVICE

In the first stage, we constructed a device called "OPA-B-2018 shaft dynamometer", which is only used for measuring frontal impact forces, because according to the available literature in this field, the recorded values of hoist vessel frontal forces acting on shaft reinforcement are usually greater than lateral forces.

The main elements of the device include the following (Fig. 1):

- roller (1) – a rotating wheel with a diameter of 300 mm,
- longitudinal guide (2) used to shift the bearing-supported rotating roller in a plane perpendicular to the frontal area of the guide,
- hydraulic actuator (3),
- pressure transducer with a recorder (4),
- adapter (5) used for attaching the dynamometer to the structure of the hoist vessel,
- girder counter (6) used for determining the location/depth in the shaft.

The OPA-B-2018 shaft dynamometer, both in terms of its design and measurement method, is a new solution used for determining the value of hoist vessel forces acting on shaft reinforcement in mining shaft hoists. According to current knowledge, it is the only device on the Polish market that enables the reliable measurement of actual impact forces. The OPA-B-2018 dynamometer consists of a measuring roller (1) with a diameter of 300 mm. Mounted under the frame of the hoist vessel head, it takes over the task of the front guide of the vessel head, which for the duration of measurements is moved ca 10–15 mm away from the working position, thus playing a protective role together with a cast steel slide.

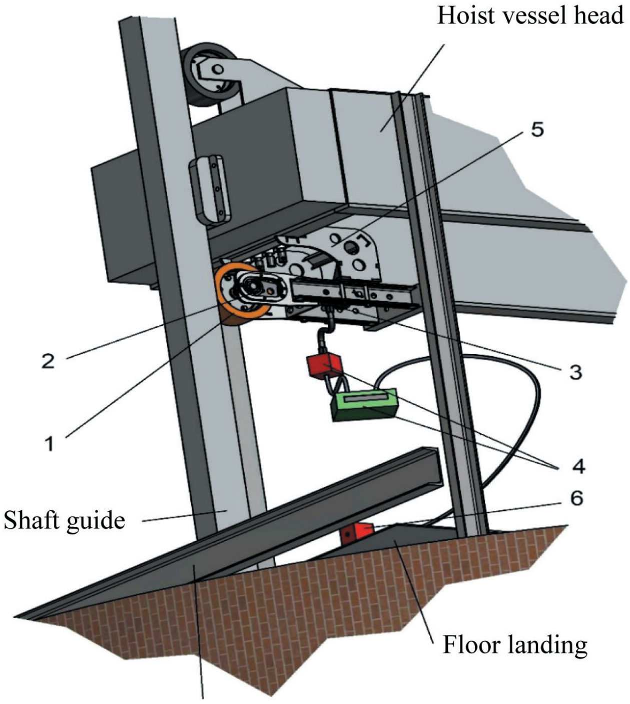

Fig. 1. Diagram of the OPA-B-2018 dynamometer installation under the head of the hoist vessel

The measuring roller with its bearing can move along the guide (2) – on the extension of the axis of vessel frontal forces acting on the shaft guide. Movement of the measuring roller (1) resulting from the action of the above-mentioned forces is transmitted to the piston of the hydraulic cylinder (3), generating a change of pressure which is measured by a high-class pressure transducer (4); next, the result converted into a force value ($F = p \cdot S$) and is recorded by a computer program.

As a result, a graph of the force value as a function of the path (depth in the shaft) is obtained. The position of the hoist vessel in the shaft is determined by a girder counter (6) installed next to the dynamometer. It counts the girders passed in the shaft, which are the reference of the distance in relation to the surface level. A signal from the above-mentioned sensor together with a signal of the measured value of the hoist vessel impact force is recorded directly by the computer program, which presents these quantities in the form of a graph. The dynamometer is attached to the hoist vessel by means of an adapter (5), which can be modernized depending on the design of the hoist vessel.

4. MEASUREMENT METHOD

The essence of the measurement of hoist vessel impact on shaft reinforcement using the OPA-B-2018 shaft dynamometer is the direct absorption of the measuring roller (1) impact by the guide, which is an element of shaft reinforcement, during the travel of the hoist vessel, and transferring this force to the measuring element, i.e. a hydraulic actuator (3) connected with a pressure transducer (4) cooperating with the computer program, to which a signal from the girder counter (6) is transmitted so as to determine the position of the vessel in the shaft.

The detailed manner in which the hoist vessel forces acting on shaft reinforcement by means of the OPA-B-2018 dynamometer are measured is presented below:

- After positioning the top floor of the hoist vessel on the surface level, the above-mentioned dynamometer with measuring equipment (4 and 6) is mounted to the structure under the vessel head by means of an adapter (5).
- Next, the measuring roller (1) is set in the working position of the original front guide of the hoist vessel. Then, the entire dynamometer structure is secured against possible movement by means of a vertical hydraulic strut, rigidly connected to the rear part of the dynamometer. The chains attached to the elements of the hoist vessel structure ensure additional protection that prevents the dynamometer from moving beyond the outer contour of the vessel.
- To obtain the correct indications and operation of the measuring system (using the proportional dependence of the value of the measured vessel force impact on the pressure change in the hydraulic cylinder, which is an important element of this measuring method), the initial operating pressure of 0.5–1.0 MPa is applied to the cylinder by means of a manual pressure pump.
- Next, the hoist vessel head is moved to the surface level and the position of the front guide is changed on the side where the dynamometer is installed. This guide is moved approximately 10–15 mm away from the working position so that the outer surface of its tread is aligned with the frontal plane in the immediate vicinity of the cast steel sliding guide. The alignment of the position of the outer plane of the front roller tread and the cast steel sliding guide provide protection for the measuring roller of the OPA-B-2018 dynamometer in the event of the overload of the measuring system. The aim of the described change of the front guide position is to enable the absorption of the entire front force of the hoist vessel impacting the guide by the measuring roller of the dynamometer (1) previously mounted under the vessel head.
- After checking the efficiency of the dynamometer and measuring equipment, the expert and the auditor travel through the shaft on the hoist vessel floor at a speed of 1 m/s, in order to check both the effectiveness of the dynamometer structure mounting and the correctness of the measuring equipment indications.
- Upon completion of the test run, the hoist vessel is loaded with a useful load, the recorder is switched on and a ride through the shaft at the permissible speed is begun.
- Upon completion of measurements, the dynamometer and the measuring equipment are disassembled, and after the vessel head has been positioned on the level surface, the front guide of the vessel is shifted to its working position (it is returned to the state before the measurements of forces was initiated).

– Next, the same steps are taken to measure the vessel forces acting on the guides (shaft reinforcement) – on the opposite side of the vessel head.
– Based on the obtained measurement results, an analysis is carried out and, if necessary, the safety factors of the shaft reinforcement of individual elements are recalculated.
– During some measurements, an accelerometer was additionally installed in the hoist vessels for research purposes so as to enable the recording of accelerations as a function of the position in the shaft.

The correctness of the OPA-B-2018 dynamometer indications of impact force were tested in the ITG KOMAG accredited applied research laboratory, which concluded that the above-mentioned measuring device can be used for measuring the impact of hoist vessel forces acting on the shaft reinforcement structure. The digital recorder sampling frequency is 20 kHz and the maximum delay time of the force measuring system determined during the tests in the above-mentioned accredited laboratory is 2.5 ms, whereas the maximum difference between the force determined on the basis of the measured pressure and the directly recorded force did not exceed 5% of the obtained value.

In addition, a patent application for the OPA-B-2018 dynamometer was filed with the Patent Office under the number P.428789 entitled "Method and device for measuring hoist vessel forces acting on shaft reinforcement" – Ref.: OPA.B.SZYB.19. The device was granted patent No. 237918.

5. MODERNIZATION OF THE OPA-B-2018 DYNAMOMETER

In the second stage, the dynamometer structure was modernized by strengthening its adapter and equipping it with two additional rollers used for measuring hoist vessel lateral forces acting on shaft reinforcement. The measurement of lateral forces was based on the same principles as the measurement of frontal forces, i.e. the measurement of the pressure change in the actuators caused by the impact of the side rollers on the shaft guide.

In the further part of the article, photos of the measuring device structure and the method of its mounting on the hoist vessel are presented (Figs. 2 and 3).

As in the case of the first version of the OPA-B-2018 dynamometer, the modernized measuring device equipped with three rollers was also subjected to tests in terms of the correctness of indications of the values of impact forces (both frontal and lateral) under conditions of static and dynamic loading in the ITG KOMAG accredited applied research laboratory. The subsequent photos show the dynamometer on the test stand (Fig. 4).

Fig. 2. Construction of the measuring device installed on the hoist vessel

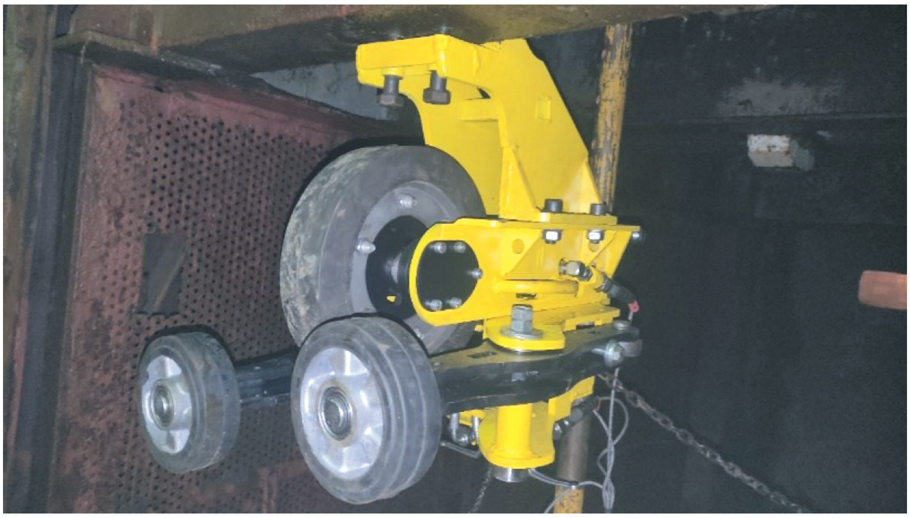

Fig. 3. Method of mounting the OPA-B-2018 dynamometer under the hoist vessel head

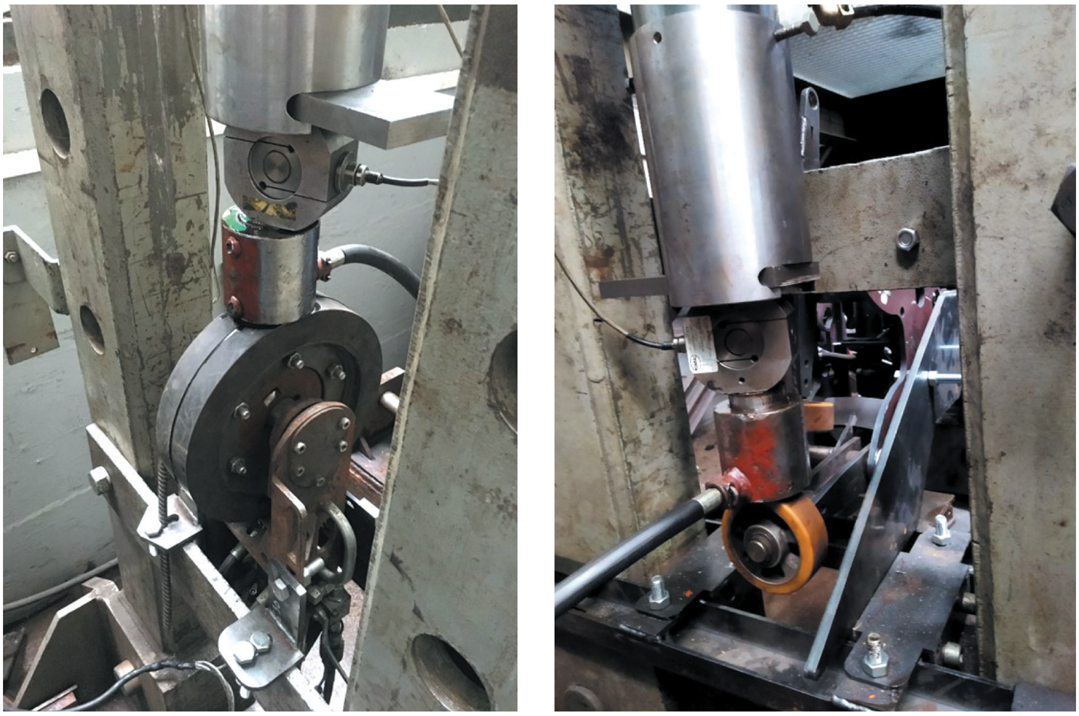

Fig. 4. Elements of the OPA-B-2018 dynamometer on the ITG KOMAG test stand

6. OBTAINED RESULTS

To date, measurements of forces have been carried out in 27 mining shaft hoists, both in coal and copper mines. The diagrams below (Figs. 5 and 6) show the frontal and lateral forces during the hoist vessel ride through the shaft, both up and down.

These charts indicate that during the hoist vessel ride, both downwards and upwards, the measuring device shows similar characteristics of the variable distribution of impact forces in the same regions of the shaft. This repeatability proves the correctness of the method and its sensitivity to changes in the straightness of the tracks and the related dynamics of the hoist vessel. Comparative measurements of impact forces (in the same shaft hoist, with the same operation parameters) carried out by various methods in 2009 by four market-leading expert companies revealed a discrepancy in the obtained results of up to 500%. Our method, as the only one on the market, is based on measuring a physical quantity (pressure) that is directly proportional to the impact force, which gives it an advantage over other methods currently used.

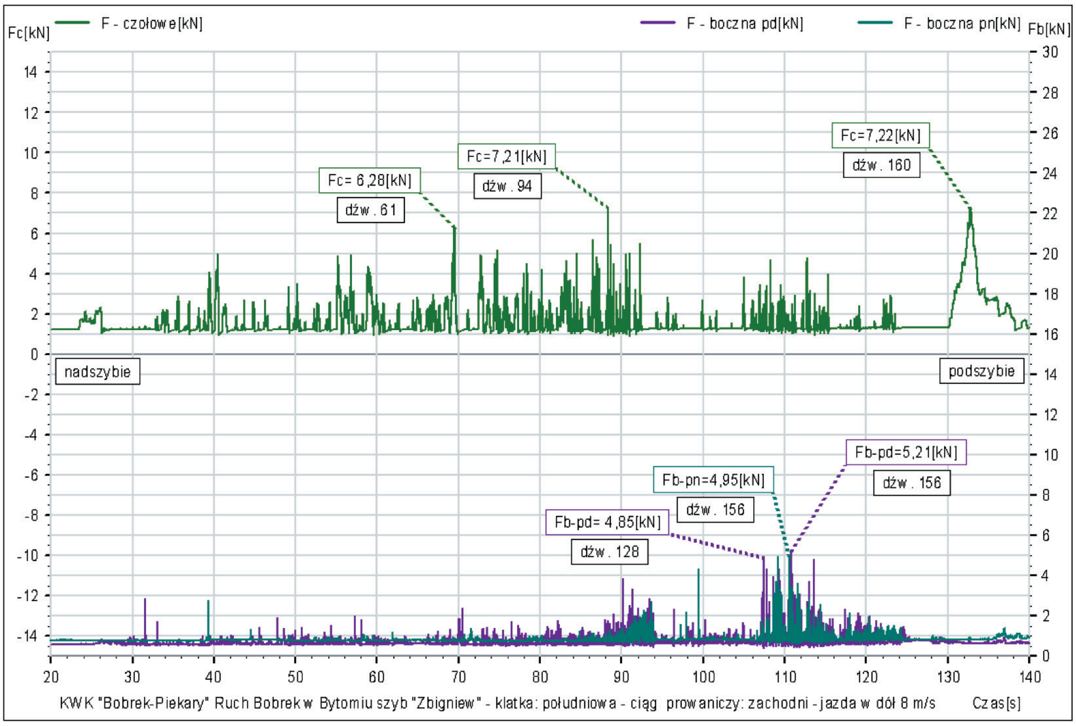

Fig. 5. Graph of the frontal and lateral forces during the downward ride of the hoist vessel

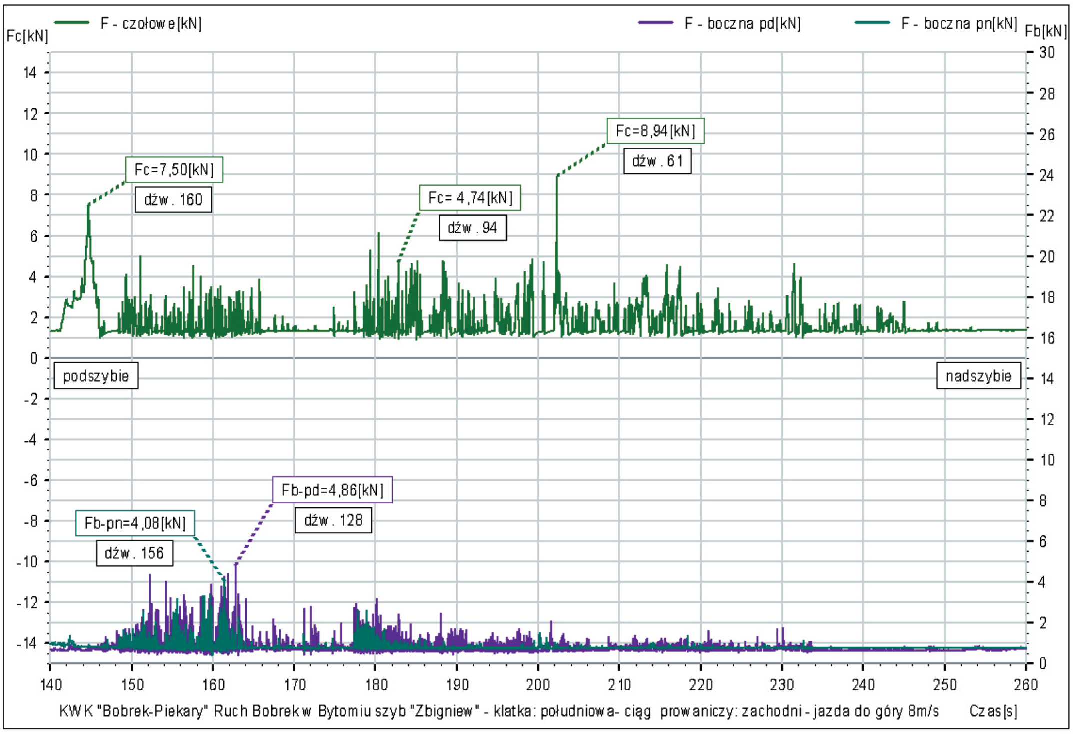

Fig. 6. Graph of frontal and lateral forces during the upward ride of the hoist vessel

7. CONCLUSIONS

Measurements carried out with the modernized OPA-B-2018 dynamometer allowed the following conclusions to be drawn:

1. It general, it has been confirmed that lateral forces do not exceed 80% of frontal forces.
2. It cannot be assumed that the values of the measured accelerations of the hoist vessels are directly proportional to the values of the forces that cause them, which was found by comparing the diagrams of forces and accelerations of the hoist vessel as a function of the location in the shaft.

3. The method presented above:
   - is based on direct measurement of a physical quantity (pressure) that is convertible (using the well-known formula $F = p \cdot S$) into a force value;
   - has a specific measurement accuracy (verified in an ITG KOMAG accredited laboratory);
   - is more reliable than methods based on accelerometric measurements or on the variability of the distance between the sliding guides and the shaft guide, in which the conversion of the measured value of a physical quantity into a force value requires the use of theoretical assumptions or coefficients and is difficult to verify;
   - currently it is the only method on the market that has been verified by an accredited laboratory with regard to the accuracy of measurement of the impact of actual forces of hoist vessels on shaft reinforcement in mining shaft hoists.

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KRZYSZTOF ĆWIERTNIA, Ph.D., Eng.
OPA Bytom Sp. z o.o.
ul. Strzelców Bytomskich 87b
41-914 Bytom, Poland
krzysztof.cwiertnia@opabytom.pl