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Measurements of rope elongation or deflection in impact destructive testing

Adam Szade[*], *Mariusz Szot*, *Adam Ramowski*

Central Mining Institute, Plac Gwarków 1, Katowice, 40-166, Poland

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ABSTRACT

The computation of energy dissipation in mechanical protective systems and the corresponding determination of their safe use in mine shafts, requires a precise description of their bending and elongation, for instance, in conditions of dynamic, transverse loading induced by the falling of mass. The task aimed to apply a fast parallactic rangefinder and then to mount it on a test stand, which is an original development of the Central Mining Institute's Laboratory of Rope Testing in Katowice. In the solution presented in this paper, the measuring method and equipment in which the parallactic laser rangefinder, provided with a fast converter and recording system, ensures non-contact measurement of elongation, deflection or deformation of the sample (construction) during impact loading. The structure of the unit, and metrological parameters are also presented. Additionally, the method of calibration and examples of the application in the impact tests of steel wire ropes are presented. The measurement data obtained will provide a basis for analysis, the prediction of the energy of events and for applying the necessary means to maintain explosion-proofness in the case of destructive damage to mechanical elements in the mine atmosphere. What makes these measurements novel is the application of a fast and accurate laser rangefinder to the non-contact measurement of crucial impact parameters of dynamic events that result in the destruction of the sample. In addition, the method introduces a laser scanning vibrometer with the aim of evaluating the parameters of the samples before and after destruction.

1. Introduction

The calculation of energy dissipation in the mechanical protection system made from stretched ropes, composing the artificial bottom of the shaft, requires precise measurement of bending and extending of the rope during the fall of dynamic load weight. The computation of energy dissipation in the mechanical systems, which are for instance made from austenitic steel (Akai, Shiozawa, Sakagami, Otobe, & Inaba, 2012), including the application of novel measuring technologies, such as thermovision and lasers (La Rosa & Risitano, 2000; Lipski & Mroziński, 2008; Pieczyska, 1999), can be found in the methodology of testing of monotonic or cyclic tensioning of steel samples. Designing steel protective systems, and consequently creating the framework for their safe use in the shaft and other mine workings, requires a precise description of the bend and elongation, e.g. of the rope, in the course of dynamic, transverse or longitudinal loading with falling mass. These are the tests that determine the capability

* *Corresponding author*. Tel.: +48 32 259 22 40.
E-mail addresses: aszade@gig.eu (A. Szade), mszot@gig.eu (M. Szot), aramowski@gig.eu (A. Ramowski).

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of the material for transmitting sudden impact loads. The most frequently applied impact tests are the impact bending test and the impact elongation test.

Impact tests are carried out with the aim of assessing the behaviour of the material in conditions that give rise to the brittle cracking produced in the sample by a high rate of deformation, due to the dynamic action of force and temperature.

When testing the impact resistance of steel wire ropes, the parameter of dynamic elongation in the time up to the moment of breaking is of particular importance. The short amount of time and a high amplitude acceleration energy require a device that will reliably measure these parameters as a function of the force acting at the time.

For the purposes of such measurements, the Central Mining Institute's Laboratory of Laser Technology (in Katowice) has developed a measuring unit which makes use of a fast parallactic rangefinder. The principal issues were its metrological parameters (including signal recording and analysis) and, also, its size and resistance to electromagnetic and mechanical interference. This resulted in the rangefinder being contained in purpose-designed casing and holders. After the laboratory calibration testing was completed, initially in the accredited Laboratory of Technical Acoustics, the whole measuring system was installed in the testing stand of the institute's Rope Testing Laboratory.

The ropes used in the tests were composed of a core wire which had one layer of round wires wound around it. Such ropes (called single-lay) are characterized by small elongation and high stiffness. Their main technological parameters are their angle of lay, multiplicity of pitch, and coefficient of lay. Constructional and technological parameters are strictly interrelated and they determine the final characteristics of the rope. The ropes are generally produced from carbon steel, with a carbon content in the range of 0.33–0.98%. The requirements for round wires intended for the production of strand ropes are included in the standard PN-ISO 6984. The material for the wire is smelted in an OH furnace or electric furnace, by using a basic oxygen process or an equivalent method. The ready-made wire must not have either surface or internal defects that may adversely affect its use. In cases where this has not been specified, the wires must be zinc covered. The zinc applied must have a cleanness of 99.9%. Steel with other chemical compositions with enhanced corrosion resistance are currently only applied in a small scale. Their composition depends on the ropes application and its working conditions, typically, being chromium–nickel steel with a low carbon content ($C = 0.12\%$). For high-strength wires, high-carbon steel is used, with a carbon content not lower than 0.75%.

The most popular ropes are those produced from 6 round strands helically wound around the core. The strands may contain 1–4 wire layers, in the case of the single wire ropes tested.

2. Methods

2.1. *Mechanical strength testing methods*

The static experimental testing of real rope-breaking force is conducted in full on the testing machine, calibrated to class I accuracy, of WPM-Leipzig, with a measurement range of 0–5000 kN. This machine has a horizontal layout and a manual-control hydraulic drive.

The rope section being tested is fastened in the holders of the testing machine, and then loaded starting from an initial force of P_0 up to breaking point. Simultaneously, the elongation of the rope and the rise of the load are measured. The test is assumed to be completed when the break of a strand occurs, so in this case, the breaking of only one wire. The procedure is applicable to steel ropes with a diameter of up to 70 mm.

Dynamic loads differ from static loads. The resistance and reaction load are different (Siemieniec et al., 2002). Tests conducted in the Central Mining Institute, e. g on rock bolts at impact loads, have confirmed the difference between mechanical strength parameters, determined on their basis, and parameters determined in static tests (Pytlik, 2002). As an example, the energy that is needed for the penetration of laminate in dynamic conditions can be several times higher than that for static penetration (Barcikowski, 2012).

The impact phenomena may differ depending on the value of velocity, energy and mass of the impactor, mass of the target, geometrical characteristics, such as shapes of the bodies taking part in the process, or the direction of the velocity vector relative to principal directions in the sample. Here, the impact velocity is of particular importance (Zukas, 1990).

The GIG Laboratory for Testing Mechanical Equipment has a testing stand in which the impact mass falls from a given height on to a cross bar that preliminarily loads the ropes being tested, in two variants of fastening (Fig. 1). One is used for the impact test of transverse loads, and the other for longitudinal loads. The design of the testing stand also imposed a method for mounting a rangefinder. It was assumed that the laser sensor would be installed on fixed base elements of the machine, either under or over the cross bar. Variants of the measuring sections (red arrows) are shown in Fig. 1.

The method relies on a single impact by dynamic force produced by the mass falling on the initially loaded rope mounted in the test stand, with a simultaneous measurement of load, displacement and time up to the moment of breakage. The *Spider 8* recorder was used with a HBM measuring amplifier (DMCplus) and provided with A/D converters (HBM Operation Manual, 2002) to which force sensors and a laser displacement sensor were connected.

The test stand with construction elements for impact tests of transverse and longitudinal loads of steel wire ropes and the same configuration as in Fig. 1 can be seen in Fig. 2.

The deformation measurements of mechanical elements in impact destructive testing were performed for ropes composed of 6 round strands which are wound helically around the core.

Steel wire ropes and other flexible connectors are not able to resist bending, nor are they able to transfer compressive loads. Tensile forces, and consequently stresses existing in the ropes (flexible connectors), fastened in two points should be calculated according to the formulas of theoretical mechanics, taking into account the form of sag as the chain curves.

Impact phenomenon is produced through the contact of at least two bodies which have different velocities. The forces which occur during this contact are called instantaneous. They act in a very short time and reach very high values. They