Evaluation of elements loading in the metal structures of powered support units

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Abstract. In the paper the evaluation results of elements loading in the metal structures of powered support units are presented performed in the laboratory and plant conditions using the developed test samples of portable strain-gauge transducers on the basis of a spring element and a mobile multifunctional automated strain-gauge system.

1. Introduction

Performance of the units of powered roof support, operating elements of heading and shearing machines and other mining equipment to a large extent depends on the safety margin provided by design, manufacturing quality, nature and magnitude of operational loads, timely repair and restoration work.

Possibility of the rapid assessment of actual loads acting on the elements of metal structures both at the stage of manufacturing during the strength tests and during the operation is important for the improvement of existing equipment and development of new one.

Metal structures loading is characterized by a set of acting loading forces and can be assessed through deformations and stresses on the surfaces of their element and in the joints.

At present the existing method of strain-gauge control used during industrial tests does not allow the location of deformation measurements of the investigated metal structures surfaces to be immediately corrected due to impossibility of the repeated use of the gluing strain gages as the primary measuring transducers (PMT). Besides, the gage sensitivity factor $k$ of the used wire strain gages made of constantan and nichrome is usually not higher than 2-2.5 units.

Thus, the question of direct assessment of the elements loading in the metal structures of powered support units is not fully resolved and has prospects for its development. One of the decisions, which allows the PMT mobility to be provided, i.e. possibility of its transfer and reinstallation, is to use the portable tensometric transducer (PTT) with an elastic element. However, inclusion of the elastic element into the measurement system greatly reduces the transducer sensitivity [1]. In contrast to the traditionally used strain gages, which are associated with the control object by every point, the sensitivity and metrological characteristics of PTT directly depend on the elastic element design, fixing method and the strain gauges used.
2. Development and methodology
In FRC CCC SB RAS laboratories of coal mechanical engineering, coal deposits geo-
mechanics the development and experimental implementation of a technical complex used for
diagnosis of the coal mines and open pit mines equipment [2]. By the present moment, the
software and instrumental complex of a mobile multi-function automated strain gage system
(MFATS) and PTT with an arch type of elastic element are brought to practical
implementation in the form of prototypes.

As part of this work, in order to identify the geometric parameters of the arch elastic
element, providing maximum sensitivity of the PTT, a study of influence of the elastic
element configuration on deformation level in the strain gage installation zone was carried
out. Sensitivity of the elastic element in the general form is characterized by the deformation
level in the strain gages installation zone at similar deformations of the control object. As a
result, the configuration of the arch PTT elastic element with a base of 100 mm with a
concave arch of variable section and radial arches conjugation, as shown in Figure 1, is
substantiated. Calculation of geometric parameters of elastic elements models was made by
the finite element method.

Depending on the stated tasks of analysis two methods for fixing the elastic element on th e
control object surface are proposed and tested. The first one – the elastic element with the
threaded connection is secured by special screw stands, which are reusable glued platforms
with a threaded element. The second one – the elastic element is fixed to the surface with the
permanent magnets made of the magnetic alloy NdFeB. It is more appropriate in cases of
short-term static loads, such as the experimental determination of the of metal structures
elements deformation.

![Figure 1. Test samples of arch PTT: 1 – elastic element, 2 – strain gage installation zone, 3 –fixing
elements, (screw stands are shown), 4 – connectors, 5 – connecting wires.](image)

The main characteristics of PKS type (Russia) and KSP (Japan) are studied in statics and
dynamics in relation to the strain gages for PTT with the use of certified instruments and
equipment of Siberian Aeronautical Research Institute n.a. S.A. Chaplygin [3] (installation for
of the glued strain gages, certificate RU.E.28.007.A No. 27992, GRSI No. 34927-07 and
tenso-system MMTS-64.01, certificate RU.C.34. 007. A No. 44412, reg. No. 21760-01) [4]. It
is shown that semi-conductor KSP strain gages can be used to measure the structures relative
deformations including short-time shocking processes.

As a result, on the basis of KSP strain gages and the proposed configuration of the arch
elastic element PTT are manufactured on a screw stand and magnetic mount. Based on the
research of static characteristics of the manufactured PTT the calculation of tensor-sensitivity coefficient values $k_i$ by the formula was made:

$$k_i = \left| \frac{(N_{\text{maxi}} - N_{0i}) + (R_{0i} - R_n)}{K_{\text{coni}} R_n \cdot \varepsilon_{\text{max}}} \right|$$  (1)

where $N_{\text{maxi}}$ – value of the measuring tenso-system code for $i$-th PMT at maximal deformation; $N_{0i}$ – value of the measuring tenso-system code for $i$-th PMT on the unloaded beam; $K_{\text{coni}}$ – conversion factor for $i$-th channel of the measuring tenso-system; $R_{0i}$ – resistance of $i$-th PMT with the unloaded beam; $R_n$ – rated resistance of $i$-th PMT; $\varepsilon_{\text{max}}$ – maximal relative beam deformation.

For PTT $k_i$ when mounted on a screw stand was 29.76, with pressure (magnet) mounting – 26.71, that in spite of elastic element influence greatly exceeds $k$ value of standard PKS-type strain gages.

Next, operation of the test sample of mobile tensometric system and PTT was checked on the metal structure element of powered support unit in laboratory conditions and also in the process of assembling the powered support unit in the industrial conditions. MFATS prototype includes PTT, transmitter, ADC, computer software “Stend-Info” for registration, visualization, and analysis of experimental data (FIPS certificate No. 2011618442).

Testing method development of deformation rapid analysis by the output MFATS prototype signal $U_{\text{out}}$ was performed with the help of a lateral bending of the metal structure weld sample at the laboratory loading bench (Figure 2a). As a sample the powered support unit MKYu.2U-12/25 traverse lever was used. Deformation evaluation of the lever front surface in twenty five control zones is presented. With this aim the researched front surface conventionally as a matrix was divided into control areas according to Figure 2b.

![Figure 2. Rapid analysis of the unit MKYu.2U-12/25 traverse lever in laboratory conditions: a – laboratory loading bench with MFATS prototype equipment, b – partitioning scheme of traverse lever front surface of the unit MKYu.2U-12/25 into control zones.](image-url)
The idea of the method consists in fixing the PTT with the magnets at each control zone on metal structure surface and registration of output $U_{out}$ signal which characterizes deformations along the axis coinciding with PTT axis when the sample is loaded.

Testing of the MFATS prototype at Yurginsky Machine Engineering Plant was carried out during the test of powered support unit MKYu.2U-07/19 at the “Gluckauf” bench for research and certification tests of powered support units in accordance with GOST R 52152-2003 (Figure 3).

With this purpose at the control points of the roof lower surface of the powered support parallel to the authorized tensometric system with the glued tenso-resisters of PKS type – 5 TPP – 1 and the equipment of mobile tensometric system were installed: transmitter – 2, ADC – 3, temperature indicator – 4, as it is shown in Figure 3b.

![Figure 3](image.png)

**Figure 3.** MKYu. 2U-07/19 unit at the loading test bench “Gluckauf” of LLC “Yurginsky Machine Engineering Plant”: a – with the installed PTT and MFATS prototype equipment, b – PTT and strain gages (PKS type) layout in the control zones of the roof lower surface.

After this the support unit loading cycle was conducted at the bench for the application of conformity scale between the MFATS prototype – $U_{out}$ signal and mechanical stresses values at the control points. The support unit material is 30HGSA steel. Such mechanical calibration
was carried out on the basis of standard tensometric system data. As a result of the loading cycle the calibration chart of the MFATS prototype is built (Figure 4).

![Calibration chart](image)

**Figure 4.** Calibration chart.

For the current level $K_{coni}$ of the MFATS measuring transducer the dependence of mechanical stresses $\sigma$ of the surface on $U_{out}$ MFATS was expressed as:

$$\sigma = 1.149 - 249.1 \cdot U_{out}. \quad (2)$$

After that the support unit according to the methods approved by the plant was loaded in a stepwise manner until the pressure in the props became equal to 5, 17, 26, 34, 39, 43, 46, 49, 52 and 56 MPa with the intermediate unloading up to 5 MPa. In the process of sample testing MFATS prototype $U_{out}$ in the control points depending on the load for each of the installed PTT.

3. Results and discussion

The data acquired as a result of the rapid analysis are summarized in the surface chart shown in Figure 5a, which allows the actual deformed state of the studied front surface to be visualized. These data allow the comparison of evaluation with the results of the modeling of this loading by the finite element method to be performed (Figure 5b).

According to the results of numerical error estimation of lever surface rapid analysis it is stated, that relative measurement error was less than 12%.
On the side lever surface such rapid analysis allowed to determine not only the amount but also the type of deformation (expansion/contraction) for each control zone, depending on the longitudinal or transverse surface partition.

Figure 5. Rapid analysis method: a – the output stress $U_{out}$ in the study of the lever front surface along the axis $x$ under load, b – the calculated values of equivalent deformations of support unit lever when loaded on the bench by finite element method.

Test results obtained in the industrial conditions allowed the mechanical stresses dependence in the control points of the load for each of the installed PTT to be received. It was determined that maximum stress value according to the PTT data totaled 428 MPa (Figure 6).

In the comparison of the evaluation of the measurement results with the calculated values the average data error did not exceed 5.1 % for the PTT.

Figure 6. The character of stress changes, registered by the installed PTT on the left (PTT1) and right (PTT2) side of the roof section.
When comparing the obtained data with the results of the regular strain gauge system the errors for PTT were not more than 2%. Wherein PTT may be repeatedly used and replaced along the studied surface in order to adjust the measuring area and for the rapid assessment of the controlled object loading.

4. Conclusions
The use of modern semiconducting materials and nonlinearity characteristics of compensation software algorithms allow highly sensitive PTT to be created, which help to study the elements loading in the mining machines metal structures under static loads at the bench. It can be used as an experimental supplement to the theoretical and practical evaluation and forecasting of the elements loading of powered support unit in the working face [5].

The proposed rapid analysis using the developed arched PTT allows the deformation along the axis to be assessed at any place of the studied element flat surface of metal structure, which coincides with the PTT axis with an error of no more than 12%. It can be used for an operational definition of the greatest deformation zones of elements in the metal structures of mining equipment or for pre-visualization of the deformed state of control object.

The proposed prototype of a software-instrumental complex of mobile strain gauge system when placing PTT on the inner surfaces of roof planes, bases, arm traverses and powered support section guards provides measurement of mechanical stresses of metal structures the in the range from 0 to 450 MPa with an error of no more than 6% from the calculated values.

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