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DEVELOPMENT OF CONICAL PROBE FOR STRESS MEASUREMENT BY BOREHOLE OVERCORING METHOD

Lubomír STAŠ *, Jaromír KNEJZLÍK and Zdeněk RAMBOUSKÝ

Institute of Geonics, Studentská 1768, 708 00 Ostrava-Poruba
* *Corresponding author's e-mail*: stas@ugn.cas.cz

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ABSTRACT
We have been engaged in the stress measurement in rock massif by the hydrofracturing method. This method enables measurement of stress in plane normal to the axis of bore, when one of the principal stresses parallel to the axis is assumed. But, in complex geo – mechanical conditions connected with the geology and mining action, the parallelism of the principal stress to the axis of borehole can not be assumed with certainty. That is why we decided to develop a device making the determination of the total state of stress tensor possible.
In design we started from experiences of K.Sugawara and Y.Obara that have been using the compact conical borehole overcoring system CCBO. Conical shape of the strain gauge probe CCBO makes the fixation of the probe in borehole easy and makes the measurement of stress in independent directions possible.
In this paper the principle of the measuring method and developmental sample of the apparatus, the objective of which is making the continual measurement of stress in course of overcoring possible, is described.

KEYWORDS: stress measurement, stress tensor, overcoring, CCBO, field measurement, design of equipment, strain gauges, optical communication

INTRODUCTION

Detection of stress condition in rock massif is one of basic conditions of successful solving of numerous projects within domain of underground construction both of exploratory and technology service nature. Rough estimates of stress field based solely on assumption of elastic behavior of rock massif and derived only from corresponding geostatic load can be very unfavorably affected in view of accuracy especially in tectonically faulted areas, or in areas disturbed by mining activity, or eventually in areas influenced by additional forces due to geological actions.

In Institute of Geonics of AS CR we have dealt for a number of years with problematic of detecting of stress condition of in situ rock massif, above all in Czech part of Upper Silesian hard coal basin. Predominantly measuring equipment based on hydraulic fracturing of borehole walls has been applied. This equipment is featured by many advantages, but also by many limitations. One of its principal limitations among other is practical impossibility of measuring of absolute stress tensor in a given location. We decided, therefore, to develop some other equipment, which in a given case would enable such kind of measurement.

The newly developed equipment is based on well-known principle of stress measurement based on evaluating of deformation changes of drill hole core by means of overcoring method. We apply the CCBO modification of the method (compact conical-ended borehole overcoring) designed and tested in Japan by professor Sugawara and by professor Obara.

The choice of conical shape of surface to be measured is actually a compromise between other types of this kind of stress measuring method. By this approach the advantages have been merged both of possibility of measuring of absolute stress tensor in a single place and of a simple installation which is additionally featured by self-centering effect and by a relatively short compact section necessary for overcoring with full relieving. A disadvantage is that the evaluation is possible only by numerical methods, but at present this is not a problem, which cannot be solved.

MEASURING PRINCIPLE

Into a special cone form adapted borehole bottom the conical probe with a set of metal strain gauges on its lateral area is cemented in. The cone form safeguards various orientation of measuring strain gauges in space, by a sufficient number of which it is possible after overcoring to reconstruct the total stress tensor. A schematic representation of arrangement of strain gauges on measuring probe is shown in Fig. 1.

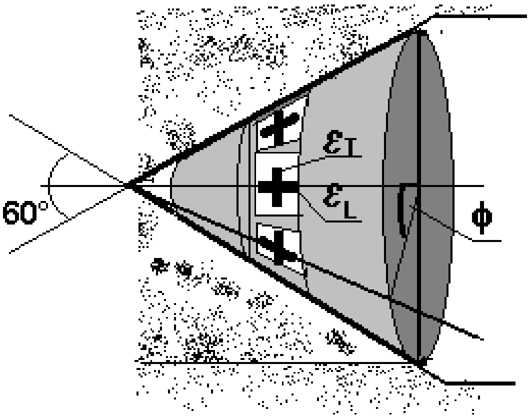

Fig. 1 A schematic representation of arrangement of strain gauges on measuring probe

In our case of application six pairs of mutually perpendicular strain gauges, uniformly distributed on lateral area of cone have been applied. For calculation of original ambient stress the strain gauges by which deformation of lateral area of cone in direction of its gradient from apex to base is measured shall be designated by "L" and the strain gauges by which tangential deformation of surface of lateral area of cone area is measured shall be designated by "T". As mentioned by Kang the transformation of stress tensor to deformation on cone is given by the following relations:

$$|\varepsilon_T| = \begin{vmatrix} A_{11} + A_{12}\cos 2\Phi, & A_{11} - A_{12}\cos 2\Phi, & C_{11}, \\ A_{21} + A_{22}\cos 2\Phi, & A_{21} - A_{22}\cos 2\Phi, & C_{21}, \end{vmatrix}$$

$$\begin{vmatrix} D_{11}\sin\Phi, & D_{11}\cos\Phi, & 2A_{12}\sin 2\Phi \\ D_{21}\sin\Phi, & D_{21}\cos\Phi, & 2A_{22}\sin 2\Phi \end{vmatrix} \{\sigma\}/E \qquad (1)$$

where:
$\{\sigma\}$ is stress tensor in format $\{\sigma_x, \sigma_y, \sigma_z, \tau_{yz}, \tau_{zx}, \tau_{xy}\}^T$
E is Young's modulus of elasticity
$\varepsilon_T, \varepsilon_L$ are deformations on lateral area of cone in places of strain gauges
Φ is angle of rotation of corresponding strain gauge towards selected direction x
$A_{nm}, \cdots, D_{kl}$ are coefficients of deformation

The values of coefficients of deformation depend on geometry of probe ad on Poisson's ratio. They are not represented analytically and they are determined numerically. With regard to the fact that our probe has had essentially the same geometry as the probes of Sugawara and Obara we can equally use the same table values of deformation coefficients for isotropic environment, as had bee applied by them, see Table 1.

The calculation of stress tensor itself is performed by optimization of its form by least square method of differences of measured and calculated deformations in individual measuring points.

The original tensor of stress can be expressed by the following matrix equation:

$$[A]\{\sigma\} = E\{\varepsilon\}, \qquad (2)$$

where [A] is matrix of dimension nx6. The elements are calculated by substitution of corresponding coefficients and angles of rotation Φ_n to strain gauges in corresponding relations (1).

After normalizing and adapting of the relation we will obtain the equation representing the most probable form of original stress tensor (Kang):

$$\{\sigma\} = E\left([A]^T [A]\right)^{-1} \left([A]^T \{\varepsilon\}\right) \qquad (3)$$

DESCRIPTION OF EQUIPMENT

The equipment is constructed for boreholes of 76 mm diameter. It consists of three co-operating instruments – see block diagram in Fig. 2.

The strain gauge probes bonded up within borehole scans and evaluates the deformation in real time of overcoring. The communication device fixed in rear part of core barrel will safeguard transmission of measuring data from strain gauge probe to data recorder or to data concentrator (DR). The strain gauge probe and scanning device are not interconnected, neither mechanically nor electrically. The transmission of information proceeds by optic way. In this way the basic technological problems has been solved: (a) dangerous loading of measuring head by mechanical impacts during drilling caused by connecting cable passing through rotating drill rod; (b) dangerous loading of measuring head by own

Table 1 Deformation coefficients for lateral area of cone with apex angle of 60° and with strain gauges located at half height of cone.

μ	A_{11}	A_{12}	A_{21}	A_{22}	C_{11}	C_{21}	D_{11}	D_{21}
0.1	1.002	-1.762	0.109	0.343	-0.155	0.655	0.082	1.542
0.2	1	-1.752	0.022	0.365	-0.263	0.641	0.095	1.627
0.25	0.999	-1.733	-0.021	0.373	-0.317	0.636	0.101	1.673
0.3	0.997	-1.704	-0.065	0.380	-0.371	0.632	0.108	1.716
0.4	0.989	-1.611	-0.154	0.386	-0.481	0.630	0.123	1.787

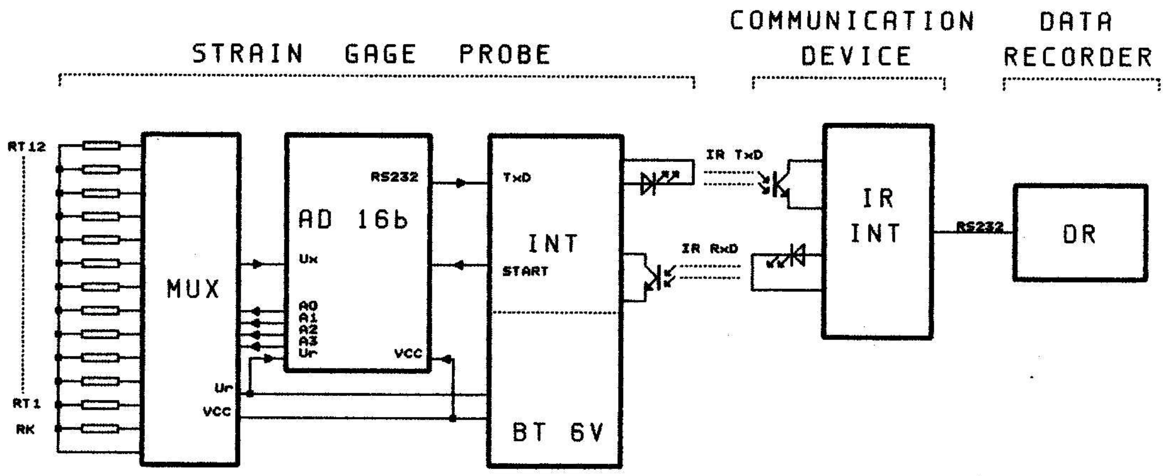

Fig. 2 Block diagram of measuring apparatus

weight of instrument especially when locating data concentrator and measuring head within a single sleeve in a horizontal or in an inclined borehole.

The strain gauge probe is designed as a multiplexed bridge (hereafter MUX), to which 12 measuring strain gauges RT1 – RT12 and a compensating strain gauge RK are connected. In MUX the signals of strain gauges are also amplified. An analog-to-digital converter AD (hereafter AD), after initiation by impulse START, will measure up gradually signals on all strain gauges and transmit them in form of serial code TxD to optic interface of probe (hereafter INT). From the INT interface the serial code will be transmitted as infra-red radiation IR TxD to receiving interface IR INT. Out of this interface such data are transmitted in standard RS232 to data recorder DR. The MUX is controlled by AD through address signals A0-A3.

A BT 6V battery powers circuits of the probe. At rest the probe is in standby state during which only the circuits of receiver of IR interface are energized. The supply of power to probe circuits will be switched on for a preset time after receiving of starting command by means of IR RxD. After a preset period the supply will be automatically switched off and the power source will be returned again into “standby” state.

As a data recorder (DR) a microprocessor data concentrator of a standard type of computer can be used (notebook, mobile terminal Psion Workabout). The microprocessor data concentrator would be located directly in the rotating core barrel. In case of application of a standard type of computer it is necessary to solve the problem of transmission of data between the computer and the scanning device in rotating part of drilling equipment. Here we have assumed an application of commercially available elements, such as radio modems.

The 3x strain gauges of probe cannot be balanced after having been the probe bonded to the borehole. Therefore a relatively small measurement range of relative deformations has been chosen (± 2500 μStrain) by which a linear processing of measured deformation is possible even at a starting imbalance of strain gauges. When using a 16 bit AD converter also small deformation values are sufficiently quantified (0.15 μStrain/LSB). A balancing of starting deformations will be made in numerical way only after processing of measured data. Equally corrections due to temperature changes or due to elimination of drift of amplification circuits will be made in numerical way according to signal of compensating strain gauge.

The apparatus is currently in development stage. The strain gauge probe and scanning device have been developed. Photos of prototype of strain gauge probe are shown in Fig. 3.

The body of probe is made by grouting of electronic circuits with elastic substance in a mould and by subsequent milling out of grooves in conical surface.

Prior to sticking to borehole the probe is activated by short-circuiting of micro connector (in Fig. 4 between positions 3 and 4). The capacity of power source is 260 mAh. If it is assumed that the measurement will be performed during two shifts, in course of the first one the probe will be checked up and installed in borehole and in course of the second one the proper measurement will be performed and the probe will be continuously switched on (pessimistic assumption), then the charge would take about 160 mAh. It is able to remain in a “standby” regime only for 4 days prior to installation.

For checking-up of optical communication a waterproof scanning equipment (IR_INT) was realized with cable connection to serial input of PC – see Fig.4. For laboratory testing a communication program was compiled.

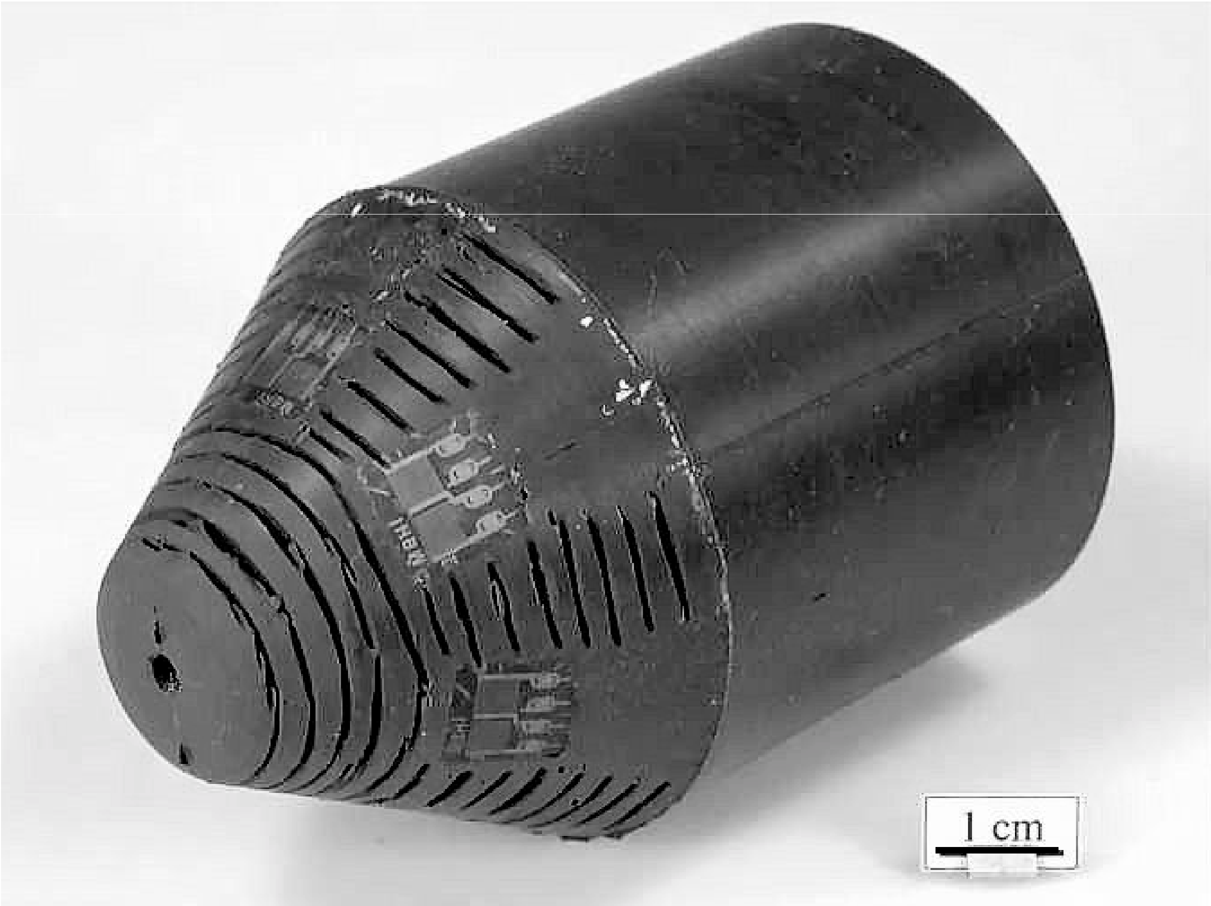

Fig. 3 Prototype of probe in view of strain gauge side

Fig. 4 Communication device with cable connection to serial input of PC

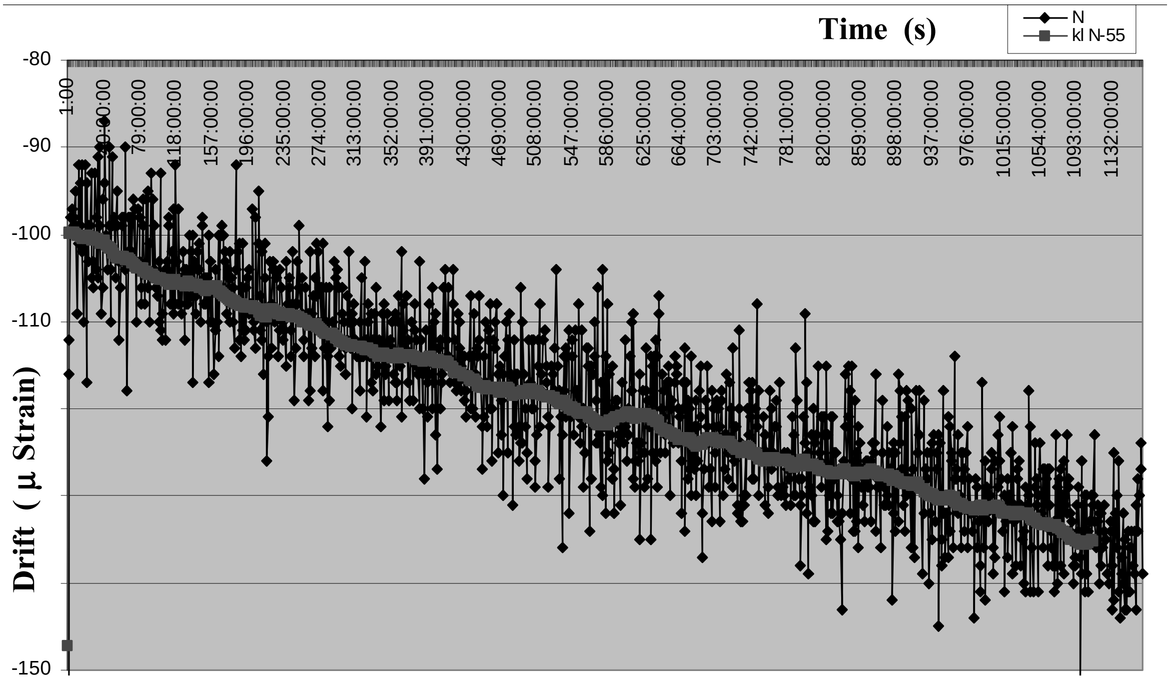

Fig. 5 Graph of values of compensating strain gauge (Axis x - time, axis y – relative deformation μStrain)

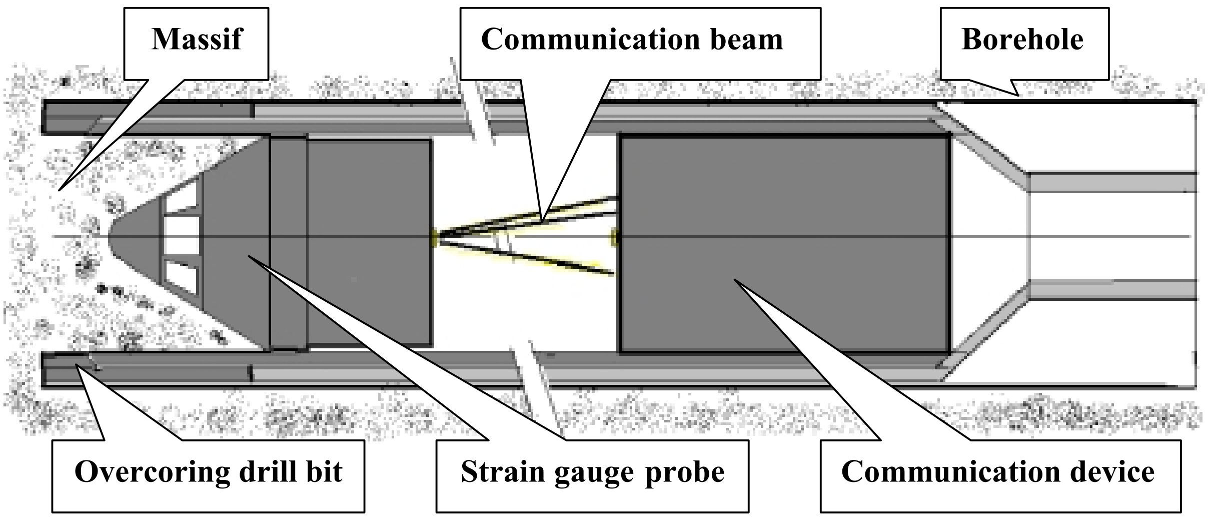

Fig. 6 Schematic representation of disposition of equipment within borehole

OBTAINED RESULTS

The parameters of developed probe are being laboratory checked-up. The graph in Fig. 5 represents measured data (thin black) and by running average (of 55 values) the filtered data (thick gray) from compensating strain gauge, being measured up within range ± 2500 μStrain. From course of the graph it is obvious, that the noise amplitude of filtered course of graph is approximately ± 5 μStrain. By a descending trend the changes of temperature and offset of amplifiers are represented.

Based on first checking-up measuring results it can be assumed that it will be possible to achieve a resultant accuracy of numerically corrected data of about 2.0 μStrain. However, a precise instantaneous compensating of influence of dependence of strain gauges on temperature was impossible due to difference of time constants of measuring strain gauges glued on cone surface as well as of the compensating strain gauge within probe.

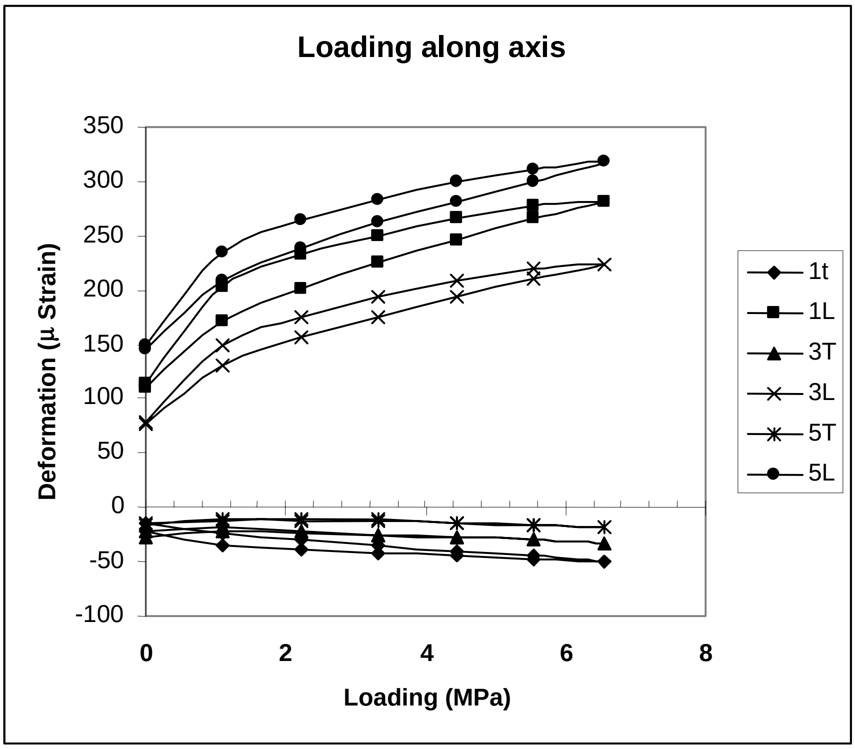

Fig. 7 A response to loading along axis of probe

METHODOLOGY OF MEASUREMENT

After selecting of locality and drilling-up of borehole up to a corresponding depth and its scavenging, the checking of quality of borehole at its bottom by means of TV camera follows. If the quality is satisfactory, forming of borehole bottom by special conical bits will proceed. Then again checking-up of quality of conical bottom follows so that the conical surface would not be damaged in any place. Prior to sticking the surface is washed by spirit and dried up by air. The feeding rods for sticking of strain gauge probe are fitted with orientation equipment of Pajari Company. In this way information about spatial orientation of probe is safeguarded. After hardening of adhesive the overcoring stage will be possible. Schematic representation of disposition of equipment within borehole is presented on Fig. 6. For evaluating of measured stresses it is naturally necessary to determine experimentally the deformation characteristics of material within which the strain gauge probe is located.

EXPERIMENTS

For checking-up of methodology of bonding of strain gauge probe to borehole and of function of this cone geometry a simplified version was constructed which is connected to portable measuring equipment by means of cable. A simplified probe was cemented in a drill hole in cube 300x300x300 mm of Godula sandstone and loaded by press. On the picture Fig. 7 a response can be seen to loading along axis of probe. This type of simplified probe was applied and it is being used equally for monitoring of stress variations in rock massif by means of inserted body method in a locality of ČSM Colliery during long-term monitoring of stress condition changes provoked by an advancing longwall face.

CONCLUSION

The outcome of development of measuring apparatus is booth prototypes of strain gauge probe and of its scanning equipment. It has enabled performing of basic tests of the measurement methodology, i.e. the method of installing of the probe to borehole and checking-up of overcoring process (measuring with drilling machine stopped). By this it will be possible to obtain basic methodological information, such as about contamination of elements of optical communication during drilling process as well as about effect of warming-up of rock massif during wet drilling.

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