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EXAMPLES OF ROTATIONAL COMPONENT RECORDS OF MINING INDUCED SEISMIC EVENTS FROM THE KARVINÁ REGION

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ABSTRACT
Russian electrodynamic seismometer named S-5-S is adaptable for measurement of rotational ground motion. In this paper brief information about mentioned adaptation is presented. Initial results from experimental measurement in Karviná region in 2011 with high mining induced seismicity are documented. Measured values for the horizontal component reached up to 1 mrad s^{-1}, while the seismic energy of these events did not exceed the value of 10^5 J and hypocentral distances were within 2 km.

KEYWORDS: rotational component, rotational seismometer, mining induced seismicity

INTRODUCTION

To describe the situation during vibration generated by an earthquake, the general motion of particles or a small volume in a solid body can be divided into three parts: translation (along the x, y, and z axes), rotation (about the x, y, and z axes), and strain (e.g. Båth, 1979; Teisseyre et al., 2006). Rotational ground motion has been ignored for centuries due to a widespread belief that rotation is insignificant in measuring it. Theoretical work in modern rotational seismology began in the 1970s, and attempts to deduce rotational motion from accelerometer arrays begun in the 1980s (according ScienceDaily, April 27, 2009, also Lee et al., 2009). Figure 1 left shows the axes in a Cartesian coordinate system for translational velocity measured by seismometers typically used in seismology, and Figure. 1 right shows the corresponding axes of rotation rate measured by rotational sensors. Pham et al. (2010) deduced that an earthquake-induced rotation of an almost perfectly symmetrical structure was difficult to explain without at least some local rotational acceleration.

Sensors for measurement of rotational component have also been developed in the Czech Republic. For example: Jedlička et al. (2009) presented a strong-motion fluid rotational seismograph; Štrunc et al. (2009) described a rotational sensor based on a capacitance detector of angular displacement; Brokešová and Málek (2010) presented a rotational sensor based on differential evaluation of signals from pairs of geophones mounted along the perimeter of a rigid disk. The current situation within the running Czech-USA AMVIS Grant on "Fluidal Seismo" was presented by Kozák (2010) at the IWGoRS workshops (International Workshop on Rotational Seismology and Engineering Applications) in Prague 2010.

The Russian pendulous S-5-S seismometer can be adapted for measurement of rotational components of seismic signal. This adaptation was developed at the Institute of Geonics ASCR, Ostrava, Czech Republic in 2010 (Industrial Property Office of Czech Republic registered Utility model, No. 21679, 2011). An output signal can be proportional either to rotational velocity or rotational displacement. Laboratory tests on the new S-5-SR seismometer were realized on the test vibration table that is located at the Geophysical Institute of the ASCR, Prague.

MECHANICAL ADAPTATION OF S-5-S

Original mechanical oscillating system of the original S-5-S seismometer consists of sensing (SET) and damping (DET) electrodynamic transducers mounted on the unsymmetrical double-arm pendulum. This pendulum is suspended on a footing using a pair of two crossed flat springs, which operate as the axis of rotation. The pendulum is equilibrated with an additional astatic spring suspension. This astatic spring suspension determines stiffness of a mechanical system of the S-5-S and enables to control its natural period. Oscillating system is possible to install into a case in configuration for a vertical or horizontal component of a seismic signal measurement. More detailed description is presented by Aranovic et al. (1974).

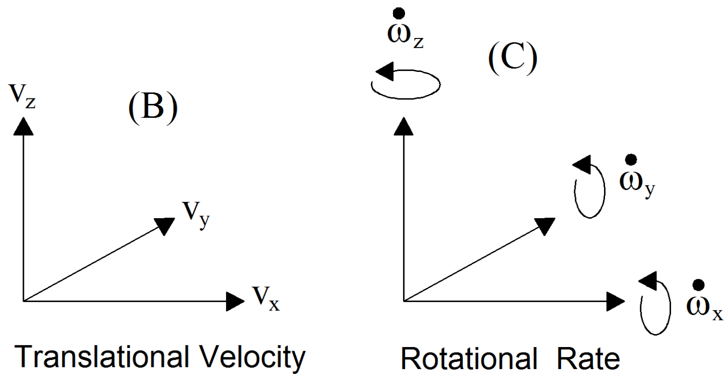

Fig. 1 Cartesian coordinate system for translation (B) and rotational (C) movement explanation (according Pham et al., 2010).

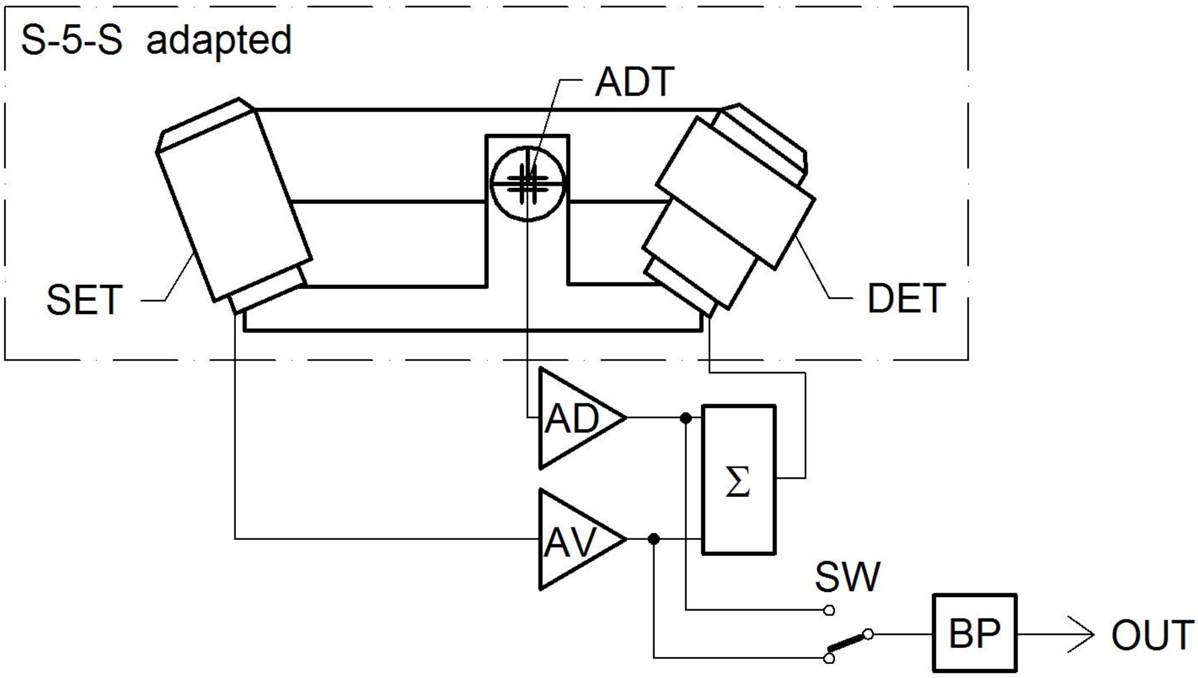

Fig. 3 Simplified block circuit diagram of S-5-SR seismometer.
Key to Figure 3: SET – Sensing electrodynamic transducer; DET – Damping electrodynamic transducer; AD – Amplifier of angular displacement signal (*φ*); AV – Amplifier of angular velocity signal (*dφ /dt*); ∑ - Summing circuit; SW – Switch; BP – Band pass filter; OUT – Output of signal.

The main steps of adaptation were:

- Original astatic spring suspension removed.
- Due to the static balancing of the pendulum an additional mass was mounted on the magnet of a damping transducer situated on its shorter arm.
- Due to the precise dynamic balancing of the pendulum two adjustable counterweights were mounted on it in perpendicular directions.
- Sensor of angular displacement, installed on one of the crossed flat springs, was included as a new electronic element.

Adapted seismometer was signed as the S-5-SR (Fig. 2). Natural period of the adapted mechanical system dropped to T_0 = 3.3s although original natural period with the astatic spring suspension was T_0 = 5 s. Adapted mechanical system was not possible to damp optimally using a short-circuited coil of damping transducer only. In order to adjust a natural period, damping and zero horizontal position of the adapted system of seismometer, there are used two active feedback currents wired-in to the DET. Simplified block circuit diagram of S-5-SR seismometer is presented in Figure 3.

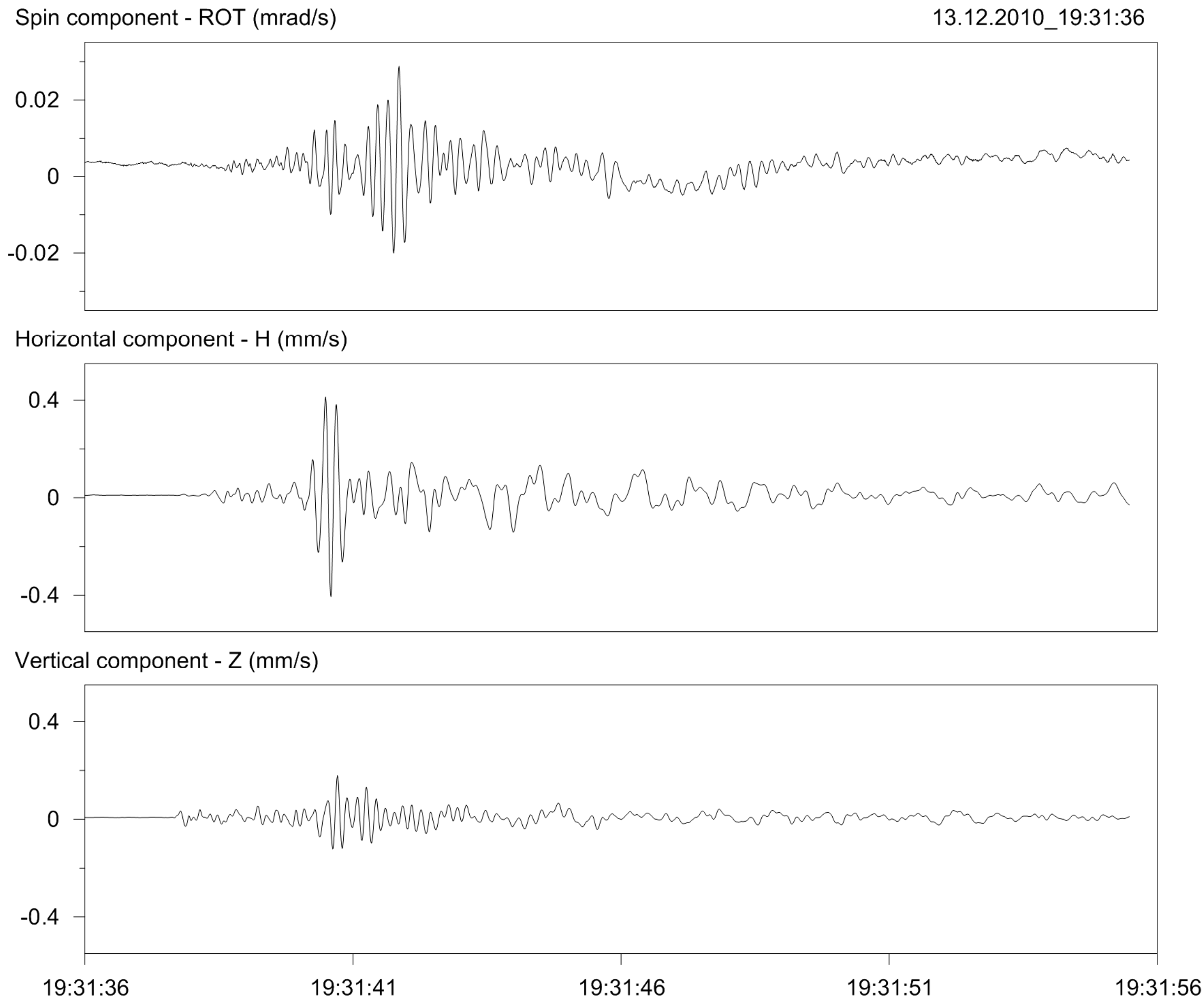

Fig. 6 Wave pattern of mining induced seismic event from the Karviná region, recorded at the Doubrava station on 13 December 2010 at 19:31.

Output signal of the S-5-SR can be proportional either to the rotational velocity *dφ /dt* or rotational displacement *φ*, depending on position of SW. Selected signal goes to the OUT through BP which consists of high-pass and low-pass filters (3-pole Bessel 25 Hz). High-pass filter with limit frequency 0,005 Hz removes dc offset of signal, low-pass filter limits frequency range of seismic signal to 25 Hz. The positive feedback current for natural period adjustment is derived from output signal of AD. The negative feedback current for damping adjustment is derived from output signal of AV. Both feedback signals are summarized in ∑ block and connected to the DET. More detailed description is presented by Knejzlík et al. (2011a, b).

Just as the original S-5-S the adapted system of S-5-SR is possible to install into a case in configuration for measurement of rotational movement around both horizontal and vertical axis.

LABORATORY TESTS OF THE S-5-SR SEISMOMETER

Laboratory tests of the S-5-SR were carried out to obtain information about the new seismometer behaviour and to calibrate its basic parameters. A test vibration table, that is located at the Geophysical Institute of the ASCR, Prague, was used. Both translation and rotational movements of the table is possible to set up. Anchoring of the S-5-SR on the desk is presented in Figure 4. Natural period of pendulum was setted-up to 5s and system was optimally damped.

To obtain maximum accuracy of measurement, an output signal from the seismometer was analysed using Brüel & Kjær Spectral Analyzer Type 2031. Sensitivity constant for angular velocity $k(d\varphi/dt) = 52.6$ V.s.rad^{-1} was obtained and sensitivity constant $k(\varphi) = 1393$ V.rad^{-1} was set for an angular displacement channel. Sensitivity $kp = 1.1$ mV/Hz

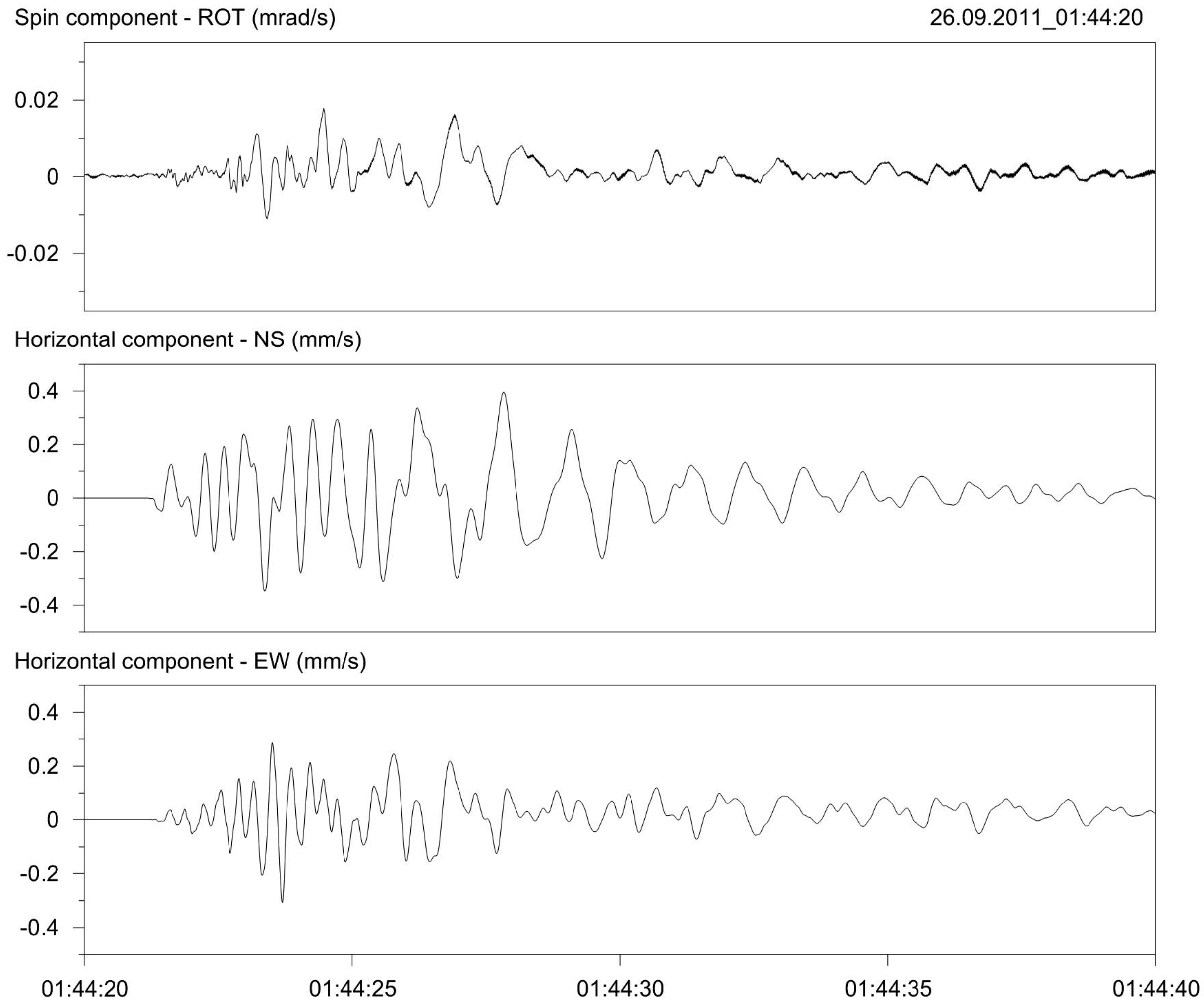

Fig. 7 Wave pattern of mining induced seismic event from the Karviná region, recorded at the Orlova station on 26 September 2011 at 1:44.

was taken for a parasitic sensitivity on a translational oscillation perpendicular to the pendulum and its rotational axis on stationary amplitude 50 µm (peak-peak). As a result, *k(dφ/dt)* to *kp* ratio is better than 40 dB within frequency range 0.2 – 25 Hz. Due to non-linearity of SET and limited amplitude of damping feedback signal, the range of measured amplitudes is limited to 10 mrad/s. Sensitivity is limited by noise level 1.1 µrad/s below 0.5 Hz.

EXPERIMENTAL FIELD MEASUREMENT OF THE S-5-SR SEISMOMETER

The first experimental field of measurement with the S-5-SR seismometer was realized from December 2010 ill May 2011. The experimental seismic station of DOU1 was located in the village of Doubrava in the Karviná region, which is loaded by a highly intensive mining induced seismicity (e.g. Kaláb and Knejzlík, 2002, 2006; Martinec et al., 2006; Holub et al., 2004). In this area, sedimentary layers (about 500 m) cover Carboniferous rock massif. Seismometers, i.e. the S-5-SR configured for the measurement of rotational component around vertical axe, the SM-3 horizontal seismometer oriented in a parallel way with the pendulum of the S-5-SR, the SM-3 vertical seismometer, and the three-component ViGeo 2 sensor oriented in geographical configuration, were located in the cellar of a big building which is a town hall (Fig. 5). There was used a recorder PCM3-EPC4 with 100 Hz sampling frequency of signal.

During the time of experiment, more than 500 records were obtained using triggered regime of a seismic station. The majority of these records represents mining induced seismic events from the Karviná area (often very weak); the only number of events represents mining induced seismicity from the Polish part of the Upper Silesian Coal Basin or from the Lubin area. Technical vibrations, like vibrations generated by traffic, were also included into the given

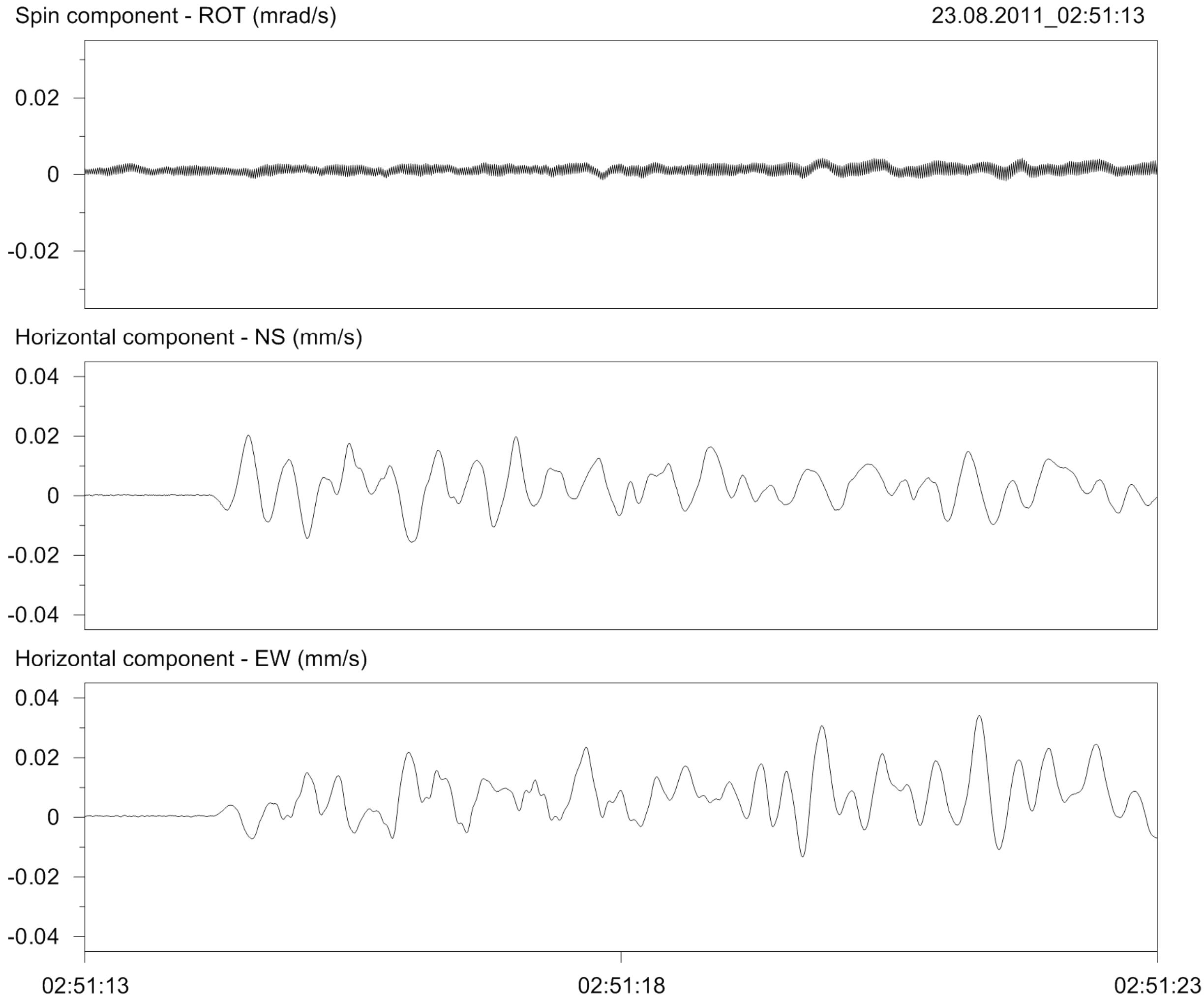

Fig. 8 Wave pattern of mining induced seismic event from the Polish part of the Upper Silesian Coal Basin, recorded at the Orlova station on 23 August.2011 at 02:51.

number. The main aim of this experiment with new seismometers was to obtain information about the application in the field of measurement.

A rotational component recorded during far seismic events practically does not exist (e.g. Lee et al., 2009). Our observations correspond with this common knowledge that rotational components occurred in a small epicentre area and its value is very quickly attenuated with an epicentre distance. The rotational component is also not possible to identify in records of vibrations generated by traffic. Nevertheless, several mining induced seismic events from the Doubrava area and several more intensive events from the Karvina region were recorded. The wave pattern in Figure 6 presents events from the second mentioned group of events (hypocentral distance up to 9 km, seismic energy more than 10^6 J, local magnitude approximately 1). Down from the top there is presented a horizontal rotational component SPIN [mrad.s^{-1}] and two translational horizontal components (N – S and E-W), both in [mm.s^{-1}]. Time axis (local time synchronized by DCF 77.5 kHz) is the same for all components. This figure documents that the character of the rotational component (signed as a spin) is quite different from other records of translation components. Inputs of significant rotational oscillations are in the group of S-waves. It is necessary to add that the character of these wave patterns can be probably markedly influenced by the response of a building in which seismometers were located.

The next experimental field measurement with the S-5-SR seismometer started in September 2011. This seismic station is located in the village of Orlová. From the geological point of view this area is not covered by Tertiary and Quaternary sedimentary layers. Seismometers were again located in the cellar of a big house. To document the existence and character of the rotational component for local events, wave pattern is presented in Figure 7. Hypocentral distance is up to 7 km. Parameters of events were used from the database composed by Green Gas DPB, a.s.

Obtained records of wave patterns from the both locations of seismic station illustrate the existence of a very small rotational ground motion in this area. The values of rotational components for the strongest event exceed 1 mrad.s^{-1} (in the Doubrava area). The character of this rotational component is quite different from records of the translational components. Although the seismometers were located in a building, the influence of this structure is not possible to specify. Therefore, a seismic pillar will be realized for the next experimental measurements.

The following figure (Fig. 8) documents records of the given components of mining induced seismic event from the Polish part of the Upper Silesian Coal Basin (distance about 20 km). Measured values of the rotational component are negligible in this record.

CONCLUSION

Rotational seismological signal components are generally considered to be negligible in comparison to the translational components. Nevertheless, movements during an intense earthquake document that these movements apparently deal with a rotary motion. The brief concept of adaptation of the pendulum S-5-S sensor for measuring rotational component (named S-5-SR) is presented in this paper. Frequency range of described pilot S-5-SR is 0.2Hz – 25 Hz. Sensitivity constants for the angular velocity are 52.6 V.s.rad^{-1} and for the angular displacement is 1393 V.

Experimental measurement of rotational components for mining induced seismic events from the Karviná region performed in the Doubrava station showed that occurring intense events in the epicenter area produces a rotational motion. Measured values of the experimental measurements in 2011 for the horizontal component reached up to 1 mrad.s^{-1}, while the seismic energy of these events exceeded the value of 10^6 J and hypocentral distances were within 9 km. The number of records of more intensive seismic events is small. Therefore, it is not possible to deduce more detailed conclusions. It should be noted that the seismometers were placed inside buildings, which could affect the records by their constructional dynamic characteristics. On the contrary, the records of distant events such as mining induced seismic events from the Polish part of the Upper Silesian Basin, and the technical records of vibration, where vibrations are caused by traffic, have a rotational motion unidentifiable.

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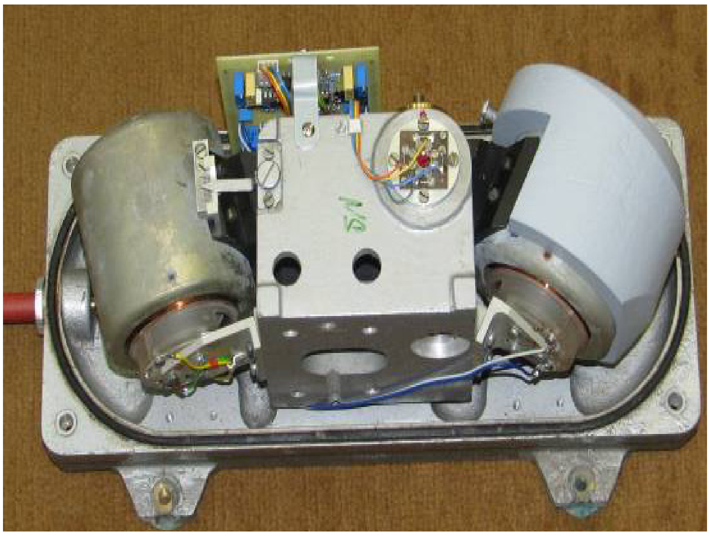

Fig. 2 Seismometer S-5-SR – horizontal orientation; on the right arm there is an additional mass, a new electronic system is at the back, on the upper crossed flat springs there are installed strain-gauge angle sensors.

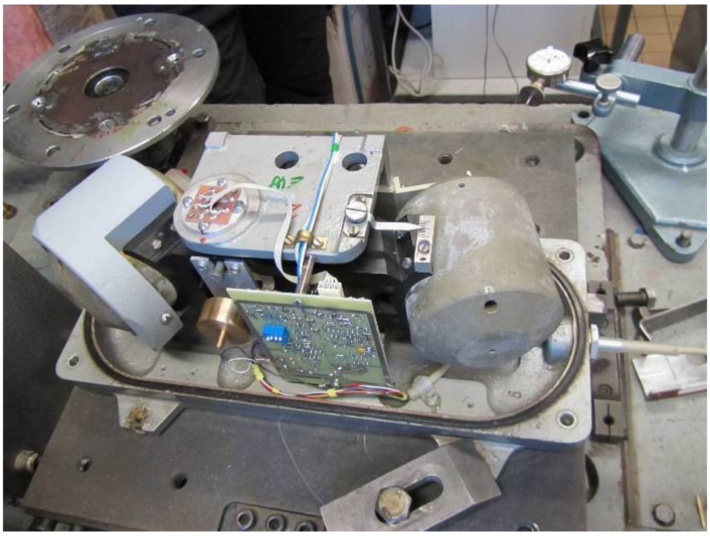

Fig. 4 The S-5-SR seismometer anchored on the translation movement desk during laboratory tests; links - rotational desk.

Fig. 5 Rotational horizontal seismometer S-5-SR (uncovered), three component sensor ViGeo 2 and two seismometers SM3 (uncovered) in the cellar of DOU1 (December 2010).