Slow Rotations in Earthquake Motions Detected in Nuclear Power Plants

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Abstract: *The paper informs about seismic behaviour of the reinforced concrete reactor shaft body of WWER Type Slovak NPPs. The information concerns observed displacement motions due to the earthquakes obtained by instrumentation that serves for the control of reactor vessel position. The nuclear reactor shaft tilt measuring sensitive systems, that utilise the hydro-levelling and pendametric methods, have registered motions excited by different far large earthquakes. The paper presents some of the records illustrating the effects of earthquake Sumatra, 26th Dec., 2004.*

Keywords: Earthquake, Seismic Response, Hydrostatic Sensor, Pendametric Sensor, Nuclear Power Plant (NPP)

1. Introduction

The different monitoring systems are running in every NPP. They support the control and safety of respective NPP during its operation. One from such systems is devoted to monitoring of the concrete reactor shaft tilt as required by technical directives. The tilt vector of reactor main jointing plane is usually measured once each year during reactor shutdown by method, called 'precise levelling'. It involves measuring relative height differences at the points and the immediate calculation of the reactor tilt vector from this data. Besides this classical method , two independent methods were incorporated to the authorised methods. These are hydro-levelling and pendametric methods. These methods are advantageous as they allow practically continuous measurement of tilt vector even during reactor operation. Such systems are nowadays operating in both Slovak NPPs Jaslovské Bohunice and Mochovce [2]. The measurement of the pressure vessel considers the quasi-static process, therefore the used time step of recording was chosen as 5 minutes.

2. Measuring methods and systems used for tilt control

Tilt measuring systems running in the Slovak EBO, EMO power plants use methods of hydro-levelling and pendametry with unified optoelectronic measuring of hydrostatic liquid level and damped pendulum wire position, respectively (Fig.1). In contrast with classical levelling method, which allows measurement of this quantity only during the reactor shut-down state (which is not the operational state), the used measuring principles and applied methods allow a practically continuous measuring of reactor tilt vector. The amplitude of tilt vector in this paper is defined as maximum height difference of two points in the reactor flange plane on the flange diameter basis. The angle of tilt vector is given by angle orientation of line with maximum tilt lying in flange plane to the reactor coordinate system.

Hydro-levelling is a well known levelling method, and in connection with the application of optoelectronics and information technology has some advantages to purely optical methods. A minimum of three hydro-levelling sensors are necessary in order to measure reactor shaft tilt vector. Three hydro-levelling sensors that were developed and made in the Institute of Measurement Science, Slovak Academy of Sciences are used for reactor tilt vector measurement [1, 2]. The optoelectronic sensor in system of connected vessels consists of a flat window cell and an optoelectronic system for hydrostatic liquid level height measurement. All sensors are interconnected with the central industrial computer and power supply. This optoelectronic part is based on a CCD line image sensor. Liquid temperature in sensors is measured by means of thermometers built in the sensors. This temperature is used for the correction of measured data that are influenced by different temperature of sensors. The liquid levels in individual vessels lie in one horizontal plane when certain physical conditions are fulfilled. This plane can then serve as the reference plane for the elevations differences measured between individual points. The range of height difference measurement is ±10 mm, the precision is 0.01 mm.

The pendametric method uses the properties of a damped pendulum. The pendulum hinging point is connected to the measured object. The position of the pendulum wire is measured bi-axially in a reference horizontal plane. The wire's position in the reference plane and its length determine the reactor shaft tilt vector. The optoelectronic method is used for this position measurement similarly as in the hydro-levelling method. Although one biaxial pendametric sensor is sufficient for tilt vector measurement, the measuring system incorporates two pendametric sensors as a purpose-built redundancy. Interconnection of sensors with computer and power supply is common with hydro-levelling sensors one. The measuring range of the pendameter wire position is ±2 mm in both coordinate axes; the resolution is 0.001 mm.

The topology of the three hydro-levelling sensors located on the reactor shaft perimeter allows measurement of its tilt vector in the power plant coordinate system. All sensors are fixed in the reactor shaft body.

Central personal computer allows an user-friendly computation, presentation, and archiving/storage of measured data of the reactor shaft tilt. The measurement regime, including the measuring (sampling) interval, may be programmed according to the user requirements.

3. Records obtained during different seismic events from reactor tilt measurements

In the next text are presented the records obtained from tilt measurement due to Sumatra earthquake. These records show the time dependences of the reactor tilt vector reference amplitudes given in relative units (mm per flange diameter).

The signals recorded by the tilt measuring systems are depicted in Figure 2. The Figure 2 shows two perturbations: the first one started on 23rd December 2004 at 15.40 UTC caused by the earthquake between Australia and Antarctica and the second one started on 26th December 2004 at 01.20 UTC caused by the earthquake off the Indonesian coast with

magnitude 9.3. These records were obtained in NPP EBO-V2. Amplitudes detected with pendametric sensors P1, P2 reached higher values, smaller amplitude values were recorded by hydro-levelling sensors. The reason of smaller amplitudes is due to the delay that was caused by time needed for reaching the equilibrium positions of used liquid.

The time of this earthquake effect corresponds to regular seismological records obtained by national seismic stations network.

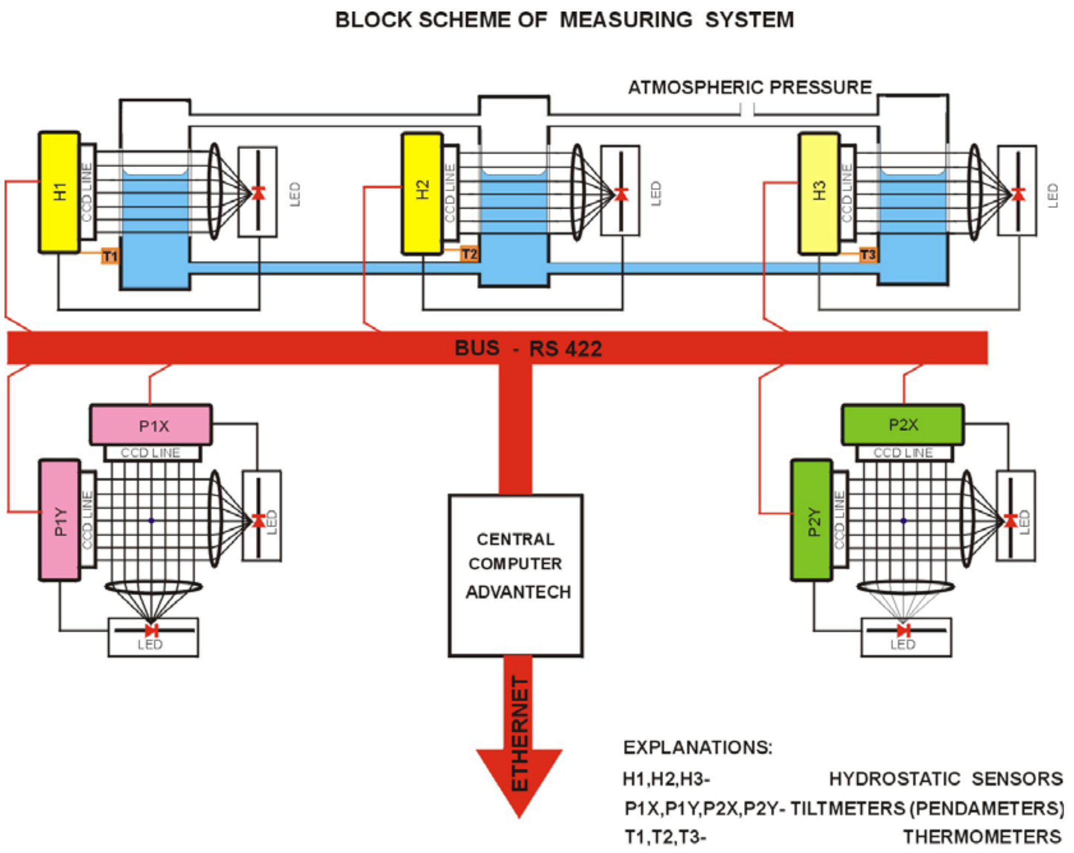

Fig.1 . Measurement system block scheme

4. Data analysis and discussion of obtained results

From Figure 2 can be seen the effects of seismic events on tilt motion of reactor shaft. Either these values are low and pretty far away from those that could call for any action, this information can be generally utilised. The obtained pendametric data can be converted into horizontal plane considered as a part of rotation seismic motions. However, time histories of the registered tilt vectors and their shapes are influenced by the sampling time step that was about 5 minutes. Actually, the measuring system was designed and serves for quasi-static tilt measurement. Therefore, the obtained data suggest that there exist the intermediate values of these slow motions which can be smaller or higher than the registered values. Philosophy of tilt measurements is based on incremental values related to the geodetic measurements executed during the last shut-down of the respective NPP unit. Figure 3 give original uncorrected position of pendametric wire in horizontal plane which corresponds to starting points of pendametric records P1 and P2. Either registrations of P1 and P2 were not executed at the same moment, their common traces indicate the existence of variable intermediate values in quasi-static tilt motions. It has been proved that the safety margin is sufficiently high and in all cases the quasi-static tilt motions have returned back to the original position. In spite of that, the idea of intermediate values recording should be re-estimated and re-assessed.

In terms of safe operation of the power plant, it would be feasible and more valuable to have directly measured information about reactor position changes in terms of displacements, than those obtained by doubled integration with filtering of recorded response accelerations, e.g. from the NPP seismic response monitoring system.

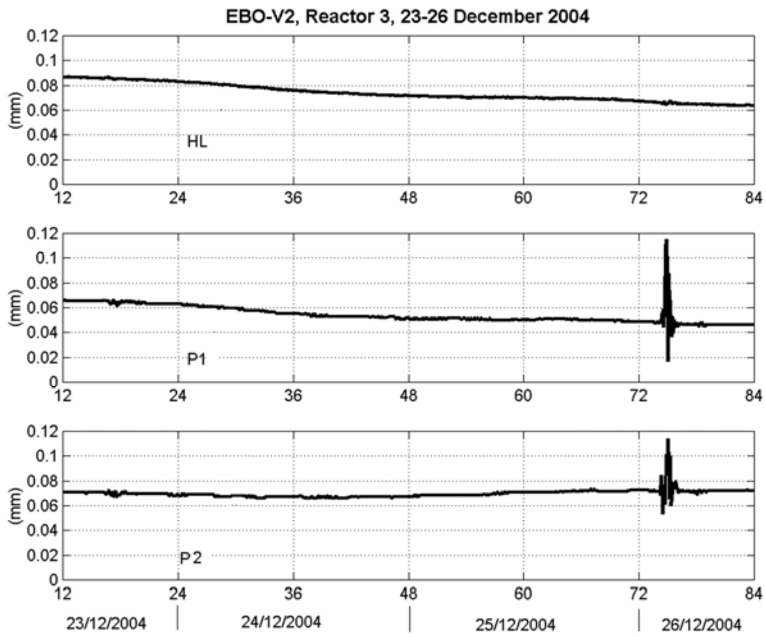

Fig. 2 NPP Jaslovské Bohunice EBO-V2. Reference shaft tilt amplitude records. Records of hydro-levelling (HL) and two pendametric subsystems (P1 and P2) from 23rd – 26th December 2004. The larger perturbation corresponds to the Sumatra earthquake on 26th December 2004, the smaller perturbation corresponds to earthquake between Australia and Antarctica on 23rd December 2004.

5. Conclusions

The structures built on stiff subsoil (hard rock) and on the soft one present different response to the actions of far or near source earthquakes. Any information available from monitoring systems can contribute to the knowledge about motions of NPP structures or, in general, about seismic effects at a site. Uncertainties connected with the very low frequency components in acceleration records can be limited when displacement/rotation supporting records are available.

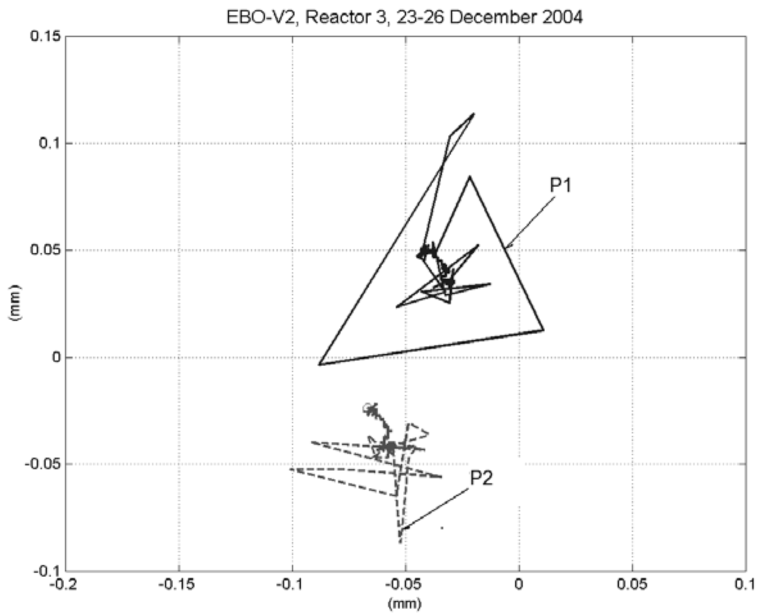

Fig.3 . NPP Jaslovské Bohunice EBO V-2. Reactor 3. Records from Figure 1 transferred into horizontal plane.

Records of such static-dynamic displacements based on measured data of reactor shaft tilt can be utilised in two directions: firstly giving the proof that the temporary tilt of shaft during any earthquake has not exceeded the limit value; secondly providing the information whether seismic displacement or seismic rotation at a site has not exhibited residual quasi-static components. To this end, the prepared special set of instrumentation could cover the frequency range that content is usually unknown and therefore is disregarded.

The movements detected on reactor shaft suggest the option of assessment and evaluation of seismic motions in view of direct displacement records rather than those obtained by acceleration and/or velocity sensors. This approach gives additional data that could be utilised like the proof that the temporary tilt of reactor shaft during the earthquake has not exceeded the limit value. In addition to the basic purpose of these measuring systems, it has been observed their capability to record time histories in very low frequency domain caused by earthquake events. Then, the challenging task is in the analysis of such data and their potential use both for safety control of NPP and for general objectives of earthquake engineering and seismology.

For the sake of more credible and precise measurement of the reactor body position during the earthquake, the option exists to extend and/or improve the operating reliable measuring system. The solution can follow the prevention of the existing measuring system, with consequent completion with the additional units. In such complementary recording units, firstly the measuring frequency should increase app. up to 10 Hz and then faster pendametric sensors would support higher sampling frequency or smaller sampling time step. The full synchronisation of local power plant time with UTC is to be completed.

In view of safe operation of the power plant, is important the fact, that the reactors' positions after the tilt low frequency motions due to far large earthquakes were the same as before the seismic event.

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References

[1] Ondriš Ľ, Trnovec M, Keppert M, Rusina V, Buzási J. An optoelectronic hydrolevelling system, *Meas. Sci. Technol.*, 5, 1287-123, 1994.

[2] Ondriš Ľ, Lukáč Š, Rusina V, Buzási J, Krušinský D. The optoelectronic systems for vertical shifts and tilt measurement of objects and technological equipment. Proceedings of FIG Working Week 2004 "The Olympic Spirit in Surveying", Athens 22-27 May, Technical Chamber of Greece, Athens. Paper TS3.6/1-13, 2004.

[3] Juhásová E. Seismic Effects on Structures. Elsevier, Amsterdam, 340 p. 1991.

[4] Juhásová E, Ondriš Ľ, Rusina V. Displacements caused by earthquake motions detected in nuclear power plants. In Proceeding of SMIRT 19 – Structural Mechanics in Reactor Technology, Toronto 2007, paper F01/4 -8p.