



SEISMIC QUALIFICATION OF BOURDON TUBE PRESSURE GAUGES WITH SWITCH CONTACTS IN UNITS 5 AND 6, NPP KOZLODUY

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ABSTRACT

The objective of the seismic qualification tests performed on two types of bourdon tube pressure gauges with switch contacts (with magnetic snap-action contacts and with reed switch contacts) was to certify that the two types of pressure gauges can perform their functions before, during and after an earthquake defined as Required response spectra (RRS) for the specified location of installation. The seismic qualification tests were performed according to the applicable international standards and codes for such kinds of tests, separately for each of the three components of the seismic excitation X, Y and Z direction. Five tests with Operational basis earthquake (OBE) followed by one with Safe shutdown earthquake (SSE) excitation for each direction were performed.

No resonance search tests were performed due to the high rigidity of the structure on which the pressure gauges were mounted during seismic qualification tests.

Functional tests of the elements were done before, during and after seismic qualification tests, as the tests during and after the seismic qualification tests were performed in a certified metrological laboratory. During the test the two types of pressure gauges were checked for chattering of the contacts. Registration of functional state of the samples during seismic tests was carried out by A/D converter.

No mechanical damages were registered to the gauges and to their fixing to the rigid structure. Anyway the pressure gauges with magnetic snap-action contacts did not functioned reliably (chattering of the contacts for a period of about 5 seconds for SSE excitation, as duration of wrong working of the contacts was for more than 5 ms). This type of pressure gauges was not approved for installation in Kozloduy NPP. The pressure gauges with reed switch contacts functioned reliably and there was no evidence of improper behavior of the contacts during and after the seismic excitations. This type of pressure gauges was approved for installation in Units 5 and 6 at Kozloduy NPP.

INTRODUCTION

This paper presents seismic qualification by test of two types of bourdon tube pressure gauges with switch contacts (with magnetic snap-action contacts and with reed switch contacts), produced by WIKA, foreseen for installation in Units 5 & 6 of WWER-1000 MW NPP Kozloduy.

The purpose of the seismic qualification tests, performed on the two types of pressure gauges, is to certify that the referenced herein pressure gauges "can" / "can not" perform their functions before, during and after an earthquake defined as RRS as required by the applicable standards and codes [1], [2], [3], [4] and also to demonstrate satisfactory mechanical behaviour (integrity) of the samples.

In this paper is presented an overview of the: technical input data for the two types of pressure gauges; data for the shaking table and the seismic test instrumentation; data for the way of mounting on the shaking table; data for the seismic test excitation and definition of RRS; data from the seismic qualification tests; steps for the functional tests and the tracking and registration of the switch contacts. Finally are presented conclusions about the functionality and structural integrity of the tested samples of pressure gauges with magnetic snap-action contacts and with reed switch contacts.

TECHNICAL INPUT DATA FOR TWO TYPES OF BOURDON TUBE PRESSURE GAUGES

Two types of bourdon tube pressure gauges, production of WIKA, were tested. These pressure gauges are foreseen for installation in different rooms and elevations in Units 5 and 6 of NPP Kozloduy. The first type of pressure gauges had magnetic snap-action contacts and the second type had reed switch contacts. Two samples from each type of pressure gauges were tested, as the first sample had pressure range from 0 to 10 bar and the second from 0 to 100 bar. Two pieces of each sample were tested in order to get reliable results.

Technical data for the two types of pressure gauges is presented below.

Technical data for pressure gauges with magnetic snap-action contacts

As described above two samples of this type were tested. The two samples were model PGS23.160, as the first sample had pressure range from 0 to 10 bar and the second from 0 to 100 bar. The sample with pressure range from 0 to 100 bar was filled with silicone oil. Its weight was approximately 3.5 kg. The sample with pressure range from 0 to 10 bar was “dry” with approximate weight of 1.5 kg. The pressure range and the weight were the difference between the two samples. All other physical and functional characteristics are one and the same for both samples.

The nominal size of the two samples is 160 mm and their dimensions are as follows:

- height x width x depth: 203 x 204 x 120 mm

For mounting of the pressure gauges to existing stands and racks in Kozloduy NPP, plate with thickness 2 mm and four openings with diameter 7 mm on them are point welded to the back side of each gauge. Bolts M6 are used for mounting the pressure gauges to the stands and racks.

On figure 1 below are shown pictures of the two samples of pressure gauges with magnetic snap-action contacts.



Figure 1 View of two samples of pressure gauges with magnetic snap-action contacts

The basic function of the two samples of pressure gauges is to register the pressure in systems UJ and YT, respectively for the “dry” sample and the sample filled with silicone oil. In case of increasing the pressure in the system above a critical maximum or lowering the pressure under a critical minimum, the switch contacts of the pressure gauges switch a circuit and send a signal to the respective safety system.

The main technical characteristics of the two samples are as follows:

- number of switches for 1 piece of the sample – 2 pieces;
- model of the switch contacts – 821.21;
- type of contacts – magnetic snap-action contacts;

- action of switch contacts – 1-st contact switches off, 2-nd contact switches on when reaching the adjusted pressure value;
- maximum operating voltage of switches – 250 V;
- admissible natural temperature for operation of pressure gauges with switch contacts – from -20 °C to +60 °C;
- admissible operating temperature of the fluid in the pressure gauges with switch contacts – up to +100 °C;
- precision class of pressure gauges – 1.0;
- degree of protection of cable connections – IP 65;
- type of steel for the main elements of pressure gauges – stainless steel 316L;
- material of the pointer registering the real pressure in the system – aluminium.

Technical data for pressure gauges with reed switch contacts

As described above two samples of this type were also tested. The two samples were also model PGS23.160, as the first sample had pressure range from 0 to 10 bar and the second from 0 to 100 bar like the pressure gauges with snap-action contacts. The sample with pressure range from 0 to 100 bar was filled with silicone oil. Its weight was approximately 2.5 kg. The sample with pressure range from 0 to 10 bar was “dry” with approximate weight of 1.2 kg. The pressure range and the weight were the difference between the two samples. All other physical and functional characteristics are one and the same for both samples.

The nominal size of the two samples is 160 mm and their dimensions are as follows:

- height x width x depth: 218 x 223 x 87 mm

For mounting of the pressure gauges to existing stands and racks in Kozloduy NPP, plate with thickness 1.5 mm and additional strengthening at contours and three openings with diameter 7 mm on them are point welded to the back side of each gauge. Bolts M6 are used for mounting the pressure gauges to the stands and racks.

On figure 2 below are shown pictures of the two samples of pressure gauges with reed switch contacts.



Figure 2 View of two samples of pressure gauges with reed switch contacts

The basic function of the two samples of pressure gauges is the same as the pressure gauges with magnetic snap-action contacts, but used to register the pressure in other safety systems of Kozloduy NPP.

The main technical characteristics of the two samples are as follows:

- number of switches for 1 piece of the sample – 2 pieces;
- model of the switch contacts – 851.3.3;

- type of contacts – reed switch contacts;
- maximum operating voltage of switches – 250 V;
- admissible natural temperature for operation of pressure gauges with switch contacts – from -20 °C to +60 °C;
- admissible operating temperature of the fluid in the pressure gauges with switch contacts – up to +100 °C;
- precision class of pressure gauges – 1.0;
- degree of protection of cable connections – IP 65;
- type of steel for the main elements of pressure gauges – stainless steel 316L;
- material of the pointer registering the real pressure in the system – aluminium.

DATA FOR SHAKING TABLE AND SEISMIC TEST INSTRUMENTATION

The seismic qualification tests are performed in the laboratory of University of Architecture, Civil Engineering and Geodesy in Sofia. The seismic excitation in horizontal direction is performed by means of a shaking table with a mounting surface of 1.5 by 1.5 m. This is a uniaxial shaking table (horizontal translation in one direction and rotation about a vertical axis). It is used for a single axis testing in both horizontal axes (X and Y respectively).

For vertical axis tests, one of the actuators is mounted in vertical position. A platform with a mounting surface of 1.0 by 1.0 m is attached to the piston.

The drive mechanisms for both shaking tables are servo-controlled, electro-hydraulic actuators, manufactured by INSTRON Ltd, England. They have the following capabilities given in Table 1.

Table 1

Frequency Range	0-100 Hz
Dynamic Load Capacity	± 50 kN
Maximum Stroke	± 50 mm
Maximum Velocity	270 mm/sec
Maximum Acceleration	10 g

For registration of accelerations at different points sufficient instrumentation was provided. The testing equipment includes accelerometers [5], amplifiers [6], low-pass filters [7], Analogue to Digital (A/D) and Digital to Analogue (D/A) converters [8], computers and software [9]. The measuring system has an accuracy class of the amplifiers 0.1. Data acquisition and control system has a resolution of 12 bits for both A/D and D/A converters.

All equipment items used to monitor the tests were checked and calibrated in accordance with an established quality control program. The accuracy of the measurements performed to monitor the parameters was as follows:

- the measured acceleration values were within 5% of the true value;
- TRS generation equipment produced a plot within 10% of the true plot.

MOUNTING OF THE TWO TYPES OF PRESSURE GAUGES ON THE SHAKING TABLE

During the seismic qualification tests the two pieces of each sample of the two types of pressure gauges were mounted in their normal service position to a rigid steel frame. The steel frame was produced in the Steel Structures Research Laboratory and formed by 2T profiles and welded to the shaking table surface. Openings with diameter 7 mm (four openings for the pressure gauges with magnetic snap-action contacts and three openings for the pressure gauges with reed switch contacts) were formed in the front side of the frame to mount the pressure gauges.

Each of the two samples (two pieces per sample) of each type of pressure gauges was mounted on the shaking table for horizontal excitation - first in X direction (X was the horizontal axis perpendicular to the façade of pressure gauges). Then it was rotated around vertical axis by 90 degrees for testing in Y direction.

For testing in Z direction the pressure gauges were mounted on shaking table for vertical seismic excitation. Mounting of the steel frame with two pressure gauges mounted on it is designed in a way to prevent from unwanted dynamic effects that might influence over the dynamic response of the pressure gauges during seismic tests and unwanted damage of the shaking table (damage of the actuator), though in this specific case the tested equipment with the steel frame had small weight and could not lead to damage of the actuator.

On Figure 3 below are shown pictures of the pressure gauges mounted on the shaking table for horizontal excitation and on the shaking table for vertical excitation.

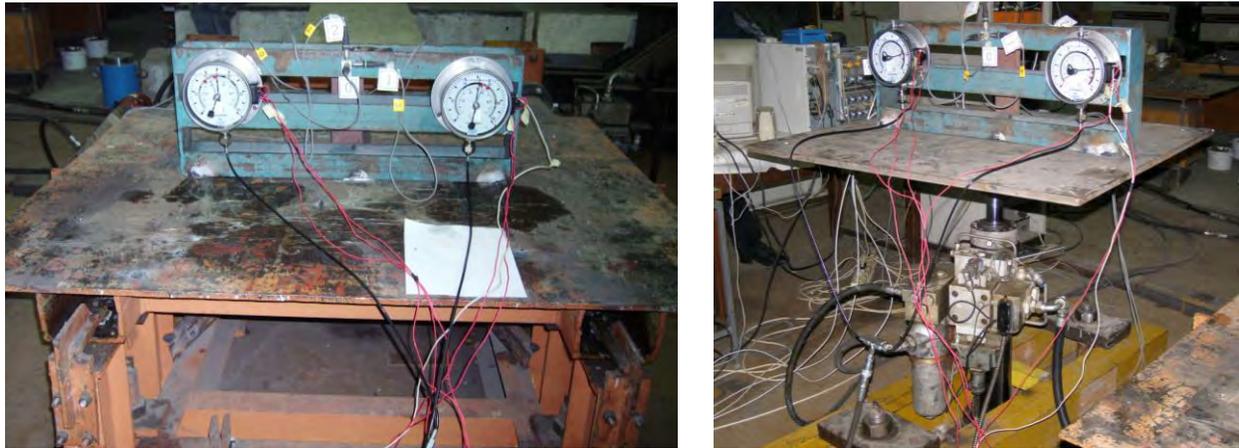


Figure 3 Pressure gauges mounted on shaking table for horizontal and on shaking table for vertical excitation

SEISMIC TEST EXCITATION

Seismic qualification of two types of bourdon tube pressure gauges with switch contacts was performed for two levels of excitation – Operating basis earthquake (OBE) and Safe shutdown earthquake (SSE) with respect to defined RRS. RRS were specified as an envelope of floor response spectra [10] for three rooms per Unit 5 and three rooms per Unit 6 of Kozloduy NPP where the pressure gauges are to be mounted. The floor response spectra were multiplied for the three directions with coefficient of 1.5 which accounts for imperfections in the installation of the pressure gauges and possible coupling effects in case of simultaneous seismic excitation in three directions when seismic qualification tests are performed on uniaxial shaking table. Because of the great variety of stands and racks on which the pressure gauges will be mounted in Kozloduy NPP, thus replacing the existing ones, the pressure gauges were mounted on rigid structure and RRS were broadened in the range of 5 to 20 Hz in order to account for the amplification at height from the stands and racks. On excitation level OBE (low level) and excitation level SSE (high level), the tests were performed in the three directions – X, Y, Z sequentially. During all seismic excitations the pressure gauges are under pressure higher than 4 MPa for the pressure gauges with pressure range from 0 to 10 MPa and higher than 40 MPa for the pressure gauges with pressure range from 0 to 100 MPa. As required per [3], [4] both samples of the two types of pressure gauges should be tested consequently 5 times with low and once with high level of seismic excitation in each of the three directions. In this manner the seismic aging is simulated as per requirements of the applicable standard [3]. Because of the necessity to test the behavior of the pointer of the two types of pressure gauges in the two most

unfavourable states (vertical – at pressure 5 MPa for the pressure gauges with pressure range from 0 to 10 MPa, respectively 50 MPa for pressure gauges with pressure range from 0 to 100 MPa and horizontal – at pressure 8 MPa for the pressure gauges with pressure range from 0 to 10 MPa, respectively 80 MPa for pressure gauges with pressure range from 0 to 100 MPa), the pressure gauges were tested consequently 4 times with low and twice with high level of seismic excitation in each of the three directions. At the beginning of the tests one preliminary OBE level test in X direction was done in order to demonstrate the proper function of the excitation, measuring and data acquisition equipment. On Figure 4 below are presented RRS spectra for both seismic levels of excitation (horizontal and vertical component of the seismic excitation). The spectra are generated for 5% damping.

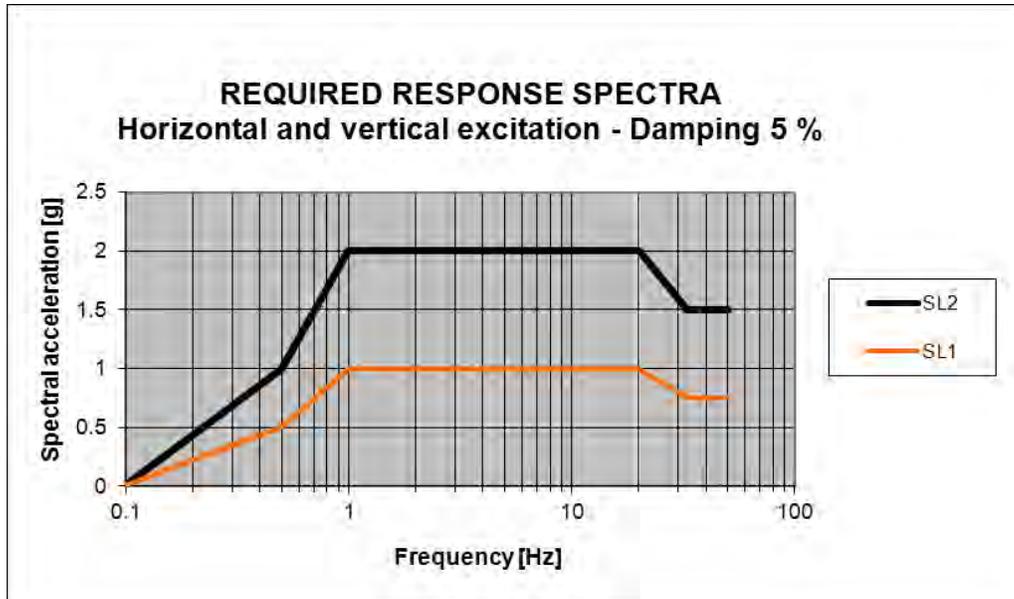


Figure 4 Required Response Spectra for SSE (SL2) and OBE (SL1) levels of horizontal seismic excitation (directions X & Y) and vertical seismic excitation (direction V)

The seismic excitation to the shaking table was assigned through generated acceleration time histories. They were derived from the RRS scaled to relevant Zero period accelerations (ZPA) for OBE (SL1) and SSE (SL2) level earthquake respectively. Seismic motions of the shaking table were recorded and the corresponding TRS was generated.

Tests were performed with multi-frequency random waveform with 56 sec duration and strong motion part 25-30 sec. The SIMQKE program [9] for artificial motion generation was used to obtain multi-frequency random waveforms.

SEISMIC QUALIFICATION TESTS

As the structure on which the pressure gauges were mounted during seismic qualification tests was rigid, then no resonance search tests were needed to be performed.

Only three accelerometers (recording channels) were used for acceleration registration during seismic qualification tests, as the structure on which the pressure gauges were mounted was rigid and no amplification was expected. The accelerometers were arranged in one and the same scheme for each one of the testing directions of the gauges, as recording channel 0 was parallel to direction X, channel 1 was parallel to direction Y and channel 2 was in vertical direction. On figure 5 below are shown pictures with location and orientation of accelerometers mounted on the rigid structure during seismic excitation in horizontal and vertical direction.

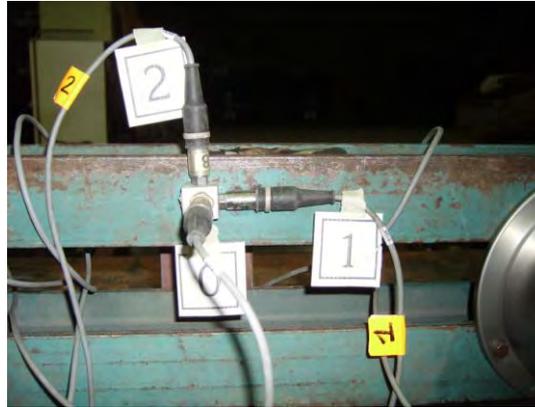


Figure 5 Location and orientation of accelerometers mounted on the rigid structure during seismic excitation in horizontal and vertical direction

The seismic qualification tests were performed in the way described in the point „Seismic test excitation” above. On Figure 6 below are presented the time history excitation (channel 0) for the test with fourth OBE, first and second SSE for X direction of testing of the pressure gauges with reed contacts, sample with pressure range from 0 to 100 bar.

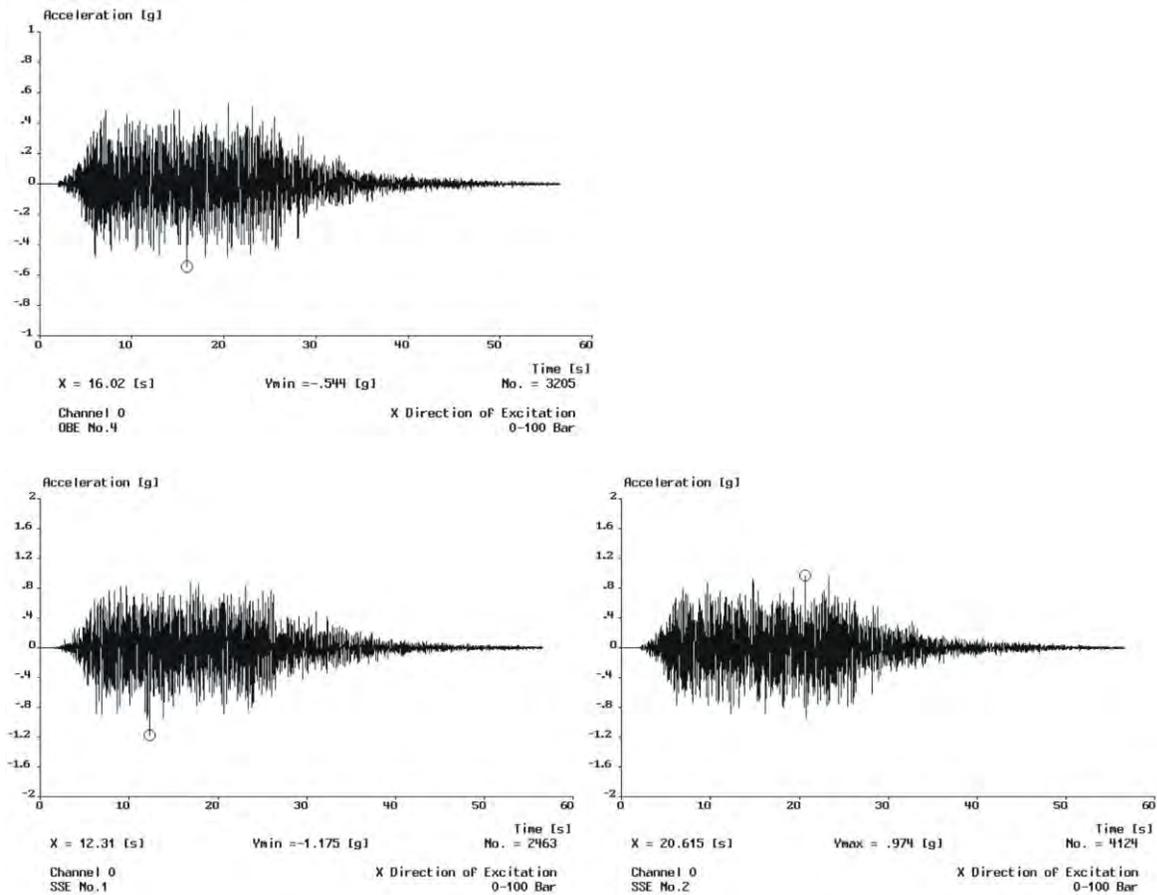


Figure 6 Time history excitation for the test with OBE4, SSE1 and SSE2 for X direction of testing of pressure gauges with reed contacts, sample with pressure range from 0 to 100 bar

On figure 7 below are shown RRS and TRS for the fourth test with OBE and the two tests with SSE for the same direction of testing (direction X) for the same pressure gauges with reed contacts, sample with pressure range from 0 to 100 bar. It is shown that the TRS fully enveloped the RRS above 3.0 Hz (should be enveloped above 3.5 Hz according to [3], [4] as resonance frequencies are above 5 Hz). Excitation in the range 1 to 3 Hz was maintained in accordance with the capability of the shaking table as required in [3], [4].

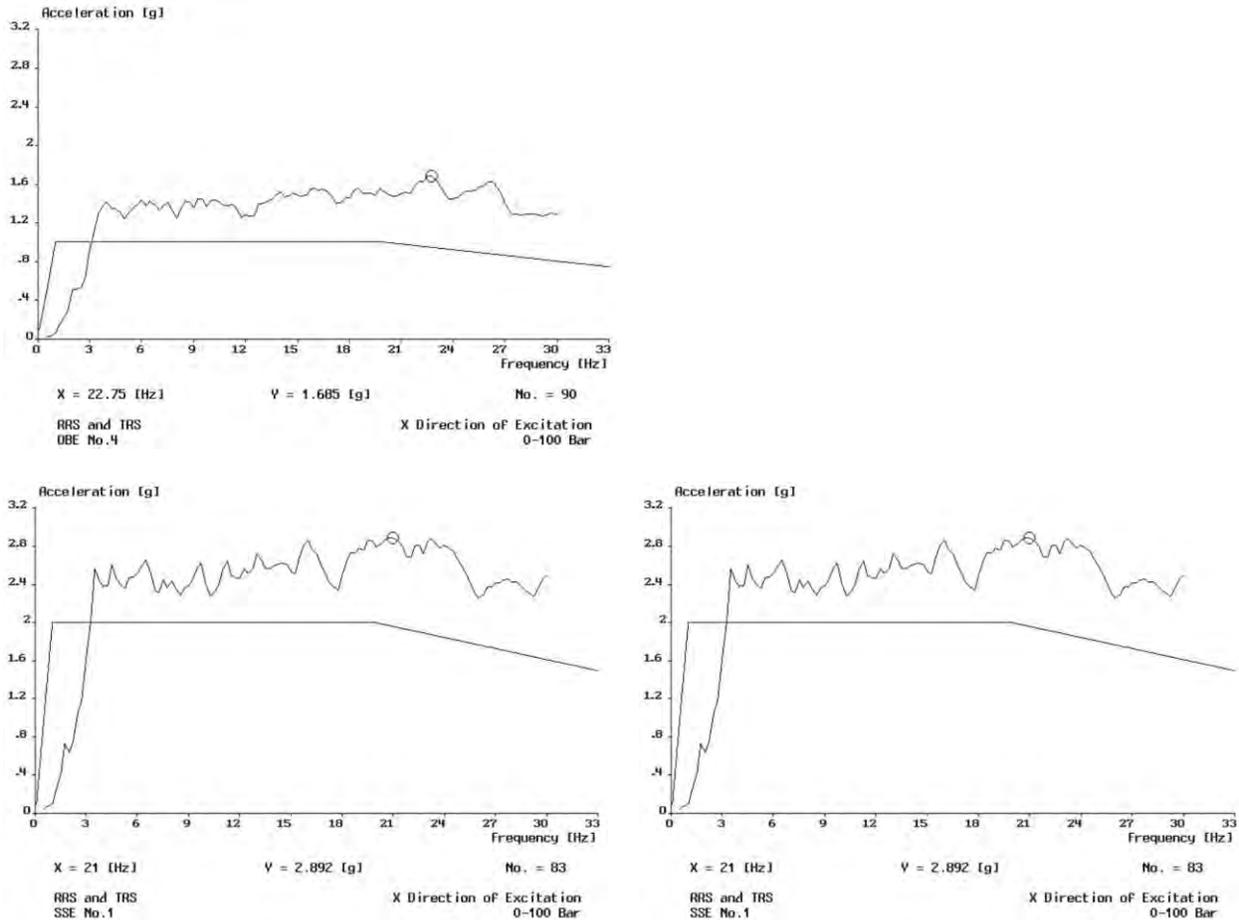


Figure 7 RRS and TRS for the test with OBE4, SSE1 and SSE2 for X direction of testing of pressure gauges with reed contacts, sample with pressure range from 0 to 100 bar

FUNCTIONAL TESTS

The two types of pressure gauges were checked before, during and after the seismic qualification tests. Before the seismic qualification tests the two types of pressure gauges were checked for: proper measuring (within the precision class) in a certified metrological laboratory; damages during transportation and handling; proper functioning of the contacts by increasing the pressure through the hydraulic press. During the seismic qualification tests the two types of pressure gauges were checked for chattering of the contacts, as seismic tests for SL1 (OBE1 to OBE4) were made with different pressure and different position of the contacts adjustment in relation to the working pressure. The two seismic tests for SL2 (SSE1 and SSE2) were performed at: pressure 5 MPa for the pressure gauges with pressure range from 0 to 10 MPa, respectively 50 MPa for pressure gauges with pressure range from 0 to 100 MPa for SSE1 excitation and pressure 8 MPa for the pressure gauges with pressure range from 0 to 10 MPa,

respectively 80 MPa for pressure gauges with pressure range from 0 to 100 MPa for SSE2 excitation. After the seismic qualification tests the two types of pressure gauges were checked for: damages as a result of seismic excitation; proper functioning of the contacts by increasing the pressure through the hydraulic press; proper measuring (within the precision class) in the same metrological laboratory.

During the seismic qualification tests of the pressure gauges with magnetic snap-action contacts was found chattering of the contacts for a period of about 22 seconds (from 4 sec to 26 sec of the seismic excitation) for SSE excitation. The duration of wrong working of the contacts at a given moment was for about 5 ms, which was inadmissible. The wrong working was not due to physical movement of the pointer during SSE excitation and thus causing wrong switch, but chattering of the contacts themselves.

On figure 8 below is shown the oscillogram of the contacts of pressure gauges with magnetic snap-action contacts, sample with pressure range from 0 to 100 bar, for SSE 1 excitation in X direction. It can be seen chattering of the contacts (falling of voltage from 5.2 V to 0 V) in the range from 4 to 26 sec. On the same figure is presented additionally part of the seismic excitation at a given moment where can be seen wrong working of snap-action contacts for about 5 ms.

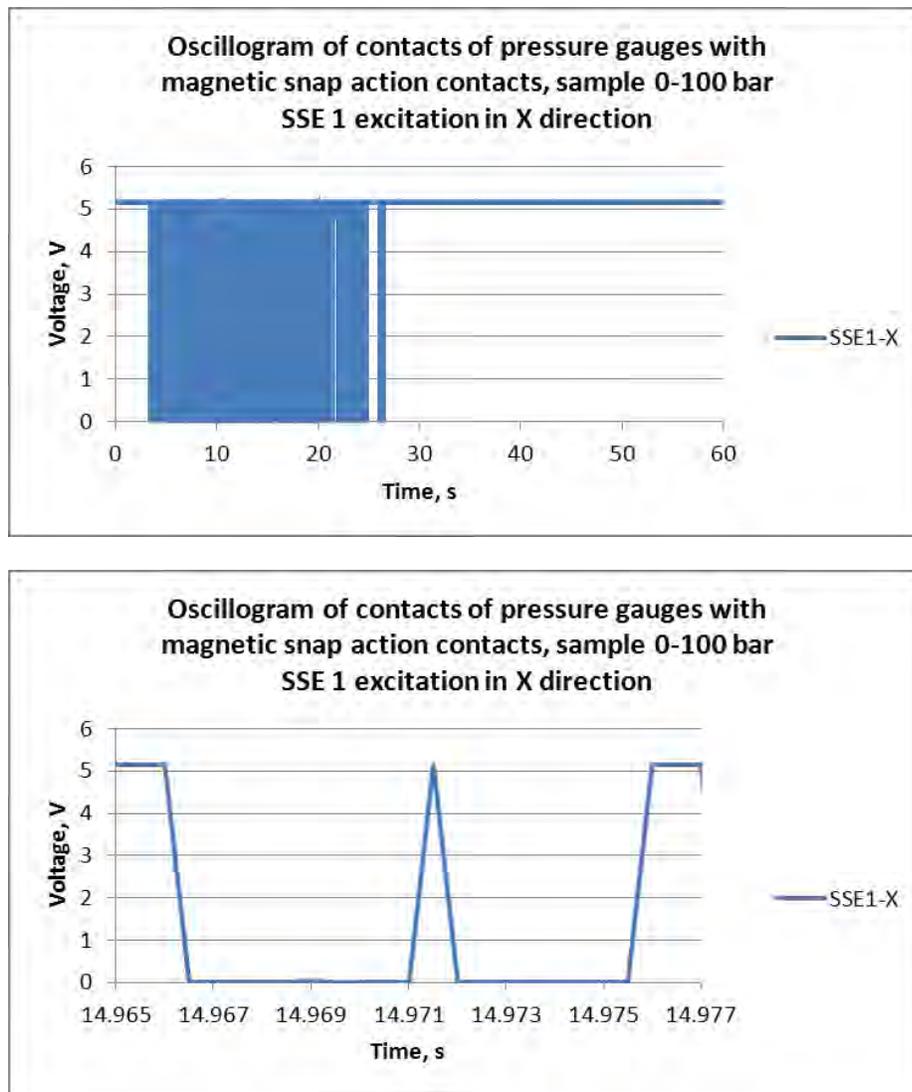


Figure 8 Oscillogram of the contacts of pressure gauges with magnetic snap-action contacts, sample with pressure range from 0 to 100 bar, for SSE 1 excitation in X direction

During the seismic qualification tests of the pressure gauges with reed switch contacts was not registered any chattering or wrong work of the contacts for all excitations in the three directions X, Y and Z separately. Nevertheless, it was found that the movement of the pointer for the sample with pressure range from 0 to 10 bar was bigger than the pointer of the sample with pressure range from 0 to 100 bar. This was due to the fact that sample with range from 0 to 10 bar was dry and the sample with pressure range from 0 to 100 bar was filled with silicone oil. Seismic qualification tests of samples with range from 0 to 10 bar were repeated again after they were filled with silicone oil. The movement of the pointer was reduced at maximum.

Tracing and registration of functional state of the contacts of the two types of pressure gauges was carried out by A/D converter, model DAS16/F [8] with scanning rate of 2000 accounts per second of a channel. It was provided single-phase power supply of 220V AC during seismic qualification tests.

CONCLUSIONS

The performed seismic qualification tests on the two types of bourdon tube pressure gauges lead to the following conclusions:

- Tested equipment preserved their structural integrity and no damage were registered;
- Fixing of the samples to the rigid steel structure by bolt connections as well as the fixing of the structure to the seismic platform were reliable;
- Tested pressure gauges with magnetic snap-action contacts DID NOT functioned reliably and therefore WERE NOT approved for mounting in Kozloduy NPP;
- Tested pressure gauges with reed switch contacts functioned reliably and there was no evidence of improper behavior of the contacts during and after the seismic excitations;
- Filling of dry samples with silicone oil reduced at maximum the movement of the pointer during the seismic qualification tests.

The performed seismic tests certify that bourdon tube pressure gauges with reed switch contacts passed the seismic qualification tests successfully and can be installed on the prescribed locations in Units 5 and 6 of Kozloduy NPP.

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