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CURRENT SITUATIONS ON VIBRATION FIELD AT NMCC AND CALIBRATION OF SIGNAL CONDITIONER

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Abstract: This paper introduces the current calibration and measurement capabilities (CMC) in the field of mechanical vibrations field at National Measurement and Calibration Center (NMCC) operating under the Saudi Standards, Metrology and Quality Organization (SASO) in Kingdom of Saudi Arabia. Calibration facilities enable to carry out calibrations of vibration pick-ups at primary and secondary level in accordance to relevant ISO standards. The calibration system is also capable to calibrate different type of signal conditioners. The system performance was proved by calibration of many vibration pick-ups with a long history. In addition, calibration of signal conditioner was carried out by independent system at TÜBİTAK UME and newly established system at SASO NMCC and acceptable agreement between the measurement results obtained at NMCC and TÜBİTAK UME was achieved.

Keywords: Calibration, accelerometer, signal conditioner

1. INTRODUCTION

TÜBİTAK UME is involved in bilateral project, "Development and Realization of National Measurement and Calibration Center at SASO". The aim of this project is to establish the basic infrastructure for metrology laboratories and to provide the necessary training and consultancy services within this scope to the Saudi Standards, Metrology and Quality Organization's National Measurement and Calibration Center (SASO - NMCC). One of the laboratories within the scope of the project is Acoustic and Vibration Laboratory. Scope for calibration and measurement facilities were decided after collating the information on calibration demands from industry and infrastructure at the existing laboratory building in NMCC. In addition, experience of the Turkish National Metrology Institute on the way of establishment and operation of Acoustics and Vibration Laboratory over the past 20 years has been also taken into account at this stage.

Two staff from NMCC was trained at TÜBİTAK UME using existing calibration facilities. The calibration and vibration measurement systems were purchased, delivered to TÜBİTAK UME, where they were tested for performance and sent to SASO NMCC, where they were finally installed in September 2015. Extensive training of NMCC staff was continued in 2016 on the installed calibration and measurement systems at NMCC.

The calibration system was temporarily installed at TÜBİTAK UME. The shaker was just placed on a heavy marble plate and not secured on it because of the absence of mounting hole. Vibration isolation of laser head was maintained as required. By this configuration functional tests for primary accelerometer calibration, secondary accelerometer calibration, calibration of portable vibration exciter, calibration of vibration meter and calibration of signal conditioners were performed. Performance of the system was proved by calibration of various vibration pick-ups at TÜBİTAK UME. The sensitivities of reference standard accelerometers at 160 Hz obtained by this calibration system was taken as the criteria and it was found that results were in compliance with the sensitivities obtained by UMEs calibration system. The functionality of the system for the demanded calibrations was the other performance criteria of the calibration system at this stage. In addition, calibration of signal conditioners was carried out to check and validate the system's performance.

The types of signal conditioner used in combination with an accelerometer are charge, charge to voltage converter, conditioner for accelerometer with built in electronics and voltage amplifier. Some of the signal conditioners were calibrated by using the existing calibration system at NMCC and by using the existing calibration system at TÜBİTAK UME. Results obtained by two different systems are evaluated and are presented in this paper.

2. CALIBRATION AND MEASUREMENT SYSTEMS IN VIBRATION FIELD AT SASO NMCC

Calibration system for the vibration pick-ups installed at NMCC is a combined system, which enables both primary and secondary calibrations. The uncertainty levels for primary calibration of standard reference accelerometers at 95% confidence level (k=2) is in the range from 0.5% to 1.2% and from 0.5º to 1.0º for 10 Hz to 10 kHz frequency range. This value increases to 1.6% at 10 kHz for secondary level calibrations.

Although the basic Spektra CS18P HF calibration system is commercially available, it was configured to calibrate accelerometer, calibration exciter (portable vibration calibrator) and vibration meter and signal conditioner at the purchase stage considering the demands of NMCC. Views of calibration system installed at NMCC are presented in Fig. 1 and Fig. 2.

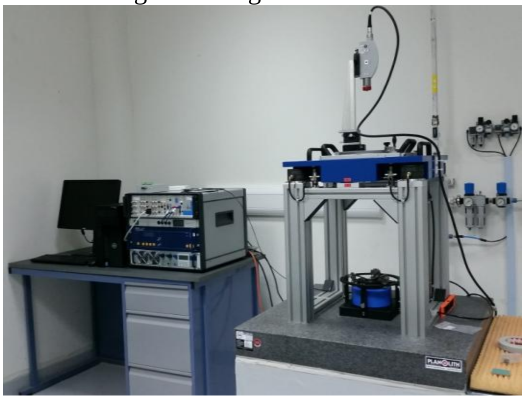

Fig. 1. Calibration system for vibration pick-ups and auxiliary equipment used in vibration field.

Calibration system in Fig. 1 and Fig. 2 was installed on an 80x80 cm granite table fixed on a concrete block. The dimensions of concrete block are (240 x 80 x 150) cm. Concrete block is floating on sand that is about 15 cm in thickness. The portion of the concrete block above ground level is 75 cm and total height is 150 cm. This is the static system to isolate surrounding vibrations. Laser head is mounted on a Positioning Unit allowing exact positioning and adjustment of the laser spot on device under test. This positioning unit, blue section in Fig. 1, has also vibration isolation. The positioning unit is mounted on a four of mount inflated by compressed air about five bars and each mount is supported by mechanical adjustment system. Compressed air is maintained continuously. In order to extend frequency range for further capability, a space was reserved on the concrete block for low frequency shaker.

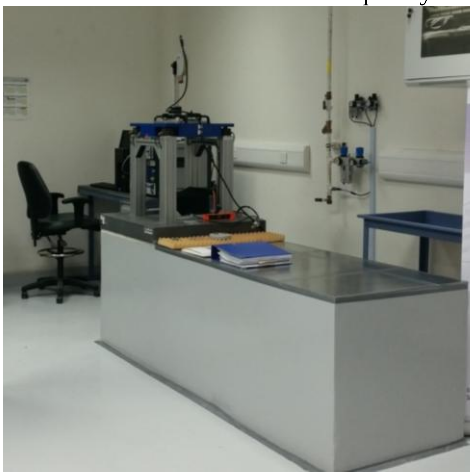

Fig. 2. Calibration system installed on concrete block.

Acoustic and Vibration Laboratory is located in basement floor in NMCC. The temperature and humidity in the laboratory is measured by the sensors mounted at four different positions and controlled by a control system. The environmental conditions are measured regularly at certain intervals and checked against the tolerances (23 ± 3) ºC for temperature and (50 ± 15) rh% for relative humidity. An e-mail is sent to the responsible staff message in case of exceeding the defined tolerances.

Laboratory has two back-to-back reference standard accelerometers Brüel & Kjaer type 8305 and two single ended reference standard accelerometers Brüel & Kjaer type 8305-001. Laboratory has also different kinds of signal conditioners and measuring amplifiers. References standard accelerometers and signal conditioners are constitutes measuring chains. These are used as transfer standards and reference standards in the calibration of calibration exciters in the laboratory.

Beside calibration capabilities, NMCC has four channel measurement and analysis system based on Brüel & Kjaer Multichannel Pulse analysis software platform, various types of accelerometers and hand held vibration calibrator. The accelerometers are the types of three axial and single axial. Some of them are general-purpose accelerometers and some of them are suitable for floor vibration measurement in low frequency range. Typical vibration measurement set-up is given in Fig. 3.

Fig. 3. Vibration measurement set-up.

3. PROOF OF PERFORMANCE OF CALIBRATION SYSTEM

Performance of the calibration system was tested by TÜBİTAK UME by means of calibration of various types of accelerometers belonging to the institute. They are back-to-back and single ended reference standard accelerometers (Brüel & Kjaer Type 8305), general-purpose accelerometers, etc. All these accelerometers are in use at TÜBİTAK UME for more than 20 years and long-term history data for sensitivity of these accelerometers exist. Final proof of the calibration system was performed at NMCC after the system installed in Acoustic and Vibration Laboratory. A transfer standard accelerometer was calibrated at primary level at NMCC in the frequency range 10 Hz to 20 kHz and then normalize error E_n was calculated. It was found that E_n<1for all frequencies as clearly seen in Fig.4.

Similar comparisons were performed by using NMCC's reference standard accelerometer since they were calibrated at DPLA/Denmark. A formal bilateral comparison between TÜBİTAK UME and SASO/NMCC was performed recently for calibration of reference standard accelerometer in the frequency range 10 Hz to 10 kHz. The measured quantities were magnitude and phase shift of complex charge sensitivities of a back to back accelerometer and a single ended accelerometer. Preliminary results proved that E_n<1for all frequencies. As an additional tool for proving the system performance intersystem comparison for calibration of signal conditioners were carried out. The details of such an exercise are presented below.

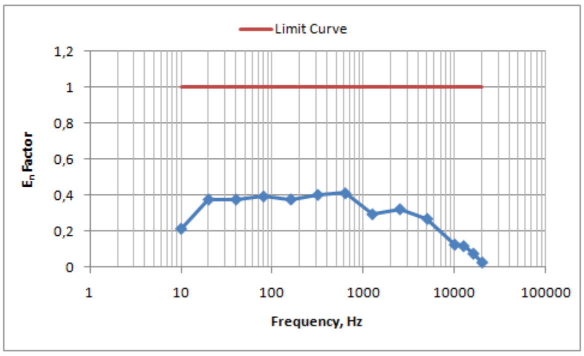

Fig. 4. E_n factor graph obtained from the comparison measurement at the final installation stage at NMCC.

Signal conditioner is a device used in combination with transducer during the calibration or vibration measurements. Transducer and signal conditioner combination is called as measurement chain in measurement terminology. In general, signal conditioners amplify, attenuate and filter the signal applied to their input and outputs a signal normalized to sensitivity of the transducer used together. Sometimes they are called as signal amplifier. In general, four types of amplifiers are available. They are charge amplifier, ICP/IEPE/DeltaTron amplifier, voltage amplifier and charge to ICP/IEPE/DeltaTron converter. Charge amplifier is a device that accepts charge and produce voltage output. ICP/IEPE/DeltaTron amplifier is a device that supplies rated current and voltage to the ICP/IEPE/DeltaTron type accelerometer and delivers conditioned voltage as output. Voltage amplifier accepts voltage as input signal, which results to voltage as output signal. Charge to ICP/IEPE/DeltaTron converter is a kind of charge amplifier and includes an electronic circuitry. The function of the circuitry is to convert charge applied to its input to voltage. They need rated current to do this.

3.1 Calibration System for Signal Conditioner in TÜBİTAK UME

TÜBİTAK UME has calibration facilities for all kinds of signal conditioner described briefly in section 3. Calibration setup includes a signal source, reference capacitor and digital voltmeter. An accelerometer (sensor) simulator replaces reference capacitor when calibrating ICP/IEPE/DeltaTron amplifier. Gustavo P. Ripper et al reported on investigation and characterization of a general sensor simulator [1]. Similar sensor simulator with three channels presented in Fig.5 was designed and manufactured at TÜBİTAK UME. Each channel has the same circuitry.

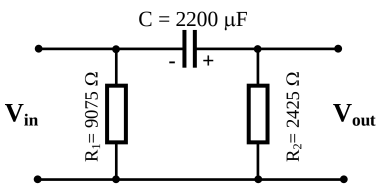

Fig. 5. Electrical circuitry of sensor simulator designed in TÜBİTAK UME

Gain factor of the sensor simulator is calculated by using the following equation:

$$Gain = V_{out} / V_{in} = R_2 / [R2 + 1/jwC] \qquad (1)$$

where $w=2\pi f$ and f is frequency. Gain and phase characteristics of the sensor simulator are calculated by Matlab and their frequency dependence are given in Fig. 6.

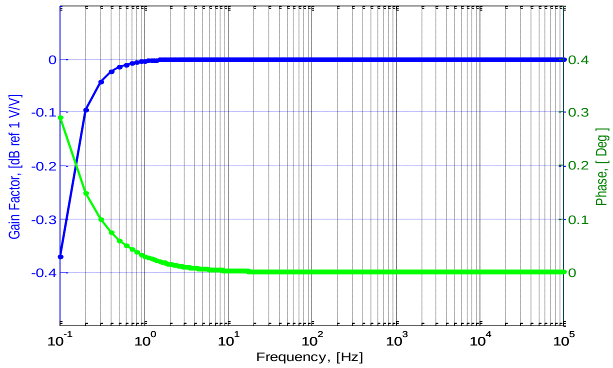

Fig. 6. Gain and phase characteristics of the sensor simulator designed and manufactured in TÜBİTAK UME

Performance of the sensor simulator i.e. its gain is determined by using calibration by using the setup presented in Fig. 7.

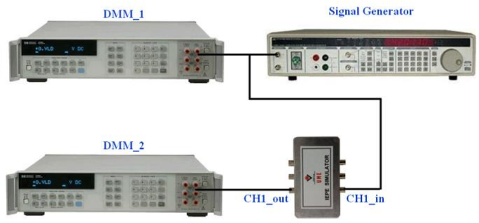

Fig. 7. calibration setup for sensor simulator.

Sinusoidal signals with nominal amplitude of 100 mV (rms) generated by signal generator in the frequency range from 10 Hz to 10 kHz at one-third octave band center frequencies were applied to channel 1 (CH1) of the sensor simulator. Input and output signals were measured by two digital multimeters. Then the gain was calculated as the ratio of output voltage to input voltage and this calculation repeated for CH2 and CH3. Calibrated performance of the sensor simulator is shown in Fig. 8.

Calibration of ICP/IEPE/DeltaTron signal conditioner B&K type 2694 was performed by using sine approximation method described in ISO 16063-11 standard [2]. The sine approximation can be explained briefly as the following for the output signal of an accelerometer. The output signal of the accelerometer in combination of signal conditioner is sampled. The total N+1 samples are then approximated to the function in the form of

$$V(t_i) = A \cdot \cos(\omega t_i) - B \cdot \sin(\omega t_i) + C \qquad (2)$$

where, ω is the vibration frequency, t_i is the time for ith sample. The parameters A, B and C are calculated using the least-squares sum method (sine-approximation) by solving N+1 system of equations. Then the amplitude and initial phase angle of the output signal of the accelerometer are calculated respectively by using the equations given below.

$$Amplitude,\ u = (A^2 + B^2)^{1/2} \quad (3)$$

$$Phase\ angle,\ \phi = \arctan(B / A) \quad (4)$$

Sinusoidal signals with nominal amplitude of 100 mV (rms) generated by signal generator in the frequency range from 10 Hz to 10 kHz at one-third octave band center frequencies were applied to CH2 of the signal conditioner through CH1 of the sensor simulator. Input signal to the sensor simulator and output signal of signal conditioner Brüel & Kjaer type 2694 were sampled at 10 MHz using NI DAQ 6115 Data acquisition board. Then these signals were approximated to sine in order to calculate amplitude and phase angle and then gain factor is calculated as the ratio of output signal to the input signal.

Gain of CH2 of B&K type 2694 was calculated by taken into account the gain of CH1 of the sensor simulator. The same procedure was applied for determination of the gain of CH3 and CH4 of the signal conditioner. Calibration results are given in Fig.9.

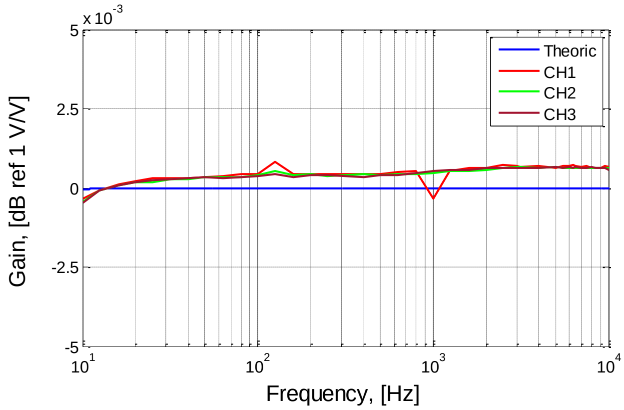

Fig. 8. Gain of sensor simulator determined experimentally and theoretically

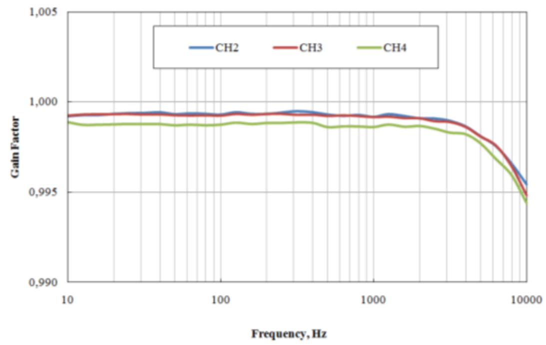

Fig. 9. Calibrated gain factor of Brüel & Kjaer type 2694 signal conditioner in TÜBİTAK UME.

3.2 Calibration of Signal Conditioner at NMCC

Calibration of signal conditioner in NMCC was performed by using a commercially available Spektra CS18 HF calibration system. Calibration system contains two reference capacitors, signal source and internal electronics. User is able to define frequency range and signal amplitude to be applied to the signal conditioner in Test Description module in Spektra CS18 HF software. Then the calibration is performed automatically. Calibration results of the same signal conditioner by Spektra CS18 HF calibration system are presented in Fig.10.

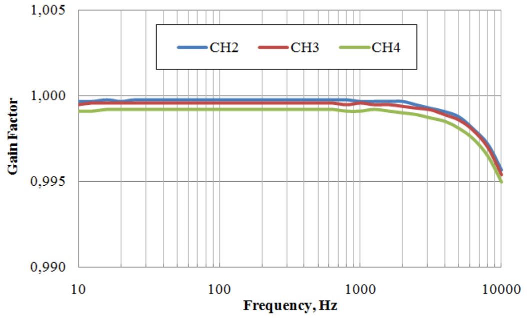

Fig. 10. Calibrated gain factor of Brüel & Kjaer type 2694 signal conditioner in NMCC

Calibration of ICP/IEPE/DeltaTron signal conditioner was performed by the systems at NMCC and TÜBİTAK UME in the frequency range of 10 Hz to 10 kHz. Taking into account, the gain factors and calibration uncertainties for the frequency range 10 Hz to 10 kHz; normalized error values E_n were calculated. Results are presented in Fig 11.

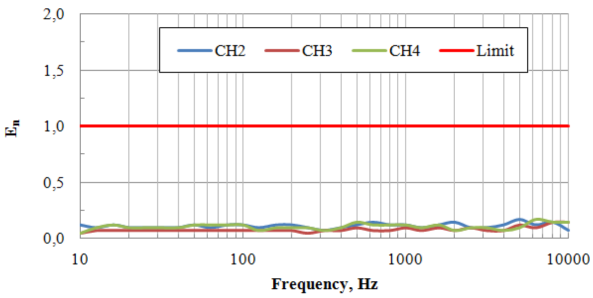

Fig. 11. E_n factors for the Gain of the Brüel & Kjaer type 2694 signal conditioner calibrated at TÜBİTAK UME and NMCC.

5. CONCULUSION

Calibration system for the vibration pick-ups was installed at NMCC. Performance of the installed calibration system was proved by using various tools; one of them was inter-system comparison on calibration of signal conditioner. Signal conditioner B&K type 2694 was calibrated at TÜBİTAK UME and NMCC within the frequency range from 10 Hz to 10 kHz. E_n values were calculated from the gain factors and their uncertainties. It has shown that the declared uncertainty values of TÜBİTAK UME and NMCC for the calibration of signal conditioner are fulfils the requirement of $E_n \leq 1$ for the frequency range of 10 Hz to 10 kHz.

5. REFERENCES

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