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A CALIBRATION SYSTEM FOR LASER VIBROMETERS AT NIMT

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Abstract: Laser Vibrometers have been used in many applications such as automotive and hard disk drive industries. In metrological field, laser vibrometers are employed as reference standards for the calibration of accelerometers. To have the traceability chain to the International System of Units (SI), several National metrological institutes (NMIs) and companies have developed calibration systems for laser vibrometers. National Institute of Metrology (Thailand), NIMT, is one of those NMIs. This paper describes the set-up for the primary vibrometer calibration system used at NIMT and presents the methods used according to methods 1 and 2 shown in the international standard ISO16063-41 [1]. The calibration results are also discussed.

Keywords: calibration, laser vibrometer, primary calibration

1. INTRODUCTION

The development of laser vibrometer calibration system has received increasing attention in many NMIs. There have been several studies on this development [2-8]. In most studies the sine approximation method was employed to obtain the calibration results. Ripper *et al.* [2] developed a homodyne quadrature interferometric system for the calibration of Laser Doppler Vibrometers (LDV). This system was capable to calibrate LDV in the frequency range from 10 Hz to 10 kHz. The calibration results were obtained using the sine-approximation method. Later, the new system has been developed by Ripper *et al.* [3] to allow calibration of vibrometers with both analog and digital output. Buehn *et al.* [4] employed sine approximation method and used the laser vibrometer as a reference standard. The calibration results were also presented.

Sine approximation method was also employed by Oota *et al.* [5]. A modified Michelson-type homodyne laser interferometer was used. Also the effects of fours parameters on the calibration results were investigated. Those were acceleration amplitude stability, mechanical distortion, position of measuring beam, and spot diameter of measuring beam. In [6], Oota *et al.* investigated the effect of demodulator unit characteristics on the calibration of laser vibrometer using two commercial laser vibrometers with analogue demodulator units.

G.S. Pineda *et al.* [7] evaluated the accuracy of the different standard methods shown in ISO 16063-41 [1] and concluded that method 1, method 2 and method 3 are applicable up to frequencies of 100 kHz or higher if special vibration exciters generating sufficient displacement or velocity are used.

Bruns *et al.* [8] employed a dual frequency excitation for laser vibrometer calibration using a modified Michelson interferometer as reference to calibrate laser vibrometer up to 90 kHz.

The aim of this work is to develop the calibration system for laser vibrometer by modifying an existing primary system for accelerometer calibration. The developed system employs a fringe-counting method for the calibration frequency between 40 and 800 Hz and uses a minimum-point method for the frequency range from 1 to 5 kHz. Also the system is verified by comparing the calibration results with those reported in SPEKTRA certificate [9].

Following this introduction, the experimental set-up and the methods to calibrate laser vibrometer are described. The calibration results are presented in section 3. The developed system is evaluated by comparing the calibration results with those obtained from the calibration certificate issued by SPEKTRA. Finally, section 4 contains some conclusions.

2. EXPERIMETAL APPARATUS AND METHODS

Experiments were conducted to investigate the performance of the developed system for laser vibrometer calibration. The photograph of this developed calibration system is shown in Fig. 1.

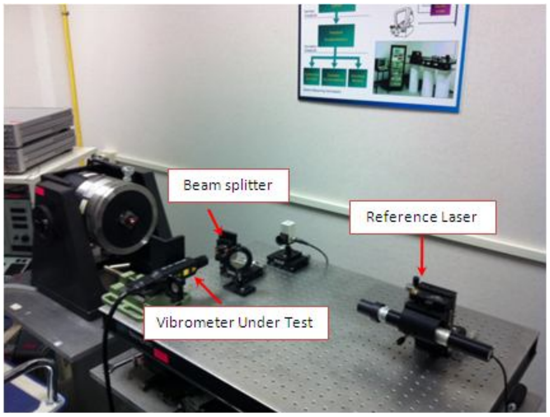

Fig. 1. Primary calibration system for the calibration of laser vibrometer.

FRINGE-COUNTING METHOD

The experimental set-up for the fringe-counting method is shown in Fig. 2. In the experiments, a reflecting mirror was connected to the top of a B&K exciter head model 4811. A B&K sine generator model 1051 generated an input signal to drive a B&K exciter model 4805 through a B&K power amplifier model 2707. Michelson Interferometer, consisting of a beamsplitter, a reference mirror, a photodetector and a Helium-Neon laser with wavelength of 632.8 nm, was used to measure reference displacement amplitude. The laser spot was pointed to the middle of the reflecting mirror through a beamsplitter 2. The photodetector output was amplified by a B&K measuring amplifier model 2636. The amplifier output was sent to oscilloscope to be monitored during the laser beam adjustment procedure.

For fringe counting method, the output from the amplifier model 2636 was compared in frequency with the excitation frequency from the sine generator by using an Agilent universal counter model 53131A. The displacement amplitude, $\hat{s}$, and the acceleration amplitude, $\hat{a}$, generated by reference standard can be calculated by using equations (1) and (2) respectively [1].

$$\hat{s} = \frac{\lambda}{8} R_f \tag{1}$$

$$\hat{a} = (2\pi f)^2 \hat{s} \tag{2}$$

where λ is the wavelength which is 632.8 nm. Here R_f is the ratio of the fringe frequency (f_f)come from the photodiode signal to the vibration frequency (f) generated by the sine generator.

A Polytec laser vibrometer model CLV-1000 with a decoder model CLV-M050 was used as a device under test (DUT). As same as the beam generated by the reference homodyne laser, the laser spot from the DUT was pointed to the reference mirror through the beamsplitter 2 as shown in Figs 2. Both laser beams, which were generated from DUT and reference laser, were pointed to the same position on the mirror. The measured analogue voltage from the DUT was sent to an Agilent digital multimeter model 3458A and the oscilloscope. The output from the digital multimeter was sent to PC for analysis. The acceleration generated by DUT can be determined from

$$\hat{a}_D = (2\pi f) V_D R_D \tag{3}$$

where V_D and R_D are the analogue voltage output from the DUT given in V and the measurement range in $\frac{\text{mm}}{\text{s}}/\text{V}$ respectively. The DUT used here has three measurement ranges, which are $2\ \frac{\text{mm}}{\text{s}}/\text{V}$, $10\ \frac{\text{mm}}{\text{s}}/\text{V}$ and $50\ \frac{\text{mm}}{\text{s}}/\text{V}$. The experiments shown in this paper were conducted for all three ranges.

MINIMUM POINT METHOD

The set-up for the minimum point method is shown in Fig. 3. This set-up is similar to that for the fringe-counting method. But for the minimum point method, the output from the measuring amplifier was analyzed to find the minimum points during Bessel measurements using a B&K signal analyzer model 2035. As the helium neon laser with $\lambda = 632.8$ nm was used, the reference displacement amplitudes for the minimum points were selected from Table 9 in [1] and the reference acceleration was calculated using equation (2). Also the acceleration of the DUT was determined from equation (3).

3. CALIBRATION RESULTS

In this section, the calibration results using system shown in Fig. 1 are presented. In order to verify this developed system, the resulted are compared with those obtained from the certificate issued by SPEKTRA.

The calibration method specified in SPEKTRA certificate is the primary calibration method according to ISO 16063-11. The SPEKTRA calibration was performed using a SPEKTRA vibration exciter model SE-09, an APS vibration exciter model 113AB, a Polytec standard laser vibrometer model CLV1000 and a SPEKTRA calibration system model CS18 HF-DKD. Both standard laser vibrometer and vibrometer under test measured velocity at the same point on the shaker surface. The calibration was done by comparing the acceleration of the vibrometer under test with that of the standard vibrometer [9].

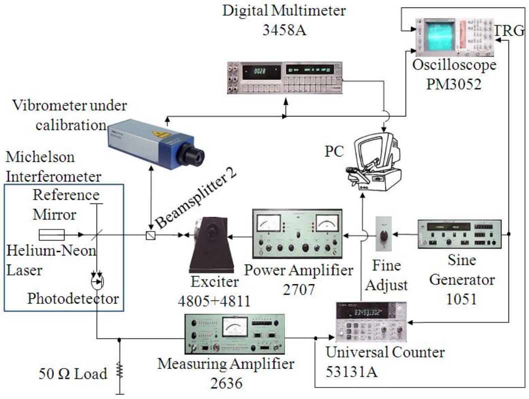

Fig. 2. Experimental set-up for laser vibrometer calibration using fringe-counting method.

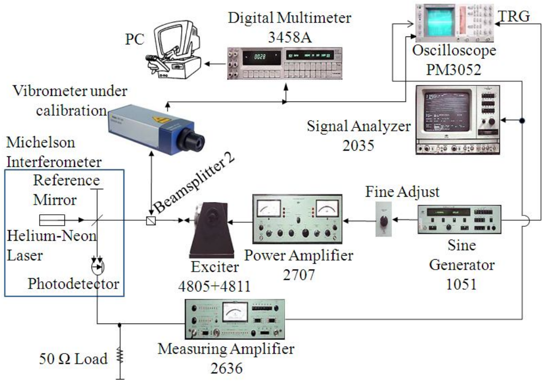

Fig. 3. Experimental set-up for laser vibrometer calibration using minimum point method.

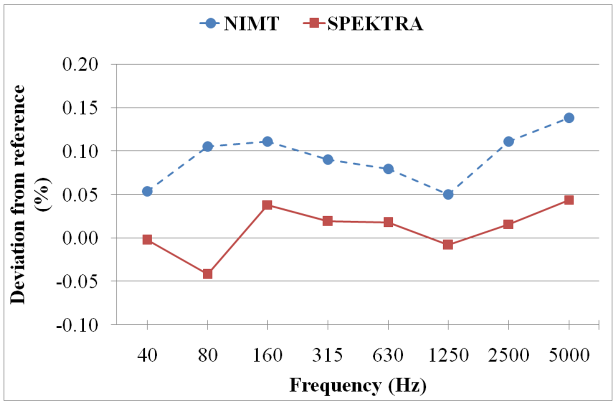

Fig. 4. Deviations of acceleration amplitudes from the reference standard for the range of 2 $\frac{\text{mm}}{\text{s}}$/V: -●- measured by NIMT and -■- obtained from SPEKTRA certificate.

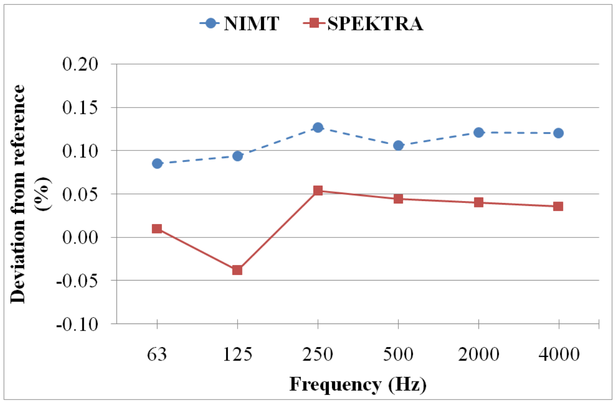

Fig. 5. Deviations of acceleration amplitude from the reference standard for the range of 10 $\frac{\text{mm}}{\text{s}}$/V: -●- measured by NIMT and -■- obtained from SPEKTRA certificate.

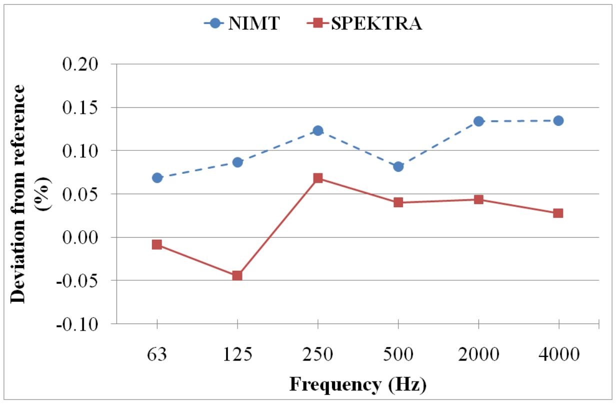

Fig. 6. Deviations of acceleration amplitudes from the reference standard for the range of 50 $\frac{\text{mm}}{\text{s}}$/V: -●- measured by NIMT and -■- obtained from SPEKTRA certificate.

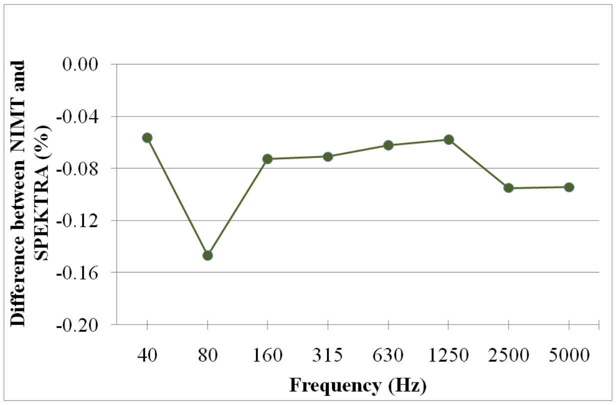

Fig. 7. Difference between acceleration deviation measured by NIMT and that obtained from SPEKTRA certificate for the range of 2 $\frac{\text{mm}}{\text{s}}$/V.

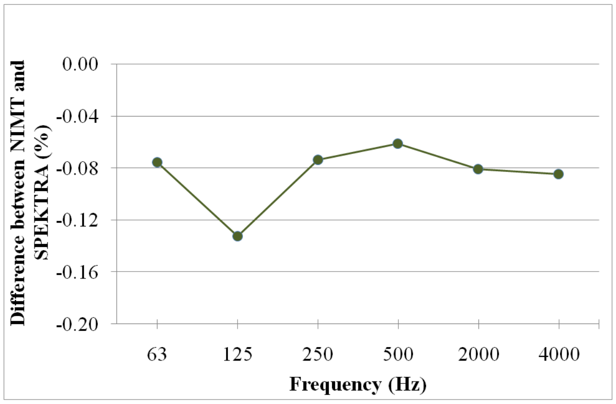

Fig. 8. Difference between acceleration deviation measured by NIMT and that obtained from SPEKTRA certificate for the range of 10 $\frac{\text{mm}}{\text{s}}$/V.

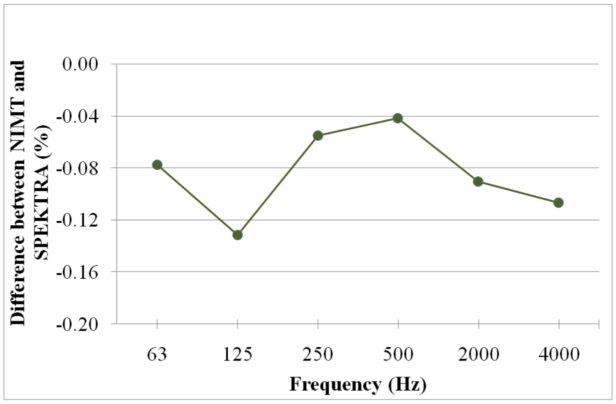

Fig. 9. Difference between acceleration deviation measured by NIMT and that obtained from SPEKTRA certificate for the range of 50 $\frac{\text{mm}}{\text{s}}$/V.

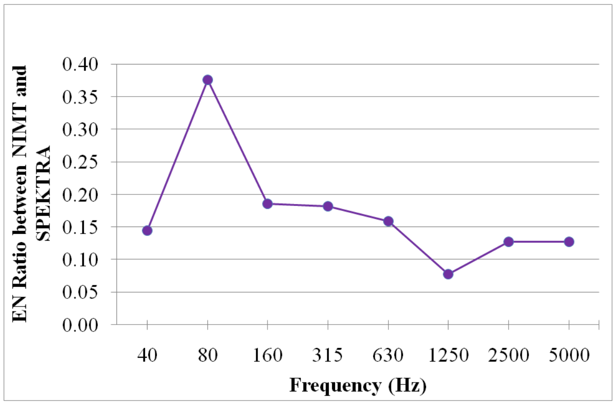

Fig. 10. EN Ratio between the results obtained from NIMT and SPEKTRA certificate for the measurement range of $2\,\frac{\text{mm}}{\text{s}}/\text{V}$.

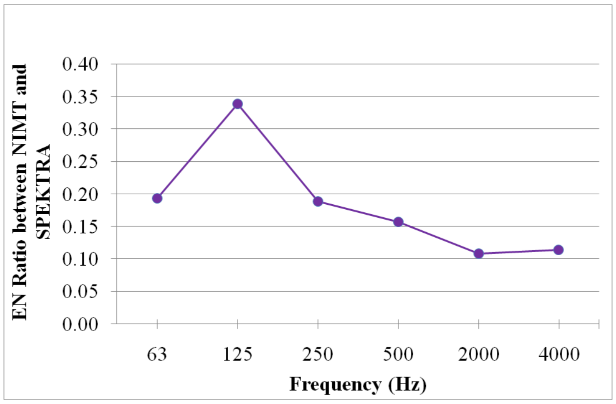

Fig. 11. EN Ratio between the results obtained from NIMT and SPEKTRA certificate for the measurement range of $10\,\frac{\text{mm}}{\text{s}}/\text{V}$.

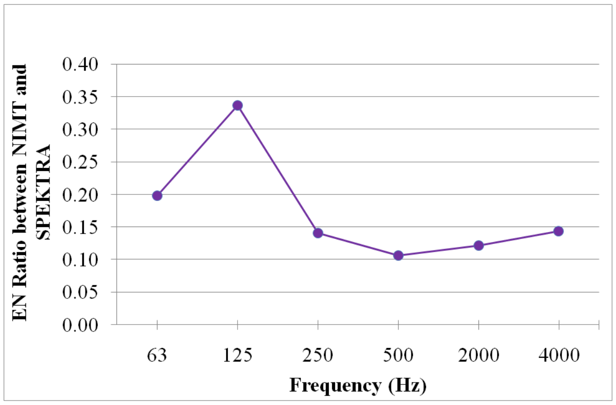

Fig. 12. EN Ratio between the results obtained from NIMT and SPEKTRA certificate for the measurement range of $50\,\frac{\text{mm}}{\text{s}}/\text{V}$.

Figs. 4, 5 and 6 present the comparison results between NIMT and SPEKTRA certificate for the measurement ranges $2\,\frac{\text{mm}}{\text{s}}/\text{V}$, $10\,\frac{\text{mm}}{\text{s}}/\text{V}$ and $50\,\frac{\text{mm}}{\text{s}}/\text{V}$ respectively. The vertical values shown in those figures are the deviation of acceleration amplitudes measured by reference laser and laser under test. This deviation is given in % and calculated from

$$100\left(\frac{\hat{a}_D-\hat{a}}{\hat{a}}\right). \qquad (4)$$

In Figs. 4-6, (-●-) represents the deviation of acceleration amplitudes measured by NIMT, while (—■—) shows the deviation obtained from SPEKTRA certificate. The results obtained by NIMT were calculated as the arithmetic mean of three repeated calibrations performed on different days. It can be seen that the deviations of acceleration amplitudes obtained by NIMT are higher than those reported by SPEKTRA. This occurs for the whole frequency ranges and for all three measurement ranges.

Figs. 7-8 show the difference between acceleration deviation measured by NIMT and that obtained from SPEKTRA certificate. This difference is determined from

$$D_S - D_N \qquad (5)$$

where D_N and D_S are the deviation of acceleration amplitudes measured by NIMT and SPEKTRA respectively.

It can be seen from Fig. 7 that the maximum difference between NIMT results and SPEKTRA results for the measurement range of $2\,\frac{\text{mm}}{\text{s}}/\text{V}$ occurs at frequency 80 Hz. However, it is found in Figs. 8-9 that the highest deviations for the frequency range of $10\,\frac{\text{mm}}{\text{s}}/\text{V}$ and $50\,\frac{\text{mm}}{\text{s}}/\text{V}$ present at 125 Hz. These maximum deviations are -0.15%, -0.13% and -0.13% for the measurement range of $2\,\frac{\text{mm}}{\text{s}}/\text{V}$, $10\,\frac{\text{mm}}{\text{s}}/\text{V}$, and $50\,\frac{\text{mm}}{\text{s}}/\text{V}$ respectively.

In order to illustrate the agreement between the calibration results from NIMT and SPEKTRA, EN ratio was calculated using the following equation.

$$E_\text{N} = \left|\frac{D_S-D_N}{\sqrt{U_S^2+U_N^2}}\right| \qquad (6)$$

where U_N and U_S are the expanded uncertainty of measurement declared by NIMT and SPEKTRA respectively with the coverage factor of 2. Here $U_S$is 0.25% for frequencies up to 5 kHz and U_N is 0.3 % for the frequency range between 40 and 800 Hz and is 0.7 % for the frequency range from 1 to 5 kHz.

Figs. 10-12 present the EN ratio of the results between NIMT and SPEKTRA certificate for the measurement range of $2\,\frac{\text{mm}}{\text{s}}/\text{V}$, $10\,\frac{\text{mm}}{\text{s}}/\text{V}$, and $50\,\frac{\text{mm}}{\text{s}}/\text{V}$ respectively. It is found that the EN ratio is between 0.08 and 0.38 approximately. Again, the maximum EN Ratio occurs at frequency 80 Hz for the measurement range $2\,\frac{\text{mm}}{\text{s}}/\text{V}$ and at 125 Hz for the ranges of $10\,\frac{\text{mm}}{\text{s}}/\text{V}$, and $50\,\frac{\text{mm}}{\text{s}}/\text{V}$.

4. CONCLUSIONS

The primary calibration system used for laser vibrometer calibration at NIMT has been presented in this paper. The system is capable of calibrating laser vibrometer in the frequency range from 40 Hz to 5 kHz. The methods that this system uses are a fringe-counting method for the calibration up to 800 Hz and a minimum point method for the frequency range between 1 kHz and 5 kHz. The calibration results are determined in terms of the deviation of acceleration amplitudes measured by the standard heterodyne reference and by the vibrometer under test.

The calibrations of a Polytec laser vibrometer model CLV-1000 with a decorder model CLV-M050 were performed and the calibration results were compared with those reported in SPEKTRA certificate to verify the calibration system developed at NIMT. The calibration results show the reasonable agreement between the results presented by NIMT and SPEKTRA certificate. Although the deviations of acceleration amplitudes reported by NIMT were larger than SPEKTRA, the highest difference between NIMT and SPEKTRA was satisfactory, which was about -0.15 % at 80 Hz. Also the EN ratio showed acceptable agreement between the results from NIMT and SPEKTRA certificate. The maximum EN ratio was 0.38 approximately.

5. REFERENCES

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