900. Experimental research of vibrations of angle measurement comparator

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Abstract. The aim of the presented research was to determine calibration error caused by mechanical instability of angle measurement comparator system. Vibrations were measured at the significant points of the system and dynamic characteristics of the system were subsequently established.

Keywords: angle measurements, comparator, dynamic characteristics.

Introduction

Despite achieved progress in the research in the field of metrology, precise mechatronic systems are typically too complex and it is difficult to adapt these achievements to them directly. Design and development of such mechatronic systems would be based on the research findings obtained from very specific field of study. For example, calibration error is the unique characteristic of angle measurement comparator, because it ant its components depend on specific measurement conditions.

One of the main criterions of design of such mechatronic systems is the error budget (structure), which regulates the ranges of errors that can be tolerated at every design, production and use stage of the life cycle of the system. It is not aimed to reduce the errors, but to control them and their impact. Therefore it is necessary to determine dominating errors, investigate possibilities to compensate them and establish the impact of these errors on calibration error budget.

Consequently, precise mechatronic systems are designed based on precision engineering principles, which consolidate their own distinctive approach to the synthesis of such systems. The knowledge and appropriate application of these principles requires systematic understanding of the problems, deep knowledge, and ability to analyze, evaluate and synthesize new complex ideas. It is very important that the designed precision equipment would be mechanically stable and its dynamic characteristics would be established [1-7].

The aim of this research work is to evaluate vibrations of elements of the angle measurement comparator system caused by its mechanical instability. The following investigations of dynamic stability of mechanical parts of the comparator were performed:

Vibrations of concrete foundation of the comparator were measured and analyzed;

Vibrations of comparator base (granite plate and support) were measured and analyzed;

Vibrations of granite guide and carriage were measured and analyzed in cases of foundation external excitation and shock excitation;

Results of experimental investigation were used to improve the design of angle measurement comparator.

Experimental technique and results

Experimental means. Vibrations were measured and analyzed using following "Brüel&Kjær" equipment: LAN-XI Type 3660-D data acquisition hardware, computer and accelerometers (Mod. 8344).

Accelerometers 8344 were attached to the special block, which allow to measure vibration in three perpendicular directions. The blocks with accelerometers then were attached to the object at the vibration measuring points.

Data analysis was performed with the aid of Microcal Origin and Brüel&Kjær Pulse Reflex software. Spectral analysis was performed and the following statistical parameters were calculated:
arithmetic mean:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \,, \tag{1}$$

standard deviation:

$$S_X = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} \,, \tag{2}$$

standard error:

$$S_{\bar{X}} = \frac{S_X}{\sqrt{n}} = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} \,, \tag{3}$$

spread:

$$x_{spr} = x_{\max} - x_{\min} \,, \tag{4}$$

where n is the number of measurements, x_i is the i-th measurement result.

Vibrations were measured in points A, B, C, D, E and F in three perpendicular directions X, Y and Z as shown in Fig. 1. Measuring point A is located on the massive foundation near the comparator, B – on the frame, C – on the granite plate, D – on the granite support, E and F – on granite guides.

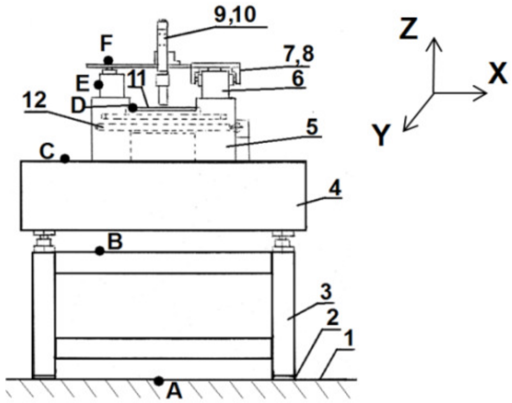

Fig. 1. Experimental stand and measuring points (A–F): 1 – foundation; 2 – vibration isolators; 3 – frame; 4 – granite plate; 5 – granite support; 6 – granite guide; 7, 8 – carriages; 9, 10 – microscopes; 11 – indexing table; 12 – worm wheel

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Vibrations of the foundation transmitted from technological equipment. Vibrations of the foundation were measured during the operation of technological equipment as well as other external vibration excitation sources (ventilation system), located in the adjacent premises. Time plot of vibrations and their spectrum plots are presented in Fig. 2, statistical characteristics are presented in Table 1.

Table 1. Statistical characteristics of the vibrations of the foundation

Measurement direction	Vibration acceleration amplitude					
	Arithmetic mean $\bar{x}$, mm/s^2	Standard deviation S_x, mm/s^2	Standard error $S_{\bar{x}}$, mm/s^2	Minimum value x_{min}, mm/s^2	Maximum value x_{max}, mm/s^2	Spread, mm/s^2
Z	-6.101E-3	1.38	0.0108	-5.15	5.77	10.92
Y	2.109E-3	0.823	0.00645	-3.17	3.15	6.32
X	2.393E-3	1.02	0.00799	-3.79	4.3	8.09
Measurement direction	Displacement amplitude					
	Arithmetic mean $\bar{x}$, µm	Standard deviation S_x, µm	Standard error $S_{\bar{x}}$, µm	Minimum value x_{min}, µm	Maximum value x_{max}, µm	Spread, µm
Z	-0.868	9.836	0.0768	-25.355	18.46	43.81

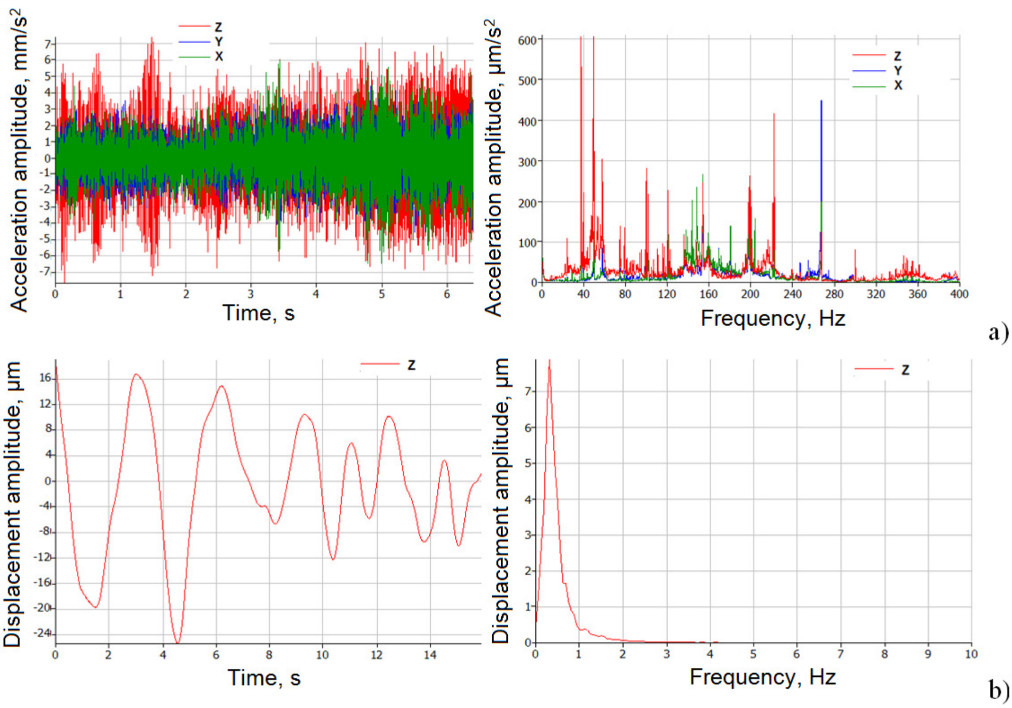

Fig. 2. Time and spectrum plots of vibrations of foundation, measured in the point A (Fig. 1): a) vibration acceleration amplitude; b) displacement amplitude

It can be observed from Fig. 2 and Table 1 that vibrations of the foundation are similar in all measuring directions. The maximum displacement amplitude reaches the value of 43.81 µm and acceleration amplitude reaches the value of 10.92 mm/s^2. Low frequency (to 0.5 Hz) vibrations are significant only, their amplitudes become insignificant at higher frequencies.

Vibration behavior of comparator frame and of granite support. Vibrations were measured in points C and D. All pneumatic systems (aerostatic bearings) were turned off during measurements. Measuring direction along the guide was considered as most important direction, because vibrations in this direction are the most dangerous. Results are presented in Figs. 3-4, calculated statistical characteristics are presented in Table 2.

Table 2. Statistical characteristics of the vibrations of granite plate and support

Measuring point (Fig. 1)	Measurement direction	Vibration acceleration amplitude					
		Arithmetic mean $\bar{x}$, mm/s^2	Standard deviation S_x, mm/s^2	Standard error $S_{\bar{x}}$, mm/s^2	Minimum value x_{min}, mm/s^2	Maximum value x_{max}, mm/s^2	Spread, mm/s^2
C	*Z*	-2.263E-3	3.22	2.518E-2	-10.96	10.64	21.6
	Y	1.298E-3	0.346	2.704E-3	-1.19	1.56	2.75
	X	-6.948E-3	0.296	2.316E-3	-1.35	1.11	2.46
D	*Z*	-1.911E-3	3.25	2.537E-2	-10.29	10.16	20.45
	Y	-1.58E-2	1.51	1.177E-2	-12.3	12.34	24.64
	X	-8.994E-3	0.755	5.901E-3	-3.78	3.2	6.98
Measuring point (Fig. 1)	Measurement direction	Displacement amplitude					
		Arithmetic mean $\bar{x}$, µm	Standard deviation S_x, µm	Standard error $S_{\bar{x}}$, µm	Minimum value x_{min}, µm	Maximum value x_{max}, µm	Spread, µm
C	*Z*	-0.403	9.395	0.0734	-22.57	21.24	43.81
D	*Z*	-0.0777	11.03	0.0862	-22.15	20.44	42.59

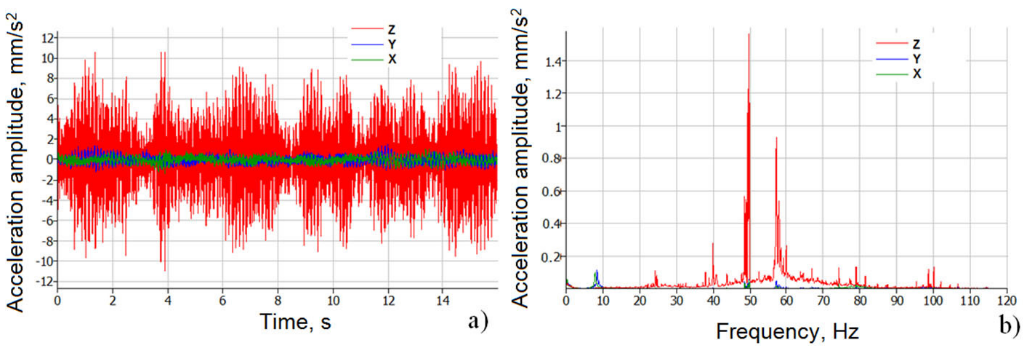

Fig. 3. Time (a) and spectrum (b) plots of vibration acceleration of granite plate (measured in the point C (Fig. 1))

It is can be observed in Figs. 3-4 and Table 2 that vibrations measured at points C and D are different in horizontal plane only. Differences are well discerned in frequency range of 40 – 110 Hz.

Vibration behavior of comparator system in the case of dynamic excitation. The aim of investigation was to establish how vibrations are transmitted from foundation to the granite support. Vibrations were measured in vertical (*Z*) direction at points A, B, C, D (Fig. 1), foundation was excited with shock signal by means of the vibrator. Results are presented in Fig. 5.

It can be observed in Fig. 5 that vibration isolation between foundation and frame reduces vibrations mainly at high frequencies of the order of 110 Hz and higher. In the range from 0 to

110 Hz acceleration amplitudes measured at points B, C and D are larger than acceleration amplitudes of foundation measured at point A (Fig. 1). In the range from 40 to 64.5 Hz maximum amplitude of the comparator increases from 1.66 (at frequency of 40 Hz) to 8.23 times (at frequency of 64.5 Hz) as compared with amplitude of foundation. The results reveal the inefficiency of the vibration isolation at low frequencies.

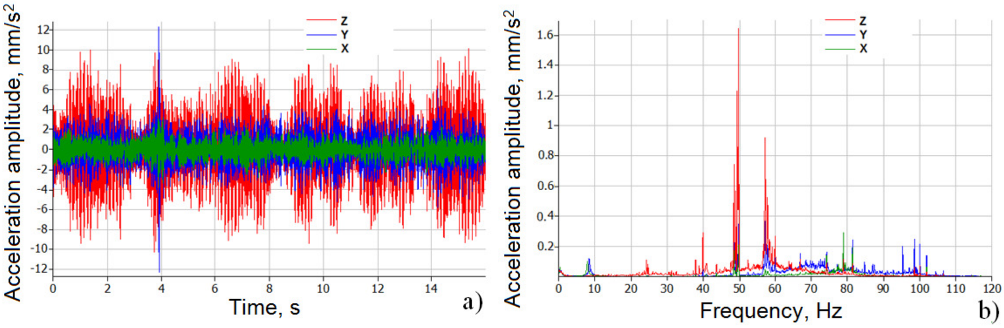

Fig. 4. Time (a) and spectrum (b) plots of vibration acceleration of granite support (measured at point D (Fig. 1))

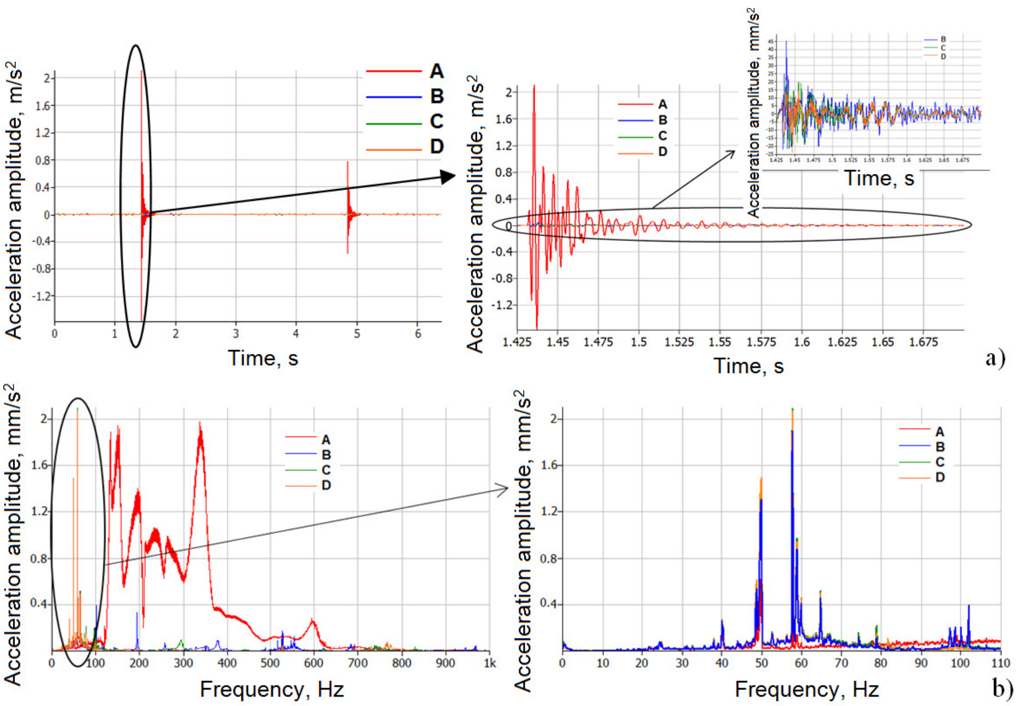

Fig. 5. Time (a) and spectrum (b) plots of vibration acceleration of the comparator system, measured in the points A, B, C and D (*Z* direction, Fig. 1)

Fig. 6 presents time plot of the excitation response of the comparator system (a part of time plot presented in Fig. 5, from 1.5 to 1.625 s) and its spectrum plot.

It is evident from Fig. 6 that vibration acceleration amplitudes of frame (point B), granite plate (point C) and support (point D) are the same in the range of 0 – 70 Hz. In the range of

70 – 1000 Hz acceleration amplitudes recorded at points C and D are less than those measured at point B except for frequencies of 296 Hz and 770 Hz.

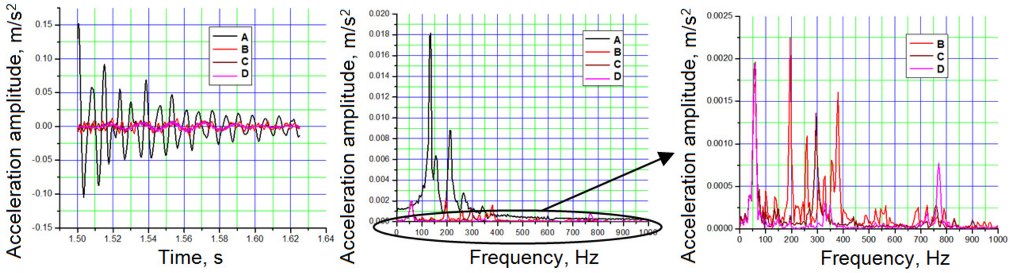

Fig. 6. Time and spectrum plots of vibration acceleration measured at points A, B, C and D (*Z* direction, Fig. 1)

The results indicate that high-frequency vibrations of granite plate and granite support are much lower than vibrations of the frame. This can be explained by mass difference between plate, support and frame.

Conclusions

1. External excitations of the comparator system transmitted through foundation were studied in the presented research work. It was established that vibration amplitudes become significant in the frequency range of 0 – 0.5 Hz only.
2. Vibration isolation between foundation and comparator frame does not influence low-frequency vibrations of the system.

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