510. Measurement errors of comparator on carriage vibrations

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Abstract. The main note in this article is to establish the influence of carriage construction and gear mounting modification on the dynamic characteristics of the system. The article investigates how the gear type influences the movement of the carriage. Two cases were considered. In the first case the carriage was moving with friction - gear, in the second case - with strip (string) gear. In this study reliability of vibration measurement system is assessed, which is characterized by measurement estimate uncertainty.

Keywords: carriage construction, vibration measurement system, uncertainty, dynamics.

Introduction

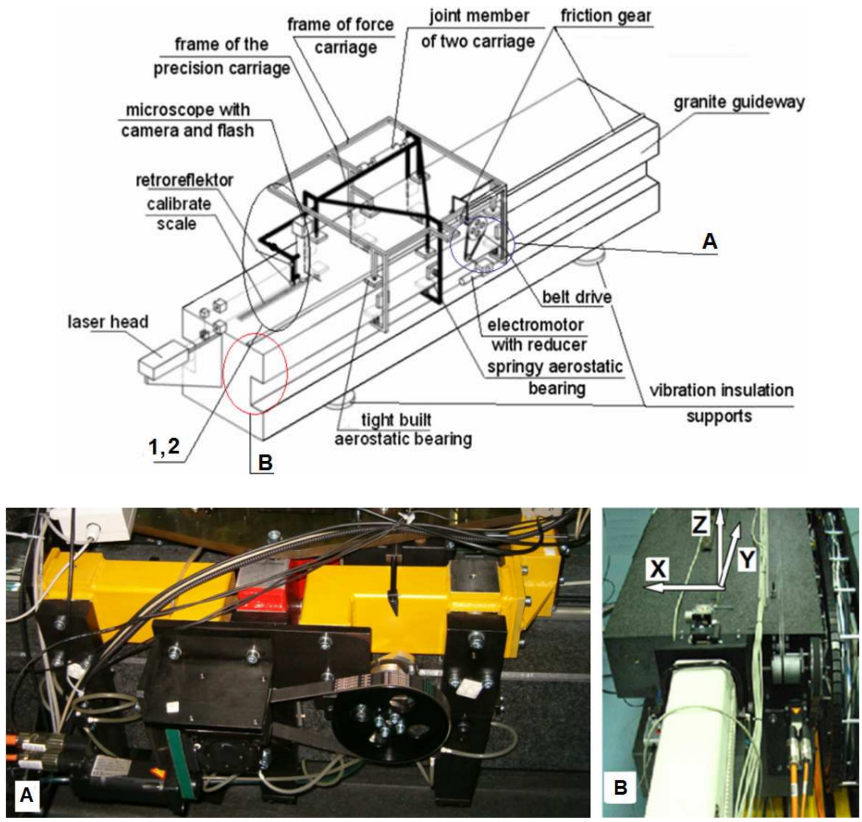
The main objective of this study is to establish the influence of carriage construction and gear mounting exchange on the dynamic characteristics of the system. This research is applicable to the large course metrological associated bar metrics to solve the tasks of comparator. Its results have wider meaning and could be used in the development of other high-precision systems [1-4].
Increase of bar length calibration accuracy required to take into account vibrations and their effects. To assess the impact of vibrations it is necessary to face many new scientific and technical challenges [5-7].

Vibration measurement system reliability could be characterized by uncertainty estimate [8, 9]. For example, the smaller the uncertainty of measurement results, the smaller is the distortion of information resulting in more accurate real technical condition rendering of the object.

Research object

Comparator is made of 4-meters long massive and fine structure granite beams, which are in the horizontal plane on four pneumatic supports, which suppress high-frequency vibrations and carriage that moves along the beam. When the carriage is filled with compressed air into the aerostatic bearings, it starts slipping on the air bearings along the rack crossing six high-precision guides. The carriage is moving along the rack by the program which is managed by the friction gear. The carriage is made from two parts – force and precision parts. Force and precision carriages are joined with elements.

Comparator scheme and gear fixing positions are presented in Figure 1.



a) b)

Fig. 1. Vibrations measurement points (1, 2) and fixing position of the gear on the length measurement comparator a); gear fixing points an overall picture b): A gear is fixed to the force carriage, B gear is fixed on granite guides near laser head

Research measures and methods

The measurements of vibrations are widely applied in controlling measurement systems, machinery and plant condition. On the basis of vibration measurement results we could fix object condition and make decisions on further actions. The reliability of these measurements depends on object features, structure of measurement system, environment where the device or machinery is operating, the work of service operator. Vibration measurement system reliability, in this case, is understandable as the probability of erroneous decision-making, which should be minimized. This could be achieved by analyzing factors that influence reliability.

For measurement of vibration parameters B&K instrumentation was used (Figure 2): 1. Accelerometers 8306 (with vibrometer 2511) and 8341; 2. Linear displacement transducer Hottiger TR102 (with amplifier Hottiger KWS 503D). Measuring results are processed by means of „Machine Diagnostics Toolbox Type 9727“ with the software Pulse.

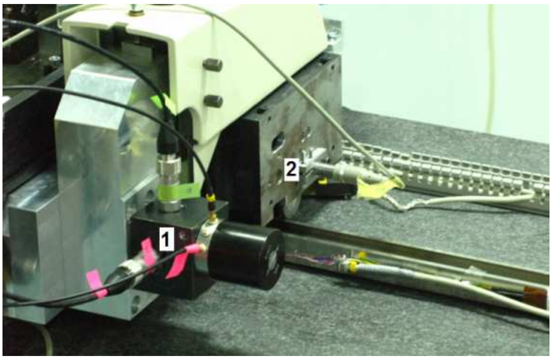


Fig. 2. Carriage vibration measurement points: 1 - absolute precision carriage (accelerometers 8306); 2 - relative microscope interferometer mirrors respect (linear displacement transducer Hottiger TR102) vibration

Vibration measurement data and uncertainty assessment

Based on real data, the calculation of the statistical uncertainty assessment u^2_{stat} in accordance with the measured data and on the basis of the literature [10, 11]:

$$U_{SVMS} = 2 \cdot \sqrt{u_{stat}^2 + u_{mat}^2 + u_{\hat{K}}^2 + u_{K_{ss}}^2 + u_T^2 + u_H^2 + 2 \cdot u_T u_H r(T,H) + u_{stip}^2 + u_{keit}^2 + u_{mat,duom}^2 + u_{tr}^2} \quad (1)$$

u_{stat} – statistical component of uncertainty;
u_{mat} – measuring instrument calibration uncertainty;
$u_{\hat{K}}$ – device transmission coefficient uncertainty component;
$u_{K_{ss}}$ – transformation coefficient uncertainty component;
u_T – affect of temperature uncertainty component;
u_H – humidity affect uncertainty component;
u_{stip} – component of uncertainty of the initial signal amplifying;
u_{keit} – uncertainty component of the analogue signal conversion to the digital code;
$u_{mat,duom}$ – component of uncertainty of the measurement data processing;
u_{tr} – uncertainty component due to a noisy environment.

The statistical component of uncertainty:

$$u_{stat} = \frac{S_X}{\sqrt{n}} \quad (2)$$

S_X – the standard deviation of the mean, which could be expressed by the formula:

$$S_X = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}\ ; \quad (3)$$

here n – units of measurement results, x_i – i[th] measurement result, $\bar{x}$ – arithmetic mean:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \ ; \tag{4}$$

Vibration measurement data and uncertainty assessment is presented in table Nr. 1.

Table 1. Vibration measurement data and uncertainty assessment

Vibration measurement transducer	Arithmetic mean $\bar{x}$, μm	Standard deviation S_x, μm	The statistical component of uncertainty u_{stat}, μm
Seismic accelerometer 8306	-0,0993	0,2039	0,0016
Linear displacement transducer “Hottiger Tr102”	0,00118	0,00474	0,000105

Vibration measurement results in uncertainty when the precise carriage of length measurement comparator moves with speed 3 mm/s. Absolute vibrations of point 1 (Fig. 2) and relative vibrations of the laser microscope with respect to mirrors of laser interferometer were measured. The analysis of the experimental results provided the following statistical parameters of vibration: S_X = 0,2039 μm and u_{stat} = 0,0016 μm (measured by seismic accelerometer 8306) and S_X = 0,00474 μm and u_{stat} = 0,000105 μm (measured by linear displacement transducer "Hottiger Tr102"). These parameters indicate that due to the large amount of data, the statistical uncertainty component, describing the main difference between the data (when absolute oscillations of the precise carriage measured), is small, and uncertainty estimates, provided that the statistical uncertainty component is negligible, would be the following:

$$U_{SVMa} = 2 \cdot \sqrt{u_{mat}^2 + u_{\hat{K}}^2 + u_{K_{ss}}^2 + u_{stip}^2 + u_{keit}^2 + u_{mat,duom}^2} \tag{5}$$

During the evaluation of the linear displacement transducer, the statistical uncertainty component cannot be considered negligible. Then the measurement system uncertainty can be expressed as:

$$U_{VMSs} = 2 \cdot \sqrt{u_{stat}^2 + u_{mat}^2 + u_{\hat{K}}^2 + u_{K_{ss}}^2 + u_{stip}^2 + u_{keit}^2 + u_{mat,duom}^2} \tag{6}$$

Temperature and humidity uncertainty components are taken equal to zero. Noise component also can be taken near to zero, because the room in which measurements were performed is isolated from external noise sources. Uncertainties of absolute and relative vibration measurement results are the following: the absolute vibration measurement result is 0,47% uncertainty, the uncertainty of relative vibration measurement results is 1,03%.

Measurement results

To assess the value of changes is chosen continuity of the motion criteria, when the carriage is moving at different speeds. The measurement results of comparator carriage vibrations when the carriage is moving at different velocities, is presented in Fig. 3. To assess the continuity of the motion, the main criteria are:

- Absolute vibrations on precision carriage along the measurement of motion;
- Relative vibrations of the microscope with respect to mirrors of laser interferometer.

This paper presents graphical representation of measurement results after implemented changes and after carriage improvement. The common results before changes are scrutinized in [5-7], statistical parameters are given in Table 2. The results of measurement with carriage speed values 0 mm/s, 1 mm/s, 2 mm/s and 3 mm/s are presented in Fig. 3 and 4. The adequate results of carriage speed values 4 mm/s, 5 mm/s and 10 mm/s are presented in Fig. 5 and 6.

Measuring signals were processed on computer using software Origin 6 and Pulse. Signal spectra, distributed and statistical parameters were determined as a result of computer analysis.

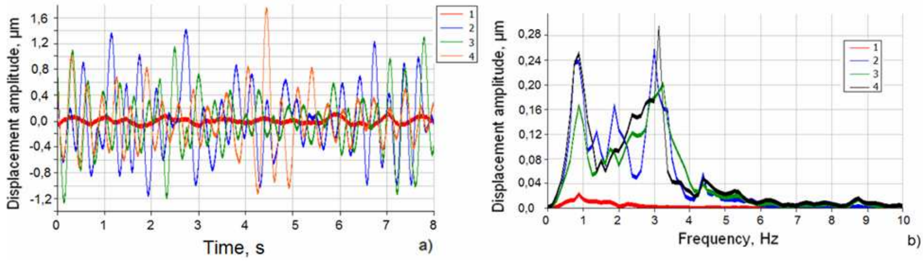


Fig. 3. Point 1, which is on precision carriage (Fig. 2), absolute vibration (a) and vibration spectrum (b) graphs, longitudinal direction: 1 – speed of carriage 0 mm/s, 2 – speed of carriage 1 mm/s, 3 – speed of carriage 2 mm/s, 4 – speed of carriage 3 mm/s

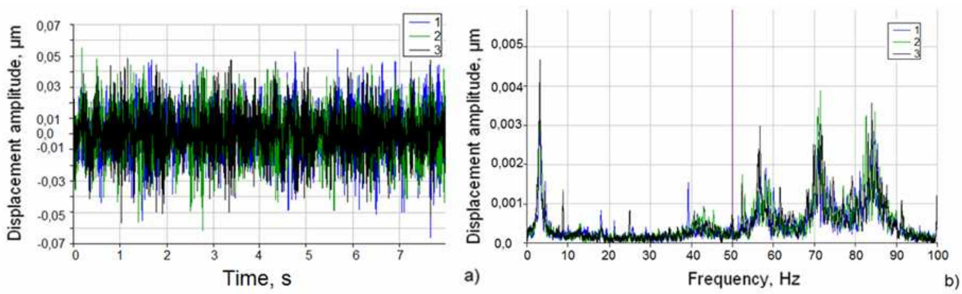


Fig. 4. Point 2 (Fig. 2) the relative vibrations of the microscope with respect to mirrors of laser interferometer (a) and vibration spectrum (b) graphs: 1 – speed of carriage 1 mm/s, 2 – speed of carriage 2 mm/s, 3 – speed of carriage 3 mm/s

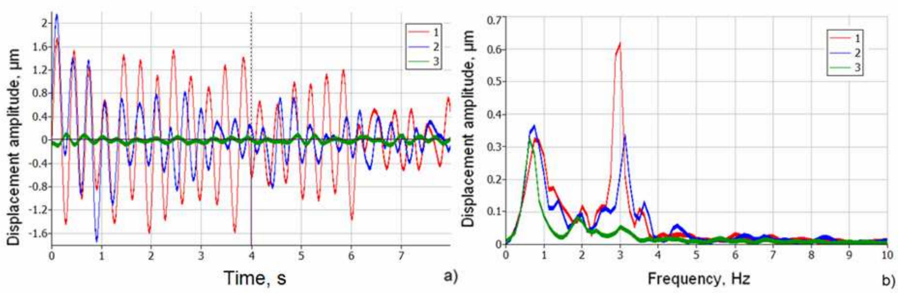


Fig. 5. Point 1, which is on precision carriage (Fig. 2), absolute vibration (a) and vibration spectrum (b) graphs, longitudinal direction: 1 – speed of carriage 4 mm/s, 2 – speed of carriage 5 mm/s, 3 – speed of carriage 10 mm/s

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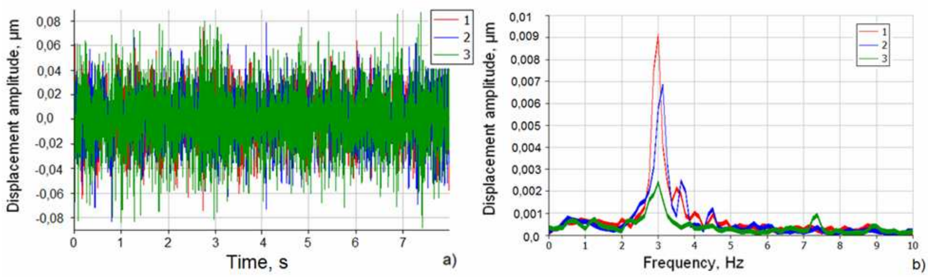
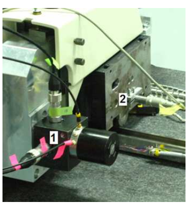


Fig. 6. Point 2 (Fig. 2) relative vibrations of the microscope with respect to mirrors of laser interferometer (a) and vibration spectrum (b) graphs: 1 – speed of carriage 4 mm/s, 2 – speed of carriage 5 mm/s, 3 – speed of carriage 10 mm/s

Measurements were carried out in longitudinal direction. Supply of air to the comparator frame supports and carriage aerostatic bearings was controlled. The illustrations show the selected points at which vibration amplitudes reach maximum values at the respective frequencies. The obtained experimental results indicate that the spectral amplitudes absolute vibrations of Point 1 (Fig. 2) at 0 – 4 Hz frequencies fluctuate from 0,024 to 0,028 μm (when carriage speed values are 0 mm/s, 1 mm/s, 2 mm/s and 3 mm/s) and from 0,036 to 0,06 μm (when carriage speed values are 4 mm/s, 5 mm/s and 10 mm/s), whereas at other frequencies vibration amplitudes are inconsiderable. Maximum amplitudes at the relative vibrations of the microscope with respect to mirrors of laser interferometer reach 0,0045 µm at 5 Hz frequency, at frequencies varying from 56 to 60 Hz the amplitude fluctuates from 0,002 to 0,003 µm, and at frequencies varying from 70 to 75 Hz and 80 to 90 Hz - amplitude reaches about 0,0035 µm (when carriage speed values are 0 mm/s, 1 mm/s, 2 mm/s and 3 mm/s). The relative vibrations of the microscope with respect to mirrors of laser interferometer reach 0,002 – 0,009 µm at 3 Hz frequency (when carriage speed values are 4 mm/s, 5 mm/s and 10 mm/s).

Table 2. The statistical characteristics of vibrations

Measuring place	Measuring direction (measurement point)	Drive fixing place (Fig. 7)	Standard deviation S_x, µm	Minimum value x_{min}, µm	Maximum value x_{max}, µm	Dominant vibration amplitude is at a frequency, Hz	Values of the dominant vibration amplitude, µm	Carriage speed, mm/s
 absolute vibration of the point on the precise carriage along the measurement motion (1) and relative vibrations of the microscope in respect of mirrors of laser interferometer (2)	*Y (1)*	A	0,684	-2,812	2,233	10	0,27	1
	Y (2)	A	0,510	-1,599	1,533	60	0,12	
	Y (1)	B	0,522	-1,136	1,397	1; 3	0,24 0,26	
	Y (2)	B	0,017	-0,066	0,054	3; 72	0,0032 0,003	
	Y (1)	A	1,258	-4,241	3,775	10	0,74	3
	Y (2)	A	0,662	-1,747	1,787	60	0,175	
	Y (1)	B	0,420	-1,103	1,737	1; 3	0,255 0,295	
	Y (2)	B	0,016	-0,059	0,049	3; 85	0,0046 0,0035	
	Y (1)	A	1,461	-5,797	6,214	2	0,35	5
	Y (2)	A	0,355	-1,253	1,303	70	0,058	
	Y (1)	B	0,508	-1,72	2,13	1; 3	0,36 0,335	
	Y (2)	B	0,023	-0,083	0,079	3; 66	0,0068 0,0092	

Measurement results (Table 2) demonstrate that after the changes absolute (point on the precision measurement of the motion along the carriage) vibration and relative vibrations of the microscope with respect to mirrors of laser interferometer decreased significantly.

Conclusions

1. Construction of carriage and position of gear fixation significantly influences stability of the system.
2. Improvement of carriage construction and replacement of area of gear fixation results in approximately 9-fold reduction of the relative vibrations of the microscope with respect to mirrors of laser interferometer, while reduction of absolute vibrations constitutes on average 42%.
3. Due to implemented modifications the amplitude of absolute vibrations in the range of frequencies from 9 till 10 Hz dropped to lower frequency range from 1 till 3 Hz.

References

[1] **Sawabe M., Maeda F., Yamaryo Y., Simomura T., Saruki Y., Kubo T., Sakai H. and Aoyagi S.** A new vacuum interferometric comparator for calibrating the fine linear encoders and scales // Precision Engineering, Volume28, issue 3, July 2004, p. 320-328.

[2] Creation and Research into Precision Length Calibration Systems // 2003 Report on the VMSF Research Program Reg. No B-03008, Kaunas 2003, p. 181.

[3] NANO 3: Line Scale Standards, WGDM-7, Preliminary comparison on nanometrology according to the rules of CCL key comparisons // FINAL REPORT, Braunschweig, August 29, 2003, p. 119.

[4] NANO 4: 1D gratings, WGDM-7: Preliminary comparison on nanometrology according to the rules of CCL key comparisons // Final report, Draft B, Wabern, 30. November 2000, p. 34.

[5] **Kilikevichus A., Vekteris V.** Research of vibrations acting the comparators Carriage. Journal Materials, Methods & Technologies, Internetional Scientific Publications Vol. 2, Part 1. Bulgaria 2008, ISSN 1313-2539, 11-23p.

[6] **Kasparaitis A., Vekteris V., Kilikevičius A.** Precision Measurement of the Carriage Vibrations at the Different Speeds. Solid State Phenomena, 2009, v.147-149, ISSN 1012-0394, p.690-695

[7] **Kilikevičius A., Vekteris V., Kasparaitis A.** Definition of the comparator dynamic reading errors. Proceedings of the International conference Vibroengineering 2008, ISSN 1822-1262, p 68-72

[8] **Eidukevičiūtė M., Volkovas V.** On the impact of vibration measurement uncertainty to diagnostics in vibromonitoring systems //Vibroengineering 2006 : proceedings of the 6th international conference, Kaunas University of Technology. ISSN 1822-1262. Kaunas: Technologija. 2006, p. 116-120

[9] **Volkovas V., Eidukevičiūtė M.** Uncertainty in vibromonitoring systems of rotating machinery // Vibroengineering 2004 : proceedings of 5th International Conference, October 14-15, 2004, Kaunas, Lithuania. ISSN 1392-8716. 2004. p. 111-113.

[10] **Vekteris V., Jurevičius M., Daktariūnas A.** Kompiuterinė diagnostinių matavimų sistema // Matavimai, Nr. 2(11), 1999, p. 11-17.

[11] **Vekteris V., Jurevičius M.** Technologinių mašinų diagnostiniai matavimai // Matavimai, Nr. 3(13), 2000, p. 21-26.