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Numerical and experimental analysis of high precision positioning system

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Abstract. In this paper numerical and experimental analysis of high precision positioning system is investigated. The positioning system is designed with or without mechanical reductor. The functionality of mechanism and its stiffness and strength characteristics were checked by the finite element method. Magnitudes of displacement of reductor was checked by numerical and experimental method. It was found out that it is sufficient to use an actuator without mechanical reductor to achieve the required accuracy of the positioning system.

Introduction

Precise positioning is demand in almost every industry branch, manufacturing process automation, material division, product palletizing, etc. In most cases, positioning accuracy in tenth of millimetres is sufficient. In microelectronics, laboratory instruments, etc., precision requirements are increasing, but production costs are also increasing. However, in such cases, the positioning of small loads with masses of the order of few kilograms is concerned. In the precision positioning of larger loads is necessary to consider the deformation of the elastic members which are part of the positioning systems. The numerical modelling using the finite element method is the most commonly used to verify the required strength and stiffness. The outputs of numerical modelling are applied not only in the optimization of structural parts, but also in the kinematic analysis of movements of the whole supporting system. The basic aim of the kinematic analysis is to verify the range of reference point movements depending on the actuator movements, taking into account real bonds. The precise positioning system depends on the accuracy of the manufacturing of the individual components and at the same time it is necessary to perform a control measurement of it on real stands [1-6].

The paper presents the procedure of experimental verification of achieving the required accuracy of the precise positioning system without and with mechanical reductor. The key elements of the designed system consist from elastic members whose shapes and dimensions have been checked by numerical modelling [3]. The aim was to achieve positioning accuracy of load with mass 600 kg and repeatability of positioning. Experimental measurements aimed to verifying the accuracy of the positioning system were carried out on the designed stand without and with load.

Design of methodology for testing the positioning system

The aim of the methodology is to design the measurement system so that the results obtained by numerical modelling can be verified by experimental measurement on a real model. The stand should allow a vertical positioning of load with mass 600 kg. Two variants of precise positioning of load are analysed. The first variant consists of vertical actuator in combination with an elastic member. The second variant contains in addition to the horizontal actuator and elastic members mechanical reductor commonly used in precise positioning systems [1, 2]. Optimization of shape and dimensions of chosen parts of positioning system is realised by the finite element method [7]. The object of numerical modelling is to obtain the dependence between the horizontal displacement by the actuator in the range ±5 mm and vertical displacement of the selected point of the load. In the Fig. 1 is shown a model of the analysed positioning system with elastic members and mechanical reductor.

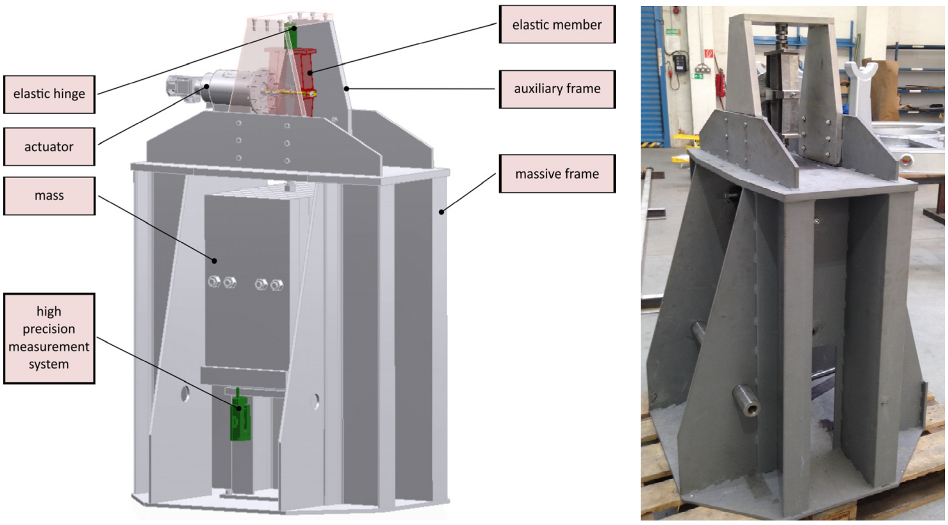


Fig. 1: Numerical and real model of the stand with elastic member and reductor

The displacement field in positioning system is shown in two directions – in the x-axis direction (Fig. 2 left) and in the y-axis (Fig. 2 right). If the system is loaded by the mass of 600 kg, then the vertical displacement of the bottom part is equal 0.2355 mm. This value is taken as reference value. In the Tab. 1 are given the values of displacements of bottom part for the values of displacement of vertical actuator. In addition to the analysis of displacement fields, a stress analysis is performed. In this analysis the critical points of the positioning system are analysed. The maximum values of von Mises stresses do not exceed the value 560 MPa, which is below the yield strength for the material 34CrNiMo6 (WNr. 1.6582) [3].

Table 1: Displacement of bottom surface of mass

Prescribed displacement in Y direction [mm]	Displacement of bottom surface of weight in X direction [mm]
0	0.0000
0.5	-0.1002
1	-0.2000
2	-0.3999
3	-0.5998
4	-0.7996
5	-0.9994

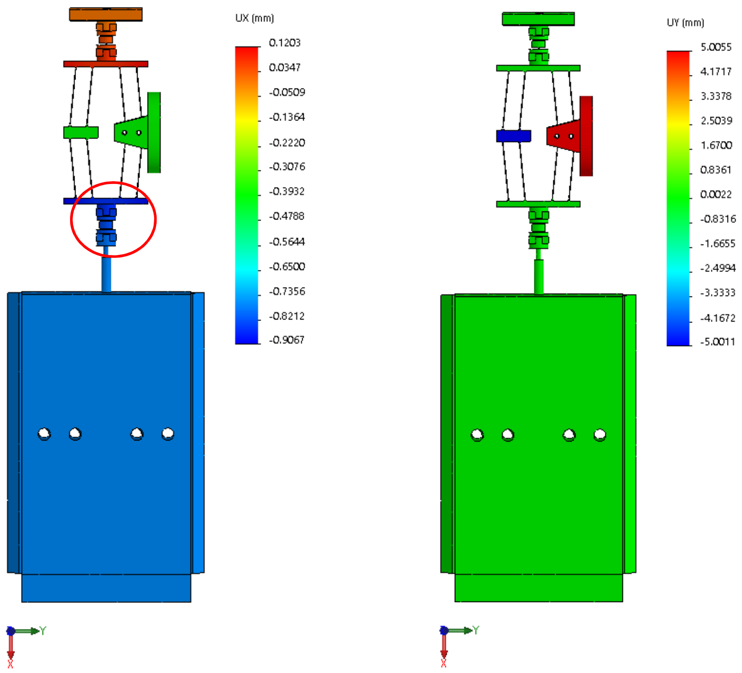


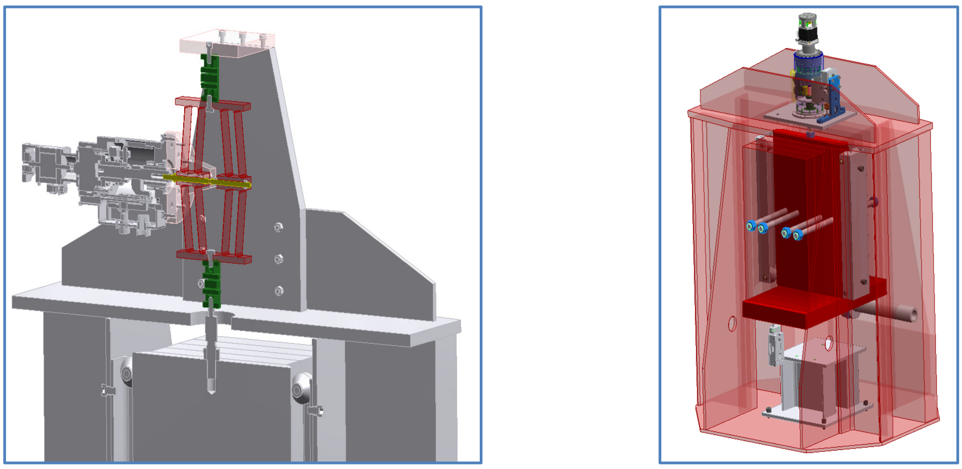
Fig. 2 Displacement fields of points in X and Y direction, respectively

The numerical simulations have not been performed for the positioning with the vertical actuator, since the mechanical movement of the actuator is identical as the movement of the mass.

Differences between the analysed variants can occur on real objects due to inaccuracy of the production of individual components, the backlash of the mechanical parts of the actuator and the like. For this reason, verification experimental measurements on real models are realized.

Experimental verification of accuracy of positioning system

To compare the above mentioned variants, a measurement chain is designed, which includes a stand allowing experimental verification of positioning accuracy with and without mechanical reductor under operating conditions for defined load states. In the Fig. 3 is shown 3D model of the stand with and without mechanical reductor.



a) b)

Fig. 3 Model of stand a) with mechanical reductor, b) without reductor

In the Fig. 4 is shown the stand with and without mechanical reductor, respectively. For the stand without reductor is used the same massive frame, the difference is only in the design for mounting the actuator. In the case of positioning with the mechanical reductor, a radial actuator RLA with maximal loading 100 kg is used, in the case of mechanical reductor a vertical actuator VLA with maximal loading 500 kg is used. The basic parameter for selecting the actuator was the maximum load required for trouble-free positioning of the load with the prescribed weight. The load was caused by the weight of the steel plates themselves.

a)

b)

Fig. 4 Stand a) with mechanical reductor, b) without mechanical reductor

Fig. 5 Preview of used actuator

Mechanical sorting and calibration of linear actuator

The first phase after the mechanical production of components and the mechanical assembly of the linear actuator is its electro-mechanical recovery and alignment to the specified reference point. The reference point is the basis of every accurate measurement system and ensures repeatability of accuracy of the device even after its repairing or service interventions. A very important task of mechanical sorting and calibration of actuator is to eliminate partially or completely defective parts that would render the device inoperable over time. In any case, if a component's continuous test results appear outside the tolerances, the component must be removed and replaced with a new component to avoid significant future damage that occurs sooner or later as a result of this defective part. The result of the above process is a assembling protocol that contains all of the parameters that are essential to the proper operation of the actuator.

Complex test without load

The first test is performed without load. The test is run for approximately 45 minutes and ended automatically. At the beginning of the test, the actuator output piston center position is set. The test consisted of positioning the actuator within ±3 mm, with one step corresponding to 0.2667 µm (i.e. 3 mm = 11 250 steps). Three main parameters were registered during the test: repeatability, linearity and mechanical backlash of transmission system. In the Fig. 6 is shown the protocol from the test without load, where the maximal deviations for the respective actuator step are given.

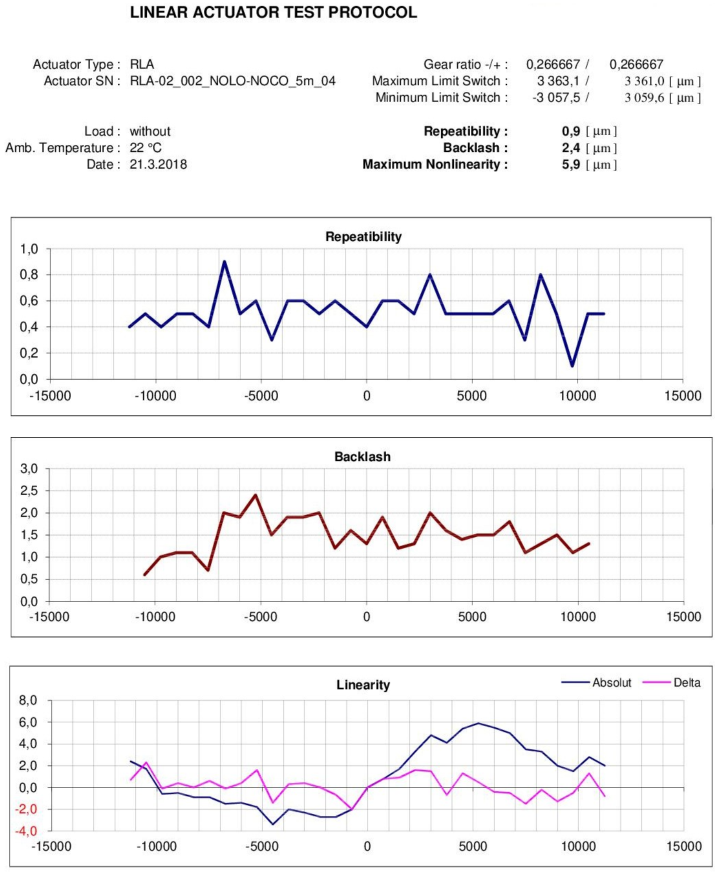


Fig. 6 Linear actuator test protocol without load

Complex test with load

After performing the test of the actuator without load, the tests with the load are performed (the ambient temperature is about 22-23°C). Vertical actuator VLA (Fig. 3b) is loaded by a mass of 600 kg and the horizontal actuator RLA (Fig. 3a) by mass of 120 kg. The masses represent a 20% overrun of the manufacturer's maximum values. The test of the actuator under full load verifies its performance parameters.

A precision displacement sensor (Fig. 7) is used to verify the real displacement of the lower load. In addition, the precision displacement sensors are used to identify the response of the mechanical parts of the actuator – backlash.

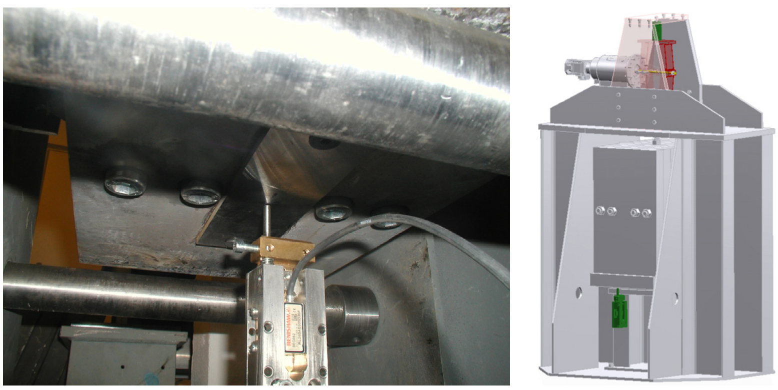
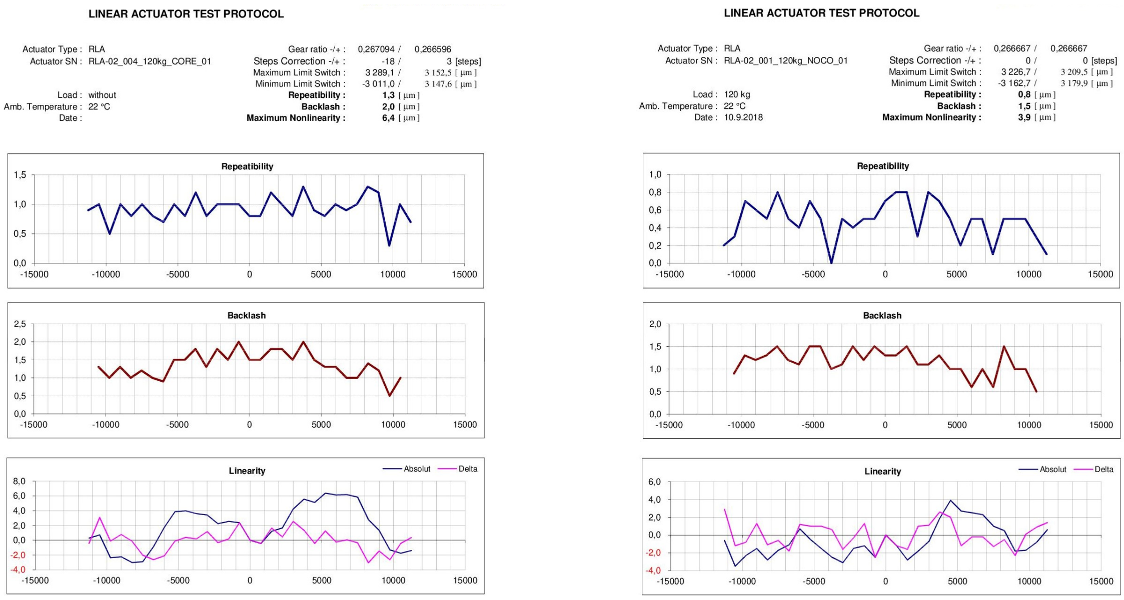


Fig. 7 The displacement sensor located at the bottom part of the stand

The results of the test of precisions actuators have confirmed that the parameters measured during the activation, mechanical sorting and calibration of individual actuators do not change due to the load of the actuator. In the Fig. 8 are shown the protocols from functionality and reliability testing of actuators.



a) b)

Fig. 8 Test protocol of actuator RLA a) without load, b) with load

In the Tab. 2 are given the most unfavourable variations regarding of repeatability, mechanical backlash of the actuator gear system and linearity detected during testing.

Table 2: Variations during testing

	Actuator VLA without mechanical reductor		Actuator VLA with mechanical reductor	
	without load	with load	without load	with load
Repeatability [µm]	2.1	0.9	1.3	0.8
Backlash [µm]	2.6	1.6	2.0	1.5
Nonlinearity [µm]	6.5	4.9	6.4	3.9

From the test results, it is clear that the solution with the mechanical reductor gives a slightly better values than is the case without the mechanical reductor.

In Tab. 3 is given the displacement of the lower surface of mass. The results are obtained by numerical modelling and experimental measurements. From the results can be stated that the values are little different, which is probably caused by the production of a mechanical stand. Despite this, it can be stated that a very good agreement of results is achieved. In the production of a real device with the mentioned type of positioning mechanism, it is necessary to pay increased attention to the production of individual parts as well as the assembly itself. Since the welding process is used in the manufacture of the positioning device, it is also necessary to pay extra attention to residual stresses, which may adversely affect the desired positioning accuracy. Non-destructive [8] or semi-destructive residual stress [9-11] methods are most commonly used to quantification of residual stresses.

Table 3: Displacement of the lower surface of mass

Horizontal displacement (actuator RLA) [mm]	Vertical displacement	
	FEM [mm]	Experiment [mm]
0	0.0000	0
0.5	-0.1002	-0.1025
1.0	-0.2000	-0.2047
1.5	-0.2999	-0.3073
2.0	-0.3999	-0.4062
2.5	-0.4998	-0.5054
3.0	-0.5998	-0.6038

Discussion

The rapid development of hardware and software contributes significantly to experimentation. Computer support is objectively conditioned mainly by the level of electronization, objective social specifics and subjective factors of users, and thus also by the experiment. The computer application in the technology is affected the experiment from various perspectives:

- the computer becomes a direct part of the experiment, while changing their structure and level,
- there are new possibilities to prepare an experiment consisting of planning measurements and computer-aided preparation of multi-factorial and extremalization experiments,
- the quality, quantity and way of realization of computational works performed within individual stages of the experiment are changed by using experimental software,
- the performance parameters of the experiment have increased considerably, namely the speed and operability of the measurement itself, the evaluation of the measurement results, the processing of the extensive information gathered,
- it is possible to realize new forms of information processing and storage for the creation of databases of experimental quantities, direct transfer of experimental results as inputs for the following calculations, real-time experiment control, control of various metallurgical, technological, chemical and other processes, activity management (acquisition of material characteristics for various loads, etc.).

Conclusions

In the paper was described numerical and experimental analysis of high precision positioning equipment. The computations were accomplished for different types of loadings including self-weight of structure and prescribed displacement of parts due to movement of actuator. From the computations can be stated fact that the most stressed parts of structure withstand the applied loading. The aim of such analysis was to verify range of movement of reference points on positioning axes of the object. The problem of this analysis was that this system is statically undetermined and accordingly the stiffness of joining elastic members have to be considered for the computations**.** The main interest of authors was focused on verification of results obtained by numerical modeling and by experimental measurements on a real stand.

Moreover, the experimental analysis of movement of reference points of the stand with and without elastic member was realized. The measurements showed that the stand with elastic member improved the system behavior. In addition, the temperature tests of the actuator were also made, where its temperature sensitivity coefficient was determined. Its value ranged from 0.9 to 1.1 μm/°C.

Based on the experimental measurement, it can be concluded that the required positioning mechanism accuracy has been achieved. It should be noted that several mechanical details such as different concentrators and the like have to be solved when using a mechanical reductor. Due to the finding of relatively small differences in deviations when using a mechanical reductor and without it, it is sufficient to use an actuator without a mechanical reductor to achieve the required accuracy of the positioning system.

Acknowledgments

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