606. Research of positioning accuracy of robot Motoman SSF2000

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Abstract. Research of the dynamic properties, positioning precision and repeatability of MOTOMAN SSF2000 movement is presented in this article. Dynamic properties were analyzed using a mobile equipment of measuring „Machine Diagnostic Toolbox Type 9727“ with a DELL notebook. The manipulator vibrations were measured in two robot's positions: vertical and horizontal, and at three different speeds. The research was made under three different conditions, changing the tool mass and speed.

Keywords: manipulator, precision, positioning, dynamic properties.

Introduction

At present time, once technologies advanced recently, number of robots having precise movement is increasing. According to the Federation of robotics, during 2005 year market of industrial robots has increased about 30 %. Market of industrial robots in the world grows very rapidly due to influence of small and middle enterprises in fields of food processing, packaging, plastics and rubber, pharmaceutics, house holding industries, wood processing and furniture production. Industrial robots also penetrate into field of medicine where high accuracy of robots is required [1].

Since industrial robots existing at contemporary market demonstrates high accuracy, nevertheless lifetime of robots still is limited, and also it is necessary to check robots technical properties – are they still fulfilling producers requirements [2]. Accuracy of performance of industrial robots is defined by positioning error which is one of the main their characteristics. Positioning accuracy depends on many factors – errors of robot's moving drives, part production errors, errors from robot components flexibility. Depending on type of robot, its live load operating conditions, each of these errors can be a key error in position accuracy [3].

Accuracy of robot positioning also depends on surrounding where research was performed, from external vibration and temperature changes [4].

The aim of this article is to investigate dynamic properties of the mentioned robot, create methodic for positioning accuracy evaluation and measure accuracy of robot's movement.

The object and methodology of the research

Object of the research is robot „Motoman SSF2000“, which is shown in fig.1. Recently positioning accuracy of robots series „Motoman“ varies from ±0.02 mm (types HP3J, HP3XF...) to ±0,5 mm (for types PX2850, EPX2800R, EPX2900, PX1750-F50, PX2050-F50, PX2850-F50). For particular this robot SSF2000 accuracy is ±0.08 mm. Other technical parameters of the robot are as follows: number degree of freedom - 6; maximal live load - 6 kg; maximal accessibility of robot - 1378 mm; weight - 130 kg; installed electrical power - 1.5 KVA.

During technological process robot gripper must occupy certain position in the space, which is prescribed by software as values of generalized coordinates of robot links. During robot operation it happens, that generalized coordinates of robot have errors of real position of robot links. Due to this occurs kinematic error of robot links, which is estimated as positioning error. This error can be expressed as linear or angular.

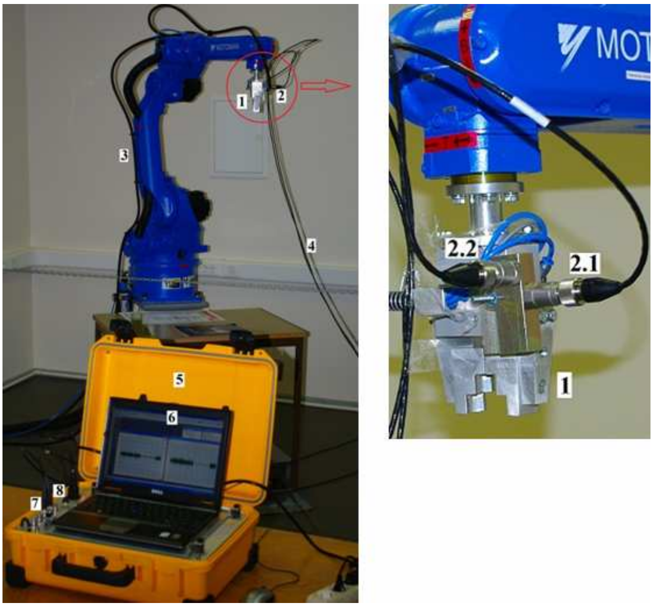

Fig. 1. Test rig of robot absolute vibration research. 1 – gripper, 2 – accelerometers, 3 – manipulator, 4 – wire, 5 – vibration measurement equipment, 6 – computer, 7, 8 – inputs

Linear kinematic error of gripper can be evaluated according:

$$\Delta r = \sum_{i+1}^{n} \frac{\partial r_i}{\partial q_i} \Delta q_i \qquad (1)$$

where Δq_i – generalized coordinates q_i error of i^{th} link.

Angular error of manipulator is called angle, which is necessary to apply to gripper to achieve that axes of coordinate system $O_1'x_1'y_1'z_1'$ would be parallel to axes of coordinate system $O_1x_1y_1z_1$.

While the whole positioning process consists from linear and angular movement, overall robot's positioning error would be expressed as:

$$\Delta_{\sum} = \sum_{i+1}^{n} \Delta S_i + \sum_{i+1}^{n} \Delta\varphi_i \leq [\Delta] \qquad (2)$$

where ΔS_i – linear movement link error, $\Delta\varphi_i$ – angular movement link error.

Allowed robot positioning error is assumed to be :

$$[\Delta] = \frac{\Delta_0}{K_\Delta} \qquad (3)$$

where Δ_0 – allowed base error, defined by manipulated object placing position requirements [5].

Experimental research

During research it was noticed, that when movement velocity increases, natural frequency of vibration is increased. In order to define system frequencies from every servo motor operation and how it could influence the positioning accuracy, robot performance was researched in three velocities regimes: 3 mm/s; 16 mm/s; 30 mm/s.

Robot gripper (shown in fig.1 as pos. 3) absolute system vibrations were measured on tip (pos. 1). Accelerometers were attached so, that one of them measures vibration on X axis, and other – on Y axis (2.2).

For tests there were used equipment of Danish company „Bruel & Kjaer“ for vibrations and other dynamic characteristics measurement and analysis equipment: movable measuring equipment „Machine Diagnostics Toolbox Type 9727” with computer DELL and accelerometers 8341 [6].

Measurement signals were processed with Computer aid using „Origin 6“ and „Pulse“ software packages [7, 8, 9].

The measurement results were analyzed and the signal spectra and statistical parameters (mean value, the standard deviation and the standard deviation of the mean) were statistically processed using the following equations:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i, \quad S_X = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}, \quad S_{\bar{X}} = \frac{S_X}{\sqrt{n}} = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}, \qquad (4)$$

where n is the number of measurement results, x_i – value of measurement.

Vibrations of robot arm, when robot position is vertical and horizontal, is shown in fig 2. and fig 3.

Positioning accuracy was investigated in special workbench in order to measure theoretical coordinate system axis $O_1x_1y_1z_1$ displacements relativelly to real position coordination system $O_1'x_1'y_1'z_1'$. Robot gripper was equipped by calibrator, which has shape of right-angle slab and positioned relatively to robot. During experimental research distance sensors, placed rectangular to each other to respect orthogonal coordinate system axis, was contacting with caliper slab surfaces.

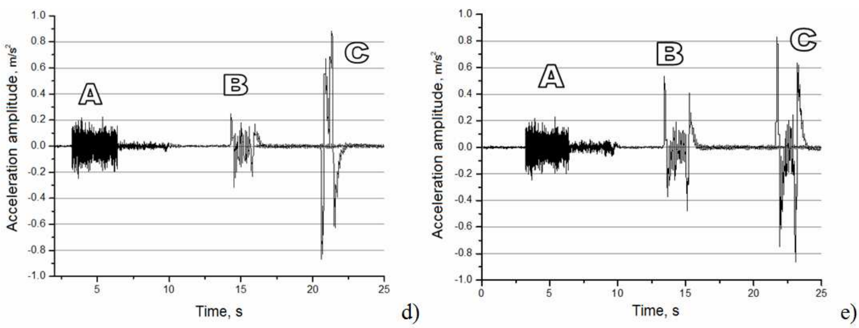

Fig. 2. Tool center point (TCP) vibrations while Z axe is moving in three different speeds and the robot positions are vertical (d) and horizontal (e): A – 3 mm/s, B – 16 mm/s, C – 30 mm/s

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In start position robot is placed into position so, that position of it links can be fixed. Sensor positions was set to zero. Than robot move according to prescribed program and comes back to initial position. At the end after transient process of robot arm vibration is over, sensor data was stored.

There were performed 150 experimental trials with 3 different movement velocities and 3 masses.

Each experimental research was taken with permanent mass and three different velocities was tried .There were used velocities: 3 mm/s, 16 mm/s, 30 mm/s; masses on gripper: 1.210 kg, 2.910 kg, 5.900 kg.

Below in the fig . 3 and fig. 4 there are shown corresponding experimentaly given displacement mean values.

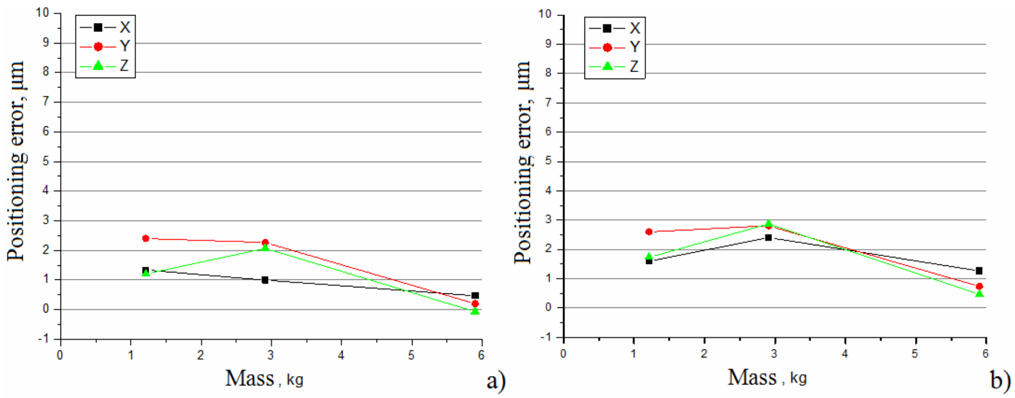

Fig. 3. The robot positioning error with respect of mass when robot‘s linear speed is 3 mm/s (a) and 16 mm/s (b)

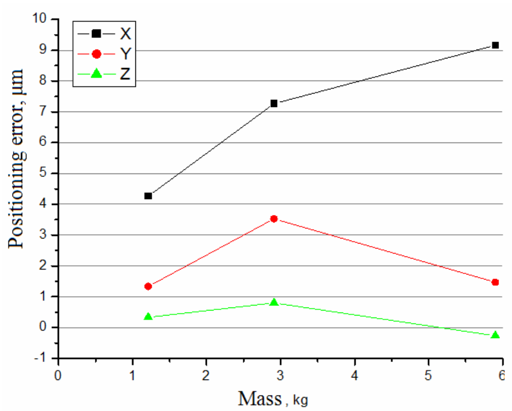

Fig. 4. Robot positioning error with respect of mass when robot‘s linear speed is 30 mm/s

Research Results

Research has shown that when speed of robot’s movement and carrying mass is increasing, positioning error increases, too.

During research of absolute vibrations of robot arm, when arm is in vertical or horizontal position, there are given results, presented in table 1.

During research it was found values of vibration amplitude and their statistical parameters in measured directions with different movement velocity and carried mass.

Table 1. Statistical parameters of the vibration acceleration measurement

Robot arm velocity, mm/s	Measuring direction	Standard deviation S_x, mm/s^2	Minimum value x_{min}, mm/s^2	Maximum value x_{max}, mm/s^2
3	X	0,044	-0,228	0,247
	Y	0,046	-0,315	0,289
16	X	0,039	-0,401	0,309
	Y	0,039	-0,288	0,271
30	X	0,075	-1,12	0,882
	Y	0,063	-0,907	0,888

During this research experimentally was proven dependency of positioning of robot arm to carried mass and arm velocity, how errors of positioning increasing during this parameters change. Also, it is necessary to state, that most inaccuracies are developed in X-axis movement. Stiffness and movement cinematic accuracy is much bigger in Z-axis direction. This observation is valid for mass experimental research as well as velocity series.

Conclusions

1. Vibration of robot arm shows stable stiffness increase and stability of robot in vertical direction rather than horizontal;
2. Positioning research shows definite but not significant decrease of positioning accuracy from load increase;
3. Experimental research proved that experimentally measured inaccuracies of loaded robot arm movement are not exceeding 25 % from allowed tolerance and mean error not exceeding 16,67 % of it.

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