UDC (07)621.7:621.8

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WORKING ACCURACY OF INDUSTRIAL ROBOTS AND METHODOLOGY FOR ITS VERIFICATION

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ТОЧНІСТЬ РОБОТИ ПРОМИСЛОВИХ РОБОТІВ І МЕТОДОЛОГІЯ ЇХ ПЕРЕВІРКИ

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ТОЧНОСТЬ РАБОТЫ ПРОМЫШЛЕННЫХ РОБОТОВ И МЕТОДОЛОГИЯ ИХ ПРОВЕРКИ

Article for short describes the importance and method of verifying the working accuracy of the applying the methodology in accordance with valid international standards. It also describes a method for obtaining of the necessary data to verify of one-way accuracy and repeatability of positioning of selected industrial robot.

***Key words:** industrial robot, working accuracy, verification.*

Fig.: 6. Tab.: 3. Bibl.: 3.

Коротко описано важливість і спосіб перевірки робочої точності застосування методології відповідно до діючих міжнародних стандартів. Також досліджено спосіб отримання необхідних даних для перевірки односторонньої точності і повторюваності позиціювання обраного промислового робота.

***Ключові слова:** промисловий робот, точність обробки, перевірка.*

Рис.: 6. Табл.: 3. Бібл.: 3.

Кратко описына важность и способ проверки рабочей точности применения методологии в соответствии с действующими международными стандартами. Также исследован способ получения необходимых данных для проверки односторонней точности и повторяемости позиционирования выбранного промышленного робота.

***Ключевые слова:** промышленный робот, точность обработки, проверка.*

Рис.: 6. Табл.: 3. Библ.: 3.

Introduction. The deployment of industrial robots in various fields of industrial production is confronted with the hard conditions imposed on their work accuracy. It's mainly due to the fact that most of the operations executed by the robot falls in precision technology.

For a description and analysis of applications with robots can be used an approach assessing bonds of functional relations of kinematics (load, precision, speed, ...), its parameters and parametric characters that together determine the usability of the robot for the forthcoming applicationThis approach is one of the basic steps to project preparation of robot applications for the specific production and non-production processes.

Characteristic of robot. In robotics were for the classification of the robots created the general classification systemic characters that categorize the robots when it comes on:

– their load, Tab. 1,

– from the standpoint of achieving the repeated positioning accuracy, Tab. 2,

– in terms of classification their zones of operation (volume of space accessible to the robot end effector), Fig. 1.

Table 1

Classification of robots in accordance of load (max. load)

Category	Labeling	Load [kg]		
		Minimum	The middle	Maximum
Very heavy	**G**	300	1 000	3 000
Heavy	**T**	30	100	300
Middle	**S**	3	10	30
Easy	**L**	0,3	1	3
Very easy	**M**	0,03	0,1	0,3

Table 2

Classification of robots by unidirectional accuracy of positions

The class	Category	Range [mm]
0	ultra accurate	(±0,001 ; ±0,01〉
I.	very accurate	(±0,01 ; ±0,1〉
II.	with increased accuracy	(±0,1 ; ±0,5〉
III.	with normal accuracy	(±0,5 ; ±1〉
IV.	with low accuracy	> ±1

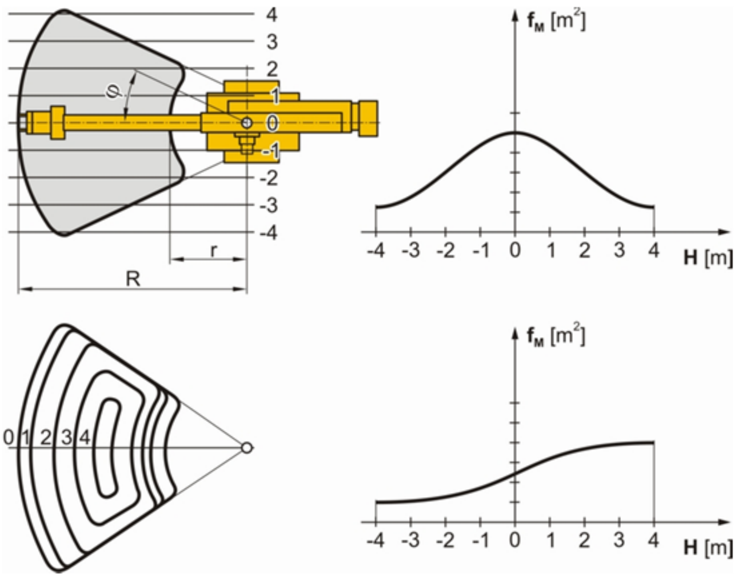

Fig. 1. Zones of the robot service

Sources of errors. The physical implementation of the mechanism of the robot assumes that each of the kinematic pair comprises a number of mechanical parts, Figure 2, showing a certain type of binding necessary with a tolerance (a given of design) and manufacturing tolerances (tolerances dimensions, pairing).

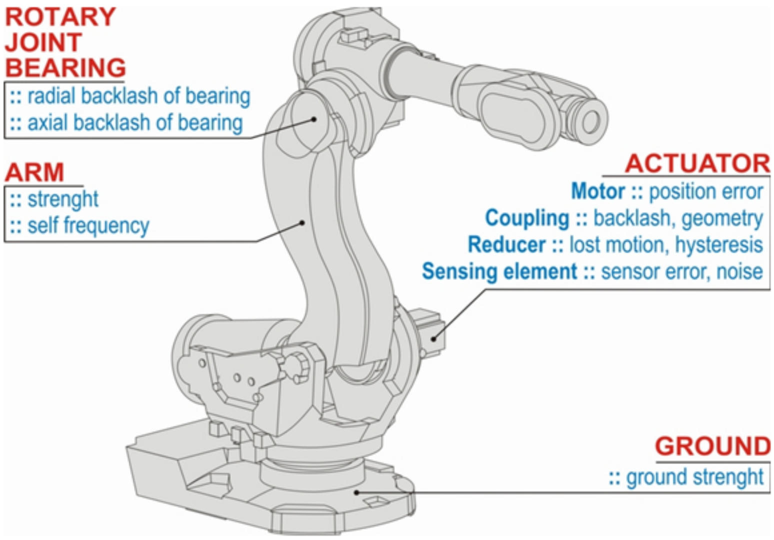

Fig. 2. Sources of errors in kinematics of robot

All these deviations and backlashes are added together and result in a member of kinematic pair performs movements (strokes, rotation), whose range and accuracy are noted these errors ((backlashes). The actual movement is a little (less accurate) than programmed, causing the moving part of the mechanism of the drive system (engine) is spent to compensate for these clearances.

According to their origin backlashes in locomotive organs of kinematic pair of the robot can distinguish on

a) ***the basic backlashes*** v_Z - a given of contruction documentation and an accuracy of production (production outside the tolerances specified of construction documentation is not permitted), which shows a pair mechanism after assembling and commissioning,

b) ***backlashes from wear*** v_O - a given of traffic loading effect of robot and share of operation time of kinematic pairs at the time of operation of the robot.

The total clearance of the action mechanism of the robot, respectively. mechanism of kinematic pairs of the robot is generally given as

$$v_C = v_Z + v_O = n \cdot v_Z \tag{1}$$

where n is a factor whose size is proportional to the length of time of operation (use) of kinematic pairs. Total backlash v_c results in an error Δ when positioning to the coordinate one single motion unit (kinematic pairs) of the action mechanism of the robot.

When a general motion of action mechanism of the robot are a movement made up of program-arranged move his of motion units (each kinematic pairs), each unit brings to the overall movement of his own error. Subsequently, the resulting error of the action mechanism of the robot Δ_C is given by the sum of the geometric errors of individual coordinates $(\Delta_1, \Delta_2, \Delta_3, ...)$

$$\vec{\Delta}_C = \vec{\Delta}_1 + \vec{\Delta}_2 + \vec{\Delta}_3 \tag{2}$$

The criterion for working accuracy of the action mechanism of robot is that the total error $\vec{\Delta}_C$ does not exceed the tolerance (determined) the inaccuracy of positioning (position, orientation)

$$\vec{\Delta}_C < \vec{\Delta}_{Cdov} \tag{3}$$

As an example of the determination of the resulting lists inaccuracies the interpretation of the general principles of the theory of robot mechanisms into the mechanisms of RTT type (cylindrical system), Figure 3.

- set position $A_1(R, \varphi_z, z)$
- actual position $A_2(R + \Delta R, \varphi_z + \Delta\varphi_z, z + \Delta z)$
- positioning inaccuracy on partial coordinates (errors of kinematic pairs)

$$X \ldots\ldots \Delta_X = X_2 - X_1 \tag{4}$$

$$X_1 = R \cdot \cos\varphi_z \tag{5}$$

$$X_2 = (R + \Delta R) \cdot \cos(\varphi_z + \Delta\varphi_z) \tag{6}$$

$$Y \ldots\ldots \Delta_Y = Y_2 - Y_1 \tag{7}$$

$$Y_1 = R \cdot \sin\varphi_z \tag{8}$$

$$Y_2 = (R + \Delta R) \cdot \sin(\varphi_z + \Delta\varphi_z) \tag{9}$$

$$Z \ldots\ldots \Delta_Z = Z_2 - Z_1 \tag{10}$$

$$Z_1 = z \tag{11}$$

$$Z_2 = z + \Delta z \tag{12}$$

- Overall inaccuracy of the end unit of the action mechanism of the robot while simplifying that $\varphi_z = 0,\ \Delta z = \Delta R,\ z = 0$ is

$$\Delta_C \equiv \overline{A_1 A_2} = \sqrt{2\Delta R^2 + 2(1 - \cos\Delta\varphi_z)(R.\Delta R + R^2)} \tag{13}$$

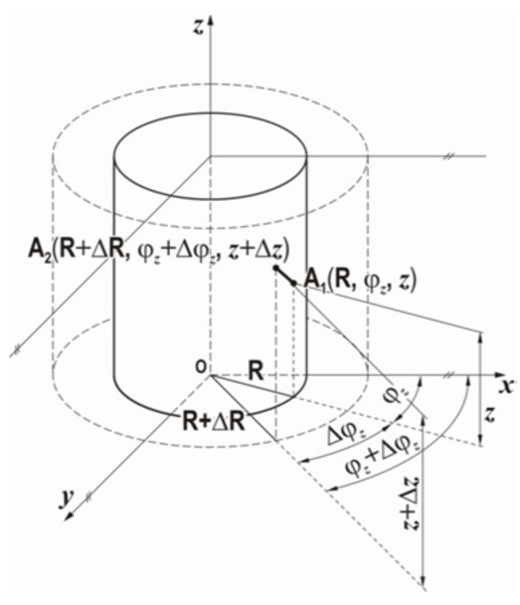

Fig. 3. Position errors in the area of the cylindrical coordinate system

As the accumulation of deviations (errors) must be controlled, it is necessary to determine the robot purchaser of the total value of these errors. It is necessary to establish a working robot accuracy.

Working precision of robot. Working precision of industrial robot is defined by ISO 9283 as a set of characteristics, tab. 3, the most important are: one-way precision positioning (orientation) and the unidirectional repeatability of position (orientation). One-way positioning accuracy of show the deviations between the programmed position and diameter of the current position when moving to a preset position from the same direction. Unidirectional repeatability position reflects the degree of correlation between the position and orientation of the current position by n-repetitive movements programmed in the same position in the same direction.

Table 3

Characteristics of robot for definition it's working accuracy

	CHARACTERISTIC	LOADING (% of nominal value)		SPEED (% of nominal value)			POSITIONS (on measuring plane)	NUMBER OF CYCLES
		50	100	10	50	100		
1.	One direction accuracy of position (AP)	◐	●	◐	◐	●	P_1-P_2-P_3-P_4-P_5	30
2.	One direction repetition of position (RP)	◐	●	◐	◐	●	P_1-P_2-P_3-P_4-P_5	30
3.	Variation of multi-direction accuracy of position (vAP)	◐	●	◐	◐	●	P_1-P_2-P_4	30
4.	Accuracy of distance (AD)	○	●	◐	◐	●	P_2-P_4	30
5.	Repetition of distance (RD)	○	●	◐	◐	●	P_2-P_4	30
6.	Time of position stabilization	◐	●	◐	◐	●	P_1-P_2-P_3-P_4-P_5	3
7.	Overshoot of position	◐	●	◐	◐	●	P_1-P_2-P_3-P_4-P_5	3
8.	Drift of accuracy the position (dAP)	○	●	○	○	●	P_1	*)
9.	Drift of repetition the position (dRP)	○	●	○	○	●	P_1	*)
10.	Accuracy of trajectory (AT)	◐	●	●	●	●	**)	10
11.	Repetition of trajectory (RT)	◐	●	●	●	●	**)	10
12.	Error of crown radius (CR)	○	●	●	●	●	E_1-E_2-E_3-E_4	3
13.	Crown overshoot (CO)	○	●	●	●	●	E_1-E_2-E_3-E_4	3
14.	Stabilization of path lenght (SPL)	○	●	●	●	●	E_1-E_2-E_3-E_4	3
15.	Accuracy of trajectory velocity (AV)	◐	●	◐	●	●	**)	10
16.	Repetition of trajectory velocity (RV)	◐	●	◐	●	●	**)	10
17.	Fluctuation of trajectory velocity (FV)	◐	●	◐	●	●	**)	10
18.	Minimal time of positioning	◐	●	○	◐	●	P_1-...-P_m ***)	3
19.	Static fexibility	****)		--	--	--	P_1	3

Key: ● - obligatory *) - 8 hours of continuous cycling
◐ - optional **) - linear path between points E_1-E_3 and E_3-E_1
○ - free ***) - details in standard text
****) - 10% progressive increase in value of load from 10% until 100%

For the manufacturer is therefore the customer's responsibility to give reliable information about this parameter. Conversely, the customer (or design firm) must meet the requirements of the application to know the value of working accuracy.

In order for producers were to construct mechanical part of the robot and its control system must have an idea on how to reach that target, but also re-measured and thus validate data then provides the customer.

To harmonize the measurement results generated in verifying the working accuracy of the robot at the manufacturer and at the user must be a binding methodology for carrying out the tests, which are intended to determine the parameters that characterize the working accuracy.

For this reason (and in connection with the project solution) we at the Department drawn up a set of methodological sheets for conducting the tests of the robot (for structural design robots with serial architecture arrangement kinematic pairs: RRR and SCARA). Credibility of results obtained under prescribed methodology is guaranteed by incorporating the principles established in the ISO 9283 in these procedures and the subsequent verification of the measurement of a particular robot (industrial robot ALMEGA AX-MV6 the company OTC Daihen, Japan).

Order to be able perform a set of measurements specified of standards (tab. 3), be followed a few basic rules:

– Record the measurement conditions (parameters of used energy labeling and specifications of tested robot, set the operating speed of robot, load value of the end flanges, parameters characterizing the working environment: temperature, relative humidity atmospheric pressure);

– Determine the dimensions so called "measuring cube", Fig. 4, and the coordinates of its location in the robot workspace, Fig. 5;

– Determine the coordinates of the points in which the measurement is running (or points between which is measure any parameter);

– Compile a list of the measurement means with its characteristic parameters;

– Establish a set of measured parameters of robot by choosing from a list of declared the norm, see Table 3;

– By the list of existing measurement methodological order make of measurement protocol in the number and the content corresponding to the selecting set of measured parameters (as above);

– Pursuant to the rules and recommendations in methodical sheets measure the required number of data needed for statistical evaluation and record the measured values (minimum of 30 measurements);

– According to the mathematical recommended of standards and in methodical sheets set the final value of the measured parameter and record it for every point of measure (or process in tabular form);

– In the processed measuring protocol mention a verbal comments of measurements;

– summarized the set of sub-protocols in the final version of the measurement protocol with the dates, persons performing the measurement and evaluation of measured results in accordance with applicable internal rules of the tests executor.

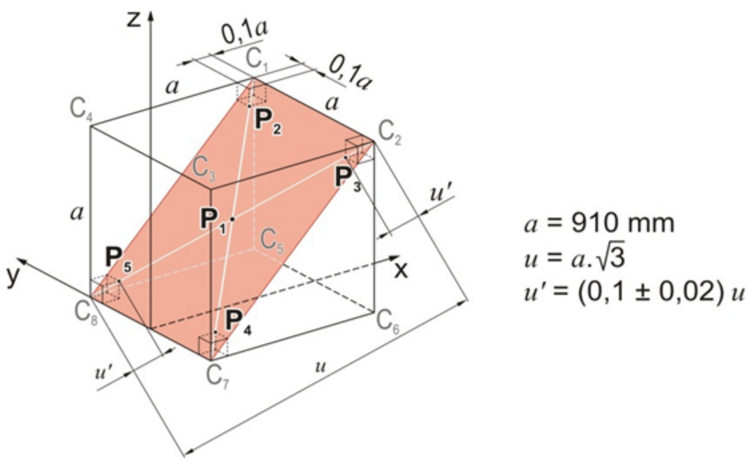

Fig. 4. Testing cube

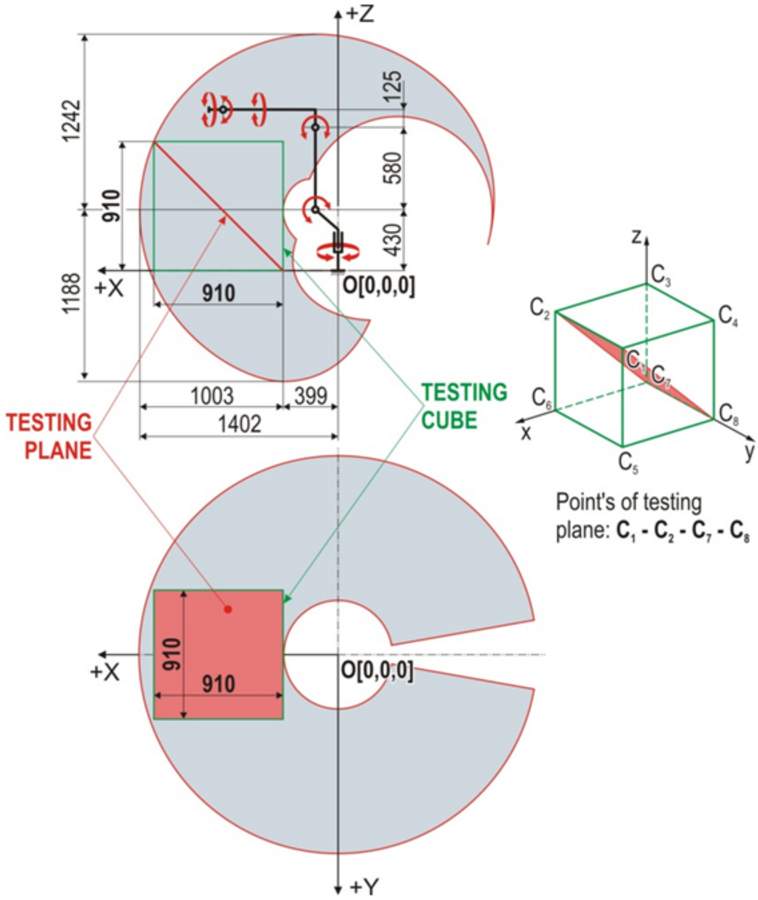

Fig. 5. Localization of testing cube in robot's working space

Conclusion. The described procedure was carried out at our department within the measurement of said of industrial robot (OTC Daihen ALMEGA AX-MV6) as a secondary exit activities during solutions to project tasks. Methodological sheets for measuring characteristics of the robot were then used to create a methodology for measuring 3° wrist as the output project tasks Figure 6.

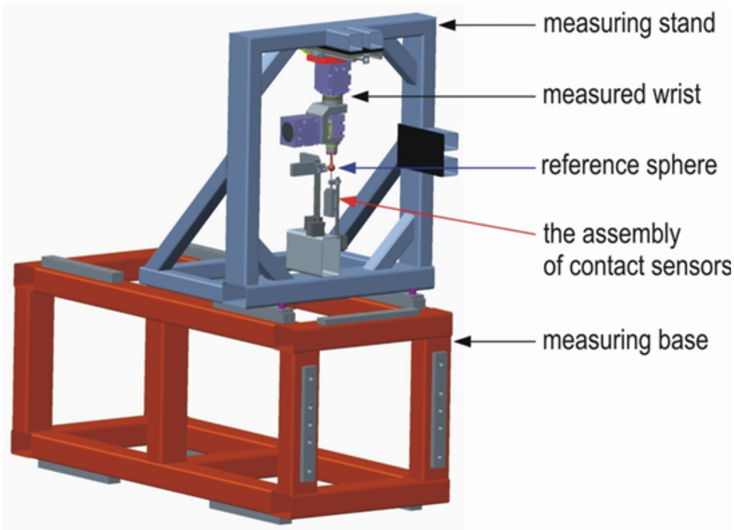

Fig. 6. Model for measuring of 3° wirst

This contribution is the result of the project implementation: Research modules for intelligent robotic systems (ITMS: 26220220141) supported by the Research & Development operational Program funded by the ERDF.

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Tuleja, P. (2016). Working accuracy of industrial robots and methodology for its verification. *Technical sciences and technologies*, no. 4 (6), pp. 182-188.