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Positioning Accuracy and Repeatability of a Class of Technological Robots

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1. Pose characteristics. General description

Command pose – pose specified through teach programming, manual data input or explicit programming.
Attained pose – pose achieved by robot under automation mode in response to command pose.

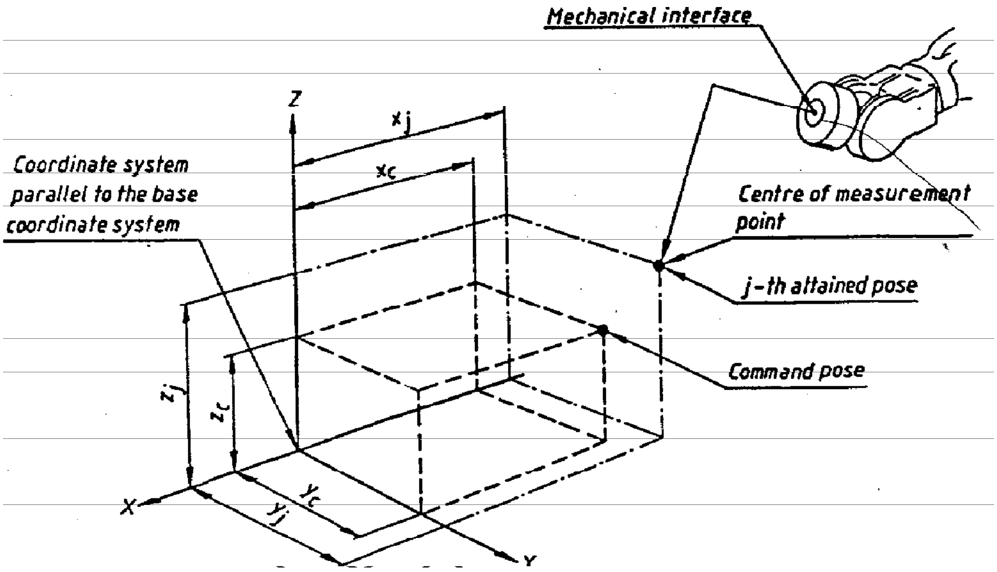


Fig. 1. General view of the accuracy scheme

Pose accuracy and repeatability characteristics quantify the deviations which occur between a command and attained pose, and the fluctuations in the attained poses for a series of repeat visits to a command pose. These errors may be caused by internal control definitions, co-ordinate transformation errors, differences between the dimensions of the articulated structure and those used in the robot control system model, mechanical faults such as clearances, hysteresis, friction, and external influences such as temperature.

2. Pose accuracy

Pose accuracy expresses the deviation between a command pose and the mean of the attained poses when approaching the the command pose from the same direction. Pose accuracy is divided into:

– the difference between a command pose and the barycentre of the cluster of attained points, i.e. positioning accuracy

– the difference between command angular orientation and the average of the attained angular orientation.

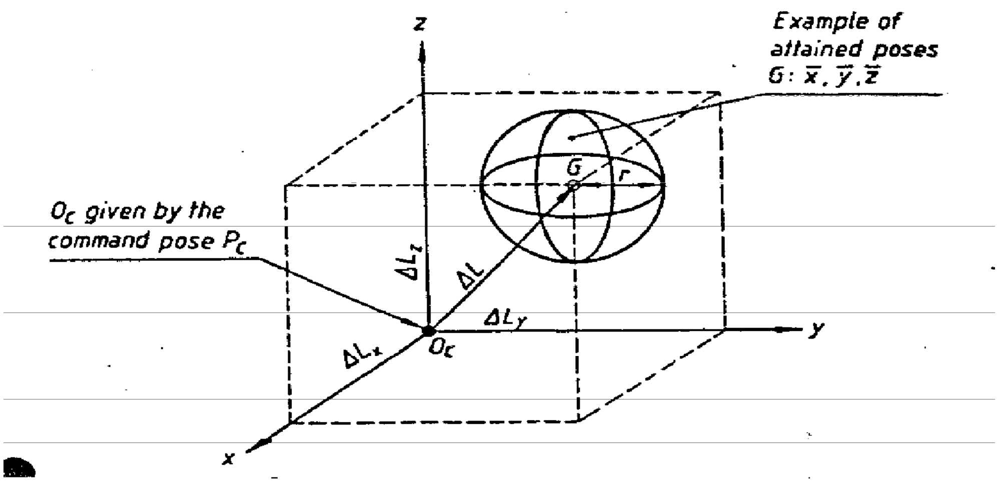


Fig.2. Positioning accuracy and repeatability

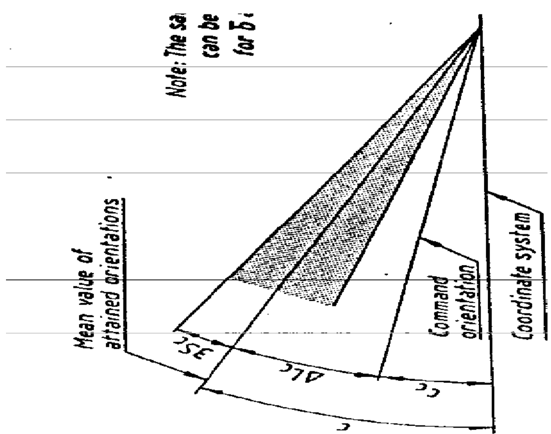


Fig.3. Orientation accuracy and repeatability

The pose accuracy is the maximum deviation obtained in position and orientation. The positioning accuracy is expressed as follows:

(1)
$$\Delta L = \sqrt{(\bar{x} - x_c)^2 + (\bar{y} - y_c)^2 + (\bar{z} - z_c)^2},$$
$$L = (\bar{x} - x_c),$$
$$L = (\bar{y} - y_c),$$
$$L = (\bar{z} - z_c),$$

where: $\bar{x} = \frac{1}{n}\sum_{j=1}^{n} x_j;\quad \bar{y} = \frac{1}{n}\sum_{j=1}^{n} y_j;\quad \bar{z} = \frac{1}{n}\sum_{j=1}^{n} z_j;$

x, y, z are the coordinates of the barycentre of the cluster of points obtained after repeating the same pose n times;

x_c, y_c, z_c are the coordinates of the command pose;

x_j, y_j, z_j are the coordinates of the j-th attained pose.

The orientation accuracy is expressed by:

(2)
$$\Delta L_a = (\bar{a} - a_c),\quad \Delta L_b = (\bar{b} - b_c),\quad \Delta L_c = (\bar{c} - c_c),$$

$$a = \frac{1}{n}\sum_{j=1}^{n} a_j;\quad \bar{b} = \frac{1}{n}\sum_{j=1}^{n} b_j;\quad \bar{c} = \frac{1}{n}\sum_{j=1}^{n} c_j.$$

These values are the mean values of the orientation angles obtained at the same pose repeated n times;

a_c, b_c, c_c are the angles of the command pose and a_j, b_j, c_j are the angles of the jth attained pose.

Starting from P_1, the robot successively moves its mechanical interface to poses P_5, P_4, P_3, P_2, P_1. Each of the poses should be visited using a uni-directional approach. Paths used during the test shall be similar to those used when programming. For each pose, positioning accuracy (ΔL) and orientation accuracy (ΔL_a, ΔL_b, ΔL_c) are calculated.

3. Pose repeatability

Pose repeatability expresses the closeness of agreement between the positions and orientations of the attained poses after n repeat visits to the same command pose in the same direction. For a given pose, the repeatability (r) is expressed by:

– the value of r, which is the radius of the sphere whose centre is the barycentre and which is calculated as below.

– the spread of the angles $\pm 3S_a$, $\pm 3S_b$, $\pm 3S_c$ about the mean values a, b, c, where S_a, S_b, S_c are the standard deviations:

(3)

$$r = \bar{D} + 3S_D,$$

$$\bar{D} = \frac{1}{n}\sum_{j=1}^{n} D_j ,$$

$$D_j = \sqrt{(x_j - \bar{x})^2 + (y_j - \bar{y})^2 + (z_j - \bar{z})^2},$$

where x, y, z and x_j, y_j, z_j are defined in 1.

(4)

$$S_D = \sqrt{\frac{\sum_{j=1}^{n} (D_j - \bar{D})^2}{n-1}}$$

$$r_a = \pm 3S_a = \pm 3\sqrt{\frac{\sum_{j=1}^{n} (a_j - a)^2}{n-1}},$$

$$r_b = \pm 3S_b = \pm 3\sqrt{\frac{\sum_{j=1}^{n} (b_j - \bar{b})^2}{n-1}},$$

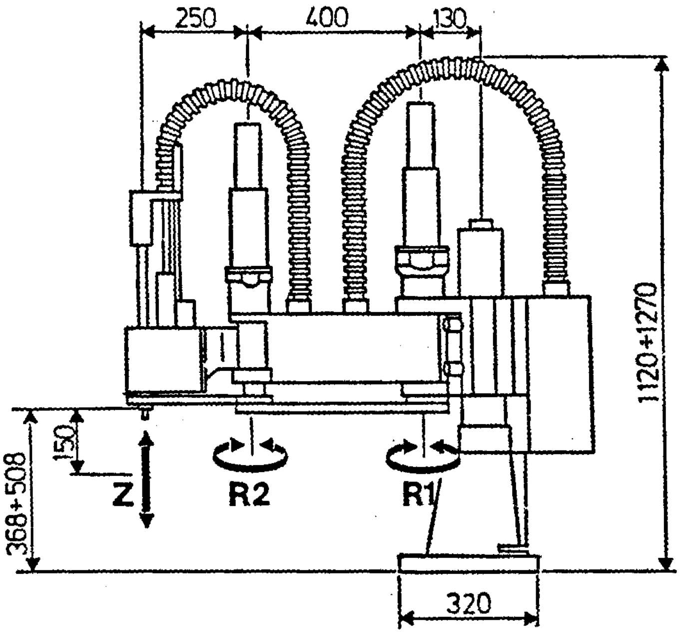
$$r_c = \pm 3S_c = \pm 3\sqrt{\frac{\sum_{j=1}^{n} (c_j - \bar{c})^2}{n-1}}.$$

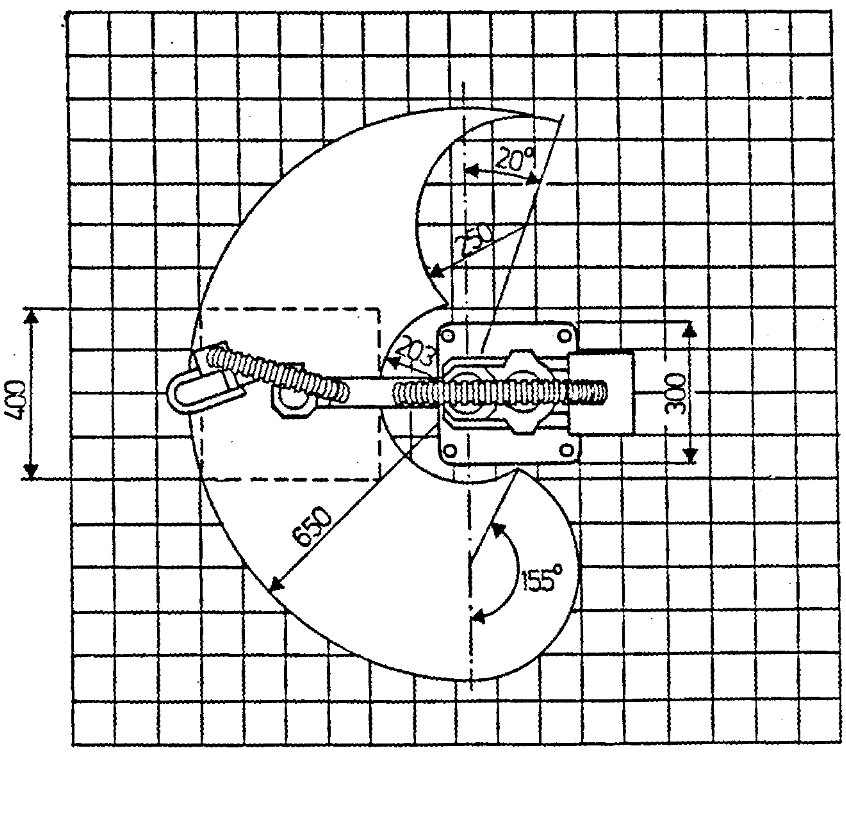
The procedure is the same as in 1. For each pose r and angular deviations r_a, r_b and r_c are calculated.

3. Examination of the positioning accuracy and pose repeatability of robot REM 10-01

The object of exploration is the manipulation robot REM 10–01 (Fig.4). The regional structure of the robot is type SCARA, R||R||T. The actuators of the rotational pairs are DC motors, and the translational pair is pneumatic with two fixed positions – up and down. For measuring the accuracy of the robot, it is taught for five points, which are in its working field. The working field is defined by the angles R1 – 200°, and R2 – 155°, and represents a part of plane, perpendicular of the axes of rotation.

The control system is realised on the basis of the universal controller 84 EA. The controller gives the possibility to control up to four DC servo axes. The method of control is “point to point”. The maximal velocities of the two axes are 0.958 rad/s and 1.57 rad/s.


250
400
130
1120÷1270
150
368÷508
Z
R2
R1
320


20°
25°
203
400
300
650
155°

The experimental device consists of electronic apparatus for linear measurements with analogue output - "TESA MODUL", memorise measuring oscilloscope, camera and personal computer. The oscilloscope is Tektronix 2230, the camera – SHARP 12 and the PC is type 486DX-2/60 with a videoblaster.

The manipulation robot is taught in five points. According to the requirements for carrying out the measurements, the positioning points are forming a square in the working area, as the intersection point of its diagonals is point P_1. The joint co-ordinates of the taught points are shown in Table 1.

Table 1

Point	Joint Coordinates, rad	
	q_1	q_2
P_1	1.17	1.79
P_2	1.06	0.9
P_3	1.77	0.79
P_4	2.11	2.236
P_5	0.345	2.215

They have been executed 30 measurements with maximum load – in this case 10 kg in the taught points. The results for the positioning accuracy are illustrated in tabl. 2. The data, presented in the table are written in μm.

Table 2

Δ	P_1	P_2	P_3	P_4	P_3
ΔL_x	–8	–5.7	–1.5	1.07	3.46
ΔL_y	6.9	1.4	–1.1	–1.1	–2.3
ΔL	10.56	5.78	1.86	2.24	4.15

The obtained data show that the positioning accuracy of the robot is between 0.01 and 0.02 mm.

The measurements for pose repeatability are similar to the positioning accuracy ones and the procedure is the same. According to the equations for the pose repeatability, they have been made calculations after the tests. The results are shown in tabl.3. The data, presented in the table are written in μm.

Table 3

Parameters	P_1	P_2	P_3	P_4	P_3
D	2.48	1.47	2.16	4.1	2.99
S_d	1.36	0.94	1.05	1.97	1.33
r	6.56	4.56	10.7	2.24	6.98

4. Conclusion

The described experiments are intended for use mainly when checking the individual characteristics of robots and for new constructive solutions as well. The precise determination of the positioning accuracy and pose repeatability under different conditions of work, manipulation of objects with different mass, their positioning in different points of the working area with different velocity, is important in order to define the possibility of application of the robot for proper industrial task.

References

1. ISO/DIS 9283
2. Wei-Shiu, Wang, Chang-Huan Liu. Implementation and experimental study of a multiprocessor system for real-time model-based robot motion control. – In: IEEE Trans. on Industrial Electronics, Vol. 41, No 2, 1994, 163–172.

Точность позиционирования и позиционная повтаряемость одного класса технологических роботов

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(Р е з ю м е)

В статье обсуждается методика испытаний манипуляционных индустриальных роботов. Методика позволяет определение специфических характеристик роботов, которые воздействуют на их работу, дает способ их определения и процедуры измерения. Исследованы две из самых важных характеристик роботов – точность позиционирования и позиционная повтаряемость. В соответствии с предлагаемой методикой исследован манипуляционный робот РЕМ-10-01.