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DEVELOPMENT AND APPLICATION OF AN ACCURACY AND REPEATABILITY DEVICE ANALYSIS IN INDUSTRIAL ROBOTS

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Abstract. *The competitiveness in the current market, ally to a demand for quality and productivity of the products, has generated a significant increase in the job of robots in the productive processes of the industries. However, these equipments can present some problems, more specifically, accuracy and repeatability errors in operations. The proposal of this paper consists of perfecting the agreement of the existing methodology for evaluation of industrial robots performance, presented for norm ISO 9283, "Manipulating industrial robots - Performance criteria and related test methods", to make possible its applicability in instrumentation tests for industrial robots. The projected device consists of a known system as cube-cradle, projected, constructed and applied in an industrial robot. The accuracy and repeatability characteristics of positioning had been experimentally measures on the constant criteria basis in the specific norm. The data had been gotten of the three-dimensional measurement errors between the test positions reached and the robot programmed positions, through a practical measurement system and low cost. The measurement device is constituted by three digital gages, assembled in each axle of the robot coordinate basis system, under a metallic structure, and connected to an electronic system, for the data collection and registers. The presented results had shown satisfactory, making possible the use of the methodology presented in the norm, as well, of the projected device of performance evaluation in this study.*

Keywords*: Robot, Performance Evaluation, Cube-Cradle System, Accuracy and Repeatability of Positioning*

1. INTRODUCTION

At the current times, the manufacture companies come facing diverse challenges, they are related to the market each more competitive or forces to the increase of the technological development. This way, a constant change in the productive systems is demanded, objectifying the increase of the productivity, the reduction of the operational costs, the reduction of the supplies levels, and consequently, the increase of the competitiveness.

Inside of this context, the application of machines and technologies that assist in the productive processes improvement, bringing as immediate and expressive advantages the possibility to execute the operations in lower time and with superior quality, are fundamental for the automation and industry modernization.

The automation inside of an industrial context can be defined as a technology that if occupies of mechanical, electronic systems and to the base of computers in the operation and control of the productive processes. Industrial robots, as controlled equipment through programmable commands, can easily be integrated in modern flexible systems of manufacture, what it makes with that its use comes increasing significantly in the industries.

The programming characteristics allow to the robot to be used in the most diverse industrial operations: manuscript of materials or parts, applications of processing (welding, painting, cut, etc.), shipment operations and unloading (Gonzalez et al., 1987), assembly of sets and inspection in the productive process (Groover, 1987).

Had the great variety of the available industrial robots models on the market, the task of choice of the equipment must not only consider the load capacity, but also the adjusted operational conditions for one given application. It's necessary to know performance parameters comparable so that if they can select the equipment correctly. The parameters described for some manufacturers are incomplete, in the direction that many of the performance pointers are not supplied or are inconsistency, due to confused terminology and the not clearly of the tests method specification.

2. PERFORMANCE EVALUATION IN INDUSTRIAL ROBOTS

The performance evaluation of an industrial robot is a verification of its capacity in the accomplishment of the functions for which it was constructed (Guenther and Pieri, 2000). Of one it forms generality, the industrial robot functions are the movements of materials, parts, tools or devices. In such a way, the performance evaluation results in a measure of the effectiveness of the robot in the accomplishment of these movements. The performance evaluation can be assist in the choice between robots of different manufacturers, whenever possible to compare the characteristics informed for the same ones, under one same optics of reference.

To evaluate the performance of a robot is important also in its acceptance in an industrial environment. Chosen from the requirements of the task and the specifications of the manufacturer it is basic that in the act of receiving of the equipment these specifications are evaluated.

It's considered that during the functioning of the robot can occur modify its characteristics, demanding that its performance comes to be conferred throughout the time can assure that the functioning continues adequate for the accomplishment of one determined task. Difficulties verified in the performance evaluation can indicate necessities and facilitate the maintenance of the equipment.

3. METHODOLGY AND PERFORMANCE TESTS CONDITIONS

The norm ISO 9283 (1995) is part of a series of international norms and defines the performance criteria and the tests methods for manipulation of the industrial robots. The main purpose of this norm is to facilitate to the agreement between users and manufacturers of robotic systems, where the main characteristics of performance are defined, the description of as these must be specified and general recommendations of as to test them.

The characteristics that must be tested are the ones that significantly affect the robot performance and these characteristics are not rigid, allow that the user defines which is most pertinent, that is, the ones that have greater influence in the equipment performance for one given application. The tests described in this norm are applied in all or part of the robot, depending on the type and the requirements demanded in the manipulation of the same.

3.1. Performance General Conditions

The used systems of measurement in the tests must be calibrated and its uncertainties of measurement must be described in the report.

For dynamic measurements, the tax of the data acquisition must be high the sufficient to assure that the representation of the acquired characteristics is adjusted. Unless specified in another way, the measurement must be made after reached the stabilized position. The maximum error of the measurement system doesn’t have to be superior 25% of the quantified characteristic amplitude.

All the tests are executed in 100% of the load conditions, that is, mass, position of the gravity center and moments of inertia in accordance with the manufacturer specifications. To characterize robots with the dependent performances of loads, optional tests can be made with other values of mass. When a part of the instrumentation is joined the robot, its mass and position is considered as part of the load has tested. All the position characteristics must be tested in the maximum executable speed between the specified positions; tests you add can be made with 50% and 10% of this speed.

3.2 Position Characteristics

The accuracy and repeatability characteristics of position, as defined in the norm, quantify the deviations that occur between a commanded position, a reached position and the fluctuation of this in a series of repeated visits to that position commanded.

The commanded position is defined as the position specified manually through *teach pendant* or programmed *off-line* through the computer in the robot language in question. The reached position is the real position gotten for the robot under automatic way. The programming way of the test positions must be defined in the tests report.

3.2.1 Positioning Unidirectional Accuracy (AP_p)

The positioning unidirectional accuracy (Eq.1) express the deviation between the commanded position (x_c, y_c, z_c) and the positions reached average ($\bar{x}$, $\bar{y}$, $\bar{z}$) when approached of this position, corresponds to the difference between the commanded position and the baricenter of the reached points set when approached of the position for the same direction.

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

3.2.2 Positioning Unidirectional Repeatability (RP_p)

The positioning unidirectional repeatability (Eq.2) express the positions dispersion and orientation reached after repeated visits to the same position commanded in the same direction, and corresponds to the sphere centered ray in the baricenter of the reached positions set.

$$RP_p = \bar{l} + 3S_l \quad (2)$$

The tests characteristics cited are illustrated in figure 1.

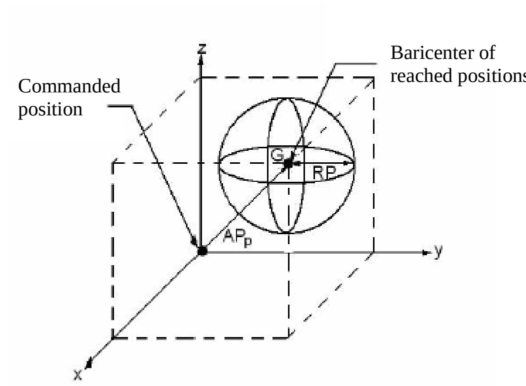

Figure 1. Positioning unidirectional accuracy and repeatability.

4. MEASUREMENT METHODS IN INDUSTRIAL ROBOTS MANIPULATION

4.1 Methods of Positioning Sensors

The position characteristics can be measured through a device that contains an enough number of transducers or proximity sensors adapted in the robot extremity. Diverse types of sensors exist that can be used in this method, figure 2 illustrate a typical device, known as system cube-cradle (ISO TR 13309, 1995). Processing of the sensors data, the mechanic interface can be located of the robot (TCP) through six degrees of freedom in relation to the coordinated base system (Lafratta, 1990).

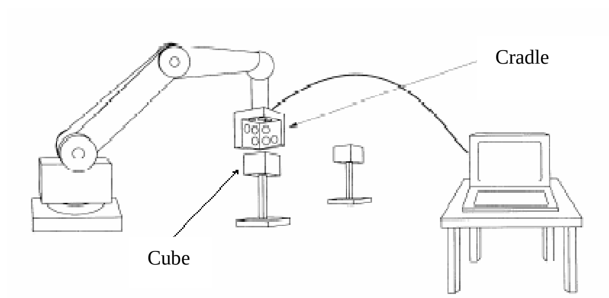

Figure 2. Cube-Cradle System to measurement of accuracy and positioning repeatability.

5. CUBE-CRADLE DEVICE

The application of a cube-cradle measurement system implies in dimension the reference cubes, selecting and to define the measuring devices, and consequently, to dimension the cradle structure and its disposal in the layout of the test area. The system metrology characteristics must consider possible geometric errors of the reference cubes, inherent accuracy of the measuring devices and other elements to the measurement chain.

5.1 Techniques Characteristics

The ideal or necessary techniques characteristics for the positioning repeatability measurement system considered in the project take care of the following premises (Lafratta, 1990):

- ✓ System installation: to be fast, as much in practice as in laboratory, that inside allows a good mobility of the work volume;
- ✓ Assays execution: it collects automatized of the data without it has the operator intervention;
- ✓ Attainment results: effected of electronic form, through spread sheets, where the results of the performance characteristics evaluated are pointed;
- ✓ Metrology and operational requirements: to allow to measurement of the error components in six degrees of freedom with an uncertainty of lesser measurement that 25% of the error valued of the evaluated characteristic;
- ✓ Load and speed conditions: to allow that the robot can be assayed using changeable speeds, accelerations and loads, taking care of norm specifications (ISO 9283, 1995).

5.2 Measurement Device Project

The cube-cradle test system considered consists basically of three digital comparing clocks, a cube of reference, a device for setting of the clocks (cradle of measurement) and a computational system, as schematized in figure 3.

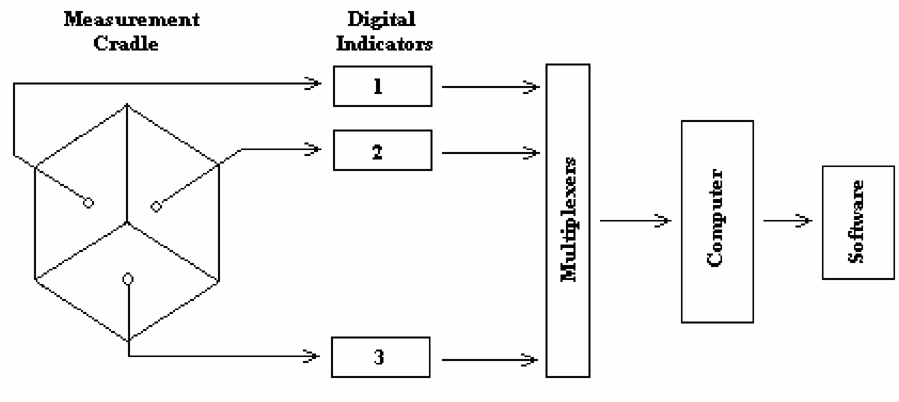

Figure 3. Schematically representation of the cube-cradle test system.

The functioning of the cube-cradle test system consists of locating and tying the coordinated system of the assay, situated next to the cradle measurement device with the extremity robot coordinated system, through the reference cube. By if dealing with assays of positioning unidirectional accuracy and repeatability, the coordinated values of the test in the three are supplied through the difference raised in the comparing clocks, that is, breaking itself of defined positions, the same ones are zeroed and later registered the values read to each repetition of the search of the same commanded position the robotic manipulator.

5.2.1 Unidirectional Displacement Gage Selection

Considering some principles of functioning that could be adopted to measure displacement, it was opted to use of the digital comparing clocks, specifically of the Mitutoyo mark and model 543-250B, illustrated in figure 5, considering the following factors:

- ✓ resolution of 0,001 mm;
- ✓ reading accuracy of ±0,003 mm;
- ✓ measurement uncertainty lesser or equal 0,0008 mm;
- ✓ operation band in the order of 12 mm;
- ✓ low cost investment;
- ✓ portable system;
- ✓ allow the reading automatization.

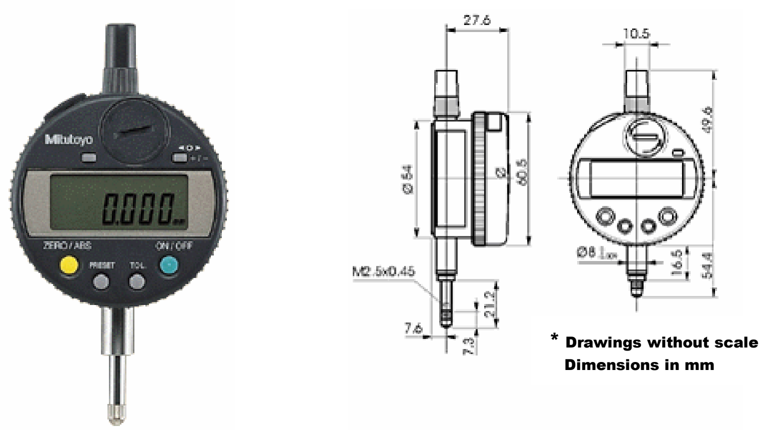

Figure 4. Digital comparing clock MITUTOYO 543-250B.

5.2.2 Standard Blocks Dimension

The definition of the standard blocks dimension it takes care of necessity of three distinct loads for the accuracy and repeatability assays described as in norm ISO 9283 (1995), where it consists that the robot can be assayed with 10%, 50% and 100% of its nominal load capacity. In the case, one became necessary to the construction of three volumes with masses of 0.5 kg, 2,5 kg and 5,0 kg, to take care of the demanded specifications. In virtue of the dimensional one and the system of setting of the flange located in the robot extremity, as illustrated schematically drawing in figure 5 (ABB Robotics, 1995), was opted to constructing to the reference cubes with only three passing punctures and degradation for the head of the screws, in intention to increase the measurement area of the comparing clocks on the surface of the same ones.

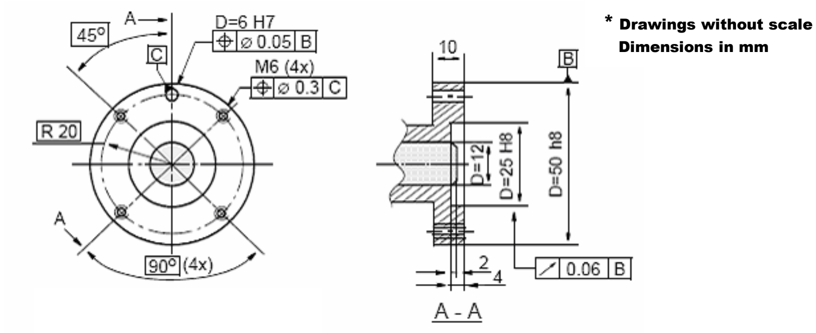

Figure 5. Schematically drawing of the robot setting flange.

To optimize the volumes manufacture and the device of setting of the clocks, beyond guaranteeing that the system was compact, it was opted to constructing to the blocks with a square shaped section of 50 mm. The figure 6 illustrates the configuration of the used reference blocks with its respective masses. Beyond the test block, other blocks are applied only for effect load, not having contact with the comparing clocks at the moment of the measurement (Weidlich, 2006).

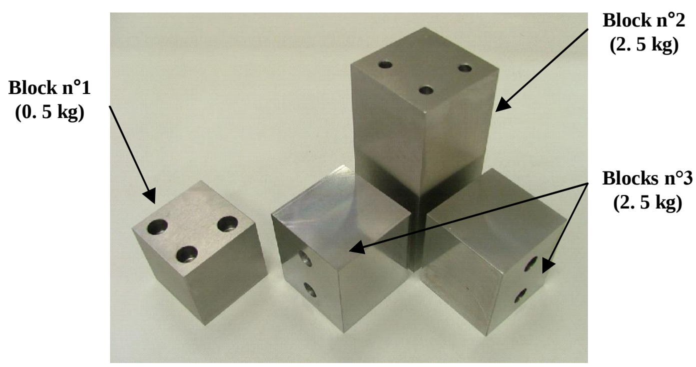

Figure 6. Blocks used in the accuracy and repeatability assays.

To guarantee a measurement uncertainty that allows to use this test system of in positioning assays of the industrial robots, in the construction of the same ones constructive tolerances had been considered, in function of the plan and orthogonally errors, on the readings of the displacement measurers, beyond the superficial finishing of the parts.

5.2.3 Measurement Device Dimension

The dimension and conception of the measurement device are tied with the necessity of the assembly of the three digital comparing clocks in the three coordinate axles and the measurement of the standards blocks fixed in the robot extremity. In the conception of the project the main points considered correspond:

- ✓ rigidity mechanics enough to fix the digital measurers, safe from damages interference in the reading;
- ✓ orthogonally between the three coordinate axles;
- ✓ dimensions adjusted for the use of the different configurations of standards blocks;
- ✓ assembly easiness; parts of simple forms settled by screwed unions.

In virtue of the necessity of three-dimensional orthogonally, the three clocks are located in the same way and perpendicular between itself, with setting carried through the squeeze in the clocks body, having allowed a good rigidity of the system and no type of blockage or interference in the measurements. Figure 8 illustrates the model of the device, projected indicating the rabbet of the clocks mounted in the directions of the orthogonal axles (Weidlich, 2006).

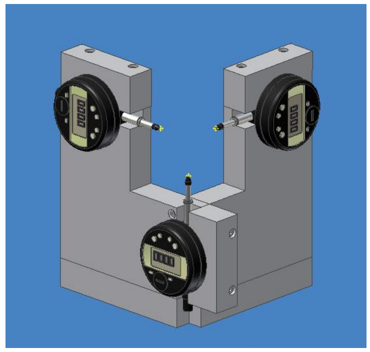

Figure 7. Measurement device model.

6. EXPERIMENTAL APPLICATIONS

The developed experimental applications in the robotic laboratory had served as base for the validation of the methodology of performance evaluation of the industrial robots and elaboration of the cube-cradle project.

As specification of the norm, for effect of tests, inside optimized the assays volume of the work space of the robotic manipulator. For the carried through experimental tests, the dimensions of the virtual cube of test had been defined, that is, the position of the 5 points of measurement in the test plan C_1-C_2-C_7-C_8 (figure 8), next to the limits of the same. In relation to the measurement points, the point P_1 is situated in the center of the cube in question and the points P_2 and P_3, as well as, P_4 and P_5 are symmetrical and equally equidistant ones to the others.

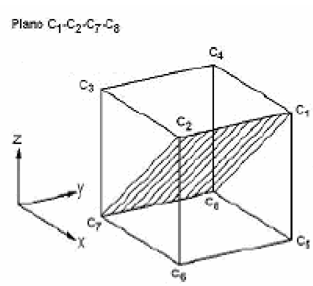

Figure 8. Test plan C_1-C_2-C_7-C_8.

The representation of the robot work space and the position of the measurement assay points are illustrated in the sights of figure 9. The illustrated robotic manipulator corresponds to model IRB 1400 - ABB.

The characteristics of the accuracy and repeatability positioning measured on the assays search to quantify the deviation that occur between a commanded position, a reached position and the fluctuation in the position reached in a series of repeated visits to the commanded position. In the case, the commanded position is programmed *off-line* through the computer in the robot language, and the reached points, are the pinpoints gotten 30 after repeated cycles of the robot under automatic way.

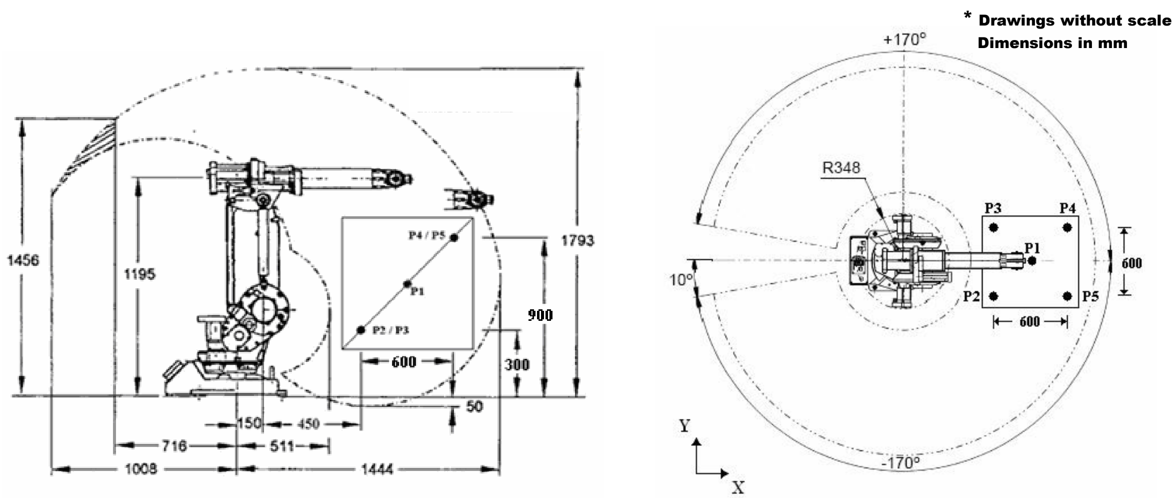

Figure 9. Top and lateral sights of the test cube in the robot work space.

It defined the test positions, the program in language RAPID, specific of the robot in test was developed, that if dislocating from an initial position or rest, allowed to the execution of the cycles of measurement in each one of the points contained in the test virtual cube, executing the sequences of cycles established in the norm.

In the evaluated positioning, the cycles of tests are happened again respectively for speeds of 10%, 50% and 100% of the maximum speed of the equipment, that in the case of the analyzed manipulator corresponds 7,0 m/s. The same percentages for applied loads had also been considered, in relation to the nominal capacity, that in the tested model corresponds the 5,0 kg.

In virtue of the dimensional characteristics of the projected system (figure 10), the programs of carried through tests, had allowed the variation of the parameters of the assay of practical form, as much the speed for each point measured modified to each 30 cycles automatically, as the load, adjusted to the end of each 90 cycles.

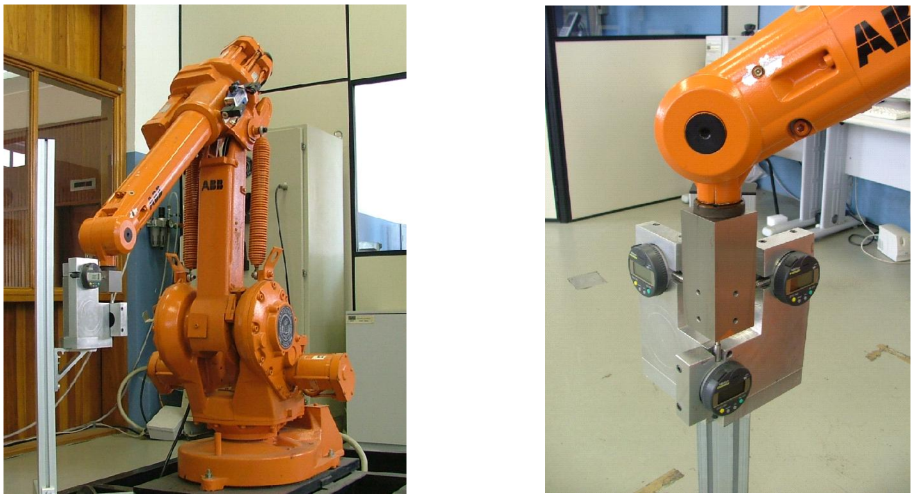

Figura 10. Illustrated pictures of the cube-cradle device.

The tests had been carried through following a logical sequence, repeated for all the points of measurement by robot work volume, as described procedure in the following stages:

1. Drive of the equipment;
2. Insertion of the test program in the robot panel command;
3. Shipment of the program through *teach-pendant*;
4. Setting of the standard block in the robot extremity;
5. Execution of the program under security way to verify possible fails;
6. Positioning of the robot in the specific point of measurement;
7. Positioning of the system of measurement in contact with the standard block;
8. Accomplishment of the digital measurers reset;
9. Conduction of the manipulator the rest position;
10. Execution of the program under automatic way;
11. Collection of the data in the computer to each cycle of measurement;

For the calculations of unidirectional accuracy and repeatability all had been used the collected data, with treatment of the information in mathematical spread sheets, with specific formularizations for each one of the evaluated performance characteristics. The tests had been become fulfilled in steady considered readiness's of the robot, with thermal radiation and protecting airflow equipment, as well as the temperature and humidity in accordance with the values described in the norm.

7. ASSAYS AND RESULTS

The collected data had been treated in mathematical spread sheets and the values of the unidirectional positioning accuracy and repeatability errors of defined in tables and graphs for the points considered in the experimental tests. For visualization of the measures dispersions, these are treated in software MATLAB®, and represented graphically in three-dimensional form, where the located data illustrate the points reached in each one of the test positions. It had been considered the worse and best ones resulted in each one of the five evaluated points. In the example of the figure 11, it's imagined distribution of the positioning errors in the three-dimensional space of the point P_1.

It observes in this case, that the assayed results had been satisfactory, therefore the rays of the baricenter of positions reached after 30 repeated visits are little significant in both the cases, and its centers sufficiently are lined up with the intersection of the three coordinates axles. With the increase of speed and load, the dispersion presents a little bigger and lightly dislocated in the graph of the right.

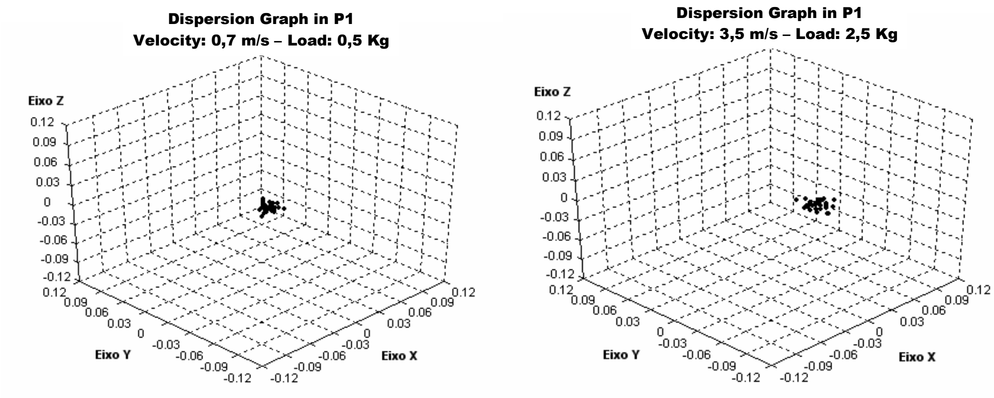

Figura 11. Three-dimensional dispersion graphs in the point P_1 [mm] assays.

In table 1, the final results of the positioning characteristics of the assays carried through in the position P_1 are illustrated, point located in the center of the test virtual cube, where the values of the accuracy errors (A_P), repeatability errors (R_p) and standard deviation (S_i), for the different tested parameters.

Table 1. Results of the accuracy and repeatability assays in the point P_1.

	Assays Parameters	**AP_p (mm)**	**RP_p (mm)**	**S_i (mm)**
1	Velocity - 0,7 m/s Load - 0,5 kg	0,0102	0,0209	0,0043
2	Velocity - 3,5 m/s Load - 0,5 kg	0,0115	0,0217	0,0045
3	Velocity - 7,0 m/s Load - 0,5 kg	0,0124	0,0181	0,0034
4	Velocity - 0,7 m/s Load - 2,5 kg	0,0398	0,0212	0,0039
5	Velocity - 3,5 m/s Load - 2,5 kg	0,0497	0,0274	0,0053
6	Velocity - 7,0 m/s Load - 2,5 kg	0,0449	0,0247	0,0049
7	Velocity - 0,7 m/s Load - 5,0 kg	0,0265	0,0226	0,0043
8	Velocity - 3,5 m/s Load - 5,0 kg	0,0419	0,0280	0,0060
9	Velocity - 7,0 m/s Load - 5,0 kg	0,0485	0,0295	0,0043

On the same way, for the located final values (figure 12), a specific behavior when of the speed and load variation are observed, that is, the results had gotten worse in virtue of the increase of speed and load, and in relation to this as parameter, with sufficiently significant impact already with 50% of the nominal capacity of the robot.

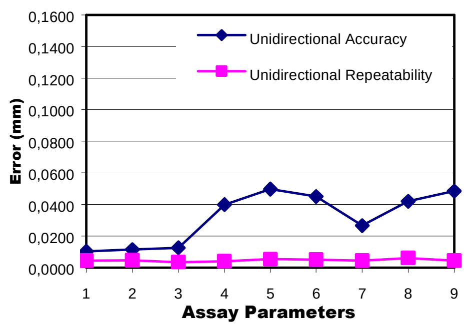

Figure 12. Unidirectional accuracy and repeatability graph in the point P_1.

8. CONCLUSIONS

The results gotten in the present paper fulfill the main established objective, that is, to conceive a measurement device, that based in the methodologies of the performance evaluation describes in norm ISO 9283 (1995), allows to measure the characteristics of the positioning unidirectional accuracy and repeatability of an industrial robot.

With the development and implementation of the propose system the considered results was waited, a time that the device reaches all the test positions and the measurement total uncertainty in the quantification of the performance characteristics of the robots meets inside of the specified parameters, enough had been reached for evaluation of the robot assayed in the validation of the considered work.

An interesting aspect of the measurement device considered is that its portable characteristic opens space for the rendering of services of the performance evaluation in robots of diverse types, or at least, makes with that this type of equipment can inside be used of industries with low costs, in the evaluation of the productive processes where these machines are inserted.

9. ACKNOWLEDGEMENTS

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