# ASSESSING THE IMPACT OF OVERHAUL ON THE ACCURACY AND REPEATABILITY OF A KUKA KR6 R900

**PETER MARCINKO[1], JAN SEMJON[1], RUDOLF JANOS[1], JOZEF SVETLIK[1]**

[1]Technical University of Kosice, Department of Production Systems and Robotics, Kosice, Slovakia

**DOI: 10.17973/MMSJ.2026_11_2026100**

**peter.marcinko@tuke.sk**

This paper investigates the effect of a major overhaul on the positioning accuracy and repeatability of a KUKA KR6 R900 industrial robot. The robot has been used extensively for teaching and programming activities, during which occasional collisions and long-term mechanical wear may have affected its positioning performance. To assess the changes resulting from the overhaul, experimental measurements were carried out before and after the maintenance intervention under defined operating conditions, using a methodology based on ISO 9283. Positioning deviations and repeatability were evaluated at two operating speeds using a measurement system equipped with six contact displacement sensors. The results show how the robot's positioning performance changed after the overhaul and highlight the importance of verifying its technical condition before returning it to regular operation.

**KEYWORDS**

Industrial robot, performance criteria, ISO 9283, pose accuracy, repeatability

## 1 INTRODUCTION

Robotics includes the development, research, design, and application of robotic systems. Advances in materials, sensor technologies, and control systems have led to increasingly stringent requirements for robot performance. Industrial applications place particular emphasis on reducing errors, ensuring process stability, and minimizing operating costs. These requirements directly influence the expected positioning accuracy and repeatability of industrial robots, as well as their selection and evaluation for specific applications [Semjon 2020]. Positioning accuracy and repeatability are key parameters in the design of robotic applications, as they directly determine the robot's ability to repeatedly reach the required position and follow a defined trajectory at specified speeds and loads [Bozek 2021]. Therefore, robot selection should not be based solely on the manufacturer's specifications but should also consider the robot's actual technical condition, operating history, and the conditions of its intended application [Makulavicius 2026].

This requirement is particularly important for used robots or robots that have been in operation for extended periods, where joint wear and increased backlash in gear mechanisms may lead to a deterioration in robot performance. In practice, reliable information about maintenance history, operating conditions, and previous collisions is often unavailable. Such events may compromise the mechanical integrity of the robot arm and negatively affect the positioning accuracy of the entire kinematic chain [Raksiri2020].

Robots that have undergone a major overhaul represent a specific category. Although maintenance and repair procedures generally restore their operational capability and reliability, the recovery of the required performance characteristics cannot be confirmed without subsequent verification. Since the KUKA industrial robot examined in this study has undergone a major overhaul and is intended for further use, it was necessary to systematically evaluate its suitability for continued operation. Therefore, a measurement methodology was developed and applied to assess the key performance characteristics, particularly positioning accuracy and repeatability, which directly affect the robot's ability to meet the tolerance requirements of a given task [Khirani 2026].

The proposed procedure is based on standardized testing principles and uses the international standard ISO 9283 as a reference, which defines the performance characteristics of industrial robots and the recommended methods for their measurement. The aim of this paper is to verify the applicability of this methodology for evaluating a robot after a major overhaul and to provide an objective basis for assessing its suitability for further operation. The results include an evaluation of positioning accuracy and repeatability under defined test conditions, together with an interpretation of the robot's suitability for continued use in educational activities [Kuric 2020].

Various measurement technologies are used to evaluate the performance and geometric characteristics of industrial robots. These technologies differ in accuracy, measurement speed, measurement conditions, and acquisition costs. In industrial practice, optical tracking systems, particularly laser trackers, are widely used in combination with specialized software for calibration and error compensation [Klarak 2022]. Additional methods include laser interferometrs, ballbar tests for evaluating circular path deviations, and simpler contact sensors designed for basic verification of selected performance parameters [Tlach 2018, Marcinko 2024].

## 2 FORMULATION OF THE PROBLEM

The problem addressed in this study arises from the practical operation of educational robotic workstations, where robots are repeatedly used for a wide range of tasks involving frequent changes in programs, tools, and work objects. During training activities, particularly when learning robot programming, teaching points, and adjusting trajectories, occasional collisions with fixtures, workpieces, or other parts of the workstation may occur. Although such events do not necessarily result in immediate robot failure, they may cause localized mechanical stress, changes in the geometric relationships within the kinematic chain, increased backlash in gear mechanisms, and shifts in reference settings. These changes may gradually affect the robot's positioning performance without causing any obvious signs of mechanical damage or operational failure.

As a result, the systematic component of positioning error may change, and under unfavourable conditions, the variation in positioning repeatability may also increase. These changes can lead to deviations in the tool center point (TCP) position when identical motion commands are executed. The practical problem is that routine operational checks often confirm only the functional condition of the robot, rather than its metrological capability to perform tasks with strict tolerance requirements.

Without objective verification, it is difficult to reliably determine whether a robot continues to provide consistent results after extended operation, collision events, or maintenance procedures, and whether its performance meets the requirements for safe and effective educational use.

Furthermore, in an educational environment, it is important that robot positioning errors do not negatively affect learning outcomes, such as the creation and interpretation of robot programs, the definition of work coordinate systems, or the evaluation of trajectories by students [Song 2022].

For these reasons, periodic verification of the performance characteristics of the KUKA KR6 R900 industrial robot is necessary, particularly in educational environments where the risk of collisions is naturally higher than in established industrial production processes.

It is crucial to assess the extent to which the robot's actual behaviour deviates from its nominal kinematic model and whether the measured accuracy and repeatability parameters meet the limits required for subsequent use in training. Such verification also provides a basis for decisions regarding the operating mode, speed selection, end-effector load limits, or the need for further maintenance measures [Slamani 2013].

The subject of the experimental evaluation was the KUKA KR6 R900 six-axis industrial robot, designed primarily for handling, assembly operations, and other tasks requiring high dynamic performance within a relatively small working range. Belonging to the KUKA AGILUS product line, the robot features a compact design, a payload capacity of 6 kg, and a maximum reach of approximately 900 mm. Within the educational workstation, it is used primarily for teaching the fundamentals of industrial robot programming, creating and optimizing motion instructions (PTP, LIN, CIR), interpolation, and approximation, as well as for working with coordinate systems and verifying designed robotic tasks [Svaco 2014].

The basic technical specifications of the KR6 R900 robot which are decisive in terms of workspace, load capacity, and performance characteristics are listed in Table 1.

| Parameters | Value | Unit |
|---|---|---|
| **Number of controlled axes** | 6 | piece |
| **Weight** | 52 | kg |
| **Payload** | 6 | kg |
| **Maximum reach of robot** | 901.5 | mm |
| **Pose repeatability** | ±0.03 | mm |
| **Axis A1** | ±170 | ° |
| **Axis A2** | −190 to +45 | ° |
| **Axis A3** | −120 to +156 | ° |
| **Axis A4** | ±185 | ° |
| **Axis A5** | ±120 | ° |
| **Axis A6** | ±350 | ° |

**Table 1.** Technical parameters of KUKA KR6 R900

Due to intensive use during training sessions and repeated collisions, the robot underwent a major overhaul after a period of operation. The service intervention aimed to restore its technical condition and operational reliability. However, the overhaul itself does not provide definitive information on whether the robot's performance characteristics were also restored to a level suitable for its continued use. Even after mechanical repairs and adjustments, deviations in positioning accuracy and repeatability may remain and require experimental evaluation. Consequently, following the overhaul, it was necessary to experimentally verify the robot's positioning accuracy and repeatability, as these are critical parameters for assessing its continued suitability for educational use [Le Reun 2022].

## 3 MATHEMATICAL MODEL OF THE ROBOT

The geometric structure of an industrial robot determines the relationship between the angular positions of individual joints and the resulting position and orientation of the end-effector [Coranic 2023]. For serial robotic mechanisms, the Denavit-Hartenberg convention is frequently used to mathematically describe the kinematic chain, enabling the definition of the relative positions of adjacent links through a set of geometric parameters. The robot's nominal kinematic model is based on ideal geometric dimensions and the reference positions of the individual axes [Cheng 2025].

However, under real-world conditions, actual geometric parameters may differ from nominal values. Causes for this include manufacturing and assembly tolerances, mechanical component wear, changes in transmission backlash, structural deformations, or maintenance interventions. In robots operated over long periods, these deviations can also be influenced by collisions. Individual geometric deviations propagate through the entire kinematic chain, manifesting as a discrepancy between the commanded position and the actual position achieved by the end-effector. These effects highlight the importance of verifying positioning accuracy, particularly after prolonged operation or mechanical interventions that may alter the geometric relationships within the robot's kinematic structure [Svaco 2014].

For the six-axis articulated robot KUKA KR6 R900, $\theta_i$ is a variable parameter, while $a_i$, $d_i$, and $\alpha_i$ are geometric parameters of the mechanism. The transformation between two adjacent coordinate systems can be expressed as follows:

$$^{i-1}T_i = R_z(\theta_i)T_z(\mathrm{d}_i)\ T_x(\mathrm{a}_i)\ R_x(\alpha_i) \quad (1)$$

by expanding the individual rotational and translational transformations, the homogeneous transformation matrix is obtained as follows:

$$^{i-1}T_i = \begin{bmatrix} \cos\theta_i & -\sin\theta_i\cos\alpha_i & \sin\theta_i\sin\alpha_i & a_i\cos\theta_i \\ \sin\theta_i & \cos\theta_i\cos\alpha_i & -\cos\theta_i\sin\alpha_i & a_i\sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

The position and orientation of the end effector relative to the robot base coordinate system are obtained by sequentially multiplying the transformation matrices of all six joints:

$$^0T_6 = {}^0T_1{}^1T_2{}^2T_3{}^3T_4{}^4T_5{}^5T_6 \quad (3)$$

The resulting transformation matrix can be expressed as follows:

$$^0T_6 = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

where the first three columns define the orientation of the end effector, while the elements $p_x$, $p_y$, and $p_z$ define its position relative to the robot base coordinate system.

$$\mathrm{P} = \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} \quad (5)$$

Figure 1 illustrates the kinematic structure of the KUKA KR 6 R900 robot, including its individual rotational axes and local coordinate systems [Bingol 2021].

Table 2 presents the DH parameters. However, in a real robotic mechanism, the actual geometric parameters may not exactly correspond to their nominal values. These differences may result from manufacturing and assembly tolerances, wear of mechanical components, backlash in gear mechanisms, structural deformations, or changes in the reference positions of individual axes.

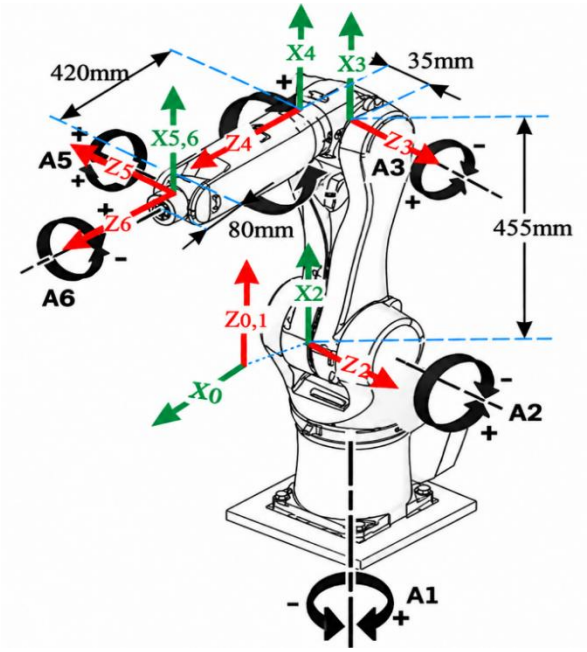



**Figure 1.** KUKA KR6 R900

During long-term operation, these deviations may also be influenced by collisions or subsequent maintenance interventions. Geometric errors and deformation-related deviations propagate through the entire kinematic chain, resulting in changes in the final position of the end effector.

| Link i | $d_i$ [mm] | $\Theta_i$ [°] | $a_i$ [mm] | $\alpha_i$ [°] |
|---|---|---|---|---|
| 1 | 400 | $\Theta_1$ | 25 | 90 |
| 2 | 0 | $\Theta_2$ | 455 | 0 |
| 3 | 0 | $\Theta_3$ | 35 | 90 |
| 4 | 420 | $\Theta_4$ | 0 | -90 |
| 5 | 0 | $\Theta_5$ | 0 | 90 |
| 6 | 80 | $\Theta_6$ | 0 | 180 |

**Table 2.** DH parameters of KUKA KR6 R900

## 4 MEASUREMENT METHODOLOGY

The experimental measurement was designed to evaluate the performance characteristics of the KUKA KR6 R900 industrial robot following a major overhaul. The evaluation focused on positioning accuracy and positioning repeatability, which allow an objective assessment of the robot's ability to reach a required position and repeatedly return to it under identical conditions. The methodology was based on the requirements of ISO 9283 and followed previous experimental evaluations of robotic systems using a contact measurement method. The use of this method provides a technically simpler and more cost-effective alternative to spatial optical measurement systems. With a suitable arrangement of sensors, it allows direct measurement of small changes in the end-effector position along individual coordinate axes [ISO 9283 1998].

In contact-based measurements, it is important to minimize any additional mechanical influence on the measured position, Figure 2. Therefore, the measuring element must establish contact with the sensor without applying excessive force that could cause deformation of the mechanism or displacement of the robot. For this reason, a pneumatic mechanism was used to extend and retract the contact elements, thereby reducing friction between the measuring element and the sensors [Semjon 2024].

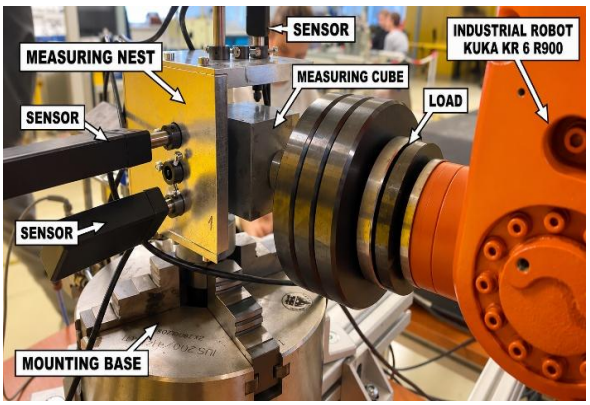



**Figure 2.** Experimental (contact-based) measuring nest

The experimental measurements were performed on a KUKA KR 6 R900 industrial robot, which was securely mounted on a rigid measurement stand to minimize the effects of deformation, vibration, and unwanted base movements during testing. The evaluation focused on positioning accuracy and positioning repeatability, using a contact measurement method with Heidenhain MT 12 and MT 25 displacement sensors to record the actual position of the end effector. For each test configuration, 30 repeated measurement cycles were performed, allowing the evaluation of both the mean position and the dispersion of individual measurements. This approach also enabled an assessment of the stability of the robot's positioning performance under the defined experimental conditions [Semjon 2019].

In accordance with the requirements of ISO 9283, experimental measurements were performed at different robot load levels, including 50% and 100% of its rated payload. The maximum payload was 6 kg. However, the results presented in this paper focus on two motion speed levels, 50% and 100% of the set speed, to evaluate the influence of motion speed on positioning accuracy and repeatability. All measurements were performed at a stable ambient temperature of approximately 21 °C to minimize the effects of temperature variations on the robot's mechanical structure and the measurement system, Figure 3.




**Figure 3.** Experimental setup for measurement AP and RP

The selected experimental conditions and repeated measurement cycles provided a basis for evaluating the robot's performance characteristics following the major overhaul [Pollak 2023, Sigron 2024].

The measurement program was designed to guide the robot sequentially through defined test positions within the selected measurement area. The arrangement of these positions was designed to ensure that all six joints changed their configurations during movements between individual positions, allowing the measurements to represent the robot's behavior within its actual working area. Each test position was reached along the same trajectory and from the same approach direction, thereby minimizing the influence of different approach directions on the measurement results. This consistent motion sequence ensured comparable conditions across repeated measurement cycles and reduced the influence of variations in robot movement on the evaluated positioning parameters [Yang 2018].

After reaching the corresponding test position, the robot was held stationary for a short period to minimize the effects of residual motion and allow the contact sensor readings to stabilize. The position values were then recorded along three mutually perpendicular directions. A stabilization time of 3 s was applied before recording the measurements to ensure sufficiently stable conditions for repeated measurements. The same procedure was followed at all test points and for all combinations of motion speed and payload [Slamani 2012].

The measurement points within the selected measurement plane, as well as the position of the measurement cube, were defined in accordance with ISO 9283, as illustrated in Figure 4. The test cycles were also performed in accordance with the standard. Vertices $C_1$ to $C_8$ represent the corners of a cube located within the region of the robot's workspace where it is expected to operate most frequently. Measurements were performed at all defined test points; however, due to the extensive amount of experimental data, this paper focuses on the detailed evaluation of point $P_1$ [Marcinko 2020].

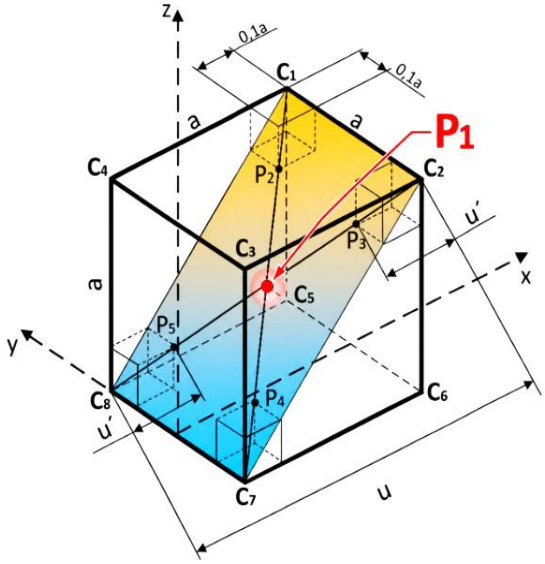



**Figure 4.** Measuring cube

For each test position, the mean values of the measured coordinates are first calculated from n repeated measurements as follows:

$$\bar{x} = \frac{1}{n}\sum_{j=1}^{n} x_j \tag{6}$$

$$\bar{y} = \frac{1}{n}\sum_{j=1}^{n} y_j \tag{7}$$

$$\bar{z} = \frac{1}{n}\sum_{j=1}^{n} z_j \tag{8}$$

where $x_j$, $y_j$, and $z_j$ represent the values obtained during the j-th repetition of the measurement cycle. Positioning accuracy along the individual coordinate axes can be calculated using the following equations:

$$AP_x = \bar{x} - x_c \tag{10}$$

$$AP_y = \bar{y} - y_c \tag{11}$$

$$AP_z = \bar{z} - z_c \tag{12}$$

where $x_c$, $y_c$, and $z_c$ represent the coordinates of the programmed reference position. The resulting spatial positioning accuracy is calculated as follows:

$$AP = \sqrt{(\bar{x} - x_c)^2 + (\bar{y} - y_c)^2 + (\bar{z} - z_c)^2} \tag{13}$$

The AP value represents the distance between the programmed position and the mean position actually reached by the robot. It therefore primarily expresses the systematic component of the robot's positioning error [Marcinko 2020].

Positioning repeatability characterizes the dispersion of individual achieved positions around their mean position. For each measurement cycle, the distance of the corresponding point from the barycenter of all achieved positions is first calculated as follows:

$$l_j = \sqrt{\left(x_j - \bar{x}\right)^2 + \left(y_j - \bar{y}\right)^2 + \left(z_j - \bar{z}\right)^2} \tag{14}$$

The mean distance of the points from the barycenter is calculated as follows:

$$\bar{l} = \frac{1}{n}\sum_{j=1}^{n} l_j \tag{15}$$

The standard deviation of these distances is calculated using the following equation:

$$S_l = \sqrt{\frac{\sum_{j=1}^{n}(l_j - \bar{l})^2}{n-1}} \tag{16}$$

The resulting positioning repeatability is then calculated as follows:

$$RP = \bar{l} + 3S_l \tag{17}$$

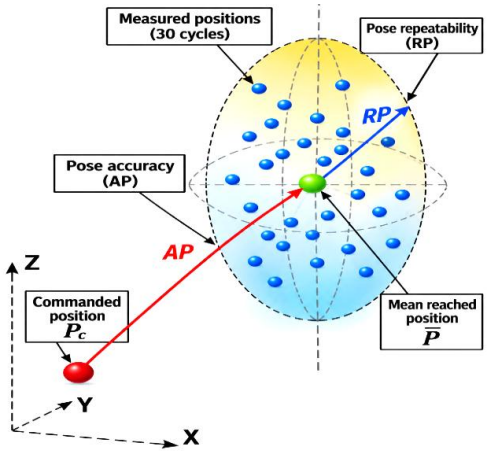



**Figure 5.** Geometrical interpretation of AP and RP

The RP value can be geometrically interpreted as the radius of a region around the barycenter that characterizes the dispersion of repeatedly achieved positions. Figure 5 illustrates the geometrical interpretation of positioning accuracy (AP) and positioning repeatability (RP). Measurements were performed at all defined test points. However, the results presented in this paper focus on reference point P1, which was selected for a detailed comparison of positioning accuracy and repeatability before and after the major overhaul at both speed settings.

## 5 RESULTS AND DISCUSSION

The experimental evaluation of the performance characteristics of the KUKA KR6 R900 industrial robot focused on assessing changes in positioning accuracy and repeatability resulting from the major overhaul. Measurements were performed at reference point P1 at two movement speed settings, 50% and 100%, while the load was maintained at 100% of the specified load in both cases. For each operating condition, 30 repeated measurement cycles were recorded. The data obtained in this way made it possible to quantify changes in systematic positioning error and the dispersion of achieved positions, thereby providing an objective assessment of the effectiveness of the major overhaul.

During each measurement cycle, the robot followed a predefined trajectory involving the movement of all six rotational axes. Upon reaching reference point P1, the contact sensors were extended and the position of the measurement cube attached to the robot's end effector was recorded. After the measurement was completed, the sensors were retracted and the robot returned to its initial position. This procedure allowed repeated measurements to be performed under comparable operating conditions. Maintaining the same trajectory and approach direction to reference point P1 minimized the influence of differences in motion conditions on the resulting positioning deviations.

Six contact sensors arranged in three measurement pairs were used to record positioning deviations. The X1–X2, Y1–Y2, and Z1–Z2 pairs were oriented along the corresponding coordinate axes, with the sensors in each pair contacting the measurement cube at two different points. This arrangement allows the combined response of both sensors to be evaluated while also monitoring differences between their readings. Table 3 presents the statistical characteristics of the individual measurement channels obtained after the major overhaul.

The initial processing of the results focused on calculating the arithmetic means and sample standard deviations of the individual measurement channels. These statistical characteristics allow the mean value of the measured signal and its variability to be compared between the two speed settings. Particular attention was paid to differences between the sensor pairs, which may indicate variations in the positional response of the measurement cube [Biezhenko 2023].

| Sensor | Average 50% [mm] | SD 50 % [mm] | Average 100 % [mm] | SD 100 % [mm] |
|---|---|---|---|---|
| X1 | 0.02227 | 0.00754 | 0.03120 | 0.00379 |
| X2 | 0.02073 | 0.00658 | 0.02843 | 0.00371 |
| Y1 | −0.01463 | 0.00389 | −0.01940 | 0.00839 |
| Y2 | 0.00330 | 0.00296 | 0.00653 | 0.00670 |
| Z1 | 0.00913 | 0.00840 | 0.02640 | 0.00441 |
| Z2 | - 0.00940 | 0.00615 | 0.00177 | 0.00677 |

**Table 3.** Statistical characteristics of individual measurement channels after the overhaul (SD – standard deviation)

The results presented in Table 3 show that the individual measurement channels exhibited different mean values and levels of variability. At 50% speed, the highest standard deviation was recorded for sensor Z1, whereas at 100% speed, it was recorded for sensor Y1. Increasing the movement speed did not lead to a uniform increase in the variability of all measured signals. Variability decreased for sensors X1, X2, and Z1, while higher variability was observed for sensors Y1, Y2, and Z2.

The measured values recorded during the individual measurement cycles are shown in Figure 6. The graph provides a more detailed view of changes in positioning deviations over 30 repeated cycles and highlights differences in the behaviour of the individual measurement sensors.

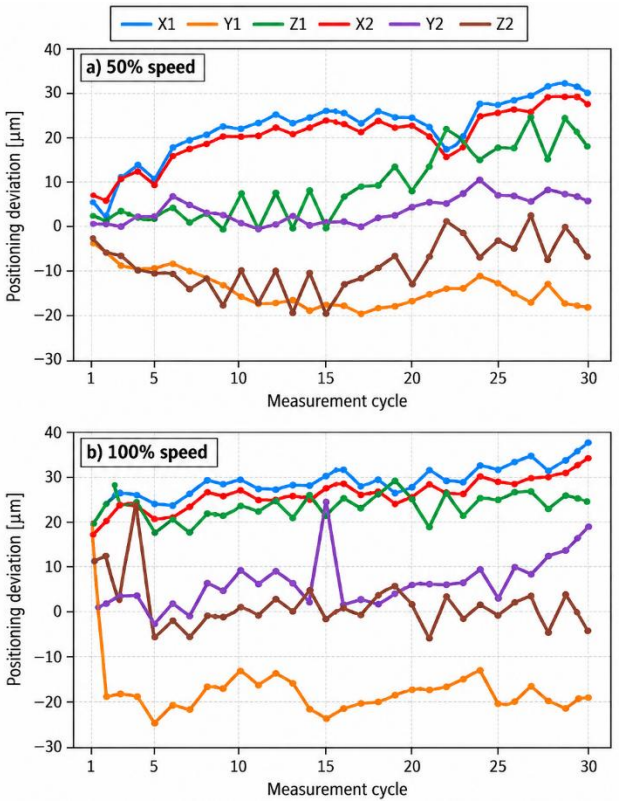



**Figure 6.** Measurement channel readings over 30 cycles at 50% and 100% speed

At 50% speed, a gradual increase in the measured values of sensors X1 and X2 can be observed, with both sensors exhibiting a similar trend. This suggests a common displacement of the measurement cube along the X-axis. More pronounced fluctuations in the measured values are observed particularly for the sensors oriented along the Z-axis.

At 100% speed, the measured values of sensors X1 and X2 exhibit more stable trends, although their mean values are higher. Greater differences between individual measurement cycles are observed along the Y and Z axes. A more pronounced deviation was recorded during the first measurement cycle of sensor Y1, where the value reached 0.022 mm. This value was retained in the calculations because no measurement error was confirmed. Changes in the measured values over individual cycles may be related to the thermal state of the robot, mechanical stabilization, or the stability of the measurement system.

### 5.1 Evaluation of positioning accuracy

Positioning accuracy expresses the difference between the commanded position and the mean position achieved by the robot. When evaluating this parameter, the arrangement of the measurement system must be considered, since the values recorded by individual sensors may not directly correspond to the coordinates of the robot's reference point. Therefore, to determine positioning accuracy (AP) according to ISO 9283, the relationship between the measured values and the actual position of the measured point must be known. For a preliminary comparison, the mean values of the three sensor pairs were used.

Before starting the measurements, the robot was moved to the reference point P1, where six contact displacement sensors were extended towards the measurement cube. The sensors were then set to zero, establishing the initial reference position

for the experiment. During each measurement cycle, the robot followed the predefined trajectory and returned to P1, where the sensor readings were recorded. The readings from each sensor pair were averaged to obtain the displacement components along the X, Y, and Z axes. These values were subsequently used to calculate the spatial positioning deviation reported in Table 4.

| Robot status (v50%) | X [mm] | Y [mm] | Z [mm] | D [mm] |
|---|---|---|---|---|
| Before overhaul | 0.02650 | −0.00920 | 0.00600 | 0.02868 |
| After overhaul | 0.02150 | −0.00567 | −0.00013 | 0.02223 |
| **Robot status (v100%)** | **X [mm]** | **Y [mm]** | **Z [mm]** | **D [mm]** |
| Before overhaul | 0.03600 | −0.01050 | 0.01900 | 0.04207 |
| After overhaul | 0.02982 | −0.00643 | 0.01408 | 0.03360 |

**Table 4.** Values of AP at v50% and v100% before and after overhaul

In the comparison at 50% speed, the magnitude of the average position vector decreased from 0.02868 mm before the overhaul to 0.02223 mm after its completion, representing an improvement of approximately 22.5%. A similar result was achieved at 100% speed, where the value dropped from 0.04207 mm to 0.03360 mm a reduction of approximately 20.1%. In both cases, the results indicate a beneficial impact of the overhaul on the robot's positioning accuracy.

The observed reduction in average positional deviation may be associated with the restoration of geometric relationships within the kinematic chain and the correction of mechanical defects accumulated during operation. The varying magnitude of changes across different coordinate directions suggests that the service interventions performed do not necessarily affect all components of the positional deviation equally. Therefore, when evaluating the effectiveness of the overhaul, it is important to monitor not only the resulting spatial deviation but also its individual coordinate components.

A comparison of the two speed modes also reveals that, following the overhaul, the robot exhibited higher average positional signal values at 100% speed. However, the resulting deviation is influenced not only by the set speed but also by acceleration and deceleration profiles, the configuration of individual axes, and the approach path to the measurement point. Table 4 presents values of AP before and after overhaul at v50% and v100%.

## 5.2 Evaluation of positioning repeatability

Positioning repeatability was evaluated based on the spatial distances of individual achieved positions from their barycenter. For each measurement cycle, coordinate signals were obtained from the mean values of the three sensor pairs. The mean position was then calculated, along with the distance of each measured position from the barycenter. Table 5 presents a comparison of positioning repeatability before and after the major overhaul at 50% and 100% speed.

At 50% speed, positioning repeatability improved from 0.02830 mm to 0.02190 mm, representing a reduction in deviation of approximately 22.6%. At 100% speed, the improvement was even more pronounced, with the value decreasing from 0.02790 mm to 0.02027 mm, a reduction of approximately 27.3%.

| Robot status (v50%) | $\vec{l}$ | $S_L$ | Rp [MM] |
|---|---|---|---|
| Before overhaul | 0.01180 | 0.00550 | 0.02830 |
| After overhaul | 0.00911 | 0.00426 | 0.02190 |
| **Robot status (v100%)** | $\vec{l}$ | $S_L$ | **Rp [MM]** |
| Before overhaul | 0.01050 | 0.00580 | 0.02790 |
| After overhaul | 0.00658 | 0.00456 | 0.02027 |

Table 5 Comparison of RP before and after overhaul at v50% and v100%

In both cases, there was a reduction in the average distance of measured positions from their barycenter, as well as in the dispersion of individual measurements. These results indicate improved positioning stability following the major overhaul.

Furthermore, the improved repeatability may suggest a beneficial impact of the service interventions on the robot's mechanical properties.

After the major overhaul, the positioning repeatability value recorded at 100% speed was approximately 7.4% lower than that obtained at 50% speed. However, this difference does not necessarily indicate that the robot generally achieves better positioning repeatability at higher speeds, as the results are specific to the selected trajectory, measurement point P1, and experimental conditions.

Experimental measurements enabled the evaluation of the KUKA KR6 R900 industrial robot's performance after the major overhaul under two speed settings. The results showed that changes in speed did not affect all coordinate directions equally. At 100% speed, measurement variability decreased along the X-axis, while it increased along the Y-axis. Despite these differences, the resulting spatial positioning repeatability was slightly better at the higher speed.

From the perspective of the major overhaul, the most important aspect is the evaluation of changes in positioning accuracy and repeatability. The comparison indicates a reduction in mean positioning deviations of approximately 20–23% and an improvement in positioning repeatability of 23–27%. However, improvements in these parameters do not automatically mean that the robot meets the requirements of every technological task. The decisive factor is the comparison of the achieved values with the required tolerances.

The measurement system, consisting of six contact displacement sensors, enables the monitoring of positioning deviations along three coordinate axes and the comparison of responses from individual sensor pairs. The pneumatic extension of the sensors only after the robot has stopped also reduces the risk of damage to the measuring elements and allows repeated measurement cycles to be performed under comparable conditions.

When evaluating the performance characteristics of the KUKA KR6 R900 industrial robot, its year of manufacture and long-term operational loading must also be considered. Since the robot is primarily used for teaching and programming activities, frequent trajectory modifications, adjustments of programmed positions, and occasional collisions, together with the gradual wear of mechanical components, may affect its positioning accuracy and repeatability. Measurements performed after the major overhaul therefore make it possible to verify its benefits while also providing baseline values for monitoring the technical condition of the robot during subsequent operation.

Since the results presented in this study are limited to reference point P1 and two speed settings, they do not allow a comprehensive evaluation of the robot's performance characteristics throughout its entire working space. Additional

information on its behavior could be obtained by measuring position drift according to ISO 9283, which would allow changes in positioning deviations over time to be monitored and positioning stability during operation to be assessed. Nevertheless, the proposed procedure provides a suitable basis for comparing the technical condition of the robot before and after the major overhaul, as well as for subsequent periodic inspections.

## 6 CONCLUSION

This paper focused on the evaluation of positioning accuracy and repeatability of the KUKA KR6 R900 industrial robot in relation to a major overhaul. Experimental measurements performed at two speed settings revealed differences in positioning deviations along individual coordinate axes, as well as in the stability of reaching the reference point. The obtained results provided a more detailed assessment of the robot's performance after the overhaul and highlighted the importance of regularly verifying its performance characteristics. The comparison of the robot's condition before and after the major overhaul also provides a basis for evaluating the effectiveness of the maintenance procedures and assessing its suitability for further operation. The proposed methodology, based on six contact displacement sensors, represents a practical approach to monitoring positioning deviations that can also be applied in subsequent verification measurements. Future experiments involving additional measurement points throughout the robot's workspace and position drift measurements according to ISO 9283 would enable a more comprehensive assessment of the robot's technical condition and long-term stability.


## ACKNOWLEDGMENTS

This paper was prepared with the support of the grant project KEGA 043TUKE–4/2024 - Creation of prospective educational tools for the field of additive manufacturing with the implementation of progressive elements of virtual reality, and VEGA 1/0215/23 - Research and development of robotic workplaces equipped with industrial and collaborative robots.


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**CONTACTS:**

**Peter Marcinko, Ing, PhD.**
Technical University of Kosice
Faculty of Mechanical Engineering
Department of Production Systems and Robotics
Letna 9, 04200 Kosice, Slovakia
+421556022523, peter.marcinko@tuke.sk

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