Measurement of industrial robot pose repeatability

Ivan Kuric[1], *Vladimír* Tlach[1,*], *Zuzana* Ságová[1], *Miroslav* Císar[1], *Igor* Gritsuk[2]

[1]University of Žilina, Faculty of Mechanical Engineering, Department of Automation and Production Systems, Univerzitná 1, 010 26 Žilina, Slovak Republic
[2]Kherson State Maritime Academy, Department of Operation of Ship Power Plants, 73000 Kherson, 20 Ushakova avenue, Ukraine

Abstract. The article deals with measurement of pose repeatability of industrial robot Fanuc LR Mate 200iC. Laser interferometer Renishaw XL-80 and digital indicator Mitutoyo Absolute Digimatic ID-F are used for the measurement. The measurement methodology is based on so-called ISO cube placed in the most used part of robot workspace. Individual steps of the solution, the analysis of measurement data and results are presented in the article.

Keywords: Industrial robot, Pose repeatability, Laser interferometer, Digital indicator

1 Introduction

The primary role of industrial robots was to relieve man from physically demanding and monotonous work and from working in harmful and hazardous environment. With development of production facilities and increasing production flexibility, the requirements for industrial robots are also increasing and new areas of deployment are emerging. [1, 1] One of the trends is the use of industrial robots for tasks that have so far been carried out by dedicated devices, or for performing non-production tasks like operating CNC machine tools by an industrial robot. At the same time, automation is constantly increasing the number of industrial robots. Based on a press release issued by IFK (International Federation of Robotics), an estimated global growth of more than three million industrial robots is expected in 2020 [3].

The choice of an industrial robot for a particular application is determined by its basic criteria such as the payload, the number of degrees of freedom, the robot's reach based on the size of the workspace, and the like. [4] The features of an industrial robot can be viewed in more detail through its performance criteria. One of the most frequently mentioned performance criteria listed by industrial robot manufacturers in the respective datasheets is the repeatability value. More specifically, this is a pose repeatability, which represents the ability of the robot to repeatedly return to the same position from the same direction. [5]

* Corresponding author: vladimir.tlach@fstroj.uniza.sk

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Pose repeatability and many other performance characteristics are defined in the International Standard ISO 9283. This standard defines the importance of individual performance criteria, the method of their calculation, together with the recommended procedure and the measurement conditions. [6] Another document related to this issue is the ISO/TR 13309 technical report, published by the International Standards Organization in 1995. Its aim is to provide an overview of metrological methods and devices for measuring performance criteria in accordance with ISO 9283 standard.

The measurement of performance criteria of industrial robots is a complex task requiring different measuring devices and measurement methods. This issue is addressed by a number of scientific papers. [7] The most frequently measured performance criteria include accuracy and repeatability. Measurements are carried out with the use of various measuring devices such as laser tracker [8, 9], indicator [10, 11], camera systems [12, 13], and the like. Increasingly used are measuring devices primarily designated to assess the condition of CNC machine tools. We are talking about the laser interferometer and the ballbar measuring device [5].

The article deals with measurement of pose repeatability of industrial robot Fanuc LR Mate 200iC with the use of the Renishaw XL-80 laser interferometer and the Mitutoyo Absolute Digimatic ID-F digital indicator.

2 Pose repeatability of industrial robot positioning

Pose repeatability (RP) stands for the ability of the TCP (Tool Centre Point) of the robot to always return to the same (programmed) position from the same direction. One-way acquisition of the required position minimizes the effects of backlash in the individual joints of the industrial robot and their effect on the measurement result. Bidirectional or multidirectional repeatability may be several times greater than one-way repeatability. [5] For graphic display (Fig. 1.a), the pose repeatability is the radius of the sphere whose centre is located in the so-called barycenter. The barycenter (G) represents the point whose coordinates in the space correspond to mean values calculated from the repeatedly acquired TCP positions of the given robot.

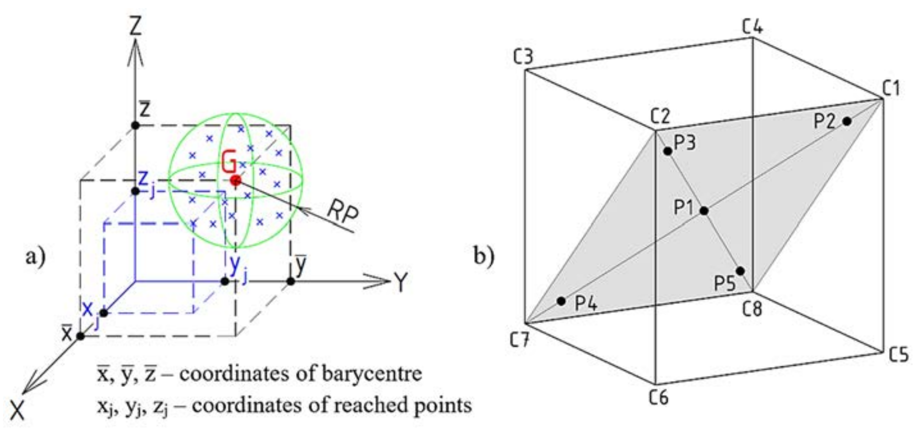

Fig. 1. Graphical displaying of pose repeatability and ISO cube

The ISO 9283 standard for measuring pose repeatability cites the procedure based on the so-called ISO cube. This is an imaginary cube placed in the robot's workspace, at the point where its most frequent use is assumed. The ISO cube should have the maximum admissible volume and, in the case of six-axis robots, an inclined plane with five measuring points P1-P5 (Fig. 1.b). The measurement process itself consists of at least thirty cycles during which the TCP point of the robot moves in a prescribed manner between the five measurement points. 13Each position of the TCP point is acquired by a one-way accession, precisely because of the minimization of effects of the backlash on robot joints.

3 Measurement methodology

The article presents a procedure for measuring pose repeatability on the industrial robot Fanuc LR Mate 200iC. It is robot with serial kinematics, located in the laboratory of the Department of Automation and Production Systems, of the University of Žilina. The robot is part of an automated assembly workplace in which it performs tasks related to the final assembly and handling of the assembled product. Based on standard recommendations, an imaginary ISO cube with a 470mm long edge was placed in the robot workspace (Fig. 2). Individual cube edges are parallel to axes of the robot's World Coordinate System (WCS). The size and location of the ISO cube was chosen to maximally cover the area of the robot's workspace associated with its work at the workplace.

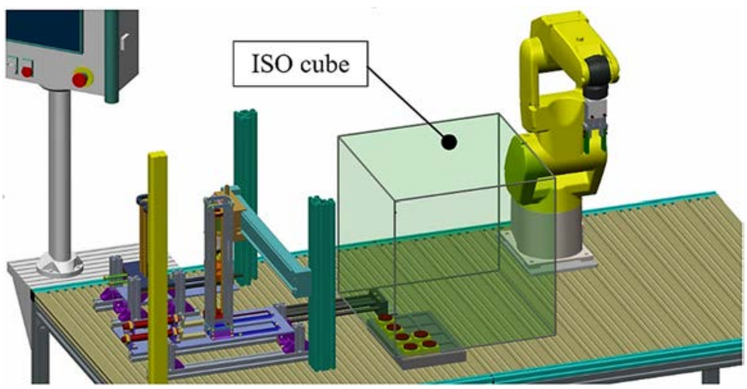

Fig. 2. Location of ISO cube in the robot workspace

3.1 Laser Interferometer Renishaw XL-80

The laser interferometer Renishaw XL-80 is mainly used for measuring machine tools. The system consists of the XL-80 laser unit, the XC-80 compensation unit for sensing environmental conditions (temperature, pressure, humidity) and measuring optics. Depending on the selected measurement optics, several types of measurements can be implemented with this device. Linear measurement was used to measure pose repeatability of the industrial robot. The principle of linear measurement lies in moving the reflector (moving mirror) along the transmitted laser beam. As the measurement runs alongside the line along the laser beam, it is not possible to measure five points located on the slanting plane as defined by ISO 9283.

The proposed method consists of three separate measurements along X, Y and Z axes. The starting point of all three measurements is P0, located at the vertex of the ISO cube (Fig. 3a). For each of the measurements, five measuring points (P1 - P5), spaced along edges of the ISO cube, are selected. To these points, the already mentioned point P0 and the point P6 are added. Measurement is not performed at those points, but they are used by the Renishaw LaserXL measuring program to detect a recurring measurement cycle. Thanks to this, the entire measurement process may be automated. During the measurement, the TCP point of the robot moves between points P0 and P6, with the stop and acquisition of the measuring position in both directions. During this type of measurement, measured values make it possible to observe, among other things, the effect of backlash on robot joints.

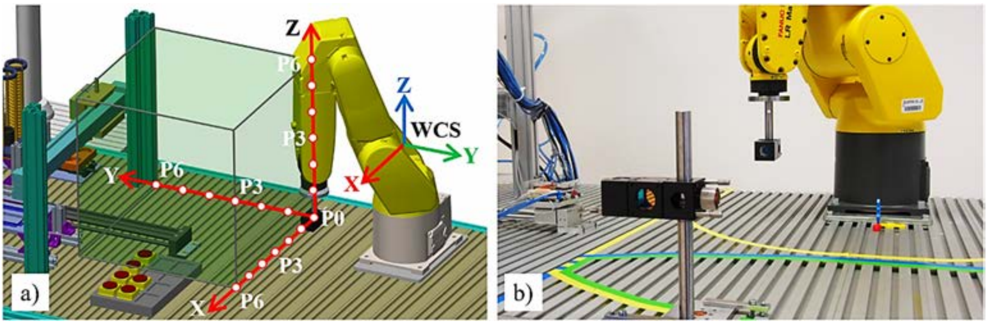

Fig. 3. Location of measuring points in ISO cube and realization of measure with laser interferometer

Each of P1 - P5 points was measured 30 times in the positive direction of the motion (P0 - P6) and 30 times in the negative direction of the motion (P6 - P0). During the measurement, the end of robot´s arm was loaded with a weight of 0.75kg, which contained the measuring optical apparatus and the accessories for its clamping onto the end of robot´s arm. Since the purpose of the workplace of the robot's location (Fig. 3b) is to make presentations and to teach specialist courses; measurements are made at the TCP point velocity value of 2m/s (50% of the robot's maximum velocity). The selected velocity is the velocity used at the given workplace.

3.2 Digital indicator Mitutoyo Absolute Digimatic ID-F

Using an indicator to measure industrial robot performance criteria is a relatively simple and not too costly solution. For pose repeatability measurement, digital indicator Mitutoyo Absolute Digimatic ID-F with a resolution of 0.001mm was selected. Repeatability of the Fanuc LR Mate 200iC robot is stated at ±0.02mm by its manufacturer. To make the repeatability measurement at the given robot possible, a measuring device of at least one order of precision greater must be chosen for the purpose.

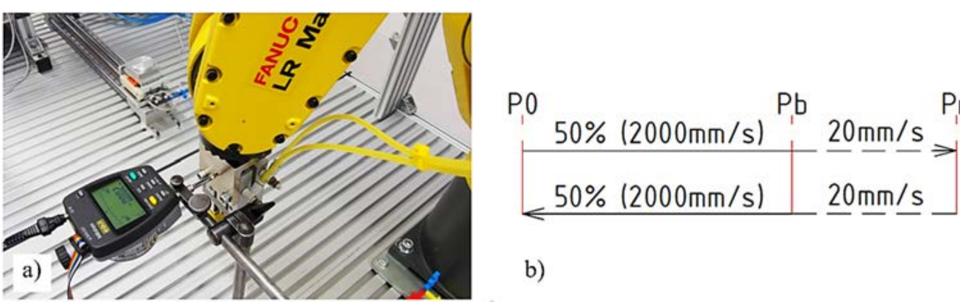

Fig. 4. Measurement methodology with digital indicator

The measurement methodology has been chosen to approximate laser interferometer measurement as closely as possible. However, each of measured axes must consist of five separate measurements to cover points P1 to P5, because the measuring range of the selected indicator does not cover all measured points. The indicator contact is applied to the flange during the measurement by means of which the gripper is clamped on the end of robot´s arm (Fig. 4a). This is the gripper used during work performed by the robot at the assembly workplace. The flange with the gripping head represents a 0.71kg load on the end of robot´s arm. The measurements were made at 50% of the velocity for reasons already mentioned above. The work does not take place at maximum velocity, but even at this velocity, the contact spot of the indicator would be impacted with great force, possibly damaging the measuring system. Therefore, an auxiliary point Pb was placed on the path between P0 and the measuring point Pq, where the velocity decreases to 20mm/s (Fig. 4b).

4 Evaluation of measurement

The AP & RP program was used for the purpose of processing and evaluating measured data presented in this article (Fig. 5), created at our department as a diploma thesis. It is designed for the calculation and processing of pose accuracy and pose repeatability measurements when those are taken with a laser interferometer and a digital indicator. In case of the laser interferometer, measured data are recorded by Renishaw LaserXL program, the output of which is the *.rtl file. This file is loaded into the AP & RP for processing. When measurements are taken with a digital indicator, the above-mentioned program serves not only the purpose of processing measured values but also for the purpose of their receipt via serial communication. In addition, it possible to store the sorted measured values in two file types - Microsoft Excel and a text file.

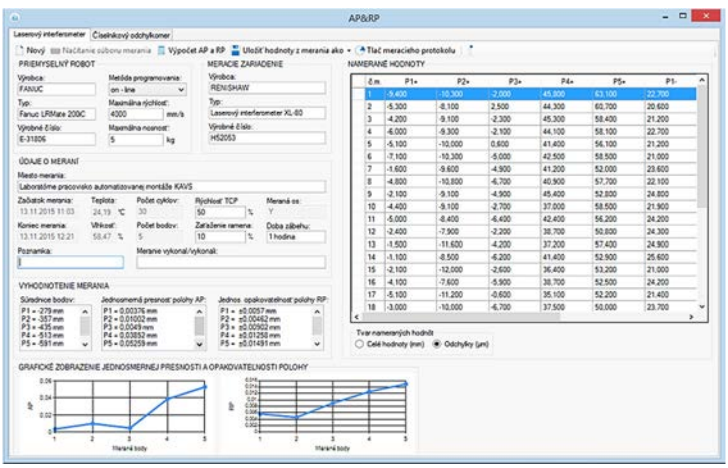

Fig. 5. User interface of AP&RP program

The calculation of pose repeatability both measuring devices is done by the relation (1), based on the sample standard deviation S_{Pq}.

$$RP_{Pq} = \pm 3S_{Pq} = \pm 3\sqrt{\frac{1}{n-1}\sum_{j=1}^{n}\left(Pq_j - \overline{Pq}\right)^2} \tag{1}$$

Where Pq is point of measurement.

4.1 Evaluation of measurement by laser interferometer

The pose repeatability was calculated in the AP&RP program, with the mean of measured values for X, Y and Z axes given in Table 1. The Fanuc LR Mate 200iC manufacturer states the robot's repeatability value ± 0.02mm. This is a certain average repeatability with which the robot should acquire the programmed position in any area of the workspace. If this value is compared with values in Table 1, it is possible to say that calculated repeatability values confirm the value reported by the manufacturer. They are even better.

Table 1. The average value of pose repeatability

Axis of measuring	Axis X	Axis Y	Axis Z
The average value of pose repeatability	±0,016mm	±0,009mm	±0,012mm

Fig. 6, Fig. 7 and Fig. 8 is a graphical processing of measured values for both the positive and negative direction of the robot's TCP point motion. Based on individual charts, and a more detailed view of measurement results can be obtained, and few conclusions can be made.

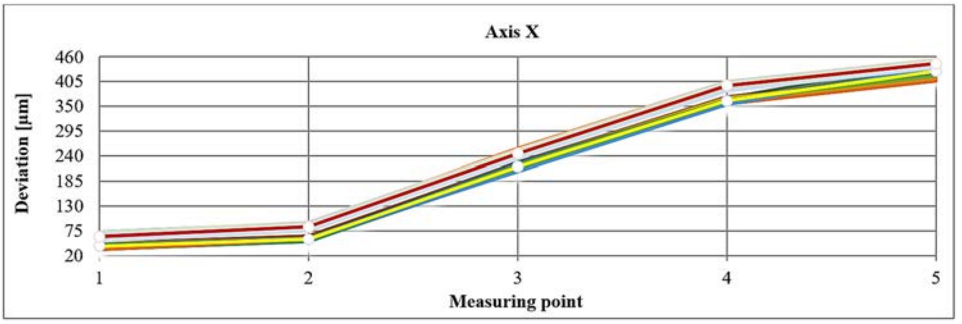

Fig. 6. Graphical processing of X axis measurement

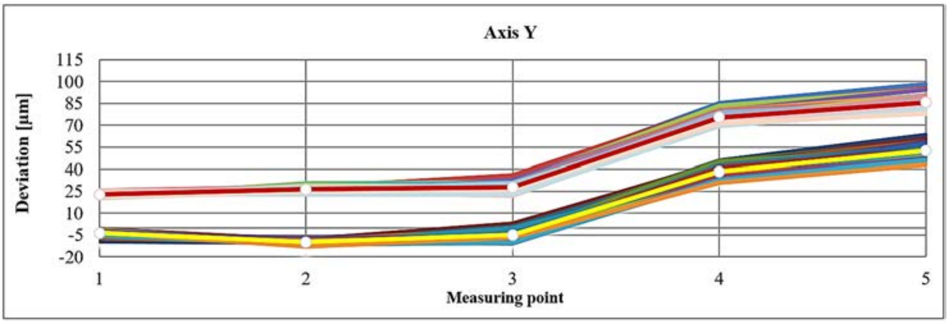

Fig. 7. Graphical processing of Y axis measurement

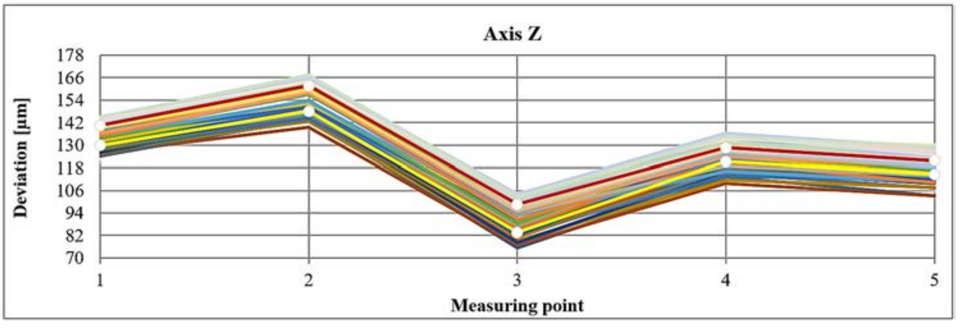

Fig. 8. Graphical processing of Z axis measurement

In case of X and Y (Fig. 6, Fig. 7) axis measurements, the increasing distance of the TCP point of the robot from the beginning of measurement translates into the increasing value of pose repeatability. This trend is likely a result of serial kinematics, where the greater the extension of the robot's arm, the greater the effect of bending forces impacting its end of arm.

This statement is also supported by chart results for the Z axis (Fig. 8), where an upward trend of such significance is not observable.

Since a bidirectional measurement method has been chosen, backlash manifestation in robot's joints can be observed in the graphic processing of measured values. The most significant manifestation of backlash is observable in measurements in direction of the Y axis (Fig. 7). The graph consists of two separate value bundles, the lower of which consists of values obtained in the positive direction of motion (P0 - P6) and the upper bundle represents values obtained in the negative direction of motion (P6 - P0). The difference between mean values of both bundles is caused by the backlash of robot joints. Obtained measurements do not facilitate determination of the backlash value for specific robot joints. This is due to the fact that the motion of the robot arm during the measurement process consists of simultaneous motion of several controlled robot axes. Also, a different expression of the backlash in measured axes X, Y and Z is due to a different range of movements of robot joints.

At the same time, it should be noted that all presented results refer only to the part of the robot workspace in the selected ISO cube and under selected measurement conditions. In other workspace areas, these claims may not apply.

4.2 Evaluation of Measurement by Digital Deviation Meter

The chosen measurement method, in which the indicator contact is applied to the flange of the gripper, does not allow for measurements of the Z axis in the positive direction of motion (measurements with the starting point P0). Conversely, if the negative Z-axis measurement is used with the starting point at P6, the shortness of the magnetic stand used to hold the indicator allows measurements to be made only at points P1 and P2. For this reason, experiments were performed only in the positive direction of X and Y axis movement.

Figures Fig. 9 and Fig. 10 show a graphic comparison of pose repeatability values when measured by the laser interferometer and the digital indicator. Since the indicator was re-set after measuring each of points, it is not possible to evaluate the average pose repeatability on both measured axes. The comparison shows that in both measured axes better repeatability is achieved when digital indicator is employed. This result may be caused by a decrease in the robot's speed at point Pb before reaching the measuring point.

In addition, measured values show the same trend of increase in the value of pose repeatability, depending on the robot's arm extension, as is the case of laser interferometer measurement.

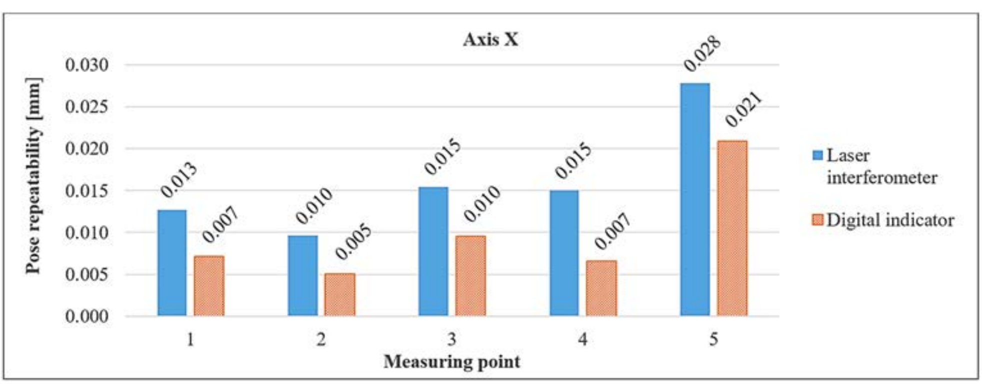

Fig. 9 Comparison of pose repeatability values when measured by the laser interferometer and the digital indicator for X axis

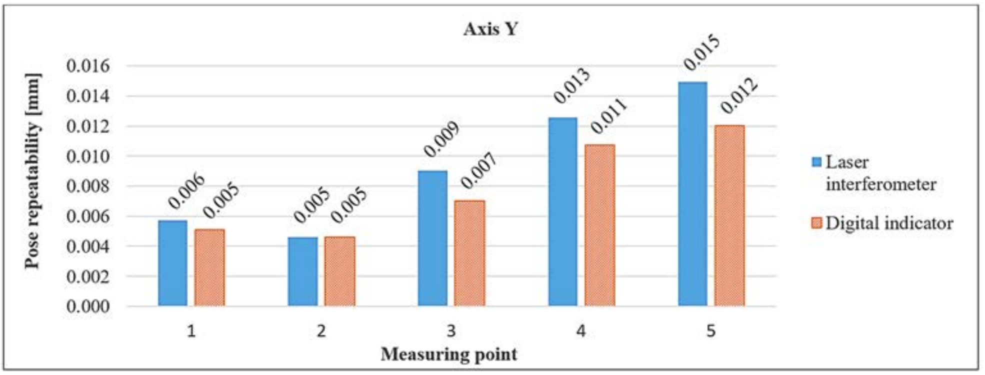

Fig. 10 Comparison of pose repeatability values when measured by the laser interferometer and the digital indicator for Y axis

5 Conclusion

This article presents pose repeatability measurement of the industrial robot Fanuc LR Mate 200iC. The measurement methodology is based on the so-called ISO cube located in the workspace of the robot, in the area of its most common use. Individual experiments are carried out using the laser interferometer and the digital indicator.

Measurement results, obtained by both of measuring devices, were processed in the AP&RP program, developed at the Department of Automation and Production Systems as a diploma thesis. This program was designed to simplify the processing of measured data obtained by laser interferometer and digital indicator.

By evaluating results of pose repeatability, it can be said that the repeatability of the robot at the selected area of its workspace corresponds to the repeatability value stated by the manufacturer (± 0.02mm). At the same time, the trend of repeatability increase was observed, depending on the robot's arm extension, which may be attributed to the bending force acting on the end of robot´s arm. Furthermore, reference is made to the fact that better results are achieved in digital indicator measurements, but those are most likely related to the chosen measurement path. Although the measurement procedure was chosen so that measurement with the digital indicator would be as close as possible to the laser interferometer measurement, certain differences could not have been avoided. Specifically, slowing down of the robot's TCP point prior to position acquisition. It might have been indeed this reduction in velocity that probably caused the difference between two measurements. In order to verify the theory, however, it is necessary to repeat measurements in the future by unifying measurement procedures of two measuring devices.

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