Vladimír TLACH[1], Miroslav CÍSAR[2], Ján STANČEK[3]

Supervisor: Ivan KURIC

INDUSTRIAL ROBOT TESTING WITH THE RENISHAW BALLBAR QC20-W: VERIFYING THE EFFECT OF PROGRAM'S PARAMETER ON THE MEASUREMENT DURATION

Abstract: The paper presents the method of measurement by the Renishaw Ballbar applied on the industrial robot Fanuc LR Mate 200iC. This method can be used to diagnose a change in selected performance criteria of the industrial robot. Regular performance of such measurement is important in applications requiring high repeatability and accuracy. The conducted experiments focus on assessing the influence of the control program's motion command parameter value on the measurement time. The reason for this is the fact that the measurement time is essential requirement for periodic inspection of the industrial robot's technical condition, performed in real conditions of the production process.

Keywords: Renishaw Ballbar, Industrial robot, CNT parameter, Measurement duration

TESTOWANIE ROBOTA PRZEMYSŁOWEGO ZA POMOCĄ SYSTEMU BALLBAR QC20-W: WERYFIKACJA WPŁYWU PARAMETRÓW PROGRAMU NA CZAS POMIARÓW

Streszczenie: W artykule opisano metodę przeprowadzania pomiarów za pomocą komercyjnego systemu Renishaw Ballbar. Pomiary przeprowadzono dla robota przemysłowego typu: Fanuc LR Mate 200iC. Omawiana metoda może być stosowana do diagnozowania robota przemysłowego w wybranych trybach pracy (dla zmiennych kryteriów). Regularne przeprowadzanie takich pomiarów jest ważna dla zapewnienia wysokiej powtarzalności oraz precyzji/dokładności pracy robota. Przeprowadzone eksperymenty dotyczyły oceny wpływu wartości parametrów sterowania ruchem na czas pomiarów. Powodem tychże analiz jest to, iż czas pomiarów jest istotny dla przeprowadzania okresowych inspekcji stanu technicznego robotów przemysłowych – przeprowadzanych w warunkach trwającego procesu produkcyjnego (a zatem w warunkach przemysłowych).

Słowa kluczowe: system Renishaw Ballbar, robot przemysłowy, parametry eksploatacyjne, czas pomiarów

---

[1] inz., Department of Automation and Production Systems, Faculty of Mechanical Engineering, University of Žilina, vladimir.tlach@fstroj.uniza.sk

[2] dr inz., Department of Automation and Production Systems, Faculty of Mechanical Engineering, University of Žilina, miroslav.cisar@fstroj.uniza.sk

[3] dr inz., Department of Automation and Production Systems, Faculty of Mechanical Engineering, University of Žilina, miroslav.cisar@fstroj.uniza.sk

1. Introduction

At present, industrial robots are increasingly used in applications requiring high repeatability. These are precise assembly tasks or pre-machining application. At the same time, there is an increasing pressure on the reduction of cycle times in CNC machine tools. In addition to optimizing the machining process itself, it is possible to reduce this time by moving the final measurement operations outside the machine. The role of measurement can then be taken over by an industrial robot. [1] In such applications, it is very important to carry out periodic measurements of the industrial robot to check its technical condition. The long-term monitoring of the industrial robot's condition may facilitate planning of its maintenance or maintenance shutdown. This can easily prevents occurrence of collisions, malfunction of the robot, or production of defective products resulting from the deterioration of the performance criteria. [2]

The performance criteria of an industrial robot are defined by the ISO 9283 standard. However, this standard has several shortcomings, including the missing specification of the measuring device for testing the individual performance criteria. Measurement of performance criteria is a complex task with a number of methods and different approaches to measurement requirements [3, 4]. Several measurement methods and devices have been presented in the field-specific papers, such as digital indicator [5,6], laser interferometer [7,8], laser tracker [9,10], and camera systems [11,12]. Another method is based on measuring the change in the radius of a circular path, using a ballbar device [13,14]. This device is used as the standard tool for measuring the performance criteria of CNC machine tools. Its main advantage is that it can perform fast and simple measurements. The obtained data are processed in the Ballbar 20 software and used to calculate the total machine accuracy value in accordance with effective international standards. [2, 15] However, its use on an industrial robot requires special approach to measurement and data analysis. This stems from the fact that the circular motion of the machine tool is generated by simultaneous movement of two perpendicular linear axes, which is not possible for industrial robots with serial or parallel kinematics. Because a modification of the measurement methodology for use on an industrial robot is necessary, the amount of information thus obtained is not the same as with the CNC machine tools. Nevertheless, we can easily and quickly monitor the technical condition of industrial robots with such measurements.

This article presents a measurement application using Renishaw Ballbar on an industrial robot Fanuc LR Mate 200iC. This is an industrial robot of standard design with six controlled axes, located in the laboratory at the Department of Automation and Production Systems, University of Žilina. The conducted experiments focus on assessing the effect of the change in the motion command parameter (in the Fanuc robot control program) on the measurement time. The result is determination of a suitable value of the above-mentioned parameter, at which the performance of measurement is recommended and the conclusions derived therefrom are the basis for carrying out further tests.

2. Method of measurement

The measuring assembly was made up of the aforementioned industrial robot Fanuc LR Mate 200iC and the Renishaw Ballbar QC20W diagnostic system, the base of which is a precise linear sensor with precise steel ball on the ends. They fit into magnetic mounts, one located on a magnetic center pivot clamped onto the table. The second magnetic mounts (magnetic tool cup) was clamped at the end of robot's arm by means of an extension attachment. Unlocked magnetic center pivot have three degrees of freedom what allows simple aligning of mounts with setting ball in order to precisely set center of measuring circle. [4] The magnetic center pivot represents a fixed point of rotation when circular paths are completed. Using various extension attachments, measurements can be performed on radii from 50 to 600 mm. [2] In our case, a single radius of 100mm was used and the measurement was performed in the XY plane with respect to the World Coordinate System (WCS) of the robot. The end of robot's arm was loaded with 360g (7.2% of the robot's total load capacity) during the measurement.

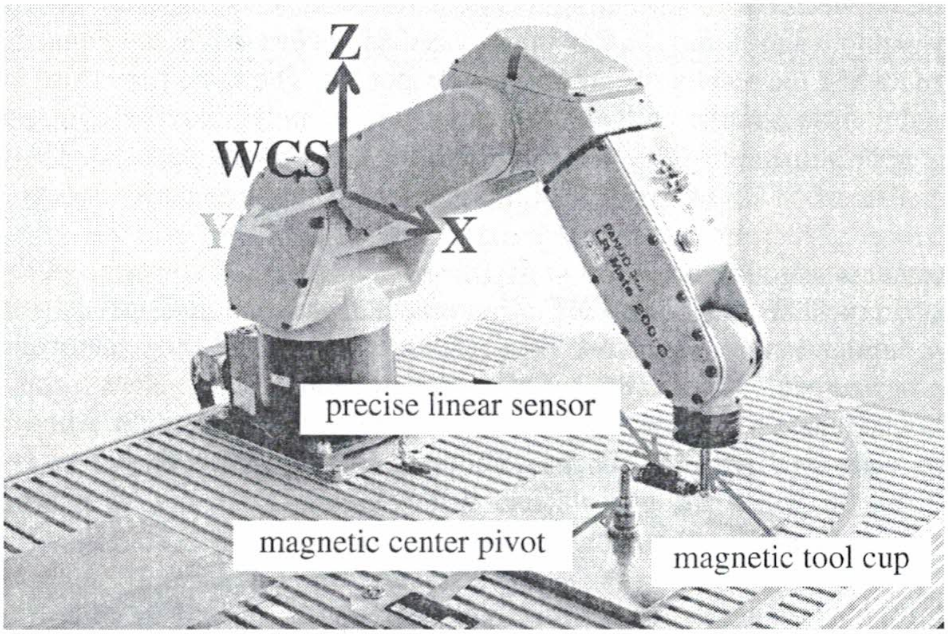

Figure 1. Measuring assembly

The Ballbar measurement is based on the measurement of the radius deviations between the programmed and the actual radius of the circular path of the robot‘s end segment. In the Fanuc's programming environment, the circular path can only be created using two semicircles. During the execution of the path thus created, the TCP point of the robot stops at its end point after describing the first semicircle. It then re-starts to describe the second semicircle. A smooth path can be achieved by using the endpoint circumvention function, but in this case, the circular path is deformed to an elliptical one. The circular path made up of two semicircles is therefore inappropriate for Ballbar measurement.

In previous experiments performed on a CNC machine tool, two circular paths were compared, generated by two methods. The first circle was created using standard circular interpolation commands.

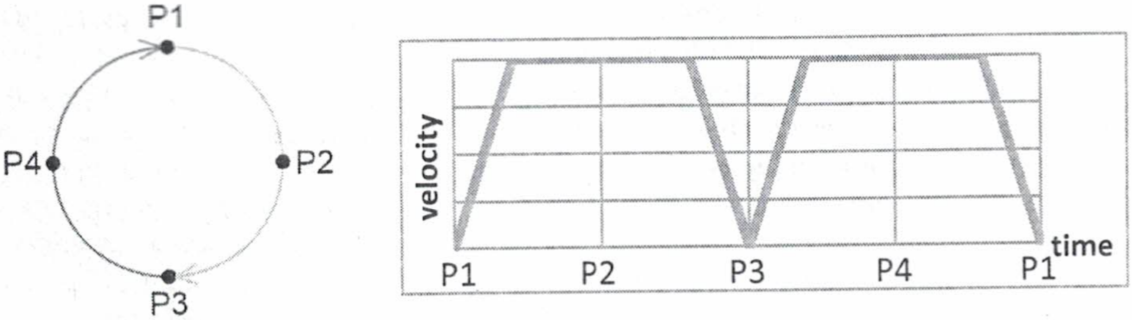

Figure 2. The circular path created in Fanuc programing environment

The second circular path was formed by 512 points joined by lines. By comparing the measurement results of both these path, showed negligible difference similar to the deviation between two consecutive identical measurements. Measurement with the circular path created in the same manner was also performed on the Fanuc LR Mate 200iC robot and the results are published in paper [2]. The same paper also describes polygonal pseudo circular path experiments, with the polygon representing the most accurate approximation of the circle required for Ballbar measurement. The polygon used consists of 512 points, the maximum length of the line between two adjacent points being 1.2281 mm.

Measurements were performed to verify the effect of the CNT parameter change on the measurement results. The CNT (Continuous Termination Type) is part of the motion command in the robot control program, which defines the circumvention size of the programmed point (Figure). This parameter can assume values from 0 to 100. The CNT100 stands for the largest circumvention and vice versa when defining a motion command with CNT0, the TCP point of the robot will stop at individual points [2].

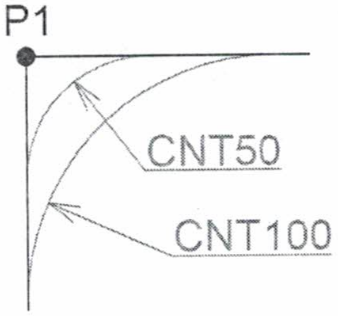

Figure 3. Method of circumvention a programmed point using CNT function

Conducted laboratory tests consisted of five series of measurements, each series performed at a different CNT parameter (CNT100; CNT75; CNT50; CNT25 and CNT5 respectively). At the same time, five reps were performed in each series. In all measurements in each series, the maximum linear velocity, which is 4000 mm / s for this robot model, was defined. The measurements were made on a radius of 100 mm and the center of the circle was at the coordinates {X = 200; Y = 500; Z = -179}.

3. Measurement results

The main parameter in the tests performed was time. The time was measured using the function entered directly in the Fanuc robot control program, which eliminated the operator's influence on the values obtained and also minimized further delays. The measured time represents the time required to complete two circular paths in one direction. In Table , two effects of CNT reduction can be observed.

Table 1. The time required to complete two circular paths in one direction

Measurement number	Time [s]				
	CNT100	CNT75	CNT50	CNT25	CNT5
1	16.77	49.54	95.84	167.77	249.86
2	16.77	49.54	95.87	167.66	249.81
3	16.77	49.54	95.92	167.70	249.70
4	16.77	49.55	95.87	167.61	249.85
5	16.77	49.54	95.93	167.78	249.70

The lower the CNT value, the more time was needed to complete two circular paths in one direction. At the same time, with the CNT100, the time for all five repeated measurements remained unchanged. With CNT75, there was only one change in the value, which could be attributed to the measurement error, but starting from CNT50, the measured time values became scattered. In our opinion, this phenomenon is due to the fact that the lower the point circumvention, the closer is the TCP point proximity to the programmed point, thus requiring the reduction of speed and repeated acceleration. With such a large number of points (512) used, the rate of velocity change is very high, resulting in not only an increase in time, but also oscillation of the end of robot's arm. The vibrations indeed constitute another observed manifestation of low CNT values. They can also be the cause of scattering of measured values at CNT50 to CNT5. In addition, the open kinematic chain of robot also contributes to generation of vibrations.

Another finding is the significant difference between the actual velocity of the TCP point of the robot and the velocity specified in the control program. As already mentioned, the maximum linear velocity was defined for each series. Table shows that the lower the CNT value, the lower the measured velocity values.

Table 2. The effect of the CNT value change on the velocity of the robot's TCP

Measurement number	Velocity [mm/min]				
	CNT100	CNT75	CNT50	CNT25	CNT5
1	4659.4	1542.0	790.7	451.2	302.7
2	4655.9	1541.0	791.7	451.7	302.6
3	4657.7	1541.0	791.5	451.2	302.7
4	4657.7	1540.5	791.2	451.5	302.7
5	4655.9	1541.5	791.2	451.2	302.6

The velocity values given were obtained from Renishaw's Ballbar 20 software for the analysis of measured data. The increasing time required to complete two circular paths directly affects the velocity at which the TCP point of the robot moves. This confirms our hypothesis that the stated maximum velocity is only the theoretical velocity obtained from the robot's mathematical model and from the maximum angular velocities of the individual robot joints.

The Ballbar 20 software provides several diagnostic values based on the analysis of the obtained chart and measured data. For industrial robot tests, in order to monitor their status in the long term, the value of the circularity is of interest from the diagnosed values. This value represents the difference between the largest and smallest radius recorded by the ballbar when completing the circular path. This value is related to the accuracy of the machine in terms of the higher the circle value, the worse the machine accuracy. The circularity value obtained from regular measurements done on the same positions of industrial robots can tell whether the accuracy of the robot, as well as its repeatability, is deteriorating. The reason is that the repeatability is expressed as the ability of the robot to repeatedly acquire the same TCP point position.

In Figure , it is possible to see the development of the circularity value in repeated measurements and change of the CNT parameter. Unlike the time value, which the shortening of the CNT impacted in a major way, it is not possible to see any certain trend in development of circularity resulting from the change in CNT. Based on this, it can be said that changing the CNT parameter does not have a significant effect on the circularity value.

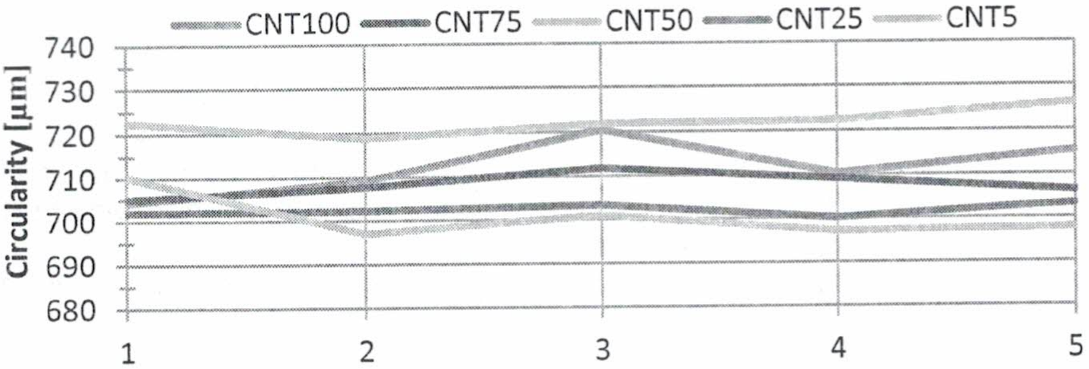

Figure 4. The effect of the CNT value change on the circularity value

4. Conclusion

This paper presents the method of measuring the performance criteria of the Fanuc LR Mate 200iC industrial robot using the diagnostic system Renishaw Ballbar QC20-W. The said method is based on a polygonal pseudo circular path that represents the most accurate approximation of a circle required for a Ballbar measurement. This procedure allows not only making measurements on Fanuc robots, but can also be a universal method applicable to industrial robots of other manufacturers. At the same time, due to the Ballbar high accuracy and the limited measuring range (± 1 mm), it may not be possible for this device to perform measurements on less precise, larger types of robots. In such cases, the presented method offers the possibility to modify the control program so that measurements can be performed. This modification lies in decomposition of the measured profile by Fourier transformation and is further described in our paper [2].

The conducted experiments showed a significant influence of the change in the motion command parameter on the time of measurement and the velocity of the TCP point of the robot completing the circular path. Where time is concerned, at CNT100, it took 16.77 seconds to complete two circular paths in one direction. Gradual reductions in the parameter value result in considerable increase in time to as many as 249.78 seconds for CNT5. This considerable influence of the CNT parameter on the time of measurement can be seen in Figure . We also observed the same effect concerning the robot TCP point velocity. Conversely, in case of the circularity value, which is one of the diagnostic values analysed by the Ballbar 20 software, the change therein has no effect on the CNT parameter.

Based on the presented results, it is possible to recommend further measurements to be done with the CNT100 parameter value, i.e. its maximum. Because lowering this value will not increase the accuracy of the measurement, on the contrary, the measurement time will be considerably longer and the results may be affected by any vibrations we observed at low CNT values. Moreover, in order to practically use the proposed methodology for the long-term monitoring of the condition of an industrial robot, it must meet two basic criteria, namely simplicity and speed. Subsequently, performance of regular tests and collection of sufficient amount of data will facilitate making predictions regarding change in the observed characteristics of the industrial robot and thereby bring financial savings in terms of its maintenance.

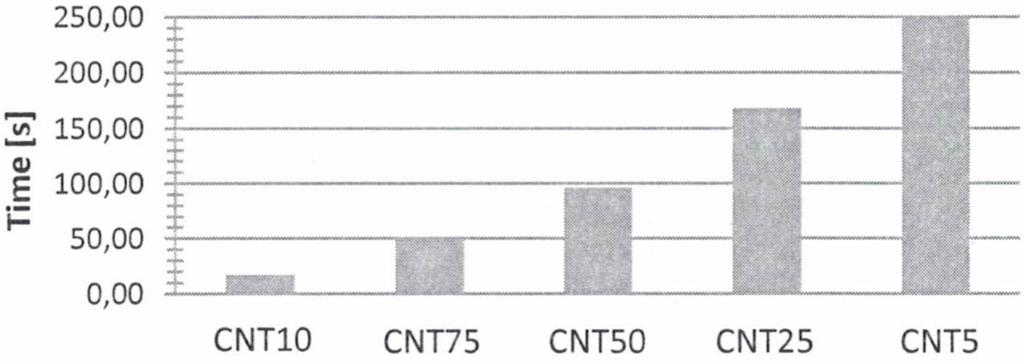

Figure 5. The effect of the CNT value change on the measurement time

Acknowledgement: This article was made under the support of APVV project – APVV-16-0283 Research and development of multi-criteria diagnosis of production machinery and equipment based on the implementation of artificial intelligence methods.

References

1. BLUM - Novotest, s.r.o.. Robotické meranie pomocou sondy BLUM BG60. In *Strojárstvo / Strojírenství*, ISSN 135-2938, 2017, vol. 21, no. 5, pp. 111
2. Tlach V., Cisar M., Kuric I.: Meranie charakteristík polohy priemyselného robota. In *Údržba: časopis pracovníkov údržby*, ISSN 1336-2763, 2017, vol. 17, no. 3, pp. 8-10

3. Kumičakova D., Tlach V, Cisar M.: Testing the performance characteristics of manipulating industrial robots. In *Transactions of the VŠB - Technical University of Ostrava: mechanical series*, 2016, vol. 62, no. 1, pp. 39-50
4. Císar M., Zajačko I, Kuric I.: Diagnostics based on poositioning performance during circular motion. In *Inżynier XXI wieku: projektujemy przyszłość*, ISBN 978-83-65182-51-7, pp. 536-542
5. Şirinterlikçi A., Tiryakioğlu M., Bird A., Harris A., Kweder K.: Repeatability and Accuracy of an Industrial Robot: Laboratory Experience for a Design of Experiments Course. In *Technology Interface Journal*, 2009, vol. 9, no. 2
6. Brethé J., Lefebvre D.: Risk ellipsoids and granularity ration for industrial robot. In *International Journal of Factory Automation Robotics and Soft computing*, 2007, Vol. 2, pp. 93-101
7. Slamani M., Nubiola A., Bonev I. A.: Assessment of the positioning performance of an industrial robot. In *Industrial Robot: An International Journal*, 2012, vol. 39, pp. 57-68
8. Slamani M., Bonev I. A.: Characterization and experimental evaluation of gear transmission errors in an industrial robot. In *Industrial Robot: An International Journal*, 2013, vol 40, pp. 441-449
9. Nubiola A., Bonev I. A.: Absolute calibration of an ABB IRB 1600 robot using a laser tracker. In *Robotics and Computer-Integrated Manufacturing*, 2013 vol. 29(1), pp. 236-245
10. Newman W. S., Birkhimer C. E., Horning R. J., WilkeyA. T.: Calibration of a Motoman P8 robot based on laser tracking. In *Robotics and Automation, 2000. Proceedings. ICRA'00. IEEE International Conference on.* 2000, vol. 4, pp. 3597-3602
11. Józwik J., Ostrowski D., Jarosz P., Mika D.: Industrial robot repeatability testing with high speed camera Phantom v2511. In *Advances in Science and Technology Research Journal*, 2016, vol 10, pp. 86-96
12. Abderrahim M., Khamis A., Garrido S., Moreno L.: Accuracy and Calibration Issues of Industrial Manipulators. In *Industrial Robotics- Programming, Simulation and Applications*. 2007, pp. 131-146
13. Nubiola A., Slamani M., Bonev I. A.: A new method for measuring a large set of poses with a single telescoping ballbar. In *Precision Engineering*, 2013, vol. 37, pp. 451-460
14. Slamani M., Nubiola A., Bonev I.A.: Effect of servo systems on the contouring errors in industrial robots. In *Transactions of the Canadian Society for Mechanical Engineering*, 2012, vol. 36, pp. 83-96
15. QC20-W wireless ballbar system description and specifications. (2013) [online] Available on Internet: www.renishaw.com/media/pdf/en/bc37e3f237284417baa57889d207cf97.pdf