www.czasopisma.pan.pl PAN www.journals.pan.pl

ARCHIVES
of
FOUNDRY ENGINEERING

ISSN (2299-2944)
Volume 18
Issue 2/2018

187 – 190

DOI: 10.24425/122526

34/2

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

Increasing the Capability of the Process of Placing Inserts in Foundry Moulds

J. Jaworski, R. Kluz *, T. Trzepieciński
The Faculty of Mechanical Engineering and Aeronautics, Rzeszow University of Technology,
al. Powstańców Warszawy 8, 35-959 Rzeszów Rzeszów, Poland
* Corresponding author. E-mail address: rkktmiop@prz.edu.pl

Received 06.04.2018; accepted in revised form 19.06.2018

Abstract

This article discusses the issue of the preparation of the foundry moulds with the use of an industrial robot. The methodology is presented for the determination of the process capacity index for placing inserts with flat and cylindrical faces. On the basis of the relationships developed, the process capability indices were determined at various points in the workspace, which are characterised by different values of the repeatability positioning error. It was shown that the value of the process capacity index can be increased by the selection of a suitable location for the process of placing the inserts in the workspace. It should also be noted that the value of the process's capability index depends on the selection of the place in the robot workspace where the process is carried out. Implementation of the joining process at an analysed point in the robot workspace leads to an increase of the process capability index MC_p for inserts with flat faces up to 1.1 (+4.5%) and for inserts with cylindrical faces up to 1.3. This results in an increase of 13% to a level corresponding to the global standard for process reliability (MC_p = 1.33).

Keywords: Mechanisation and automatisation of casting processes, Foundry robotic automation, Product development, Process capability indices

1. Introduction

Current trends in the development of industry are associated with the robotisation of technological processes [1]. Industrial robots have been successfully used in a wide range of industries such as welding technology, assembly technology and foundry engineering [2, 3].

In most cases, the robots working in the foundry industry do not have high positioning accuracy. They are used for relatively simple operations such as removing a solidified cast from a foundry mould or the casting cooling process. An exception, however, is the process of placing inserts into the foundry mould. In this case, the robot must be precise enough to properly orient and place the insert [2]. An important issue in the scope of operation of robotic casting work-stands is the problem of ensuring the required level of reliability, which can be obtained by ensuring appropriate values of the process capability index. The investigation of process capability consists in relation to the process of spreading to the width of the assumed tolerance range. In the case of the process of placing the steel inserts in the mould (which is an example of the assembly of typical machine parts), this investigation consists in the evaluation of errors generated by the robot (linear and/or angular). Next, the errors are compared with the tolerance range of the relative displacement or the torsional deflection of the inserts' axes [4, 5].

There are many methods for determining the multidimensional capability indices which can be found in literature [5, 6]. In most cases, they consist in comparing the volume or area of dispersion of the feature examined to the volume or range of tolerance [6]. The disadvantage of these methods is primarily the high labour consumption resulting from the complexity of the calculations necessary. The results obtained in many cases may not reflect the actual nature of the errors made by the robot which leads to incorrect results. Therefore, this paper proposes a method for determining the process capability indices, which takes into account the specific conditions during its realisation. The method developed is simple enough to be applied in real production conditions using commercially available software.

2. Investigation of the process capability

The investigation of the process capability of the placing of the inserts inside the casting mould is a difficult and laborious task. The tasks related to the robotisation of the process of placing the inserts can be facilitated by decomposing the sequence of placing according to the shape of the insert face. From this point of view, the process of placing the typical and most widespread type of insert can be considered as a typical series of operations whose purpose is to join parts with a flat and a cylindrical face [7].

The classical methods for determining the values of the process capability indices for the flat face depend on the relationship of the modified tolerance range of the relative displacement of the insert axis to the form (expressed in the form of an ellipse surface inscribed into a rectangle) of the process spreading field. In the case of the inserts with a cylindrical face, the tolerance for mutual displacement of the insert axis with respect to the mould can be expressed in the form of a roll volume or surface area of its projection on a plane perpendicular to the axis of the joined parts [5]. The values of the process capability index MC_p obtained correspond to the probability of the event that the random variable of the robot error will be within the range of the permissible displacement of the axis of the insert and the mould (in the clearance range) (Fig. 1).

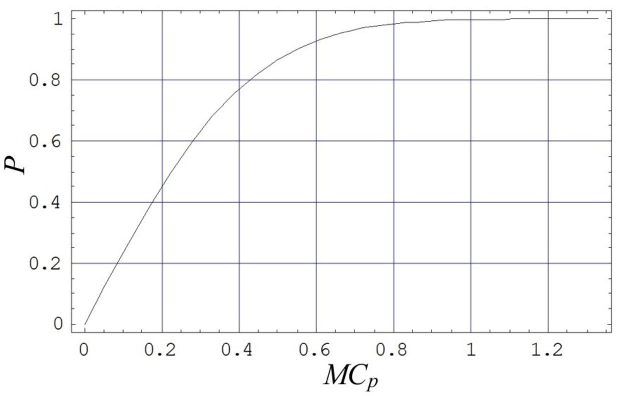

Fig. 1. The relationship between the value of the MC_p index and the probability of the joining of parts

The calculation of the probability of the correct placement of the insert enables the unambiguous determination of the value of the process's capability and its assessment. The probability of placing the inserts in the mould can be determined by integrating the function of the probability density $f(\Delta x, \Delta y)$ describing the robot error in the area of the circle with the radius r corresponding to half of the joint clearance (0.5 δ) (Fig. 2).

$$P = \iint_{\Delta x^2+\Delta y^2 \le (0.5\delta)^2} f(\Delta x, \Delta y)\,dxdy \tag{1}$$

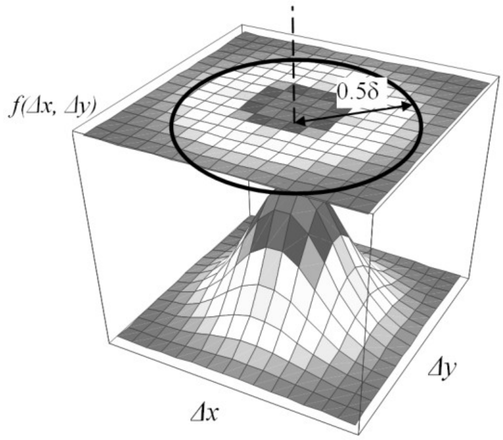

Fig. 2. Method of determining the probability of placing cylindrical inserts

When considering the placing of inserts with flat faces, due to the lack of symmetry of the parts, the robot error should be corrected for the linear errors of the insert (l_i), thus determining a new random variable $f(\xi\Delta x, \xi\Delta y, l_i)$ (Fig. 3). Then, the probability of the connection P can be determined by integrating the density function in an area corresponding to the area of a rectangle with lengths of sides corresponding to the joint clearance in the direction of the x- and y-axes, δ_x and δ_y, respectively:

$$P = \int_{-0.5\delta_x}^{0.5\delta_x} \int_{-0.5\delta_y}^{0.5\delta_y} f(\xi_{\Delta x}, \xi_{\Delta y})\,d\xi_x d\xi_y \tag{2}$$

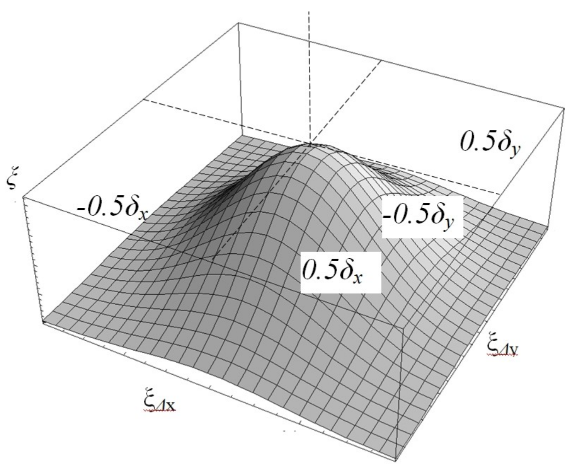

Fig. 3. The method of determining the probability of placing the flat inserts

3. Errors of an industrial robot

The position error of the parts being connected is a random variable that depends on the repeatability positioning error of the assembly robot and errors in the actuating devices. Typical devices included in the technological equipment of the robots include industrial grippers, automatic tool changing devices and anti-collision devices. The results of the experiments conducted showed [7] that the relative displacement of the part axis $f(\Delta x, \Delta y)$ and the error corrected by the linear dimensions of insert $f(\xi\Delta x, \xi\Delta y, l_i)$ can be characterised by a random variable subjected to the law of the normal probability distribution, with a probability density f determined by Eq. (3). The matrix of the expected values $\mu^T = [\mu_1, \mu_2]$ corresponds to a static error of the robot and the covariance matrix Λ:

$$f = \frac{1}{2\pi\sqrt{|\Lambda|}} \exp\left[-\frac{1}{2}(x-\mu)^T \Lambda^{-1}(x-\mu)\right] \tag{3}$$

where: Λ - covariance matrix, μ^T - matrix of expected values.

Table 1 shows the results of the measurements of the repeatability positioning of a Mitsubishi RV-M2 robot. The measurements were repeated 30 times using displacement inductive sensors GT61 in two sample locations in the robot's workspace. On this basis, the values of the standard deviations were determined by the errors, in the directions of the axes x and y of the coordinate system adopted. The error values of the linear displacements of inserts $f(\Delta x, \Delta y)$ were calculated by evaluation of the displacements of the centre of the measuring block (50×50×50 mm). The errors of displacements $\Delta\xi_x$ and $\Delta\xi_y$, which take into account the linear dimensions of the insert, were determined by measuring the position of the measuring block near its edge. In this way, the effect of the errors of the robot orientation were taken into account. The values of the standard deviation of results obtained are shown in Table 1, while Figs. 4 and 5 present the results of measurements recorded in each cycle for selected points in the robot's workspace (Table 1, 1st row).

Table 1.
Repeatability positioning errors of robot

Joint coordinate, rad	Standard deviation of variable $f(\Delta x, \Delta x)$		Standard deviation of variable $f(\Delta\xi_x, \Delta\xi_y)$	
	$\sigma_{\Delta x}$, mm	$\sigma_{\Delta y}$, mm	$\sigma_{\Delta\xi x}$, mm	$\sigma_{\Delta\xi x}$, mm
$q_1 = 1.3963$ $q_2 = 0.3839$ $q_3 = 1.2217$ $q_4 = 0.7330$	0.016	0.023	0.018	0.025
$q_1 = 1.0472$ $q_2 = 1.0472$ $q_3 = 1.2217$ $q_4 = 1.3963$	0.015	0.015	0.017	0.018

Figure 6 shows a histogram of a random variable of the repeatability positioning error of the robot. The correlation coefficient between the variables x and y is equal to $\rho_{xy} = 0.132$.

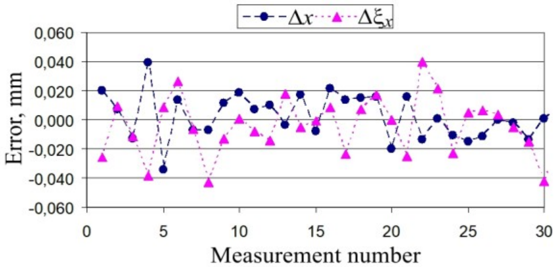

Fig. 4. Errors of the Mitsubishi RV-M2 robot in the x-axis direction

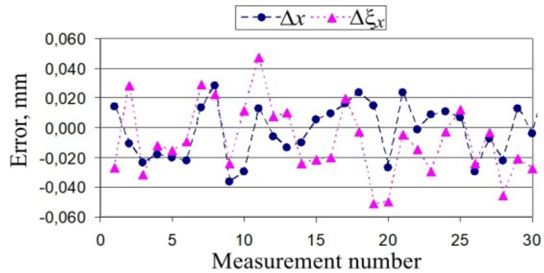

Fig. 5. Errors of the Mitsubishi RV-M2 robot in the y-axis direction

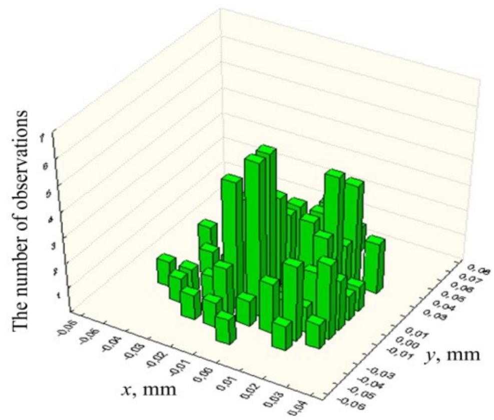

Fig. 6. Histogram of the error of the random variable $f(\Delta x, \Delta x)$

4. Determination of the process capability of placing the inserts

In order to determine the probability of correct realisation of the process of placing the inserts, it was assumed that assembly can take place at the point of the robot workspace which is characterised by a repeatability positioning error determined on the basis of the results of measurement. It was assumed that the value of clearance of inserts with a flat face is $\delta = 0.18$ mm. In the case of the inserts with cylindrical faces, the clearance value in the x- and y-axis directions of the adopted coordinate system is the same and is also equal to $\delta = 0.18$ mm. On the basis of Eqs. (1) and (2), the probability of connecting the parts and the corresponding value of the MC_p index (Fig. 1) were determined. In the case of cylindrical inserts, the probability value was $P = 0.9993$, which corresponds to a value of $MC_p = 1.15$ (Fig. 7). In the case of the inserts with a flat face, the probability value is lower by 0.2%, however, due to the character of dependence of the probability *vs.* the value of the MC_p index, this results in a reduction of probability value by 8.5%. The smaller value of the MC_p index for inserts with a cylindrical face is caused by the influence of the orientation errors of the insert being placed, which in the case of cylindrical (rotational) parts do not affect the process.

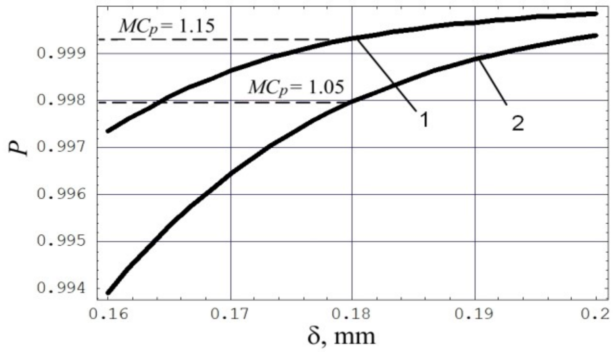

Fig. 7. Effect of the clearance δ on the probability of placing the inserts with (1) cylindrical and (2) flat faces

The inserts with flat faces may also have different clearance values on the axis directions of the adopted coordinate system ($\delta_x \neq \delta_y$) (Fig. 8). Where the accuracy of placing the insert is only required for one of the directions of the adopted coordinate system, e.g. in the direction of the x-axis, then the value of the MC_p index increases by 52.3% to a value of 1.6.

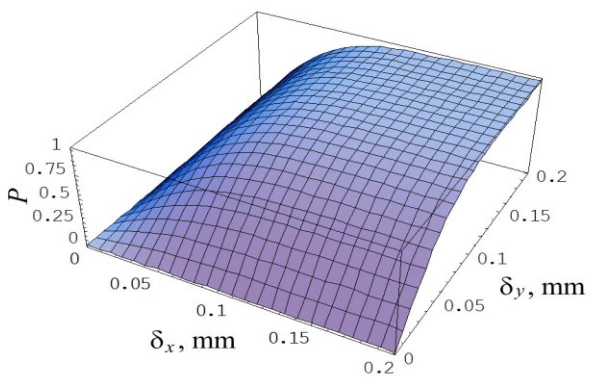

Fig. 8. Probability of placing the inserts with a cylindrical face as a function of the joint clearances δ_x, δ_y

It should also be noted that the value of the process's capability index depends on the selection of the place in the robot's workspace where the process is carried out. Carrying out the joining process at the point characterised by the error value presented in Table 1 (2nd row) results in an increase in the process capability index MC_p up to 1.1 (+4.5%) for the inserts with flat faces and up to 1.3 for the inserts with cylindrical faces. It results in an increase by 13% to a level corresponding to the global standard for process reliability ($MC_p = 1.33$).

5. Summary

Existing quality management standards demand that companies continuously improve the quality of processes carried out. An indispensable element of control and improvement of the quality of processes is the process capacity index. Due to the complexity of placing inserts in casting moulds, a significant number of companies use a simplified analysis of determination of capability of the joining process and assembly stand. Such an approach may lead to incompatibilities in the course of the processes and generate additional costs related to shutdown. The method presented in the work takes into account the possibility of stochastic dependence between variables, which is the main reason for the inaccuracy of simplified methods. The method developed allows one to determine the process capability in an arbitrary location in the robot's workspace and choose the place in the stand workspace where it is to be carried out.

References

[1] Moser, P., Isaksson, O.H.D., & Seifert, R.W. (2017). Inventory dynamics in process industries: an empirical investigation. *International Journal of Production Economics*. 191, 253-266. DOI: 10.1016/j.ijpe.2017.06.019.

[2] Zdanowicz, R. (2003). *Automatization of Technological Processes*. Gliwice: Publishing House of the Silesian University of Technology. (in Polish).

[3] Matsas, E., Vosniakos, G.C. & Batras, D. (2018). Prototyping proactive and adaptive techniques for human-robot collaboration in manufacturing using virtual reality. *Robotics and Computer-Integrated Manufacturing*. 50, 168-180.

[4] Shinde, R. L. & Khadse, K. G. (2009). Multivariate process capability using principal component analysis. *Quality and Reliability Engineering International*. 25(1), 69-77. DOI: 10.1002/qre.954.

[5] Kwon, H.J. & Kwon, H.K. (2018). Computer aided engineering (CAE) simulation for the design optimization of gate system on high pressure die casting (HPDC) process. *Robotics and Computer-Integrated Manufacturing*. (accepted for publication). DOI: 10.1016/j.rcim.2018.01. 003.

[6] Shen, P. & Li, H. X. (2017). The consistency control of mold level in casting process. *Control Engineering Practice.* 62, 70-78. DOI: 10.1016/j.conengprac.2017.02. 011.

[7] Kluz, R. (2009). Marking the optimum configuration of robotized assembly stand. *Archives of Mechanical Technology and Automation*. 29(2), 113-122.