Capability Assessment of Robotized System for Casting Measurement

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Abstract

Assurance of required casting quality is an important element of the manufacturing process. The control should be realized fast, accurately and cheap. These requirements may be fulfilled by application of an industrial robot to realize the measuring process. In the article the methodology of capability assessment of robotized system to control specified casting feature based on analysis of repeatability and reproducibility is presented. It is demonstrated that industrial robots produced serially have the accuracy allowing for their application to control process of both die-casting and pressure casting dimensions.

1. Introduction

Quality control is the significant element of manufacturing process and should be performed in sufficiently accurate and fast way. Nowadays the simplest and the most popular control method of casting depends on accurate measurement and assessment by qualified personnel. For that purpose the simple measurement instruments as slide calipers, micrometers and masters for comparative control (patterns) are used. Casting control also depends on visual assessment of performance correctness or a place of element e.g. in prepared master or the die so that it can be possible to determine correctness of its preparation [1-5]. The manual methods are simple and cheap. Their main disadvantage is long time of realization and small productivity. The probability of mistakes increases in comparison with the automatized assessment of castings.

Automatization of measurements most often is connected with the usage of a coordinate measuring machine or the industrial robot. The coordinate measuring machine allows for spatial measuring (3D) of complex elements. Most often this is equipped in three measuring systems to measure in three coordinate axes XYZ and a probe for localization of element surface position. Application of drives with high precision and computer measuring system makes it possible to realize fast measurements characterized by very high accuracy and objectivity. The great advantage of application of this measuring technique is realization of measurements of different parts with complex shape, which cannot be measured using basic measuring instruments. However in case of castings subjected to further processing, the usage of coordinate measuring machine is inadequate taking into consideration cost and required measurement precision (50–400 μm) [6]. The alternative solution

is the industrial robots which guarantee a similar functionality. They are characterized by increased speed of arm motion (up to 0.5 m/s) for the coordinate machines. They can move with several times higher acceleration (up to 4m/s), increasing considerably productivity of measuring system.

The basic units of robotized measuring position are [6]:
- carrying unit assuring the possibility to move the measuring head in axes X, Y i Z,
- measuring system – to measure the distance between points determined by contact of gauge plunger of the probe and surface of measured part,
- measuring head (probe) for localization of measuring points, which are the base for determination of dimensions of parts,
- computer with accessories including software for processing of measurements results for required form.

Accuracy of robotized measuring stands has to correspond to specified requirements in order to cost of castings was reliable. Generally index of suitability of measurement system (measurement system capability) is relation between uncertainty of measurement and tolerance of controlled feature. In industrial plants, especially in automotive industry, the suitability criterion is determined on the basis of the results of both repeatability and reproducibility analyses of measurement results (R&R). This method was proposed by concerns of Ford, Chrysler and General Motors and it was implemented as a set of quality system requirement according to QS 9000 standard [7]. After suitable modifications the QS 9000 standard may be also used for assessment of robotized measurement system. This problem is discussed in further part of the article.

2. Repeatability of measurement system

To control the repeatability of the measurement system, the analysis of potential sources of measurement uncertainty in the context of measurement components have to be done. If the real value of measured parameters is marked by x_p then the result of measurement will be involved by systematic and random error of measurement instrument and the robot, according to the equation:

$$W = x_p + \Delta_{pp}x + \Delta_{pr}x + \Delta_s x \qquad (1)$$

where: $\Delta_s x$ – systematic error of measurement,
$\Delta_{pp}x$ – random error of measuring instrument (measuring head)

The first component of measurement uncertainty is the component of dispersion of the measured results observed in conditions of measurement realization. The measurement of the first component of measurement uncertainty is experimental standard deviation σ_{pp} determined on the basis of the series of measurements according to the equation:

$$\sigma_{pp} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_{\acute{s}r})^2}{n-1}} \qquad (2)$$

According to the method of localisation of measuring points, the measured heads are divided into contactual and one of these heads are both impulse (generated zero-one signal) and measured (generated values of point coordinates) heads as well as non-contactual heads e.g. laser triangulational heads. These heads are characterized by high precision. Uncertainty of impulse heads measurements is in the range of 0.2-2 μm, whereas the uncertainty of laser heads is in the range of 0.5-4 μm [6]. Measurement uncertainty of heads is most often small percentage of measured system error.

The second component of measurement uncertainty is the component of repeatability error of industrial error positioning. This error is the result of setting inaccuracy of generalize coordinates values by programmed drives. During the measurement measured head mounted on the robot arm at any time should take up unique position definite in the workspace and fixed by programmed values of joint coordinates q_i.

Any position of the characteristic point M of the head can be determined, in an accepted stationary coordinate arrangement, by a certain function of the joint coordinates [8]:

$$
\begin{aligned}
X &= X(q_1, q_2, \ldots, q_n), \\
Y &= Y(q_1, q_2, \ldots, q_n), \\
Z &= Z(q_1, q_2, \ldots, q_n)
\end{aligned}
\qquad (3)
$$

In reality, these values are with certain errors Δq_i ($i = 1, 2, \ldots, n$), which result in deviation of positioning of the head from the programmed position.
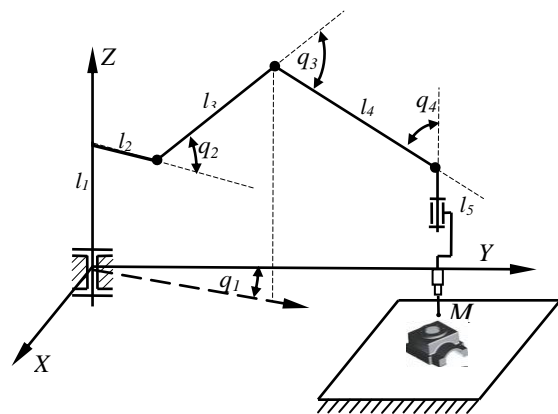

Fig. 1. The kinematic scheme of the industrial robot making measurement treatment

Results of investigations and their analysis for Mitsubishi RV industrial robot are presented in the paper [8]. Conducted investigations demonstrated that repeatability error of robot's positioning in each X, Y and Z axes of Cartesian coordinate system may be described using random variable subjected to normal probability distribution, with an expected value equals 0 and with standard deviation σ_{pr} (N(0,σ_{pr})). The results of repeatability error of robot's positioning in two random points of the workspace are presented in Table 1 and in Fig. 2.

Table 1.
The value of the random variable parameters of the Mitsubishi RV - M2 robot's error

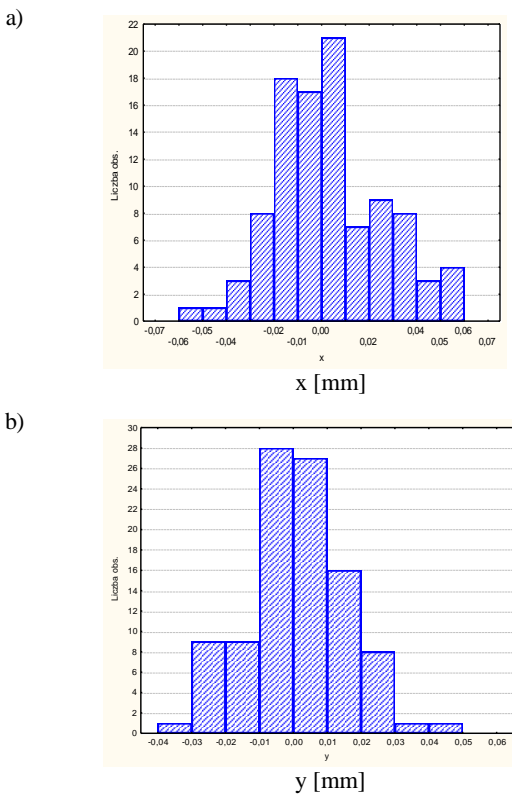| Values of joint coordinates [rad]		The parameters of normal distribution of probability density describing robot's error evaluated on the basis of measurements				
		Random variable	Min [mm]	Max [mm]	Standard deviation [mm]	Skewness
1	$q_1 = 0.5235$ $q_2 = 0.8726$ $q_3 = 1.3962$ $q_4 = 1.0471$	Distribution parameters evaluated theoretically: σ_x= 0.014 mm, σ_y =0.016mm,				
		Δx	-0.054	0.057	0.018	0.287
		Δy	-0.032	0.043	0.014	0.067
2	q_1=1.3963 q_2=0.3839 q_3=1.2217 q_4=0.7330	Distribution parameters evaluated theoretically: σ_x= 0.016 mm, σ_y =0.021 mm				
		Δx	-0.048	0.027	0.016	-0.406
		Δy	-0.046	0.068	0.023	0.225

a)

x [mm]

b)

y [mm]

Fig. 2. Histograms of linear errors of Mitsubishi RV – M2 in the point of workspace described by set of generalised coordinates specified in Table 1, position 1.

3. Reproducibility of measured system

Assessment of measured system accuracy also requires to take into consideration the reproducibility. Reproducibility means the variation determined for one of a variable factor in the conditions of repeatability. The factor that is different in the following tests of reproducibility examination in the production plants is most often operator. In the case of automated measured systems the factor may be environmental conditions e.g. temperature or humidity of air. The systematic error results from temperature variation may be compensated. However, it requires complicated computations and continuous monitoring of the temperature value. If the correction is not known then the value of the error connected with them are determined on the basis of forecast range in which the correction is included. It is assumed that systematic error value may be in the range of $(0 \pm \delta)$. If in the measuring position the temperature is stabilized in the specified level and the lowest working temperature exists equally rarely as the highest working temperature then randomization of systematic error may be carried out using normal distribution. However, if exists identical probability of occurring both the highest and the lowest temperature then for the estimation of the error the rectangular distribution may be used. After coupling the normal distribution (repeatability) and rectangular distribution (reproducibility) we get the flat-normal distribution. The density function of its distribution is described by equation:

$$g(\eta) = \frac{1}{2\sqrt{6\pi}\, r} \int_{\eta-\sqrt{3}}^{\eta*\sqrt{3}} \exp\left[-\frac{\varsigma^2}{2}\right] d\varsigma \tag{4}$$

In general, the density functions of its distribution are characterized by the constant value in the range of expected value and step slopes described by Gauss function (Fig. 2). The range of stability of density function depends on distribution parameter r which defines the relation of rectangular component σ_o of standard deviation and normal component σ_p of standard deviation [9]:

$$r = \frac{\sigma_o}{\sigma_p} \tag{5}$$

As shown in Fig 3, if the standard deviation σ_o (reproducibility) value is less than or equal to standard deviation σ_p (repeatability) value then the form of flat-normal distribution is close to Gauss distribution. This situation takes place for the analyzed Mitsubishi RV – M2 robot, where the standard deviation of the error produced by the change of temperature at 20°C is equal of 19-30% of the standard deviation of repeatability positioning error [10]. So it may be assumed that these errors in

this case may be randomized in the shape of normal distribution of probability density.
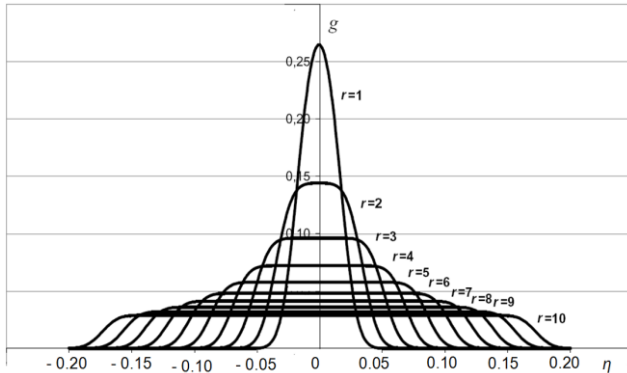

Fig. 3. Functions of flat-normal density distribution in the dependence of parameter r value.

If during accuracy assessment of robotized measuring system the systematic errors become randomized then variance of total error σ^2 will be resultant of both variance characterizing repeatability of measuring instrument σ^2_{pp} and variance characterizing reproducibility of the robot σ^2_o:

$$\sigma^2 = \sigma^2_{pp} + \sigma_{pr} + \sigma^2_o \qquad (6)$$

According to QS 9000 range of distribution is determined on the basis of confidence level $1-\alpha =0.99$, based on the formula [7]

$$R_{0.99} = 2k_{0.99}\sigma = 2 \cdot 2{,}575\sigma = 5.15\sigma \qquad (7)$$

So, the repeatability and reproducibility (R&R) as the resultant of these factors may be determined in the following manner:

$$R\&R = 5{,}15\sqrt{\sigma^2_{pp} + \sigma_{pr} + \sigma^2_o} \qquad (8)$$

As the index of measuring capability of automated measuring system for the control of specified feature of casting may be assumed the ratio between R&R value and tolerance of feature T. If ratio R&R/T ≤ 10% then it may be assumed that measuring system is qualitatively correct. If the ratio is in the range of 10% < R&R/T ≤ 30% then the system is suitable to control the second-class measurements, in the rest of cases system is unsuitable to operating.

Used in the study the measuring system consists of industrial robot Mitsubishi RV-M2 in the operating point specified by set of joint coordinates presented in the Table 1 (position 1) and the measuring head equipped in Tesa GT61 inductive gauge with measuring accuracy of $\sigma_{pp} = 0.0008$ mm. The aim of analysis is determination of casting tolerance values for which range of the system will be used. It was assumed that during measurement the temperature may varied in the range of ±10°C (σ_o=0.0025 mm). The analysis showed that the system may be used for measuring of castings at the tolerance of not less than 0.366 mm. That

tolerance corresponds to economical dimensional tolerances of die-casting (0.2-0.6mm) and pressure casting (0.1-0.4mm) [11].

4. Conclusions

The quality control of finished castings depends on assessment and its comparison with requirements concerning dimensions, structural defects and surface texture. Depending on casting type and the lot size the quality control of casting may be a visual character using measuring instruments or may run in automatic cycle. Nowadays, the most popular and the most often used method of casting assessment is manual method using proper strickle boards. This method is inexpensive but simultaneously labour-consuming and low flexible. The article shows that for quality control of castings the industrial robots may be used. The use of robot is justified when the measurements are carried out in multi points and access to measuring points is difficult. Furthermore, the robot's usage is justified when high speed, repeatability and objectivity of measurements is required. The following argument argues for choice of the robot are low single cost of robot's purchase and low costs of maintenance. Robotized stand assures high flexibility and thanks to multiaxialness of robot's arm the stand become more universal. The robot may be used in the other purposes after re-programming.

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