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Assessment of Reliability of Measurement Data and Adequacy of the Measurement Systems in Improving Quality of Casting Products

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Abstract

The study summarises the analysis of reliability assessment of measurements of a selected critical property of a high-precision casting product. Measurement data must be sufficiently reliable to be used in decision-making relating to quality control and the selection of the casting manufacturing technology.
The applied procedure is illustrated by study of the variability range of readouts depending on the measurement conditions, obtained by the computer methods. The applied R&R (Repeatability and Reproducibility) procedure is major component of the widely employed Measurement System Analysis (MSA).

Keywords: Control of cast quality, Measurement System Analysis MSA, Repeatability and Reproducibility (R&R) analysis.

1. Introduction

The quality planning starts with the Production Part Approval Process (PPAP), releasing the product for production. The PPAP methodology has been developed by the Automotive Industry Action Group AIAG (www.aiag.org)

Quality planning is based on the following procedures [1,2]:

- Control Plan, taking into account the critical properties of interest (specified by the customer) and the reference documents- instructions and control cards;
- Measurement System Analysis- analysis of measurement systems to control the capability of measuring devices in checking the quality of manufactured products;

Testing the capability of measurement system is required when the critical properties are to be determined. Testing involves the assessment of accuracy, repeatability and precision, reproducibility, stability and linearity of measurements [3-7].

The adequacy of the gage to be used in acceptance tests needs to be demonstrated as well.

Two methods are available that can be used to assess the capability of gages and measurement systems:

- Measurement of a standardised item under constant conditions repeated 50 times and calculation of the standard deviation of the measurement system;
- R&R analysis involving the checking of gage repeatability and reproducibility, this method is universal and hence widely employed;

Input data in R&R analysis are repeated readouts (2-3) of measurements (about 10) of the sample part by several (2-5) operators, the minimal number of readouts being 30. The calculation procedure based on the average range approach yields the approximate components (standard deviations) of the observed Total Variation; R&R- standard uncertainty (involving Equipment Variation, Appraiser Variation, Process Variation). The analysis of variance ANOVA yields the Total Variation TV component as an interaction between the operators and measurement results [6].

Of particular importance in R&R analysis is finding the relevant Measurement Capability Index, as 1% fraction of the R&R Total Variation introduced by the measurement system within the determined variation range (MCI_1) and a percentage fraction of the Total variation R&R due to the measurement systems within the tolerance limit given in the product specification (MCI_2).

2. Results of Measurement System Analysis under the R&R procedure

The measurements were carried out in one of the pressure casting foundries. The object of the research was cast – cover of fuel filter, manufactured for diesel engines used in trucks. Before analysis and measurements, foundry reported some problems with dimensions in the cast - testing was performed on selected castings in order to eliminate the influence of the measuring device.

Reliability of measurement data was assessed basing on the capability of the gage used for measuring the critical property: the arm height in the casting product. This parameter determines the quality of a high-precision casts made of aluminium alloy in a cold-chamber die casting machine [8].

Arm height measurements were taken with a digital height meter Mitutoyo- Digimatic with the measuring range up to 300 mm and accuracy of ±0.02 mm.

In accordance with the R&R methodology, measurements were taken by 3 operators (A,B, C) responsible for quality control, who conducted three series of 10 repeated measurements of randomly selected castings, placed on the bench plate.

Measurement data were entered in the spreadsheet. Data analysis was supported by the Microsoft Excel and the software package Statistica 10.0.

Centring (h, hm) and scattering (s, R) parameters are summarised in Table 1.

Table 1.
Centring and scattering of height measurement readouts

Operator	A			B			C		
Series of measure	1	2	3	1	2	3	1	2	3
Sample mean	134.441	134.441	134.446	134.439	134.443	134.442	134.440	134.443	134.445
Mediana	134.455	134.460	134.455	134.445	134.445	134.455	134.450	134.455	134.455
Standard deviations	0.08774	0.08850	0.09348	0.09219	0.09141	0.09090	0.09006	0.08975	0.08997
range	0.26	0.27	0.27	0.27	0.27	0.28	0.26	0.27	0.26

The measurement system was assessed using the module Industrial Statistics- Process Analysis available in the package Statistica. Thus obtained data are compiled in Table 2 and 3. Table 2 summarises the variance components- estimated standard deviations of repeatability values (error due to the differences between the series of measurements), reproducibility (error due to differences between operators) and part variation. Table 3 gives the values of precision components and the percentage fractions of their variation.

Table 2.
Range and variance assessment

	Variance; Zmn1			
	Averange=134.442 ,262222			
	Operators:3 Parts: 10 Trials:			
Source Sigma=Rśr./d2)	Est. Sigma	Est. Variation	% R & R	% Whole
Repeatability	0.008075	0.000065	100.000	0.9492
Reproducibility	0.0000	0.0000	0.0000	0.0000
Height readouts	0.082484	0.006804		99.050800
Total R&R	0.008075	0.000065	100.000	0.949200
Whole	0.082879	0.006869		100.0000

Table 3.
Range method, tolerance (percentage fraction)

	Tolerance analysis: Zmn1			
	Averange=134,442 ,262222 sigma 5,15			
	Operators:3 Parts: 10 Trials: 3			
Source (Sigma=Rśr./d2)	Measurement unit	% Proc Variation.	% whole	% tolerance
Repeatability (var.of measures)	0,041584	9,7426	0,949	4,1584
Reproducibility (var.of operators)	0,0000	0,0000	0,0000	0,0000
Variation of measurement readouts	0,424795	99,524300	99,0508	42,479500
Total R&R interval R&R (0,997)	0,041584	**9,742600**	0,949	**4,158400**
Overall process variation	0,426825	100,0000	100,0000	42,6825
Design tolerance zone	1,000000			100,0000

The analysis of variance yields the coefficients MCI_1= 9.74% and MCI_2= 4.16%.

The results of R&R analysis are shown graphically in Fig 1 and 2 and summarised in Table 4.

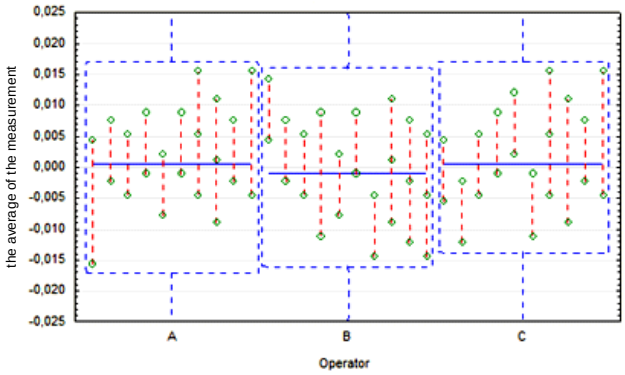

Fig. 1. Range of measurement results of R&R, number of operators – 3, number of castings – 10, number of trials - 3

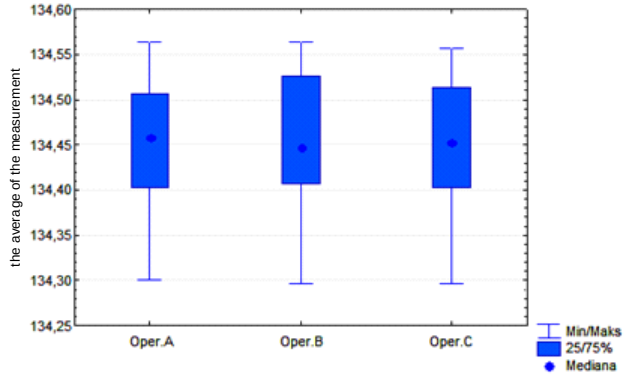

Fig. 2. Range of measurement results, number of operators – 3, number of castings – 10, number of trials - 3

Table 4.
Characteristics of the measuring system estimated by the R&R method

Characteristic	unit of measure	% Variation
Repeatability	0,04	9,74
Reproducibility	0	0
R&R gauge	**0,04**	**9,74**
Variations of parts	0,42	99,53
Overall variation	0,43	100

Thus obtained value %R&R indicates that the measuring system is acceptable. When %R&R <10% the system is deemed to be capable and is recommended for use in quality assessment and process control (for highly capable processes with narrow control limits).

3. Conclusions

Effective control of quality of castings products and the casting processes basing on the measurement data, requires reliable readouts and system evaluation. A simple procedure of the gage evaluation uses the %R&R indicator, the variability of R&R relating to the precision components: repeatability and reproducibility.
Results of R&R analysis performed to test the critical property of interest indicate whether the measuring system is found capable. Reliable measurement data allow for using quality control tools, such as control cards and acceptance cards.

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