POSSIBILITIES OF DATA NON-NORMALITY SOLVING AT PROCESS CAPABILITY ANALYSIS IN TERMS OF PART SYMMETRY

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Abstract

Many of metallurgical companies are joined to the chain of suppliers of automotive producers. Automotive industry suppliers must submit evidence about capability of their processes, which is evaluated on the basis of quality of products produced by these processes. In the cases of normally distributed quality characteristics process capability analysis is performed according to standard procedure. Problems are in the cases, when data of monitored quality characteristic are not normally distributed. Example is symmetry of produced parts. This paper is focused on capability analysis of overmoulding process in terms of achieving part symmetry. Measured part consists of metal rod and overmoulded eye. There are presented various approaches to process capability analysis in this case and suitable procedure for non-normality solution is proposed in this paper.

Keywords: process capability analysis, non-normal quality characteristic, symmetry

INTRODUCTION

Proper product quality planning is default assumption for market success and customers satisfaction. Part of proper quality planning is not only design of product which fully satisfies customer requirements but also process capability analysis. Capability analysis is defined as the process ability to consistently provide products meeting required quality criteria. Submission of process capability evidence is required in the process of approving parts into serial production (e.g. PPAP) in the field of automotive suppliers.

Process capability analysis is statistical method, therefore it is important to emphasize the correctness of used procedure and correct results interpretation [1]. Standard process capability analysis is based on certain assumptions which may not be met in real processes. One of them is assumption of normality which may not be met in a number of quality characteristics [2]. This paper is focused on possibilities of data non-normality solving at process capability analysis in terms of part symmetry.

Kotz and Lovelace [3] shows examples of quality characteristics which naturally do not correspond with normal distribution. Quality characteristics which are usually expressed by deviation (deviation of position, angle deviation, etc.) could not be often described by normal distribution.

1. PROCESS CAPABILITY ANALYSIS FOR NORMAL DATA DISTRIBUTION

The process capability is expressed by capability indices. Values of commonly used indices C_p and C_{pk} are derived by ratio between tolerance range and real variability of observed characteristic expressed by standard deviations in cases of data normality [4]:

$$C_p = \frac{USL - LSL}{6\sigma} \quad (1)$$

$$C_{pk} = \min(C_{pl} = \frac{USL - \mu}{3\sigma}, C_{pu} = \frac{\mu - LSL}{3\sigma}) \quad (2)$$

where:

σ – standard deviation,

LSL – lower specification limit,

USL – upper specification limit,

μ – mean of monitored quality characteristic.

Capability index C_{pk} is less or equal to C_p. The equality of these indices occurs when the mean of monitored quality characteristic is in the middle of specification limits [1]. As capable is usually considered process whose capability index C_{pk} is greater than 1.33.

2. PROCESS CAPABILITY ANALYSIS FOR NON-NORMAL DATA DISTRIBUTION

Percentile method or data transformation method are most commonly used to determine capability indices in the cases of data non-normality. Real variability of monitored quality characteristic is expressed by percentile differences in case of using percentile method [5]:

$$C_p = \frac{USL - LSL}{X_{99,865} - X_{0,135}} \quad (3)$$

$$C_{pk} = \min(C_{pl} = \frac{X_{50} - LSL}{X_{50} - X_{0,135}}, C_{pu} = \frac{USL - X_{50}}{X_{99,865} - X_{50}}) \quad (4)$$

where X_p are percentiles based on distribution of monitored quality characteristic.

In the case of data transformation are data transformed into new variable by suitable transformation function. Transformed variable could meet normality when transformation is successful. After specification limits transformation are used standard formulas for calculation of capability indices.

In the cases of data non normality it is also used Clements method which is based on percentiles calculation using Pearson family curves of probability distribution [6].

Many quality characteristics whose probability distribution does not naturally meet normal distribution are assessed in the field of metallurgy and engineering. Examples are quality characteristics which are based on absolute value of deviation from some standard. A little attention is dedicated to capability analysis of given processes due to quality characteristics so far. For example, Czarski [7] performed case study where process capability in terms of thickness of hot rolled steel strip was analysed. Quality characteristic was specified as absolute deviation of thickness from nominal value. Process capability analysis was performed using percentile and Clement´s methods. The results of this case study shows that the application of quantile method based on three-parameter Weibull distribution and application of Clement's methods can lead to approximately the same results.

3. CASE STUDY

The subject of case study was proposal of suitable approaches to process capability analysis of overmoulding process in terms of symmetry of the produced parts.

3.1. PREPARATION AND DATA COLLECTION

The symmetry belongs to the quality characteristics which naturally do not meet data normality. Symmetry is defined as tolerance zone which is limited by two parallel planes a distance **t** apart symmetrically disposed about the median plane, with respect to the datum **a** (Fig. 1). Letter **t** marks symmetry and **t/2** marks deviation of symmetry [8].

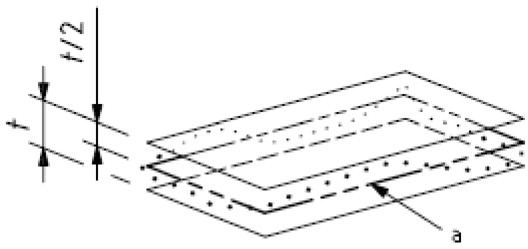

Fig. 1 Definition of symmetry tolerance zone [8]

During overmoulding process is plastic eye moulded into metal rod. One of the most important quality characteristic is symmetry of centre of plastic moulding in relation to the axis of metal rod. Upper specification limit USL=0.3 mm for symmetry is prescribed in accordance with drawing specification.

At the output of overmoulding process they were sampled subgroups of products with size n=5 in periodical time intervals. Values of symmetry were measured on 3D optical measurement device Excel 6XX. Data about 25 subgroups of products were obtained which represent totally 125 values. Figure 2 shows graphical distribution of symmetry values using histogram.

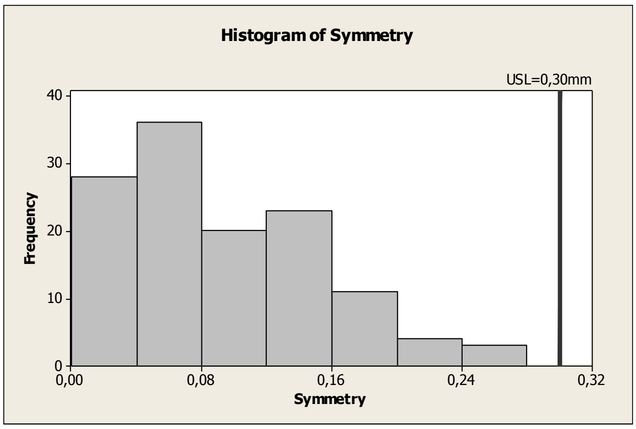

Fig. 2 Histogram of part symmetry

It is obvious from Fig. 2 that distribution of symmetry could be a part of normal distribution. Missing part can never be obtained because symmetry has a natural border at the beginning of coordinate system. Symmetry is calculated as absolute value of twice deviation of symmetry ($t=|2.t/2|$). It can be assumed that symmetry distribution corresponds to half-normal distribution. Two approaches for process capability assessment in terms of part symmetry were proposed:

- Simulated recalculation of symmetry values into deviations of symmetry using random assignment of negative signs (Method A),
- Adding of same values with negative sign (at the same operation is each value divided by two) (Method B).

For comparison process capability analysis was also performed using the procedures applied in the cases of data non-normality such as percentile method, Clement´s method or data transformation method.

Capability analysis results were compared with process capability analysis calculated for the really measured deviations of symmetry.

3.2 APPLICATION OF PROPOSED PROCESS CAPABILITY ANALYSIS APPROACHES

METHOD A

As first, simulated recalculations of symmetry values into deviations of symmetry using random assignment of negative signs were performed. Ten data files from standard normal distribution were generated to verify reproducibility of achieved results. Value -0.5 were assigned to negative values, 0.5 were assigned to positive values. Then measured symmetry values were multiplied by these numbers (±0.5). Ten data sets of simulated values of deviations of symmetry were obtained by this way. For all ten data sets it was found that differences in arithmetic means and standard deviations are minimal and data correspond to normal distribution. After that capability indices C_p and C_{pk} were calculated for these created files. Determined C_{pk} values ranged from 0.89 to 0.91, average value was 0.90 (see Table 1).

METHOD B

Second proposed approach recalculated values of symmetry to absolute values of deviations of symmetry (divided by 2) and these values were supplemented by the same values with negative sign. This approach is easier in comparison with method A. Disadvantage of this method is artificial increase of number of values (twice values) and fact, that probability distribution is symmetrical with respect to zero. Even in this case conformity with normal distribution was confirmed (p-value 0.052) and capability index C_{pk} could be rightly calculated (see Table 1). Worse conformity with normal distribution may relate with higher number of data.

Table 1 shows that both proposed methods present very close results of process capability. There is difference in their rate of conformity with normal distribution. Fact that Method B shows the same values of C_p and C_{pk} values confirms symmetry of new data set distribution with regard to zero.

Table 1 P-values and C_{pk} indices based on the proposed methods of process capability analysis

Method A (125 values;, LSL=-0.15; USL=0.15)			
Probability distribution	P-value	C_p	C_{pk}
Normal	0.236	0.91	0.90
Method B (250 values; LSL=-0.15; USL=0.15)			
Probability distribution	P-value	C_p	C_{pk}
Normal	0.052	0.91	0.91

3.3 APPLICATION OF CLASSICAL PROCESS CAPABILITY ANALYSIS APPROACHES

For comparison, process capability analysis in terms of part symmetry was also performed using conventional approaches for capability analysis in cases of data non-normality. In this case it is prescribed upper specification limit only (USL=0.3).

Applying of percentile method based on the best theoretical probability distribution led to the best conformity with three parameters Weibull probability distribution (p-value = 0.237). Then appropriate percentiles were found and capability index C_{pk} was calculated in accordance with formula (4). Also Clement´s method was used as percentile method alternative.

In the case of data transformations they were used Box-Cox and Johnson transformations. While Box-Cox transformation was unsuccessful, using of Johnson transformation shows very good conformity of transformed data with normal distribution (p-value = 0.736). C_{pk} index was calculated by classical formula (2) for normal distribution after specification limit transformation.

Comparison of achieved results is performed in Table 2. Table 2 summarizes p-values and capability indices calculated by percentile method, using data transformation and Clement´s method. The comparison shows that there are significant differences between results achieved by different methods. Higher values achieved by Clement´s method are expected, because this method usually overestimates capability analysis results. Surprised is very high C_{pk} evaluated by Johnson transformation.

Table 2 P-values and C_{pk} indices determined with using classical methods.

Method	P-value	C_{pk}
Quantile method: 3-Parameter Weibull dist.	0.237	0.83
Clements method	-	1.13
Johnson transformation	0.736	1.60

As already mentioned, the symmetry is calculated as absolute deviation of symmetry multiplied by two [8]. In this case it was possible to trace measured values of deviation of symmetry and perform a results confrontation obtained by using different methods with the results obtained on the basis of really measured values of deviation of symmetry. Achieved results are shown in Table 3.

Table 1 P-values and capability indices for real deviation of symmetry

Probability distribution	P-value	C_p	C_{pk}
Normal	0.083	0.96	0.85

It is evident that proposed approaches (Method A and Method B) for process capability analysis in terms of achieving part symmetry provide results which correspond very well with reality.

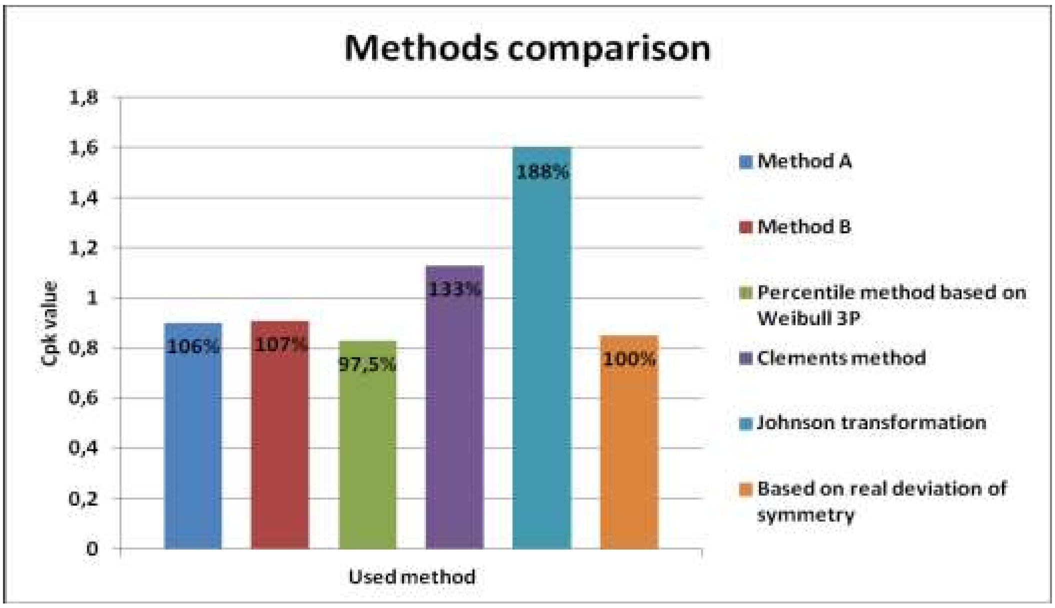

Fig. 3 Comparison of various ways of C_{pk} calculation

Difference between C_p and C_{pk} indices indicates that real mean of deviation of symmetry did not correspond to zero value (it was 0.09).

Comparison of the C_{pk} values calculated by all mentioned approaches is shown on Figure 3. If we choose index C_{pk} calculated on the basis of real deviation of symmetry as reference (100%), then proposed capability analysis approaches lead to C_{pk} values about 6% or 7% higher. Best fit in this particular case was found using quantile method, when index C_{pk} was only about 2.5% lower. The significantly higher value of C_{pk} (about 33%) was achieved by using Clement´s method. This significantly higher value could be caused by difference of given distribution from Pearson distribution curves. The most expressive difference was found using Johnson transformation. Calculated value of C_{pk} index was about 88% higher in comparison with analysis based on real deviation of symmetry.

CONCLUSION

This paper draws attention on the fact that in some cases non-normality of monitored quality characteristic is created artificially. One example is symmetry whose value is determined as absolute value of deviation of symmetry multiplied by two. In this case and also in similar cases may not be the most suitable techniques for process capability analysis percentile method or data transformation method. Moreover these techniques could not be applicable. The most suitable theoretical probability distribution could not be found or, in the case of data transformation, normality could not be achieved or specification limits could not be transformed. Two possible approaches based on character of monitored quality characteristic are proposed in this paper. Their applicability was verified in presented case study.

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REFERENCES

[1] PLURA, J.: Plánování a neustálé zlepšování jakosti (in Czech) (Planning and Continuous Improvement of Quality). Prague: Computer Press, 2001, 244 pp., ISBN 80-7226-543-1

[2] PLURA, J., NEPRAŠ, K., KLAPUT, P.: The influence of skewness of the monitored quality characteristic distribution on the process capability analysis results. In: METAL 2014 – 23rd International Conference on Metallurgy and Materials. Ostrava: Tanger, 2014, p. 1458-1463, ISBN 978-80-87294-54-3

[3] KOTZ, S. – LOVELACE, C. R.: Process Capability Indices in Theory and Practice. New York: Oxford University Press, 1998, ISBN 0-340-69177-8

[4] KOTZ, S. – PEARN, V. L.: Encyklopedia and Handbook of Process Capability Indices. Singapore: World Scientific Publishing Co. Pte. Ltd. 2006, ISBN 981-256-759-3

[5] HOSSEINIFARD, S. Z.: A transformation technique to estimate the process capability index for non-normal processes. London, International Journal of Advanced Manufacturing technology, 2009.

[6] CLEMENTS, J. A.: Process Capability Calculations for Non-Normal Distributions. Quality Progress 22:95-100.

[7] CZARSKI, A.: Estimation of process capability indices in case of distribution unlike normal one. Archives of material science and engineering, 2008.

[8] ISO 1101 Geometrical Product Specifications (GPS) — Geometrical tolerancing —Tolerances of form, orientation, location and run-out, ISO, 2004.