Monitoring and Evaluation of the Production Process of Automotive Connectors

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Abstract – Paper deals with the regulation of the production process in the production of connectors for the automotive industry. Connectors are produced by spraying metal contacts with thermoplastic material using overmolding technology. For the analysis of the measurement system and the evaluation of the process performance, a qualitative characteristic was selected, namely the length dimension. The analyzed product is produced in an injection mold with two cavities. Products from individual cavities were analyzed separately. In the first phase, the analysis of the measurement system (MSA) was evaluated. In the second phase, process performance was evaluated using process performance indices. After the first phase, the measurement system was found to be satisfactory. In the second phase, it was found that the production process is not in very good condition. This means that the products produced in this process may show poor quality properties.

Keywords – Automotive, Quality, Connector, Production, Process performance.

1. Introduction

The international standard IATF 16949 serves as the main tool for assessing the quality of products manufactured in the automotive industry. It was developed by (AIAG), Automotive Industry Action

Group. It serves as a manual and includes five tools for comprehensive quality management in the automotive industry [1], [2].

In the article, the authors Shirodkar et al. [3] dealt with the study of Gage Repeatability & Reproducibility of the measuring system. The authors focused on solving the possible inaccuracies of measurements of controlled products performed by production operators, which may cause a reduction in the quality and reliability of the production process. Operators were replaced by three different factors that could affect the measurement results. The analysis showed that the change of these three factors did not affect the measurement of properties.

In another study authors Burdick et al. [4] focuses on the use of computer simulations as a suitable tool for solving the reliability of the production system. The paper of the authors Doshi et al. [5] dealt with the practicality of using the measurement system analysis (MSA) for the needs of improving quality in the automotive industry. The article describes the case studies of four car manufacturers supplying original parts for cars. Analyzes were performed based on the MSA - Gauge R&R study. The obtained results of analyzes showed the possibility of increasing the quality, specifically in the measuring system between the appraiser and the instrument. The obtained recommendations were implemented into real conditions of companies.

The aim of the standard is to develop and implement a quality management system that enables continuous improvement, while emphasizing the prevention of errors and the reduction of variability and losses in the supply chain in the automotive industry. The standard, together with the use of specific customer requirements, sets out the basic requirements for a quality management system for companies that undertake to apply this document. The IATF16949 standard is intended for every company that wants to be a supplier to the automotive industry. It is used to verify the quality management system according to this standard. It represents a guarantee for customers including functionality and efficiency of the system and at the same time a guarantee of the required level of production quality [6].

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At present, great emphasis is placed on reducing the variability of the process of manufacturing companies. In their study, the authors Knowles et al. [7] dealt with and briefly evaluated the currently used methods of evaluating the quality of data of monitored processes for their continuous improvement, because the use of erroneous data in the production decision-making process reduces the quality of this process and increases the cost of implementing the necessary measures. The authors Song et al. [8] dealt with the method of performance evaluation using GRR indices for two parallel measurement systems. In the article, the authors dealt with Pearson correlation, where they proved that it is possible to analyze the GRR performance of two parallel measuring systems by this correlation, which saves time compared to commonly used methods. Similarly, Cepova et al. [9] deals with the description of the Average and Range method (AIAG), as well as the method of the honest Gauge Repeatability and Reproducibility (GRR). The measurements were applied to the plastic parts on which the thickness was measured and the obtained results were evaluated by both methods. The obtained results as well as the used methods were compared for their direct use in the production process.

The quality and stability of production processes are currently the most represented by regulatory processes. Basically, stability determines whether the value we prescribe at the input is also obtained at the output. Each organization is currently trying daily to withstand the pressures and threats by their competitors. The success of any organization depends largely on the speed and ability of the organization to adapt to the requirements and needs of the end customer. Requirements for the properties of final products of customers are recording an ever-increasing progress and overall form the final quality of the production process of the product [10], [11].

In the current competition on the market, quality plays a priority role in obtaining, resp. maintaining an adequate market share. The use of statistical methods in production processes helps to find the causes of process instability, checks the effectiveness and efficiency of corrective actions. Their use can stabilize the course of the process, thereby increasing the quality and productivity of work. The More statistical methods we know more we offer several possibilities of analysis, and hereby, achieving a higher probability of successful solutions to the potential problem.

Statistical process control (SPC) is one of the quality management methods that use statistical methods. It is used for monitoring and controlling production processes. The method consists of two phases. In the first phase, the initial specifications of the selected process are set. The second phase aims

to routine use in production processes. The advantage of the application of the SPC method in comparison with other methods of quality management lies in the priority of early detection and subsequent prevention of the occurrence of problematic situations before the correction of already existing situations [12], [13].

The aim of the presented article is to determinate the quality of the manufacturing process in the production of connectors for the automotive industry. The length characteristic was chosen as the monitored qualitative parameter. In the first stage, the measuring system was analyzed. In the second stage, the capability of the production process was assessed using performance indices and control charts.

2. Quality in Automotive Production

The Automotive Manufacturers Group (IATF) is concerned with the quality of the automotive supply chain worldwide. Standard marked IATF 16949:2016 is used for setting Quality Management System (QMS) specifications primarily for the automotive industry. Originally created in 1999, the ISO/TS 16949 was developed to harmonize numerous evaluation and qualification systems throughout the automotive supply chain worldwide. IATF 16949 enables continuous improvement of production quality with an emphasis on error elimination and supply chain variability and waste. The specification, together with the relevant customer requirements (CSR), specifies the QMS specifications for the manufacture, service and/or accessories of automobiles [14].

IATF 16949 is a separate, completely compatible QMS standard with ISO 9001:2015 framework and specifications. The IATF 16949 cannot however be applied alone as a stand-alone text but must be applied in accordance with ISO 9001:2015 as a replacement [15].

Defection to perform the audit within the appropriate scheduling criteria allows the company to initiate an initial audit of the credential. The transition audit is the length of a recertification audit plus extra time for a review of the paperwork. The transitional audit covers all necessary tasks on site or at a remote location.

A method of quality control, based on IATF 16949 [16] comprises:

- Is it possible to describe how a company should meet the requirements of its customers and other stakeholders?
- It holds the idea of continuous improvement;
- It needs companies to identify their priorities and constantly try to use systems to achieve those priorities;
- Highlights error prevention;

- It contains specific requirements and basic tools used in the automotive industry;
- Advanced Product Quality Planning (APQP);
- Failure Mode and Effects Analysis (FMEA);
- Statistical Process Control (SPC);
- Measurement Systems Analysis (MSA);
- Production Part Approval Process (PPAP);
- Supports error management and supply chain errors;
- It requires a documented and implemented responsible business policy.

The use of the IATF 16949 standard provides customers with quality products and their services. This brings them many business benefits. IATF 16949 describes the requirements for a quality management system when an organization wishes to:

- Describe the capability to supply reliably customer fulfilling goods and the applicable legislative, regulatory and product protection specifications;
- Increase customer service by making good use of the program;
- Implement Program Development Processes;
- Describes the overall context that is affected by it;
- It concisely sets goals and identifies possible new business opportunities;
- Customers specify their needs and check that they are consistently satisfied and increase their satisfaction;
- Use the same customers, try to increase customer loyalty, look for new customers and increase the volume of your business;
- Look for potential new markets;
- Find and address potential risks in your organization;
- Work to increase productivity and efficiency in a more efficient way, reducing internal costs;
- By reporting and enforcing corporate responsibility programs, becoming more socially responsible [17].

A strategic decision is the determination of the organizations to create and implement some new or enhanced QMS. Both activities will concentrate on recognizing and mitigating risk while achieving and fulfilling customer and corporate goals and strategic criteria.

Organizations should make a commitment to [18]:

- Specify direct and indirect clients who will benefit from organizational value;
- Understanding current and potential consumer needs and expectations;
- Connect the organization's priorities to the needs and desires of its clients;

- Express the needs and desires of consumers through the organization;
- Design, produce, manufacture, supply and support goods to meet the needs and demands of the customers;
- Track and assess customer service, and take necessary action;
- Assessing and taking action on the needs and desires of interested parties that can affect customer service;
- Effectively monitor customer relations for consistent success;
- Take on social responsibility;
- Include the tools required to ensure that product protection standards are met.

3. Material and Methods

A plastic product was used to monitor the production process. The monitored product is manufactured in the company Metalis Slovakia by the technology of plastic injection (overmolding). The product is used as a lock in the car door. The product is shown in Figure 1. The door lock is produced in two versions as the left version (LH) and the right version (RH). Each design is manufactured in an injection mold with two cavities. Therefore, the products will be assessed separately from each mold cavity [19].

Figure 1. Measured plastic product

The dimensional characteristic 64.1 ± 0.1 mm was chosen to monitor the production process. The measured dimension characteristic is shown in Figure 2. The qualitative characteristic was measured on a 3D coordinate measuring device by quality controllers twice per shift.

Figure 2. Measured dimension characteristic

Two methods were used to evaluate the production process. In the first step, the analysis of the measurement process was performed. In the second step, the capability of the production process was assessed using process performance indices.

3.1. Measurement System Analysis Method (MSA)

The average and span method is used to evaluate the repeatability and reproducibility of the measurement. It consists of three steps: preparation, self-measurement and evaluation.

First, it is necessary to verify whether the correct quantity is measured. Furthermore, it is also necessary to select the instrument with sufficient resolving power, e.g., to be able to read min. 1/10 of the expected variability. The following is the determination of the parameters of the analysis of the measurement system: number of operators, measured pieces, repetitions. In the same process, each operator measures the measured pieces (parts, samples, etc.) in random order. Shewhart regulation chart for the values of variation range of the repeated measurements:

$$CL = \bar{\bar{R}} = \frac{1}{h} \sum_{i=1}^h \bar{R}_i \quad (1)$$

$$\bar{R}_i = \frac{1}{r} \sum_{j=1}^r R_{ij} \quad (2)$$

$$LCL = D_3 \cdot \bar{\bar{R}} \quad (3)$$

$$UCL = D_4 \cdot \bar{\bar{R}} \quad (4)$$

Assessment of statistical coping with the process from the regulation diagram is correct if all values of the testing criterion (R_{ij}) do not occur within regulation limits:

- measurement method of one operator differs from the other methods – the measurement methods must be unified,
- with all operators – the measurement system is extremely sensitive to activity of the operator – the better measurement system must be developed. [19], [20]

Measurement Repeatability EV (Equipment Variation) is calculated if the measurement process is statistically coped with from the point of view of reached variability:

$$EV = 5.15 \cdot \sigma_e = 5.15 \cdot \frac{\bar{R}}{d_2^*} \quad (5)$$

σ_e – refers to standard deviation of repeatability, (estimated by R), $5.15 \cdot \sigma_e$ corresponds to the width of the sphere in which it occurs provided that 99 % of all values is distributed as standard,

d_2^* – is coefficient dependent on number of measurement repeatability and product of number of the measured components and operators.

Measurement Reproducibility AV (Appraiser Variation) characterizes variability among operators:

$$AV = \sqrt{5.15 \cdot \frac{R_0}{d_2^*} - \frac{EV^2}{n \cdot r}} \quad (6)$$

R_0 – is variation range of arithmetical means of all pieces measured by one operator.

Gage Repeatability and Reproducibility GR&R:

$$GR \& R = \sqrt{EV^2 + AV^2} \quad (7)$$

Part Variation (PV):

$$PV = 5.15 \cdot \sigma_p = 5.15 \cdot \frac{R_p}{d_2^*} \quad (8)$$

σ_p – is standard deviation of the values of the feature of the quality of measured pieces,

d_2^* – is coefficient dependent on number of repeated measurements and product of number of the measured components and operators,

R_p – is variation range of arithmetical means of all measurements of the individual pieces.

Total Variation (TV):

$$TV = \sqrt{GR \& R^2 + PV^2} \quad (9)$$

Expressing of EV, AV, GR&R, PV in % of overall variability:

$$\% EV = \frac{EV}{TV} \cdot 100 \quad (10)$$

$$\% AV = \frac{AV}{TV} \cdot 100 \quad (11)$$

$$\% GR \& R = \frac{GR \& R}{TV} \cdot 100 \quad (12)$$

$$\% PV = \frac{PV}{TV} \cdot 100 \quad (13)$$

if

% GR & R $\leq$ 10 – measurement system is acceptable,

10 $\leq$ % GR & R $\leq$ 30 – measurement system can be acceptable,

% GR & R $>$ 30 – measurement system must be improved. [21], [22]

3.2. Statistical Process Control method (SPC)

Evaluation of production process performance is using indices. P_{pk} is a process performance index that tells us how well the system meets the set specifications. The P_{pk} process performance index calculations use real sigma and show us how the system works, compared to established specifications. [23], [24]

- If the index $P_{pk} = 1.0$ – the production system produces 99.73 % of its performance within the specifications. If the value of the P_{pk} index is larger, then there are smaller differences between the process output and the set specifications.
- If the value of the P_{pk} index is between 0 and 1.0, not all outputs of the production process meet the established specifications.

- If the production system is focused on its target value, the process performance index P_{pk} should be used together with the P_p index. If the production system is focused on its target value, the values of P_{pk} and P_p will be the same. If the performance indices are not the same, the smaller the difference between these indices, the process is more centered [25], [26].

4. Results and Discussion

The experiment consisted of two phases. In the first phase, it was necessary to analyze the measuring system used in the second phase. In the second phase, the capability of the production process was assessed using performance indices and control charts. Measurement system analysis:

- Nominal dimension: 64.1 mm
- Upper tolerance: 64.2 mm
- Lower tolerance: 64.0 mm

Table 1 shows the measured values by the individual controllers that were used to evaluate the measurement system.

Table 1. Measurement values for MSA

Controller	Measurement	Sample									
		1	2	3	4	5	6	7	8	9	10
1	1	64.07	64.08	64.08	64.09	64.08	64.08	64.08	64.09	64.07	64.08
	2	64.07	64.08	64.08	64.09	64.08	64.08	64.08	64.09	64.07	64.08
	3	64.07	64.08	64.08	64.08	64.08	64.08	64.07	64.09	64.07	64.08
2	1	64.07	64.07	64.08	64.09	64.08	64.09	64.07	64.09	64.07	64.08
	2	64.07	64.08	64.08	64.09	64.08	64.08	64.08	64.09	64.07	64.08
	3	64.07	64.08	64.08	64.09	64.08	64.09	64.07	64.09	64.07	64.08
3	1	64.07	64.08	64.08	64.09	64.08	64.08	64.08	64.09	64.07	64.08
	2	64.07	64.08	64.08	64.08	64.08	64.08	64.07	64.09	64.07	64.08
	3	64.07	64.08	64.08	64.09	64.08	64.08	64.07	64.09	64.07	64.08

Based on the measured values, the indicators of the measurement system were evaluated, which are listed in Table 2. The GRR method (average and range method) was used to evaluate the measurement system. The values of the indices EV, AV, PV, GRR and ndc were evaluated using the PALSTAT CAQ program.

Table 2. MSA indicators

%EV	%AV	%PV	%GRR	ndc
4.726 %	0 %	18.876 %	4.726 %	5

The percentage representation of repeatability %EV (4.726 %) refers to the percentage value of total variability that redounds to the equipment variability. Parameter % AV (0 %) refers to the percentage value of total variability that redounds to the operator variability. The parameter called % PV (18.876 %) refers to the percentage value of total variability that redounds to the part to part variability.

The repeatability and reproducibility of the measurement is %GRR $\leq$ 10. This criterion states that the measurement system is acceptable. In this case, the value is $4.726 \leq 10$ and therefore the measuring system is at an acceptable level and

corresponds to the international statistics of AIAG. Palstat CAQ calculated the parameter of the number of categories distinguishable by the measuring system (ndc) with a value of 5. This value is approximately corresponding to the condition $ndc \geq 5$.

4.1. Process Capability

Figure 3 and Figure 4 show control charts of the average and range for evaluating the suitability of the

manufacturing process of products from the cavity 1. As we can see in the Figure, all measured values are within the tolerance limits.

The process performance index P_p had a value of 1.30 for this cavity, which means that the process is not in good performance. It is necessary to check the setting of technological parameters and repeat the process check.

Figure 3. Average regulation diagram – Cavity 1

Figure 4. Range regulation diagrams – Cavity 1

Figure 5 a Figure 6 show control charts of the average and range for evaluating the suitability of the manufacturing process of products from the cavity 2. As can be seen in the figure, all measured values are within the tolerance limits similar to the cavity 1.

The process performance index P_p had a value of 1.03 for this cavity, which means that the process is not in good performance. It is necessary to check the setting of technological parameters and repeat the process check.

Figure 5. Average regulation diagram of statistical manageability of the process – Dimension 3 – Cavity 6

Figure 6. Range regulation diagram of statistical manageability of the process – Dimension 3 – Cavity 6

5. Conclusion

The article deals with the assessment of the performance of the process in the production of automobiles connectors. The connectors, specifically the car door lock, are made of polymer by overmolding technology. In the first phase, the analysis of the measurement process revealed that the measurement system is acceptable. This decision was made based on two criteria used in the average and range method (%GRR and ndc). Both criteria confirmed that the measurement system is acceptable and the measurement system provides reliable information about the process changes.

In the second phase, we approached the evaluation of process performance using process performance indices and regulation diagrams. It was found that the production process is not in good condition and needs to be better adjusted. After corrective action is taken, the process needs to be checked again. Process performance measurement are activities that are intended to provide objective and accurate information about the course of processes so that these processes can be their owners on an ongoing basis, operational, managed to meet all process requirements [27], [28]. The role of the producer is to achieve higher process performance indices. In this way, the producer declares to the customer the required quality of the delivered products.

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