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QUALITY MANAGEMENT IN MANUFACTURING PROCESSES FOR SERIAL PRODUCTION ORGANIZATION – CASE STUDY

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Abstract: The basis for the control work for the quality in manufacturing process is the supervision of the effects of this process and the verification of the correctness of the employees' activities. The continuity of the control activities carried out indicates the need to supervise all production elements of the offered products. The article presents unit guidelines of quality analyzes for the production and assembly of car brake calipers. The presented analyzes constitute the basis of a complete supervision system and are an element repeated in each subsequent production batch. The quantitative analysis of production non-conformities was supplemented with the determination of the causes and effects for these errors, and the analysis of statistical indicators of qualitative ability. The results for one production batch were presented along with the adopted procedure, which are a component of the system of supervision over the results of control processes included in the production process.

Keywords: quality control, risk analysis, FMEA method, SPC

1. INTRODUCTION

Meeting the requirements and needs of customers is one of the most important steps that production and service companies should aim at. In times of dynamic development and the emergence of strong competition, in particular due to the rapid development and increase in production in eastern and Asian countries, enterprises face many challenges. In order to be competitive on the market, production and service companies must pay more and more attention to the quality and durability of the products and services they offer. The changes caused by the increase in the offered products and services have made the concept of quality take a new face and it has become one of the main factors in the development of enterprises and competitiveness between organizations.

The quality of products and services can be interpreted in various ways (Czyżewski B., 2013, Kardas E. 2016). It can be said that it is the perfection of the products and services, which are offered by the companies. In fact, measuring quality is difficult. Enterprises are constantly focusing their goals on achieving the highest possible level of quality for their products or services (Jagusiak-Kocik M., 2014). In order to improve quality, companies are looking for new technologies, new raw materials or better use of already adopted raw materials. They look more closely at their processes and production means, looking for ways to optimize and improve them. They pay more attention to their machinery, which largely determines the quality of products or services offered by the company. Employees also play an increasingly important role in production companies, because their experience and skills directly affect the quality of products and services offered by the companies. (Borkowski S., Knop K., 2013, Pacana A., Woźny A., 2016). All the above-mentioned factors as well as the conscious and continuous improvement of enterprises contribute to increasing the pace of their development and improving the quality of products and services offered by them. (Knop K., Jagusiak-Kocik M., 2016). The desire to improve the quality, competitiveness and position of enterprises as well as striving to meet the increasing expectations of customers, made enterprises more and more often develop quality management systems, which are the basic tool to achieve these goals. Quality management systems contain methods and tools by which enterprises can increase their ability to meet customer satisfaction and needs. It is important that they are properly designed in subsequent production processes, so that they guarantee control for critical production stages (Wolniak R., Skotnicka B., 2007).

2. AREA FOR PROCESS ANALYZES

The research entity is a world leader in the field of design, development and production of brake systems and parts for cars, motorcycles, industrial vehicles and machines, both in the field of original equipment and the market of spare and racing parts. The plant produces steel hubs, which are one of the elements of steel-cast iron discs produced on the prototype brake line. The process scope in the plant also includes casting. The casting process produces both brake discs and parts for brake calipers, which are a component of the final product that is offered to customers.

Due to its global activity, the company implements processes of continuous improvement and improvement of its products and services, due to the competitiveness of the car market. This is supported by integrated management systems (quality, environmental protection, and occupational health and safety) operated by enterprises, as well as industry-specific quality guidelines.

The concern, as a world leader in the production of brake systems and spare parts for cars, motorcycles and industrial vehicles, is constantly working on improving its products. The constant pursuit of innovation requires a constant search for new technologies, materials, shapes and new markets. One of the manufacturing processes in the company is the production of a brake caliper, which is one of the components of the company's finished product, i.e. the brake system. The presented analyzes refer to this particular production part of the company and determine the process quality capability as well as continuous monitoring of the quality level and statistical regulation of the process.

The full braking system in each car consists of brake discs, disc brake calipers with a pad, or a drum brake shoe. In addition, the control mechanism of this system, which includes: the brake pedal, the brake pump, the brake force corrector and the ‘servo’ brake support mechanism. The correct operation of all these elements is a guarantee of the safe use of the car and stopping its driving at any time necessary on the basis of the actions taken by the driver.

The brake calipers are one of the components of the braking system. Thanks to their structure, they make the vehicle slow down, stop and immobilize it when stationary. Figure 1 shows a diagram of the parts of a single-cylinder disc clamp manufactured on the analyzed production line.

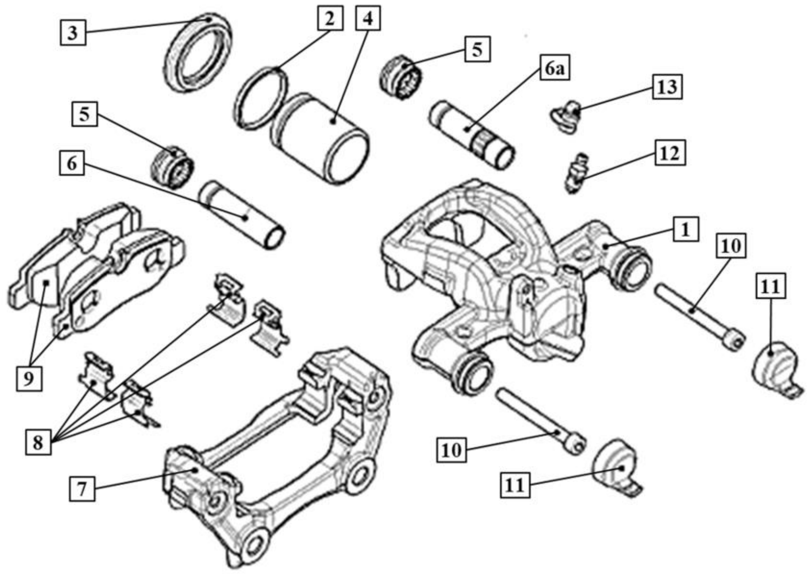

Fig. 1. Single cylinder single cylinder disc caliper parts diagram

A rubber seal (2) is installed in the groove in the piston seat made in the body (1). At the entrance of the piston seat in the body, one end of the dust bellows (3) is mounted. Then, the piston (4) is installed in the body, which has a specially profiled channel in the upper part, on which the other end of the dust bellows (3) is placed. The next stage is the assembly of the anti-dust bellows sleeves (guides) (5). They are mounted at one end in slots (grooves) made in the seats of the body sleeves. After their assembly, the sleeves (6) and (6a) are inserted into the sleeves of the sleeves, which also have special grooves in which the other ends of the anti-dust bellows (5) are placed. Then the screws (10) will be placed in the sleeves (6) and (6a). The next step in the production of the clamp is to install the springs (8) on the "teeth" of the bracket (7). The blocks (9) are placed between the springs (8). The bracket (7) with mounted springs (8) and blocks (9) is placed on the body (1) and connected to the sleeves (6) and (6a) by screws (10). Then, the plugs (11) are mounted on the specially machined outer parts of the sleeve sockets. The final stage of clamp production is screwing the vent (12) into the body and installing a protective cap (13) on the vent (12).

The production process of a brake caliper is a complex process. To produce it, specialized machining machines (i.e. computer-controlled machining centers) and specialized assembly lines are used. Compliance checks of the components, machined brake calliper bodies and supports, as well as the assembled brake calliper, are carried out using control devices built into the processes. Among the specialized control devices on the production line, the following can be distinguished:

- hardness testers (Brinell, Rockwell, for rubber),
- a machine for testing compressibility,
- 3D coordinate machines,
- pressure bank built into the assembly line,
- electric and pneumatic wrenches integrated with the computer system,

- roughness measuring instruments,
- projector for examining profiles,
- X Ray machine and instruments for testing the thickness of the coating.

The control processes for the analyzed product include the following: control of components (first patterns of execution from suppliers), control of the machining process and the galvanizing process of the produced parts of the clamp, and control of the assembly process. Quantitative guidelines for the conducted controls are defined for the production in the initial production phase and for the continuous control in the serial production phase for a given component.

3. Risk analysis for key production non-conformities

The analyzed manufacturing processes are composed of three basic areas: machining, galvanizing and assembly. Therefore, quality information from individual stages is recorded in non-compliance cards dedicated to individual processes, on which non-conformities occurring during the production of a given part at machining stations are recorded. Out-of-specification pieces, which are produced during the machining process of a given part, are entered by the operator into a sheet that conforms to the established standard. The data is further reported collectively in a spreadsheet, which is the basis for the calculation of KPI and PPM indicators of machining and material defects.

If there is a greater number of non-conforming products, apart from registering them in non-conformance cards, an analysis of the cause of its occurrence is also carried out. Most often, this analysis is performed using an effective problem solving method (Ingaldi M. 2014).

The problems occurring in the process of mounting a single-cylinder disc brake caliper were investigated. The process of assembling 15,000 brake calipers was inspected, i.e. in relation to one production batch. The observed discrepancies were subject to quantitative and qualitative analysis. For two types of non-compliance, the causes and effects were determined and the risk index was estimated in accordance with the FMEA method (table 1).

The results of the FMEA analysis for the two selected processes of manufacturing the brake caliper showed that it was not well protected against the possibility of its inconsistency. The obtained results of the Risk Index above the value of 250 in terms of legibility, completeness and accuracy of the label result in the immediate necessity to implement corrective actions. The high result of the Risk Index in this case is also related to the traceability, because the only method of control is to verify the legibility of the label using a scanner, which is performed by the assembly quality control inspector once a day. For other non-compliances where the Risk Index is above 250, the detection rate is also low as it is mainly based on visual inspection by the operator. Which in this case also turned out to be unreliable, which made it the basis for generating non-compliance.

Table 1. Analysis of selected points in the brake caliper assembly process

Process step	Potential incompatibility	the effects of ncompatibility	OCC	the cause of ncompatibility	DET	Current process control	SEV	Risk Priority	Recommended actions
Assembling the sleeve plug (CAP)	Failure to install the rubber plug	complaint: dirt on the socket of the sleeves, which may block the clamp or make it difficult to move the body in relation to the bracket	7	The operator skipped the assembly of the rubber stopper	6	Assembly operations card (FAOM); instructions / 100% visual inspection	6	252	Periodic operator training / use of a vision system to check for the presence of a sleeve plug
Assembling the sleeve plug (CAP)	Installation of a different cap code	Complaint; customer dissatisfaction	7	Incorrect component marking	6	Process standardization - Only one code for ferrule rubber stopper is used	1	42	N/A
Assembling the sleeve plug (CAP)	Movement of the pads, bushing and bracket when installing the plugs	Complaint; difficult assembly at the customer's site	7	Installation of the plug outside the assembly station	6	Assembly operations card (FAOM); instructions / Tooling and assembly sequence to ensure correct positioning	1	42	N/A
Sticking the customer's label	No label	Complaint; loss of traceability of terminals; the need to stop the customer's line;	6	Skipping the sticking operation labels by the operator	7	Assembly operations card (FAOM); instructions / 100% visual inspection	6	252	periodic training operators / use of a vision system to check the presence of the label
Sticking the customer's label	Wrong code on the label	Complaint; client-side line stop	7	Error in setting the program	6	Program setting control each time it is started / 100% visual inspection; label control with a scanner by the control inspector once per day	6	252	periodic operator training / implementation of compliance checks using a code reader and program
Sticking the customer's label	Unreadable label (wrong code position) – Data Matrix on the label	Complaint; client-side line stop	7	Operator error; Wrong setting or dirt on the printer	6	Printer inspection once a week / 100% visual inspection; control labels with a scanner by the quality control inspector once a day	6	252	Periodic operator training / use of the code reader

Process step	Potential incompatibility	the effects of ncompatibility	OCC	the cause of ncompatibility	DET	Current process control	SEV	Risk Priority	Recommended actions
Sticking the customer's label	Unreadable label (incomplete Data Matrix at the label)	Complaint; line stop at the customer side	7	Wrong setting or dirty printer	6	Printer inspection once a week / Label inspection by QC inspector once a day	7	294	use of a code reader
Sticking the customer's label	Sticking the same labels on two different clamps	Complaint; stopping line at the customer side	7	Operator mistake	6	100% visual control	6	252	Periodic operator training / use of a code reader

The first preventive actions that were defined to improve the detection of production errors is related to the improvement of human factors occurring in the process. They related to the organization of additional training for operators. The detailed scope of these trainings was to be the issues of responsibility for performance at work and emphasizing the importance of their work, and the impact of operators' work on the image of the entire company. Increasing employee motivation and commitment was planned through the implementation of a new incentive action plan, based on production bonuses and periodic salary increases. The increased intention for motivational activities was also intended to appreciate experienced and long-term employees. The second planned improvement action is the organization of the implementation of visual control systems. Visual inspection with regard to the analysis that the rubber stopper is present in the indicated location as well as the label on the assembled clamp. The third issue identified for quality improvement is the use of barcode readers, similar to the customer's system. This solution eliminates non-compliance related to the illegibility of the label, as it prevents the product from being registered in the system and requires immediate repair of this defect. After implementing the recommended preventive actions, an update of the FMEA analysis is scheduled.

4. STATISTICAL INDICATORS OF MANUFACTURING PROCESSES IN PRODUCTION SERIES

The performed assessment of the qualitative capacity of the brake caliper assembly process with the use of the Cp, Cpk indicators is intended to ensure the continuous monitoring of the quality level in the implemented processes. All stages of the manufacturing process are subject to statistical control, on the basis of which the quality condition is monitored in a continuous system. Cyclical analysis of indicators requires the results of measuring parameters in accordance with the guidelines of the procedure. One of the tested parameters is the measurement of the spacing of clamps after assembly.

For measurements, samples are taken from the production, 5 pieces of the test object, with a frequency of once a shift. In total, each analysis cycle includes 125 measurements of the tested feature. For each sample, the average value for the dimension and the range in the sample were calculated. These data become the basis for the construction of Shewart control charts for the tested feature. The dimension of the tested feature in the brake caliper production process must be within the tolerance of 13.5 +/- 0.5 mm in order to meet the customer's requirements. In determining the indicators of the qualitative ability Cp and Cpk, the results were obtained with the use of calculation formulas:

$$\sigma = \frac{\overline{R}}{d_2} = \frac{0,0626}{2,326} = 0,0263 \tag{1}$$

$$Cp = \frac{DGS - GGS}{6\sigma} = \frac{14,00 - 13,00}{6 * 0,0263} = 6,33 \tag{2}$$

$$Cpk_d = \frac{\bar{\bar{x}} - GGS}{3\sigma} = \frac{13,5607 - 13,00}{3 * 0,0263} = 7,10$$

$$Cpk_g = \frac{DGS - \bar{\bar{x}}}{3\sigma} = \frac{14,00 - 13,5607}{3 * 0,0263} = 5,57 \tag{3}$$

Where: GGS – upper tolerance limit (specified in the specification),
DGS – lower tolerance limit (specified in the specification),
σ – intra-sampling standard deviation

All the results obtained become the result of the statistical analysis on the control cards that are used in each production batch. Fig. 2 shows the results for the tested properties.

As shown in Figure 2, the obtained capability index calculations, the tested feature of the brake caliper assembly process meets the customer's requirements, and the process is qualitatively capable. The value of the Cp = 6.33 index confirms that the scatter of the examined process is smaller than the set tolerance limits. The process is potentially qualitatively capable of meeting the assumed customer requirements, and the ability is excellent and the process does not need any improvement actions. The results of the indicator are confirmed by the chart of the control chart of the values and the means, on which all the measurements are within the prescribed limits. On the other hand, the value of the Cpk index = 5.57 indicates a slight shift in the process and lack of centering. But this shift from the tolerance limits is acceptable and no adjustments are needed. This indicator is confirmed by the results of the control card in the first phase of the analysis. Measurements from sample no. 1 to 15, and from number 40 to 50 confirm the measurement result below the average value of the coefficient. They are still within the limit indications but concentrated on one side of the CL line

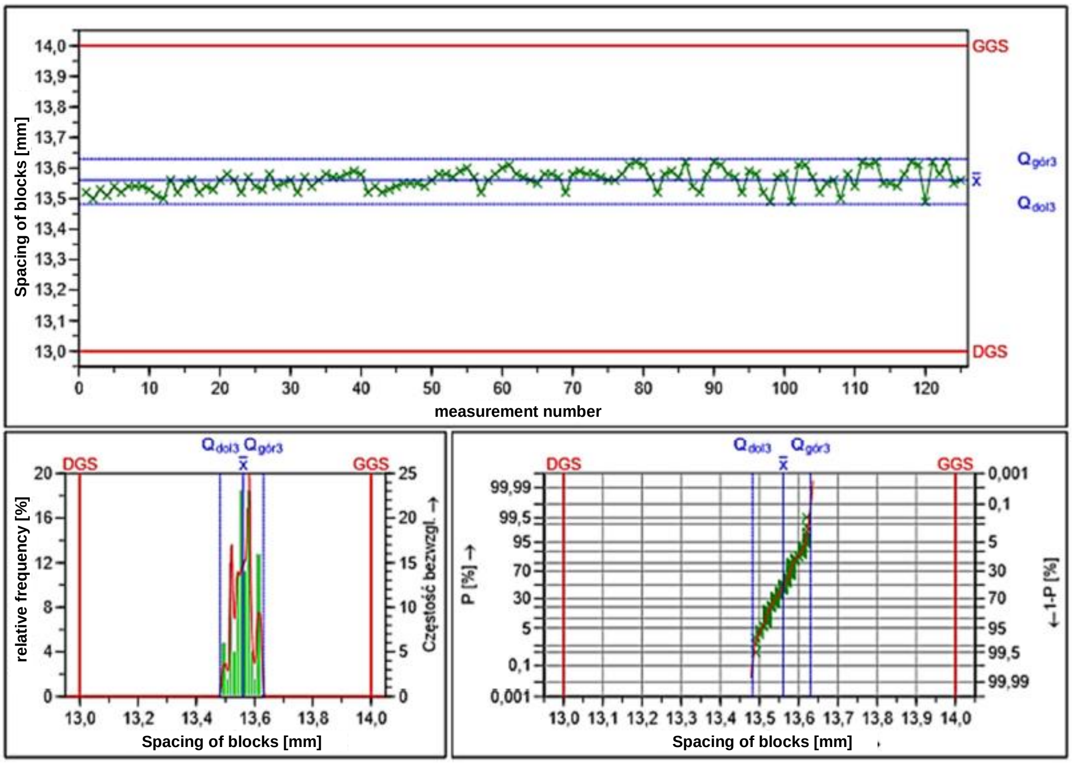

Fig. 2. Distribution of measurement results for the tested feature.

5. CONCLUSION

The process of monitoring nonconformities that result from processes is an important part of the quality management system. The collected data and their subsequent analysis as well as the implementation of appropriate corrective actions, which will allow for the improvement of processes and elimination of the causes of non-compliance, allow to improve the quality of manufactured products and reduce the costs of their production.

After all the recommended corrective actions were performed, the Risk Number Index was lowered. The assembly process has been improved, and the implemented corrective actions have brought the expected effect, which resulted in a reduction in the number of defective parts and a reduction in production costs. The applied preventive action in the form of a vision control system, the use of which was used to detect non-compliance in the absence of a label and no rubber stopper, allowed to eliminate the occurrence of another critical non-compliance - no supply hole plug.

The analysis of the data of non-compliance cards in the production process and the analysis of the causes and effects of the most important of them allowed to take actions in the field of label legibility and the location of the rubber plug (CAP). The proposed actions indicated the necessity to supplement the process with a visual inspection system for the presence of rubber and the use of a code reader to control the readability and compliance of the customer's label. In addition, all activities were attached to periodic employee training in order to increase employee involvement in the quality of control activities performed.

A research entity as a leader in the automotive industry, in which there is a quality assurance system, uses a set of quality analyzes as the basis for supervision and improvement for the implemented manufacturing processes. The main starting point for the analyzes is the definition of improvement activities that include both technical solutions and staff development (Klimecka-Tatar, D., Shinde V., 2019). The research entity puts a lot of emphasis on the continuous improvement of employees following training. These trainings, both in the field of new activities on the production line, also cover the issues of managing employee teams, work in task teams and motivation. (Ulewicz et all. 2019). The quality management tools that have been presented constitute the basis of process documentation, thanks to which they are implemented on quantitative data in a continuous system, obtained in real time from processes.

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