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Manufacturing Quality: Performance and Capability Indices, Method, Results

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Abstract
In order to create products that meet customer requirements, organizations consider specific, systematic quality planning actions. To plan the quality of a product and draw up the control plan, the APQP concept (Advanced Product Quality Planning) is applied in the automotive industry. In this context, the article presents how the process capability analysis is used, as a method included in APQP, before starting serial production, but also during the operation of a system, in order to assess the ability of the processes to produce goods according to the requirements. In this context, the ability and performance indices of the processes were defined and in the presented case study, the ability of an assembly line of components in the automotive industry was determined. Capability analysis is part of the preventive methods of statistical process control. The importance of process capability evaluation was emphasized to characterize the manufacturing quality (reduce scrap and rework, increase productivity, improve overall quality, streamline the process, continuously monitor processes to maintain control), in general and the efficiency of the considered assembly process, in particular.

Keywords
manufacturing quality, process capability, 6σ

1. Introduction

One of the central objectives of organizations is to achieve the quality of products or services. Currently, at the level of the entire organization, the quality approach implies the implementation of systematic actions for planning, control and improvement of the quality of products and processes.

Product quality control is carried out in a planned manner, at various stages of the product manufacturing process, with the aim of detecting products with non-conformities. The term "non-conformity" is used with the meaning of deviation/ failure to fulfill a requirement. When it is found that the product deviates from the characteristics in the specifications (project, technical drawings, standards, etc.), the product must be repaired/reworked, if it is possible; otherwise, the product is declared scrap. At the same time, in quality-oriented organizations, information about non-conformities is the basis of corrective actions - actions on the causes of non-conformities to prevent their repetition.

For the manufacture of products, the main indicators for characterizing the quality of manufacture [1] are the rate of scrap (non-conformities), the cost of rejects goods and the cost of rework. The scrap rate represents the percentage share of parts with non-conformities in the total number of products made, in a certain period of time. High levels of scrap rate suggest low quality of technological manufacturing processes. In order for the scrap rate not to negatively influence deliveries, organizations sometimes included the scrap rate in the production plan. This means it will be manufactured a larger quantity than what was ordered by customers. The situation could cause unjustified expenses, so it does not meet the efficiency requirements.

The alternative is to prevent the occurrence of non-conformities, which is achieved within organizations through different specific methods. For example, the maintenance of the machines carried out in a planned way provide information on their technical condition and allow the assessment of their availability to carry out processing / assembly operations according to the requirements set out in the technical documentation of the products to be manufactured.

In the last decades [2] to prevent the occurrence of scraps, preventive methods of statistical control of processes [3], such as variability analysis and process capability analysis, are increasingly used.

The concept of capability [1, 2] refers to the ability of a process or system to achieve outputs according to technical specifications.

A high level of process capability is the result of optimizing the interactions between machines, materials/components, operators, work processes and control. A high level of process capability is a reflection of a low volume of nonconformities.

2. Case Study on Determining the Capability of Automotive Component Assembly Processes

2.1. Performance and capability indices of the processes

Process capability indices such as Process Capability Index (C_p), Corrected Process Capability Index (C_{pk}), Process Performance Index (P_p) and Process Performance Corrected Index (P_{pk}) are fundamental tools in the area of quality management, especially in the manufacturing area, but also in industrial processes [3, 4]. They define values that allow determining the capabilities of production processes, indicating whether the obtained values fall within designated specifications and tolerances; this is a key aspect for maintaining high quality of products and services.

Performance and capability indices suggest how one or more characteristics of a product or process (the technological system) behave in relation to the engineering specifications (the technical system). The performance and capability indices link the design specifications, established as a result of the client's requirements, and the calculated control limits.

There are several performance and capability indexes that can be used in practice, the most used being the capability indexes C_p and C_{pk} and the performance indexes P_p and P_{pk}.

According to [3] process capability is defined as the ratio between the distance from the center of the process to the nearest specified limit and a measure of process variability, relation (1):

$$C_P = min\left(\frac{USL-\mu}{3\sigma} - \frac{\mu-LSL}{3\sigma}\right), \tag{1}$$

where: USL and LSL are the specified upper and lower limits;
μ - average value of the measured values;
σ – standard deviation for individual measurements of the characteristic of interest;
μ and σ values are estimated from the data collected from the process.

Or, more simply, process capability is defined as the ratio between the tolerance field of the measured variable, imposed by the technical specifications and 6σ, relation (2).

$$C_p = \frac{USL-LSL}{6\sigma}. \tag{2}$$

If the process data are collected in subgroups, P_{pk} and C_{pk} are used as performance and capability indices, relations (3) and (4), [3, 5]:

$$P_{PK} = min\left(\frac{USL-\bar{\bar{X}}}{3\sigma_S} - \frac{\bar{\bar{X}}-LSL}{3\sigma_S}\right), \tag{3}$$

$$C_{PK} = min\left(\frac{USL-\bar{\bar{X}}}{3\hat{\sigma}_{\frac{\bar{R}}{d^2}}} - \frac{\bar{\bar{X}}-LSL}{3\hat{\sigma}_{\frac{\bar{R}}{d^2}}}\right), \tag{4}$$

where: $\bar{\bar{X}}$ – the general average used to estimate the average of the studied process μ;
$\hat{\sigma}$, $\hat{\sigma}_{\frac{\bar{R}}{d^2}}$ – different estimates of the standard deviation of the process σ
σ_S – estimate given by the standard deviation of the entire data sample, relation (5)

$$\sigma_S = \sqrt{\frac{1}{nm-1}\sum_{j=1}^{n}\sum_{i=1}^{m} X_{ij} - \bar{\bar{X}}^2} \tag{5}$$

where: X_{ij}, i = 1,...m, j = 1,...n, are the data collected from processes in unit j in subgroup of order i;
m - the total number of subgroups;

n – the total number of measurements in the subgroup (the sample).

Therefore, considering that several indices can be calculated, the question arises as to which estimate provides a better measure of the variability of the process. The answer is given from the customer's perspective. It follows from the practical activity that the main purpose of using the ability indices is to report to the client, therefore it is indicated to consider those indices that the client wants to know.

It is considered that the studied process is proceeding normally if the deviations fall within the limits of an established interval, called confidence interval - 6σ and there was no subgroup – to- subgroup variation (figure 1).

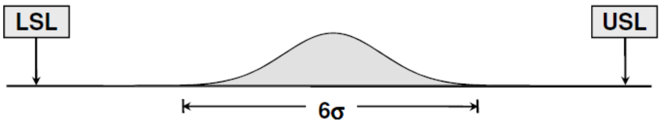

Fig. 1. Process capability, centered and stable

The specification represents what the customer will accept. Process capability compares the variation of the process to the specifications. The capability indices tell us about the risk of producing outside the specifications limits. Also, capability Indices are valid if, and only if, the data are normally distributed. If the data are not normally distributed, capability indices are only a number and have no value in assessing process capability.

2.2. Basic information for the case study

The objective of the case study is to determine the capability of the assembly line in order to validate it. The validation of the assembly line means the certification of the fact that all the workstations – the assembly stations – are capable of producing sub-assemblies without non-conformities – according to the customer requirements expressed in the specifications and technical drawings.

The standards of the automotive industry (AIAG – Automotive Industry Action Group) [6] require carrying out the station capability study in the following cases:

- the production line is new – the procedure is necessary to check the stability of the processes, as part of APQP concept;
- transfer of the production line from one location to another;
- changing the location of the line in the production hall;
- major interventions on the workstations within the line, such as: automation, robotization, modification of the work method, etc.

In this context, the development of the component assembly process on a line specialized in the manufacture of subassemblies used in the powertrain area of automobiles was monitored (Figure 2).

The assembly line that must be validated consists of 11 workstations. Figure 3 shows the flow diagram of the assembly process of the finished product.

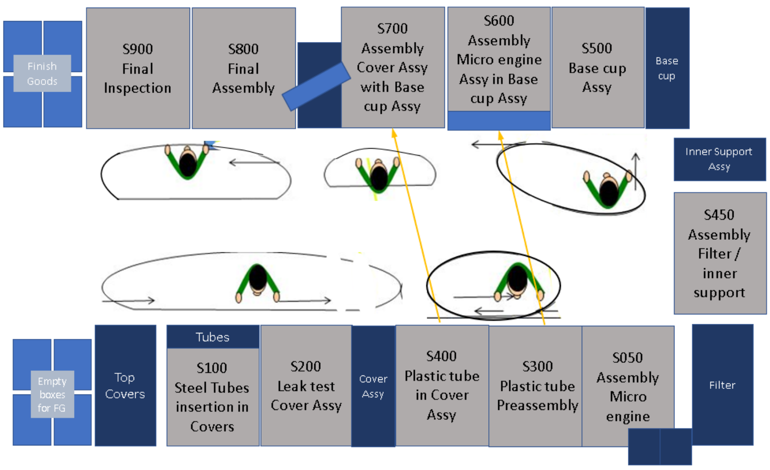

Fig. 2. Layout assembly line

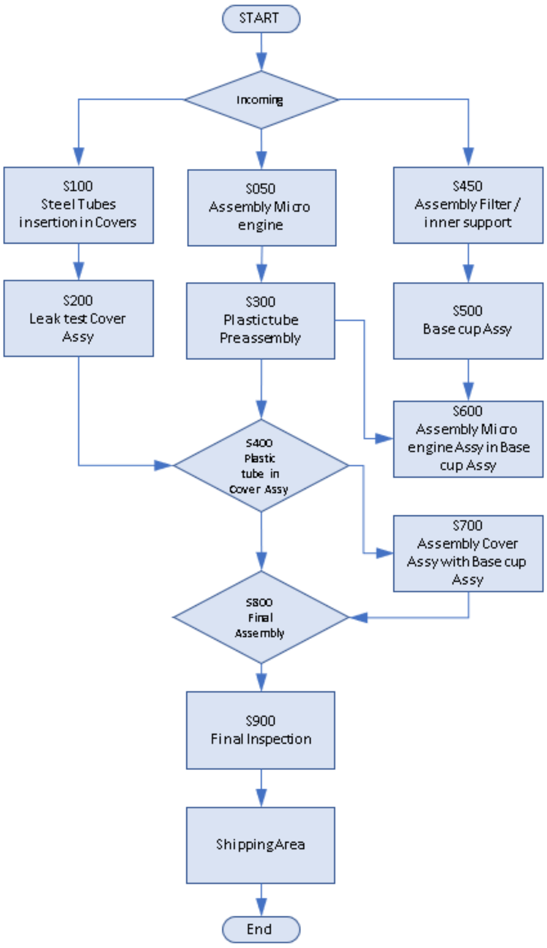

Fig. 3. Process flow diagram

In the flow diagram (figure 3) the Incoming block suggests that all the components that are going to enter the assembly line go through an initial check, from the point of view of compliance with the requirements established by the technical documentation of each component within the assembly.

In the rectangular blocks (S100, S200, S400, S300, S050, S450, S500, S600, S700) assembly processes of the components in subassemblies take place.

The decision-making blocks mean that in addition to the actual assembly process, verifications of the respective sub-assemblies are also carried out.

To determine the capability of a process, the following steps are taken:

- Tthe data is collected - measured values following the assembly processes so that the respective subassemblies comply with the specifications;
- enter the data in a special software for data processing (eg Minitab, Statistica Six sigma);
- it is tested if the data under study belong to the normal distribution;
- the capability of the process is analyzed.

According to the requirements of the automotive industry [6], before the start of series production, it is mandatory that the first three deliveries be checked by sampling for each order received.

Due to the specificity of the processes carried out at each workstation, the following procedure was used to determine the capability:

- data were collected at stations: S100, S200, S050, S600 (Table 1). A minimum number of 50 measured values, considered representative for the description of the processes, were taken into account;
- in the case of the other stations, even if assembly processes are taking place at some of them, the type of checks was of the Ok/No Ok form, or of the qualitative type, so that they were not taken into account in the present study.

Table 1. Collected data

Stations	S100		S200	S050	S600	Stations	S100		S200	S050	S600
No.	Tube 1	Tube 2				No.	Tube 1	Tube 2			
1	117.14	117.15	4	2.1	101.4	26	117.10	117.13	11	1.9	101.2
2	117.17	117.20	9	1.8	101.2	27	117.19	117.21	12	1.9	101.2
3	117.10	117.15	10	1.9	101.2	28	117.04	117.17	9	1.9	101.2
4	117.16	117.17	12	1.8	101.2	29	117.16	117.18	12	1.9	101.2
5	117.16	117.18	10	2.0	101.2	30	117.11	117.14	12	1.9	101.2
6	117.05	117.10	11	1.8	101.2	31	117.13	117.16	11	1.9	101.2
7	117.19	117.21	11	1.9	101.1	32	117.15	117.17	10	1.9	101.2
8	117.14	117.18	12	1.8	101.0	33	117.10	117.16	10	1.9	101.0
9	117.16	117.17	12	1.8	101.0	34	117.06	117.10	11	1.8	101.1
10	117.17	117.19	13	2.0	100.9	35	117.11	117.15	11	1.9	101.2
11	117.20	117.22	13	2.0	100.7	36	117.14	117.17	12	1.8	101.2
12	117.12	117.16	7	1.9	101.2	37	117.08	117.12	11	1.9	101.0
13	117.09	117.13	10	1.9	101.2	38	117.16	117.19	11	1.9	101.2
14	117.15	117.17	10	1.8	101.2	39	117.14	117.16	12	1.9	101.2
15	117.00	117.07	9	1.9	101.2	40	117.09	117.10	11	1.9	101.1
16	117.18	117.18	13	1.9	101.2	41	117.11	117.13	12	1.9	101.2
17	117.13	117.15	12	1.9	101.2	42	117.14	117.17	12	1.9	101.2
18	117.07	117.10	12	2.0	101.1	43	117.11	117.14	11	1.9	101.2
19	117.10	117.14	12	1.9	101.2	44	117.11	117.13	11	1.9	101.2
20	117.08	117.11	12	1.8	101.2	45	117.11	117.15	11	2.0	101.2
21	117.12	117.14	11	1.8	101.2	46	117.13	117.16	11	2.0	101.2
22	117.09	117.11	10	1.9	101.2	47	117.13	117.16	11	1.9	101.2
23	117.11	117.13	11	1.8	101.2	48	117.14	117.16	12	1.9	101.2
24	117.17	117.19	12	1.9	101.2	49	117.10	117.14	10	1.9	101.2
25	117.07	117.10	12	2.0	101.2	50	117.10	117.13	11	1.9	101.2

According to [6], it is considered that the performance requirements of the ongoing processes are defined by the client. For the studied assembly line, the performance and capability indices values were set by the client. These are:

$C_p \geq 2$; $C_{pk} \geq 1.67$; $P_p \geq 2$; $P_{pk} \geq 1.67$

If the client does not establish these values, the following values can be considered [6]:

$C_{pk} \geq 1.33$ – means stable processes and data that are distributed according to the normal distribution,

$P_{pk} \geq 1.67$ – means chronically unstable processes whose output meets the specifications, the data is distributed according to a predictable pattern.

3. Results

The evaluation of the capability of each station was carried out based on the data from Table 1 using Minitab software.

Capability and performance indices were determined for each station. The calculations were made considering the values of the upper and lower limits related to the technical documentation of the subassemblies that are assembled at each station that was analyzed.

Analyzing the five samples, it can be seen that all the data series are normally distributed and the values of the capability and performance indices respect the values set by the client, for all five samples (figures 4, 5, 6).

For the other work stations within the line, the quality check of the subassemblies is carried out. The check involves 100% automatic control with the presence sensors, end-of-race sensors, video cameras. The validation of the sensors is done with the ACE (Automatic Control Efficiency) test, which demonstrates that they are capable of differentiating good subassemblies from those with non-conformities.

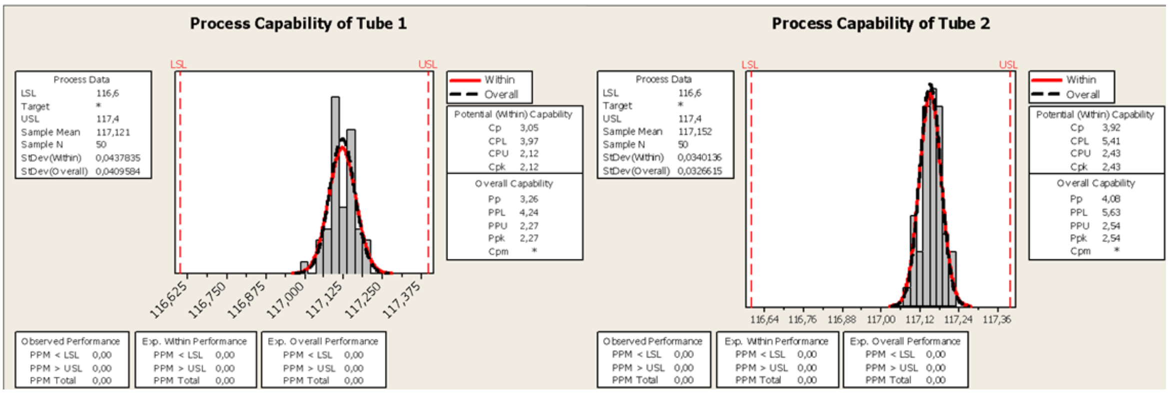

Fig. 4. Process capability at S100

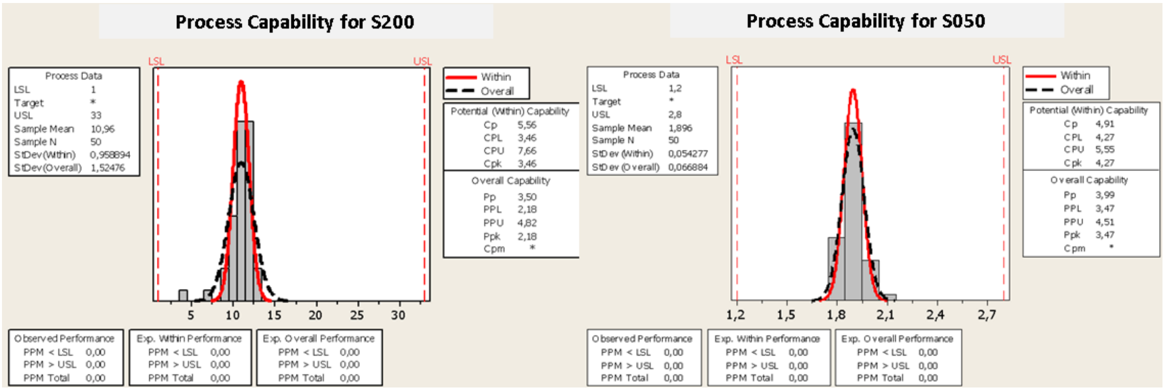

Fig. 5. Process capability at S200 and S050

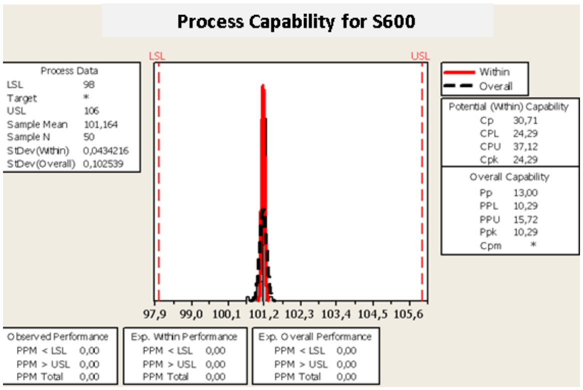

Fig. 6. Process capability at S600

4. Conclusions

Following the results obtained, it appears that the assembly line studied from the point of view of the stability of the ongoing processes, has been validated, thus demonstrating its capability. Considering the requirements of various quality standards, for the study of other situations, the management of the organization must also consider the length of time for which the capability must be demonstrated, which sampling method should be used and how the data should be reported.

Performance and capability indices provide important information to both clients and suppliers. At the request of the customers, the suppliers have the obligation to offer the customers these indices for all the critical characteristics of the product or process. Also, suppliers can use these indices to evaluate products and processes, their evolution over time and to establish priorities in the continuous improvement activity [3, 4].

The process capability study refers to determining their performance and checking if the natural variation of the processes falls within the established limits. Determining the capability of the technological processes leads to the determination of the real performance of the process in this way inducing customers to be guaranteed that the manufactured products are of quality.

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