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Solving quality problems in tyre production preparation process: a practical approach

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Abstract

This work was carried out at Continental tyre factory in Portugal, regarding the APEX machines production process, with the main goal of improving of their performance and product quality rate. Main possible causes of defect generation were identified and proposals to enhance the functioning of the bead APEX production process were also carried out. By applying Six Sigma, variables that influence the quality of the production were identified. DMAIC cycle (Define, Measure, Analyse, Improve and Control) was applied in the process analysis, enabling a structured analysis and the identification of different causes that negatively affect the process studied and consequently allowed the identification of opportunities for improvement.
With the help of the DMAIC method, a series of experiments were developed in order to achieve improvements in product quality rate and process control and stabilization.

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Keywords: Tyre, Production, Quality, Lean, Six Sigma, DMAIC

1. Introduction

The automotive industry is now facing a significant amount of changes in view of the constant technological evolution, new competitors and the industry shift from mass production to mass customization paradigms. This new scenario provides challenges but also opportunities [1]. Among those challenges is the present economy recession

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that started in 2009. Thus, the improvement in productivity, quality, and flexibility, reducing in this way the cost, are necessary steps to respond to these challenges and seize these opportunities [2]. The tyre is an automotive part and, as a result, this automotive industry segment is also facing the same challenges.

The tyre is composed of many parts, such as tread, steel and textile cord plies, inner liner, bead APEX and bead core, and has a production system divided into five stages: mixing, preparation (hot and cold), construction, vulcanization and final inspection.

This work was carried out at Continental tyre factory in the bead APEX production process, with the purpose of improving machine performance and bead quality rate. This part consists of a metal hoop wrapped in rubber, and has the function of transmitting the rotational force of the rim to the tyre. The main goal was to optimize the manufacturing process of beads in automotive tyres, a part produced in the preparation stage. Concerning the final product fabrication, the main problem was identified as bubbles (retained air) inside the tyre and, after a detailed analysis from Continental quality and process department, the conclusion was that the origin of retained air is the bead, most precisely the production process of bead APEX and assembly to the bead core.

The methodology applied was the DMAIC cycle, at an earlier stage and after the production process analysis that will be described in session 3. After the initial Pareto analysis, the focus of the project was defined: control bead APEX dimensions in order to reduce the number of non-conforming beads. As the weight results from the overall dimensions, it was also controlled. As the factory has a series of different product types, twelve APEX machines and three working shifts, and due production schedule, only one product and the corresponding production machine were selected to be studied.

Experiments and statistical process control (SPC) was defined and data collection was carried out throughout six months. Correlations between the defined variables were calculated but, since the results showed a very weak correlation, it was decided to use average and amplitude control chart, *X-R*, regarding widths and thickness parameters, and individual observations and amplitude control *I-AM* charts to weigh parameter. Also, a process capability analysis was performed for the variables studied, using capability histograms to calculate process C_p and C_{pk}. Consequently, suggestion and implementation of improvements were made by the authors in order to achieve the better quality rate of the component, to achieve six-sigma Continental goals and reduce/eliminate the amount of scrap due to retained air.

This paper is organized as follows: section 2 presents a literature review on the techniques used, section 3 presents the case studied and the methodology applied to do the data collection and its analysis and presents the results. Section 4 presents the main conclusions, limitations and future work.

2. Literature review

The Lean Production Paradigm is one of the approaches that can be used to achieve productive and quality goals [3]. Created by Taichi Ohno, the Lean Manufacturing philosophy [4,5,9], also known as Toyota Production System (TPS) due to the early work developed at Toyota's production plant in the fifties was applied to car engine manufacturing, in the sixties to car assembly and in the seventies to the supply chain. Ever since its success and results fostered a worldwide application in other industries beyond automotive [5]. It aims to identify and remove every activity in design, production and supply chain management-related processes that do not add value from the customer’s point of view [4,5]. It is an approach to the production flow and has waste elimination (cost reduction) as a main goal, through quantity and quality control, using specific tools and techniques from a continuous improvement perspective, producing when needed at the time needed in the quantities needed [6]. Six Sigma is an extension of lean principles and it is focused on process continuous improvement with the main goal of zero process defects [7]. Every process has variation and with Six Sigma the process characteristics can be defined and, with proper tools, reduced. The impact of Six Sigma on lean production systems is the reduction of defects, with less stoppage and machine adjustments due to the variation of incoming parts. Many quality characteristics can be expressed in terms of numerical measurement. A single measure quality characteristic is called a variable [13]. Statistical process control (SPC) tools charts are widely used in industries [10, 14] to assess and control industrial processes [15], being referred to as the most popular method used for the productive process in systems quality assurance [12]. SPC involves statistical techniques to measure and analyse the variation of the process to check product quality and maintain processes to a fixed target [12], being one of the main tools used in DMAIC cycle [13]. DMAIC cycle is a way to implement Six Sigma in existing production processes, consisting in a five steps methodology: Define, Measure, Analyse, Improve and Control - using tools as Histograms, Pareto Charts, SPC and Analysis of Variance (ANOVA). This methodology is similar to Deming cycle (Plan-Do-Check-Act) problem approach [9]. One disadvantage of univariate monitoring schemes is that for a single process, many variables may be monitored and even controlled. In order to overcome this problem, multivariate tools can be used [11]. The production process quality output can be measured by the joint level of several correlated characteristics [10, 11], supported by modern data-acquisition equipment. In automotive and parts industries, considering the standards' specifications used for quality assurance, the commonly quality tools used are charts *X-R* and *X-S* as parameters control [11]. Traditional control charts *X-R* are used to analyze the process critical points. The order of action to implement *X-R* is [12, 13]: (1) Analysis of production process; (2) Choice of estimation features of the product; (3) Settlement of the size sample and as well the frequency of taking sample size, at least four; (4) Project of form to assembling dates; (5) Designing of control charts according to references [12, 13, 16].

3. Study definition and Problem approach methodology

In order to develop improvements in an industrial context or machine process, it is first necessary to define the production system to be studied, the corresponding initial status, and define the analysis focus and goal.

3.1. Bead Apex production system

The bead is produced in a machine named APEX, see figure 1, which is composed of different modules, from an extruder to the drum. The APEX machine is divided into eight modules: extruder, conveyor belt, cooling drum, loop system, slitter, cutting/transport table, application drum and automatic spacer and bead core transporter. Each module has a different role in the production process. The process can be described as follows:

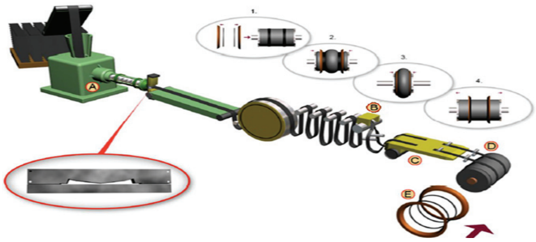

Fig. 1 - APEX machine and bead APEX application scheme

1. The extruder (A) is fed with rubber compound, which is melted and pressed against a die with the bead APEX desired dimensions. This process occurs under a specific temperature, pressure and speed;
2. After the extrusion process, the originated rubber strip is transported on a belt conveyor to the cooling drum. This conveyor has a specific speed in order to keep de rubber profile dimensions;
3. The cooling drum and loop system have the role of maintaining the rubber temperature at a specific value to make allow cutting and applying the rubber strips. Also, the loop system operates as a waiting zone and production flow regulator. The system has a set of infra-red sensors to promote the speed adjustment of the extruder and conveyor belt as a function of the rubber position in the loop system;
4. In the slitter (B) the rubber strip is divided, generating two strips with the same width dimensions;
5. Next, the two strips are pushed by an automatic mechanism to the cutting table (C), and oriented by a set of guides to proceed to the length cutting process. This process is performed by a blade positioned with a specific angle that presses and cuts the two strips;
6. The strips are pushed by the automatic mechanism and are guided towards the drum (D) to which they are applied with one edge overlapping the other, generating two rubber circles. The drum is composed by an elastic material and filled with compressed air and, with specific pressure the rubber strips are fixed to the drum and

applied on the bead core;

7. The bead core is produced previously in a different machine, and here a pair of bead cores are introduced, by the worker, in steel claws which automatically move the cores to the correct position on the drum.

3.2. DMAIC

The problem approach methodology was based on the DMAIC cycle, using quality tools in order to develop improvements. The DMAIC cycle consists of defining the problem and its causes, collecting data and measuring the process initial status, analysing process data in order to develop improvements and controlling the implemented changes in the production process. These steps will be described in detail in the next paragraphs.

Define step: The identified problem was non-conforming beads, which means that the beads produced do not comply to the quality requirements, see table 1, of this product regarding factors such as weight and dimensions. For a better understanding of the analysed problem, figure 2 A, B and C represent non-conforming beads and D represents a well-applied bead.

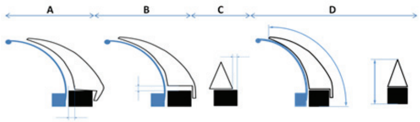

Fig. 2 - Bead APEX application: non-conforming bead (A, B and C) and a well-applied bead (D)

After studying the production system, the next step was to perform a root-cause analysis, see appendix 1. The authors, with the collaboration of APEX machine workers, built a cause-effect diagram and a cause-effect matrix, where each involved person in the study classified the importance level of each cause. Through a Pareto analysis, see figure 3, the main causes of the problem were established. Although the major causes detected were: bead APEX dimensions out of specification limits, wrong bead APEX application on bead core and wrong bead APEX application on diaphragm, and due to the project timeline, it was decided to start to analyse the causes with higher representation on non-conforming beads. i.e., bead APEX dimensions and bead APEX weight outside specification limits, which can be correlated. The bead APEX application process is on D point and the dimensions are generated by the A, B and C points (see figure 1) of the APEX machine. Variables to be controlled were defined, as can be seen in data collection method section. Correlation analyses were calculated and very weak correlations were found. Hence, it was decided to use traditional univariate charts, applied only to one defined bead product (in production) and in the corresponding bead production machine, as every machine has its own characteristics and every different bead product has different parameters. In future, the achieved improvements will be extended to the remaining products and APEX machines.

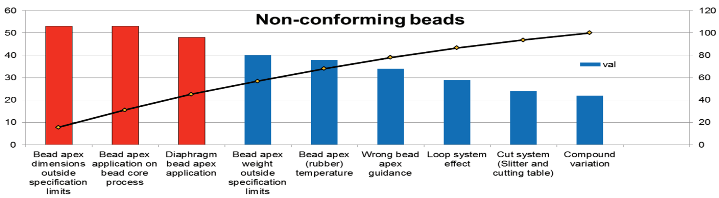

Fig. 3 – Pareto's causes analysis

Data collection method: The first step in data collection was to identify the important data type for this study, i.e. to choose and register the information of everything that influences the bead APEX dimensions and, consequently, the product. After a previous analysis, the chosen variables were: compound data, extrusion setup speed, extrusion real speed, extrusion setup temperature, extrusion real temperature, die abrasion, conveyor belt speed and rubber strips position in the loop system. The analysis's output allowed the identification of the following variables: bead APEX thickness (before and after application), bead APEX width (before and after application), bead APEX weight, splice overlap and splice overstep. A brand new die was fabricated to eliminate the abrasion factor, so this was not deemed a variable any more. The data collection method consisted of two phases:

1. With a notebook, the compound data, then speeds and temperatures, rubber strips position in loop system were registered through a schematic analysis;
2. Widths, thickness, weight, overlap and overstep splice were measured and registered using a scaler and a scale. Quality evaluation was also achieved by registering the non-conformity types as well as well-applied beads.

The sample size was defined based on time restrictions, productive planning and machine availability. It was composed by twenty beads, corresponding to ten bead pairs collected at the same time (as the machine produces one bead pair at a time), in a defined moment of the day and shift, during different days. In the beginning of the analysis five samples were collected and, in the experimental phase, three samples were collected at each trial. For each sample, the width and thickness were registered three times at different places of the bead body (one quarter, middle, and three-quarters), being the weight registered just once at phase 1.

Data analysis method: To control the process, weight, width and thickness dimensions of bead APEX were measured using $\bar{X}-R$ charts in order to achieve quality improvements. For each dimension, using Minitab software that implements SPC and the $\bar{X}-R$ charts referred to in section 2, the average, upper and lower control limits were defined, based on production specifications (see appendix 2). After the collection process, the data was registered in an MS Excel® file. Speeds and temperatures were analyzed using line charts, and quality was analyzed through attribute histogram analysis. A process capability analysis for the variables studied was also performed using capability histograms to calculate process *cp* and *cpk*.

Production specifications: Each product has its own specifications, both for input and output variables. Thus, one type of bead was select to study. There are two types of beads: narrow (≤15 mm) and large (>15 mm). Continental control quality knows that tyres with retained air often occur with narrow beads. Based on that information, a narrow bead was chosen, which is produced daily in the APEX machines. The specifications for the chosen product are also presented in appendix 2.

Measure step: In this step the data was collected and statistically analysed from the initial process at the bead APEX production process, see table 1. Considering appendix 2 specifications and analysing the mean, minimum and maximum of each variable from table 1, it is possible to note that the extrusion speed and extrusion temperature presented values out of production specifications and showed some significant deviations from the average value. The bead APEX weight was also out of specification limits.

Table 1- Data from the initial process status analysis in terms of dimensions and weight

Variable	Data		
Input speed (rpm)	Average: 7,24 rpm	Min: 7 rpm	Max: 7,5 rpm
Extrusion speed (rpm)	Average: 6,71 rpm;	Min: 5,9 rpm;	Max: 10 rpm
Input temperature (°C)	Average: 79 °C;	Min: 73°C;	Max: 85 °C
Extrusion temperature (°C)	Average: 85,6 °C	Min: 79°C	Max: 92°C
Bead APEX width before (mm)	Average: 13,48 mm	Min: 12,87 mm	Max: 14,43 mm
Bead APEX thickness before (mm)	Average: 7,08 mm	Min: 6,73 mm	Max: 7,38 mm
Bead APEX weight (g)	Average: 88,95 g	Min: 82 g	Max: 98 g
Bead APEX width after (mm)	Average: 12,93 mm	Min: 12,33 mm	Max: 13,73 mm
Bead APEX thickness after (mm)	Average: 6,41 mm	Min: 6,13 mm	Max: 6,73 mm

Figure 4 presents Minitab output of the process control charts and capability data for both dimensions and weight of the bead APEX, before and after its application.

Width: In terms of process control charts rules [12, 16], by analysing the red dots, it can be concluded that the process is out of control with several points outside of control limits of *X* charts before and after application. The data variability is also visible, meaning that the bead APEX width is affected, on different days, by different workers, using different parameters and work methods. Regarding the process capability, this study was focused just on C_p and C_{pk} because short term capability values are negligible regarding the good values of C_p and C_{pk} obtained (see table 2) [12].

Thickness: The process is also out of control in terms of thickness. Before bead application C_p was equal to 1,54, while after application it lowered to 1,14, meaning that this parameter is out of the company standard requirements.

Weight: This variable presents C_p and C_{pk} values above the literature reference values.

Table 2- Experiments capability results

Input Speed	Variable	Cp	Cpk	Ideal Cpk	Evaluation	Quality Rate
6 rpm	Width B	3.98	1.37	≥1.33	NOK	0 % (0/40)
	Weight	1.12	-0.46	≥1.33		
	Thickness B	1.25	0.22	≥1.33		
	Width A	3.08	1.71	≥1.33		
	Thickness A	1.49	-0.56	≥1.33		
7 rpm	Width B	3.05	2.11	≥1.33	OK	52.5 % (21/40)
	Weight	1.54	1.18	≥1.33		
	Thickness B	1.49	0.37	≥1.33		
	Width A	2.41	2.19	≥1.33		
	Thickness A	1.68	1.63	≥1.33		
8 rpm	Width B	2.85	2.32	≥1.33	NOK	15% (6/40)
	Weight	1.28	0.15	≥1.33		
	Thickness B	1.12	-0.45	≥1.33		
	Width A	2.99	2.93	≥1.33		
	Thickness A	1.85	0.44	≥1.33		

Analyse step: Knowing the initial status of the production process, the next step was to define the causes of dimensions and weight outside of control limits. After a Pareto's analysis, see appendix 3, the APEX production inputs were analysed: compound, extrusion speed and extrusion temperature. It was possible to conclude that speed and temperature have a significant role in the bead APEX dimensions, so those were the input variables studied.

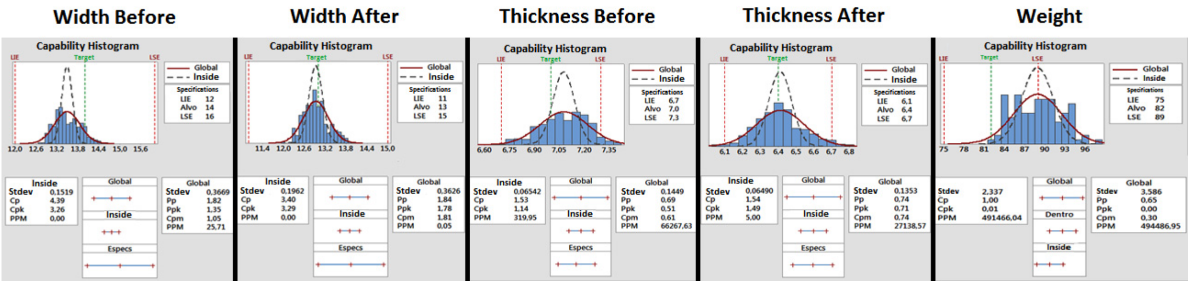

Fig. 4 - Bead APEX dimensions: width and thickness before , after bead APEX application and weight capability charts and data

Improvement step: In this step the work group decided to define a series of experiments in order to find the optimum extrusion speed and temperature, i.e. to find the speed and temperature input values that generate dimensions and weight data in statistical control, with good capability indicators and the best quality rate.

Instead of generating random combinations of speed and temperature (Taguchi DOE method), a set of workable combinations was designed in order to reduce the number of experiments. As in the initial APEX machine process analysis, the temperature values were always defined in a range from 75 to 80°C and, for the speed, in a range from 6.5 to 7.5 rpm. Two different temperatures were used, 75 and 80°C, and for each temperature value the input extrusion speed was varied within the values of 6, 7 and 8 rpm, and every experiment was done twice, resulting in a total twelve experiments. As an example, only one of the twelve experiments is presented, the one with the best results. Figure 4 presents the results of capability and quality analysis of the experiments with a temperature of 75°C. The experience that presents the best process capability indicator and the best quality rate was the one with a temperature of 75°C and an extrusion speed of 7 rpm, with width, thickness and weight with good C_p and C_{pk} values and with 52.5% well-applied beads.

Control step: In order to validate the experimental results a data collection and analysis procedure was carried out again, as can be seen in tables 3 and 4. This control experiment shows that with a temperature of 75°C and a speed of 7 rpm, the process presented very good capability values and a better quality rate, of 60%. Figure 6 presents the comparison values between initial status and after improvement process status. The quality rate increased by 41%.

Table 3- Control experiment capability results.

Process Initial Status			After Improvement Process Status		
Variable	Cpk	Quality Rate	Variable	Cpk	Quality Rate
Width B	3.26	19% (19/100)	Width	4.49	60% (24/40)
Width A	3.29		Width A	3.89	
Thickness B	1,14		Thickness	1.2	
Thickness A	1,49		Thickness A	1.55	
Weight	0.01		Weight	0.89	

Table 4- Process initial status versus after improvements status

Input	Variable	Cp	Cpk	Ideal Cpk	Quality Rate
Speed: 7rpm Temperature:75°C	Width B	6.68	4.49	≥1.33	60% (24/40)
	Thickness B	1.54	1.20	≥1.33	
	Weight	2.45	0.87	≥1.33	
	Width A	4.34	3.89	≥1.33	
	Thickness A	1.71	1.55	≥1.33	

4. Conclusions

Statistical process control (SPC) system has been implemented in Continental tyre manufacturing quality assurance system This work presents the implementation of SPC to bead production. From an initial process analysis and a Pareto analysis, the tyre non-conformity with the highest rate was *retained air*. The cause-effect analysis performed, revealed that the cause of retained air originated from the beads production, mostly in the narrow beads. A DMAIC cycle and SPC was applied on that type of bead production, and on the APEX machine that produced it, during a six months' period. Parameters to be controlled were defined as the bead dimensions and weight, as well as the variables to measure them. Twelve experiments were defined and carried out. It was concluded that the value specified for the temperature parameter was 75°C and, for the extrusion speed, 7 rpm, with width, thickness and weight with good C_p and C_{pk} values. After the project, the number of non-conformities was reduced, and consequently the quality rate increased by 41%, as did the process control and capability. In future, the improvements achieved will be extended to the remaining products and Apex machines.

This work proves that the application of lean manufacturing and six sigma to companies improves their business performance, confirming that this philosophy brings profits to companies.

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Appendixes

Appendix 1- Cause-effect matrix output of major causes extracted from a defined MS Excel® sheet with all detected likely causes by team.

	Bead production problems analysis						
	Classification(0-9)						
Outputs (KPOV'S)	CC	BB	RS	HO	OP1	OP2	Total
Bead apex dimensions outside specification limits	8	9	9	9	9	9	53
Bead apex application on bead core process	9	9	9	9	9	8	53
Diaphragm bead apex application	8	8	8	8	8	8	48
Bead apex weight outside specification limits	7	7	7	7	6	6	40
Bead apex (rubber) temperature	6	7	7	6	6	6	38
Wrong bead apex guidance	6	6	6	6	5	5	34
Loop system effect	6	5	5	5	4	4	29
Cut system (Slitter and cutting table)	4	4	4	4	4	4	24
Compound variation	3	3	3	3	5	5	22

Appendix 2- Bead production specifications

Die	A
Compound	B
Rim	17 in
Number of steel cord bead wires	25 (5x5 steel cords, 1mm² each)
Bead APEX idth before application	14±2 mm
Bead APEX thickness before application	7±0,3 mm
Bead APEX weight	82±7 g
Bead APEX width after application	13±2 mm
Bead APEX thickness after application	6,4±0,3 mm
Extrusion speed	5,8 rpm
Conveyor belt speed	6,2 m/min
Extrusion temperature	80±10 °C

Appendix 3- Non-conforming beads Pareto's analysis