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AT CUSTOMER SITES: A CASE STUDY ON METAL PIPES

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ABSTRACT

This research presents the creation of artifacts to solve a problem regarding the external diameter exceeding the maximum tolerance of welded steel tubes, reported by a customer. Two artifacts were developed, with characteristics of Poka-Yoke tools, manufactured by Additive Manufacturing, and used in the dimensional detection of the external diameter of the claimed and lots of other parts in customer stock. The increase in sales, accompanied by increased competition, has made on-time delivery and good quality two essential requirements for competitiveness. Basically, in the quality control process, all supplies and production processes are inspected, but there are many products with defects that are passed on to the consumer. Therefore, the objective of this research is to apply Poka-Yoke concepts to the complaining customer's stock, in addition to proposing a commercial agreement, to bring to the factory floor justifications for implementing inspection on 100% of the items. The theme: application of error-proof devices, has grown significantly in companies, especially those that follow the Zero Defects philosophy or with specific programs to improve manufacturing processes. Applying the concepts of the Poka-yoke method to 100% of products can prevent defective products from reaching customers, and

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this type of dissatisfaction does not occur later. The research successfully met its objective since artifacts were created capable of measuring the external diameter and classifying many parts into approved and disapproved, at the customers' sites, without the need for excessive handling.

Keywords: Poka-Yoke. Zero defects. Quality. Inspection. Deviations.

INTRODUCTION

The lack of stability in manufacturing systems is one of the main causes of losses and is a barrier to the implementation of Lean Production – LP, which aims at continuous flow. Quick responses to market requests are essential for business success, as they directly affect the time to offer new products. Among the possible strategies, Poka-Yokes have aroused growing interest in industry and academia, due to the apparent simplicity of implementation and intuitive nature of their operation. The literature presents a series of applications in different environments, such as civil construction, the automotive industry, metallurgy, health, and logistics, among others [1].

In recent years, numerous social, political, economic, and technological changes have occurred, forcing significant changes in the productive sectors, to improve performance and consequently increase their competitiveness. The scenario at the beginning of the 21st century has presented organizations with constant challenges arising from globalization, competition, legislation, new technologies, consumer demands, and the economic crisis. Expanding sales and increasing foreign exchange generation have been the basic premises for any company that wishes to prosper economically, meeting demand through appropriate solutions [2,3].

In this context, the steel sector, manufacturer of steel tubes, is relevant to the country's economic development. The Brazilian steel industry has 31 plants, managed by 12 business groups, with approximately 126 thousand employees and an installed capacity of 51 million tons/year. In 2022, it produced 34.1 million tons of crude steel. The production of steel products reached 31.5 million tons that same year, with exports of 11 million tons to more than 100 countries, and a positive trade balance of US$6 billion in transactions [4].

The term Poka-Yoke has its origins in the experiences of the Toyota Motors Company, which aimed to obtain zero defects in production and eliminate quality inspections. The methods for achieving these goals were initially called “fool-proof (Baka-Yokes)”, but it was later recognized that this was offensive to workers and the name changed to “mistake-proof” or “failure-free” (Poka-Yoke). Initially, the objective was to prevent human error at work, seen as the main cause of defects [5].

The expression poka-yoke is not very precise, ranging from studies that understand that they are limited to physical devices that control defects to studies with a comprehensive view, that understand them as quality assurance systems and reduction of variability. Furthermore, the methods for the design, operation, and maintenance of Poka-Yokes are disconnected from the concepts of statistical process stability [7].

Such a link should exist, as statistical quality control allows the identification of the frequency of random causes of a given process, which constitutes a group of information for potential developments and implementations of these systems [8].

It is worth mentioning that one of the reasons why Poka-Yokes were disseminated at Toyota was precisely the attempt to reduce dependence on statistical quality control, since this, by definition, accepts margins of error that are incompatible with the goal of zero defects.

Shingo [9] however, states that this argument has limitations such as:

(a) Poka-Yokes cannot replace Statistical Process Control in 100% of cases, either due to the technical impossibility of designing the device or due to the nature of the quality characteristic to be inspected (for example, mechanical resistance of components, whose verification may require destructive testing).

(b) Poka-Yokes are also prone to failure, as they are often made up of components with less than 100% reliability (e.g. sensors).

(c) statistical control can support the Poka-Yokes project when it points out at which points in the process, they are a priority

The present study has as its general objective the creation of Poka-Yoke artifacts, via Additive Manufacturing, through the 3D Printing technique capable of carrying out dimensional inspection of the external diameters, in steel tubes, still in their original packaging (with strap and grouped in bales of 10 units) in the complaining customer's warehouse.

A set of Poka-Yoke classifications and concepts identified in the literature were also analyzed, to propose guidelines for their design, operation, maintenance, and use. To this end, the research contextualizes the role of Poka-Yokes in quality control, emphasizing their contribution to inspection operations [9].

THEORETICAL FRAMEWORK

The likelihood of companies surviving and thriving is affected if there is no constant concern for the continuous improvement of their processes, aiming to reduce costs and waste. The reduction in quality failures and the production of high-quality products do not result from inspection activities but fundamentally from process improvement activities, making them more effective, and simpler, with fewer non-conformities and more insurance.

Juran [10] reinforces this idea when he argues that the quality of processes is based on the interrelationship of three fundamental activities (commonly known as “Juran’s Trilogy”):

1. Quality planning – consists of developing products and processes necessary to satisfy customer needs.
2. Quality control – consists of evaluating quality, comparing it with objectives, and reducing deviations.
3. Quality improvement – consists of continuous improvement of quality.

The three activities described are interrelated: the quality level (and consequently the costs of non-quality) of a product are determined, on the one hand, by the project (Quality Planning) and by the control carried out during manufacturing (Quality Control), and on the other, for improvement activities (Quality Improvement).

While Quality Control allows for identifying the occurrence of sporadic problems and consequently triggering corrective actions to eliminate them, re-establishing the normal variation of the process, improvement activities aim to reduce chronic problems, achieving a higher quality level and, consequently, lower costs.

The application of quality improvement activities can be systematized based on the improvement cycle presented by Deming (also called PDCA cycle – Plan-Do-Check-Act). Deming maintains that after launching a product, one must continue to research, modify, and improve the project, produce, and sell it again, in an endless cycle. According to the author, an improvement process must follow four essential steps [11]:

Plan the objectives for a given period and establish the methodology to achieve them.

1. Carry out the actions foreseen in the previous step and collect data for analysis.
2. Check the results obtained and compare them with the intended objectives.
3. Act based on the results obtained, implementing the necessary changes to ensure the effectiveness of actions and the achievement of established objectives.

Improving quality is, without a doubt, a current concern for companies determined to improve their performance, thus ensuring greater competitiveness in the market in which they operate. There is a set of tools capable of helping companies achieve this objective, particularly in terms of detecting and preventing failures, during the product development process or in the production process [11].

The interesting thing is that companies are not always able to achieve the desired levels of improvement. For Moore, this situation results from the fact that companies do not select the most appropriate tools for their case, without considering how to guarantee greater efficiency and effectiveness in the application of improvement tools, such as [11]:

1. Establish the conditions under which tools become incompatible.

2. Analyze the advantages and disadvantages of each tool.
3. Establish the tools that require others to maximize results.
4. Define the application conditions for each tool.

Poka-Yoke is a tool for improving manufacturing processes based on error detection. Initially, it was considered only as a physical device used to prevent errors from occurring. Nowadays, its meaning is much broader, being defined as an error prevention tool, a quality control technique, or a quality philosophy. The basic principle common to these aspects is error prevention [12].

The continuous improvement of tools that are applied in manufacturing processes to reduce non-conformities are equally effective in non-production functions, however, in these functions, it becomes more difficult to define and establish the indicators that allow measuring and monitoring performance [13].

INSPECTION CONCEPTS

The inspection consists of comparing the product with the requirements applicable to that product. Therefore, any difference between the requirements and the inspection result can be considered an abnormality. Shingo [9] emphasizes that inspections can be classified according to their objective, which can be discovering defects, reducing defects, or eliminating defects. The classes proposed are:

a) Judgment Inspection, which has the characteristic of discovering defects, being applied to products to judge them as defective or non-defective, ensuring that the defective product does not reach internal or external customers. This type of inspection is normally applied to entire production batches, after processing or in the final stages of the process, which does not prevent the production from defective products.

b) Informative Inspection, which aims to reduce defects, as there is feedback about the defects identified to the person responsible for the process. This method, in Shingo's view, is superior to inspection by judgment, however, it is ineffective in obtaining zero defects, since the emphasis is on detecting defects in the product, rather than detecting errors in the process.

Shingo [9] further classifies this method into three categories:

1) - Statistical Process Control - SPC, as well as control charts, and other techniques were developed and applied, such as the seven quality tools, so-called. Control charts are seen as powerful tools for detecting changes in processes or process parameters. In any production process, there will always be variability, as an effect of many small causes, essentially inevitable. Within SPC, this variability is understood as a “stable system of

random causes", therefore when a process operates only with random causes of variation, also defined as common causes, it is under statistical control (random causes are inherent to the process). In addition to these random causes, there are also assignable causes in process control. One of the conditions for a process to operate out of control is when the assignable causes are outside the control limits. An attributable cause is considered outside the limits when it assumes a value above or below the mean plus or minus three standard deviations, respectively. Processes operate under control for long periods. However, assignable causes typically occur randomly, resulting in a shift out of control state (process instability), where a greater proportion of the process output does not meet requirements, i.e., a greater proportion of what is being generated will be outside the specification limits (USL – upper specification limit, LSL – lower specification limit). The major objective of statistical process control is to quickly detect the occurrence of process instability (attributable causes of process change), so that process investigation and corrective action can be carried out before many units are manufactured. From this same perspective, the objective of the SPC is to monitor processes, identify special causes of variation, and signal correct decision-making, when appropriate. For the same authors, what inhibits the greater use of SPC is the fact that the statistical models developed focus on the mathematical principle and not on solving the problem on the factory floor.

2) Successive Inspection System, this modality arose from the need for 100% inspection in addition to proactive and rapid action in the event of a defect being found. This type of inspection is extended to all workstations so that each worker inspects the item received from the previous step before carrying out his operation. The positive points of this type of inspection are the fact that the rate of defects due to lack of attention is minimized, the previous steps are linked to the next step and the inspection is conducted by people independent of the processes.

3) The Self-Inspection System is considered the most effective informative inspection system, as the inspection is carried out by the operator responsible for processing, enabling instant corrective action. Furthermore, another contributing fact is that people prefer to discover their problems, rather than having them pointed out by third parties. However, the biggest limitation of SAI is the focus on detecting defects rather than detecting errors in processing. The main difference between SPC and other techniques is the form of inspection. The SPC is carried out by sampling variables and attributes. However, SAI and SIS are 100% inspections carried out on variables and attributes.

Shingo [9] still states that inspection at source is the most efficient since its objective is to act preventively and eliminate defects. Referred to in manufacturing processes as “adaptive control”, it works by compensating or correcting the error condition to prevent the manufacture of a defective item. The main advantage of source inspection is the shorter control cycle compared to other inspection methods. In this method, the error happens and is detected instantly, the cause of the error is verified, and corrective action is implemented. This way, the action takes place in the process and not on the product, which makes zero defects possible. Despite this security, Shingo [9] emphasizes that the impact of the process on other processing must be checked, to avoid unnecessary inspection at the source. For example, it is not necessary to institute inspection processes at the source for product assembly operations, but in the manufacturing operations of parts of that same product.

THE CONCEPT OF POKA-YOKE

Poka-Yokes are applied in different contexts (logistics, health, construction, information, technology), not necessarily associated with lean production implementation initiatives. However, these contexts are not always coincidence or complementary.

A Poka-Yoke is any mechanism in a Lean Manufacturing process that helps an equipment operator to avoid (Yokeru) errors (Poka).” It can be designed according to the needs of the manufacturing process, equipment, or tools, which prevent risks of rework and loss of time, which prevent risks of rework and loss of time. This way, non-conformities can be known and corrected early and quickly. Poka-Yoke tools are also known as “mistake-proof” devices, or/and “go or no go” devices [12].

Poka-Yoke has been successfully applied in several production activities, such as the cost analysis of a Poka-Yoke system in a company that manufactures stamped components for the automotive industry. The results revealed that Poka-Yoke is a tool capable of generating a satisfactory return, but that it depends on the value of the investment made. In other words, there is a value below which the application of Poka-Yoke becomes advantageous, and this value corresponds to the cost of non-quality. This way, non-conformities can be known and corrected in advance and quickly. Poka-Yoke tools are also known as “mistake-proof” devices, or/and “go or no go” devices [13].

An analysis of Poka-Yoke systems has shown that they work well in the following situations [14]:

1. Routine of a fixed sequence of operations (which form part of the value chain) with operator intervention.
2. Manufacturing in general.
3. Manufacturing operations with clearly defined specifications.

4. Reduced the number of process parameters to be controlled.
5. Statistical process control is difficult to implement or ineffective.
6. Control of qualitative and non-quantitative attributes.
7. High staff turnover and high training costs.

Biswas {15] also points out that Poka-Yoke devices do not work well in the following situations: processes with very high production rates, processes with self-control, and control charts applied effectively. processes with faster changes than Poka-Yoke devices.

In addition to the situations described above, Poka-Yoke also does not work when its implementation becomes too complex. According to Shingo [9], some companies run over the Poka-Yoke concept, developing sophisticated error detection systems that end up constituting new stages in the process, instead of being integrated into existing operations. It should not be forgotten that true Poka-Yoke is simple, obvious, practical and, above all, cheap.

Poka-yoke concepts mention defect prevention or error detection, without differentiating between the concepts of errors and defects. Differentiation is important, as it allows classifying the function of Poka-Yokes as being reactive (protective) or proactive (preventive). As defined by Shingo [9], a defect is damage to the production project, be it a product or service.

On the other hand, it states that an error can be understood as a failure in the planning or execution of an operation and is normally the immediate cause of defects. Therefore, in this study, it is considered that Poka-Yokes with a reactive function detect defects, while Poka-Yokes with a proactive function detect errors and, as a result, prevent defects [16].

Practical applications of Poka-Yoke systems are often present in the health area. However, it is possible to establish analytical categories that abstract their operational principles and differentiate devices that, although they use the same physical mechanisms, have different properties. One of these categories concerns the differentiation between proactive and reactive [1].

Another relatively well-known classification is the one proposed by Shingo [9], which classifies them according to the objective and the techniques used. When linked to the objective, they refer to the regulation function, and when linked to techniques, they refer to the detection function.

Shingo's classification divides the regulation function into a control method and a warning method. The control method is so named because it detects unexpected variability in the process and interrupts the operation, with the objectives of avoiding the production of serial defects and creating a sense of urgency for corrective action to be implemented. Another characteristic of the control method is that the operator does not have degrees of freedom for decision-making, being induced to carry out the correct action. While in the warning method, Poka-Yoke detects the abnormality but does not interrupt the process, only signaling the occurrence through sound and/or visual signals [9].

The detection function is divided into contact methods, set method, and step method. The contact method is typically applied to detect abnormalities in dimensions, using devices that remain in contact with the product. The ensemble method is used in operations performed in a sequence of identical movements or steps, ensuring that none of these steps are neglected. The step method is also used to ensure that no operations are overlooked. However, unlike the set method, in the step method, the sequential operations are not identical.

It is worth reinforcing opportunities for the integrated use of Poka-Yoke and SPC. Ghinato [16] points out that the application of poka-yoke is often restricted to processes without strong statistical control. However, the processes that are statistically controlled are those that present the greatest and best opportunities for their application, since the statistical control charts generate information that supports the choice of the most appropriate Poka-Yoke categories.

An example, in a material weighing process, weight control (kg) can be used to meet a certain quantity of parts per batch. Typically, the operator does not carry out adequate weighing due to the need to attend to multiple weighing processes during the work shift. Weight values are controlled by sampling every five weightings analyzed and recorded on a control chart. Analysis of this control chart shows that over time the weighing value tends from the nominal value to the lower part until it exceeds the lower control limit. In this case, the implementation of a Poka-Yoke that guarantees the weighing value (kg) should act to prevent the operator from removing the raw material from the scale, up to the established nominal value, ensuring that all raw material required to make the batch is met. This case illustrates Ghinato's [16] perception of the relationship between the development of Poka-Yokes systems and graphics for quality control.

McGee [7] proposed five steps: (a) identify the defect and the impact this defect will have on the customer; (b) identify at which stage of the process the defect was discovered, to later discover at which stage it was created; (c) identify the root cause of the defect; (d) brainstorm with the work team to detect ways to eliminate process deviations; (e) create, test, validate and deploy the device.

PROCEDURES AND METHODS

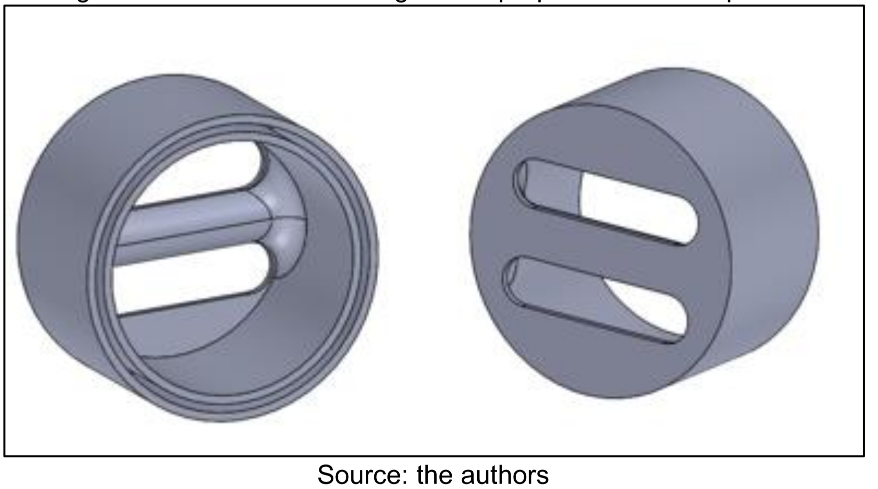
As a result of a complaint regarding irregularities in the external diameter, which exceeded the tolerance specified by standard NBR 6591 [17], in a batch consisting of 56 tons of round tubes, with a diameter of 203.20 mm, a thickness of 3.00 mm and a length of 6 meters, it was proposed to develop a Poka-Yoke approach for the inspection of the questioned lots. The tubes under evaluation came from three different suppliers, designated as Supplier A and Supplier B.

Given the analysis of the history of occurrences related to dimensional problems and geometric divergences, it was decided to design a Construct-type artifact, intended to be used as a Poka-Yoke tool for the dimensional analysis of tubes. The artifact proposals were prepared considering all restrictions and minimum usability requirements. In this way, two different types of devices were developed: the first was designed to measure the external diameter of the tubes at the ends, and the second device could measure the diameter along the length of the pieces.

The evaluation was conducted through the experimental analysis of a sample consisting of 624 pieces. The steel tubes in question were manufactured under the NBR 6591 [17] standard, with all dimensional requirements essential for carrying out measurements based on this standard, to identify external diameters that exceed pre-established dimensional tolerances.

The constructive logic of the artifact began with the identification of the problem, the analysis and resolution of the restrictions, the understanding of the environment in which the materials to be inspected were inserted, and the possible solutions that could contribute to solving the problem. Initially, according to the digital model presented in Figure 1, a Poka-Yoke artifact was proposed to check the external and internal diameter of circular section tubes, considering loose tubes outside their original packaging.

Figure 1 – Initial artifact configuration proposal for bar inspection



Source: the authors

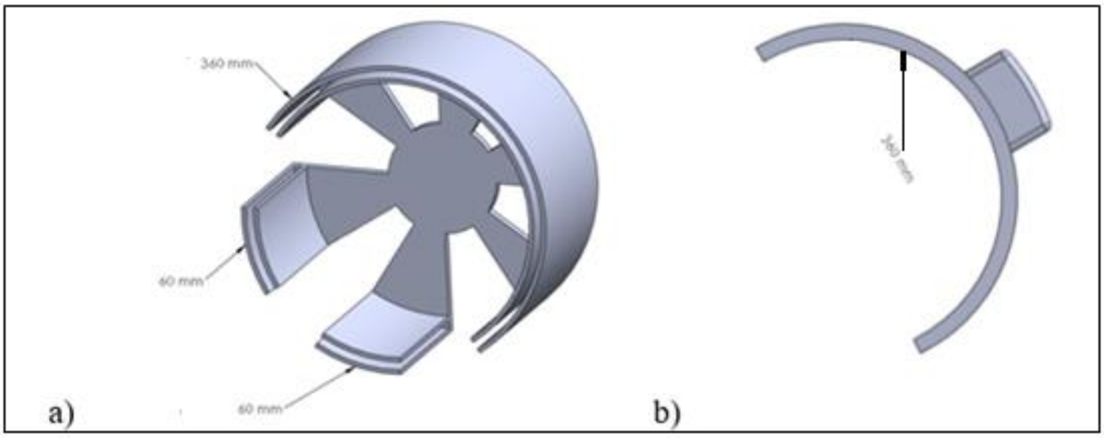
From the first measurement attempt, the need for improvement points became evident, as shown in Figure 2.

Figure 2 – Configuration of steel tube packaging and, a graphic representation of the need for meter shape and numbering of bars accessible for inspection (red).

Source: the authors

The first need to modify the project was assessed on-site, where all the bars were stacked in their original packaging, bundles of 10 tubes, arranged in a hexagonal shape. the design of the proposed artifact required consideration of the limited access area between the tubes' contact points. In this context, appropriate measurements were carried out, which resulted in the need to remodel the artifact, according to the configuration illustrated in Figure 3. The essential purpose of this device is to make it possible to measure tubes both in their original packaging and as individual pieces. This configuration was designated as Artifact 1 (A1). With this new dimensional configuration, access to six measuring points would be possible, out of a total of 10 present in the packaging.

Figure 3 – a) Artifact 1 (A1): Proposed dimensional configuration for an artifact capable of measuring bars while still in their packaging. b) Artifact 2 (A2): Proposed design for an artifact to measure diameter along the length.

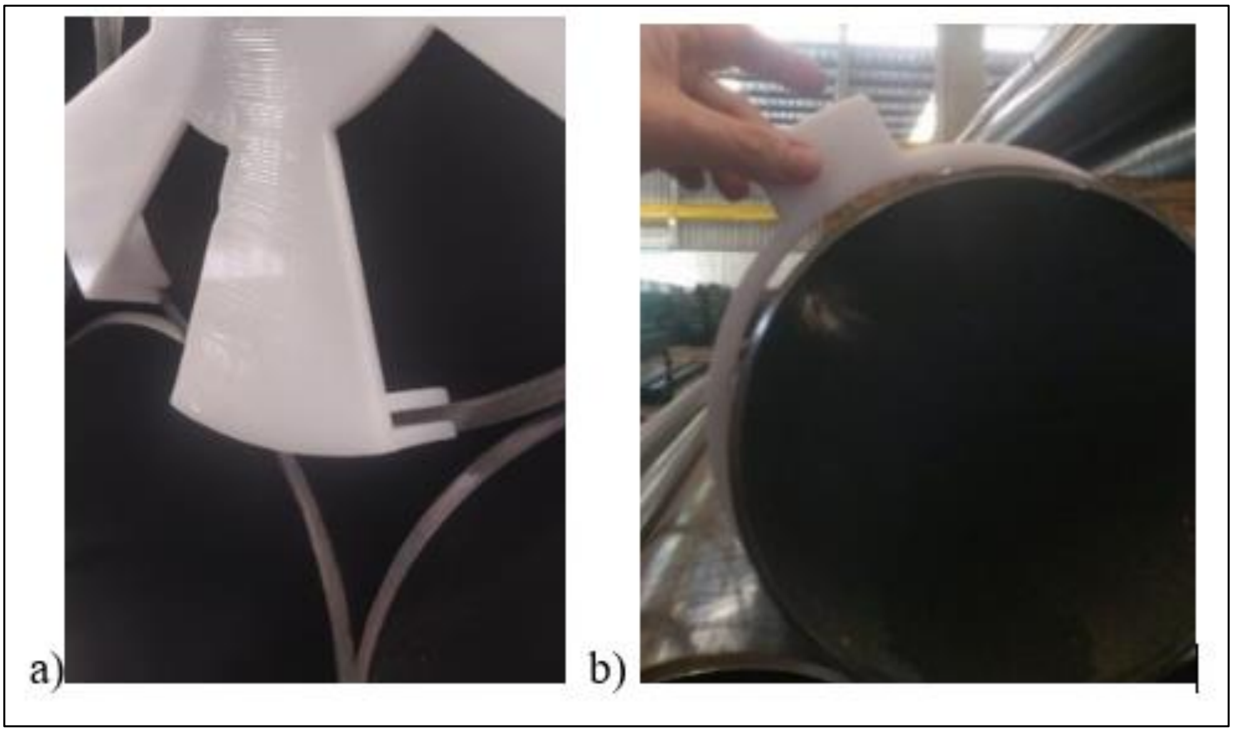


Source: the authors

The need to monitor the diameter of the tubes along their length was noted. Therefore, it was proposed to build a second artifact, identified as Artifact 2 (A2), positioned along the tube, as illustrated in Figure 3.b.

Figure 4 shows the artifacts in the initial testing phase.

Figure 4 – a) Artifact 1, measurement at the ends of the tubular piece. b) Artifact 2, checking the diameter along the tubes.



Source: the authors

In the first evaluations, it was found that for Artifact 1 (A1) it was not necessary to incorporate an internal flap, as its purpose consisted exclusively of measuring the external diameter of the tubes. This decision resulted in the expansion of the sampling scope initially outlined, since the absence of the internal flap made it possible to test the device on all tubes with a diameter of 203.20 mm, regardless of thickness. On the other hand, the use of Artifact 2 (A2) showed satisfactory performance, but with the need for improvement in terms of robustness and resistance. After identifying points that could be improved in the project, changes were made and, subsequently, the prototypes were printed.

Figure 5 illustrates Artifact 1 (black) used to check the dimensions of the tubes while still in the packaging. In turn, Artifact 2 was designed as a Poka-Yoke device intended for measuring the external diameter of the tube at different points along the length of the tubular parts (white).

Figure 5 – a) Artifact 1 and Artifact 2 being used in diameter measurements.

Source: The authors

For this study, the performance evaluation of Poka-Yokes was carried out experimentally. The results analysis revealed the feasibility of using the two artifacts to carry out dimensional inspection of the external diameter of circular section tubes, thus fulfilling the original objective of the project.

RESULTS AND DISCUSSION

A total of 624 measurements were carried out. Artifacts indicated that 38% of the tubes were outside the maximum allowable diameter. Table 1 presents in detail all the thicknesses analyzed, the approval and disapproval results, and the respective numbers of parts involved.

Table 1 Measurement results depending on thickness.

Thickness (mm)	Approved	Rejected	Total
2.65	12	-	12
3.00	204	210	414
3.75	36	-	36
4.75	36	30	66
5.50	-	30	30
6.30	-	6	6
8.00	24	-	24
9.52	12	-	12
10.60	24	-	24

Total Pieces	384	240	624
Total %	62%	38%	100%

Source: the authors

From the material analyzed, it was found that all rejections were associated with 210 pieces in batches with a thickness of 3.00 mm and 26 pieces in tubes with a thickness of 4.75 mm. The detection of 374 approved parts, covering different thicknesses, contributes to a favorable assessment regarding the effectiveness of the artifacts.

Analysis of the previous table revealed that most of the tubes examined were concentrated in pieces with thicknesses of 3.00 mm and 4.75 mm. Consequently, an analysis of the incidence of approval and disapproval was carried out based on the origin of the product, that is, the supplier, the results of which are presented in Table 2.

Table 2 – Measurement results by supplier, in thicknesses 3.00mm and 4.75mm.

Thickness (mm)	Approved	Rejected	Total
Supplier A	3.00	210	210
Supplier B	3.00	204	204
Subtotal for Thickness 3.00mm	204	210	414
Supplier A	4.75	30	30
Supplier B	4.75	36	36
Subtotal for Thickness 4.75mm	36	30	66
Total	240	240	480

Source: the authors

FINAL THOUGHTS

This research rescued and applied the Poka-Yokes technique to products already available to the end consumer. Notably, Poka-Yokes were able to identify tubular parts that did not conform to required dimensional specifications, ensuring compliance with established design parameters.

The dimensional analysis carried out on the 624 pieces revealed that all failed pieces had thicknesses of 3.00 mm and 4.75 mm. It is noteworthy that these parts came from Supplier A, totaling 240 failed units, corresponding to 38% of the total parts inspected. Regardless of current commercial agreements, this scenario highlights the lack of control in the manufacturing process on the part of this supplier.

The procedures adopted and the results obtained emphasize the importance of implementing error-proof practices to ensure not only survival but also the competitiveness of the industry under analysis.

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