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Optimization of Flow Test Quality Indicators in a PIM Air Conditioner Line

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***Abstract*— The present article aims to describe the process of detection by flow measurement in a window air conditioner refrigeration system of a company of the Industrial Pole of Manaus PIM. The equipment used is a flow sensor model SFAB-200U-HQ8-2SA-M12, which was installed in a production line, connected to a supervisory system, which will indicate through a visual device Andons, the approval of the product in real time . The process occurs through the sending of flow data, with the early detection of capillary blockage, ie, before the final assembly of the product, the objective is to optimize the quantity of products reworked internally, which will cause an increase in the indicator of FPY (First Passed Yield), as well as a reduction in field failure rates due to the non-detection of capillary obstruction in the process. For this, it was necessary to identify the normal flow of product, and to define new parameters of approval, next to this the methodology 6 sigma was applied to make the analysis of the data.*
***Keywords*— Flow meter; 6 sigma; Quality.**

I. INTRODUCTION

The manufacturing processes of air conditioners, the problem of capillary obstruction, have proved to be a complicating factor in terms of manufacturing cost and product warranty in the field. In the investigated process, the identified problem is potentially relevant since perception detection was only possible, ie if the operator visualized capillary tube freezing during the performance test of the product. The capillary tube being the expansion device in cooling systems of air conditioners, acting as pressure reducing element and coolant mass flow regulator. The study aims to analyze the flow data for parameter definition as well as the evaluation of the measurement system.

The refrigeration system is applied in several areas in today's society, with cooling of electronic components, thermal comfort of environments and food preservation. Even little known to those who do not work in the area, the capillary tube component is a key item for the refrigeration system.

Taking into account the need for a company to produce air conditioners and taking into account the late detection of capillary tube clogging (important part of the refrigeration system), this paper aims to answer the following question: what are the appropriate parameters of a flow detection device for capillary tube clogging? It is seen that controlling the flow of this component is of fundamental importance for the performance of the refrigeration system.

The idea was to detect the capillary clogging through the flow sensor model SFAB-200U-HQ8-2SA-M12, bringing it closer to where the fault is generated, not by perception and by measuring the flow rate.

II. THEORETICAL FOUNDATION

The problem of approach of the research verified through a bibliographical analysis the elements that compose the process of manufacture of air conditioners of window. It is also important to understand the process of operation of the flow sensor, which aims to solve the problem of capillary obstruction in the production process.

2.1 THE AIR-CONDITIONING FUNCTIONING THEORY

This stage shows the systems and theories that involve the operation of air conditioning, addressing concepts of thermodynamics, gas flow and sensors [1].

2.1.1 Thermodynamics

In his work [2] he states that the second law of thermodynamics deals with energetic transfers between bodies. Heat is a form of energy, hot and cold is related to temperature variations. The thermodynamic process draws the heat from an isolated system into the environment through the refrigerant. The thermodynamic systems are 3, the isolated, the open and the closed.

● Open system: exchange mass and energy;

● Closed system: only energy exchange;

● Isolated system: it does not exchange mass or energy.

Mechanical compression of steam is used in most refrigerators, which basically consist of four components: compressor, condenser, expansion device and evaporator, where the refrigerant fluid forms a thermodynamic cycle [3].

The refrigerant gas is sucked by the compressor, in the superheated vapor state and the low pressure, being compressed during the work (W). Then the fluid goes to the condenser where the cooling, condensation and subcooling occurs with the rejection of the heat (Qcond) to the external environment. Then the high pressure fluid passes through the expansion device, generating the mixture of liquid and vapor at low pressure and temperature, arriving at the evaporator that absorbs the heat (Qevap) of the refrigerated environment, becoming vapor [3].

The expansion or capillary device has the function of controlling the passage of refrigerant in the evaporator and the amount of steam that is sucked by the compressor. The most widely used expansion device in small refrigeration systems (residential air conditioners, household refrigerators, freezers and drinking fountains) is the capillary tube [4].

2.1.2 Flow concept

The flow is expressed in mass or volume, the unit of flow is the unit of volume per unit of time or unit of mass per unit of time [5]. The volumetric flow rate is the product of the velocity of the fluid through the cross-sectional area of the pipe and the mass flow is equal to the product of the volumetric flow by the specific mass of the fluid. Because direct measurement of the specific mass of the fluid is difficult, temperature and pressure measurements are used to infer it, since the gas composition is constant [6].

The complexity of fluid flow is not always subject to exact mathematical analysis. The measurement can be quite difficult, since the fluid elements can move at different speeds of acceleration [5].

2.1.3 Gas sensors

The gases have excellent compressibility and exceptional expansion capacity. The gases do not have a fixed volume, since they always occupy the total volume of the container in which they are confined. Another property inherent to the gases is that they are miscible in any proportion, that is, they form a homogeneous mixture [7].

According to [8] sensor is a term used to designate devices sensitive to some form of energy from the environment. [9] complements this concept when it states that such energies of the controlled environment can be luminous, thermal, kinetic and so on, in order to relate the information about the physical quantities to be measured, such as temperature, pressure, velocity, current , voltage, acceleration, position, and so on.

2.2 QUALITY SYSTEM

Quality can be applied in multiple directions, which depends on person to person, although there is not only a definition of quality, there are definitions adapted by expert gurus in most situations. For [10], a quality product or service is one that perfectly meets, reliably, affordably, securely and on time to the customer's needs.

The table in Figure 1 identifies how it classifies the most common points that demonstrate the breadth of inclusion or exclusion in firm quality definitions.

PRODUCT FEATURES THAT MEET CUSTOMER NEEDS	ABSENCE OF DEFICIENCIES
Superior quality enables companies to:	Superior quality enables companies to:
• Increase customer satisfaction; • Make products salable; • Increase your market share; • Obtain sales revenue; • Guarantee better prices. • The biggest effect and on sales. • Higher quality usually costs more.	• Reduce error rates; • Reduce repetition of work and waste; • Reduce usage failures and warranty costs; • Reduce customer dissatisfaction; • Reduce the deadline for launching new products on the market; • Increase yields and capacity; • Improve delivery performance. • The greatest effect and cost. • Higher quality usually costs less.

Fig. 1: Definitions of quality of enterprises, Souce: [11].

For [12] quality is everything that improves the product from the point of view of the customer. Only the customer is able to define the quality of a product. The concept of quality changes meaning in the same proportion as the needs of customers evolve.

For [13] quality is to develop, design, produce and market a quality product that is more economical, more useful and always satisfying to the consumer. "

2.2.1 QUALITY INDICATORS

Quality indicators help companies measure their performance. With the evolution of the concept of quality it was proposed the systematization of performance indicators in quality management adopting a reference model following the principles expressed in the works of [13] and [14].

According to [15], the indicators of productivity, return on investments and standard cost are the most common, and it is important that all employees of the company are trained to interpret the indicators so that they know what actions to take with the results achieved and with this information is not restricted only and management. Quality indicators need to have benchmarks, which may be benchmarking results or organizational guidelines, where tolerances are determined by these standards. It is essential to listen to the four indicators of the 6 sigma philosophy, being vital to gain acceptance of the philosophy of the administrators and employees of the organization.

2.2.2 Methodology 6 sigma

The main goal of 6 sigma is the elimination of waste, improving the quality of processes and products with consequent increase in customer satisfaction and business profitability [16].

Because there are several definitions of the methodology 6 sigma becomes complicated since methodology deals with solutions of problems, which is due to its historical evolution. Some factors emerged in the 1980s that contributed to the evolution of quality in organizations around the world. The beginning of mass production that opened the global market allowing the Japanese to introduce their electronic products in all the world markets, having an immediate acceptance of the consumers, since they had the low price and superior quality.

In their work [17] they affirm that 6 sigma represents a global approach aiming to obtain the perfection of all the processes and products of an organization, through a rigorous survey of data and statistical analysis for elimination of sources and causes of errors and forms of the to eliminate.

In the view of [18] there are two essential sides to 6 sigma methodology, statistics and business. The statistic represents the origin and essence of 6 sigma, defined as the goal for achieving less than 3.4 defects per million opportunities, equivalent to an efficiency ratio of 99.9997%, and Sigma represents process variability. In contrast, the business point of view [19] defines the methodology as a strategy to improve and optimize the efficiency and effectiveness of all the operations of a process in order to meet and satisfy the needs of the final consumer.

When a customer or consumer acquires a product or service he expects them to have quality and meet their expectations and with the 6 sigma methodology being a powerful process improvement tool together with the use of good quality practices in services, measuring customer satisfaction clients and performance results being for a selection of 6 major sigma projects hear the following four indicators:

- Customer voice;
- Business voice;
- Process voice;
- Voice of Stakeholders.

After collecting the information the methodology can be used to obtain process parameters, resulting in the improvement of them and consequently in the final product. The training in 6 sigma aims to achieve the highest level of skill for the application of techniques [20].

With daily observations and an initial knowledge of the process, the definition of control parameters can be easily achieved with the use of VOC, which is a method of easy application, correctly following the use of the tool, can guarantee improvement in quality with reduction manufacturing defects, being one of the main statistical tools for this purpose. The MSE evaluates the measurement system in order to learn as much as possible about the measurement process in a short period of time.

To reduce the variability of the process, the 6 sigma uses several statistical tools, such as simple pareto graph, analysis of variance and components of variation (VOC) [21].

In his work [22] explains that VOC (Variation components). It consists of planning the appropriate sampling strategy to define the critical parameters and where the greatest variation is found. After planning, data collection occurs where it is important to document and observe any behaviors other than expected [23]. Finally, the analysis of the data compared to the technical specification of that product or process makes it possible to establish whether the variation is acceptable and, if not, where it is necessary to act.

At this stage it is important to focus and make clear what the objectives of the experiment are, what information has already been obtained and what the experimental strategy will be. This strategy should contain:

- Response variables (Y's);
- The study factors with theories and forecasts already formulated;
- Noise variables and their control methods, when possible;
- The necessary resources, such as machine downtime for the experiment or cost with prototypes in case of a product change.

III. METHODS AND TOOLS

This study was carried out in an air-conditioning company in the city of Manaus-Amazonas, the research was developed using quality tools that will be applied.

3.1 AIR-CONDITION MANUFACTURING PROCESS

The process of manufacturing window air conditioners is initiated by attaching the compressor to the plastic base, then fitting the condenser, evaporator and the pipes as well as the suction, discharge and capillary line according to the product configuration, plus The pressure test for leak detection in the still open system is carried out. In the course of the process we have the pre-vacuum and vacuum that performs the cleaning of the system for later application of the gas charge and sealing of the product, from there it is already made the assembly of the ventilation system, hypot and leak test, ending with the final test and packaging of the product that is still submitted in the form of sampling for final product auditing.

3.2 PARAMETERS AND EQUIPMENT

The SFAB-200U-HQ8-2SA-M12 flow sensor has the function of monitoring changes in airflows for media in piping systems or end devices in the industry. The measured mass of air is emitted by SFAB. According to the value obtained after parameter setting, a signal is sent to the installed command by turning on the red (if faulty) or green (if approved) andon (visual alert), where the timer will turn off the andon after 3 seconds, the product is sent to the repair to confirm the failure and if confirmed will perform the capillary exchange, the parameter must be controlled to avoid the approval of a product with the flow that does not meet the performance of the product.

3.3 COMMON PROBLEMS OF THE PRODUCTION OF AIR CONDITIONING

Among the most common problems raised from history and added to process losses in both volume and raw material values scraped by the manufacture, it was identified that the prioritization would be to treat the failure related to the capillary obstruction from the performance test.

During the observation of the problem, the conditions under which the problem occurred were clearly indicated and also evaluated under different points of view.

Analyzing the problem variables, we verified that there is a blind spot at the time of capillary welding in the pipe, together with the ability of an inexperienced welder, the amount of reprocessing increased.

Since this is an operational failure linked to the conditions of work, method, ability and criticality of the activity, the action plan has appeared in order to contain such failure.

As a start of the actions was defined the research, identification and how to use in the process a device or equipment that is carried out the measurement of the flow of the capillaries in a post to be defined later.

It was understood that the flow sensor could be used in the process, giving continuity of the acquisition of the remaining items for its operation.

Still following the actions were made the quotations and purchases of the necessary items for execution of what was foreseen in the plan.

The materials used for the problem solving process were the items flow sensor, electrical panel, PU hose (polyurethane), quick connectors, andons (red and green).

From the implementation will be done monitoring and data collection to measure the effectiveness of the implemented solution.

The quality indicator used is the FPY. FPY (First Passed Yield) indicates the number of approved products on the line the first time they were produced. It is given by the FPY formula below:

$$FPY = (Prod\ Qty / Produced\ Qty) * 100$$

The monitoring of this indicator is done online during the production process. Being this monitoring by a system called Quality Wall, accessed from any computer connected to the intranet. The indicator is given in percent, and the closer to 100 the better, and the farther from 100 the worse.

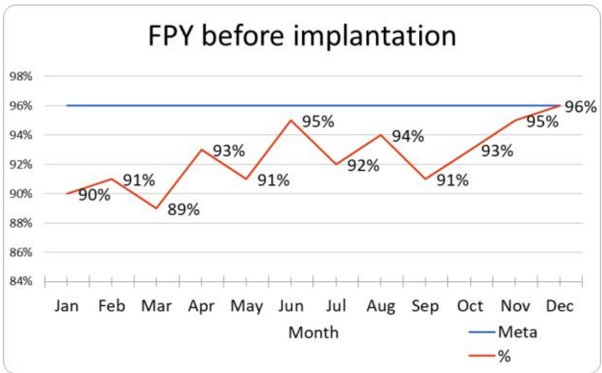

Fig. 2: FPY before Implementation

Figure 2 represents FPY data prior to project implementation.

IV. APPLICATION OF THE STUDY

During performance of the product performance test, the capillary tube freezes where it is identified through visual perception, being characterized by the clogging of the same. The product is sent to the repair where it is made the analysis and confirmation of the failure, impacting the FPY indicator as shown in Figures 3.

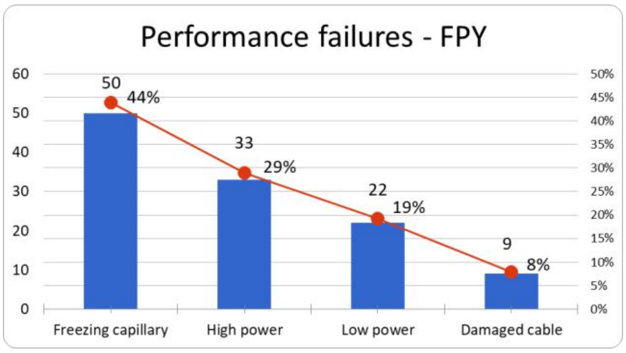

Fig. 3: Performance failures - FPY before Implementation

Figure 4 shows the causes of the problems, having as the source of the fault the welding station, due to the existence of a blind spot, the operator uses excessive welding, causing the capillary to become clogged, starting from there the study to detect the failure before the application of the gas charge on the product.

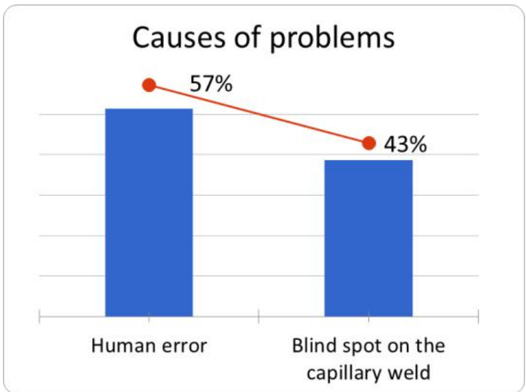

Fig. 4: Acknowledgment of reprocessing

After the analysis of the flaws shown in the previous figures, six sigma was applied in the solution of the problems.

4.1 APPLYING SIX SIGMA IN THE SOLUTION OF THE PROBLEM

The solution tool studied is the flow sensor model SFAB-200U-HQ8-2SA-M12 for the detection of capillary clogging, bringing it closer to where the fault is generated, being no longer by perception and being by flow measurement of the same.

To identify how the failure occurs the MSE and VOC were made, being important six sigma tools since they make it possible to identify which factors are relevant to the occurrence of the failure.

The tool used to evaluate the measurement system was the MSE, where it is necessary to have important characteristics in the measurement process as shown below:

Discrimination: The technological ability of the measurement system to adequately differentiate between repeated measurements.

Accuracy / Repeatability: The variation between measurements of the same characteristic in the same person, using the same instrument.

Accuracy: The difference between the mean value observed in the measurements and the master value.

Reproducibility: different operators, machines, etc. It gets basically the same average when measuring the same characteristic in the same piece.

Stability: The ability of a measurement process to maintain discrimination, accuracy, accuracy and reproducibility over time.

The related data presents the sampling tree of the measurement system evaluation (MSE) and the values found in samples collected respectively 7K and 10K.

In the Xbar charts in figure 5, below it can be seen that there is precision and repeatability since 75% of the points are outside the control limits and by rule 50% of the points must be outside the limits or the variations are between the measurements of samples.

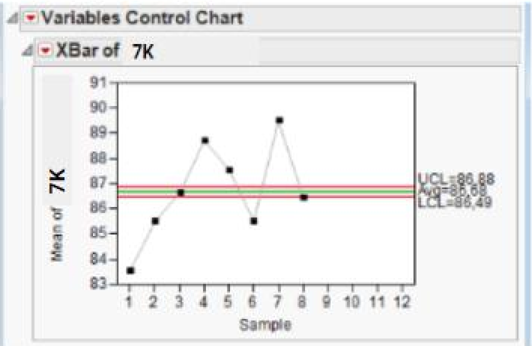

Fig. 5: Control variable 7k (MSE)

The equipment has accuracy since it is calibrated and registered, having a good state of conservation ie the equipment is accurate.

Once the measurement process manages to maintain the discrimination, precision, accuracy over time it has stability Figure 6.

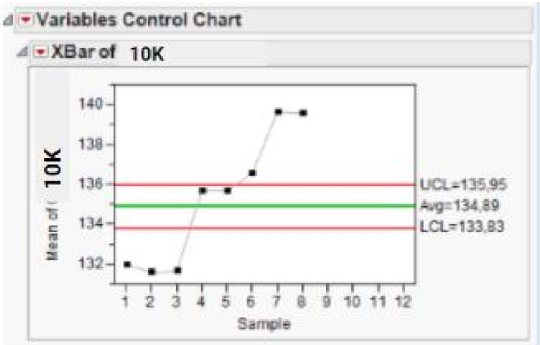

Fig. 6: Control Variable 10k (MSE)

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It is noted in chart R in Figure 7 below that the variations of the measurements repetitions vary within the amplitude of the letter R.

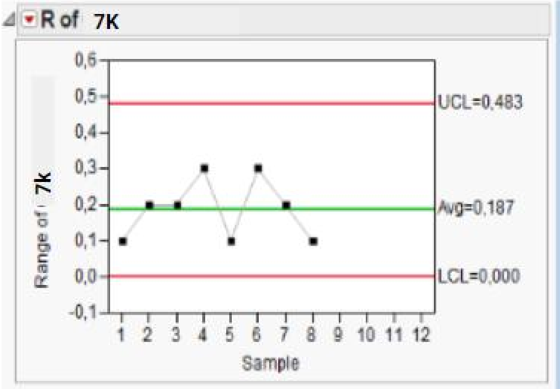

Fig. 7: Ranger 7k (MSE)

Therefore this letter is SPC (stable, predictable and constant) and has discrimination because the equipment can discriminate the variations of product flow Figure 8.

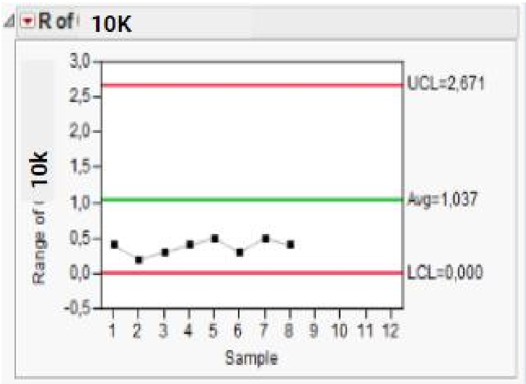

Fig. 8: Ranger 10k (MSE)

Conforme a aprovação do sistema de medição(MSE), seguimos com o COV criando a árvore de amostragem como mostra na Figura 9, coletando em 5 dias, 2 horários diferentes o total de 200 amostras.

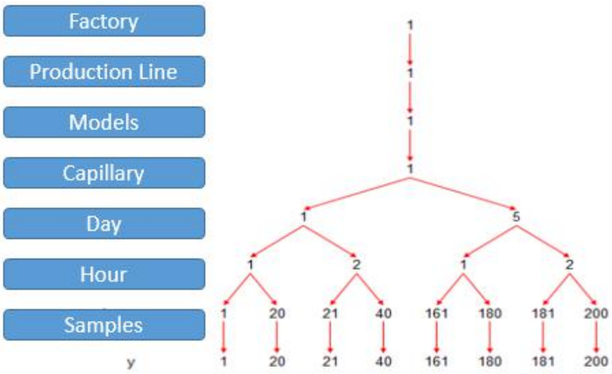

Fig. 9: Sampling Tree for (MSE)

Com a árvore de amostragem criada seguiu-se com a coleta dos dados para posterior aprendizado conforme mostra a Figura 10.

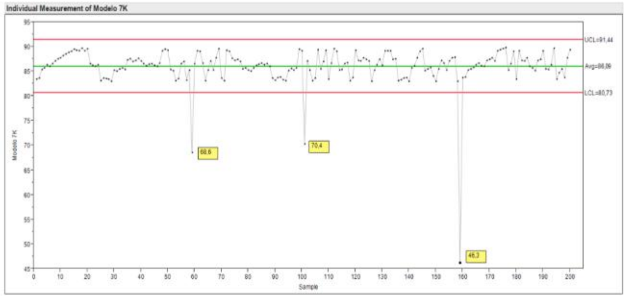

Fig. 10: Evaluation Component 7k (MSE)

Através da Figura 11, podemos observar o comportamento normal de produto dentro dos limites superior e inferior, no entanto tivemos 3 produtos identificados em amarelo que fugiram esse comportamento e foram separados para análise.

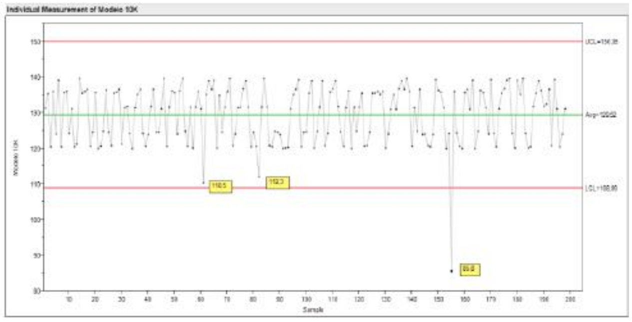

Fig. 11: Evaluation Component 10k (MSE)

The capillary tube is made of copper and is intended to receive the refrigerant from the condenser and take it to the evaporator inlet. As the refrigerant flows through the tube, the pressure decreases due to friction and the refrigerant acceleration increases, resulting in the evaporation of the fluid at the end of the capillary tube. The evaporation of the refrigerant fluids occurs at temperatures close to 0 ° C or negative up to -35 ° C. With the thermal exchange that happens in the evaporator, the interior of the refrigerators is cooled. From the analysis it was verified the capillary clogging, evidenced in Figure 12 below:

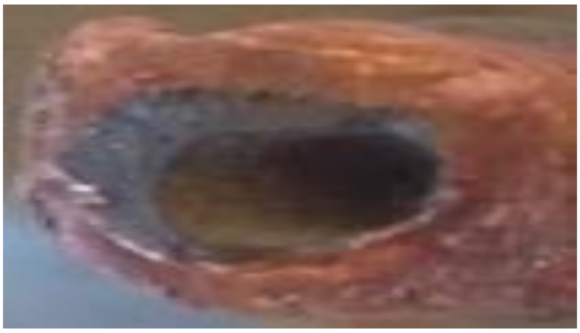

Fig. 12:Clogged Capillary Image

The internal diameter of the capillary tubes varies according to the application of each equipment, and can

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have internal diameters of 0.5 to 2.5 mm, with different lengths as well. Because it has a reduced internal diameter, special care must be taken in the installation of the capillary tubes to avoid obstruction.

Samples outside normal product behavior were excluded in Figure 13 below.

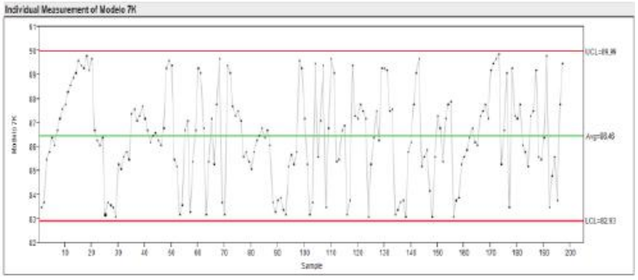

Fig. 13: Componente de variação(COV) 7K

Since as already evidenced they were with capillary obstructed and would affect of the final result for definition of the parameters figure 14.

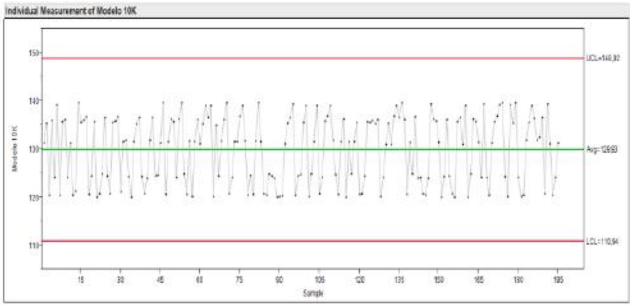

Fig. 14: Componente de variação(COV) 10K

Moisture, solid residues, or collapsing of the tube by folding may cause total or partial clogging, preventing refrigerant flow, damaging the performance of the refrigerator.

4.2 IMPLEMENTATION OF THE SOLUTION

In the process used for the implementation stages of the studied solution, it was necessary to plan until its execution, it was requested the opening of a service order for installation of the equipment at the station where the flow test will be done, request for change of working instruction and curve ramp up for pilot execution, as well as the necessary alignments for pilot execution and operator training as a new working method and the subsequent project submission for committee evaluation, if approved case the project is implemented.

4.3 SERVICE ORDER

With the flow sensor, solenoid valve, PU hose, quick connectors and accessories, we requested the opening of the maintenance order in order to install the equipment in the position where we identified the opportunity.

Initially we understood that the equipment could be installed in a station just after the welding station, however it was noticed that the piping needed a certain time to cool because of the high temperature of the torch flame. Again it was analyzed in which station we would have the opportunity to install the equipment and soon we realized that we could connect two tests in a single station and thus it was done, we installed the equipment in the same position of leak test by pressure where it starts with the flow test.

4.4 WORK INSTRUCTION

With the definition of the station for installation of the equipment, we can start with the request to change the working instruction of the affected station.

The process engineering team evaluated the takt-time for the station since the line could not be impacted by its production deliveries.

It was identified through the chrono-analysis, that for the affected station, its time would increase in 3 seconds, being above the time allowed for the station and being able to generate bottleneck and non-delivery of line productivity. We suggested to the process team to balance some of the activities already performed at the station in order to remain with the test in the station in question, the evaluation of the process team was positive, that is, a two activity balancing was done adding the time of 3 seconds, leaving the station still with 1 second of spare of its total time.

4.5 RAMP UP

With the change in the method of operation of one of the activities of the affected station, it was necessary to request a ramp-up curve from the production planning area, aiming at the gradual increase of the production and compliance of the plan according to the percentage phases of the curve. main objective is the gain of the operator's ability due to new activity inserted in the station.

4.6 PILOT TEST

According to the anticipated planning of the ramp-up curve to perform the pilot on the assembly line, training was started with the operator of the station, where despite the change in the method of one of the activities the operator was open to changes not demonstrating resistance, it was observed that the same felt more difficulties in the first two days because it is adapted to the old method of the activity, following as the training already in the fourth day it was possible to perceive an improvement in the performance of the operator who was already able to carry out the activities of the station at a rate of 80% of the production volume of the line. On the sixth day, with the line already working at 90% of its capacity, it was noticed that the operator maintained the

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ability of the new activity inserted, and that remained after the pilot in the normal volume of production of the line.

4.7 PRESENTATION TO THE COMMITTEE

In the presentation of the results and difficulties pointed out in the accomplished pilot, it was defined that first we would have to correct the sequence of activities of the station, not being necessary the realization of a new pilot due to the low risk for the operator. Due to a failure in the project approval system we are waiting for more than 30 days for the opinion of the submitted project, being approved by all the areas involved.

4.8 WORK INSTRUCTION FINAL VERSION

Due to the previously mentioned points, the process engineering team was requested to make the appropriate changes in the sequencing of the activities of the affected station, with the final version of the work statement being carried out, the implementation of the flow test was carried out within the planned deadlines.

V. ANALYSIS OF RESULTS

Figure 15 below shows the freezing of the capillary as the main offender in the FPY indicator, the fault is characterized by the clogging of the same and is detected only by visual perception in the line performance test, which is at 16 stations of the fault generating station, starting from this premise we will understand the flow behavior of the products and later define test parameters and approximation of the detection.

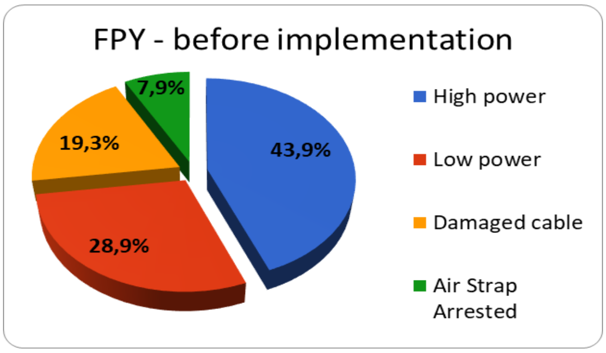

Fig. 15: FPY before Implementation

According to Figure 16, after completion of the project implementation stages, it was observed that during the first month there was no launching of the "capillary freezing" fault due to the performance, detected by visual perception by the freezing of the capillary.

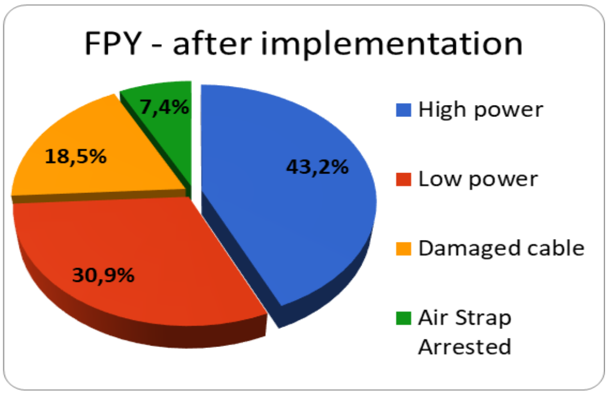

Fig. 16: FPY after Implementation

The high power and low power failure modes became more visible in the data and with this we had more assertive treatments, noting that as shown in Figure 17.

The implementation of the design and approximation of the failure detection, obtained a high failure rate in the flow test performed on the products, this shows that the test is effective in its detection, not allowing products with flow outside the parameters defined in the study go to the next station.

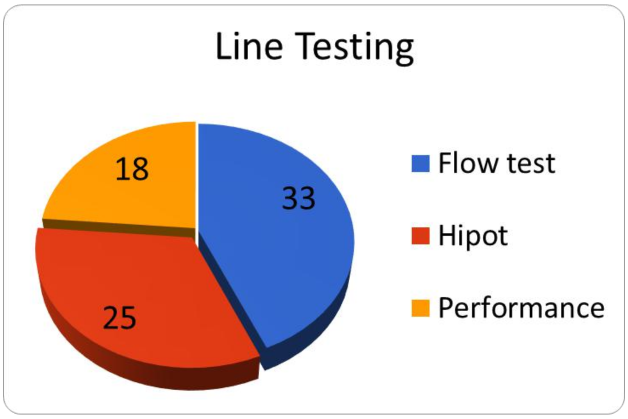

Fig. 17: FPY Line Tests

In addition to fault detection, other gains can also be noted, such as scrap reduction, due to the breakdown of the gas load that was generated prior to implementation with the freezing mode of capillary failure.

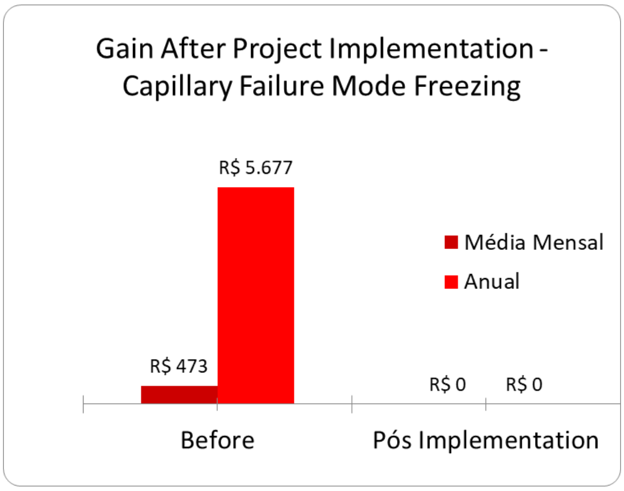

Fig. 18: Line scrap

In Figure 18 it can be observed that after the implementation, there was a reduction of the scrap related to gas load once the detection is performed before the application of the same.

VI. FINAL CONSIDERATIONS

In the face of problems that occur daily in the manufacturing processes, six sigma tools are used, which help in the improvement and solution, avoiding the occurrence of the flaws studied.

With the analysis of MSE and VOC, we can evaluate the measurement system and understand the normal behavior of the product, as well as show that the samples that did not obtain the normal behavior had capillary obstruction. Samples outside the normal product behavior were excluded for the definition of parameters, as they could impact the results. The defined parameters are confidential, so they belong to the company where the project was applied, not being fully detailed in this study due to security issues.

From the case study we can conclude that the elaborate solution is sufficiently robust. And a failure in the experiments before implementation would result in losses of company resources as well as the time spent by the professional.

Before the implementation, the detection of the fault was only made through visual perception, being a vulnerability, since it could go unnoticed by the operator at the moment of testing products in the performance. With the implementation the failure is detected near where it is generated, not allowing to move to the next station, therefore does not add value to the products with the late detection.

During the chronoanalysis performed by the process engineering team, we were informed that the position chosen to include the test activity would be 3 seconds above the standard time, we were suggested to balance activities for other stations, so that the flow test was in the previously chosen.

It was possible to perceive the existence of opportunities for new projects that improve the visualization, methods and welding techniques of the welder.

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