# STUDY OF THE FAILURES BASED ON STATISTICAL METHODS AND FMEA: CASE STUDY FOR PAPER MANUFACTURING MACHINE

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***Abstract:*** *In this work is presented a case study where is proposed a systematic approach based on statistical techniques and Failure Mode and Effect Analysis (FMEA) for qualitative analysis of reliability of a paper manufacturing machine. The increase of quality requirements by costumer, legal restrictions, time to market of new products and environmental issues contribute meaningfully to the development of maintenance planning and quality guarantee based on reliability engineering for estimation of the lifetime useful, stop and repair times for an item (machine or component) on operation. The survey of the types and conditions of the failures are fundamentals to productivity and quality of the final product. From the procedure proposed and data analysis it was possible to identify the critical component that during of its failure generate a stop time of the equipments of approximately 15%. Therefore, it was proposed change in the geometry of the bearing-pin pair analyzed by the Finite Element Method (FEM) to investigate the mechanical behavior from these modifications in the critical subsystem.*

***Keywords***: *FMEA; mechanical design; paper industry; failure.*

## 1. INTRODUCTION

The use of statistical tools during the product useful life contributes to estimate of the useful life time of its design and secondary functions for predictive and preventive maintenance and traceability and identification of design and processes failure. A "product" can be defined as a component, subassembly, machine or mechanical equipment, with electronic elements or consumers good. The development of the design and manufacturing as well as operational are guided by preventive and predictive maintenance planning for machines or equipments, mainly due long periods of use like mass production or continuous process. Therefore, considering transformation industries the operational time of equipments in operational conditions or stopped due failures must be investigated and as much as possible estimated, with the purpose to obtain the adequate cost benefit relation. The statistical approach in the product development cycle involves three interdependent knowledge areas: maintenance, reliability and costs. According to Bertche (2008) the objective of this study considering the three knowledge's areas allows to take a system considering availability and costs optimized. The costs involved during the lifetime of a machine or component can influence in decisions, like improvements or innovations and, therefore, financials investments. The information obtained by the reliability and maintenance applications during the lifetime of systems is substantial for the cost estimative of the life cycle of the product and evaluated items.

Table 1 – Life cycle stages of a "product" (Adapted: Doi *et al*. 2010).

| Life Cycle Stage | Evaluation Items | Optimization | Variables |
|---|---|---|---|
| **Design** | Functions, performance | Maximize | Scale, weight, material, structure |
| **Manufacture** | Cost, energy<br>Reusable items | Minimize<br>Maximize | Processes<br>Extend life cycle |
| **Use** | Cost (material, energy) | Minimize | Conditions |
| **Maintenance** | Cost (inspection, cleanness and repair)<br>Reliability | Minimize<br>Maximize | Assembly structure<br>Extend life cycle |
| **Disassemble (Repair)**<br>**Disassemble** | Cost<br>Assemble / Disassemble easiness | Minimize<br>Maximize | Number of parts<br>Structure (modular) |
| **Reuse**<br>**Recycle** | Proportion of reusable items<br>Easiness of recycling<br>Proportion of recycled material<br>Cost, rejected material | Maximize<br>Maximize<br>Maximize<br>Minimize | Number of parts<br>Life cycle<br>Number of materials<br>Assembly structure |

In this present paper is proposed a previous study for reliability where parameters about performance of items and elements of a machine designated to process paper sheet where obtained by traceability. This procedure is not a trivial task because it depends on a maintenance policy adopted by the company, if there is history of maintenance and if this material is reliable, it means that this material relate exactly what happens and identify, analyze and solve technical issues related to the project and building process of the machines and the final product respectively. The research work object to purpose a methodology of identification and quantification of elements or items, in potential and catastrophic failure, for equipments of paper industry, whit purpose of reduce the time of repair and stopped for critical items.

## 2. REVIEW

A complex equipment is composed by many components, each one with different mechanism of failure. The curve of conditional probability of failure is the combination of the four failure models by the proportion of each item and its temporal relevance in the main function of the system. The bath curve expresses the typical behavior of the failure mechanism of this element.

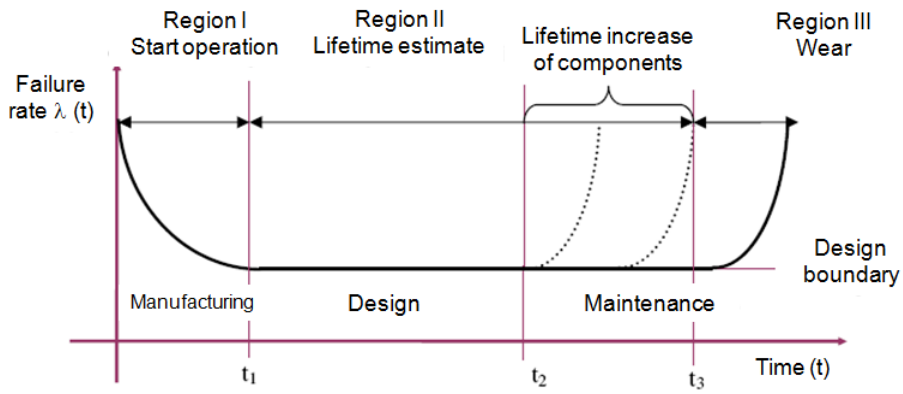



Figure 1 – Bath Curve developed for electronic components. (Adapted: Ramakumar, 1993).

In the section III (wear), the maintenance acts intensively, to extend the lifetime of an element or an item. The section II (design) for mechanical elements shows an extremely short section, causing wear quickly due the friction intrinsic of the operational condition or/and dimensioning error. The reliability engineering is developed in these three phases, mainly during the design (product design) and maintenance planning (product support). The study of reliability can be quantities or/and qualitative, as showed by Figure 2 and normally involve high costs and experimental tests that imply times. The qualitative approach searches the failures source, type, mode and causes using techniques as FMEA, Ishikawa Diagram and database operational from performance. The quantities reliability need of experimental set-up that provides information about failure rate and failures times through of the data fitting to statistical distributions. Using these data the function design can be defined as well as the maintenance planning (Silveira, 2010). A failure is characterized by an interruption or alteration of the performance of design function. There are five categories of failure: Infant (design scaled inadequate), intermittent failure (progressive or abrupt), extension (partial or complete), criticality, timing (random or premature).

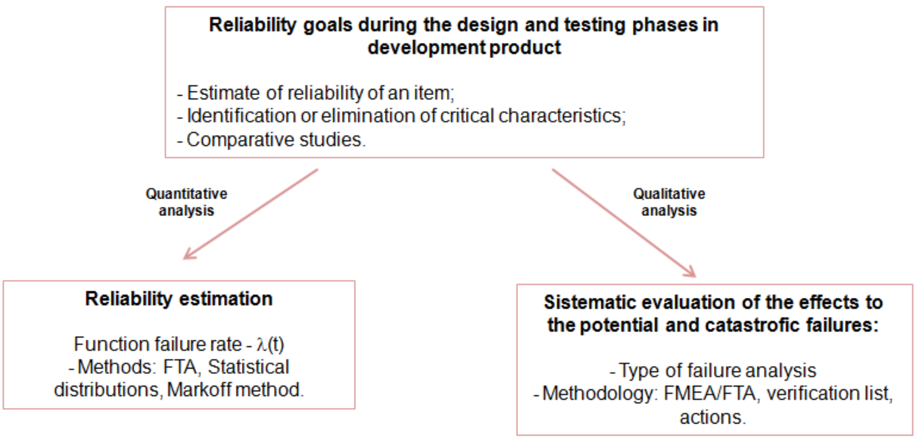



Figure 2 – Reliability engineering approach (Adapted: Bertche, 2008)

According to Bertche (2008) FMEA (Failure Mode and Effect Analysis) is used since 1980 by DIN 25448 and for *VDA 4.2 (German association of automotive industry)* standards that recommend the application of FMEA in the design and manufacturing in special for automotive industry in Germany and Europe. NASA –USA during the Apollo project developed the FMEA in 60´s. After that the FMEA has been applied as procedure in the aerospace engineering (MIL-STD-1629A) since 1965 (Bertche, 2008). The FMEA is a systematic method, which can be identified all possible ways of failure of systems, subassemblies or elements in arbitrary way, considering a same time failure it is associated an effect and its cause. The FMEA is finalized considering the risks evaluation (RPN – risk priority number) and specifications of improvement acts. The FMEA for general systems or FMEAC (Failure Mode and Effect Analysis Critical), for complex systems guide systematically the identification of each function of an installation and determine potential failure. The Pareto Law has been proposed by the Italian economist Vilfredo Pareto (1848-1923) observed that 80% of the Italian wealth was controlled for 20% of the population. The diagrams generated by the Pareto Law can identify items with higher costs in a set of items that apparently consume the same amount of production resources. The ABC diagram is a variation of the Pareto Law and also applies the 80-20 proportions and normally shows the curve shape according to the evolution of the causes and the accumulated result of their effects that normally results in a shape of a curve. The superposition of the causes results in increase with different proportion.

### 2.1 Maintenance overview

In the 1960´s, the intensive application of statistical concepts in engineering area, especially in the reliability and statistical quality control areas made that the maintenance engineering to use criterion to control of the failures. These new approaches allow the inspection process and monitoring of the equipments and machines in order to map its operation to estimated failures or unsatisfactory operation. According to Vieira (1989) the "Maintenance is the industry activity that destinies to maintain in work condition the equipments and the facilities of the industry, so that the industry gets the productivity that wants." Moubray (2008) classifies the maintenance in 3 types or generations, as presented in the Figure 3. This classification is resulted of the modifications of the industry philosophy and changes in the manufacturing and production along de last 70 years.

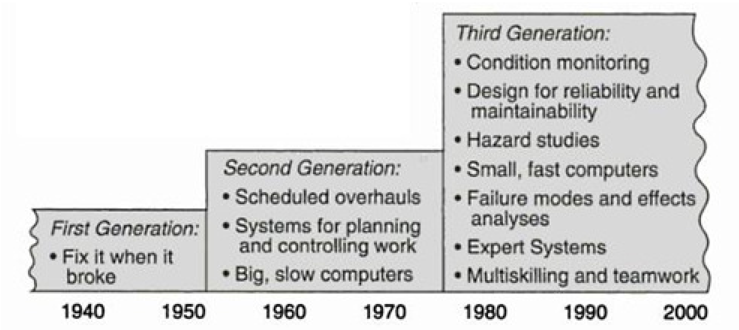



Figure 3 – Evaluation of the maintenance approach (Moubray, 2008).

## 3. CASE STUDY: PAPER MACHINE

The case study was developed from machines for processing paper presented in the Figure 4. The industry of paper is based on basically two different areas, the production of paper and the finishing area, where the paper is cut, packaged and boxed. In this research was developed a methodology to collect, identify and classify based on criticism of an equipment responsible to boxing packages of paper. The continuous advancing of industry has motivated the intern and extern market field to increase and optimized their production flow. In the industry of paper it's very notable as well, and motivated by this it has been developed a study in order to decrease the time stopped by corrective maintenance in the most critical equipment in the finishing area. Analyzing the reports and notes that contained maintenance history was possible to select the issue that ever occurs without a treatment, just corrective treatment. By guideline of the company, only failures that demand over than 60 minutes received a brainstorming in order to review the situation and develop improvements in order to prevent that. In this case, the failure demand less than 10 minutes to be fixed, but the number of occurrences made the month time of repair in approximately 5 hours per month in an equipment that should work 24/7.

Figure 4 – Boxing packages machine.

## 4. PROPOSED METHODOLOGY

The development of a program of reliability centered in maintenance involves several previous procedures that are fundamentals to estimate the lifetime useful of equipment or item, duration of stops and repairs and so, the availability and mantenability of the equipment. In this research is proposed the systematic evaluation of the effect of the potentials and critical failures as presented by Figure 2. In the figure 5 is presented the flowchart developed and implemented for the qualitative study of reliability.

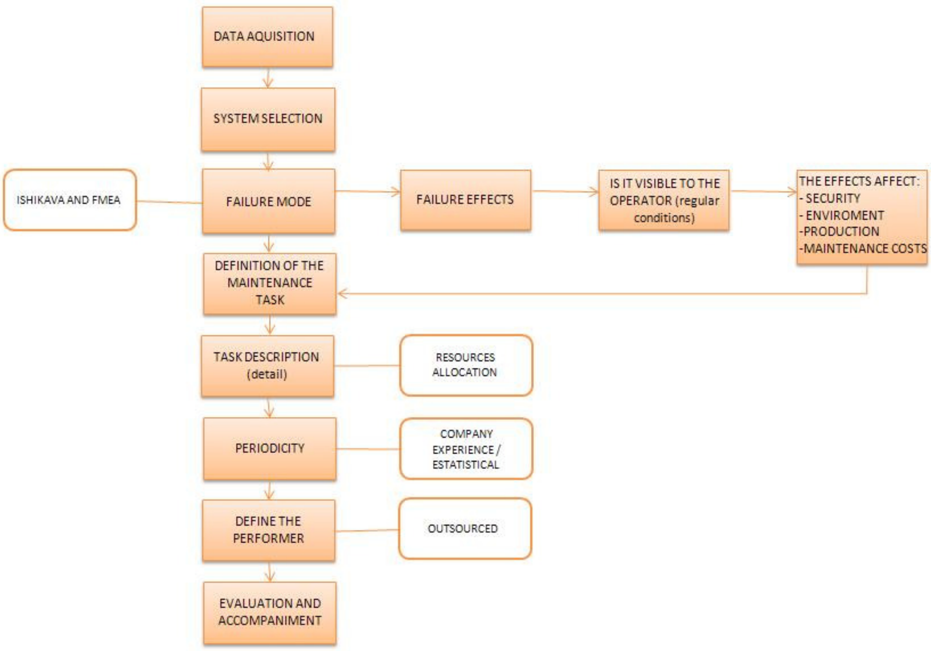



Figure 5 – Proposed flowchart to identification of the critical and potential failures.

The search of the correct identification of the failures was made the tracking of the reports and notes about the history of maintenance since 2008 until March 2010. Analyzing this notes, was possible to check a standard of failure, and according to the geometry and configuration of the machine that was divided in sub assemblies to get know the source of each failure. The boxing machine has been divided in: air finger, lid and bottom appliers, glue appliers, main drive, and bender side, lifting system, packages aligner and bottom sealer. The Pareto diagrams, as showed by Figures 6 and 7(a) and (b), present the relevance of each subassembly in the timing stopped, as example the high time and frequency of maintenance observed in period of time considered were the component "air finger" that correspond to 62% of failures.

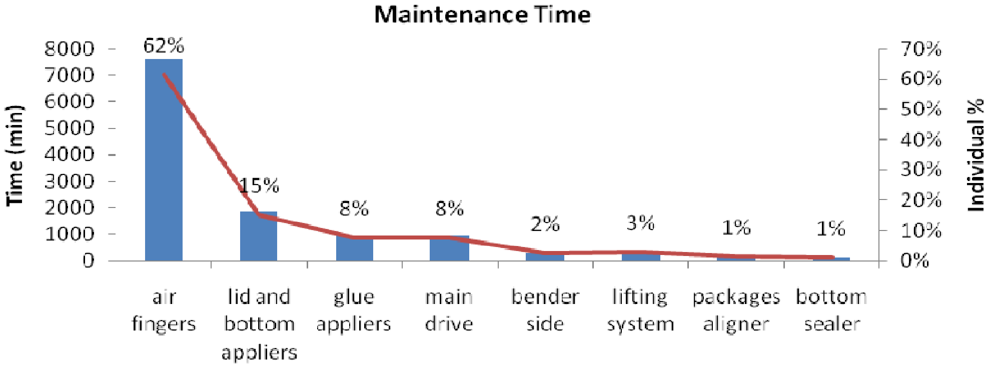
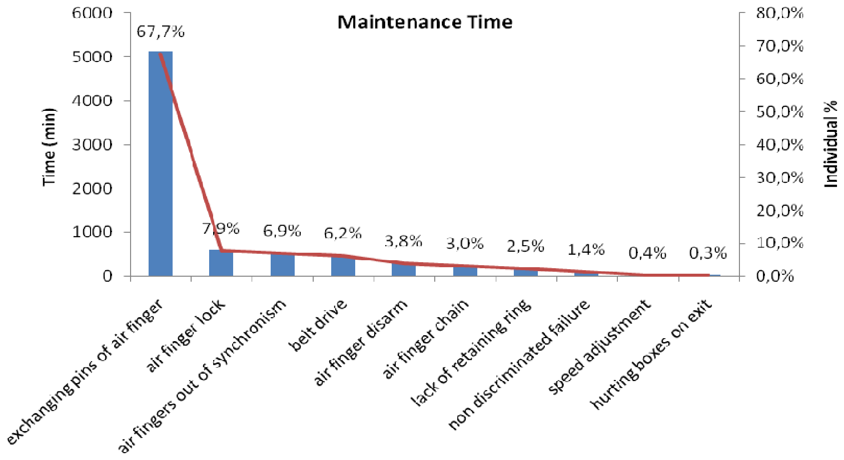
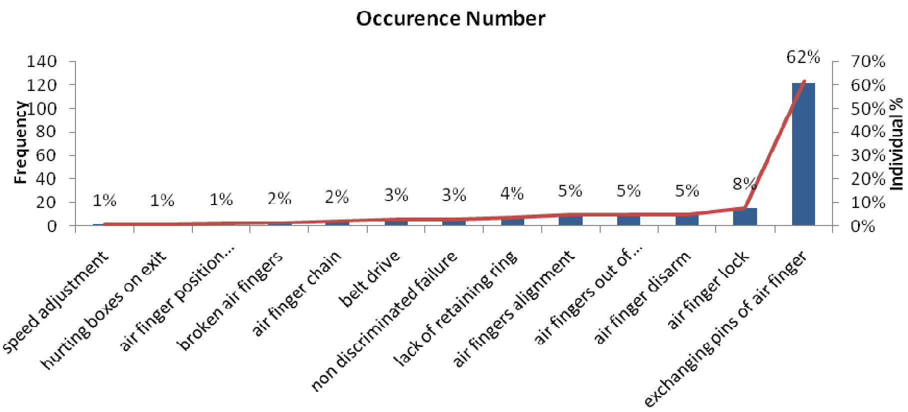



Figure 6 – Maintenance time chart of boxing package machine.




(a)




(b)

Figure 7 – Maintenance time chart and number of occurrences chart of transportation system subassembly.

With the identification of critical components was made a Ishikawa diagram presented in the Figure 8 followig of the development of a FMEA showed in the Tables 2 and 3 with the purpose to understand the relationship failures to proceed with improvements in the design and/or process.

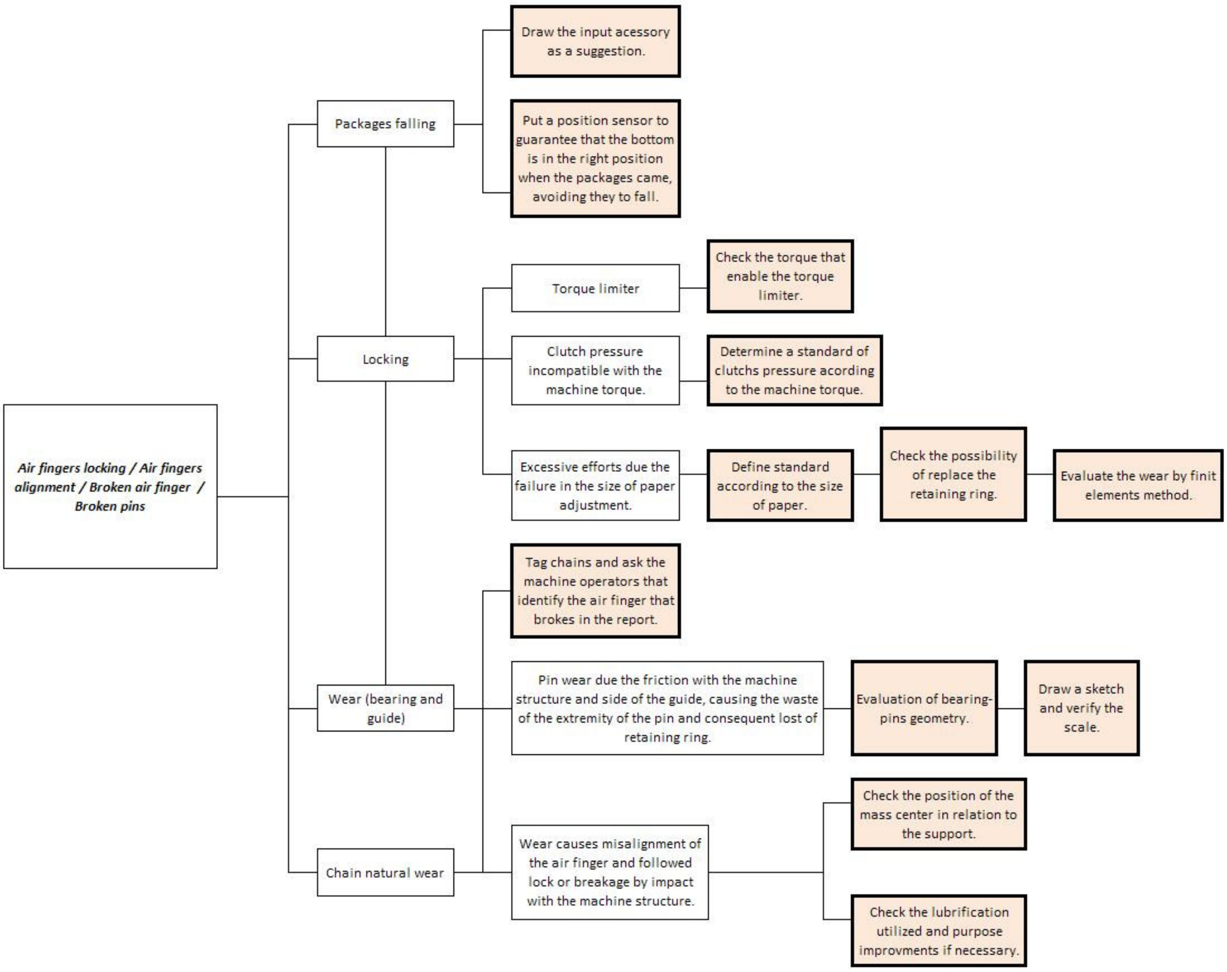



Figure 8 – Ishikawa flowchart.

In the colored boxes in the Ishikawa flowchart were considered some steps and suggestions to solve or reduce the failures; to study their impacts in other functions was made a design FMEA. According to VDA 4.2 (1996) are considered five steps to application of FMEA: System elements and system structure; functions structure; failure analysis; risk priority number; improvements. The table 2 presents the criterion SPD that indicate the items that can to carry critical failures included others items.

Table 2 – Standard values to Severity, Prevention and Detection for FMEA.

| Severity | | Prevention | | Detection | |
|---|---|---|---|---|---|
| Value | Specification | Value | Specification | Value | Specification |
| 10 | Production line penalization | 10 | There is no inspection due access difficulty | 10 | There is no access to evaluation |
| 9 | Product quality affected | 8 | There is no inspection (several reasons) | 8 | Detection of failure is difficult |
| 8 | Security | 6 | There is inspection routine | 6 | There is some difficult of detection |
| 7 | Rework | 4 | Is possible to realize before failure happens | 4 | Easy detection |
| 6 | Decrease in efficiency | | | | |
| 5 | Equipment damage | | | | |
| 0 | Non discriminated failure | | | | |

From SPD criterion was elaborating the design FMEA, considering the air finger, bearing and pin components, presented in the Table 3.

Table 3 – FMEA resolution developed to "Boxing package machine" (air finger, bearing and pin).

| System | Function Requirements | Potential Failure Mode | Potential Effects of Failure | Time | Severity | Possible Failure Reasons | Occurrence | Suggested Action |
|---|---|---|---|---|---|---|---|---|
| Air Finger | Guide boxes during glued | Air finger stopped | Air finger pins broken, excess of strain | 597 min (9 hours and 57 minutes) | 10 | Bearings and guide wear, pressure clutch incompatible with equipment torque, chain wear, packages fallen over chains once the bottom is not in the right position | 15 | Verification of the lubrication system in use, tag of the chains, verify the lock systems of pins (retaining ring), verify the draw and the mass position in relation to the support, verify the torque regulation in relation to the clutch pressure, redraw the bearing and pin and validate that by finite element methods. |
| Pin of Air Finger | Support air fingers in transport chains | Exchange air finger pins / Lack of retaining ring in air finger pins | Air finger pins broken | 5136 min / 187 min (total of 887 hours and 10 minutes) | 10 | Because of the bearing and guides wear, there is a side displacement of the pins that, in contact with the machine structure, wears the pin and it makes the retaining ring fall. The retaining ring is not resistant. | 128 | |

## 5. RESULTS

In order to reduce the stopped time by air fingers due catastrophic failures, in the previously proposed Ishikawa flowchart, has been proposed some improvements; one of the suggestions was a geometry modification that was analyzed using finite element method through Ansys® program to improve the bearing-pin pair. The Figure 9 shows the disposition and applications of the air fingers in the subsystem equipment.

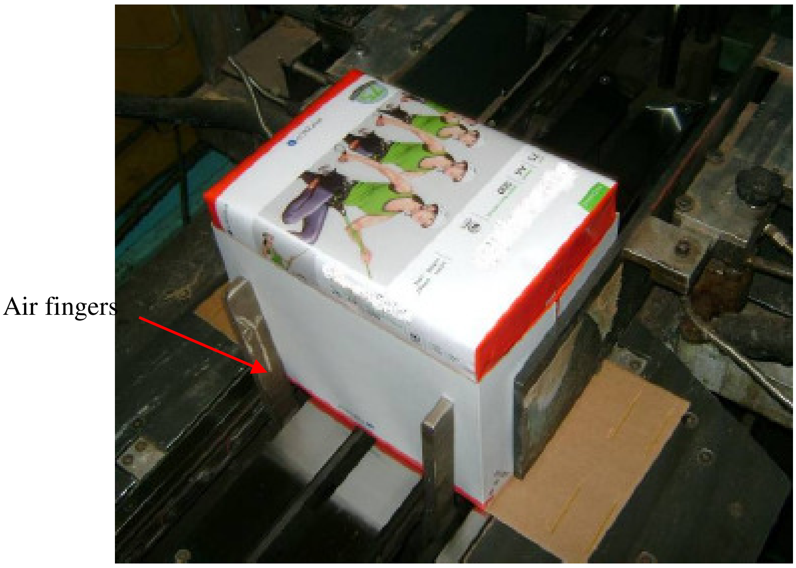
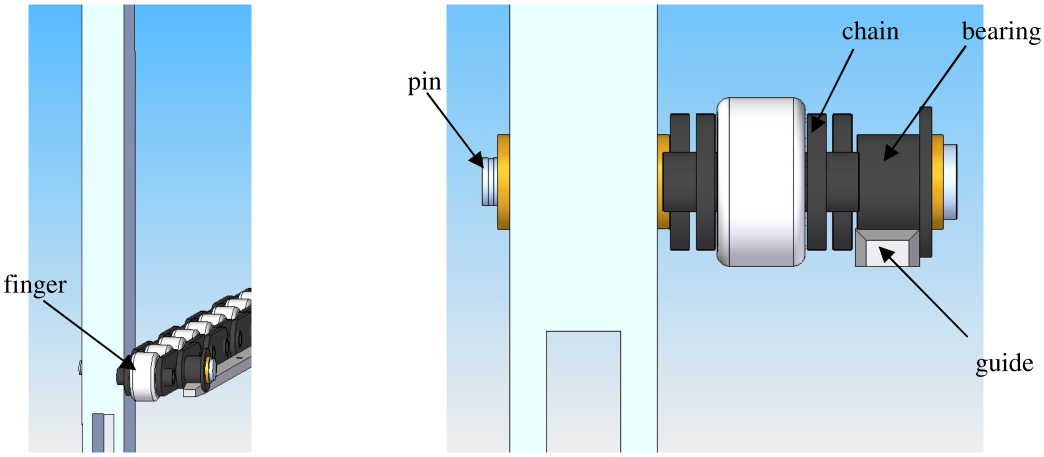



Figure 9 – Transport system.

In the Figure 10 is presented the drawing of this subsystem whose pair bearing-pin was modification showed by Figure 12.




(a) (b)

Figure 10 – Views of the assembly of the transportation system that includes (a) finger; (b) bearing, pin, chain and air finger.

In the Figure 10 it is possible to identify that the mass center is not positioned on the support. This condition means that whatever wear occurs in chain, bearing or pin, the subassembly will be misalignment increasing by the geometry of the bearing that wear itself or the guide, as follow in the Figure 11.

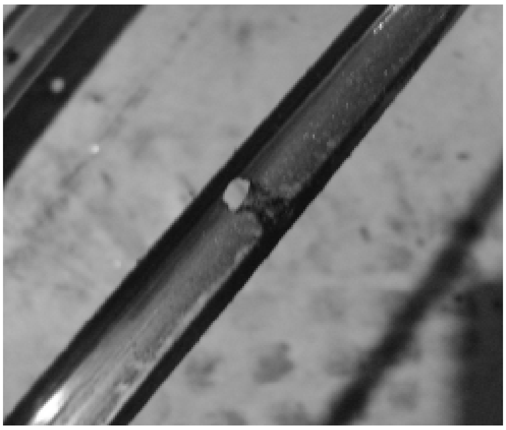
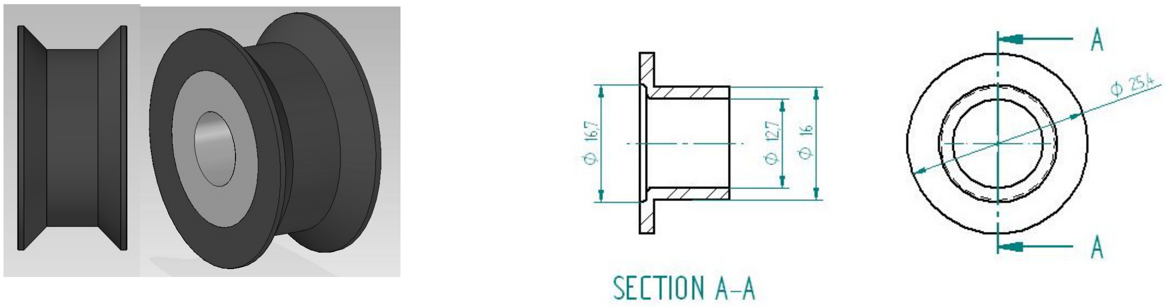
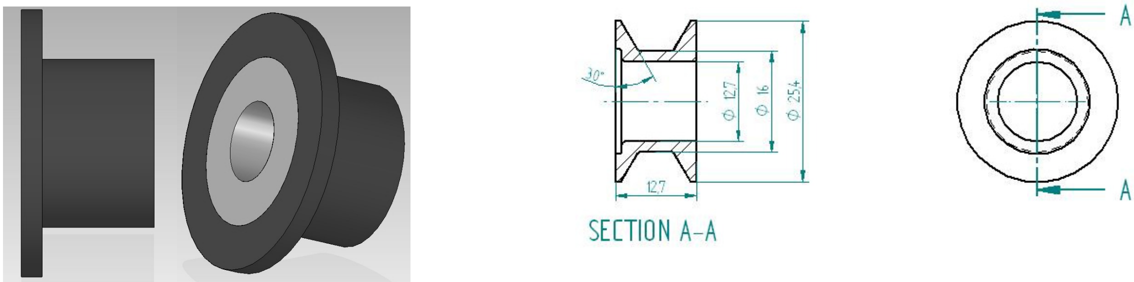


Figure 11 – Wear guide.

From the study about failures mode and causes is suggested initially geometric modifications in the bearings and guides whose objective is to increase their useful lifetime so that there was not misalignment in the air fingers and consequently wears in the guide. Therefore it was proposed a modification in the bearing-pin system. The Figures 12 (a) and (b) present the comparison between the actual geometry profiles of the guides and the bearing and the Figure 13 presents the alterations suggested in the guide.

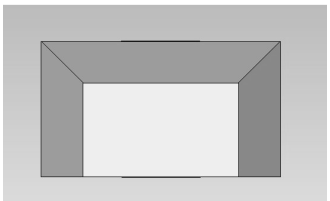



(a)

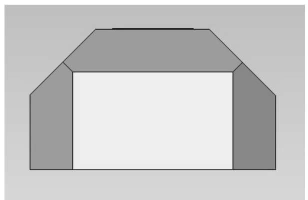



(b)

Figure 12 – Bearing geometry (a) current geometry; (b) proposed geometry.



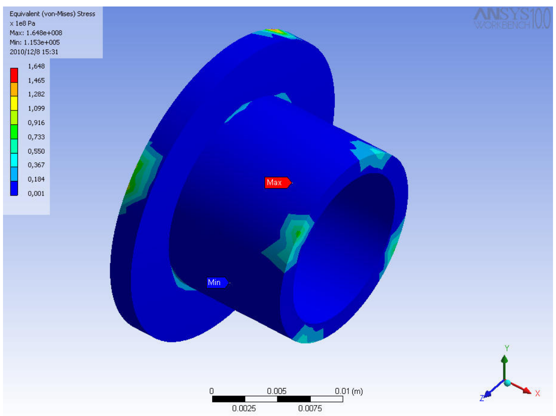
(a)



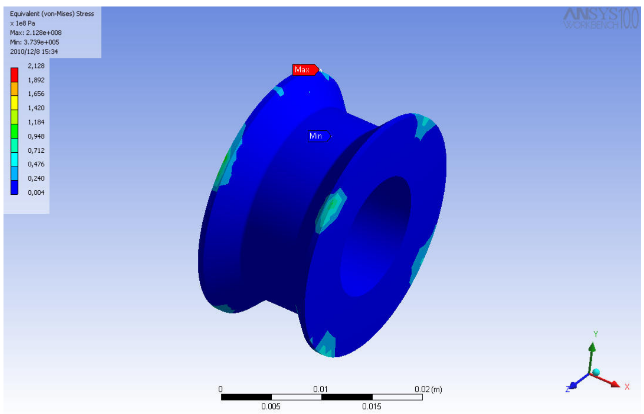
(b)

Figure 13 – Guide (a) current geometry; (b) proposed profile.

From the Free Body Diagram, material properties obtained from technical literature and boundary condition were generated geometric models these geometric and profile modifications to obtain the principal stress and strain. The data about material were obtained in Matweb site (2010). To the numerical analysis was used the Ansys ® program.




(a)




(b)

Figure 14 – Bearing geometry: (a) Current: equivalent Von Mises stress; (b) Modification: equivalent Von Mises stress.

In terms of state of stress, the current bearing presents maximum equivalent stress of the 164.8 MPa. The proposed modification to bearing presents maximum equivalent stress of the 212.8 MPa. Just for comparison, the finite elements method has been used to show that the suggested geometry will suffer wear symmetrically and it could reduce de misalignment and increase the MTBF increasing time to realize the preventive maintenance. The misalignment in this machine is very unlikely because it can cause impacts by parts of the structure and the fingers misaligned, generating potential and catastrophic failures in more systems of the boxing machine.

## 6. CONCLUSIONS

This work presented a study and application of qualitative reliability approach to paper equipment. This study allowed the identification of the potential and critical failures as well as the critical components that demand a high maintenance time of the equipment, that consequently interfere in the production chain. The identification of the critical failures leads to planning of these controls. The modifications of the geometry and profile of the bearing and guide, respectively analyzed by finite elements method were made in order to avoid the appearing of the premature wear of the same components of the boxing machine, for example the chains that involved high overload in the bearings and, therefore severe wear in the guides. The geometric alterations of the bearing pin system have not the final solution for the wear problem but must be increase the lifetime useful because that wear will occur equally in the pair bearing-guide with reducing of the misalignment so that the preventive maintenance will can to act. The next step for this work is developed an experimental set-up to obtain data about failures time considering design parameters to estimate of the reliability that lead the effective planning preventive maintenance.

## 7. ACKNOWLEDGEMENTS

The authors would like to thank to International Paper Industry for the infrastructure support to the development of this work.

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