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Application of Quality Tools for Failure Analysis in Mechanical Systems of Industrial Bench Drill Presses - A Case Study in a Farm Harvester Factory

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Abstract

The drilling process enables the penetration of the tool making a hole. Drilling machines work on a mechanical basis, presenting wearing out and showing mechanical failures throughout their life cycle, leading to the disruption of the operation and/or decreasing performance. This paper addresses the analysis of failures in the gearbox of a bench drill taken from a machine shop in a harvester factory. The quality tools (Ishikawa, 5W+2H, Brainstorming) relative to the study will be pointed out, as well as the findings in a qualitative and quantitative manner and the action plan made out as a solution to identified damages.

Keywords
Fault Analysis, gears, industrial maintenance, quality tools.

1. Introduction
Organizations are increasingly seeking for tools and management methods which lead to greater market competitiveness through improved quality and increased productivity. Industrial maintenance has strategic function, promoting the availability of the facilities allowing the increase of OEE. In order to execute maintenance activities on machines and equipments, replacing and/or repairing damaged parts is often needed. Machining processes are applied to the manufacturing and repair of these parts, where the drilling process (rotation of the tool in the material) is highly required, as most of machine components have mounting holes for joining and fixing. This drilling machine is the most efficient and economical hole-making machine process in materials, and the drilling machine is the equipment that allows its execution, hence so many models and shapes available in the market. Industrial drills, as all pieces of equipment, wear out, leading to failures during their operational life cycle, thus requiring the application of proper maintenance techniques to increase availability and performance in their operating cycle. Exploring and acknowledging the failure causes and modes of these pieces of equipment falls under the proper maintenance management. This analysis can be enhanced with the application of quality tools, which lay out the collected information in a harmonic way, systematically leading to the cause and root of failure. It also presents methods to solve problems, allowing the correct interpretation of available data for accurate decision-making, granting greater efficiency of industrial maintenance for the solution of problems.

This article presents a case study on a bench drill press from a tool room in the maintenance department of an agricultural harvester factory. This drill press showed severe wear in the gearbox, a factor that led to the interruption of its operation and the exchange of the transmission system. Brainstormed quality tools were applied for the analysis of failures and their causes in the gearbox, combined with the information gathered and organized in the Ishikawa diagram. From this analysis, a structured 5W+2H action plan was originated, which triggered actions and an effective preventive plan to avoid the occurrence of the identified causes. This action plan has led to increased availability of drill presses, highlighting the failure rate and availability before and after the implementation of the action plan, indicating the effectiveness of the use of quality tools in solving problems related to maintenance.

2. Applied Methods

This research has its data and results analysis presented in a qualitative and quantitative way; the latter expresses results in numeric data and the former presents information in a clear and objective descriptive manner. It is also an applied research by nature, as it's designed to analyze the problems in real-life situations and acknowledge practical applications for specific problem solving [4]. As to its overall objective, this study is classified as applied research as it analyzes and identifies the causes leading to the problem by observing the behavior of the element studied, explaining the occurrence modes of damages [6]. The technical procedures are classified as case study and action research, as it presents a thorough study of a specific object and comprehensive details regarding its functions and modes of failure occurrences. Involved researchers and technicians also seek solutions to solve the problem in joint work [4].

3. Application of Quality Tools in Failure Analysis

Industrial maintenance aims to maintain the availability of machines and equipment with adequate performance, so it needs to actively analyze machine failures and manufacturing facilities in order to directly act on the causes and modes of the failures, cutting them down or even completely. For organizing and directing the analysis, quality tools are used, for they provide a systemic process to structure the information in a clear and objective manner, leading to greater accuracy concerning data analysis for decision making. The Ishikawa diagram, also known as Fishbone Diagram or Cause and Effect Diagram, is one of the quality tools applied to the case study. It allows prioritizing the studied failure causes, leading to a response in a graphical simplified format. Problems can be classified into six concepts: materials, methods of operation and/or application, labor, measures, working environment of the element under study and conservation status of the machine [1, 3].

Brainstorming is a simplified tool for investigating the causes of failures through obtaining information and concepts developed in a free instant manner around the analyzed failure. It is useful for solving problems and approaching actions to be taken in a short term [7]. The 5W+2H technique involves systematically asking seven questions about the subject being studied: What, Where, When, Who, Why, How and How much. The order of these questions may vary to the need of the analysis. Extra fields may be added for more detailed information, enhancing the application of the tool in solving the identified problem. Such tool includes three steps to problem solving: (1) investigating the problems to collect information on the causes for analysis; (2) assembling an action plan to eliminate the root causes of failures; and (3) standardizing actions to be applied to the object of study, avoiding failure recurrence. Tools applied to maintenance management may be adapted to the needs of the department or company, enabling its use and increasing efficiency in helping solving problems.

4. Performance Indicator of Industrial Maintenance

Availability is a function of time, defined as the probability that a system is operating correctly and is available to perform its functions at the instant of time t. Availability differs from reliability in that reliability depends on an interval of time, whereas availability is taken at an instant of time. A system can be highly available although presents frequent periods of inoperability as long as the length of each period is extremely short. In other words, the availability of a system depends not only on how frequently it becomes inoperant but also on how quickly it can be repaired [2]. MTBF (Mean time between failures) describes the expected time between two consecutive failures for a repairable system. Therefore, MTBF is a key reliability metric for systems that can be repaired or restored. Mean time to failure describes the expected time to failure for a non-repairable system. Non-repairable systems can fail only once. Therefore, for a non-repairable system, MTTF is equivalent to the mean of its failure time distribution. Repairable systems can fail several times. In general, it takes more time for the first failure to occur than it does for subsequent failures. Therefore, MTTF for a repairable system can represent by one of two ways: (1) the mean time to first failure (MTTFF) or (2) the mean uptime (MUT) within a failure-repair cycle in a long run. MTTR is an abbreviation for Mean Time to Recovery or Mean Time to Repair which represents the average time taken to put a defective component or system back in working order. It is a measure of the maintainability of a system and predicts the average amount of time required to get the system to work again in case of a system failure [5].

5. Materials and Methods

The case study was developed in a harvester factory, of Italian origin, located in the Cidade Industrial de Curitiba (Industrial City of Curitiba - CIC).This company has a machine shop in its maintenance department specialized in the machining of parts and devices for maintenance and operation of machinery and equipment in the manufacturing area. Figure 1 shows the machine shop layout where the bench drill press is installed, which is the object of this study.

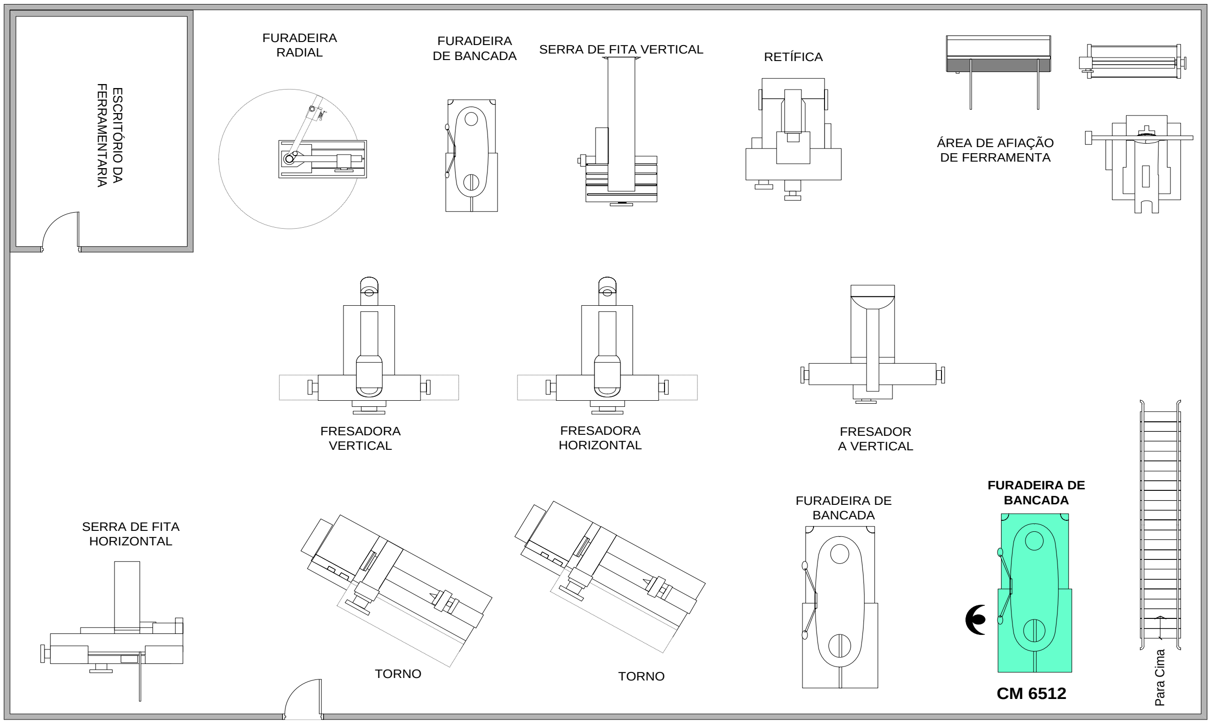

Figure 1: Tool Room Layout; Source: Own authorship

The development of this work consists in the application of quality tools for analyzing failures occurred in the helical gearbox of the transmission system of the bench drill press TAG CM6512.
This drill is used in the manufacture/repair processes of welding/assembly devices used in welding machines from the manufacturing process of harvesters. Figure 2 illustrates the types of devices, as well as the welding machines that use them.

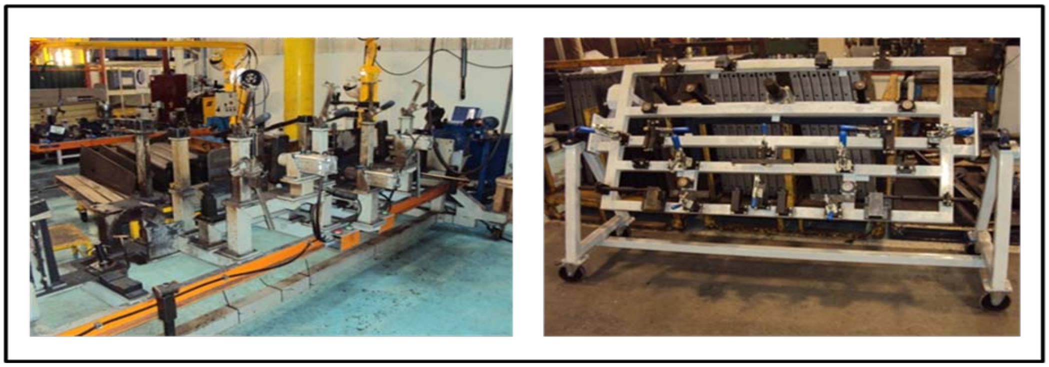

Figure 2: Welding Machines and Welding/Assembly Devices; Source: Archives from the company being studied

The bench drill press provides the manufacturing of holes, recesses and enlargement in solid materials. It is composed by an electric motor unit and a three-phase induction motor, which is attached to it and provides the drive of the helical teeth gearbox, which provides power and rotational motion to the drill spindle.
A chuck is fixed to the spindle, which is attached to the tool (drill bit) used in drilling. The tool is chosen according to standard values regarding the piece manufacturing material and the diameter size applied. Figure 3 shows the

functional tree of the bench drill press for supporting the analysis of its components and interdependencies between them.

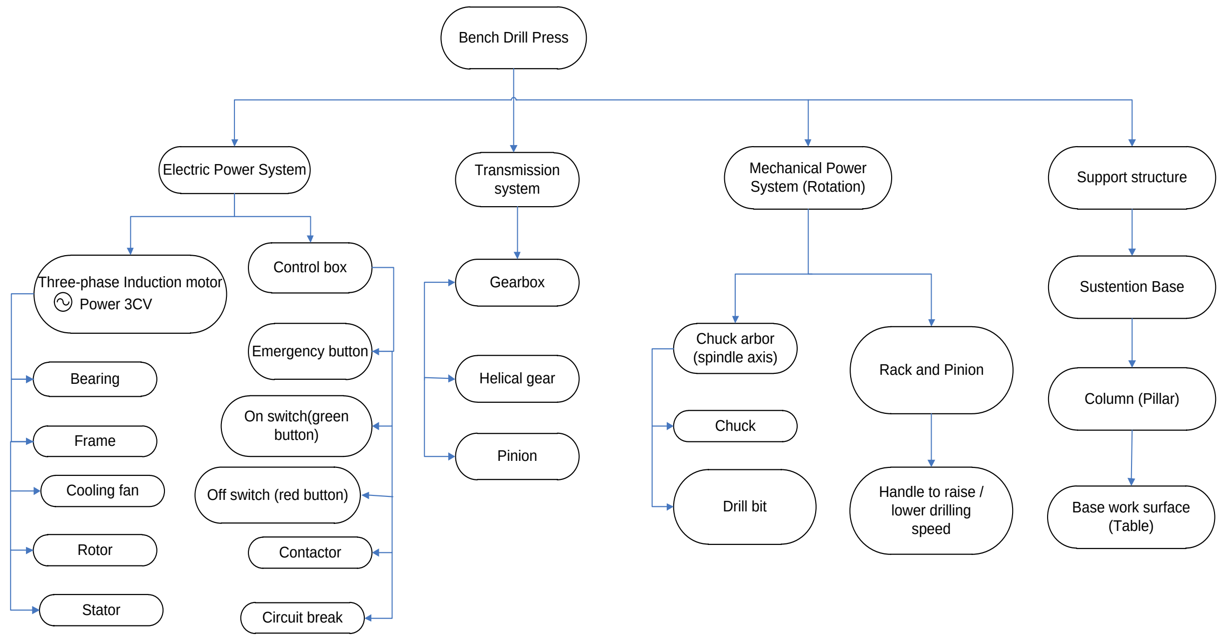

Figure 3: Functional Spindle of the Bench Drill Press; Source: Own Authorship.

This drill has a maximum drilling capacity of 35 mm and a minimum of 6 mm with an adjustable rotation from 170 rpm to 1270 rpm and uses a three-phase induction motor with 3 HP and rotation of 1170 rpm, which can be connected either to Y-shaped connections or to delta connections. The motor and its attached gearbox together allow the equipment rotational speed (rpm) to vary according to the required need of each drilling process. The speed is controlled by the rotating selector lever attached to the spindle and by the drive system, which consists of pushbutton switch, emergency switch, counter and circuit breaker.

5.1 Analysis of Failures in the Bench Drill Press Gearbox

The helical gearbox showed wear and consecutive breakages, interrupting its operation. There was superficial wear of gears and a few teeth were broken, which led to a decrease in speed/performance of the drill. At times, there was the total interruption of its operation. The electric motor was still running, but the central hub would not rotate the spindle and the tool. Changing the gear set was needed in these instances. The following table presents data from the events of the breakages, as well as the MTBF indicators (mean time between failures), MTTR (mean time to repair) and availability of the drill in relation to failures in the gearbox, from January to June of 2011. Table 1 shows the data obtained from the Manusys system, which is used by the company for management of maintenance information.

Table 1: Drill failures from January to June of 2011(Source: Manusys System, company files)

Month	**TAG / Equipment**	**Failure**	**Correction**	**Start Date**	**Start Time**	**End Date**	**End Time**	**Total Stop Time**	**Comments**
January	-	-	-	-	-	-	-	-	-
February	CM6512 – Bench Drill Press	Interruption of drill function due to breakage in the transmission box gear	Exchange of helical gear set (carburized steel 8620) of the transmission box	22/02/2011	15:00	27/02/2011	18:00	33 h	The time to repair was due to lack of gear in stock, requiring the development and manufacture of these for the exchange
March	-	-	-	-	-	-	-	-	-
April	CM6512 – Bench Drill Press	Interruption of drill function due to breakage in the transmission box gear	Exchange of helical gear set (carburized steel 8620) of the transmission box	11/04/2011	14:30	14/04/2011	17:30	21 h	-
May	-	-	-	--	-	-	-	-	-
June	CM6512 – Bench Drill Press	Interruption of drill function due to breakage in the transmission box gear	Exchange of helical gear set (carburized steel 8620) of the transmission box	07/06/2011	17:45	08/06/2011	16:30	4,75 h	-

The period of the drilling work is 102 hours/month. The MTBF and MTTR indexes and availability within 6 operational months are calculated based on Table 1 data and presented below:

$$\text{MTTR} = \text{Total Time to repair failures/ Total failures number} = 58.75 / 3 = 19.6\ \text{h} \quad (1)$$

$$\text{MTBF} = \text{Total Operational Time/Total failures number} = 612 / 3 = 204\ \text{h/failure} \quad (2)$$

$$\text{Availability} = \text{Total Time Active Operation} / (\text{Total Time Active Operation} + \text{MTTR})$$

$$\text{Availability} = 733.25 / 792 = 92.6\% \quad (3)$$

Therefore, quality tools were applied for the analysis of wear and breakage of the gears, which helped in developing an action plan. First, the involved staff brainstormed (maintenance personnel, supervisors, operators and tool makers) to diagnose the possible causes for this failure. Table 2 shows the main causes brought up with the application of this tool.

Table 2: Brainstorming of Drill fault analysis (Source: Own Authorship)

Brainstorming - Drill Press CM6512	
Failure: wear and breakage of helical gears of the spindle transmission box	Possible causes of failure
Participants: Production operators, maintenance personnel, toolmakers and supervisors of maintenance and production.	Gear wear due to operation time.
	Misalignment of gears.
	Lack of gearbox lubrication; Application of incorrect lubricant; Presence of contaminating material in the lubricant.
	Overexertion in spindle / Overload.
	Operational error: Application of +/- 45 to 50 mm drill for drilling welding device, diameter above the capacity of the drill, so greater effort exerted to perform the hole (cut), causing wear and/or breaking of gears.
	Material used in the manufacture of gears, carburized steel 8620.
	Rail rack wear due to the up and down movement of the pinion..

Then, the probable causes that led to the failure in the gearbox brought up by brainstorming were selected and they were introduced into the Ishikawa Diagram (Fishbone Diagram), to harmonize and to organize information according to its source, classified into 6 types for better analyzing the causes. Figure 4 shows the Ishikawa diagram.

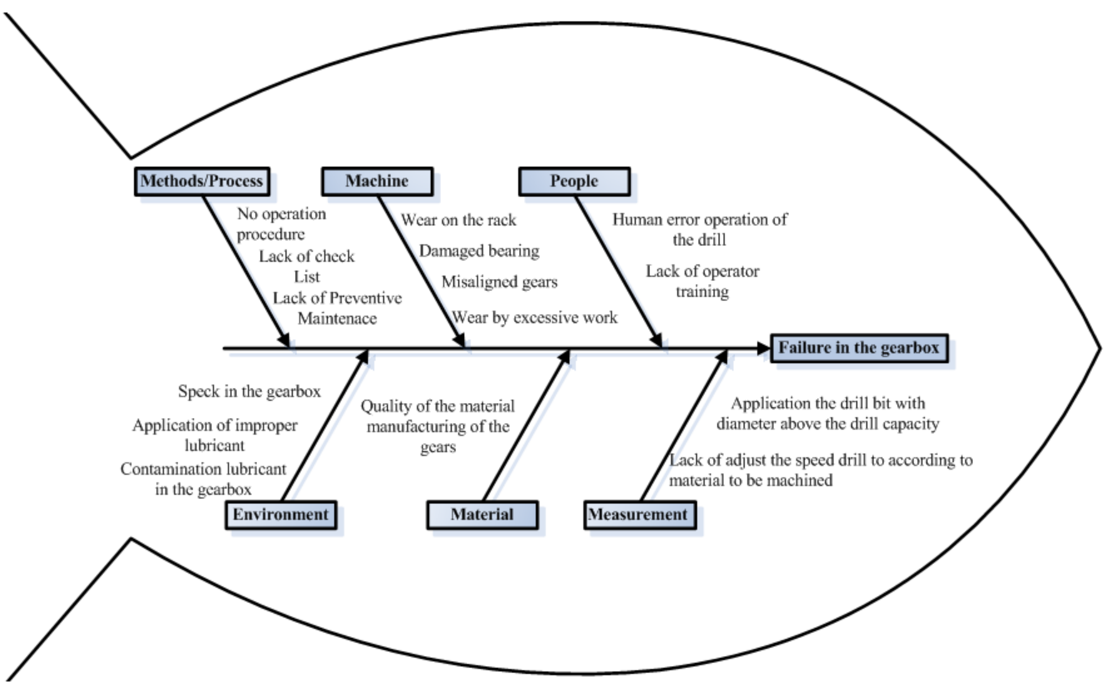

Figure 4: Ishikawa Diagram of gearbox failures (Source: Own Authorship)

With all gathered information concerning the failure causes hereby, it was developed and implemented an action plan to cut down and/or cut out recurring gear wear and breakages and, therefore, to improve availability and performance of the drill. Based on the information and data from both the Brainstorming and Ishikawa diagrams, an action plan was made based on the 5W+2H quality tool, which has been changed and adapted to the needs of the company under study. The action plan (Table 3) allowed considering all performed or selected tasks in a clear and objective manner, ensuring its implementation in an organized way and focusing on effective results. The proposed actions in the action plan have been executed within schedule in July/2011, some continuously running as the execution of procedures and check list, preventive maintenance and inventory control of spare parts (gear set) for drill maintenance.

The critical factor found during the failure analysis was the improper drill operation. Some toolmakers used tools with size and dimensions above maximum capacity specified by the manufacturer. From January to July of 2011, they often made use of 45-50mm drills. In order to fit these larger drills into the spindle, the toolmakers milled the drill rods to 35mm, in addition to failing to comply with the speed limits set for each drill diameter and type of material being drilled. These factors brought excessive stress to the operation of the gearbox, causing the wear and breaking of teeth, interrupting the drill operation and causing cost increases due to the exchange of the entire set of gears. Image 05 shows the damage caused to the transmission gear box and the larger drill with rods milled to adapt into the drill.

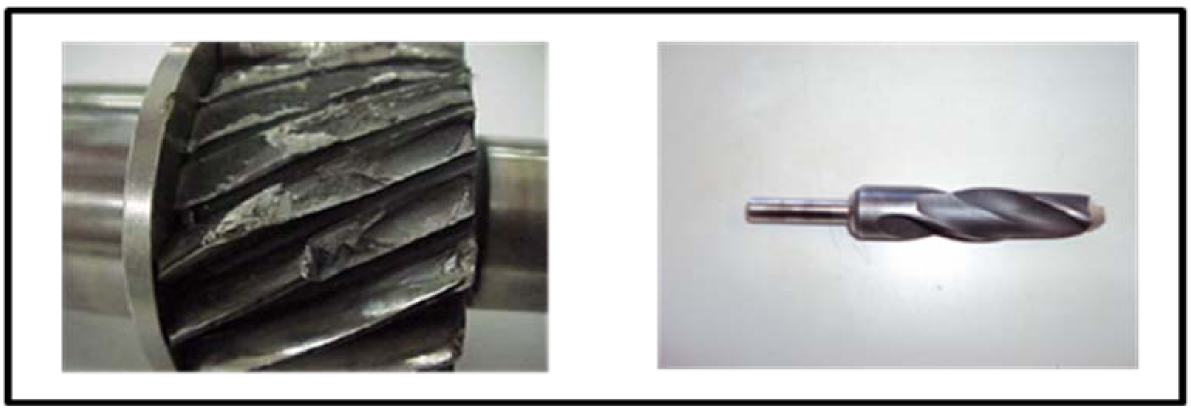

Figure 5: Transmission Gear box and drill with milled rods (Source: Own Authorship)

Table 3 presents the action plan, with the work done, workers in charge and deadlines.

Table 3: Action Plan Drill Bench Drill
Source: Own Authorship

<table>
<tr><td>Company logo</td><td colspan="4">ACTION PLAN - BENCH DRILL CM 6512 – TOOL ROOM</td></tr>
<tr><td colspan="2">Sector: Maintenance</td><td colspan="2">Responsible for: Maintenance and Production</td><td>Deadline: June - August, 2011</td></tr>
<tr><td colspan="5">Objective: Solving problems related to gearbox failures (wear and breaking of teeth)</td></tr>
<tr><th>What (Measure)</th><th>Who</th><th>Where</th><th>Why</th><th>How</th></tr>
<tr><td>Developing procedures (work instructions) for drill operation</td><td>Maintenance personnel
+
Tool Room Supervisor</td><td>Maintenance and Tool Room</td><td>To set proper drill operation parameters regarding the type of material to be processed and the type of tools to be applied, respecting the equipment capacity and developing thorough work instructions, which shall be available at the workplace (tool room)</td><td>By collecting information about the materials and parts to be manufactured from the drill, together with the information from the manufacturer's manual and information directly from this article</td></tr>
<tr><td>Developing and implementing daily inspection checklist for toolmakers</td><td>Maintenance personnel
+
Tool Room Supervisor</td><td>Tool Room</td><td>To enhance the toolmakers' responsibility regarding their equipment and work place to improve the conservation status of the drill, as well as to the improper operation of the equipment.</td><td>By raising the critical points of the drill to be checked at the beginning of each work shift and turn it into a checklist</td></tr>
<tr><td>Developing and implementing training to tool makers as to the correct drill operation, material and tool dimensions</td><td>Maintenance personnel
+
Tool Room Supervisor</td><td>Training Room + Tool Room (on the job training)</td><td>To standardize the drill operation and the use of appropriate tools for each type of material and dimensions of the tool, complying with the dimensional tolerance of the equipment. This measure is expected to eliminate/reduce the application of drills with diameter above the capacity of the machine, therefore reducing excessive stress to the gearbox.</td><td>By writing a handbook with the drilling operation parameters, the use of the proper tool for each type of material and the diameter size of the hole. Concepts in the working procedure must be applied for the drill operation, as well as a checklist training.</td></tr>
<tr><td>Purchasing spare set of gears of the gearbox and managing minimum and maximum stock</td><td>Maintenance Personnel + Stockroom Personnel</td><td>Stockroom of parts and raw materials</td><td>To maintain minimum and maximum stock of gear set for possible corrective maintenance.</td><td>By issuing purchase order with the specifications from the set of gears in the gearbox. Furthermore, the proper labeled storing of factory parts and raw materials in the stockroom.</td></tr>
<tr><td>Preventive Maintenance: Lubrication and Inspection</td><td>Maintenance Personnel</td><td>Tool Room</td><td>To avoid interrupting the drill operation, as well as to improve the performance and conservation status of the equipment machine elements.</td><td>By establishing a preventive maintenance plan, in which appropriate lubricant and its amount are identified, besides a recurrent oil analysis</td></tr>
</table>

A toolmaker checklist was developed and deployed as a solution included in the action plan. It is daily fulfilled at the beginning of each shift. This checklist is designed to enhance the employee's commitment to the work equipment and, from this change, increase availability and an improved conservation status of the drilling machine. Table 4 shows the daily check list of the drill.

With the implementation of the checklist, the maintenance management gained greater control over the toolmakers' daily activities regarding the operation and maintenance of the drill, a contributing factor in obtaining more accurate data for fault analysis and decision making. It also reduced the possibility of inadequate operations, thus avoiding wear and breaking of both gears and other machine elements.

After the implementation of activities from the action plan, failures in the gearing of the gearbox were not detected, avoiding the equipment unavailability from August to November of 2011 due to problems related to wear and/or breaking of gear teeth. It shows the effectiveness of the action plan implemented which was prepared with quality tools, thus confirming the efficiency of the application of such quality tools to help the maintenance management in failure analysis as to improve availability of machinery and equipment.

Table 4: Equipment Checklist (Source: Own Authorship)

Check List – Bench Drill			
TAG: CM6512 Location: Tool Room			
Person in charge: ____			Shift: () A () B () C
Date: _________ / _________ / ________			
Item	Description	Status	Signature
A	Check engine temperature	() OK () Not OK	
2	Check noise and vibration	() OK () Not OK	
3	Check Lubricant Level	() OK () Not OK	
4	Conservation status of the moving rack and pinion of the head	() OK () Not OK	
5	Preservation status and function of the spindle	() OK () Not OK	
6	Fixing and conservation status of the back cover of the engine	() OK () Not OK	
7	Check for noises and engine fan cleanness	() OK () Not OK	
8	Operation of on-off switch	() OK () Not OK	
9	Operation of the Emergency button	() OK () Not OK	
10	Operation of the spindle rotation	() OK () Not OK	
11	Conservation status of the head and mandrel	() OK () Not OK	
12	Fasteners (loose)	() OK () Not OK	
13	Drill cleanness	() OK () Not OK	
Comments / identified damages:			

6. Conclusion

The machining processes, especially drilling, are extremely important to the industry, both in their production processes and in the maintenance area, as devices and parts related to manufacturing and repair of machines are made and/or repaired by these processes. Operating machinery used in these processes have mechanical basis, presenting wear and damage over its life cycle, requiring proper maintenance techniques to reduce their failure rate. The present case study demonstrated the efficacy of the action plan applied to the reduction gearbox failures of Bench Drill Presses, improving availability and reducing the possibility of equipment failure with the application of training, standardization of drill machines operation and implantation of preventive maintenance activities (check list) to the operation and maintenance Tool room areas. The application of quality tools in the development of failure analysis of these machines facilitates the organization to systematically process the information, leading to greater accuracy on decision-making due to the presentation of data and information in a clear and objective perspective, increasing efficiency in industrial maintenance activities.

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