26th ABCM International Congress of Mechanical Engineering
November 22-26, 2021. Florianópolis, SC, Brazil

APPLICATION OF MAINTENANCE CONTROL AND PLANNING TOOLS IN A MANROD MILLER – MR 205

Matheus Gonçalves de Ataide, matheus.ataide@ufu.br[2]
João Charles Ferreira Gomes, joao.charles@hotmail.com[1]
Marco Tulio de Assis Riquette, marco.riquette@hotmail.com[1]
Marcus Vinicius Galdino da Silva, marcus-galdino@hotmail.com[5]
José Aécio Gomes de Sousa, josesousa@utfpr.edu.br[3]
Luiz Leroy Thomé Vaughan, lvaughan@unifei.edu.br[4]

[1]Polytechnic Institute University Center UNA - Rua dos Guajajaras 175 - Centro, Belo Horizonte-MG, 30180-100, Brazil
[2]Faculty of Mechanical Engineering, Federal University of Uberlandia - Av. J.N. de Avila 2121, Uberlandia-MG, 38.400-089, Brazil
[3]Federal Technological University of Paraná - Av. dos Pioneiros 3131, Londrina-PR, 86036-370, Brazil
[4]Federal University of Itajubá - Rua Irmã Ivone Drumond 200, Distrito Industrial II, Itabira-MG, 35903-087, Brazil
[5]SENAI - Av. Elis Regina, 370 - Santa Rosa, Uberlândia - MG, 38401-278, Brazil

Abstract. *The increase in the worldwide consumption of carbon steel and special alloys has been encouraging the modern industry to adopt marketing and product design strategies, ensuring greater competitiveness. In order to reduce costs, intensify productivity and improve services to meet consumer needs, processes must also be increasingly efficient. Quality management in maintenance is a technique that has been widely used by companies, which continuously seek better performance and distinguished results. The objetive of this work is to draw up an effective maintenance and best practices plan for the Manrod milling machine, model MR-205, by means of the exploit of quality tools, providing greater reliability in the organization with little technical intervention. The implementation of the maintenance plan, which is the outcome of this work, has not only reduced by 34 % the average time between failures, but also contributed to remedy recurring problems at operational and administrative levels.*

Keywords: *maintenance plan, milling machine, quality tools*

1. INTRODUCTION

Since the industrial revolution, machines have become indispensable in manufacturing processes, which has stimulated better automation levels. Automated equipment is now a common trend in all major stages of the production process, ranging from the receiption of the raw material, manufature, packaging and delivery (Madu, 2000).

The maintenance of machinery and equipment, although rudimentary, has always existed and has been evolving in quality as the technical knowledge of humanity advances (Otani *et al*., 2008). It was with the beginning of the industrial revolution that the first generation of large-scale optimization emerged: the corrective maintenance, the origin of which can be traced back at the eighteenth century and the beginning of the nineteenth century. In current industrial standards, all workers performing machine maintenance should receive specific training as regulated by the NR 32 (2011), a decisive factor in ensuring the reliability and the quality of services. Most training campaigns often outline topics related to personal hygiene, biological and physico-chemical risks, preventive 5S labeling and signaling, the use of PPE, accessibility, among others that positively contribute to the organizations' good operational performance (Mucida, 2017).

The preventive maintenance plan is characterized by focusing on operational routine, directing component inspections and replacements at specific intervals, thus, maintaining the desired productivity (Harrington, 1997). To accomplish that, safeguarding a timeline of equipment interventions is of vital importance for the continued improvement of the existing technology and the development of future contributions. The characteristics of these contributions depend on how the system's maintenance is carried out. In order to make the global economy and the production cycles move, it is necessary to pave the way by implementing a supportive and good maintenance plan (Teixeira, 2019). Table 1 shows the main types of current industrial maintenance.

The milling operation is a manufacturing process characterized by a continuous rotary movement of mechanical cutters that generate machined surfaces, resulting from the progressive removal of a pre-established quantity of material (Dormer, 2013). Figure 1 illustrates examples of milling operations (Machado *et al.*, 2009).

This work objectives the creating of a preventive maintenance plan for Manrod milling machines, Model MR-205 by using quality tools that provide not only operational reliability and security, but favour the build up of useful resources for an acertive mechanical intervention.

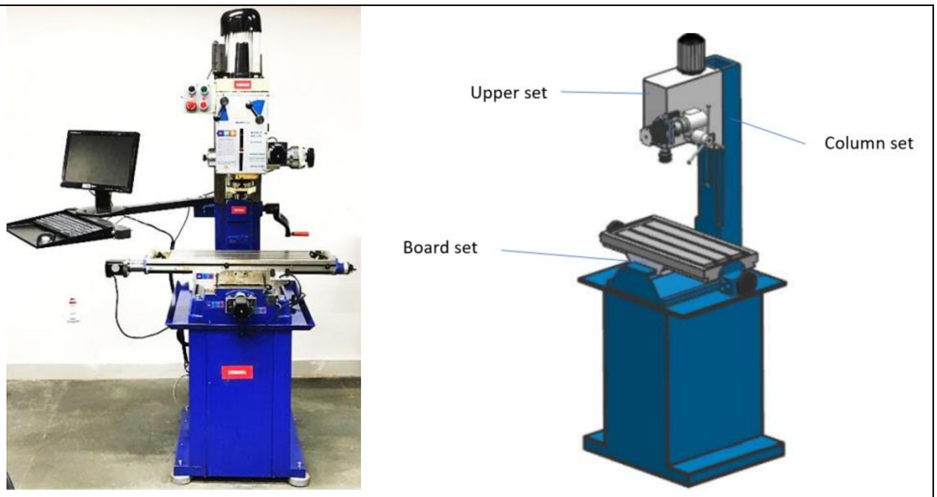
Table 1 - Maintenance Types (Almeida, 2017; Lichtenberg, 2017)

Type	Description	Advantage	Disadvantage
Corrective Maintenance	Replaces parts and components that wear out or fail unexpectedly, shuting down operations	Leverages parts and components until the end of their lifespan	Presents a catastrophic failure, resulting in a very high cost of repair
Preventive maintenance	It follows, at periodic intervals, a pre-established guideline, based on the equipment lifespan	Reduces failure risks, ageing and premature equipment degeneration	Decreases production and profitability
Predictive Maintenance	Monitors actual conditions in order to program strategies for preventing failures and breakdowns that arise from operating machines	Reduces costs by frequent and constant equipment monitoring	Involves a high investment, specially in the purchase of equipment or training, which is not always possible at all times

Figure 1 - Examples of milling operations

2. METHODOLOGY

The Manrod milling machine, model MR-205, as depicted in figure 2(a), was chosen for having a high incidence of technical problems. Machines that had similar production volumes were short listed for maintenance adequacy and their components dismembered in three main sets: upper, column and board - figure 2(b). This division has provided the best way to carry out group maintenance of components and contributed to a more holistic perspective of the installation site, as shown in table 2.



(a) (b)

Figure 2 - (a) Manrod miller, model MR-205; (b) Selected milling regions

Each component had been duly identified with regard to the maintenance frequency and inventory while issuing service orders. This has made possible to better quantify the duration of repair and the amount of inflicted damage.

Table 3 shows the major failures attributed to the component and maintenance times

Table 2 – Identifiable component group

Upper set	**Column set**	**Board set**
Engine Securing screw Oil cover retainer Transmission gear Tree flywheel Z-tree axis Tree axis scroll Bracket with head guides	Z-trapezoidal fuse Fuse wheel Back bearing Horizontal guides	Table and base guides X-Y trapezoidal axles X-Y trapezoidal nut X-Y Step Engines Table and base rulers Table Bearing Table Rear Ring

Table 3 - Measured failures of model MR-205

Failures	**Idle time (min)**	**Percentage ratio (%)**
Machine setting	1404	24
Lubrication	1216	21
Breakage	762	13
Slide or wear	640	11
Systemic breakdown	558	10
Temperature increase	414	7
Rework	299	5
Tool replacement	178	3
Power outage	162	3
Lack of raw material	121	2
TOTAL	5760	100

Figure 3 represents the information given in table 3, where it is clearly noticeable the impact of each failure affecting the total machine downtime.

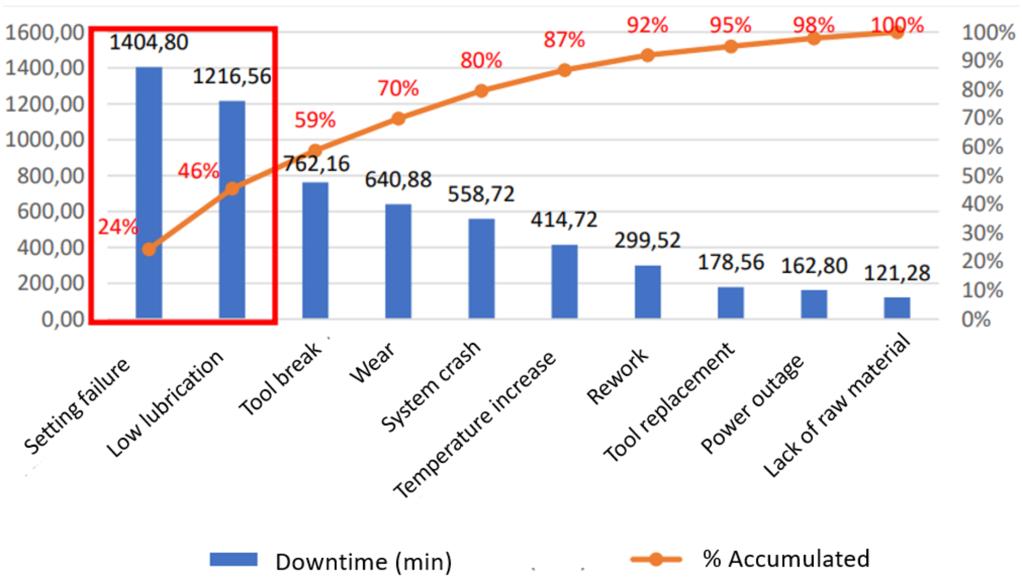


Figure 3 - Pareto chart of identified faults

While the adjustments made in the miller, making it more productive by the increased combination of movements and faster executions were positive, on the other hand, they culminated in lubrication failures, even for short intervals. The development of applications that manage and store large amounts of information in databases has made it possible to create ever more complete maintenance plans. The Excel spreadsheet editor was used as an additional resource. Each defective component had been studied and mapped. The Failure Mode and Effect Analysis technique (FMEA) was employed to structure immediate maintenance actions and predict potential interrupts, from material purchase to functionality testing, whilst letting exposed each step of the assembly analytical framework - table 4.

Table 4 - FMEA of the Manrod miller, model MR-205

Process Step	Failure	Effect	Sev.	Cause	Ocorr	Detection Control	Prevention control	Det.	Risk	Action
Planning	Exchange frequency	Poor machine, with over cycles and no inspection	6	Extrapolation of componente lifespan	3	During disassembly	Keep the plan up to date with equipment working time	4	72	Check if component lifespan has been exceeded
	Component Specification	Incorrect substitution	7	Wrong purchase of material	4	During assembly	Refer to manufacturer's catalog and check listing	3	84	Perform component model change in plan
	Inclusion of components	No referencing	6	Component will operate without preventive inspection	2	During disassembly	Every improvement to the equipment is required to be included in the plan	4	48	Add improveme nts to the plan
Organization	Schematics design	Machine parts without Inspection	8	Insufficient planning	3	During inspection check-list	Check all machine critical points	4	96	Correct strategy control of machine parts
	Definition of assemblies	Partial implementation of plan	9	Complete lack of plan	2	During inspection check-list	Check all machine critical points	3	54	List all unidentified machine parts
	Identification of inspection points	Incorrect inspection of equipment	8	Equipment will operate under unknown conditions	4	During failure identification	Implement visual controls and make them apparent	5	160	Investigate failures and analyze damage extents
Execution	Systemic Implementation	Schedule time loss	9	Insufficient financial resources to implement changes	2	When integrating components into software database	During initial tests, perform all system integrations	5	90	Contact support team for software tuning
	Evidence of Problems	Work in unwanted conditions	5	Recurrence of Fault Appearance	4	During the revision control for historical problems	Track failures periodically, as per mechanical inspection	6	120	Correct failure and check for historical problems
	Action setting	Incorrect maintenance duration	7	Loss of repair timeframe	3	During maintenance	Aggregate all items required for maintenance according to the periodicity	8	168	Schedule run control strategies according to the preventive timetable

Table 5 shows the classification criteria used for sorting out severity, occurrence and defect detections.

Table 5 - FMEA criteria for the classification of preventive maintenances

<table>
<tr><th>Class.</th><th>Severity</th><th>Class.</th><th>Ocurrence</th><th>Class.</th><th>Detection</th></tr>
<tr><td>1</td><td>Perfect implementation of the plan and full compliance with inspection points</td><td>1</td><td>No setbacks during plan execution and no impact on other repair schedules</td><td>1</td><td rowspan="2">Correct implementation of the plan, with a clearly visible maintenance periodicity that covered all components</td></tr>
<tr><td>2</td><td rowspan="2">Very low difficulty in maintenance implementation. A single failure was found, but had an effective action plan that did not impact other repair schedules</td><td>2</td><td rowspan="2">Low setbacks during plan execution, with very few problems that could be overcome and caused no impact on other repair schedules. Has an action plan</td><td>2</td></tr>
<tr><td>3</td><td>3</td><td>3</td><td>Easy to inspect, but leaves some few components without preventive control. Has an action plan</td></tr>
<tr><td>4</td><td rowspan="2">Very low difficulty in maintenance implementation. A few failures were found, but had effective action plans that did not impact other repair schedules</td><td>4</td><td rowspan="3">Moderate severity, with schedule delay and reduced equipment performance. Has an action plan</td><td>4</td><td>Easy to inspect, but leaves some few components without preventive control. Has an action plan</td></tr>
<tr><td>5</td><td>5</td><td>5</td><td rowspan="2">Moderate difficulty on the preventive control of the lifespan of two or more components</td></tr>
<tr><td>6</td><td>Moderate difficulty in maintenance implementation. Found up to three points that diverge from what had been planned, yet did not impact other repair schedules</td><td>6</td><td>6</td></tr>
<tr><td>7</td><td>High difficulty in maintenance implementation. Found more than three points that diverge from what had been planned and needed immediate action, compromising other repair schedules</td><td>7</td><td rowspan="2">High severity, with productivity losses. Has an action plan</td><td>7</td><td rowspan="2">Difficulty in finding evidence of preventative control in two or more components. Corrective actions negatively impact the schedule</td></tr>
<tr><td>8</td><td rowspan="2">High difficulty in maintenance implementation. Found more than three points that diverge from what had been planned and needed immediate action, compromising other repair schedules. The action plan was not concluded in full</td><td>8</td><td>8</td></tr>
<tr><td>9</td><td>9</td><td rowspan="2">Very high severity and did not take into account the minimum tools for an accurate maintenance. Did not follow the priority listing of components. No action plan</td><td>9</td><td>Several components are not included in preventive listings, making corrective actions difficult</td></tr>
<tr><td>10</td><td>Failure to implement schedule. Repair tools not adapted to the preventive maintenance routines. No further actions taken</td><td>10</td><td></td><td>Remote chance to comply deadlines and periodicity. No corrective actions to either include or delete items from the list</td></tr>
</table>

3. RESULTS AND DISCUSSIONS

The maintenance plan was developed to promote durability for the machine's moving components and, thus, eliminate failures caused by lack of lubrication, joint locking, overheating and increased friction. Table 6 shows the main lubrication actions in order of priority.

Table 6 - Main aspects to be addressed according to the assembly and the lube frequency

Group components		
Upper set	**Column set**	**Board set**
■ Check transmission gear housing oil level; ■ Lubricate tree flywheel; ■ Lubricate Z-tree axis	■ Lubricate Z-trapezoidal fuse; ■ Lubricate Z-tree flywheel axis; ■ Lubricate vertical guides of the column/head	■ Lubricate table and base guides; ■ Lubricate X-Y trapezoidal axles and nut; ■ Lubricate X-table bearing e Y-table rear ring

The preparation of a lubrication plan started from the identification of non-conformities and thorough analysis of the maintenance history, have the equipment manuals as the initial parameter. For a complete identification of critical lubrication points and maintenance periodicity, a Power BI visual aid structure was implemented. As a result, it was possible to further describe every important action necessary for the deployment of a successful preventive maintenance activity - figures 4 to 6.

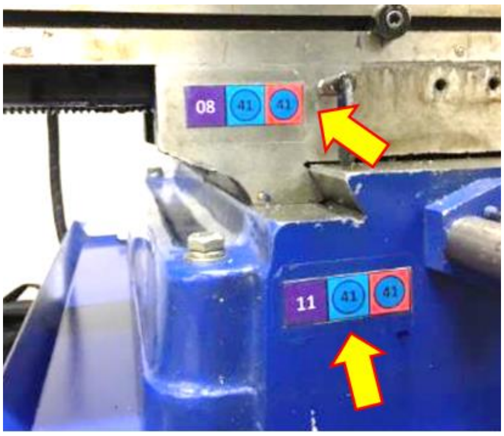


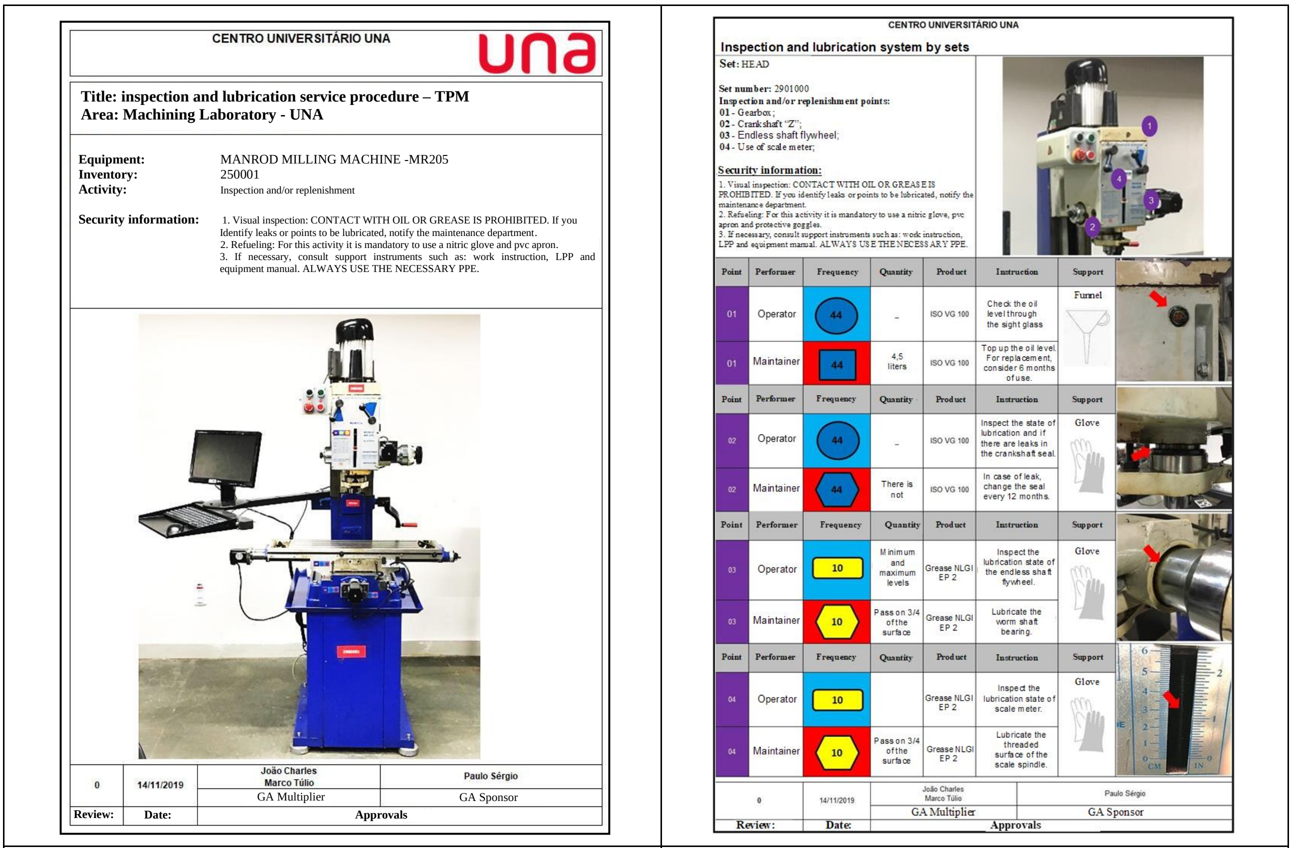
Figure 4 - Labbeling system for the preventive maintenance control

Table 7 shows the component preventive maintenance routine, the service order and the inspection periodicity.

Table 7 - Preventive maintenance control and routine

Component	Activity	Duration
Securing screw	Inspect the integrity of the thread	Monthly
Table ruler	Inspect loss of tolerance	
Table rearward ring		
Base ruler		
Motor MW 1100W – 60Hz	Inspect vibration and alignment	Quarterly
Securing screw	Inspect the integrity of the thread	
Guide support	Perform tests for dial indicator / clamping elements	
Step engine ‘X’	Inspect vibration and alignment	
Step engine ‘Y’		
Step engine ‘Z’		
Oil cover retainer	Inspect diameter and cracks	Semi-annual
Back bearing		
Transmition gears	Inspect wear and cracks	
Horizontal guides	Perform free run tests	
Vertical guides		
Table bearing	Inspect wear and cracks	
Tree flywheel	Inspect diameter and cracks	Anual
Z-tree axis		
Z-trapezoidal fuse	Inspect alignment and slack	
Fly nut		
Back bearing	Perform free run tests	
Trapezoidal Fuse ‘X’	Inspect alignment and slack	
‘X’ axis trapezoidal nut	Inspect clearances	
Trapezoidal Fuse ‘Y’	Inspect alignment and slack	
‘Y’-axis trapezoidal nut	Inspect clearances	

With all the results presented in the form of tables and graphs, it was made possible to import this information into another more intuitive graphical display platform: Power BI. This application has enabled a managerial control of multiple action plans that corresponded to specific processes and components present in our database. Figures 5 and 6 illustrate a complete set of guidelines to be followed by the maintenance team while performing checks on the milling machine.



CENTRO UNIVERSITÁRIO UNA

Title: inspection and lubrication service procedure – TPM
Area: Machining Laboratory - UNA

Equipment: MANROD MILLING MACHINE -MR205
Inventory: 250001
Activity: Inspection and/or replenishment

Security information: 1. Visual inspection: CONTACT WITH OIL OR GREASE IS PROHIBITED. If you Identify leaks or points to be lubricated, notify the maintenance department. 2. Refueling: For this activity it is mandatory to use a nitric glove and pvc apron. 3. If necessary, consult support instruments such as: work instruction, LPP and equipment manual. ALWAYS USE THE NECESSARY PPE.

0	14/11/2019	João Charles Marco Túlio	Paulo Sérgio
		GA Multiplier	GA Sponsor
Review:	Date:	Approvals	

CENTRO UNIVERSITÁRIO UNA

Inspection and lubrication system by sets

Set: HEAD

Set number: 2901000
Inspection and/or replenishment points:
01 - Gearbox;
02 - Crankshaft "Z";
03 - Endless shaft flywheel;
04 - Use of scale meter;

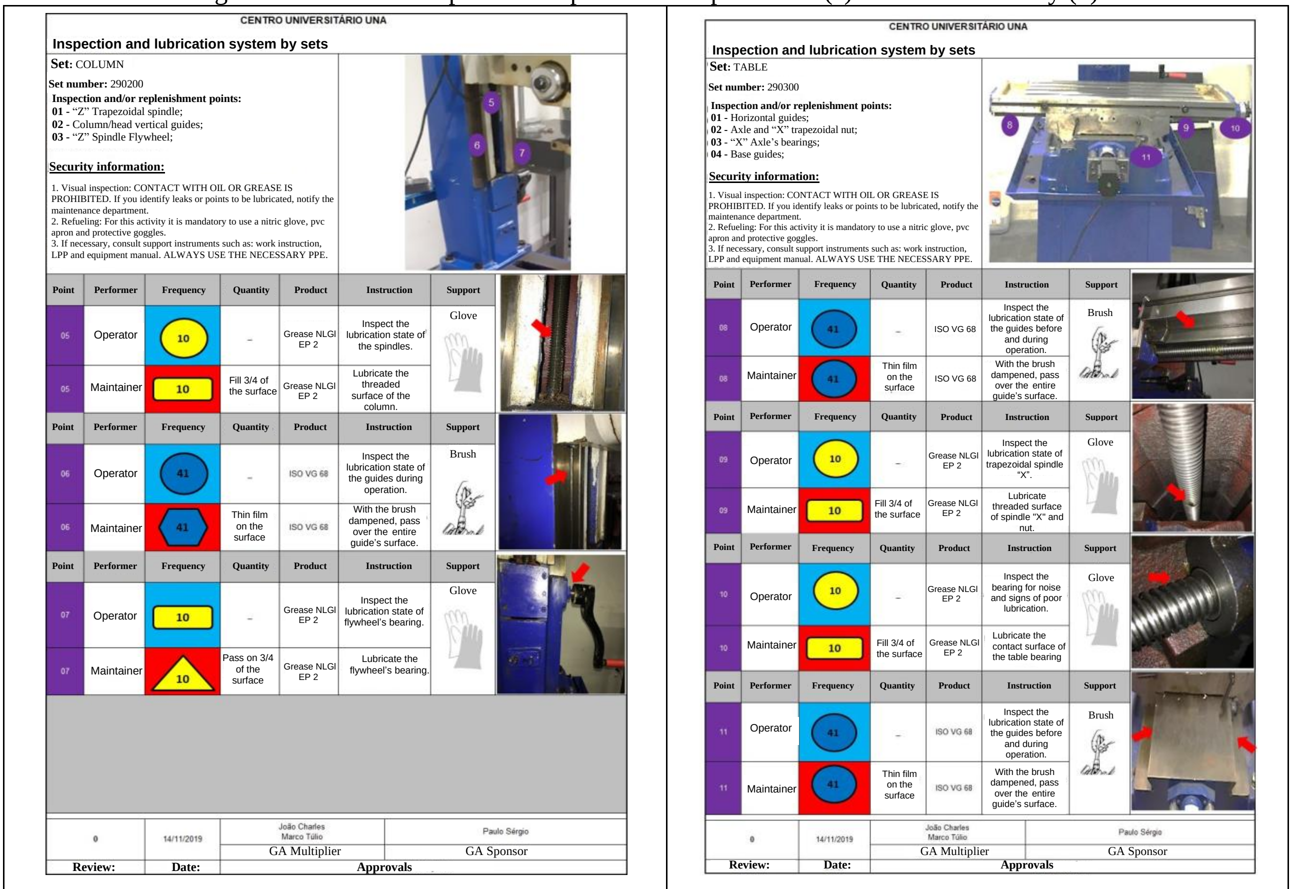
Security information:
1. Visual inspection: CONTACT WITH OIL OR GREASE IS PROHIBITED. If you identify leaks or points to be lubricated, notify the maintenance department.
2. Refueling: For this activity it is mandatory to use a nitric glove, pvc apron and protective goggles.
3. If necessary, consult support instruments such as: work instruction, LPP and equipment manual. ALWAYS USE THE NECESSARY PPE.

Point	Performer	Frequency	Quantity	Product	Instruction	Support
01	Operator	44	-	ISO VG 100	Check the oil level through the sight glass	Funnel
01	Maintainer	44	4,5 liters	ISO VG 100	Top up the oil level. For replacement, consider 6 months of use.	
02	Operator	44	-	ISO VG 100	Inspect the state of lubrication and if there are leaks in the crankshaft seal.	Glove
02	Maintainer	44	There is not	ISO VG 100	In case of leak, change the seal every 12 months.	
03	Operator	10	Minimum and maximum levels	Grease NLGI EP 2	Inspect the lubrication state of the endless shaft flywheel.	Glove
03	Maintainer	10	Pass on 3/4 of the surface	Grease NLGI EP 2	Lubricate the worm shaft bearing.	
04	Operator	10		Grease NLGI EP 2	Inspect the lubrication state of scale meter.	Glove
04	Maintainer	10	Pass on 3/4 of the surface	Grease NLGI EP 2	Lubricate the threaded surface of the scale spindle.	

0	14/11/2019	João Charles Marco Túlio	Paulo Sérgio
		GA Multiplier	GA Sponsor
Review:	Date:	Approvals	

(a) (b)

Figure 5 - Maintenance plan for inspection-lube procedure (a) and head assembly (b)



CENTRO UNIVERSITÁRIO UNA

Inspection and lubrication system by sets

Set: COLUMN

Set number: 290200
Inspection and/or replenishment points:
01 - "Z" Trapezoidal spindle;
02 - Column/head vertical guides;
03 - "Z" Spindle Flywheel;

Security information:
1. Visual inspection: CONTACT WITH OIL OR GREASE IS PROHIBITED. If you identify leaks or points to be lubricated, notify the maintenance department.
2. Refueling: For this activity it is mandatory to use a nitric glove, pvc apron and protective goggles.
3. If necessary, consult support instruments such as: work instruction, LPP and equipment manual. ALWAYS USE THE NECESSARY PPE.

Point	Performer	Frequency	Quantity	Product	Instruction	Support
05	Operator	10	-	Grease NLGI EP 2	Inspect the lubrication state of the spindles.	Glove
05	Maintainer	10	Fill 3/4 of the surface	Grease NLGI EP 2	Lubricate the threaded surface of the column.	
06	Operator	41	-	ISO VG 68	Inspect the lubrication state of the guides during operation.	Brush
06	Maintainer	41	Thin film on the surface	ISO VG 68	With the brush dampened, pass over the entire guide's surface.	
07	Operator	10	-	Grease NLGI EP 2	Inspect the lubrication state of flywheel's bearing.	Glove
07	Maintainer	10	Pass on 3/4 of the surface	Grease NLGI EP 2	Lubricate the flywheel's bearing.	

0	14/11/2019	João Charles Marco Túlio	Paulo Sérgio
		GA Multiplier	GA Sponsor
Review:	Date:	Approvals	

CENTRO UNIVERSITÁRIO UNA

Inspection and lubrication system by sets

Set: TABLE

Set number: 290300
Inspection and/or replenishment points:
01 - Horizontal guides;
02 - Axle and "X" trapezoidal nut;
03 - "X" Axle's bearings;
04 - Base guides;

Security information:
1. Visual inspection: CONTACT WITH OIL OR GREASE IS PROHIBITED. If you identify leaks or points to be lubricated, notify the maintenance department.
2. Refueling: For this activity it is mandatory to use a nitric glove, pvc apron and protective goggles.
3. If necessary, consult support instruments such as: work instruction, LPP and equipment manual. ALWAYS USE THE NECESSARY PPE.

Point	Performer	Frequency	Quantity	Product	Instruction	Support
08	Operator	41	-	ISO VG 68	Inspect the lubrication state of the guides before and during operation.	Brush
08	Maintainer	41	Thin film on the surface	ISO VG 68	With the brush dampened, pass over the entire guide's surface.	
09	Operator	10	-	Grease NLGI EP 2	Inspect the lubrication state of trapezoidal spindle "X".	Glove
09	Maintainer	10	Fill 3/4 of the surface	Grease NLGI EP 2	Lubricate threaded surface of spindle "X" and nut.	
10	Operator	10	-	Grease NLGI EP 2	Inspect the bearing for noise and signs of poor lubrication.	Glove
10	Maintainer	10	Fill 3/4 of the surface	Grease NLGI EP 2	Lubricate the contact surface of the table bearing	
11	Operator	41	-	ISO VG 68	Inspect the lubrication state of the guides before and during operation.	Brush
11	Maintainer	41	Thin film on the surface	ISO VG 68	With the brush dampened, pass over the entire guide's surface.	

0	14/11/2019	João Charles Marco Túlio	Paulo Sérgio
		GA Multiplier	GA Sponsor
Review:	Date:	Approvals	

(a) (b)

Figure 6 - Maintenance plan for (a) column and (b) table sets

4. CONCLUSIONS

The initial phase of the project corresponded to a period of adaptation, organization, understanding of the manufacturing process and motivation of the team, more specifically, in the maintenance sector.

The solutions proposed were the implementation of little but solid improvements in the criteria previously adopted, adequating outdated practices for measuring results. New goals and objectives were defined by the observation of the set of failures. Indicators have been established and periodically monitored for all maintenance services; fact that had let to the construction of a database that portrayed the most important technical characteristics of the major defective components. At the same time, all of the equipment maintenance management was reviewed and consolidated by applying the ERP's programs and the quality tools (FMEA). The initiatives have helped to improve existing actions and deploy new routines in the maintenance plan, which has made possible to change the lubrication system as well as the inspection periodicity, generating greater machine reliability due to the increased gap between failures. In general, the control of maintenance management was fundamental for the efficiency of the process of reducing failures in the components of the milling machine, also reducing problems at the operational and administrative levels.

Finally, the adopted actions contributed to an overall increase in technical knowledge of our technitians, a better understanding of our machinery, facts that greatly contributed to speed up maintenance activities by assertive decisions with consistent information as supportive background.

5. ACKNOWLEDGEMENTS

The authors would like to thank the following research organizations for their support: CAPES, Araucaria Foundation and the State Department of Science Technology for Higher Education of Paraná. They are also extremely grateful to UNA, UFU, UTFPR campus Londrina and UFEI.

6. REFERENCES

Almeida, P. S. Lubrificação industrial: tipos e métodos de lubrificação. Editora Érica 1º ed., p. 184. São Paulo - SP, 2017;

Dormer. Fresamento. 2013. Disponível em: https://www.dormerpramet.com/pt-pt/products/milling. Acesso em 06 out. 2019;

Bravo, R.R.S., De Negri, V.J., and Oliveira, A.A.M. Design and analysis of a parallel hydraulic – pneumatic regenerative braking system for heavy-duty hybrid vehicles. Applied Energy, Vol. 225, No. 1, pp. 60–77, 2018;

Harrington, H.J. Gerenciamento total da melhoria contínua. A nova geração da melhoria de desempelho. São Paulo: Makron Books, 1997;

Lichtenberg, E. Metodologia de implantação e avaliação do programa 5S na seção de manutenção de uma empresa metalúrgica. Instituto Federal de Santa Catarina. Jaraguá do Sul - SC, 2017;

Machado, A. R., Abrão, A. M., Coelho, R. T., Da Silva, M. B. Teoria da usinagem dos materiais. Editora Edgar Blucher, São Paulo – SP, 371 p, 2009;

Madu, C.N. Competing through maintenance strategies. International Journal of Quality & Reliability Management. v.17, n.9, p.937-948, 2000;

MUCIDA, S.; O que é Gestão da Manutenção e como você pode economizar com ela. Soluções Consultoria, 2017.

NR 32 - SEGURANÇA E SAÚDE NO TRABALHO EM SERVIÇOS DE SAÚDE. 2011. Disponível em: https://enit.trabalho.gov.br/portal/images/Arquivos_SST/SST_NR/NR-32.pdf. Acesso em 01 out. 2019;

Otani, M.; Machado, W. V.; A proposta de desenvolvimento de gestão da manutenção industrial na busca da excelência ou classe mundial. Universidade Tecnológica Federal do Paraná. Revista Gestão Industrial. Ponta Grossa - PR, 2008;

Teixeira, D, Revista Mercado. Industria 4.0: Os desafios do Futuro. Edição 13, pg. 22. Santa Luzia - MG, 2019

7. RESPONSIBILITY NOTICE