ESTABLISHMENT OF AUTONOMOUS MAINTENANCE PROGRAMME TO ENHANCE EFFICIENCY OF MILLING MACHINES

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DEDICATION

To my belevod family espacially to my parents:

Mr. Nazir Bin Abas and Mrs. Nazimah Binti Suyati @ Ismail

To my respected supervisor:

Prof. Madya Ts. Dr. Wan Hasrulnizam Bin Wan Mahmood

To my supportive friends in UTeM:

Especially for my coursemates from BMIW and my housemates.

ABSTRACT

The milling machine is a versatile and commonly used tool in manufacturing and machining. It plays a crucial role in accurately and efficiently shaping a variety of workpieces. In the FTKIP laboratory, milling machines are frequently used for different processes with different parameters. If failure to perform regular maintenance can have a negative impact on both the machine's performance and the user's safety. This study was undertaken with the aim of improving the functionality of the milling machine by proposing OPL (One-Point Lessons) and SOP (Standard Operating Procedures) for the elimination of abnormalities. The primary objective was to investigate and implement the most effective autonomous maintenance practices for addressing abnormalities in milling machines at the FTKIP laboratory. Fuguai analysis was conducted to identify abnormalities in the milling machine. During the machine inspection, any detected fuguai is labeled with an F-tag, indicating the need for attention and subsequent actions. The implementation of various One-Point Lessons (OPL) and Standard Operating Procedures (SOP) has been undertaken to address and eliminate the abnormalities discovered in the milling machine. This project exclusively concentrates on the implementation of autonomous maintenance practices specifically for milling machines in the FTKIP laboratory. It does not encompass other maintenance strategies such as preventive and predictive maintenance, and it does not extend to broader organizational changes beyond the framework of autonomous maintenance within the specified manufacturing facility. Most of fuguai discovered in this study belong to the physical category, especially those that can be handled by the milling machine user and operator. This research highlights the critical role of regular maintenance in ensuring the optimal performance and safety of milling machines.

ABSTRAK

Mesin pengilangan merupakan alat yang serbaguna dan kerap digunakan dalam pembuatan dan pemesinan. Ia memainkan peranan penting dalam membentuk pelbagai jenis bahan kerja secara tepat dan cekap. Di makmal FTKIP, mesin pengilangan sering digunakan untuk pelbagai proses dengan parameter yang berbeza. Kegagalan untuk menjalankan penyelenggaraan berkala boleh memberikan impak negatif kepada prestasi mesin dan keselamatan pengguna. Kajian ini dijalankan dengan tujuan untuk meningkatkan fungsi mesin pengilangan dengan mencadangkan One Point Lesson (OPL) *dan* Standard Operating Procedure (SOP) *untuk mengatasi ketidaknormalan. Objektif utama adalah untuk menyiasat dan melaksanakan amalan penyelenggaraan autonomi yang paling berkesan untuk mengatasi ketidaknormalan dalam mesin pengilangan di makmal FTKIP. Analisis Fuguai dijalankan untuk mengenal pasti ketidaknormalan dalam mesin pengilangan. Semasa pemeriksaan mesin, sebarang fuguai yang dikesan diberi label dengan F-tag, menunjukkan perlunya perhatian dan tindakan seterusnya. Pelaksanaan pelbagai* One-Point Lessons (OPL) *dan* Standard Operating Procedures (SOP) *telah dijalankan untuk menangani dan menghilangkan ketidaknormalan yang ditemui dalam mesin pengilangan. Projek ini secara eksklusif memberi tumpuan kepada pelaksanaan amalan penyelenggaraan autonomi khusus untuk mesin pengilangan di makmal FTKIP. Ia tidak merangkumi strategi penyelenggaraan lain seperti penyelenggaraan pencegahan dan penyelenggaraan prediktif, dan ia tidak melibatkan perubahan organisasi yang lebih luas di luar kerangka penyelenggaraan autonomi dalam fasiliti pengeluaran yang ditentukan. Kebanyakan fuguai yang ditemui dalam kajian ini tergolong dalam kategori fizikal, terutamanya yang boleh ditangani oleh pengguna dan operator mesin pengilangan. Kajian ini menekankan peranan penting penyelenggaraan berkala dalam memastikan prestasi dan keselamatan optimal mesin pengilangan.*

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LIST OF ABBREVIATIONS

AM	Autonomous Maintenance
CNC	Computer Numerical Control
FTKIP	Faculty of Industrial and Manufacturing Technology and Engineering
JIPM	Japan Institute of Plant Maintenance
OEE	Overall Equipment Effectiveness
OPL	One Point Lesson
SOP	Standard Operation Procedures
TCO	Total Cleanout
TPM	Total Productive Maintenance
TQC	Total Quality Control
USA	United States of America
UTeM	Universiti Teknikal Malaysia Melaka

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CHAPTER 1

INTRODUCTION

1.1 Background

Autonomous Maintenance (AM) is an essential component of the Total Productive Maintenance (TPM) system, which strives to optimise equipment performance and improve production outcomes. Considering its emphasis on empowering operators and maintenance workers, AM plays a critical role in enabling production teams, particularly operators, to take ownership of and actively enhance the operation of their assigned equipment. By actively engaging in preventative activities, operators not only avoid production stoppages but also directly contribute to improving operational efficiency, resulting in significant benefits for the overall manufacturing process.

The main objective of AM is to enable production teams, particularly operators, to take responsibility of their allocated equipment and improve its operation. Operators help to reducing production stoppages by being accountable for the maintenance and development of their machines, which has a direct impact on operational efficiency. Operators have an important part to play in avoiding minor flaws that might impair machine performance. By resolving these challenges successfully, breakdowns are reduced, resulting in higher productivity and the ability of organisations to meet consumer needs more efficiently.

Operators are entrusted with routine maintenance duties as part of their responsibilities in implementing AM. Operators establish a psychological connection and a sense of ownership to the machines they operate as a result of being given this ownership. According to research, people acquire positive opinions towards objects to which they feel emotionally related. This emotional tie encourages operators to take the initiative in maintaining their machines, thereby promoting a proactive maintenance culture. The successful application of AM is essential for enhancing overall machine efficiency and generating a higher level of awareness among machine operators regarding maintenance practises.

The successful application of AM within the TPM framework is critical for improving overall machine efficiency and raising awareness among machine operators about appropriate maintenance practises. Machine operators become important in reducing mechanical breakdowns and accidents by instilling a sense of ownership and responsibility, ensuring that their equipment remains in peak shape. Organisations can benefit from smoother operations, higher reliability, and a manufacturing process marked by increased machine performance, reduced downtime, and exceptional efficiency because the ultimate goal of implementing autonomous maintenance is to achieve zero failures, accidents, or malfunctions.

1.2 Problem Statement

In the Faculty of Industrial and Manufacturing Technology and Engineering's (FTKIP) lab at Universiti Teknikal Malaysia Melaka (UTeM), milling machine are frequently used. The milling machines are frequently employed in industry for repetitive routines, however in the FTKIP laboratory, the machines are used for various procedures with various parameters and materials. If maintenance is neglected, it will have an impact on the machine's functionality. For the safety of machine users as well as to restore the milling machines to their peak performance, proper maintenance must be performed.

The problem at hand pertains to the implementation of autonomous maintenance in the context of student learning and practical application of milling machines. While autonomous maintenance plays a crucial role in ensuring the efficient operation and longevity of these machines, students often face several challenges in understanding and applying these techniques. Insufficient practical exposure and hands-on experience hinder their ability to grasp the significance of autonomous maintenance and its practical implementation. Additionally, the scarcity of educational resources, including manuals, guidelines, and training modules specifically designed for students, further exacerbates the problem.

The lack of structured integration of autonomous maintenance into the curriculum leaves a gap between theoretical knowledge and practical application. Moreover, limited research has been conducted to evaluate the impact of incorporating autonomous maintenance techniques in student learning, hindering the assessment of its benefits. Addressing these challenges is crucial to equip students with the necessary skills and knowledge to effectively maintain and operate milling machines autonomously, ensuring their preparedness for real-world scenarios.

1.3 Research Objective

The main objective of the study are:

- To study autonomous maintenance practices for abnormalities in milling machine shop.
- To apply autonomous maintenance for selected milling machine.
- To recommend OPL and SOP for fuguai elimination for the selected milling machine.

1.4 Scope of Research

The purpose of this project is to create an autonomous maintenance program for milling machines in the FTKIP laboratory at UTeM. The research is being managed by a laboratory assistant who specialises in milling equipment. The main goal of the project is to apply the processes of autonomous maintenance to milling machines. The project began in

March 2023 and is projected to be completed in January 2024. It is important to highlight that the conclusions of this project are based on the laboratory work shop environment and are meant for academic purposes rather than industry use. As a result, the results may not be immediately applicable to different types of milling machines.

1.5 Important Of Research

The project's importance is as follows:

- Implementing an appropriate equipment maintenance regimen to spot faults early and save costly repair prices.
- To start creating a beneficial workplace that is clean and safe in order to reduce the occurrence of accidents.
- Improves machine availability and increases machine life lifetime.
- Increase student awareness of the need of machine maintenance for academic purposes.
- To prepare students for future industrial jobs by improving their machine maintenance skills.

1.6 Outline Report

This project began with Chapter 1, which introduced the background of the project, stated the issue statement and objectives, defied the scope of the project, and stated the significance of the project.

The second chapter focuses on the literature review. This chapter describes a literature review on the topic of maintenance, specifically autonomous maintenance, as well as a review of Milling machines.

The study methodology is presented in Chapter 3. This chapter describes the project's design and data collection approach in detail. Flowcharts and gantt charts are used to illustrate every aspect of the project design flow, while data gathering methods, analytical methodologies, and Fuguai investigations are detailed further in this chapter.

Chapter 4 contains an analysis and discussion of the results. This chapter shows the data obtained and visualises it using tables, charts, and graphs. Counter measures against each discovered fuguai are demonstrated and described using OPL and specific methods.

Chapter 5 summarises the project's data and countermeasures. This chapter also includes future proposals for changes.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Autonomous Maintenance

In the present study, Autonomous Maintenance (AM) is defined as a maintenance strategy where machine operators uninterruptedly monitor their equipment, make adjustment and execute minor maintenance activities on their machines. This done rather than assigning a dedicated maintenance specialist to perform maintenance and regularly scheduled upkeep. AM is performed by the operators and not by dedicated maintenance technicians.

Autonomous maintenance can be divided into two main themes, the first involving the concept of 'self' within the context of the high value system, looking at incorporating 'self-healing', 'self-monitoring', 'self-aware', 'self-configure' and 'self-protect technologies or characteristics. The second focuses upon automating maintenance practices within organizations, with a particular focus upon the use of autonomous robotics to aid, guide or take over current maintenance tasks under taken by human engineers/workers Farnsworth, M.J. et al. (2015).

In research from Hanafiah, A.H.B.M., (2019) AM have the relationship with the Overall Equipment Effectiveness (OEE) where AM has the responsible on preventing from stoppage to occur in the production. OEE take account on three major factors which are availability, performance and output quality of the equipment. Although the job of the operator is just a simple task, but they play a major rolled in the context of preventing minor breakdown that will affect the three factors of OEE. By reducing the number of breakdowns, it will increase the percentage of OEE so as the production and this will result in achieving the customer demand of product.

2.2 Concept of Autonomous Maintenance in TPM

AM is the first pillar of the TPM concept. AM is a crucial component of the TPM. TPM was industrialized by Japanese companies, trying to extend the existing concept of Total Quality Control (TQC) with the ideas of predictive and preventive maintenance lists. As a company-wide initiative, TPM is a maintenance strategy which maximizes the effectiveness and longevity of related equipment. To recognize AM properly it needs to be seen as an improvement activity within TPM, rather than production teams taking on maintenance activities. Therefore, when companies begin to implement TPM, they frequently start by pointing AM. This approach is understandable as AM is one of the most important and distinguishing features of the TPM Bozaslan, M.B. (2019). Figure 2.1 shows autonomous maintenance in TPM.

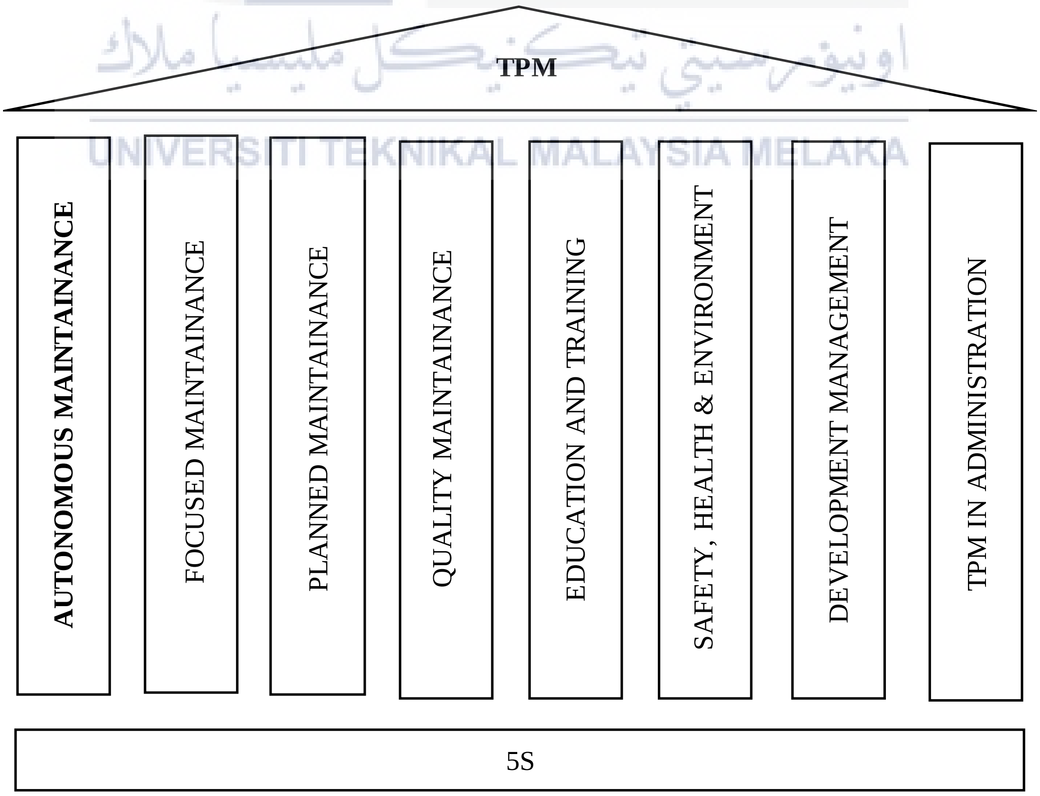


Figure 2.1: Autonomous maintenance in TPM.

Each pillar in the house of TPM has its own people that responsible to ensure that the goal of TPM is achieved. TPM is a innovative Japanese concept. The origin of TPM can be traced back to 1951 when preventive maintenance was introduced in Japan. However the concept of preventive maintenance was taken from United State of America (USA). Preventive maintenance is the concept wherein, operators produced goods using machines and the maintenance group was dedicated with work of maintaining those machines.

TPM is a maintenance strategy that aims to improve equipment efficiency, lower maintenance costs, increase employee involvement, improve product quality, and improve workplace safety. TPM implementation is motivated by the need to improve equipment performance, reduce downtime, and increase dependability. TPM strives to build a culture of ownership and accountability among employees by involving them in maintenance and improvement activities, resulting in better equipment performance and maintenance outcomes. TPM can assist minimise maintenance costs by increasing equipment reliability and decreasing breakdowns, which can improve product quality and worker safety. Overall, TPM implementation can assist organisations in enhancing operational efficiency and production while lowering maintenance costs and increasing safety.

In the study of Venkatesh V.J. (2015), TPM provides a number of indirect benefits that may contribute to developing a healthy workplace culture and boost company productivity. Increased employee confidence, a clean workplace, a better operator attitude, improved teamwork, broad creativity, knowledge exchange, and a sense of ownership among workers are all advantages. Employees can gain a sense of ownership and responsibility for equipment by applying TPM, which leads to enhanced confidence and a positive attitude towards work. TPM also emphasises the need of maintaining a clean and organised workplace, which can contribute to a safe and appealing working environment. TPM can help organisations achieve their goals and objectives by fostering cooperation and collaboration.

The same principle is extended in the research by Moscoso et al., (2019) stating that the implementation of TPM mains on preventative activities carried out by operators such as basic cleaning, lubrication, adjustment and verification. Furthermore, as the first phase in TPM implementation, autonomous maintenance decreases preventable equipment breakdowns, enhances equipment efficiency and providing operators a sense of ownership of the equipment. Implementation of autonomous maintenance requires the support from management and maintenance department as advisor when there is a need for specialized maintenance activity in finding the best solution for improvement (Pačaiová & Ižaríková, 2019).

2.3 The steps in implementation of Autonomous Maintenance

The Japan Institute of Plant Maintenance (JIPM) revolutionised the maintenance industry with their breakthrough concept of autonomous maintenance (Nakamura, 2016). This enables operators to become the guardians of their devices through an engaging step-by-step process. Considering a future in which operators have the skills and expertise to assure the safety of the machines they work with. JIPM's autonomous maintenance implementation, presented in a fascinating seven-step programme (Shankul and Buke,2019). By following these steps, organisations may develop a proactive maintenance culture that encourages operators and maintenance personnel to collaborate to improve equipment performance and reliability.

AM is based on the idea that equipment maintenance is not only the duty of maintenance personnel, but also of operators who operate with the equipment on a daily basis. AM can help prevent breaks down, minimise downtime, and enhance overall equipment effectiveness by empowering operators to perform common maintenance operations like cleaning, lubricating, and tightening bolts.

Step 0 : Preparation

Operators may be experts at running their machines to maximum capacity, but for autonomous maintenance to be effective, they must understand the details of their machine. This includes technical instruction from maintenance professionals on how the machine's components function and what they do, as well as problem-solving abilities. In short, operators should have four equipment-related skills as shows in Figure 2.2.

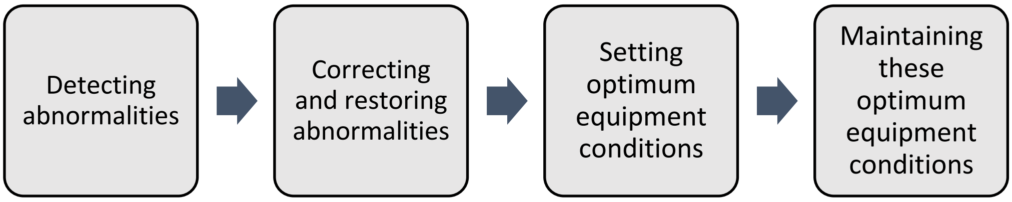


Figure 2.2: Four Equipment-related Skills

After reviewing these skills in an instructional setting, operators can conduct basic maintenance chores on their machines while maintenance specialists observe to ensure everything is covered.

Step 1 : Initial Machine Cleaning And Inspection

This phase is restoring the equipment to its original condition, as if it were completely new. On this task, everyone engaged, including manufacturing, maintenance, engineering, and operators, collaborates. They clean and restore the equipment as well as the surrounding area completely. The goal is to ensure that each piece of equipment functions optimally by detecting and repairing any symptoms of damage or wear. Teams should look for and correct things as shows in Figure 2.3.

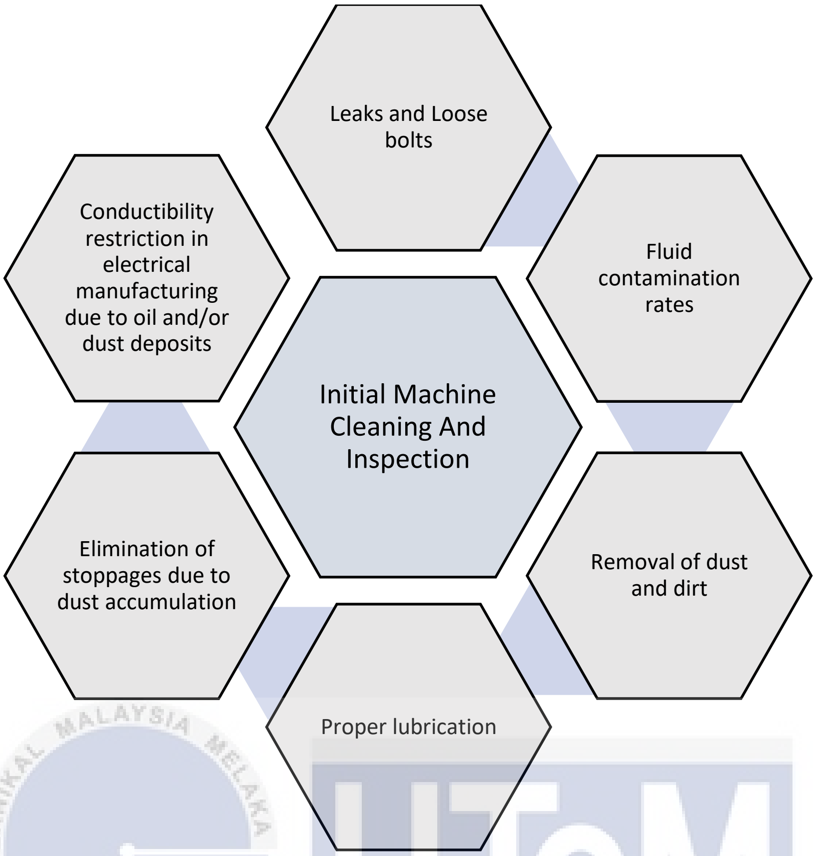


Figure 2.3.: How to do Machine Cleaning And Inspection.

Documenting the cleaning technique throughout this whole process is an important practise since it enables for easy troubleshooting and gives operators with accessible, step-by-step guidance. The operator plays an important role in selecting the suitable equipment for optimal machine cleaning during the early phase of autonomous maintenance. There is a wide variety of tools available, each with a distinct purpose in ensuring optimal machine performance. Tools such as lubrication spray and paper towels are essential for solving the difficulty of removing accumulated grease. Figure 2.4 shows an example of lubricant spray and Figure 2.5 shows an example of paper towel for cleaning machine surfaces. Next, a specialised cleaning brush can be used to gently brush away dirt, chips, and dust from the machine's surfaces, such as the worktable, spindle, and motor housing. Figure 2.6 shows example of brush cleaning tool.

Figure 2.4 Example of lubricant spray

Figure 2.5 Example of paper towel

Figure 2.6.: Example Of Cleaning Brush

Isopropyl alcohol is highly effective at breaking through and removing oils, greases, and residues that build up on machine parts. Isopropyl alcohol, known for its outstanding solvent characteristics, excels at cleaning and degreasing surfaces, leaving no residual trace. Figure 2.7 shows an example of isopropyl alcohol as a powerful solvent for complete cleaning of machine components and Figure 2.8 shows an example of cleaning rag that commonly used for cleaning oe wipe machine surface.

Figure 2.7.: Example Of Isopropyl Alcohol

Figure 2.8 Example Of Cleaning Rag

A scraper cleaning tool is a specialised tool used for cleaning and removing tenacious residue or buildup from milling machine surfaces. It is important to use a scraper cleaning tool with caution and control to avoid injuring sensitive surfaces or milling machine components. Figure 2.9 shows example of scraper cleaning tool and Figure 2.10 shows example of hand glove that provides protection and ensures operator safety while handling cleaning tools and coming into contact with potentially abrasive surfaces.

Figure 2.9.: Example Of Scraper

Figure 2.10.: Example Of Hand Glove

Next a handle dust pan is a useful tool for properly removing accumulated debris and residues. Figure 2.11 shows an example of handle dust pan. The handle dust pan complements other cleaning tools, contributing to a comprehensive and organized approach to machine maintenance.

Figure 2.11.: Example Of Handle Dust Pan

Step 2 : Counter measures to source of contamination

Now that the initial cleaning has been completed and all equipment has been recovered, make sure it isn't damaged anymore. This can be accomplished by removing all potential sources of contamination and enhancing cleaning and maintenance accessibility. This procedure also takes safety into consideration. Maintaining a running equipment is risky, thus boosting safety and visibility through improved access points is critical. One typical method is to replace opaque coverings with transparent ones for rapid and easy visibility of running parts. Removing the cause of contamination can be done as shows in Figure 2.12.

By following to these step on a consistent basis, we may reduce the risk of contamination and maintain a clean working environment. Furthermore, utilising high-quality sealing and machine coverings can help avoid soiling and protect the equipment from outside contamination. During inspections and maintenance, it is critical to promote cleanliness and remind everyone engaged of the necessity of keeping a clean and safe workplace. We may preserve the equipment in good condition and limit the chances of contamination by taking these simple yet effective methods.

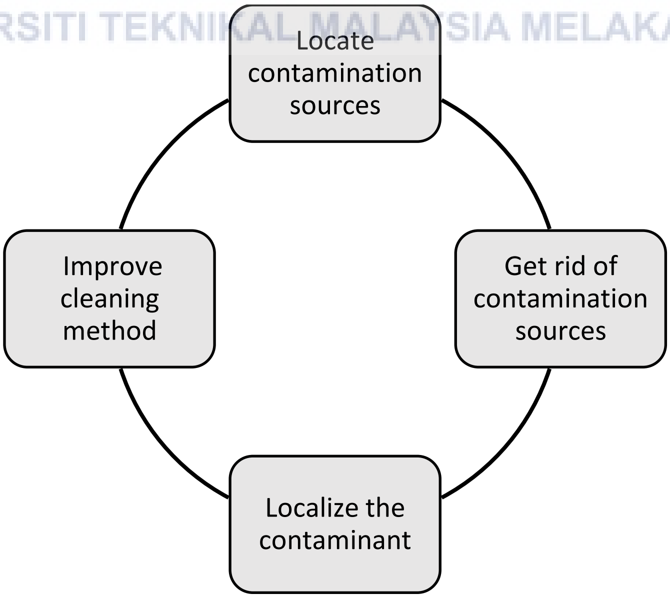


Figure 2.12.: Step approach in counter measures to source of contamination.

Step 3 : Cleaning and lubricating standards

This phase can be adjusted to each piece of equipment and its operator. Establishing cleaning, inspection, and lubrication standards for operators should begin with the current documentation on file and end with improved methods to complete these tasks. Standards should specify which components should be cleaned and lubricated, how they should be cleaned and lubricated, and what other maintenance duties should be given. The standards will differ depending on whether the machine is classified as non-critical or critical.

- Non-Critical Machine : Operators are trained by an experienced maintenance engineer to follow the established standards. Operators can then establish their own routine.
- Critical Machines : A team of maintenance engineers dedicated to maintenance methods can be created to develop standards.

Step 4 : Overall inspection

Operators can now adjust their basic maintenance routine to streamline and improve duties now that we have a set of standards to follow. To avoid work duplication, the operator's maintenance chores are logged and compared to the maintenance department's own schedules (typically via a computerised maintenance management system). Operators undertake routine maintenance duties such as monitoring lubrication levels, identifying leaks, tightening bolts, inspecting for imminent mechanical difficulties such as cracks and wear, and executing mechanical adjustments such as tension measures, sensor regulation, and so on.

Step 5 : Autonomous maintenance standards

Standardising autonomous maintenance and making equipment "visual" are critical steps in ensuring the integrity of any piece of machinery. How do you make your equipment visible? Identifying fluid movement through pipes, replacing opaque coverings with clear ones where practical, labelling the open/close direction of valves and levers, and designating "safe" or "normal" operating values on gauges and sight glasses in green with harmful levels in red are some examples. In short, make everything on the system as clear as possible.

Step 6 : Process quality assurance

At this step, operations are supplemented with previous measures to ensure product quality. This step evaluates the operators' knowledge of product quality, equipment, and strategies for continuous improvement in order to completely integrate autonomous supervision (Azizi, 2015). The duty of management is to raise standards and ensure that they are followed (Molenda, 2016). A highly dependable process is achieved to avoid generating defective items and allowing them to reach downstream operations.

Step 7 : Continuous Improvement

It is critical to take a step back and analyse standardised operations on a regular basis to determine where there is opportunity for improvement. Keeping accurate records of failures is critical because it provides data that maintenance engineers can use to build future machines that are easier to access and maintain. Continuous improvement can also result from team leaders going over operators' work on a regular basis. This not only allows them to identify areas for development, but it also allows them to praise operators on a job well done.

The purpose of step one of the autonomous maintenance programme is to improve basic machine component comprehension and teach operators to execute a total cleanout (TCO). Although cleaning is commonly regarded as a low-status, unqualified activity, it is a type of inspection in TPM. It is useful in discovering machine and component abnormalities, as well as dirt sources, tough to clean and check locations. According to Laquet. (2015), inadequate cleaning can result in component failure, quality defects, and accelerated deterioration in equipment. Additionally, the dust and dirt buildup on equipment increase wear and frictional resistance, causing speed losses such as idling and underperformance.

Priority is focused in phases two and three of the AM programme on eliminating sources of dirt that cause faster degradation, reversing deterioration, and establishing and maintaining fundamental equipment conditions. The key to these measures is not to clean just for the sake of cleaning, but to clean thoroughly. As a result, the operators shift from being reactive to proactive, establishing ideal conditions that prevent stoppages while also lowering component breakdowns and machine failures.

Steps four through seven of autonomous maintenance deal with general and autonomous inspection, and enabling the operator to control his equipment independently. Operators are trained on machine pneumatics, electrical systems, hydraulics, lubrication systems, drives, bolts, nuts, and safety standards during these processes. With this knowledge, they now have a good understanding of their machinery and can manage and improve their equipment and operations. Additionally, the operators can perform visual inspections on major parts and detect and repair minor defects based on established standards. When machines are in operation, maintenance workers cannot detect and cover all of the breakdown symptoms. Operators can help spot problems in equipment and prevent symptoms from progressing into catastrophic breakdowns by gaining technical knowledge through AM.

2.4 Importance of implementation of Autonomous Maintenance

Numerous studies have consistently demonstrated the positive impact of implementing autonomous maintenance on overall productivity. One notable research conducted by Min et al. (2011) presented an insightful case study introducing a comprehensive framework for autonomous maintenance implementation, comprising four systematic stages: AM initial preparation, AM training and motivation, AM five-step execution, and AM audit.

The findings from this study revealed a remarkable enhancement in production performance, primarily achieved by effectively minimizing machine breakdown rates through the successful implementation of autonomous maintenance practices.

Building upon these encouraging results, Blanco et al. (2020) conducted a study that further reinforces the benefits of autonomous maintenance. Their research focused on the application of seven crucial steps of autonomous maintenance within a ceramic tiles plant. The implementation of these steps yielded substantial reductions in various forms of waste and contamination, including dirt, noise, heat, and odor. This achievement highlights the transformative power of autonomous maintenance in enhancing operational efficiency and maintaining a cleaner and more sustainable production environment.

According to the findings of Guariente et al. (2017), the implementation of autonomous maintenance empowers operators to independently perform essential tasks such as cleaning, checking, and ensuring the machines are in optimal condition. This shift in responsibility contributes to the development of a proactive maintenance culture. The impact of autonomous maintenance is also reflected in reduced maintenance times, resulting in decreased processing and order waiting times. Furthermore, operators receive training in workplace problem-solving, equipping them with the skills to minimize production losses and drive productivity improvements (Morales Méndez & Rodriguez, 2017).

Taking a closer look, Iswidibyo et al. (2019) emphasize two significant benefits of autonomous maintenance. Firstly, it enables early detection of machine abnormalities, preventing serious breakdowns and their associated downtime. Secondly, it standardizes and enhances operators' fundamental machine maintenance skills. Early detection of abnormalities not only improves overall safety in the working environment but also safeguards the operators themselves.

Collectively, these insights highlight the multifaceted advantages of implementing autonomous maintenance. By empowering operators and promoting a proactive approach to maintenance, organizations can unlock efficiencies, minimize disruptions, and foster a safer and more productive work environment. By incorporating the findings from these studies, it becomes evident that autonomous maintenance holds immense potential for driving productivity improvements and streamlining operations across a wide range of industries.

2.5 Significance of Autonomous Maintenance on machine

The significance of autonomous maintenance on machines has garnered increasing attention, particularly in terms of its effect on machine performance. Previous research has primarily focused on the broader impact of autonomous maintenance, but more recent studies have delved deeper into its specific effects on machines.

In a study conducted by Azizi (2015), an in-depth analysis was performed to assess the performance of autonomous maintenance using data-driven approaches. The findings revealed that the successful implementation of autonomous maintenance resulted in a noteworthy 8.49% reduction in defect rates. Additionally, machine breakdown time experienced a significant decrease. These results highlighted the interdependency between defect rate data and machine performance, indicating that higher machine performance contributes to improved production productivity.

Building upon these insights, Lima, O., (2019) conducted research to verify the effects of autonomous maintenance. Their study demonstrated several positive outcomes, including an increase in operators' knowledge of machines and autonomous maintenance procedures, a reduction in equipment downtime, and improved machine availability. By enabling operators to handle basic maintenance tasks proficiently, technical maintenance personnel were able to allocate more time to addressing critical issues.

Similarly, Kwaso and Telukdarie (2018) presented findings that supported the implementation of autonomous maintenance. Their research revealed that this approach led to reduced downtime, enhanced machine availability, and decreased breakdown rates. Furthermore, the implementation instilled a sense of ownership among operators towards the machines, fostering a greater commitment to their maintenance. Consequently, the positive impacts of autonomous maintenance were evident as operation time increased, machine efficiency and availability improved, and the overall lifespan of the machines was extended (Aseem Acharya et al., 2019).

2.6 Milling Machine: In Review

A milling machine is a flexible and widely used machine tool in industrial operations, particularly in metalworking. It is a power-driven machine that removes material from a workpiece by using rotary cutters to mould it into the required shape or form. A milling machine's fundamental components are a cutting tool, a spindle that holds and rotates the cutting tool, a worktable that supports the workpiece, and various controls for regulating the cutting speed, feed rate, and direction.

A milling machine's cutting tool can have several cutting edges and can be of various shapes and sizes, allowing for a variety of operations such as face milling, end milling, drilling, and slotting. The spindle, which is usually powered by an electric motor, rotates the cutting tool at high speeds while the workpiece is held securely on the worktable, which can be adjusted in several directions to correctly place the workpiece. The controls enable the user to precisely manage the machining process by controlling the cutting speed, feed rate, and direction.

Milling machines provide various benefits in manufacturing operations. They can precisely generate complex shapes and contours, making them ideal for creating parts with strict tolerances. They can also remove enormous amounts of material quickly, making them suitable for high-volume production. Milling machines are flexible because they can work with a wide range of materials, including metals, polymers, and composites. Milling machines can also be mechanised using computer numerical control (CNC) technology, resulting in high levels of automation and productivity. The schematic diagram of milling machine is as shown in Figure 2.13.

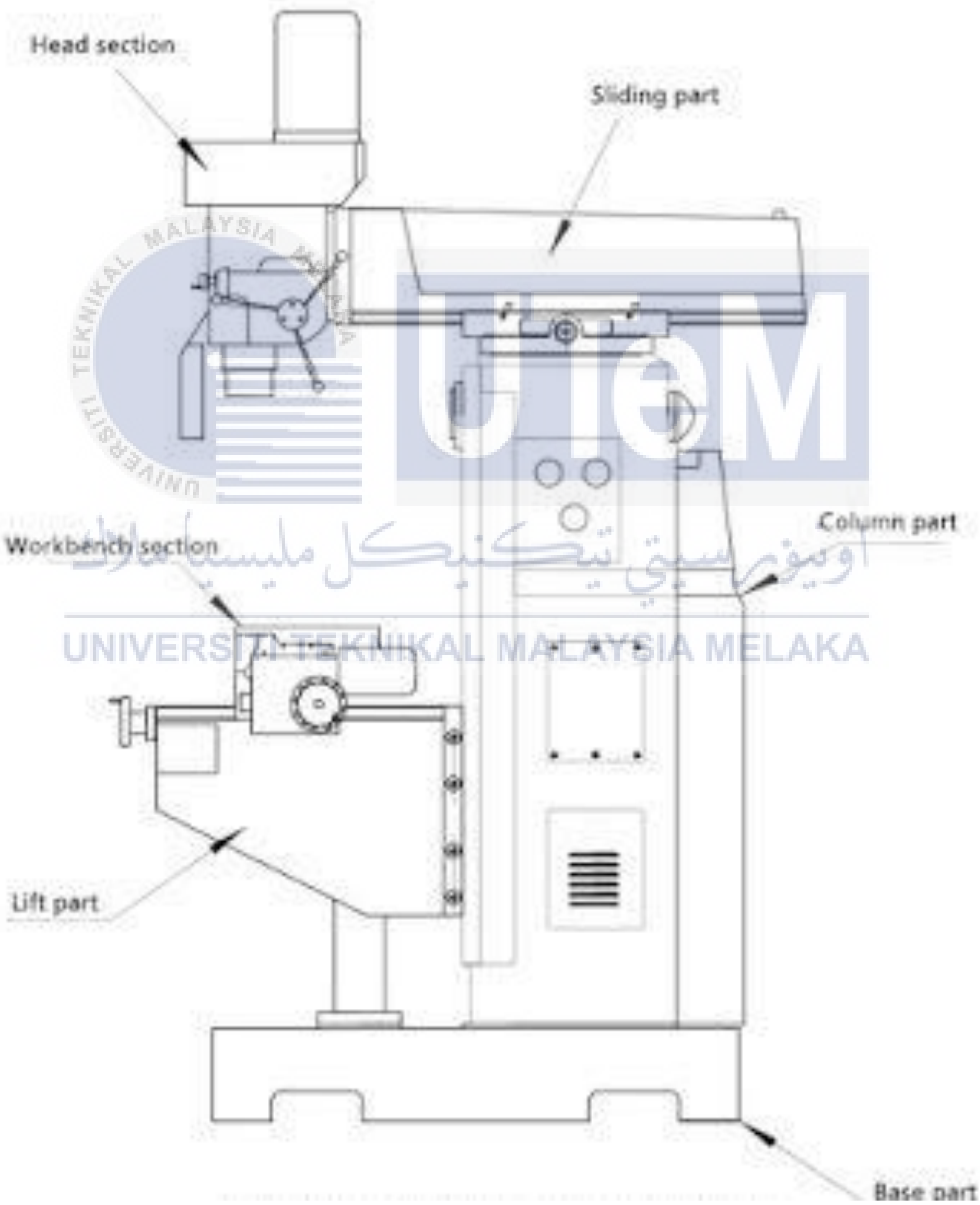


Figure 2.13.: Example of Schematic Diagram of Milling Machine

To summarise, Milling machines can produce a wide range of components, from simple flat surfaces to complex three-dimensional designs, by utilising various cutting tools and processes. Their adaptability enables producers to meet unique design specifications while producing high-quality products with tight tolerances. Furthermore, milling machines can work with a variety of materials, such as metals, polymers, and ceramics, making them useful in a variety of production applications.

2.7 Milling for job shop operation (Process based layout)

A milling machine is a versatile machine tool that is used in a wide range of industries. It removes material from a workpiece using a rotary cutter. The cutter connects to an electric motor-driven spindle. The workpiece is held in place by a moveable table, providing for fine control of cutting movements. Milling machines may handle several types of cutters for various jobs. They are capable of generating complicated processes and features with high precision on a variety of materials. DROs, CNC systems, cooling systems, and chip conveyors are examples of advanced features that can be included to boost performance. Overall, milling machines are critical in manufacturing processes for shaping and creating materials.

The first step in operating a conventional milling machine is to choose the right cutter for the project. The material being machined, the desired finish, and the size and form of the cut all influence the cutter selection. Once the cutter has been chosen, it is mounted and attached to the spindle. The workpiece is then put on the table and secured using clamps or other holding mechanisms. Handwheels or a digital control system can be used to move the table in the X, Y, and Z directions. The operator arranges the workpiece on the table so that the cutter can make the desired cut.

After that, the spindle is started, and the cutter is fed into the workpiece by the quill feed handle or the automatic feed system. To accomplish the desired cut, the operator controls the cutter's speed and feed rate (Liang et al, 2004). The cutter removes material from the workpiece as it rotates, resulting in chips that are ejected from the work area. The operator must observe the machine and make adjustments as needed throughout the machining process. Checking the coolant level, regulating the feed rate, and examining the workpiece for precision and quality are all part of this process.

The spindle is stopped and the workpiece is taken from the table once the machining is finished. After that, the operator can check the workpiece and apply any finishing touches, such as sanding or polishing, to create the desired end product. Basically, a conventional milling machine is a versatile and powerful machine tool capable of producing a wide variety of precision components. Operators can create high-quality parts with great accuracy and consistency with sufficient training and attention. Although there are many different types of milling machines, they all operate and function on the same core principles. These concepts entail shaping and removing material from a workpiece mounted on a moveable table using a spinning cutter supported by a spindle and powered by an electric motor.

2.7.1 Vertical Milling Machine

Vertical milling machines are distinguished by a vertically oriented spindle that allows the cutting tool to move up and down. This design is excellent for tiny and medium-sized workpieces since it allows for easy vision and access to the workpiece. Vertical milling machines are frequently used for face milling, end milling, drilling, and tapping. Some vertical milling machines contain a quill that allows the cutting tool to move vertically, increasing their versatility. Figure 2.14 shows the vertical milling machine.

Figure 2.14.: Example of Vertical milling machine (Raj, M., at el, 2013).

2.7.2 Horizontal Milling Machine

The horizontal milling machine, as opposed to the vertical milling machine, has a spindle that is oriented horizontally. The cutting tool is moved from side to side across the workpiece. Horizontal milling machines are intended for heavy-duty applications and larger workpieces. They are widely used for grooving, slotting, and slab milling operations. Arbour supports and other features may be present to give stability during milling. Figure 2.15 shows the horizontal milling machine.

Figure 2.15.: Example of Horizontal milling machine (Ying, J. 2023)

2.7.3 Universal Milling Machine

The ability of the universal milling machine to rotate the spindle in both vertical and horizontal positions is well recognised. This feature provides a variety of milling processes, such as angular milling, helical milling, and compound angle milling. Universal milling machines are adaptable and appropriate for a wide range of machining tasks. They can handle a variety of workpiece shapes and sizes, making them an excellent choice for applications requiring versatility. Figure 2.16 shows the universal milling machine.

Figure 2.16.: Example Of Universal Milling Machine, (Palmgren, 2017)

2.7.4 Bed Type Milling Machine

A bed milling machine has a solid and sturdy bed that supports the worktable and spindle head. This design provides for heavy workpiece handling and heavy-duty milling operations. The bed can be fixed or adjustable, providing versatility in cutting workpieces of various forms and sizes. Bed milling machines are often employed in sectors that require great precision and rigidity. Figure 2.17 shows the bed type milling machine.

Figure 2.17.: Example Of Bed Type Milling Machine (Ying, J. 2023)

2.7.5 Turret Milling Machine

Turret milling machines are distinguished by a turret that houses numerous cutting tools. The turret may be turned to select the appropriate tool for the task, avoiding the need to manually change tools. This feature improves efficiency, especially for tasks that need repeated operations with various cutting instruments. Turret milling machines are ideal for applications that demand rapid tool changes and cutting versatility. Figure 2.18 shows the turret milling machine.

Figure 2.18: Example Of Turret Milling Machine (Techsoft, 2010)

2.7.6 CNC Milling Machine

CNC milling machines are computer-controlled automated devices. They use computer numerical control to guide the cutting tool's movement with high precision and accuracy. CNC milling machines are ideal for complex milling processes, elaborate designs, and mass manufacturing due to their adaptability, speed, and repeatability. They are commonly employed in sectors where precise and efficient machining procedures are required. Figure 2.19 shows the CNC milling machine.

Figure 2.19: Example Of CNC Milling Machine, (Ying, J. 2020)

2.7.7 Types of Cutting Tools

Figure 2.20 shows example of end mills cutter, end mills are the most common milling cutters. End mills are available in a wide variety of lengths, diameters, and types. End mills are made out of either cobalt steel alloys (known as high speed steel, or HSS), or from tungsten carbide in a cobalt lattice.

Figure 2.20: Example Of End mills

Face mills are large-diameter tools used in facing operations to cut a wide, shallow path. Facing is a technique for preparing a broad flat region, often the top of a part, for further milling processes. A face mill has a solid body that houses several carbide inserts that may be replaced as they wear out. The faster the metal removal rate, the more inserts there are. The most often used cutters have a 45° lead angle. Figure 2.21 shows example of face mills cutter.

Figure 2.21.: Example Of Face mills

Drills and reamers are tools used to make holes in a workpiece. Drills are used to create new holes, whereas reamers are used to enlarge and polish existing holes to produce more exact measurements and superior surface finishes. Figure 2.22 shows example of drills and reamers.

Figure 2.22.: Example Of Drills And Reamers.

2.8 Safety Precaution For Milling Process

Following certain basic standards is required for the safe use of milling machines. To begin, it is critical to thoroughly study and comprehend the machine's instruction manual. Only authorised personnel should use the machine. It is critical that machine operators and maintenance workers understand the emergency stop switches and how to use them efficiently. Adherence to established operating procedures is required at all times while operating the unit. To avoid electric shock, avoid contacting the electrode with the workpiece during milling. Before completing any maintenance or inspection operations, such as removing covers or guards or connecting/disconnecting connectors, be sure the power is turned off. Furthermore, keeping the workshop clean and vigilant to any unexpected occurrences are critical safety precautions. Operators can ensure the safe and effective operation of milling machines by following these instructions.

2.8.1 Training For Safe Operation

A milling machine's standard operating procedure (SOP) normally contains several important phases to ensure safe and efficient operation. At first, before using the milling machine, perform a full inspection of the machine, including checking for any loose bolts, damaged or worn-out components, and sufficient lubrication of moving parts. Before proceeding, any difficulties should be addressed and resolved. Table 2.1 shows standard operation procedure.

Table 2.1 : Standard Operation Procedure

Operating Procedure	Description
Inspection	Conduct a thorough inspection of the milling machine before starting, checking for loose bolts, damaged/worn-out components, and proper lubrication.
Tool Selection	Choose the appropriate cutting tool (end mill, ball mill, drill) based on material and desired outcome, and securely install it in the spindle. Set the proper speed and feed rate.
Safety Measures	Ensure all safety measures are in place, including wearing appropriate PPE (safety glasses, gloves, earplugs) and grounding the machine.
Workpiece Setup	Securely place the workpiece on the milling table or vise, aligning and clamping it properly to prevent movement during the operation.
Calibration	Calibrate the milling machine for accuracy before starting the milling process.

Table 2.1 (Continued)

Operating Procedure	Description
Monitoring	Monitor the machine and cutting process closely during operation, watching for any unusual sounds or vibrations, and addressing any issues immediately.
Avoidance of Body Parts	Avoid placing hands or body parts near the cutting tool or moving parts of the machine during operation.
Shutdown	Follow proper shutdown procedure, including turning off power, stopping the spindle, and returning the machine to its original position.
Cleanup	Clean and clear the work area of debris or chips after milling process is complete.
Maintenance	Properly maintain the milling machine, including cleaning and lubricating as needed.

2.8.2 Hazards

Using a milling machine can present a number of hazards that must be avoided at all costs. Contact with moving parts, such as the spindle, cutting tool, and workpiece, is a significant hazard that can result in entanglement or injury if precautions are not taken. Furthermore, during the milling process, chips and debris might be discharged at high speeds, providing a danger of damage to the operator or those around. Electrical dangers may also exist, such as the possibility of electrical shock or short-circuiting if the machine is not used or grounded appropriately. Milling machine noise and vibration can also be harmful, potentially causing hearing damage or musculoskeletal disorders if correct hearing protection or posture is not used.

Poor cutting tool handling or selection can lead to tool-related dangers such as breakage or wrong cutting, resulting in potential injuries or damage to the machine or workpiece. Improper ergonomics in the workplace, such as poor workpiece arrangement or prolonged standing, can also result in musculoskeletal diseases in the operator. Finally, a lack of sufficient training in operating a milling machine can lead to errors or poor handling, which can lead to dangers. To mitigate these hazards and ensure the safe operation of the milling machine, it is critical to properly understand and follow standard operating procedures, receive adequate training, wear suitable PPE, and take the necessary safeguards.

2.8.3 Safety Precautions

The basics for safe operation of milling machines are described as follow in Table 2.2.

Table 2.2: Basics Safe Operation Of Milling Machine

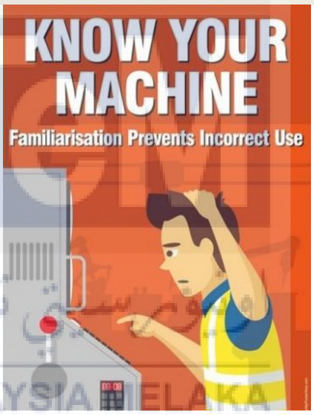
Description	Picture
Familiarise self with the milling machine that you will be operating. Read and comprehend the manufacturer's manual, which contains critical instructions and safety requirements.	
Always wear personal protective equipment (PPE). This comprises safety glasses, hearing protection, gloves, and a protective apron.	

Table 2.2 (Continued)

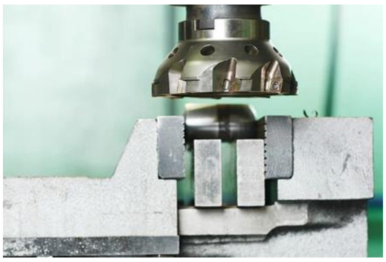
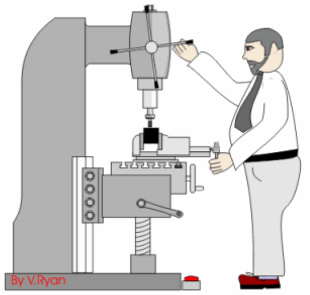
Description	**Picture**
Check that all protections and safety measures are in place and working correctly before starting the equipment. Examine the machine for any loose or damaged parts that could interfere with its function or safety.	
To securely hold the workpiece in place, use clamps, vices, or other appropriate means. This keeps it from moving or shaking while milling, lowering the danger of an accident.	
Find the right cutting speeds and feeds for the material you're working with, working within the proper parameters provides safe and efficient milling.	
Choose the appropriate cutting tools, such as end mills or face mills. Check that the cutting instruments are sharp, securely fastened, and appropriate for the work.	

Table 2.2 (Continued)

Description	**Picture**
Start the milling machine according to the manufacturer's instructions. Before beginning the machine, double-check that all adjustments, such as table height and spindle speed, are properly set.	
Remove any unnecessary tools, materials, or debris from the space around the milling machine. Keep your workstation clean and organised to avoid tripping hazards and to allow for safe movement.	
Never touch the milling machine's operating area while it is in use. Before making any modifications or removing the workpiece, wait for the machine to come to a complete stop.	
Remove chips from the work area with appropriate instruments, such as a brush or hoover.	

Table 2.2 (Continued)

Description	Picture
Concentrate entirely on the milling machine and the task at hand. While operating the machine, avoid distractions such as talking or using mobile devices.	
Properly shut off the machine according to the manufacturer's instructions. Cleaning, lubrication, and inspection should be performed on a regular basis to keep the machine in good working order.	

2.9 Standard operation procedure of Milling machine

To begin the milling machine setup, turn on the power supply and the main switch. Next, import or prepare the machining programme, as well as inspect and prepare the necessary cutting tools and accessories. Place the cutting tool securely into the spindle and adjust the worktable to accommodate the workpiece, making sure it is firmly secured in place.Using proper measuring instruments, align the workpiece to the chosen reference point and set the zero point. Adjust the cutting parameters, such as speed, feed rate, and depth of cut, to meet the exact needs of the work. Additionally, make sure the coolant system is in good operating order to help with the machining process.

Start the milling machine spindle and begin the machining process once everything is in place. Throughout the operation, keep an eye out for any unexpected sounds or vibrations that could suggest a problem. Make any necessary adjustments to the cutting parameters or tool routes. Inspect the machined surface and dimensions on a regular basis to verify they satisfy the desired quality and accuracy standards. After completing the machining process, safely stop the spindle and remove the workpiece from the machine. Clear the work area of any chips and debris that may have accumulated during the milling operation. Return the worktable to its original position and stow the tools and accessories that were used appropriately. To complete the procedure, switch off the milling machine and the main power supply, ensuring a safe and proper shutdown of the equipment. The operating procedure of the Milling machine is as shown in Figure 2.23.

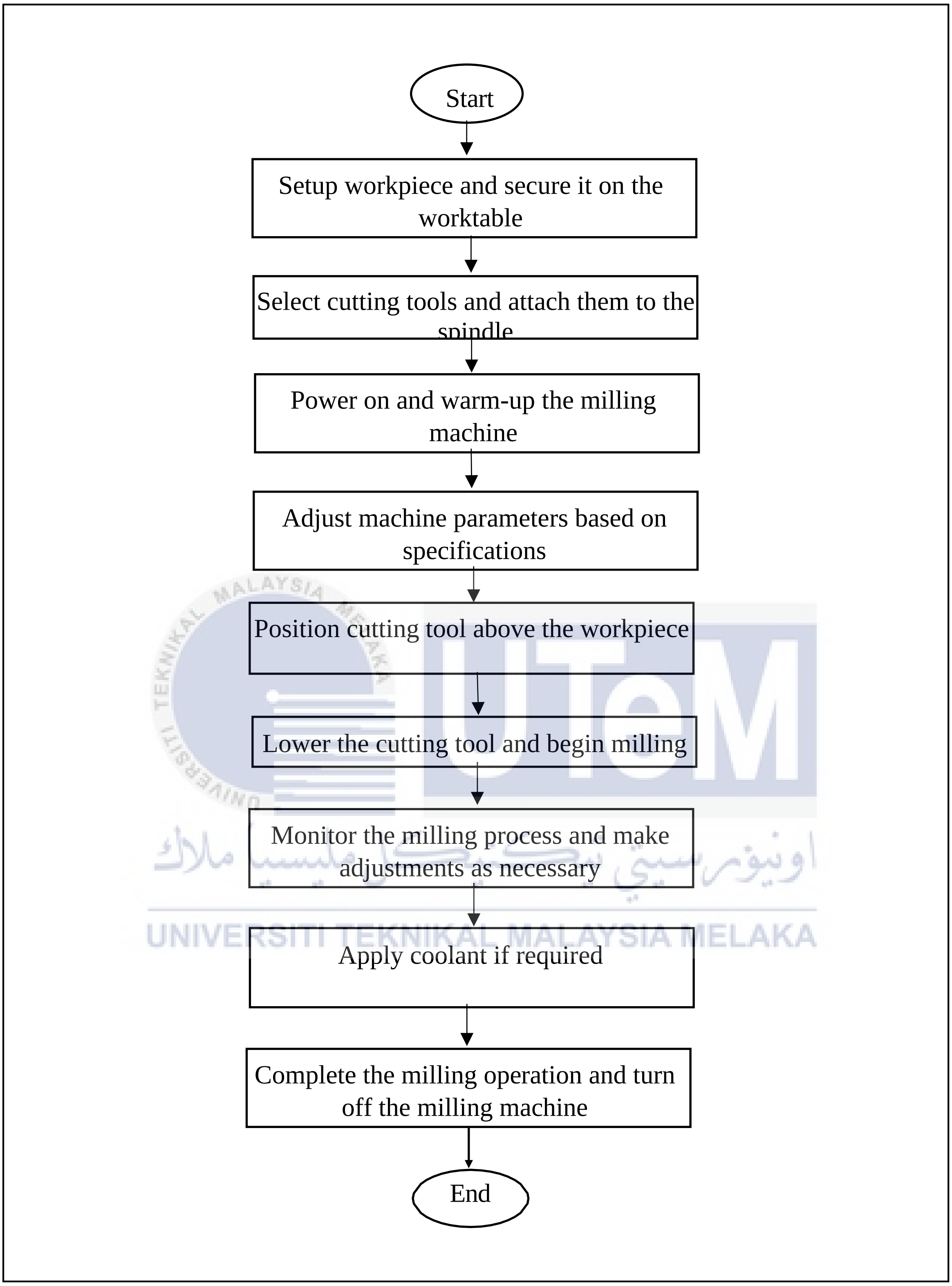


Figure 2.23: Flowchart for Milling Machine operation procedure

2.10 Maintenance Activities For Milling Machine

Maintenance should be performed on a regular basis to avoid problems and downtime.The Milling machine maintenance inspection item and measures are described in Table 2.3.

Table 2.3: Milling machine inspection items and measures.

Inspection Item	Inspection Method and Measures
Spindle Runout	Rotate a dial indicator on the spindle to measure any difference or runout. Check the measurement against the manufacturer's specified tolerance.
Table Alignment	Check the milling table's alignment with regard to the machine's axes and base.
Power Feed	During the power feed process, check for any signs of unusual noise, vibration, or uneven movement.
Coolant System	Inspect the coolant system components for leaks or damage, including the coolant tank, pipes, hoses, and fittings.
Cutting Tools	Using callipers or micrometres, measure the tool dimensions, such as diameter, length, or width, and compare them to the manufacturer's requirements.
Tool Holders	Check that the tool holders tightly clamp the cutting tools and that there are no loose or worn-out components.
Spindle Speeds	Run the spindle at various rates to ensure that the speed controls are accurately adjusting the spindle rotation.
Lubrication System	Check the lubricant levels in the system and top up if necessary

Table 2.3 (Continued)

Inspection Item	Inspection Method and Measures
Work holding Devices	Check that the workholding devices securely grip the workpieces and provide enough stability during machining operations.
Machine Alignment	To measure and verify the squareness and parallelism of the machine axes, use precision measurement equipment such as squares, straightedges, or laser alignment systems.
Motor	Run the milling machine at various speeds to evaluate the motor's startup, smooth operation, and response to speed adjustments.
Safety Guards	Test the performance of safety interlocks and emergency stop buttons to ensure they work properly and stop machine operation instantly when activated.
Overload Protection	Test the overload protection methods, such as thermal or magnetic motor overload protection, to ensure they work properly.

2.11 Types of Abnormalities

Fuguai are abnormalities discovered on the machine during the initial cleaning step in autonomous maintenance (Suryawanshi & Buktar, 2015). Fuguai are identified during the initial cleaning stage to preserve the cleanliness and tidiness of the machine, and f-tags are tagged in areas where abnormalities are discovered so that appropriate analyses and measures can be made to prevent problems (Kumar et al., 2017). Raj et al. (2018) conducted a study in which operators were educated to identify fuguai such as leakages, vibration, inaccessible spots, and risky places during the initial cleaning of autonomous maintenance.

After discussing the potential failure issues that milling machines may face, let's look at the different types of irregularities that might cause machine breakdowns. There are seven types of abnormalities that can be identified in the context of the AM pillar in TPM which are minor flaws, inaccessible areas, unfulfilled basic conditions, sources of contamination, defective components, unnecessary items, and unsafe areas (Thorat & Mahesha, 2020). These abnormalities can have an important impact on milling machine performance and dependability, potentially leading to breakdowns and disturbances in the machining process. Table 2.4 describes potential abnormalities that can be identified based on seven types categories of abnormalities, example of abnormalities and example of check point.

Table 2.4 7 types categories of abnormalities, example of abnormalities and example of check point.

Abnormalities	**Example of Abnormalities**	**Example of Check Point**
Minor defects	• Dirtiness • Scratches • Looseness • Abnormality • Adhesion	• Dust, dirt, powders, oil, rust and paint • Cracking, collapsed, deformed, chipping, bends • Bolt, nut, gauge, cover, belt, chain • Looseness, Omission, Incorrect tightening, Excessively long bolt, Battered threads, • Corrosion, Incorrect washer, Bolt direction, Double nut put in reverse.
Lubrication	• Leaking • Incorrect conditions • Incorrect indicators	• Oil depletion, dirty oil, oil type (not known, inadequate), leak • Dirty oil support port, clogging, damage, deformation, collapsed pipe, • Storage condition, inadequate oiling equipment • Dirtiness, damage, leak, wrong level indication
Source of contamination	• Products, Raw Materials • Hydraulic oil, Liquid • Gasses • Machining & Processing	• Overflow, spilling, blowing off, scattering • Fluid leakage, spillage, or penetration • Spilled air, gases, steam, vapour, and exhaust water • Burrs, chips, packing, sputters, sparks, smokes, glue, and paints. • Dropped components

Table 2.4 (Continued)

Abnormalities	Example of Abnormalities	Example of Check Point
Hard to reach areas	• Cleaning • Inspection • Lubrication • Operation	• Structure of the equipment, cover, layout, foothold, space, installing height high or low, inadequate indicators
Quality defects	• Foreign maters • Manufacturing condition	• Overflow, leaking • Humidity, vibration, impact, and temperature are all factors to consider.
Unnecessary things	• Equipment components, • Products, Tools, Jigs, Spare parts, Pipes	• Mess, disorder
Safety concerns	• Incorrect conditions • Incorrect indicators	• Floor, Steps, Stairs; unevenness, cracks, flaking off, wear Lighting; dark • Safety devices; broken or worn stoppers, wear

2.12 Fuguai tag

In the study conducted by Adhiutama et al. (2020) on total productive maintenance in Airbus part manufacturing, the concept of fuguai and f-tagging plays a significant role. Fuguai, a Japanese term, refers to deviations from regular operating conditions in which unneeded things are discovered in the inappropriate place or circumstance. To prevent fuguai, the researchers used a technique known as f-tagging, which entails inserting specialised tags directly on machine parts where irregularities are detected. The f-tags act as visual indications, allowing operators, maintenance people, and safety personnel to quickly identify and address issues. F-tags are classified as safety (yellow), operator (blue), and maintenance (red). Figure 2.24 shows three example of f-tags.

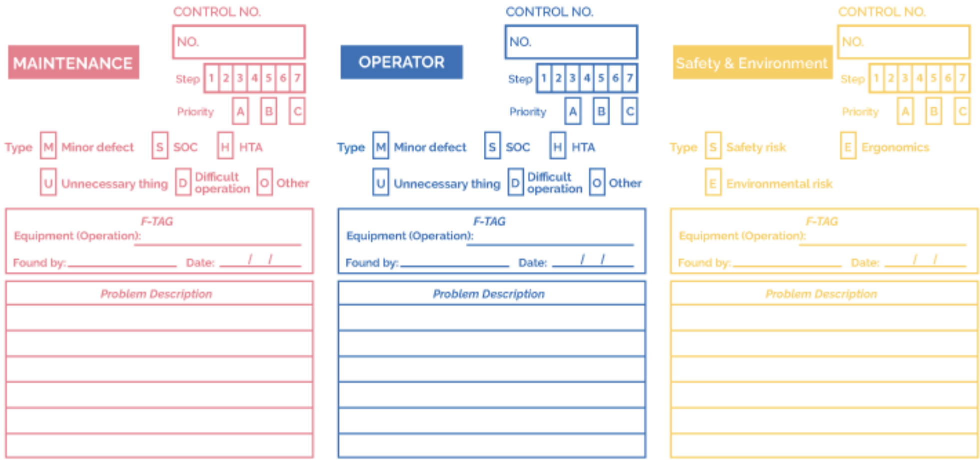


Figure 2.24 Example of f-tags (Learnfast.ca 2023).

Safety F-tags are used to draw attention to potential hazards, risks, or unsafe conditions that require quick action to avoid accidents or injury. Operator F-tags represent anomalies that have a direct impact on the machine's operation or output, potentially affecting quality, performance, or functionality. Maintenance F-tags identify problems that require maintenance intervention or repairs, such as equipment breakdown, wear and tear, or routine maintenance activities. The use of different colours for the f-tags is intended to offer a quick visual differentiation between the various sorts of irregularities and to allow rapid identification by staff responsible for addressing specific issues.

2.13 Effects on Machine Without Proper Maintenance

It is important to practise proper equipment maintenance because it might have serious consequences if not well maintained. One of the consequences is an increase in equipment operation costs as operation efficiency declines and functional failures on components become more common (Zhang et al., 2016). Similar findings, as Kiran et al., (2016), suggest that the performance of machinery will impair process plant production when maintenance procedures are not adequately executed.

According to Buica et al., (2019), lack of maintenance has consequences such as developing faults on work equipment, reducing the technical lifespan of equipment, and creating a hazardous work environment. The study also considers the influence on worker safety and health, as maintenance failures can result in damage, disruptions, work accidents, and occupational diseases if preventive maintenance is not done successfully. Similarly, Sharma et al., (2020) demonstrate that failure of process operations or equipment causes a variety of hazardous situations such as explosions and fires, which are caused by a lack of maintenance activities and sufficient preventative measures.

It is essential to consider the importance of autonomous maintenance on a milling machine workstation, as minor parts and problems that can lead to machine failure are frequently missed. Unseen elements such as trash, dust, or grease generated in processing regions can cause significant losses if problems are not addressed. By emphasising the need of regular maintenance and implementing autonomous maintenance practises, we can reduce the negative consequences of deficient milling machine maintenance. This increases not just equipment reliability, efficiency, and safety, but also productivity, operational expenses, and product quality consistency.

2.14 Summary

In summary, findings highlight the importance of implementing autonomous maintenance to ensure optimal equipment performance. The concept and approach of autonomous maintenance are discussed in this chapter, with an emphasis on their importance in preventing machine failures. Machines can run consistently, reliably, and cost-effectively by introducing autonomous maintenance, while also increasing their lifespan. The chapter also covers the milling process, machines, safety precautions, and maintenance lists. It addresses abnormalities (fuguai), f-tags, and the losses resulting from improper maintenance.

However, comprehensive studies of the milling machine maintenance method are lacking. Most existing findings are largely concerned with the milling machine's process flow and the parameters that influence the final result. Maintenance tasks that are frequently disregarded have an important effect on overall machine performance. Ignoring minor issues can lead to major machine failure and permanent harm over time. As a result, the maintenance procedure is just as important as the process parameters in terms of product quality, machine availability, and overall costs. A thorough investigation is required to create an autonomous maintenance programme for milling machine workstations that will allow for long-term operations. The following chapter will go over the methodology of research used to create an autonomous maintenance programme for milling machines.

CHAPTER 3

METHODOLOGY

3.1 Design of the Project

An efficient project plan is crucial for meeting project objectives and obtaining desired results. Specific standards should be followed in the project design to guarantee that the project stays on schedule to meet deadlines. The project outline design is divided into various stages, each of which is thoroughly examined in terms of planning and implementation.

To envisage the project's purpose in addressing the identified challenges, the first stage requires recognising the problem and stating the project objectives. Following that, the project scope is established to ensure the proper allocation of resources such as facilities, equipment, and employees. The project design then moves on to the data collecting phase, with the goal of getting a better grasp of the subject matter. Data collection is divided into two categories: primary data and secondary data. During primary data gathering, the project employs both quantitative and qualitative methodologies, including case studies, bibliographic research, observations, interviews, fugai investigations, and focused group discussions. Secondary data gathering methods include the use of the internet, machine manuals, analytical procedures, and fugai tags.

Further data collection and information gathering on autonomous maintenance, fugai detection, and milling machines is being carried out. The acquired data is then merged and compared with past research to build an effective autonomous maintenance programme for the milling machines at the laboratory. The collected data is analysed and amended to determine the best autonomous maintenance programme. Figure 3.1 shows the project design flow.

The 7 steps involved in implementing autonomous maintenance in a student laboratory are explained in Table 3.1. Each steps represents specific work and in some steps, we used 7 types of fuguai to determine which abnormalities were present, which contributes to the overall maintenance and repair of the laboratory equipment.

A Gantt chart is used as a project management tool to successfully manage the project. The Gantt chart clearly illustrates the project tasks and their associated timelines. Tasks are represented as bars in this project, with the length of each bar reflecting the task duration. The Gantt chart illustrates the planned and actual timeframe for the entire project. The Gantt chart for this project is shown in Table 3.2.

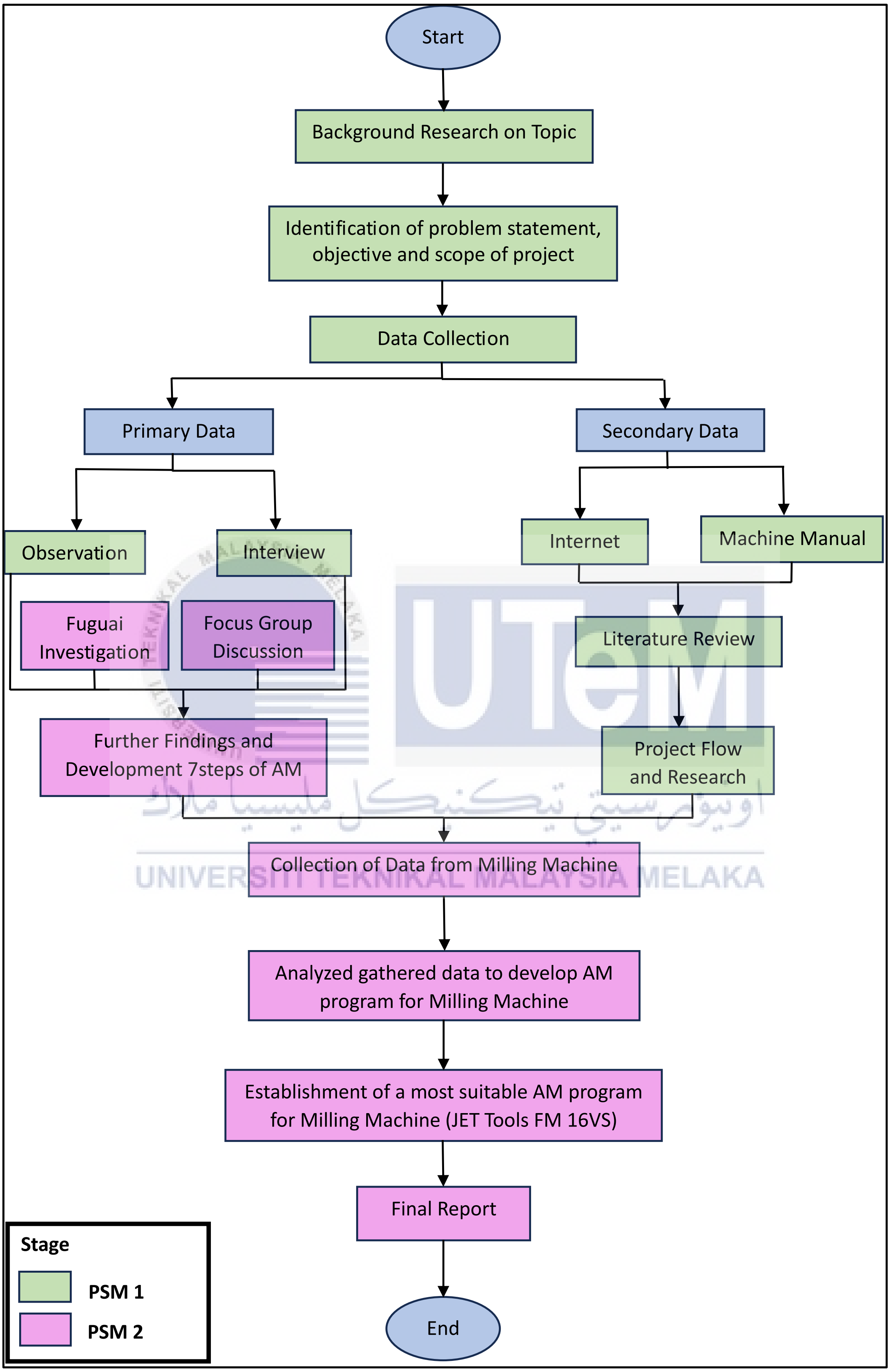


Figure 3.1: Flow chart for project design flow.

Table 3.1: 5 Steps for Implementing Autonomous Maintenance in Laboratory

Steps	Description
Step 0 : Preparation	In the laboratory, gather the tools, equipment, and information needed for autonomous maintenance activities. Ensure that cleaning chemicals, lubricants, inspection checklists, and necessary information are easily accessible. Mark any tools or materials that require replenishment or replacement with an F-Tag.
Step 1 : Initial Machine Cleaning And Inspection	Clean the laboratory equipment and its surroundings thoroughly to remove dirt, dust, and debris. This step helps maintain a clean and safe laboratory environment. During this step, we apply 7 types of fuguai to determine which type of fuguai is involved, and we use F-Tag to mark the areas or equipment that require attention.
Step 2 : Counter measures to source of contamination	Inspect the equipment on a regular basis for leaks, loose connections, and symptoms of excessive lubrication. Repair these problems as soon as possible to avoid contamination and potential defects.
Step 3 : Cleaning and lubricating standards	Develop and document standard operating procedures (SOPs) for cleaning, inspection, and maintenance tasks. These SOPs provide specific instructions to maintain consistency and effectiveness in maintenance activities.
Step 4 : Overall inspection	To detect problems, conduct visual examinations with an OPL or specialised equipment. Record any findings and submit them to the lab assistant for future action.
Step 5 : Autonomous maintenance standards	Encourage students to acknowledge and react to irregularities as soon as possible. This step encourages proactive maintenance involvement. Students should be taught effective inspection techniques, how to use inspection tools properly, and how to recognise and report abnormalities.

Table 3.2: Gantt Chart

NO.	Task Activity	2023										2024
		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
	Project Stage 1 – PSM 1											
1.	Background research on topic											
2.	Identification of problem statement, objective and scope of project											
3.	Collection of data (Internet resource, machine manual, books)											
4.	Literature Review (Autonomous Maintenance &											
5.	Design of project flow											
6.	Development of research methodology											
7.	PSM 1 report submission and presentation											
	Project Stage 2 – PSM 2											
8.	Further findings and development 7 steps of AM											
9.	Collection of data from Milling machine workstation											
10.	Analyze gathered data											
11.	Development of customised AM for Milling machine workstation											
12.	Establishment and finalisation of AM for Milling machine workstation											
13.	PSM 2 report submission and presentation											

Stage :

Planned Actual

3.2 Data collection

This project's data collection process consists of two categories of data which are primary data and secondary data. Primary data is gained directly from original sources, and secondary data is gathered from existing sources provided by other researchers. This research methodology employs both primary and secondary data to ensure the collection of relevant and thorough information.

Primary Data

Primary data is raw information acquired directly from reliable sources that directly relates to the research problem under investigation. Observation, interviews, Fuguai investigation, and focused group discussions were all used for collecting primary data for this project.

3.2.2.1 Observation

Observation is a key skill in our daily life. It is the process of capturing data or information from what we see and hear and then interpreting that data. In this project, the observation method is being used to collect data and information regarding milling machines, specifically the JET Tools FM-16VS, in the FTKIP laboratory. The goal is to document information such as the procedures involved in maintenance, the tools used during the maintenance process, and the general condition of the milling machine.

3.2.2.2 Interview

The interview is with the laboratory assistant in charge of operating the milling machine JET Tools FM-16VS. The interview will consist of questions and answers about several aspects of the machine, such as its daily maintenance, particular facts about its operation, and any issues or challenges that the operator encounters during the milling process. This may include questions about lubrication requirements, cleaning practises, and routine inspections to keep the machine in good working order. The assistant will also provide information on the recommended maintenance schedule and any manufacturer-supplied guidelines.

3.2.2.3 Fuguai Investigation

Fuguai investigation is the discovery of abnormalities detected on milling machines. The investigation is divided into three categories which are physical fuguai, function fuguai, and safety fuguai, with each representing a separate part of the abnormalities discovered. The fuguai tags are placed on milling machine parts that require repair.

3.2.2.4 Focused Group Discussion

A focused group discussion is organised among a small group of participants, supervised by an advisor, to generate an important discussion about the study at hand. The data gathering approach used in this project is focus group discussions, which involve three students working on similar project titles, focused on the autonomous maintenance program on different machines. The major goal of these discussions is to facilitate idea exchange and information sharing among group members.

Secondary Data

Secondary data refers to the collection of data by utilising existing information gathered by other researchers. This method of data collecting involves the review and analysis of previously summarised data on a given topic. Secondary data can be obtained from a variety of sources, including research reports, books, journals, and internet databases.

3.2.2.5 Internet Resources

Internet resources are invaluable for data collection, especially when it comes to gathering a wide range of information. E-books, research journals, papers, conference proceedings, and other important material are easily accessible online. This project's research findings can be found in major internet databases such as Google Scholar, Mendeley, Science Direct, and Emerald. Furthermore, several websites provide extra information regarding Milling machines and AM. Using these online resources improves our grasp of Milling machines and AM.

3.2.2.6 Machine Operation Manual

Data collecting from the machine operation manual is essential for gaining a deeper understanding of Milling machines like the JET Tools FM-16VS. The machine operator manual offers useful information such as normal operating procedures, specs, troubleshooting techniques, and specifics regarding the Milling machine. This information and details will be incredibly useful in developing a standardised method for developing an AM program for the FM-16VS Milling machine.

3.2.2.7 Analytical Techniques

a) Column Chart

A column chart, also known as a vertical bar chart, is a popular data visualisation approach for comparing results across different categories. In a column chart, each category is represented by a rectangle, and the height of the rectangle corresponds to the values being plotted. This type of chart is especially useful for visually analysing and comparing data. In the context of fuguai frequency analysis, a column chart can be used to visualise the frequency of fuguai occurrences based on distinct categories. A column chart can also be used to show the distribution of fuguai occurrences versus different F-tags. Figure 3.2 shows the prototype model for column chart.

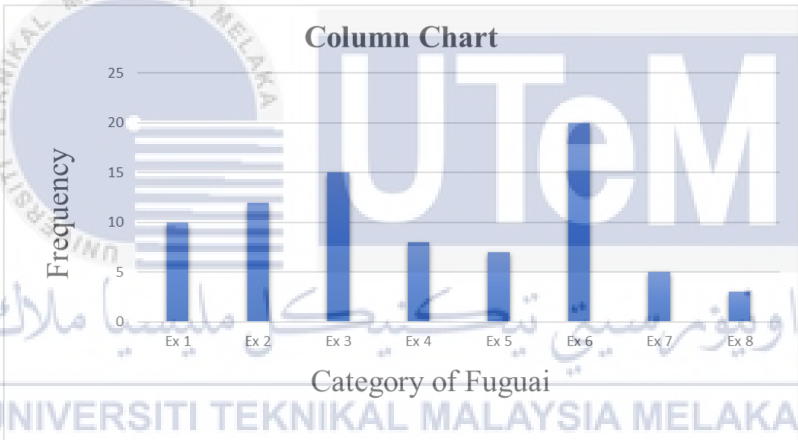


Figure 3.2 : Column Chart Prototype Model

b) Pareto Chart

A Pareto chart is a bar graph that organises data by frequency, with the longest bars on the left and the shortest on the right. This graphical representation efficiently draws attention to the most important circumstances or issues. A Pareto chart is used in this project to analyse the frequency and types of fuguai occurrences, as well as their associated areas. The chart provides a clear grasp of the most serious difficulties by visually presenting this information. Figure 3.3 shows the prototype model for pareto chart.

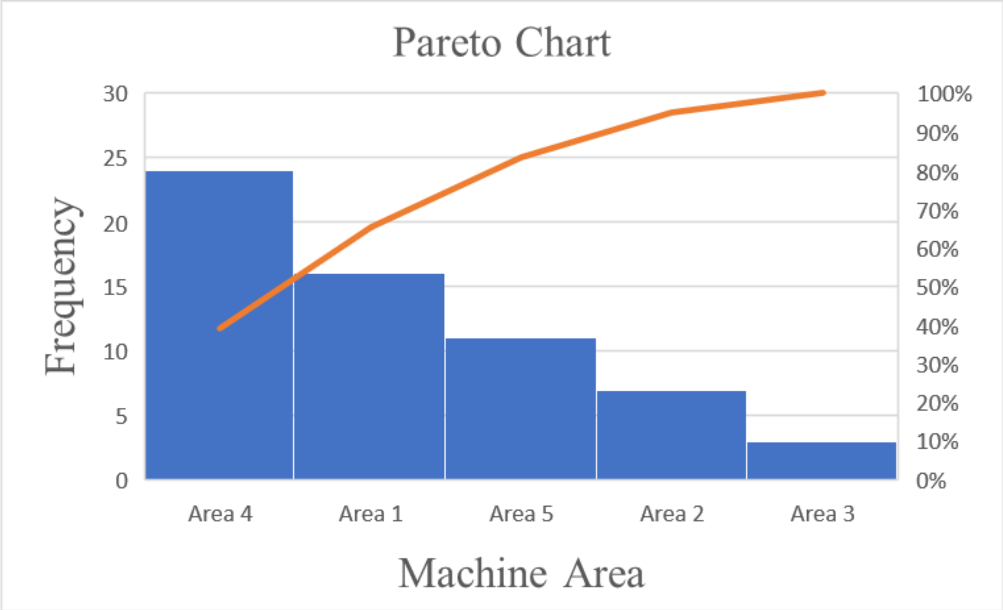


Figure 3.3 : Pareto Chart Prototype Model

c) Pie Chart

A pie chart is a graphical representation of data distribution across multiple categories. It consists of a circular figure representing the whole dataset, with distinct segments within the circle representing the proportion of data for each category. In the context of this study, the pie chart is used to categorise and analyse various varieties of fuguai. Figure 3.4 shows the prototype model for pie chart.

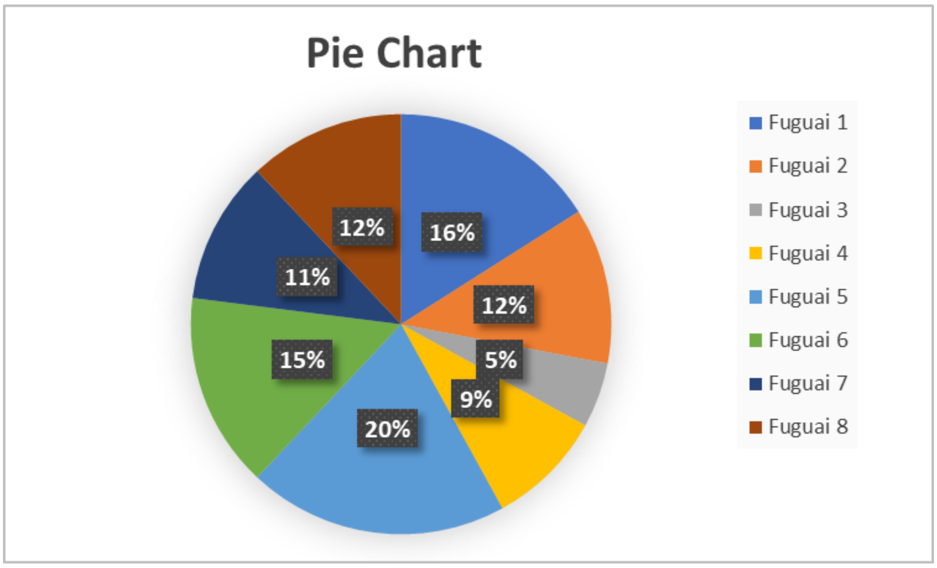


Figure 3.4: Pie Chart Prototype Model

d) One Point Lessons (OPL)

A one-point lesson (OPL) is a basic way for describing specific tasks using simple visual and brief descriptions. It acts as a guidance for carrying out a work efficiently. An OPL is often consisting of images, symbols, and brief text, resulting in a simple document. The fundamental goal of an OPL is to provide simple instructions to improve learning and comprehension during an activity. OPLs are used in this project to give students with straightforward visual documentation. The example template of one point lesson used in this project is as shown in Table 3.2.

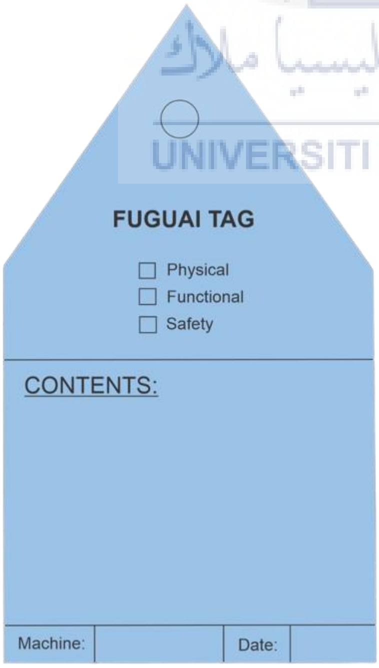
Table 3.3: One Point Lesson template

One Point Lesson	
Part:	Ref No:
	Date:
Classification: ☐ Physical ☐ Function ☐ Safety	
BEFORE	AFTER

3.2.2.8 Fuguai Tags

Fuguai tags (F-tags) are used to identify and tag abnormalities discovered during a machine's initial cleaning step. F-tags come in different kinds of colours to help identify the different types of abnormalities discovered so that appropriate action can be done. F-tags are available in two colours which are red and blue, with each serving a specific purpose in the identifying process. The details of f -tags are as described in Table 3.3.

Table 3.4: F-tags Color and Function Description

F-tags	Descriptions
 Figure 3.5: Red F-tag	The colour red is frequently connected with danger. The presence of a red f-tag in the context of maintenance indicates the identification of an issue that requires immediate attention from a highly qualified technical mechanic. As the procedure may contain possible dangers and abnormal situations, resolving such issues required maintenance staff with substantial experience and knowledge.
 Figure 3.6: Blue F-tag	F-tag in blue indicates that the observed abnormalities can be resolved by operators or employees with sufficient educational guidance. Individuals with basic training or maintenance abilities can execute tasks denoted by the yellow F-tag. These issues do not require expert maintenance knowledge and can be fixed with basic maintenance skills like cleaning or resetting components to their original locations.

F-tags of different colours allow operators or anybody who detects the tag to handle the problem, for example, with a clear view of the problem's details, such as the the category of the problem, the area of the problem, and the date on which the problem was discovered are all required. The elements on the f-tags are as described in Table 3.4.

Table 3.5: F-tags Elements with Descriptions

Elements	Descriptions
Fuguai Category	On the f-tag, there are three types of fuguai, each expressing a particular function: • Physical fuguai refers to abnormalities visible with the naked sight, such as dust or oil stains on the equipment. • Functional fuguai refers to abnormalities that can interfere with the proper operation of the machine and cause it to malfunction. • Safety fuguai refers to abnormalities that could generate hazardous circumstances for operators, putting their safety at danger.
Contents	The details explanation about fuguai.
Machine	The identification of a specific machine type.
Date	The date the tag was issued is noted so that proper actions could be taken by not ignoring the problem.
Problem Description	A detailed explanation of the situation, such as highlighting the problem location or potential resolution approaches.

3.3 Summary

This chapter provides an overview of the project's design flow and explains the data gathering and analysis research technique. A flowchart is used to demonstrate the project design, while a Gantt chart is used to present the project timeline. The chapter outlines the strategies for collecting primary and secondary data. Observations, interviews, Fuguai investigations, and concentrated group discussions are employed to obtain primary data. Secondary data sources include internet resources, machine operation manuals, analytical techniques, and Fuguai tags. Analytical approaches used in this research include column charts, Pareto charts, pie charts, and one-point lessons. Each technique is discussed in detail using prototype models and sample templates. The Fuguai tags used in the project are displayed, and their specifics are expanded upon. The design of the research methodology is critical for guiding the future findings and analysis of the project's results.

CHAPTER 4

ANALYSIS AND DISCUSSION

4.1 *Fuguai* Analysis

Fuguai are the abnormalities found on the machines. The collected data on the fuguai are analyzed based on the data collection methods as discussed in the previous chapter. Fuguai analysis is used to summarise and categorise the obtained fuguai. Fuguai analysis connects the collected data to make it easier to identify and discovers patterns in the data.

The condition of machine is being inspected and observed before the process of initial cleaning. Fuguai discovered at different parts of the machine during the initial cleaning process can be categorized into different types of fuguai. Fuguai investigation is conducted to collect the data of fuguai on the machine by using F- tagging and chart analysis.

4.1.1 Machine Area

The Milling machines are divided into smaller sections for easier identification of *fuguai* around the machine. The Milling machines are divided into 4 main areas which are front machine body (MA 1), left machine body (MA 2), right machine body (MA 3) and back machine body (MA 4),. The machine area of Milling machine are illustrated as shown in Figure 4.1 respectively.

Figure 4.1 Milling machine front and left area layout

Figure 4.2 Milling machine right and back area layout

4.1.2 Types of *fuguai*

The identified *fuguai* surrounding the Milling machines can be classified into 8 main category which are dust (F1) , dirt (F2) , leftover items (F3) , disorganized items (F4), rusty parts (F5), missing components (F6), broken parts (F7), loosen components (F8) and scratch part (F9) The identified *fuguai* types of each *fuguai* category are as described in Table 4.1.

Table 4.1 List of *fuguai* types, fuguai identified on machine and the description.

Ref.	***Fuguai* types**	***Fuguai* identified on machine**	**Description**
F1	Dust	Dusty machine surface	Visible grey deposition on the surface of machine which are made of fine particles of dry solid matters.
F2	Dirt	Oil spillage	Machine lubricating oil leakage which caused by seal or fittings failure.
		Dirty worktable	Working fluid residue deposited on the worktable.
F3	Leftover items	Leftover workpieces	Unwanted metal pieces and metal wire removed during cutting process.
		Leftover scraps between unreachable areas	Unwanted metal chips and powder dust remained after cutting process.
F4	Disorganized items	Disorganized tubes	Disorganized tubes overlapping.
F5	Rusty parts	Rusty worktable	Reddish brown substance deposited on the worktable due to action of water and air
		Rusty handle	Handle not moving smoothly due to rusty joint which affect the function.

Table 4.1 List of *fuguai* types, fuguai identified on machine and the description. (..continued)

Ref.	***Fuguai* types**	***Fuguai* identified on machine**	**Description**
F5	Rusty parts	Peeled off paint	Part of area when paint gets old, it begins to crack and eventually come apart in flakes.
F6	Missing components	Missing screw	Mislaid screw after dismantling of the machine parts.
		Missing label	Instruction or safety labelling on the machine fell off.
		Missing cover	Mislaid machine part cover.
F7	Broken parts	Broken cover	Broken cover such as broken switch cover cannot serve the protection purpose to the switch.
		Dented filter cover	Dented filter cover which may affect the function.
F8	Loosen Components	Loosen screw	Unfastened screws on machine parts after dismantling.
		Loose labels	Instruction or safety labelling on the machine is not in original position.
F9	Scratch components	Scratch worktable or handle	visible marks caused by friction, contact with abrasive materials, or other forms of surface damage.

4.1.3 Identification of *fuguai* on machine areas

The process of *fuguai* identification is conducted by tagging different colour of f -tags with the detailed description on the f -tag on each *fuguai* found. Different *fuguai* are identified on the 15 Milling machines. 15 Milling machine will divide to four different area which are machine area 1 (MA1), machine area 2 (MA2), machine area 3 (MA3) and machine area 4 (MA4).

From MA1 (front side), the most common types of *fuguai* identified are missing screw, dusty surface, rusty worktable, paint peeled off, leftover scraps, leftover workpieces, dirty and oily surface, loosen screw, loosen label and scratch surface. There is 35 *fuguai* is tagged by red f-tag which for the missing screw, scratch surface, paint peeled off, dented and broken part. As for MA2 (left side), *fuguai* such as oil spillage, dented filter cover, dusty surface, rusty worktable, leftover scraps and leftover workpieces are found. Oil spillage and dented part cover are tagged in red f-tags.

However for MA3 (right side) *fuguai* such as dusty surface, rusty surfaces, dirty surface and lossen label and screw. These *fuguai* are tagged in blue f- tags as they can be resolved by operators. As for MA4 which is back side of the machine, have the common *fuguai* which are dusty surface, dirty surface and leftover item (excess sticker). The occurrence of leftover item and scraps are frequent because no proper cleaning method is performed after the cutting process.

4.2 Data Analysis Of *Fuguai*

Data visualisation is a graphic representation of essential qualities and a data set that is typically used with large amounts of data, with the goal of identifying key characteristics and patterns in a data collection in preparation for statistical analysis and decision making (Krok, 2021). The raw data of fuguai recorded through the fuguai tagging procedure is analysed using statistical tools such as graphs and charts. The fuguai detected around the machine are analysed based on the machine area, distribution of f -tags, fuguai category, and types. The data are linked together and displayed using the statistical graphs chosen for this analysis, which are a pie chart, a pareto chart, and a column chart. The data provided is used to make decisions on resolving the fuguai.

4.2.1 Analysis Of Fuguai Types

Table 4.2 shows the *fuguai* types identified on each machine.

Table 4.2 Data collected for *fuguai* types

Fuguai	MM1	MM2	MM3	MM4	MM5	MM6	MM7	MM8	MM9	MM10	MM11	MM12	MM13	MM14	MM15	TOTAL
F1	8	10	13	14	6	11	4	9	12	7	4	5	12	9	12	136
F2	14	16	18	19	20	11	12	18	10	17	11	15	21	19	18	239
F3	3	4	1	2	2	2	2	3	3	2	2	2	2	4	3	37
F4	0	0	1	1	1	0	0	0	0	0	2	0	2	0	0	7
F5	6	5	6	6	6	7	7	7	6	6	5	4	11	6	5	93
F6	0	2	0	2	1	1	0	0	0	0	1	0	0	2	0	9
F7	1	1	0	1	1	0	0	0	0	1	0	0	0	1	0	6
F8	6	3	6	5	4	1	3	5	6	4	8	3	4	5	4	67
F9	2	1	2	1	1	2	1	1	1	1	0	0	2	1	0	16

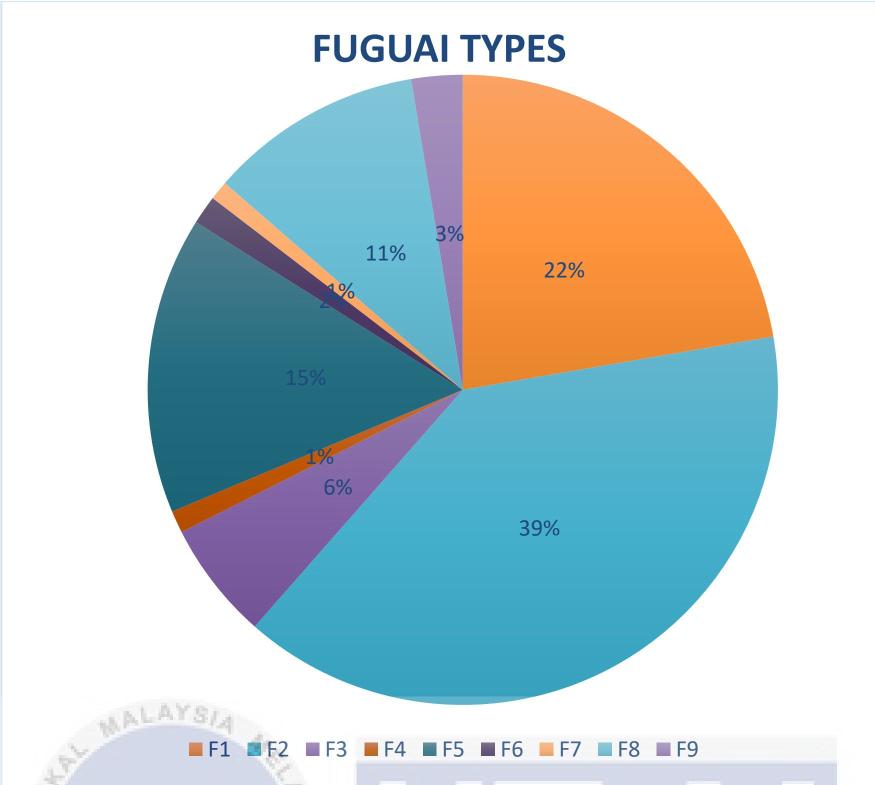


Figure 4.3 Pie chart of *Fuguai* Types

The *fuguai* types are analyzed by using pie chart as shown in Figure 4.7 to show the highest *fuguai* occurrence among the machines. From the pie chart analysis, dirt (F2) contributed the highest percentage of 39% among all 9 types of *fuguai*. The joints and worktable surface experience rusty due to its frequent exposure to oxidation and lack of persistent scheduled maintenance towards machine parts. Disorganized items (F4) and dented part or broken part (F7) has percentage of 1% which is the lowest percentage among all *fuguai*. These two *fuguai* are the least contributor as broken items only occurs occasionally while disorganized items rarely occur.

4.2.2 Analysis of F-tags distribution

Table 4.3 shows the fuguai types identified according to the distribution of f-tags.

Table 4.3 Analysis based on F-tags colour

Fuguai types	F-tags colour	
	Blue	Red
F1	136	0
F2	239	0
F3	37	0
F4	7	0
F5	81	12
F6	0	9
F7	0	6
F8	67	0
F9	0	16

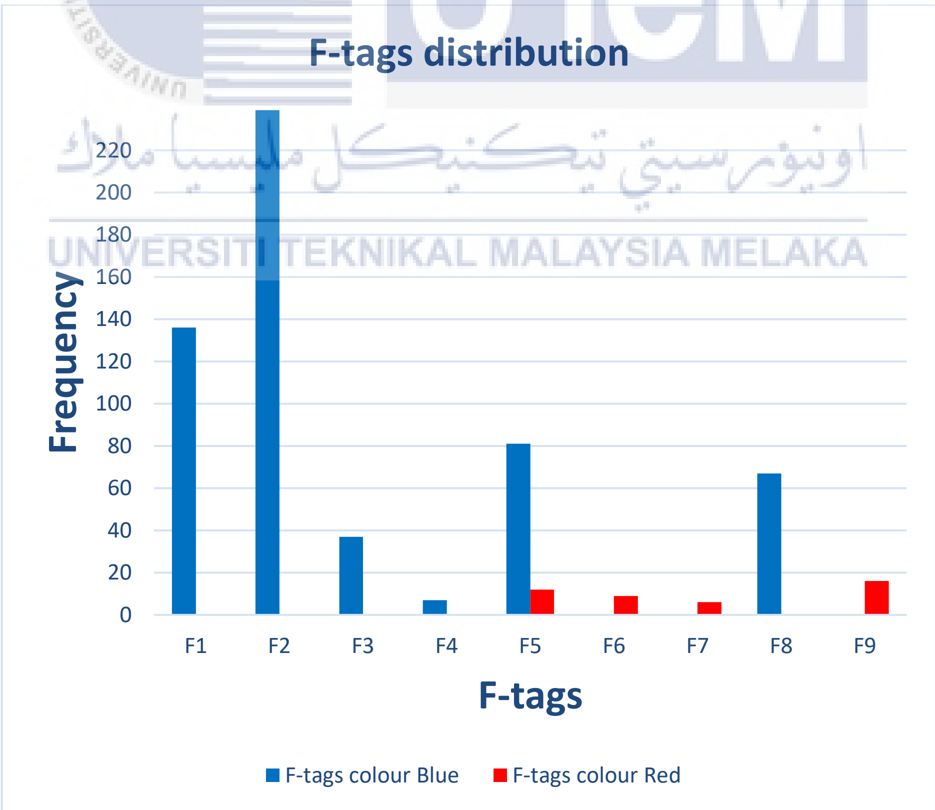


Figure 4.4.: Column Chart Fotr F-tags Distributions.

Figure 4.4 shows the distribution of blue and red f -tags on the types of fuguai found. The highest blue tagged fuguai type is the dirty surfaces (F2) with a frequency of 236. The dirty surface are tagged by blue f-tags as the fuguai can be counter measured by machine operator without the help of high technical skilled personnel. On the other hand, the highest red tagged fuguai is scratch part(F9) with a frequency of 16. Scratch part such as handle machine and machine part covers are tagged by red f -tags to indicate the stated fuguai requires the attention of higher knowledge skilled technician to resolve the fuguai as it can affect the functionality of the machine and the safety of the operator. Based on the graph, there are a total of 567 blue tagged fuguai and 43 red tagged fuguai. Most of the identified fuguai are tagged by blue f-tags which indicates the fuguai can be resolved by machine operator independently.

4.2.3 Analysis Of Machine Area

Table 4.4 shows the *fuguai* data collected around the Milling machine area.

Table 4.4 Data collected of *fuguai* on machine area

Machine Area	MA1 (Front)	MA2 (Left)	MA3 (Right)	MA4 (Back)
MM1	17	6	7	10
MM2	19	10	8	5
MM3	21	9	12	5
MM4	22	12	12	5
MM5	14	10	12	6
MM6	18	4	9	4
MM7	13	8	4	4
MM8	22	8	6	7
MM9	20	9	5	4
MM10	20	11	4	3
MM11	16	8	6	3
MM12	14	4	7	4
MM13	17	14	15	8
MM14	17	12	14	4
MM15	15	10	12	5

Table 4.5 shows the cumulative frequency of occurrence of *fuguai* around the machine area and figure 4.5 shows pareto chart for fuguai identified on machine area

Table 4.5 Cumulative frequency of *fuguai* collected on machine area

Machine Area	Frequency	Cumulative Frequency	Cumulative Percentage
MA1 (Front)	265	265	43%
MA2 (Left)	135	400	66%
MA3 (Right)	133	533	87%
MA4 (Back)	77	610	100%

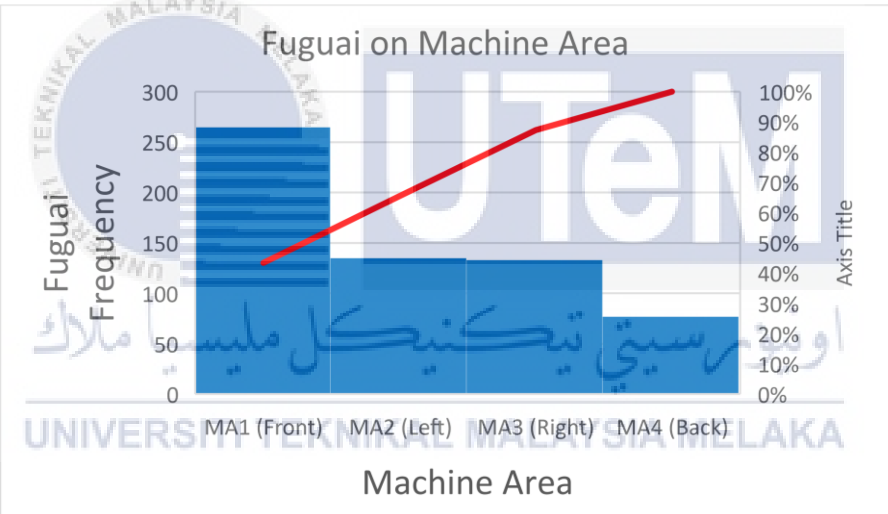


Figure 4.5.: Pareto chart for *fuguai* identified on machine areas

Pareto chart in Figure 4.5 is constructed to analyze the most frequent occurrence of *fuguai* at the machine area. The most critical part of *fuguai* occurrence on the machine is determined through pareto chart. From the pareto chart, the most critical *fuguai* occurrence area is around the front machine (MA1) with a frequency of 265 followed by left side of machine body (MA2) with a frequency of 135. The right side of machine body (MA3) with a frequency of 133 which is 3 times lesses than left side machine body (MA2). The least *fuguai* identified area is the back side of the machine body (MA4) with a frequency of 77.

4.2.4 Analysis of *Fuguai* Category

Table 4.6 shows the *fuguai* data collected around the Milling machine area according to *fuguai* category and figure 4.6 shows column chart for fuguai category on Milling machine.

Table 4.6 Data collected for *fuguai* category on machine area

Machine Area	*Fuguai* Category		
	Safety	Physical	Function
FRONT	23	175	67
BACK	0	77	0
SIDE A	0	110	25
SIDE B	3	120	30

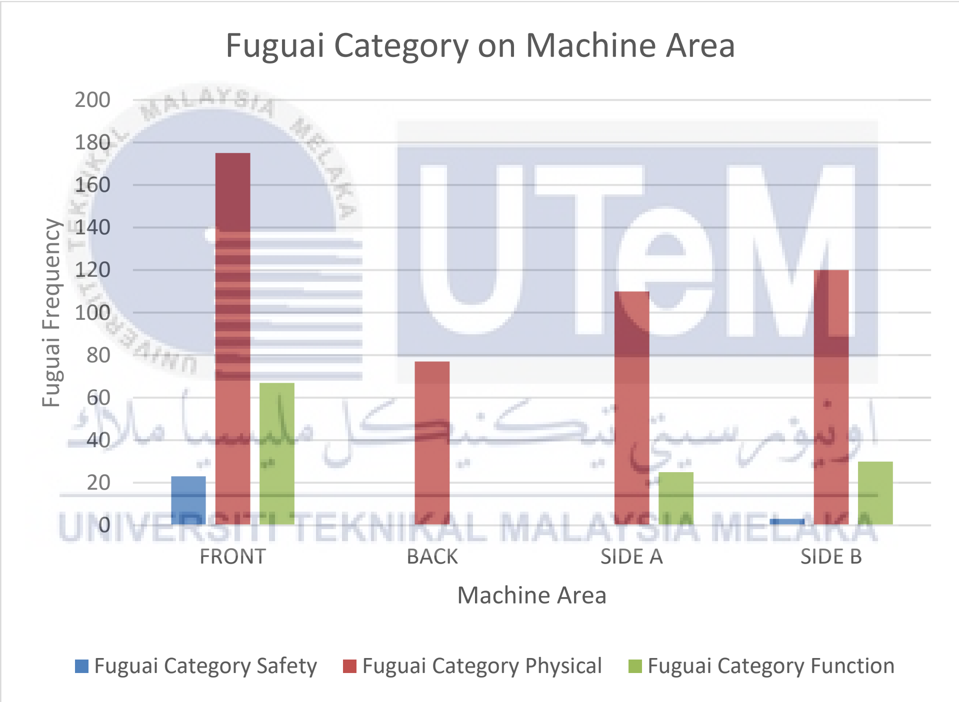


Figure 4.6.: Column Chart for Fuguai Category on Milling Machine

4.3 Standard Operational Procedure for Fuguai elimination

One Point Lesson (OPL) is employed to address process issues or enhance existing methods specific to the milling machine or related procedures. Operators or team leaders utilize OPLs to provide instructions to their teams or colleagues on particular tasks. OPLs are chosen for the elimination of fuguai due to their simplicity, basic nature, and brevity. Each OPL outlines a countermeasure to remove fuguai, illustrated by detailed graphics.

There are three forms of fuguai: physical, functional, and safety. The fuguai type and classification are specifically stated in the OPL. It also shows the state of the milling machine before and after cleaning for each recognised fuguai. This visual representation assists machine users in understanding the machine's regular state. Regardless of the common fuguai classification, the processes for cleaning or dealing with each fuguai may differ.

Table 4.7 illustrates the OPL for rusty worktable on the milling machine. The absence of comprehensive cleaning after machining activities by students results in an accumulation of oil, dirt, and ultimately, the formation of rust on the machine surface. The steps outlined for fuguai elimination, specifically targeting rust-related concerns, are meticulously detailed in Table 4.8, offering a comprehensive guide for effective maintenance and restoration of the milling machine's worktable**.**

Table 4.9 illustrate the OPL for loosen screw on handle lamp. The loosening of screws on the handle lamp can be a common occurrence, potentially affecting the stability and functionality of the equipment. Proper maintenance is crucial to ensure the longevity and efficiency of equipment, in Table 4.10 aim to assist users in promptly addressing and rectifying the specific concern of a loosened screw on the handle lamp

Table 4.7 OPL for Rusty worktable

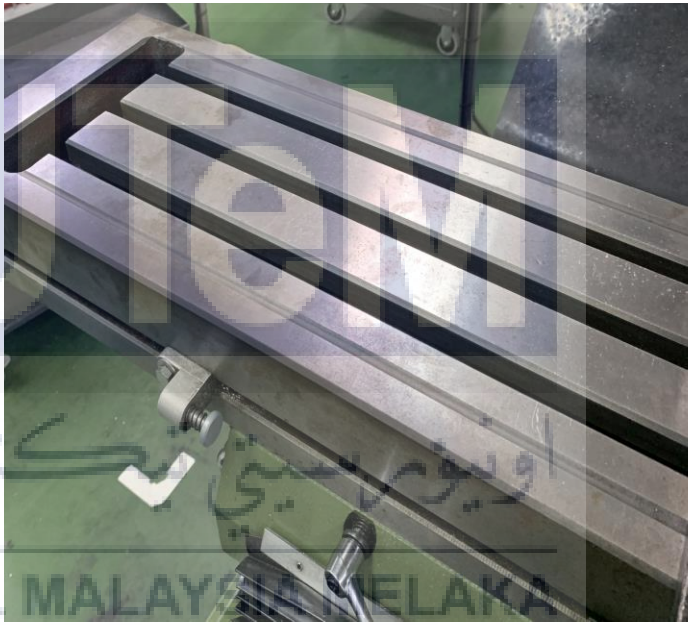
***Fuguai* : Rusty worktable**	
Classification : Physical	
Before	**After**
	
Worktable layered with rust	Visible clean worktable with no rust

Table 4.8 Steps in *fuguai* elimination (Rusty worktable)

Cleaning Process Flow	Description	Images
Start ↓ Switch off all power	1. Make sure the main switch is switched off before cleaning process to ensure safety.	
↓ Wear hand gloves	2. Wear hand gloves to protect the hands during cleaning process	
↓ Prepare cleaning tools	3. Prepare a suitable cleaning tools such as lubricant spray and clothing rag	 
↓ Spray on worktable	4. Spray the lubricant on worktable properly	
↓ Wipe the worktable using dry cloth ↓ End	5. Rub the worktable using the clothing rag untill the rust remove.	

Table 4.9 OPL for loosen screw

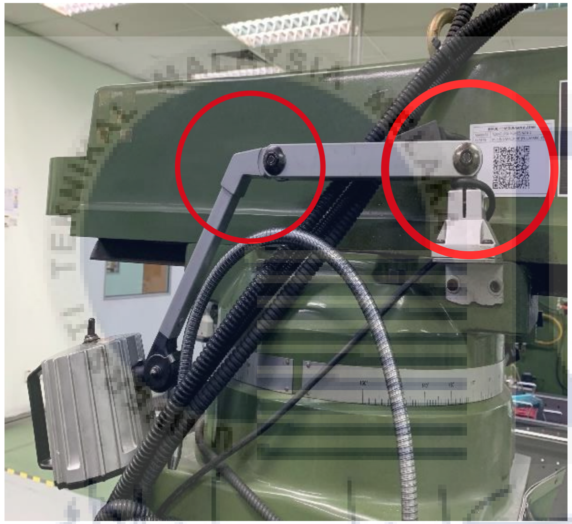
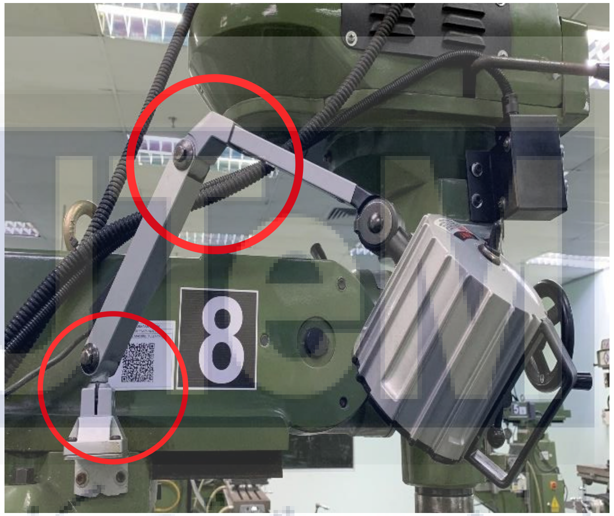
***Fuguai* : Loosen Screw**	
Classification : Safety	
Before	**After**
	
Loosen screw found on lamp handle	Fastened and secure screw in position

Table 4.10 Steps in fuguai elimination (loosen screw)

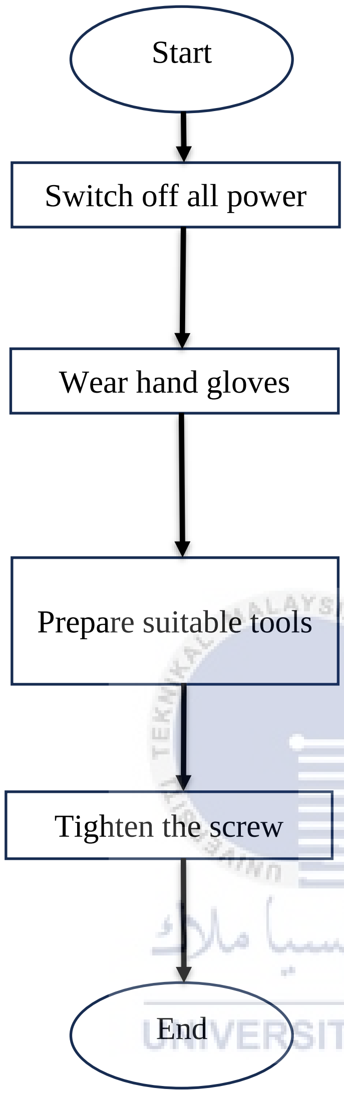
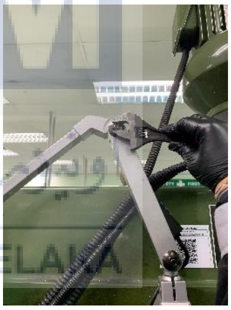
Cleaning Process Flow	Description	Images
	1. Make sure the main switch is switched off before cleaning process to ensure safety.	
	2. Wear hand gloves to protect the hands during cleaning process	
	3. Prepare suitable tools such as adjustable wrench	
	4. Tighten all the screw using adjustable wrench	

Table 4.11 presents a comprehensive overview of the OPL for addressing the issue of a panel switch covered by an accumulation of dust. The presence of dust on the panel switch can impede its functionality and potentially lead to operational issues. The SOP in Table 4.12 guide users through the process of safely cleaning the switch, minimizing the risk of damage and maximizing its operational efficiency.

Table 4.11 OPL for dusty surface

***Fuguai* : Dusty surface**	
Classification : Physical	
Before	**After**
	
Panel switch covered by full of dust	Clean the part of panel switch properly

Table 4.12 Steps in fuguai elimination (dusty surface)

Cleaning Process Flow	Description	Images
Start → Switch off all power	1. Make sure the main switch is switched off before cleaning process to ensure safety.	
→ Wear hand gloves	2. Wear hand gloves to protect the hands during cleaning process	
→ Prepare cleaning tools	3. Prepare suitable cleaning tools such as isoprophyl alcohol, brush and clothing rag	
→ Spray the area	4. Spray isoprophyl alcoho to the panel switch area	
→ Brush the area	5. Brush properly the panel switch area using a brush	
→ Wipe the area → End	6. Wipe the panel area untill dry and clean.	

Table 4.13 OPL for the removal of leftover scraps in hard-to-reach areas, like beneath expandable rubber covers. The SOP presented in Table 4.14 guide users through a careful process to reach and remove scraps and ensuring that the equipment remains free from debris that could impede its performance.

Table 4.15 illustrates the OPL for addressing the issue of a dirty surface on a roll-up cover rubber. Cleaning the surface of the roll-up cover rubber is crucial for preventing potential damage. Table 4.16 presented SOP outlines detailed instructions, guiding users through the process of effectively removing dirt and contaminants from the rubber surface.

Table 4.17 presents an OPL for addressing the issue of a dirty hose, specifically emphasizing the exterior section of the hose. Table 4.18 provides SOP for users with a detailed guide and specific instructions for cleaning the outer layer of the hose.

Table 4.19 illustrates the OPL for addressing the issue of a surface covered with dirty oil. Cleaning surfaces contaminated with dirty oil is essential for maintaining equipment efficiency and preventing degradation. Table 4.20 outlines a set of SOP instructions for users to follow in order to effectively remove dirty oil from surfaces.

Table 4.21 outlines the OPL for addressing the issue of a dusty monitor plastic cover. The accumulation of dust on the plastic cover can impair visibility, and potentially affect the functionality of the monitor. Table 4.16 details of SOP instructions for users to follow in order to effectively remove dust and restore the cleanliness of the plastic cover.

. Table 4.23 illustrates the OPL for addressing the issue of leftover or unwanted items in the workspace. The presence of these items can lead to clutter, reduced efficiency, and potential hazards. Clearing out unwanted items is essential for maintaining a safe and efficient workspace. Table 4.24 outlines a SOP of steps for users to follow in order to systematically identify and handle leftover items

Table 4.13 OPL for leftover scraps between unreachable area

***Fuguai :* Leftover scraps between unreachable areas**	
Classification : Physical	
Before	**After**
	
Expandable rubber cover full by leftover scraps	Clean and wipe all leftover scrap on expandable rubber cover

Table 4.14 Steps in fuguai elimination (leftover scraps)

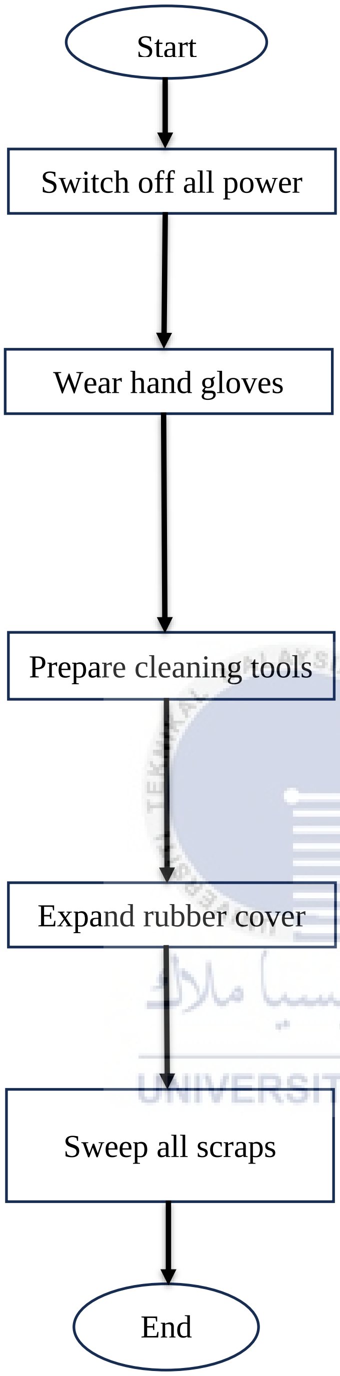
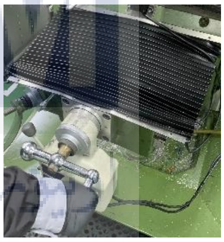
Cleaning Process Flow	Description	Images
	1. Make sure the main switch is switched off before cleaning process to ensure safety.	
	2. Wear hand gloves to protect the hands during cleaning process	
	3. Prepare suitable cleaning tools such as handle dust pan and brush.	
	4. Expand the rubber cover to make it easy to clean	
	5. Using a brush sweep all the scrap into the handle dust pan	

Table 4.15 OPL for dirty surface

***Fuguai* : Dirty surface**	
Classification : Physical	
Before	**After**
	
Roll up cover rubber covered by dust and dirty oil	Wipe all the dust and clean all the part of roll up cover rubber

Table 4.16 Steps in fuguai elimination (dirty surface)

Cleaning Process Flow	Description	Images
Start → Switch off all power	1. Make sure the main switch is switched off before cleaning process to ensure safety.	
Wear hand gloves	2. Wear hand gloves to protect the hands during cleaning process	
Prepare cleaning tools	3. Prepare suitable cleaning tools such as brush, handle dust pan, isoprophyl alcohol and clothing rag.	  
Sweep all the dust	4. Using a brush, sweep all the dust into the handle dust pan.	
Spray the area	5. Spray isoprophyl alcohol on the rol lup cover rubber.	
Wipe the area → End	6. Using a clothing rag, wipe all the dirt until clean and dry	

Table 4.17 OPL for dirty hose

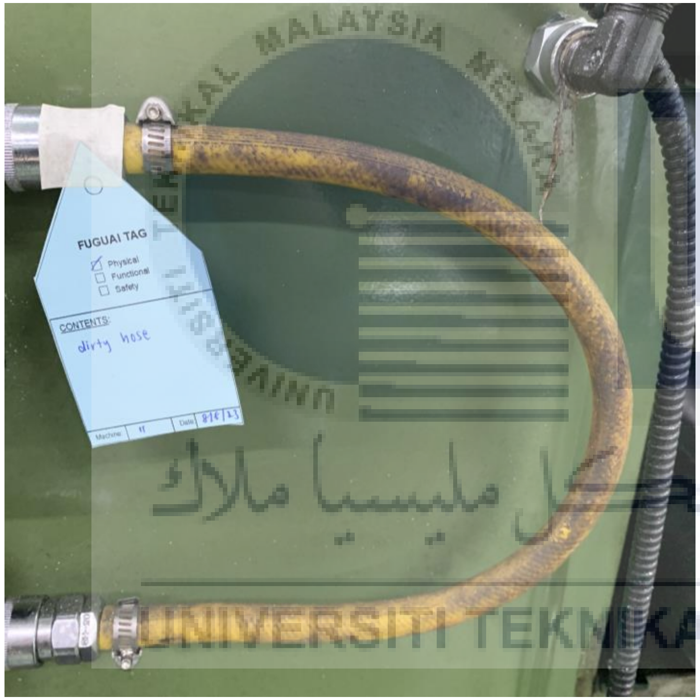
Fuguai : **Dirty hose**	
Classification : Physical	
Before	**After**
	
The hose full of dirty and must be cleaned properly	Clean each part of the hose properly

Table 4.18 Steps in fuguai elimination (durty hose)

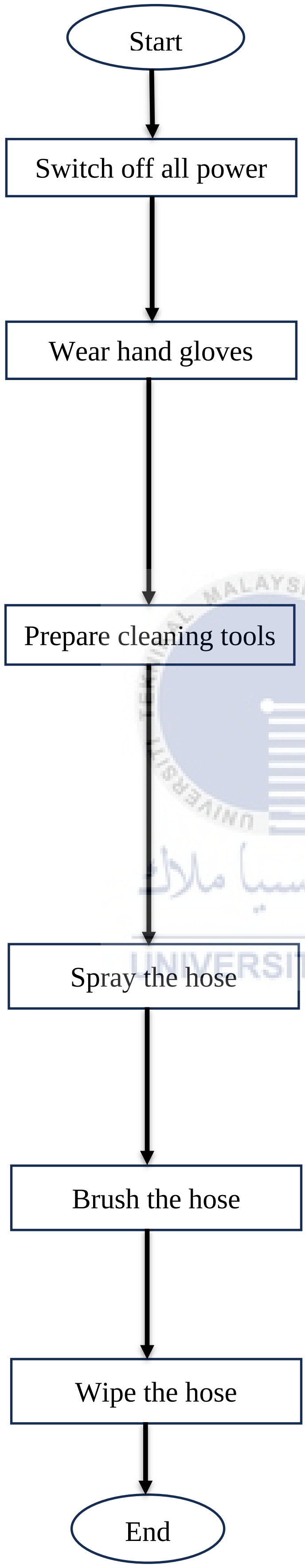
Cleaning Process Flow	Description	Images
	1. Make sure the main switch is switched off before cleaning process to ensure safety.	
	2. Wear hand gloves to protect the hands during cleaning process	
	3. Prepare suitable cleaning tools such as brush, isoprophyl alcohol and clothing rag.	
	4. Spray isoprophyl alcohol to the dirty hose area	
	5. Brush the hose properly	
	6. Wipe the hose until dry and clean.	

Table 4.19 OPL for dirty surface

***Fuguai* : Dirty surface**	
Classification : Physical	
Before	**After**
	
Surface covered with the dust and dirty oil	Clean and brush the part that hard to reach

Table 4.20 Steps in fuguai elimination (dirty surface)

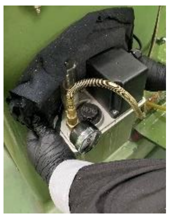
Cleaning Process Flow	Description	Images
Start → Switch off all power	1. Make sure the main switch is switched off before cleaning process to ensure safety.	
Wear hand gloves	2. Wear hand gloves to protect the hands during cleaning process	
Prepare cleaning tools	3. Prepare suitable tools such as isoprophyl alcohol, brush and clothung rag.	
Sweep down the dust	4. Brush all the surface that covered with dust and dirty oil	
Spray the surface	5. Spray isoprophyl alcohol on the covered surface	
Wipe the surface → End	6. Wipe the surface until clean and dry.	

Table 4.21 OPL for dusty monitor cover

Fuguai : **Dusty Surface**	
Classification : **Physical**	
Before	After
	
Monitor cover has been covered with full of dust make it hard to read	Open and clean each part of the cover properly and reassemble it correctly

Table 4.22 Steps in fuguai elimination (dusty surface)

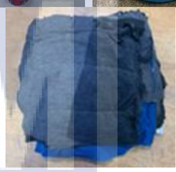
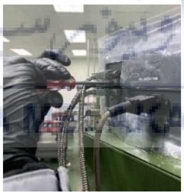
Cleaning Process Flow	Description	Images
Start → Switch off all power	1. Make sure the main switch is switched off before cleaning process to ensure safety.	
→ Wear hand gloves	2. Wear hand gloves to protect the hands during cleaning process	
→ Prepare suitable tools	3. Prepare suitable tools such as screw driver, isoprophyl and clothing rag	  
→ Loosen and remove the screw and plug	4. Using screw driver, loosen all the screw and remove the plug from the monitor	 
→ Pullout the cover	5. Pullout the cover carefully	
→ Spray and wipe the plastic cover → End	6. Spray isoprophyl alcohol on the cover and wipe it until clean and dry. Then, reinstall the plug on the monitor	 

Table 4.23 OPL for leftover item

***Fuguai* : Leftover item (unwanted item)**	
Classification : Physical	
Before	**After**
	
Unwanted item on worktable area	Take it and throw it into the rubbish bin

Table 4.24 Steps in fuguai elimination (leftover item)

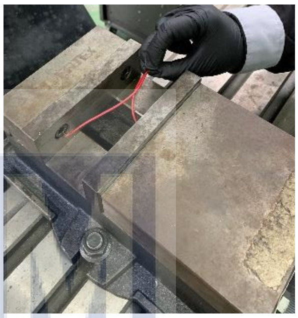
Cleaning Process Flow	Description	Images
	1. Make sure the main switch is switched off before cleaning process to ensure safety.	
	2. Wear hand gloves to protect the hands during cleaning process	
	3. Take the unwanted item from the worktable	
	4. After ensuring that the item is no longer needed, dispose of it in the waste bin.	

Table 4.25 outlines the OPL for addressing the issue of a dirty milling machine body with rust accumulation. Cleaning a milling machine body with rust requires specific attention to both dirt removal and rust prevention. Table 4.26 details step-by-step SOP for users to follow, encompassing cleaning and rust mitigation measures.

Table 4.27 presents the OPL for addressing the issue of leftover stickers on the body of the machine. Removing leftover stickers requires careful consideration to avoid damaging the machine's surface. Table 4.28 outlines a SOP of steps for users to follow in order to systematically peel off and clean any residue from stickers.

Table 4.29 delineates the OPL for addressing the issue of a loosen screw causing a component to tilt. This situation can jeopardize the stability and functionality of the affected component, potentially leading to operational inefficiencies or malfunctions. Table 4.30 outlines a SOP approach for users to identify the loose screws, tighten them appropriately, and inspect the component for proper alignment.

Table 4.31 outlines the OPL for addressing the issue of disorganized wires. Disorganized wires can lead to safety hazards, operational inefficiencies, and difficulties in troubleshooting. Table 4.32 details a SOP step-by-step instructions for users to follow in order to systematically arrange and secure wires.

Table 4.33 illustrates the OPL for addressing the issue of a dirty base on the milling machine. Table 4.34 outlines SOP instructions for users to follow in order to effectively remove dirt and maintain the cleanliness of the machine's base.

Table 4.35 outlines the OPL for addressing the issue of a label that has become loose. Securing labels is crucial for maintaining accurate information and preventing potential errors. Table 4.36 details SOP instructions for users to follow in order to identify loose labels and secure them properly.

Table 4.25 OPL for dirty machine body

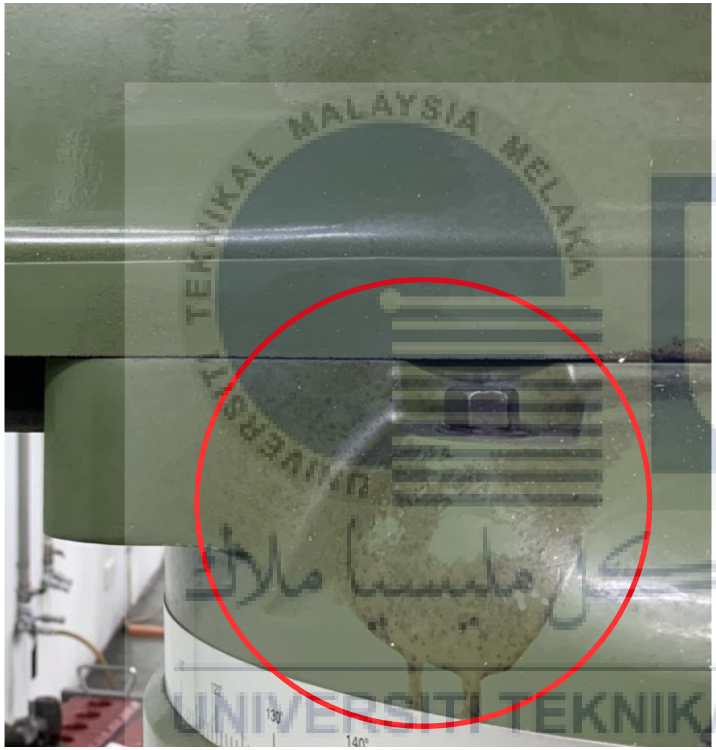
***Fuguai :* Dirty surface (covered by dirty oil)**	
Classification : Physical	
Before	**After**
	
Body of machine covered by dirty oil	Clean and wipe the body of machine until no oil covered the area

Table 4.26 Steps in fuguai elimination (dirty surface)

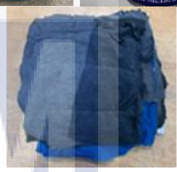
Cleaning Process Flow	Description	Images
Start → Switch off all power	1. Make sure the main switch is switched off before cleaning process to ensure safety.	
→ Wear hand gloves	2. Wear hand gloves to protect the hands during cleaning process	
→ Prepare cleaning tools	3. Prepare suitable cleaning tools such as lubricant spray, isoprophyl alcohol and clothing rag	  
→ Spray the surface	4. Spray isoprophyl alcohol on the surface.	
→ Wipe the surface	5. Using clothing rag, wipe it properly.	
→ Spray the surface → End	6. If the surface has rust on it, use a lubricant spray. Then, using clothing rag wipe it until clean and dry.	

Table 4.27 OPL for leftover sticker

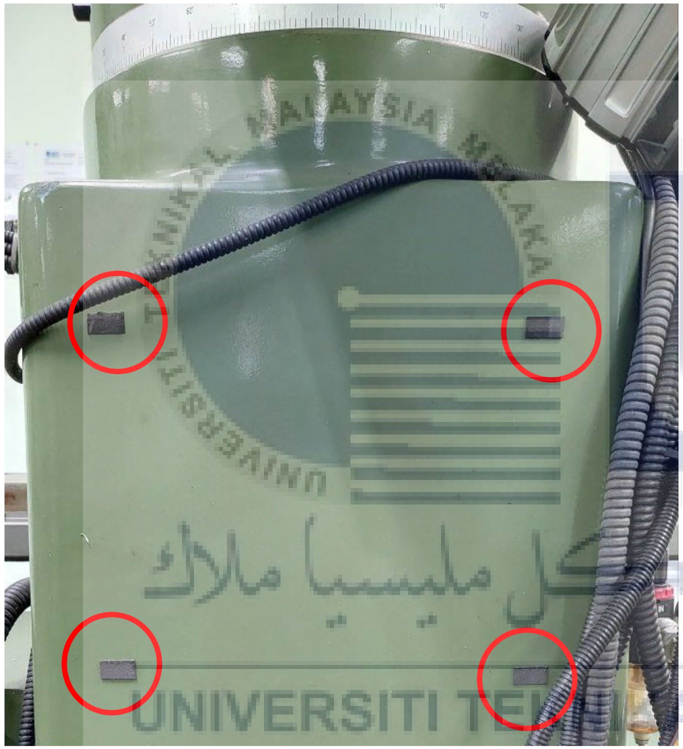
<table>
<tr><td colspan="2">Fuguai : Leftover Sticker</td></tr>
<tr><td colspan="2">Classification : Physical</td></tr>
<tr><th>Before</th><th>After</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Unwanted sticker on the body machine</td><td>Clean and wipe each part of the body machine properly</td></tr>
</table>

Table 4.28 Steps in fuguai elimination (leftover sticker)

Cleaning Process Flow	Description	Images
Start → Switch off all power	1. Make sure the main switch is switched off before cleaning process to ensure safety.	
→ Wear hand gloves	2. Wear hand gloves to protect the hands during cleaning process	
→ Prepare cleaning tools	3. Prepare suitable cleaning tools such as isoprophyl alcohol, lubricant spray and clothing rag.	
→ Remove unwanted sticker	4. Remove all unwanted sticker using your hand or scraper.	
→ Spray and wipe the machine body	5. Using lubricant spray to make sure all excess glue can be removed. Then, wipe it with clothing rag.	
→ Spray and clean the machine body → End	6. Spray isoprophyl alcohol to the body of machine to clean all the dust properly.	

Table 4.29 OPL for loosen screw

<table>
<tr><td colspan="2">Fuguai : Loosen Screw for Component Part</td></tr>
<tr><td colspan="2">Classification : Safety</td></tr>
<tr><th>Before</th><th>After</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Tilted component found on the machine because of screw not secured properly</td><td>Fastened and secure screw in right position</td></tr>
</table>

Table 4.30 Steps in fuguai elimination (loosen screw)

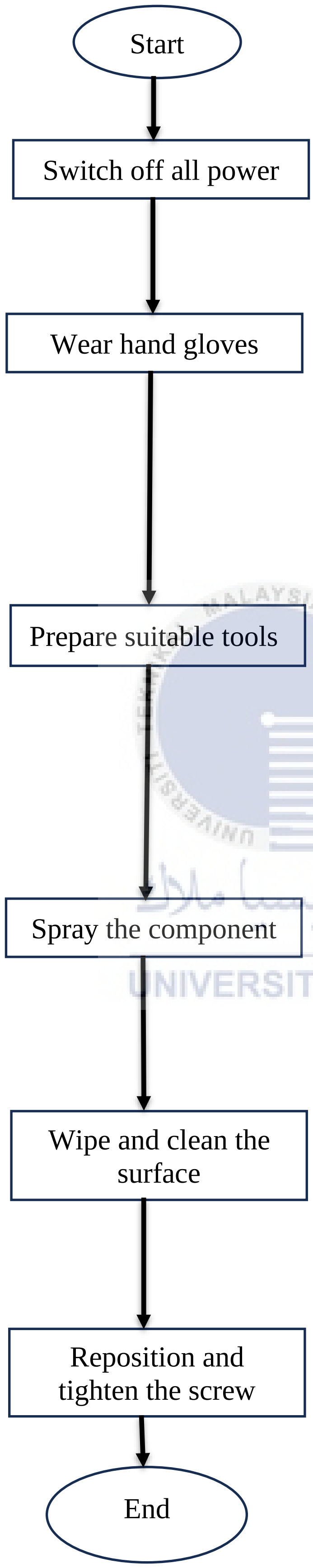
<table>
<tr><th>Cleaning Process Flow</th><th>Description</th><th>Images</th></tr>
<tr><td rowspan="6">
</td><td>1. Make sure the main switch is switched off before cleaning process to ensure safety.</td><td></td></tr>
<tr><td>2. Wear hand gloves to protect the hands during cleaning process</td><td></td></tr>
<tr><td>3. Prepare suitable tools such as align key, clothing rag and isoprophyl alcohol.</td><td>  </td></tr>
<tr><td>4. Spray isoprophyl alcohol to the component.</td><td></td></tr>
<tr><td>5. Wipe and clean all the dirty using clothing rag</td><td></td></tr>
<tr><td>6. Loosen the screw and reposition the component. Then, tighten the screw again.</td><td></td></tr>
</table>

Table 4.31 OPL for disorganized wires

<table>
<tr><td colspan="2">Fuguai : Disorganized wires</td></tr>
<tr><td colspan="2">Classification : Physical</td></tr>
<tr><th>Before</th><th>After</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Messy wires not secured in position</td><td>Neatly secure tubes in position</td></tr>
</table>

Table 4.32 Steps in fuguai elimination (disorganized wire)

Cleaning Process Flow	Description	Images
Start → Switch off all power	1. Make sure the main switch is switched off before cleaning process to ensure safety.	
→ Wear hand gloves	2. Wear hand gloves to protect the hands during cleaning process	
→ Prepare cleaning tools	3. Preapre suitable tools such as isoprophyl alcohol, cable tie and clothing rag	
→ Spray the wires	4. Spray isoprophyl alcohol to the wires	
→ Wipe and clean the wires	5. Use the clothing rag to wipe and clean the wires	
→ Put the cable tie	6. Fold the excess part of the wire, then secure them together using a cable tie	
→ Cut the excess cable tie → End	7. Using scissor, cut off the excess cable tie.	

Table 4.33 OPL for dirty surface

Fuguai : **Dirty surface**	
Classification : Physical	
Before	After
	
Base full of scraps and dirty oil	Clean and wipe the part of base properly

Table 4.34 Steps in fuguai elimination (dirty surface)

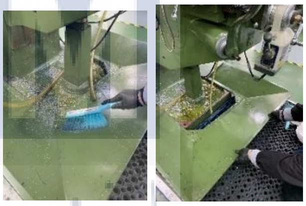
Cleaning Process Flow	Description	Images
Start → Switch off all power	1. Make sure the main switch is switched off before cleaning process to ensure safety.	
→ Wear hand gloves	2. Wear hand gloves to protect the hands during cleaning process	
→ Prepare cleaning tools	3. Prepare suitable cleaning tools such as handle dust pan, brush, isoprophyl alcohol and clothing rag	
→ Swipe the dust and scraps on cover base	4. Swipe all the scraps and dust to the base. Then, pullout the cover of the base.	
→ Spray and clean the cover base	5. Spray isoprophyl alcohol to the cover base and wipe it until clean.	
→ Wipe the hoses and swipe all scraps.	6. Wipe all the hose and wires. Then, sweep all the scraps , oil and dust from the base into the handle dust pan	
→ Absorb the oil and clean the base → End	7. Use a tissue to absorb any excess oil that may still be pooling in the base. Then, wipe it until clean.	

Table 4.35 OPL for loosen label

***Fuguai :* Lossen label**	
Classification :Physical	
Before	**After**
	
Machine part description label loosen.	Secured the machine part description label in position.

Table 4.36 Steps in fuguai elimination (loosen label)

Cleaning Process Flow	Description	Images
Start → Switch off all power	1. Make sure the main switch is switched off before cleaning process to ensure safety.	
Prepare double sided tape	2. Prepare a suitable tools such as double sided tape	
Stick the tape	3. Stick the tape to the area of loosen sticker	
Remove the cover part of the tape	4. Remove the cover part of the tape properly	
Attach the sticker → End	5. Use finger to press the top of the sticker to ensure it adheres well to the tape.	

4.4 Summary

In milling machine setups, the extent of fuguai data collecting is not as large as in industries. This is due to the fact that machines in labs often operate under less demanding conditions than their industrial counterparts, which tolerate significantly heavier workloads and longer operation times. While most of recognised fuguai are effectively eliminated a few remain due to the advanced technical expertise required. Broken parts, dented components, and missing covers are among the unsolved fuguai, which are marked by red F-tags.

Despite these problems, the milling machines' overall condition has improved, and the number of fuguai has decreased dramatically. Milling machines are currently in far better form than they were before the implementation of autonomous maintenance. The machine parts identified with fuguai can run more smoothly, increasing operating efficiency. The milling machines look clean as a result of applying autonomous maintenance, and the safety of machine users is maintained.

One Point Lessons (OPLs) are used to demonstrate countermeasures towards recognised fuguai. OPLs successfully provide instructions or targeted knowledge about a specific aspect of a fuguai-related task, process, or skill. OPLs give a clear picture of how to deal with fuguai and are understandable by all machine users or operators, establishing a common guideline for future reference. Autonomous maintenance generates non-measurable consequences in addition to the data generated via fuguai elimination.

Machine users and operators now have a greater grasp of machine maintenance, and they will be better equipped to deal with fuguai in the future if they refer OPLs. The milling machine environment has successfully promoted awareness of the significance of autonomous maintenance among machine users and operators.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In the milling machine environment, Dirt (F2) is greatest frequent fuguai found in the milling machine environment, accounting for 39% of all fuguai identified. Disorganised objects (F4) and dented or broken pieces (F7), on the other hand, have the lowest percentage of all fuguai, each at 1%. Analysis showed the front area (FRONT) as the most critical machine area. Physical and functional fuguai are most commonly seen at the milling machine's front area, with 175 physical and 67 functional fuguai identified. The bulk of the fuguai identified on the milling machine have been addressed successfully. Just a small percentage of fuguai require advanced technical abilities to be solved.

Several restrictions and obstacles were encountered throughout the milling machine project. One significant issue is the machines' lack of a scheduled maintenance schedule. Failure to perform regular maintenance on the milling machine might result in serious issues, such as component failures that could impede overall process functionality. Minor defects are frequently overlooked and dismissed. Even seemingly minor flaws, however, can have a major impact on the machine's functionality and overall operation.

Addressing these restrictions requires defining suitable criteria for fuguai elimination as part of autonomous maintenance, appealing to both student and experienced personnel. Each recognised issue determines the parameters for fuguai elimination. Depending on the context and the need for elimination, several tactics are used to deal with different types of fuguai. Each fuguai comes with a separate One Point Lesson (OPL) that provides clear instructions, and every step of the fuguai elimination process is thoroughly described. To improve accessibility, keep the OPL and the illustrated fuguai elimination actions close to the machine maintenance checklist. Daily cleaning and inspections are performed according to a planned timetable to ensure good maintenance, self-control, and the operator's dedication to the milling machine.

Lastly, the project accomplished its goal of developing an autonomous maintenance program for the milling machine. Fuguai are thoroughly examined and analysed as a proactive technique to improve milling machine productivity. Implementing autonomous maintenance is beneficial in improving machine performance, and it is critical to apply these ideas to milling machinery and the broader industry. Numerous studies show that implementing autonomous maintenance enhances machine efficiency and machine user responsibility greatly.

5.2 Recommendations

This study established separate One Point Lessons (OPL) and Standard Operating Procedures (SOP) for several types of fuguai discovered on the laboratory milling machine. The OPL acts as a demonstration of the fuguai countermeasure, providing machine users with straightforward guidance to comprehend the machine's original condition. Since there are several fuguai categories in one machine, the elimination process requires that the machine user perform particular steps. Based on machine inspection and cleaning activities, SOPs suited to each fuguai discovered on the milling machine are developed.

It is important to highlight, that this research focuses on milling machines in the FTKIP laboratory, and there is only one type of milling machine available. The majority of machines in the laboratory are only operational during student laboratory activities and have limited parameters. As this study focuses on machines used for educational purposes in a university context, future initiatives could investigate the implementation of autonomous maintenance for industrial applications. Implementing autonomous maintenance in an industrial setting requires a more thorough examination of various types of workpieces and factors. The identification of fuguai could be compared with machines with similar processing characteristics but different types.

In this project, only five steps were implemented to accomplish autonomous maintenance: preparation, initial machine cleaning and inspection, countermeasures to the source of contamination, cleaning and lubrication standards, and overall inspection. These steps are taken from the seven steps mentioned in the implementation of autonomous maintenance, which align with the objectives of this study. Future research should include all seven processes to ensure the effective use of autonomous maintenance for machine operators and the long-term viability of the autonomous maintenance activity in the laboratory.

It is important to understand that autonomous maintenance is not the only way to improve machine efficiency. Future research could go deeper into autonomous maintenance subjects like preventative and predictive maintenance, examining a more holistic approach to improving machine performance in the milling machine environment.

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APPENDICES

APPENDIX A: TURNITIN RESULT

Final Report

by Ikhwan Zahurin

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