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OPTIMIZATION OF MAINTENANCE MANAGEMENT FRAMEWORK IN LPG CYLINDER MANUFACTURING

M.Sc. Engineering (Mechanical)

By

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Candidate's Declaration

It is hereby declare that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Nomenclature

CA = Criticality Analysis

FRCA = Failure Root Cause Analysis

RCM = Reliability Centered Maintenance

MTTR = Mean time to repair

MTBF = Mean time between failure

PM = Preventive Maintenance

Abstract

Maintenance can be defined as actions necessary for retaining or restoring a piece of equipment, machine or system to the specified operating conditions to achieve its maximum useful life. Maintenance ensures that production plant and equipments are available for production with minimum cost and wastage. Any organization regardless of the size, technology, products and services must have a clear cut maintenance policy to meet its individual needs. Preventive maintenance is a set of activities that are performed on plant, equipment, machinery, and systems before the occurrence of a failure in order to protect them and to prevent or eliminate any degradation in their operating conditions. Predictive maintenance is the complement of preventive maintenance. Predictive maintenance determines equipment status before a breakdown occurs. Production may be stopped due to many reasons like breakdown of machine, maintenance work, labor issues, and inventory problems. It is necessary to reduce the breakdown of machine or equipment's in the company for the efficient production to meet the demands. The main objective of this project is to study the breakdown of a critical machine in LPG cylinder manufacturing plant. The major breakdowns were observed in hydraulic press machine, Trimming and Joggling machine, SAW welding line & MIG MAG welding line. Breakdown history of each machine was analyzed from August 2019 to November 2019 and noticed that hydraulic press machine and trimming and joggling machine contribute major loss to the industry, hence detailed study was carried out to minimize loss. Production process and machine breakdown was studied using different analysis and inspection tools like fish bone diagram, why- why analysis and counter measures to determine the machine availability, machine availability was determined by MTTR and MTBF. Based on the problems root cause analyses were carried out to develop optimized maintenance management framework and improve new preventive maintenance schedule and checklist for hydraulic press machine and trimming and joggling machine.

Chapter-ONE
Introduction

The management and control of maintenance activities are equally important to performing maintenance, maintenance of engineering equipment in the field has been a challenge. Although impressive progress has been made in maintaining equipment in the field in an effective manner, maintenance of equipment is still a challenge due to factors such as size, cost, complexity, and competition. Needless to say, today's maintenance practices are market driven, in particular for manufacturing and process industries, service suppliers (A. Parida and U.Kumar,2006). An event may present an immediate environmental, performance, or safety implication. Thus, there is a definite need for effective asset management and maintenance practices that will positively influence critical success factors such as safety, product quality, and speed of innovation, price, profitability, and reliable delivery. Each year billions of dollars are spent on equipment maintenance around the world. Over the years, many new developments have taken place in this area. Maintenance is a function that must be performed under normally adverse circumstances and stress, and its main objective is to rapidly restore the equipment to its operational readiness state using available resources. The contributing objectives of maintenance engineering include: improve maintenance operations, reduce the amount and frequency of maintenance, reduce the effect of complexity, reduce the maintenance skills required, reduce the amount of supply support, establish optimum frequency and extent of preventive maintenance to be carried out, improve and ensure maximum utilization of maintenance facilities, and improve the maintenance organization.

1.1 Engineering Maintenance in the 21st Century

Due to various factors, it was established in the previous century that "maintenance" must be an integral part of the production strategy for the overall success of an organization. The effectiveness of the maintenance activity, the 21st century must build on this. It is expected that equipment of this century will be more computerized and reliable, in addition to being vastly more complex. Further computerization of equipment will significantly increase the importance of software maintenance, approaching, if not equal to, hardware maintenance. This century will also see more emphasis on maintenance with respect to such areas as the human factor, quality, safety, and cost effectiveness. New thinking and new strategies will be required to realize potential benefits and turn them into profitability. Overall, profitable operations will be the ones that have employed modern thinking to evolve an equipment management strategy that takes effective advantage of new information, technology, and methods (A. Crespo Marquez,2009).

1.2 Problem Statement

LPG cylinder manufacturing industry started his journey lately in Bangladesh and as per the monthly production performance report, capacity utilization of August 2019 and September 2019 were 21.5 % and 47 % respectively. The main reasons not to achieve the target is operational down time (OD) & the downtime arises from machine breakdown due to poor & unorganized maintenance system of the company. There are many machines in LPG cylinder production line but as per practical data major breakdown were observed in hydraulic press machine, trimming and joggling machine, SAW welding line and MIG MAG welding line. This thesis will mainly focus on operational downtimes due to maintenance problem. Therefore, having a proper maintenance system will solve recurring machine breakdowns of LPG cylinder manufacturing industries.

1.3 Objectives

The research work has following objectives:

- To increase availability of the machine
- To improve new preventive maintenance schedule
- To perform failure root cause analysis to reduce the recurrence of failures of hydraulic press and trimming and joggling machine.
- To implement the corrective steps for hydraulic press machine and trimming and joggling machine.
- To Develop optimized maintenance management framework

1.4 Organization of the thesis

This thesis comprises of five chapters.

Chapter ONE gives a brief overview of the background and concept of this study. Finally, significance of the research and the objectives of this study are summarized. This chapter also outlines the organization of this dissertation.

Chapter TWO gives a brief overview of literature review

Chapter THREE describes the methodology and case study of criticality analysis, failure root cause analysis & reliability centered maintenance (RCM).

Chapter FOUR describes the details of the development of optimized maintenance management framework.

Chapter FIVE describes the conclusions and summary of the contributions. In addition, some directions for future work related to this study are also presented.

Chapter-TWO

Literature Review

2.1. Introduction

Since approximately three decades, companies realized that if they wanted to manage maintenance adequately it would be necessary to include it in the general scheme of the organization and to manage it in interaction with other functions (Pintelon and Gelders,1992). Once achieved this, maintenance could receive the importance that deserves and be developed as one more function of the organization, which generates "products" to satisfy internal clients, fulfilling or contributing to the fulfillment of specific goals of the organization.

Therefore, the challenge of "designing" the ideal model to drive maintenance activities has become a research topic and a fundamental question to reach the effectiveness and efficiency of maintenance management and to fulfill enterprise objectives (Prasad Mishra et al., 2006). In the historical development of maintenance, diverse authors have proposed what they consider the best practices, steps, sequences of activities or models to manage this function.

2.2. Definition of terms

2.2.1 Maintenance: Maintenance is a function that must be performed under normally adverse circumstances and stress, and its main objective is to rapidly restore the equipment to its operational readiness state using available resources. Maintenance is combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function (EN 13306, 2010). Conceptual framework is a framework that explains either graphically or in narrative form of the main things to be studied; their key factors, constructions or variables and the presumed relationships among them (Parida et al., 2015). Maintenance has traditionally been considered as a necessary evil, but it is in fact rather a center of profit than just unavoidable and unpredictable expense (Alsyouf, 2007). However, according to Kumar and Parida maintenance is defined as the combination of all the technical and administrative actions, including supervision, intended to retain an item, or restore it to a state in which it can perform a required function.

2.2.2 Maintenance Management: Maintenance management makes use of some tools and techniques to improve efficiency and minimize the impacts of unplanned stoppages looking for reducing costs (A. Parida and U. Kumar, 2006). Maintenance must be an integral part of the production strategy for the overall success of an organization and it main objective is to rapidly restore the equipment to its operational readiness state using available resources (Zweekhorst, 1996). It is becoming a major function that effects and is affected by many other functional areas such as production, quality, inventory, marketing and human resources. It is also getting to be considered as an essential part of the business supply chain at a global level. This increasing role of maintenance is reflected in its high cost, which is estimated to be around 30 percent of the total running cost of modern manufacturing and construction businesses (Al-Turki, 2011). Maintenance management is all activities of the management that determine the maintenance objectives, strategies and responsibilities, and implementation of them by such means as maintenance planning, maintenance control, and the improvement of maintenance activities and economics (EN 13306, 2010). In addition, Wireman defined maintenance as Asset Management, as the management of all assets owned by a company, based on maximizing the return on investment in the asset (Wireman, 2005).

2.2.3 Maintenance Management Framework: Maintenance performance measurement is defined as the multidisciplinary process of measuring and justifying the value created by maintenance investment, and taking care of the organization stockholders requirements viewed strategically from the overall business perspective (Parida and Chattopadhyay, 2007). A common occurrence when reviewing literature is the fact that authors use an array of terms and words to describe the same or similar concept. The study of maintenance management is no different with terms such as: maintenance models; maintenance methods; maintenance techniques; maintenance systems; maintenance types; maintenance philosophies; and maintenance strategies regularly used Maintenance management models throughout the literature to describe the same notion on maintenance (Parida et al., 2014, Parida et al, 2015 and Kym, 2015).

2.3. Maintenance concept globally

Due to the increasing technical advancements, the stimulus of productivity and quality is moving from man to machine. Productivity and quality may be increased only by implementing well-developed and organized maintenance system (Phogat and Gupta, 2017). Maintenance is normally perceived to have a poorer rate of return than any other major budget item. Yet, most companies can reduce maintenance costs by at least one-third, and improve the level of productivity, by giving maintenance the management priority it requires. That priority must span all levels of an organization's management structure to develop an understanding at each level of the significance maintenance can have upon the success or failure of organization objectives (Ahuja and Khamba, 2007). Each year billions of dollars are spent on equipment maintenance around the world. Over the years, many new developments have taken place in this area (IMCP, 1975). Wireman, 1990, Jonsson, 1999 and McKoneet al., 2001 as original sited by Naughton, 2012, Maintenance was viewed with distain by management accountants and seen as a drain on the bottom line, but with the introduction of the concept of value in maintenance, the true role of effective maintenance is slowly being recognized. This revolution is somewhat hindered by the fact that maintenance as a management strategy is somewhat underdeveloped when compared to other management disciplines such as operations management.

In 21st century, new thinking and new strategies will be required to realize potential benefits and turn them into profitability. Overall, profitable operations will be the ones that have employed modern thinking to evolve an equipment management strategy that takes effective advantage of new information, technology, and methods. The economic downturn and the dynamic business environment drive companies to seek more efficient and effective maintenance. Thus, the increasing competition in the market creates a need to search new ways in which companies can differentiate themselves and gain more profit and better competitive position (Maletic et al., 2014).

Maintenance has two parts: an engineering and management part. The engineering part of maintenance is all about to improve maintenance operations, reduce the amount and frequency of maintenance, reduce the effect of complexity, reduce the maintenance skills required, reduce the amount of supply support, establish optimum frequency and extent of preventive maintenance to be carried out, improve and ensure maximum utilization of maintenance facilities, and improve the maintenance organization.

On the other hand, the management part talks about all the activities of management that determine the maintenance objectives or priorities (defined as targets assigned and accepted by the management and maintenance department),strategies (defined as a management method in order to achieve maintenance objectives), and responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, and several improving methods including economical aspects in the organization the function of providing policy guidance for maintenance activities, in addition to exercising technical and management control of maintenance programs (Adolfo, 2007).

Maintenance organization in a plant can be centralized or decentralized by considering company size, complexity, and product produced. Past experience indicates that in large plants a combination of centralized and decentralized maintenance normally works best. The main reason is that the benefits of both the systems can be achieved with essentially a low number of drawbacks. Nonetheless, no one particular type of maintenance organization is useful for all types of enterprises (Dhillon, 2001). Whereas Haroun and Duffuaa (2009) and Wireman (2005), classify maintenance organizational structure is three types, centralized, decentralized and matrix or Hybrid structure. Establish reasonably clear division of authority with minimal overlap, optimize number of persons reporting to an individual, fit the organization to the personalities involved, and keep vertical lines of authority and responsibility as short as possible useful guidelines planning a maintenance organization. The maintenance team is an important factor that demands strategies to improve competence level. Thus, it is necessary to manage activities and resources allowing the maintenance area to accomplish its function (Marcelo et al., 2014). Literatures show that maintenance management is very important for the performance of the company (Pintelon, 2002, Enofe and Aimienrovbiy, 2010, Pintelon 2002, Parida et al., 2015).

2.4. Maintenance management

A good maintenance management system makes equipment and facilities available. Availability means the production team can demand and receive any item such as light, power, air, gas, heating,cooling, or machine tools when it is needed. If the required equipment or service is down, or if the machine stops short of completing a job, time and money are wasted. A good maintenance management system helps to accomplish minimal downtime (Kishan, 2006).

Literature on maintenance management has so far been very limited (Goyal and Maheshwari,2012). maintenance concepts vary from organization to organization. There is no one-fits-all solution and the literature published around generic commercial frameworks (Pintelon, 2002, Naughton 2012,).
Basic steps of management stated by Kishan (2006), is request, approval, plan, schedule, performing work, recording data accounting for costs, developing management information, updating equipment history and providing management control reports

Elements of effective maintenance management includes:

- Maintenance policy
- Material control
- Work order system
- Equipment records
- Preventive & corrective maintenance
- Job planning & scheduling
- Backlog control & priority system
- Performance measurement

2.5. Maintenance management framework

Vanneste and Van Wassenhove (1995) present a brief review of developments in maintenance theory and practice, and in information technology and decision support models. The model is an integrated approach that combines elements from these domains into a powerful tool for dealing with maintenance problems. They also show how this framework can be used to set up a continuous improvement program for maintenance management and apply the concepts to an industrial case. The approach has eight phases by improving Deming cycle.

Phase 1 obtain a clear picture of a current factory performance: at this stage list of questions developed in order to have a clear picture of the organization.

Phase 2. Analyze quality and down time problems. At this phase location of the majority quality and downtime problems, relative importance, frequency of occurrences, causes and consequences identified by using histogram, pareto analysis, quality control charts, cause and effect diagrams, FMEA methods.

Phase 3. Analyze the effectiveness of alternative solutions to major problems. Different solutions generated and their hidden and tangible costs identified. They mentioned that both costs as well as benefits of a solution, especially in the hidden part are uncertain and difficult to estimate an exact value. Therefore, it is necessary to include scenario analysis. By comparing one solution cost benefit analysis with another solution, it became easy to prioritize the proposed solutions.

This phase has 4 steps:

1. Obtain a list of alternative solutions to each (major) problem.
2. Estimate the cost and benefits of each solution.
3. Make a prioritized list.
4. Select one or more solution

Phase 4. Analyze the efficiency of maintenance procedures. To identify how much preventive maintenance be to performed, how many spare parts to be kept in stock decision models used. The input for the models such as cost, lifetime distribution is obtained from effectiveness analysis, additional data analysis and experts opinion. At this phase 3 models selected, maintenance and replacement model (it is a maintenance field), spare part provisioning model (it is under Inventory management) and scheduling model (it is under production scheduling). Three models under maintenance and replacement model selected, these are Deterministic age replacement model, Probabilistic age replacement model and group replacement model. A common factor in these models is that the unit deteriorates as it gets older. Deterministic age replacement model is used to find optimal age of replacement in addition it is for a single unit system. The other two models used to find the optimal preventive age limit in addition to this it is used for a group of identical components.

Phase 5. Plan action. Planning of actions and information process takes place to keep the track of the result. After defining performance measures and organizing the data gathering process target will be set.

Phase 6. Implement actions and gather data. Planned actions on phase five will be implemented and data will be collected.

Phase 7. Monitor actions, process data, and the last phase will be adapting actions or information procedures in case of undesired evaluation. The performance indicators (P.I.'s) provide a tool to measure certain quantities and to check whether and to what extent targets are met. On the integrated approach efficiency, analysis is preceded by effectiveness analysis. To study the maintenance efficiency optimal replacement frequency analysis used. In order to initiate, monitoring and measuring continual improvement efforts maintenance Management Information System (MMIS) developed. This MMIS is user friendly that have 3 main components' performance indicators, data's and models. The framework implemented on selected company in three steps. The first step is getting a picture of the quality and downtime problems, the next step is prioritizing actions (effectiveness), and the last step is improving the efficiency of maintenance procedures.

2.6 Concluding Remark

After studying the literature review, it has been found that there are many researches, related with maintenance management but didn't find any research which have been conducted on optimization on maintenance management framework in LPG cylinder manufacturing & none of them showed practical implementation in LPG cylinder manufacturing. These parameters were chosen because no studies have been done on it for this particular type of industries.

Chapter-THREE
Research Methodology

3.1 Introduction

The scope of this chapter is to establish a concept to optimize the machine maintenance time as well as to increase the productivity in LPG cylinder manufacturing. In most cases, machine operators fail to detect the actual causes behind any problem whenever a failure occurs. They are often seen treating the symptoms rather than eliminating the problem at the grass root level. This further elevates the problem to a completely new level which would have otherwise not occurred had it been treated correctly in the first place. An in depth analysis together with experience and training only prepares an individual for proper handling of failed equipment. A thorough practical knowledge of mechanical, electrical as well as electronic parts able an operator to run a complex piece of equipment like the pouch machine smoothly. Mostly operators gather the basic knowledge through experience in the field. But this has a side effect as well, till the time they had become experts in their fields they had already wasted a considerable amount of valuable production time. Analysis of root causes through brainstorming and training sessions can only give a clear picture to the operators of equipment they are handling.

3.2 Concept of Maintenance Management Framework

The Maintenance Management Framework describes and reviews the concept, process and framework of modern maintenance management of complex systems; concentrating specifically on modern modelling tools (deterministic and empirical) for maintenance planning and scheduling. It presents a new perspective of maintenance management by focusing on the course of maintenance actions, Presenting a structure that ensures proper support for current maintenance managers; clarifying the functionality that is required from information technology when applied to maintenance and the functions of modern maintenance engineering; and creating a set of practical models for maintenance management planning and scheduling. The discussion of all of these issues is supported through the use of case studies. The Maintenance Management Framework will be beneficial for engineers and professionals involved in: maintenance management, maintenance engineering, operations management, quality, etc.

3.3 Process Study and Methodology

3.3.1 Process Study of LPG cylinder manufacturing:

Process study is the systematic examination of the methods of carrying out activities such as to improve the effective use of resources and to set up standards of performance for the activities carried out. In this research process study has been carried to identify the causes of failure and remedies to overcome these failures. Hydraulic press machine is used to cut the hot rolled steel, bending & forming. Die is the main most essential tools for hydraulic press machine to cut, bending & deep drawing operation. Welding operation is done to make a complete cylinder like foot ring welding, guard ring welding and body welding. Stress relief annealing is done to increase ductility & reduce the hardness of the cylinder. After that hydrostatic test is done to check the leakage of the cylinder & surface preparation is required for painting operation. Finally, cylinder is ready for valve fitting and screen-printing.

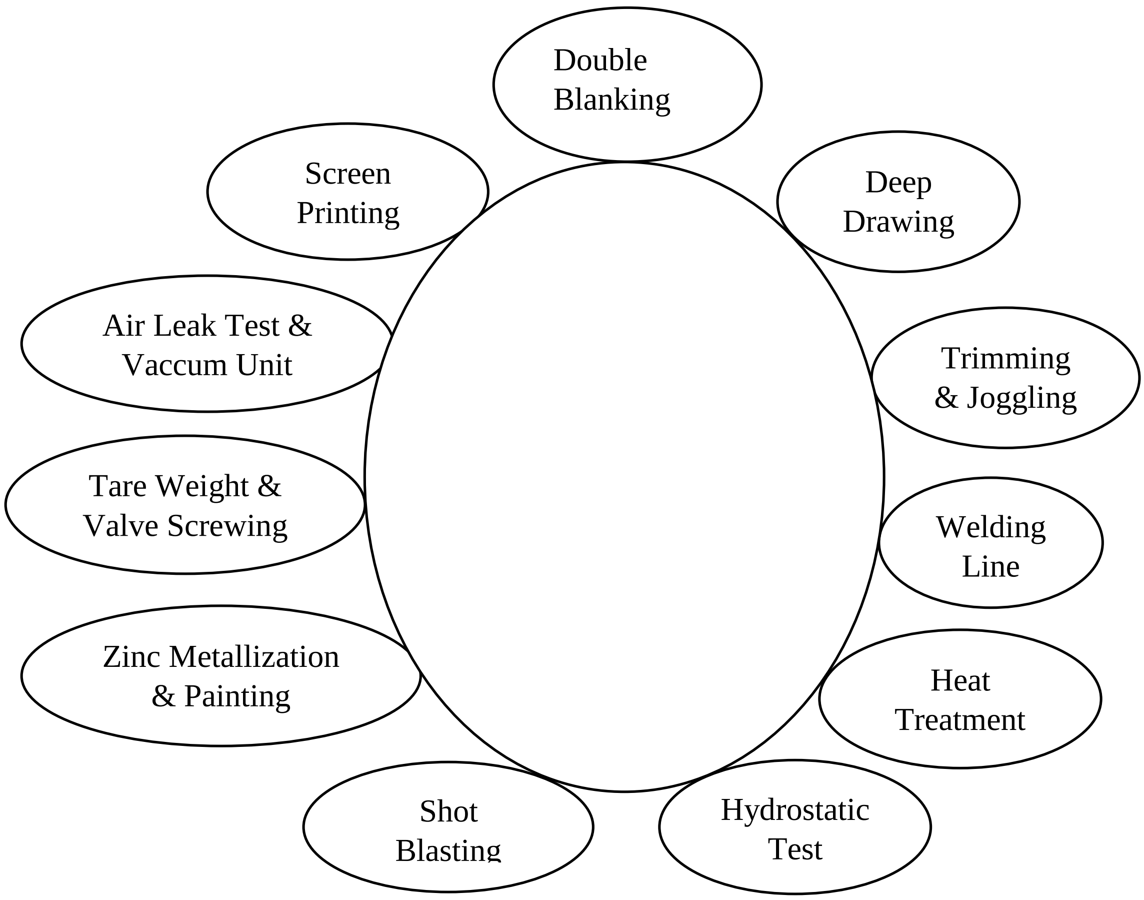

Fig 3.1: Production process flowchart of LPG cylinder manufacturing plant

Fig 3.2 : 500 Ton Hydraulic Press

Fig 3.3 : 300 Ton Hydraulic Press

3.3.2 Criticality Analysis

Criticality analysis is defined as the process of assigning assets a criticality rating based on their potential risk. Risk is defined as "the effect of uncertainty on objectives," according to ISO 31000:2009 – Risk Management – Principles and Guidelines. Since it cannot truly be quantified, risk, in this case, is thought of as all the possible ways assets can fail and the effects that failure can have on the system and operation as a whole. Determining equipment criticality is understanding how crucial a certain piece of equipment is to the industry. The answer is generally determined by the consequences in the case of failure. Therefore maintenance decisions and actions will always involve the possibility of a certain deviation from business targets, a certain loss, a certain amount of risk. The ordering in a Pareto Chart helps identify the 'vital few' (the factors that warrant the most attention i.e. factors whose cumulative per cent (dots) fall under the 80% cut off line) from the 'trivial many' (factors that, while useful to know about, have a relatively smaller effect i.e. cumulative per cent dots that fall above the 80% cut off line).

Using a Pareto diagram helps a team concentrate its efforts on the factors that have the greatest impact. It also helps a team communicate the rationale for focusing on certain areas.

Table 3.1: Machine Breakdown Data (August-2019 to November-2019)

Sl No	Date	Name of Machine	Problem Details	Machine Breakdown Time (hours)
1	4/8/2019	Hydraulic Press Machine	Hydraulic pressure fault	2
2	8/8/2019	MIG MAG Welding Line	Template Broken	3
3	15/08/2019	Hydraulic Press Machine	Hydraulic pressure fault	144
4	17/08/2019	Heat Treatment Unit	Pressure Gauge Damaged	1
5	22/08/2019	Hydrostatic Test	Gasket Damaged	1
6	27/08/2019	Hydraulic Press Machine	Hydraulic pressure fault	6
7	10/9/2019	Hydraulic Press Machine	Hydraulic Pressure fault	1
8	14/09/2019	Trimming & Joggling	Cutter Broken	1
9	20/09/2019	Hydraulic Press Machine	Hydraulic Pressure fault	8
10	22/09/2019	Hydraulic Press Machine	Hydraulic Pressure fault	96
11	3/10/2019	Valve Screwing	Wire Tear off	2
12	12/10/2019	SAW Welding	Chain Broken	2
13	9/11/2019	Hydraulic Press Machine	Hydraulic pressure fault	62
14	19/11/2019	SAW Welding	Circlip broken of roller shaft(Wire Feeding)	2

Table 3.2: Monthly Machine Breakdown Data

Name of Month & Year	Total Available Time (25 days X 8 hours)	Total Breakdown Time (hours)	Number of Breakdown
August, 2019	200	157	6
September, 2019	200	106	4

3.3.2.1 Pareto Chart Analysis:

A Pareto chart is a type of chart that contains both bars and a line graph, where individual values are represented in descending order by bars, and the line represents the cumulative total. The chart is named for the Pareto principle, which, in turn, derives its name from Vilfredo Pareto, a noted Italian economist. The left vertical axis is the frequency of occurrence & the right vertical axis is the cumulative percentage of the total number of occurrences of the particular unit of measure. Because the values are in decreasing order, the cumulative function is a concave function.

Table: 3.3 Criticality analysis (Pareto Chart)

Name of Machine	Machine Breakdown Time (50 days X 8 hours)	Cumulative Numbers	Cumulative Percentage
Hydraulic Press Machine	257	257	95.5%
MIG MAG Welding Line	3	260	96.7%
Valve Screwing	2	262	97.4%
SAW Welding	4	266	98.9%
Heat Treatment Unit	1	267	99.3%
Hydrostatic Test	1	268	99.6%
Trimming & Joggling	1	269	100.0%

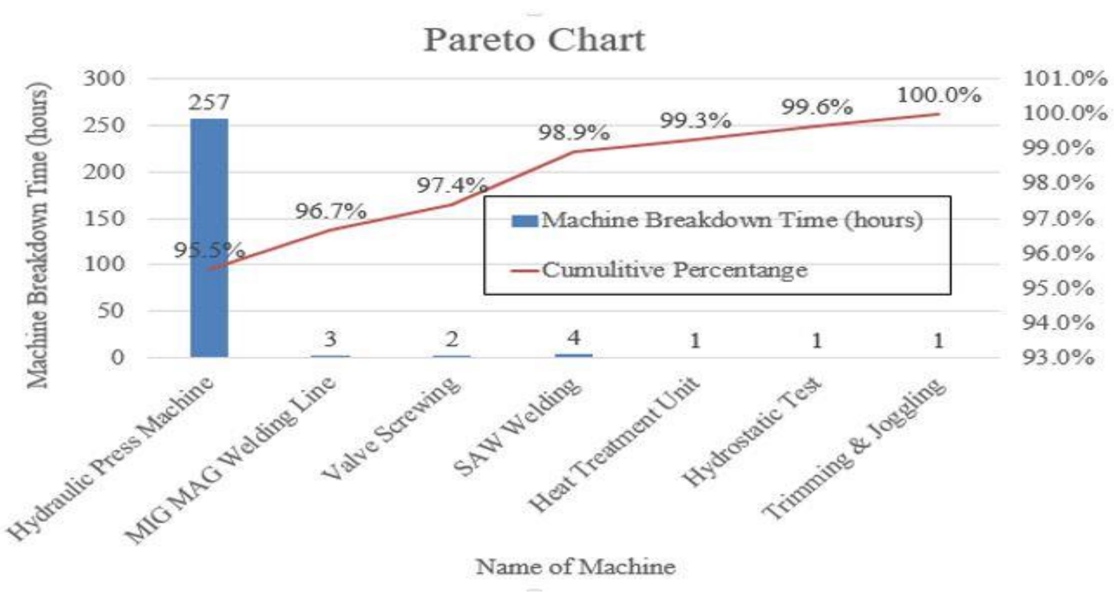

Fig: 3.4 Criticality Analysis (Pareto Chart)

Therefore, from above pareto chart analysis it has been observed that hydraulic press machine is the most critical machine.

3.3.3 Failure Root Cause Analysis for Hydraulic Press Machine

There are different methods developed to carry out this weak point analysis, one of the most well-known being failure root-cause failure analysis (FRCA). This method consists of a series of actions taken to find out why a particular failure or problem exists and to correct those causes. Causes can be classified as physical, human or latent. The physical cause is the reason why the asset failed, the technical explanation on why things broke or failed. The human cause includes the human errors (omission or commission) resulting in physical roots. Finally, the latent cause includes the deficiencies in the management systems that allow the human errors to continue unchecked (flaws in the systems and procedures). Latent failure causes will be our main concern at this point of the process.

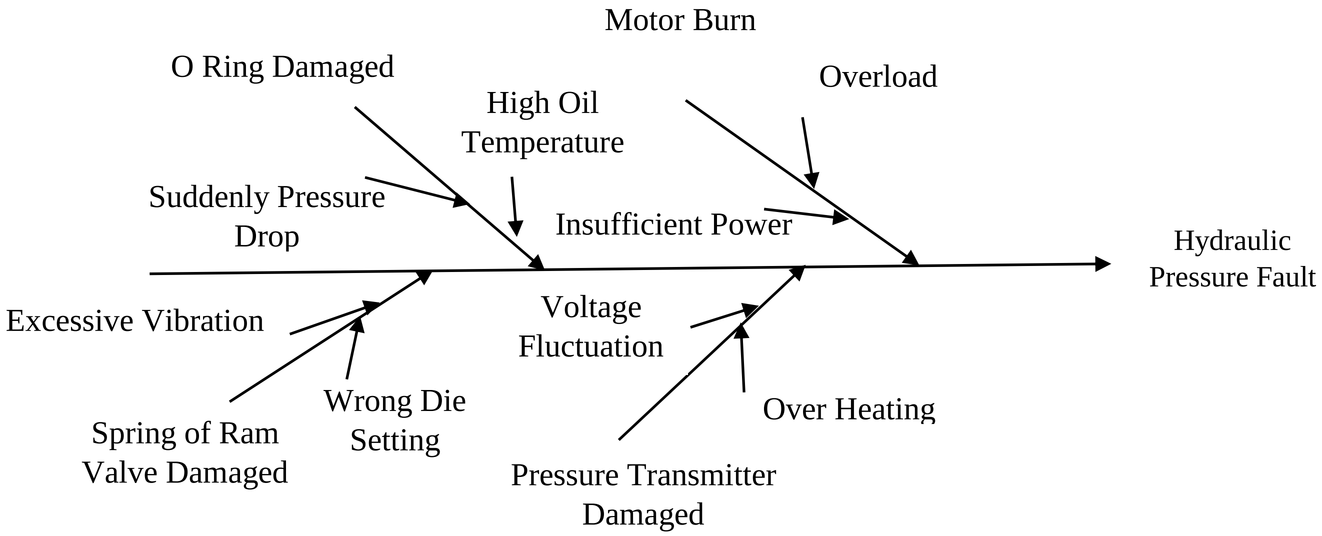

Fig 3.5: Failure root cause analysis for hydraulic press machine (Cause & Effect Diagram)

3.3.4 Five Why's Application for Hydraulic Press Machine

Sakichi Toyoda, the Japanese industrialist, inventor, and founder of Toyota Industries, developed the 5 Whys technique in the 1930s. It became popular in the 1970s, and Toyota still uses it to solve problems today. Toyota has a "go and see" philosophy. This means that its decision making is based on an in-depth understanding of what's actually happening on the shop floor, rather than on what someone in a boardroom thinks might be happening. The 5 Whys technique is true to this tradition and it is most effective when the answers come from people who have hands-on experience of the process or problem in question. The method is remarkably simple: when a problem occurs, you drill down to its root cause by asking "Why?" five times. Then, when a counter-measure becomes apparent, you follow it through to prevent the issue from recurring.

Table 3.4: Five why's application for motor burn, o-ring damaged, spring of ram valve damaged & pressure transmitter damaged.

Problem	Why	Why	Why	Why	Why
Motor Burn	Overload	Valve Partially Blocked	System Contamination Issue	Filter get Blocked	Filter Quality is not monitoring
	Insufficient Power	Internal Wear	Shaft Bearing Broken	Due to Friction	Improper Greasing
O Ring Damaged	High Oil Temperature	Chiller is not working	Chiller line Strainer blocked	Did not flash the chiller line before water filling	Lack of monitoring
	Pressure Drop	Hammering	Sudden Pressure variation in the system	Improper valve setting	
Spring of Ram Valve Damaged	Excessive Vibration	Cavitation	Formation air Bubbles	Pressure Drop	Improper valve setting
	Wrong Die Setting	Die Cushion pressure variation	Cushion plate loose	Lack of Monitoring	
Pressure Transmitter Damaged	Over Heating	Excessive temperature	Chiller line strainer blocked	Did not flash the chiller line before water filling	Lack of monitoring
	Voltage Fluctuations	Load variations	Demand variation	Lack of PFI	

3.3.5 Corrective Counter Measures for Hydraulic Press Machine

Corrective counter measures are action that the team takes to eliminate the root cause of problems & to eliminate the waste.

Corrective counter measures of motor burn:

- Bearing is greased properly during preventive maintenance
- Hydraulic oil filter is cleaned properly during preventive maintenance

Corrective counter measures of O-ring damaged:

- Checked pressure setting and resetting pressure have been done
- Improved chiller line monitoring system from HMI and reduced chiller out temperature range

Corrective counter measures of spring of ram valve damaged:

- Checked pressure setting and resetting pressure has been done
- Improved hydraulic pressure monitoring system from HMI and reduced pressure range

Corrective counter measures of pressure transmitter damaged:

- Improved chiller line monitoring system from HMI and reduced chiller out temperature range
- Improved PFI to reduce the voltage fluctuation at substation.

Table 3.5: Monthly machine breakdown data October and November 2019

Name of Month & Year	Total Available Time (25 days X 8 hours)	Total Breakdown Time (in hours)	Number of Breakdown
October, 2019	200	62	5
November, 2019	200	58	5

3.3.6 Availability for Hydraulic Press Machine

Availability is the total time of utilization of a machine. Availability is the reciprocal of the difference between the total available hours and total breakdown hours to the total available hours.

Availability for the month of August-2019

$$Availability = \frac{Total\ avilable\ hours - Total\ breakdown\ hours}{Total\ available\ hours}\ X\ 100$$

$$Availability = \frac{200 - 157}{200}\ X\ 100$$

Here Availability is 21.5 % for the month of August-2019

Availability for the month of September-2019

$$Availability = \frac{Total\ avilable\ hours - Total\ breakdown\ hours}{Total\ available\ hours}\ X\ 100$$

$$Availability = \frac{200 - 106}{200}\ X\ 100$$

Here Availability is 47 % for the month of September-2019

Availability for the month of October-2019

$$Availability = \frac{Total\ avilable\ hours - Total\ breakdown\ hours}{Total\ available\ hours}\ X\ 100$$

$$Availability = \frac{200 - 62}{200}\ X\ 100$$

Here Availability is 69 % for the month of October-2019

Availability for the month of November-2019

$$Availability = \frac{Total\ avilable\ hours - Total\ breakdown\ hours}{Total\ available\ hours}\ X\ 100$$

$$Availability = \frac{200 - 58}{200}\ X\ 100$$

Here Availability is 71 % for the month of November-2019

3.3.7 Mean time between failures (MTBF) for Hydraulic Press Machine

MTBF is the time between two failures. When failure rate is constant, the mean time between failures is the reciprocal of the constant failure rate or the ratio of the test time to the number of failures.

MTBF for the month of August 2019

$$MTBF = \frac{Total\ available\ hours - Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTBF = \frac{200 - 157}{6}\ in\ hours$$

Here MTBF is 7.16 hours for the month of August 2019

MTBF for the month of September 2019

$$MTBF = \frac{Total\ available\ hours - Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTBF = \frac{200 - 106}{4}\ X\ 100$$

Here MTBF is 23.5 hours for the month of September 2019

MTBF for the month of October 2019

$$MTBF = \frac{Total\ available\ hours - Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTBF = \frac{200 - 62}{5}\ in\ hours$$

Here MTBF is 27.6 hours for the month of October 2019

MTBF for the month of November 2019

$$MTBF = \frac{Total\ available\ hours - Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTBF = \frac{200 - 58}{5}\ in\ hours$$

Here MTBF is 28.4 hours for the month of November 2019

3.3.8 Mean time to repair (MTTR) for Hydraulic Press Machine

"Mean Time to Repair" is the average time that it takes to repair something after a failure.

MTTR for the month of August-2019

$$MTTR = \frac{Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTTR = \frac{157}{6}\ in\ hours$$

Here MTTR is 26.16 hours for the month of August-2019

MTTR for the month of September-2019

$$MTTR = \frac{Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTTR = \frac{106}{4}\ in\ hours$$

Here MTTR is 26.5 hours for the month of September-2019

MTTR for the month of October-2019

$$MTTR = \frac{Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTTR = \frac{62}{5}\ in\ hours$$

Here MTTR is 12.40 hours for the month of October-2019

MTTR for the month of November-2019

$$MTTR = \frac{Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTTR = \frac{58}{5}\ in\ hours$$

Here MTTR is 11.60 hours for the month of November-2019

3.3.9 Machine Availability, MTBF and MTTR for the month of August and September 2019

Table 3.6: Monthly data of Availability, MTBF and MTTR

Sl No	Month	Availability (%)	MTBF (in hours)	MTTR(in hours)
1	August, 2019	21.5	7.16	26.16
2	September, 2019	47	23.5	26.5

3.3.10 Machine Availability, MTBF and MTTR for the month of October and November 2019

Table 3.7: Monthly data of Availability, MTBF and MTTR

Sl No	Month	Availability (%)	MTBF (in hours)	MTTR(in hours)
1	October, 2019	69	27.6	12.40
2	November, 2019	71	28.4	11.60

3.4.1 Failure Root Cause Analysis for Trimming and Joggling Machine

There is another machine in forming line like hydraulic press and that is trimming and joggling machine. Trimming and joggling machine is operated by hydraulic principle and purpose of this machine is to reform the upper half and lower half for better welding. There are different methods developed to carry out this weak point analysis, one of the most well-known being failure root-cause failure analysis (FRCA). This method consists of a series of actions taken to find out why a particular failure or problem exists and to correct those causes. Causes can be classified as physical, human or latent. The physical cause is the reason why the asset failed, the technical explanation on why things broke or failed. The human cause includes the human errors (omission or commission) resulting in physical roots. Finally, the latent cause includes the deficiencies in the management systems that allow the human errors to continue unchecked (flaws in the systems and procedures). Latent failure causes will be our main concern at this point of the process.

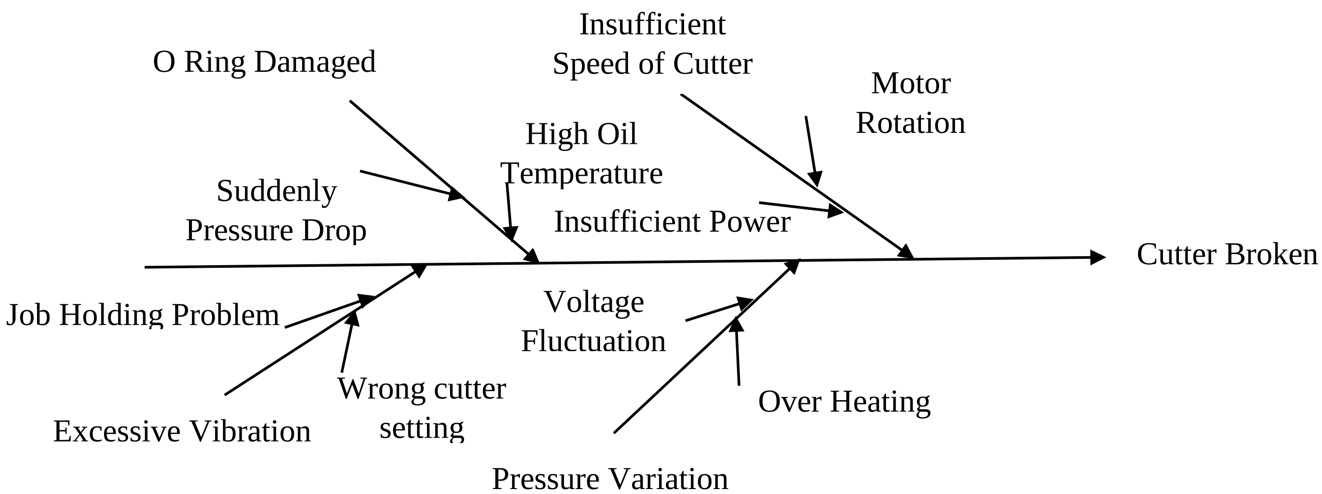

Fig 3.6: Failure root cause analysis for trimming and joggling machine (Cause & Effect Diagram)

3.4.2 Five Why's Application for Trimming and Joggling Machine

Sakichi Toyoda, the Japanese industrialist, inventor, and founder of Toyota Industries, developed the 5 Whys technique in the 1930s. It became popular in the 1970s, and Toyota still uses it to solve problems today. Toyota has a "go and see" philosophy. This means that its decision making is based on an in-depth understanding of what's actually happening on the shop floor, rather than on what someone in a boardroom thinks might be happening. The 5 Whys technique is true to this tradition and it is most effective when the answers come from people who have hands-on experience of the process or problem in question. The method is remarkably simple: when a problem occurs, you drill down to its root cause by asking "Why?" five times. Then, when a counter-measure becomes apparent, you follow it through to prevent the issue from recurring.

Table 3.8: Five why's application for insufficient speed of cutter, o-ring damaged, excessive vibration and pressure variation.

Problem	Why?	Why?	Why?	Why?	Why?
Insufficient Speed of Cutter	Motor Rotation Problem	Insufficient Flow of Hydraulic Oil	System Contamination Issue	Filter get Blocked	Filter Quality is not monitored
	Insufficient Power	Internal Wear	Shaft Bearing Broken	Due to Friction	Improper Greasing
O Ring Damaged	High Oil Temperature	Chiller is not working	Chiller line Strainer blocked	Did not flash the chiller line before water filling	Lack of monitoring
	Pressure Drop	Hammering	Sudden Pressure variation in the system	Improper valve setting	
Excessive Vibration	Job Holding Problem	Cavitation	Formation air Bubbles	Pressure Drop	Improper valve setting
	Wrong Cutter Setting	Cutter Holding Fixture Pressure Variation	Fixture Plate Loose	Lack of Monitoring	
Pressure Variation	Over Heating	Excessive Temperature	Chiller line strainer blocked	Did not flash the chiller line before water filling	Lack of monitoring
	Voltage Fluctuations	Load Variations	Demand Variations	Lack of PFI	

3.4.3 Corrective Counter Measures for Trimming and Joggling Machine

Corrective counter measures are action that the team takes to eliminate the root cause of problems and to eliminate the waste.

Corrective counter measures of insufficient speed of cutter:

- Bearing is greased properly during preventive maintenance.
- Hydraulic oil filter is cleaned properly during preventive maintenance.

Corrective counter measures of O-ring damaged:

- Checked pressure setting and resetting pressure have been done.
- Improved chiller line monitoring system from HMI and reduced chiller out temperature range.

Corrective counter measures of excessive vibration:

- Checked pressure setting and resetting pressure has been done.
- Improved hydraulic pressure monitoring system from HMI and reduced pressure range.

Corrective counter measures of pressure variation:

- Improved chiller line monitoring system from HMI and reduced chiller out temperature range
- Improved PFI to reduce the voltage fluctuation at substation.

Table 3.9: Monthly machine breakdown data September and October 2019

Name of Month and Year	Total Available Time (25 days X 8 hours)	Total Breakdown Time (in hours)	Number of Breakdown
October, 2019	200	86	8
November, 2019	200	74	7

Table 3.10: Monthly machine breakdown data October and November 2019

Name of Month and Year	Total Available Time (25 days X 8 hours)	Total Breakdown Time (in hours)	Number of Breakdown
October, 2019	200	52	5
November, 2019	200	48	5

3.4.4 Availability for Trimming and Joggling Machine

Availability is the total time of utilization of a machine. Availability is the reciprocal of the difference between the total available hours and total breakdown hours to the total available hours.

Availability for the month of August-2019

$$Availability = \frac{Total\ avilable\ hours - Total\ breakdown\ hours}{Total\ available\ hours}\ X\ 100$$

$$Availability = \frac{200 - 86}{200}\ X\ 100$$

Here Availability is 57 % for the month of August-2019

Availability for the month of September-2019

$$Availability = \frac{Total\ avilable\ hours - Total\ breakdown\ hours}{Total\ available\ hours}\ X\ 100$$

$$Availability = \frac{200 - 74}{200}\ X\ 100$$

Here Availability is 63 % for the month of September-2019

Availability for the month of October-2019

$$Availability = \frac{Total\ avilable\ hours - Total\ breakdown\ hours}{Total\ available\ hours}\ X\ 100$$

$$Availability = \frac{200 - 52}{200}\ X\ 100$$

Here Availability is 74 % for the month of October-2019

Availability for the month of November-2019

$$Availability = \frac{Total\ avilable\ hours - Total\ breakdown\ hours}{Total\ available\ hours}\ X\ 100$$

$$Availability = \frac{200 - 48}{200}\ X\ 100$$

Here Availability is 76 % for the month of November-2019

3.4.5 Mean time between failures (MTBF) for Trimming and Joggling Machine

MTBF is the time between two failures. When failure rate is constant, the mean time between failures is the reciprocal of the constant failure rate or the ratio of the test time to the number of failures.

MTBF for the month of August 2019

$$MTBF = \frac{Total\ available\ hours - Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTBF = \frac{200 - 86}{8}\ in\ hours$$

Here MTBF is 14.25 hours for the month of August 2019

MTBF for the month of September 2019

$$MTBF = \frac{Total\ available\ hours - Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTBF = \frac{200 - 74}{7}\ X\ 100$$

Here MTBF is 18.00 hours for the month of September 2019

MTBF for the month of October 2019

$$MTBF = \frac{Total\ available\ hours - Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTBF = \frac{200 - 52}{5}\ in\ hours$$

Here MTBF is 29.60 hours for the month of October 2019

MTBF for the month of November 2019

$$MTBF = \frac{Total\ available\ hours - Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTBF = \frac{200 - 48}{5}\ in\ hours$$

Here MTBF is 30.50 hours for the month of November 2019

3.4.6 Mean time to repair (MTTR) for Trimming and Joggling Machine

"Mean Time to Repair" is the average time that it takes to repair something after a failure.

MTTR for the month of August-2019

$$MTTR = \frac{Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTTR = \frac{86}{8}\ in\ hours$$

Here MTTR is 10.75 hours for the month of August-2019

MTTR for the month of September-2019

$$MTTR = \frac{Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTTR = \frac{74}{7}\ in\ hours$$

Here MTTR is 10.57 hours for the month of September-2019

MTTR for the month of October-2019

$$MTTR = \frac{Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTTR = \frac{52}{5}\ in\ hours$$

Here MTTR is 10.40 hours for the month of October-2019

MTTR for the month of November-2019

$$MTTR = \frac{Total\ breakdown\ hours}{Number\ of\ breakdowns}\ in\ hours$$

$$MTTR = \frac{48}{5}\ in\ hours$$

Here MTTR is 9.60 hours for the month of November-2019

3.4.7 Machine Availability, MTBF and MTTR for the month of August and September 2019

Table 3.11: Monthly data of Availability, MTBF and MTTR

Sl No	Month	Availability (%)	MTBF (in hours)	MTTR(in hours)
1	August, 2019	57	14.25	10.75
2	September, 2019	63	18.00	10.57

3.4.8 Machine Availability, MTBF and MTTR for the month of October and November 2019

Table 3.12: Monthly data of Availability, MTBF and MTTR

Sl No	Month	Availability (%)	MTBF (in Hours)	MTTR(in Hours)
1	October, 2019	74	29.60	10.40
2	November, 2019	76	30.50	9.60

3.5 Reliability Centered Maintenance (RCM)

Reliability centered maintenance (RCM) is a systematic process used to determine what has to be accomplished to ensure that any physical facility is able to continuously meet its designed functions in its current operating context. RCM leads to a maintenance program that focuses preventive maintenance (PM) on specific failure modes likely to occur.

3.5.1 RCM Goals and Principles

Some of the important goals of RCM are as follows:

• To develop design-associated priorities that can facilitate PM.
• To gather information useful for improving the design of items with proven unsatisfactory, inherent reliability.
• To develop PM-related tasks that can reinstate reliability and safety to their inherent levels in the event of equipment or system deterioration.
• To achieve the above goals when the total cost is minimal.

Principles of RCM are discussed below:

• RCM is system/equipment focused. RCM is concerned more with maintaining system function as opposed to maintaining individual component function.

• Safety and economics drive RCM. Safety is of paramount importance, thus it must be ensured at any cost and then cost effectiveness becomes the criterion.

• RCM is function-oriented. RCM plays an instrumental role in preserving system/equipment function, not just operability for its own sake.

• Design limitations are acknowledged by RCM. The goal of RCM is to maintain the inherent reliability of the equipment/system design and at the same time recognize that changes in inherent reliability can only be made through design rather than maintenance. Maintenance at the best of times can only achieve and maintain a level of designed reliability.

• RCM is reliability-centered. RCM is not overly concerned with simple failure rate, but it places importance on the relationship between operating age and failures experienced. RCM treats failure statistics in an actuarial fashion.

• An unsatisfactory condition is defined as a failure by RCM. A failure could be either a loss of acceptable quality or a loss of function.

• RCM is a living system. RCM collects information from the results achieved and feeds it back to improve design and future maintenance.

• Three types of maintenance tasks along with run-to-failure are acknowledged by RCM. These tasks are defined as failure-finding, time-directed, and condition-directed. The purpose of the failure-finding tasks is to discover hidden functions that have failed without providing any indication of pending failure. Time-directed tasks are scheduled as considered necessary. Condition-directed tasks are conducted as the conditions indicate for their need. Run-to-failure is a conscious decision in RCM.

• RCM tasks must be effective. The tasks must be cost-effective and technically sound.

• RCM uses a logic tree to screen maintenance tasks. This provides consistency in the maintenance of all types of equipment.

• RCM tasks must be applicable. Tasks must reduce the occurrence of failures or ameliorate secondary damage resulting from failure.

The basic RCM process is composed of the following steps:

1. Identify important items with respect to maintenance. Usually, maintenance important items are identified using techniques such as failure, mode, effects, and criticality analysis (FMECA) and fault tree analysis (FTA).

2. Obtain appropriate failure data. In determining occurrence probabilities and assessing criticality, the availability of data on part failure rate, operator error probability, and inspection efficiency is essential. These types of data come from field experience, generic failure databanks, etc.

3. Develop fault tree analysis data. Probabilities of occurrence of fault events basic, intermediate, and top events—are calculated as per combinatorial properties of the logic elements in the fault tree.

4. Apply decision logic to critical failure modes. The decision logic is designed to lead, by asking standard assessment questions, to the most desirable preventive maintenance task combinations. The same logic is applied to each crucial mode of failure of each maintenance-important item.

5. Classify maintenance requirements. Maintenance requirements are categorized into three classifications: on-condition maintenance requirements, condition-monitoring maintenance requirements, and hard-time maintenance requirements.

6. Implement RCM decisions. Task frequencies and intervals are set/enacted as part of the overall maintenance strategy or plan.

7. Apply sustaining-engineering on the basis of field experience. Once the system/equipment start operating, the real-life data begin to accumulate. At that time, one of the most urgent steps is to re-evaluate all RCM-associated default decisions.

3.5.2 RCM Components:

There are four major components of RCM: reactive maintenance, preventive maintenance, predictive testing and inspection, and proactive maintenance. Each component is described below.

3.5.2.1 Reactive Maintenance

This type of maintenance is also known as breakdown, fix-when-fail, run-to-failure, or repair maintenance. When using this maintenance approach, equipment repair, maintenance, or replacement takes place only when deterioration in the condition of an item/equipment results in a functional failure. In this type of maintenance, it is assumed there is an equally likely chance for the occurrence of a failure in any part, component, or system. When reactive maintenance is practiced solely, a high replacement of part inventories, poor use of maintenance effort, and high percentage of unplanned maintenance activities are typical. Furthermore, an entirely reactive maintenance program overlooks opportunities to influence equipment/item survivability. Reactive maintenance can be practiced effectively only if it is carried out as a conscious decision, based on the conclusions of an RCM analysis that compares risk and cost of failure with the cost of maintenance needed to mitigate that risk and failure cost.

3.5.2.2 Preventive Maintenance

Preventive maintenance (PM), also called time-driven or interval-based maintenance, is performed without regard to equipment condition. It consists of periodically scheduled inspection, parts replacement, repair of components/items, adjustments, calibration, lubrication, and cleaning. PM schedules regular inspection and maintenance at set intervals to reduce failures for susceptible equipment. It is important to note that, depending on the predefined intervals, practicing PM can lead to a significant increase in inspections and routine maintenance. On the other hand, it can help reduce the frequency and severity of unplanned failures. Preventive maintenance can be costly and ineffective if it is the only type of maintenance practiced.

3.5.2.3 Predictive Testing and Inspection

Predictive testing and inspections (PTI) is sometimes called condition monitoring or predictive maintenance. To assess item/equipment condition, it uses performance data, nonintrusive testing techniques, and visual inspection. PTI replaces arbitrarily timed maintenance tasks with maintenance that is performed as warranted by the item/equipment condition. Analysis of item/equipment condition-monitoring data on a continuous basis is useful for planning and scheduling maintenance/repair in advance of catastrophic or functional failure. The collected PTI data are used to determine the equipment condition and to highlight the precursors of failure in several ways, including pattern recognition, trend analysis, correlation of multiple technologies, data comparison, statistical process analysis, and tests against limits and ranges. PTI should not be the only type of maintenance practiced, because it does not lend itself to all types of items/equipment or possible modes of failure.

3.5.2.4 Proactive Maintenance

This type of maintenance helps improve maintenance through actions such as better design, workmanship, installation, scheduling, and maintenance procedures. The characteristics of proactive maintenance include practicing a continuous process of improvement, using feedback and communications to ensure that changes in design/procedures are efficiently made available to item designers/management, ensuring that nothing affecting maintenance occurs in total isolation, with the ultimate goal of correcting the concerned equipment forever, optimizing and tailoring maintenance methods and technologies to each application. It performs root-cause failure analysis and predictive analysis to enhance maintenance effectiveness, conducts periodic evaluation of the technical content and performance interval of maintenance tasks, integrates functions with support maintenance into maintenance program planning, and uses a life cycle view of maintenance and supporting functions.

Based on above discussion chapter 2 & chapter 3 here is given preventive maintenance schedule for hydraulic press machine and trimming and joggling machine.

3.5.3 Preventive maintenance schedule

Preventive maintenance (PM) is an important component of a maintenance activity. Within a maintenance organization, it usually accounts for a major proportion of the total maintenance effort. PM may be described as the care and servicing by individuals involved with maintenance to keep equipment/facilities in satisfactory operational state by providing for systematic inspection, detection, and correction of incipient failures either prior to their occurrence or prior to their development into major failure. Some of the main objectives of PM are to: enhance capital equipment productive life, reduce critical equipment breakdowns, allow better planning and scheduling of needed maintenance work, minimize production losses due to equipment failures, and promote health and safety of maintenance personnel.

3.5.3.1 Preventive Maintenance Elements

There are seven elements of PM. Each element is discussed below.

1. Inspection: Periodically inspecting materials/items to determine their serviceability by comparing their physical, electrical, mechanical, etc., characteristics (as applicable) to expected standards.

2. Servicing: Cleaning, lubricating, charging, preservation, etc., of items/ materials periodically to prevent the occurrence of incipient failures.

3. Calibration: Periodically determining the value of characteristics of an item by comparison to a standard; it consists of the comparison of two instruments, one of which is certified standard with known accuracy, to detect and adjust any discrepancy in the accuracy of the material/parameter being compared to the established standard value

4. Testing: Periodically testing or checking out to determine serviceability and detect electrical/mechanical-related degradation.

5. Alignment: Making changes to an item's specified variable elements for the purpose of achieving optimum performance.

6. Adjustment: Periodically adjusting specified variable elements of material for the purpose of achieving the optimum system performance.

7. Installation: Periodic replacement of limited-life items or the items experiencing time cycle or wear degradation, to maintain the specified system tolerance.

3.5.3.2 Important Steps for Establishing a PM Program

To develop an effective PM program, the availability of a number of items is necessary. Some of those items include accurate historical records of equipment, manufacturer's recommendations, skilled personnel, past data from similar equipment, service manuals, unique identification of all equipment, appropriate test instruments and tools, management support and user cooperation, failure information by problem/cause/action, consumables and replaceable components/parts, and clearly written instructions with a checklist.

There are a six number of steps involved in developing a PM program.. Each step is discussed below.

1. Identify and choose the areas. Identify and selection of one or two important areas to concentrate the initial PM effort. These areas should be crucial to the success of overall plant operations and may be experiencing a high degree of maintenance actions. The main objective of this step is to obtain immediate results in highly visible areas, as well as to win concerned management support.

2. Identify the PM needs. Define the PM requirements. Then, establish a schedule of two types of tasks: daily PM inspections and periodic PM assignments. The daily PM inspections could be conducted by either maintenance or production personnel. An example of a daily PM inspection is to check the wastewater settle able solids concentration. Periodic PM assignments usually are performed by the maintenance workers. Examples of such assignments are replacing throwaway filters, replacing drive belts, and cleaning steam traps and permanent filters.

3. Establish assignment frequency. Establish the frequency of the assignments. This involves reviewing the equipment condition and records. Normally, the basis for establishing the frequency is the experience of those familiar with the equipment and the recommendations of vendors and engineering. It must be remembered that vendor recommendations are generally based on the typical usage of items under consideration.

4. Prepare the PM assignments. Daily and periodic assignments are identified and described in detail, then submitted for approval.

5. Schedule the PM assignments on annual basis. The defined PM assignments are scheduled on the basis of a twelve-month period.

6. Expand the PM program as necessary. After the implementation of all PM daily inspections and periodic assignments in the initially selected areas, the PM can be expanded to other areas. Experience gained from the pilot PM projects is instrumental to expanding the program.

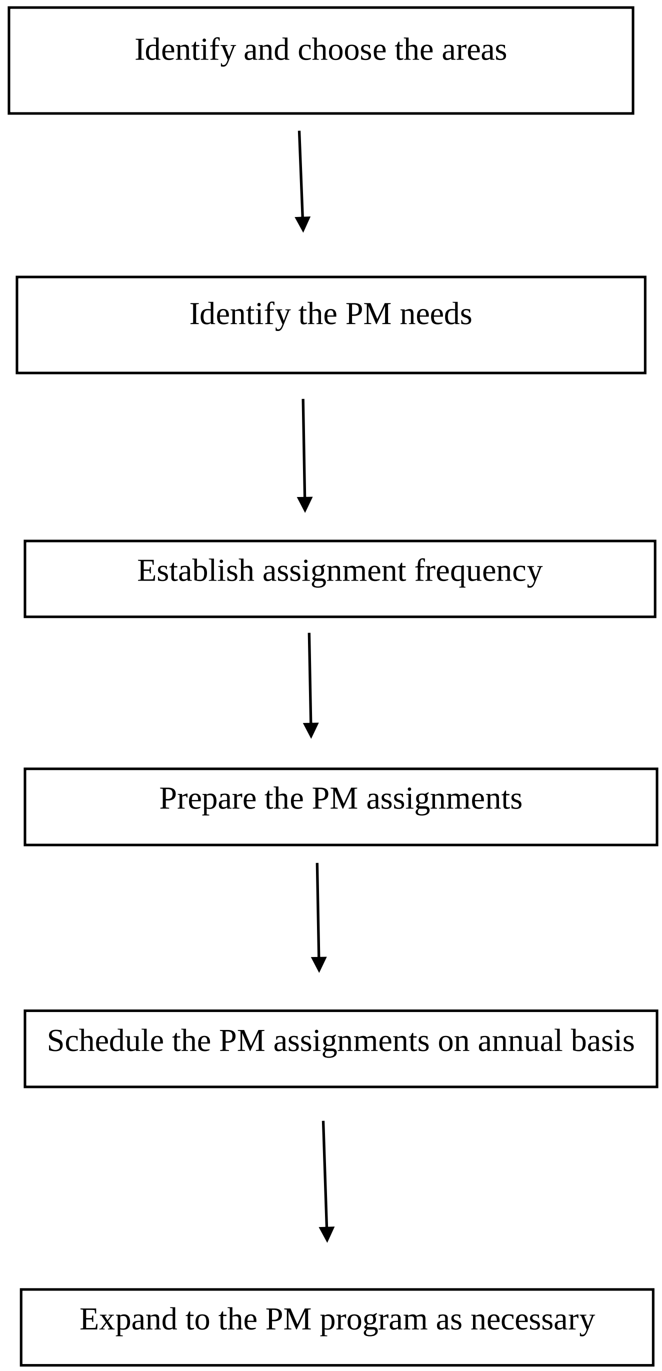

Fig: 3.7 Six steps for developing a preventive maintenance program

Table 3.13: Preventive maintenance schedule for hydraulic press machine

Sl No	Tested Object	Test Type	Hours after cold start	Daily	Weekly	Once in every Months	Yearly
1	Oil Tank	Level and Impermeability	10		**X**		
		0,5 Ltr oil Sampling for Quality Test	100				
2	Hydraulic Oil	Cleaning and Replacing	100				**X** or after 2.000 hours
3	Hydraulic Oil Filters	Contamination Indicator Control	50			**X** 3 Months	
		Filter Replacement	500			**X** 6 Months	
4	Air Filters	Cleaning	500			**X** 3 Months	
		Filter Replacement					**X**
5	Pump	Pressure, Noise and Vibration Control	10			**X** 3 Months	
6	Pump -Motor Couplings	Coupling element replacement					**X**
7	Emergency Stop Buttons	Function		**X**			
8	Limit Switches	Function and Precision	100			**X** 6 Months	
9	Bolted Connections	Loosening	10		**X**		
10	Ram Guides	Setting				**X** 3 Months	
11	Safety Units	Function	10	**X**			
12	Guide Lubrication System	Function				**X** 1 Month	
13	Sensor and Switch Control	Function			**X**		
		Cleaning			**X**		
14	Operator Panel	Exterior Cleaning		**X**			
15	Main Electric Cabinet	Exterior Cleaning			**X**		
		Interior Cleaning				**X** 1 Month	
		Air Conditioner			**X**		
16	Electric Motors	Mechanical Control				**X** 1 Month	
		Electric Cable Connections Control					**X**
17	Cable Duct Cleaning	General Cleaning			**X**		

Table 3.14: Preventive maintenance schedule for trimming and joggling machine

Sl No	Tested Object	Test Type	Daily	Weekly	Once in every … Months	Yearly
1	Dirty Surfaces	Cleaning	**X**			
	Operator Panel	Exterior Cleaning	**X**			
2	Emergency Stop Buttons and Operator Panel	Function	**X**			
		Exterior Cleaning	**X**			
3	Bolted Connections	Loosening		**X**		
4	Sensor and Switch Control	Function		**X**		
		Cleaning		**X**		
5	Exchanger with Water Cooler	Function			**X** 1 Month	
6	Main Electric Cabinet	Exterior Cleaning		**X**		
		Interior Cleaning			**X**	
		Air Conditioner		**X**		
7	Electric Motors	Mechanical Control			**X**	
		Electric Cable Connections Control				**X**
8	Guide Lubrication System	Function			**X 1** Month	
9	Cable Duct Cleaning	General Cleaning		**X**		
10	Oil Tank	Level and Impermeability		**X**		
		Sampling for Quality Test			**X 6** Months	
11	Hydraulic Oil	Cleaning and Replacing				**X** or after 3000 hours
12	Pump	Pressure, Noise and Vibration Control			**X 6** Months	
13	Pump - Motor Couplings	Coupling element replacement				**X**
14	Hydraulic Oil Filters	Contamination Indicator Control			**X 1** Month	
		Filter Replacement			**X 6** Months	

Chapter-FOUR

Development of Optimized Maintenance Management Framework

4.1 Introduction

This chapter discusses about the development of optimized maintenance management framework. The optimized maintenance management framework has been developed as per practical result. Initially collected machine breakdown data and find out critical machine by criticality analysis. Mostly used 5 why-why analysis and cause and effect diagram also applied to identify the root cause of the critical machine. Finally developed preventive maintenance schedule and applied corrective counter measures for the specific problem to reduce the breakdown time as well as to increase the machine availability.

4.2 Development of Optimized Maintenance Management Framework

The optimized maintenance management framework has been developed for a LPG cylinder manufacturing industry with the goal of developing total company maintenance for all different plants and all different installations. The maintenance management framework has six steps.

Step 1. Identification of objectives and resources: the first objective of maintenance is to secure reliability and availability, to reduce cost, protect their commercial margins, to meet the severe laws of safety and environment and to enhance productivity. In addition to the objectives requirements to meet the objective such as material, money, people and know-how needs to be identified.

Step 2. Identification of most critical machine: Depending on the objectives and the situation, weight factors can be used to underline the relative importance of each objective concerning bottlenecks, loss of production, etc. In most of the cases, quite a few criteria have to be considered. Pareto chart analysis was very helpful for this step. In addition, the process layout will influence the selection of a system as most important or not.

Step 3. Identification of the root cause of the problem: here the most critical component with in the selected most important system identified. A simplified FRCA used in table form, economic and technical aspects and knowledge in human’s head considered. The reason for this approach is that technical systems deal with layout, flow and equipment.

Their performances visualized in terms of breakdowns, set-up losses, minor stoppages and quality defects. The intent of FRCA analysis is to identify components, which failure consequences could have an impact or jeopardize the systems performance (unplanned production stops), and/or cause dangerous situations for the personnel or the environment within the selected most important system.

Most problems are due to disruptions between production and the different maintenance specialists and could be eliminated by increased collaboration between the different teams and by gathering all available tacit and explicit knowledge. The advantage of this method is that it is fast and easy to use, while subjectivity is limited through the predefined borders.

Step 4. Improvement of preventive maintenance schedule: The idea of Preventive Maintenance is to prevent equipment failure, avoid breakdown costs and reduce downtime. In order to avoid corrective maintenance actions, preventive maintenance makes sure that maintenance is performed before failure occurs. Preventive maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item.

Step 5. Performance measurement and continuous improvement: two reasons stated for limited maintenance performance measurement. The first is maintenance performance reporting is difficult and the other reason is maintenance is closely related to other activities. Most of maintenance performance indicators are ratios measuring effectiveness, efficiency and productivity. Optimized maintenance management framework has five modules.

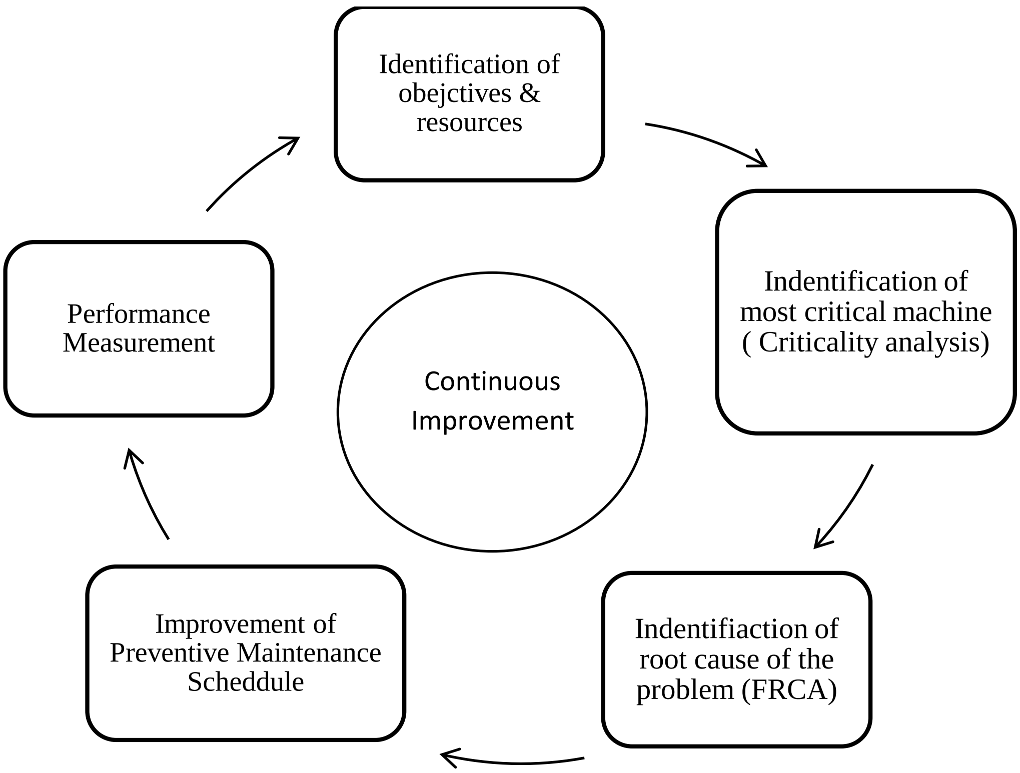

Figure 4.1: Optimized maintenance management framework.

4.3 Concluding Remarks

From the above discussion, it can be easily said that optimized maintenance management framework has been developed as per practical data and regular factory practices. Also applied the maintenance management framework in LPG cylinder manufacturing industry to increase the machine availability time as well as to increase the productivity.

Chapter-FIVE
Conclusions, Contributions and Recommendations

This chapter summarizes the conclusion of the experiment (section 5.1) and discusses research contributions of this work (section 5.2). Recommendations are discussed in (section 5.3).

5.1 Conclusions

The optimized maintenance management framework has been develop for LPG cylinder manufacturing industry & it has five steps. Those steps include identify objectives; securing resources; priorities high impact equipment; identify most critical components; improvement of preventive maintenance schedule; and decide on an appropriate maintenance strategy for selected critical components. The process measurable such as Availability, MTBF, and MTTR are calculated before and after the implementation of counter measures. Continuous monitoring of processes are done after the implementation of counter measures. After developing optimized maintenance management framework, machine breakdown time was optimized. Consequently, the production loss time and LPG cylinder production cost were reduced.

5.2 Research Contributions

- Developed optimized maintenance management framework for LPG cylinder manufacturing industry
- Improved preventive maintenance schedule for LPG cylinder manufacturing industry.
- Implemented corrective counter measures for hydraulic press and trimming and joggling machine.
- The availability of hydraulic press machine is increased from 21.5 % to 71 %.
- The MTBF of hydraulic press machine is increased from 7.16 hours to 28.40 hours.
- The MTTR of hydraulic press machine is decreased from 26.16 hours to 11.60 hours.
- The availability of trimming and joggling machine is increased from 57 % to 76 %.
- The MTBF of trimming and joggling machine is increased from 14.25 hours to 30.50 hours.
- The MTTR of trimming and joggling machine is decreased from 10.75 hours to 9.60 hours.

5.3 Recommendations

- Working safety issue has not considered in this studies. Therefore, it may be considered in future study.
- Optimized maintenance management framework can be useful for any kinds of metal forming industries.

Chapter-SIX
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TO WHOM IT MAY CONCERN

Energypac Power Generation Ltd. (EPGL) was incorporated as private limited company on July 15, 1995 vides registration number C-28822 (103)/95 under the Companies Act 1994. Subsequently, the company was converted to a public limited company on December 27, 2011. Energypac has become one of the leading Power Engineering Companies in Bangladesh. Currently, it is emerging as a first choice global supplier of electrical equipment's. The company supports the business of its customers by providing them with complete solutions. While creating better and environmentally compatible technologies, Energypac focuses on meeting customer's demand with appropriate products and solutions as well as services. It is an ISO 9001: 2008 certified organization.

"Energy works wonders" is **EPGL's** motto. Energypac Power Generation Limited is engaged in diversified business including trading of standby and base load generators, JAC brand automobiles, John Deere brand agro machineries equipment, JCB brand construction machineries and material handling equipment and operation of CNG station along with aftermarket service. The company is also engaged in EPC Contracts (Engineering, Procurement and Construction), operation and installation of CNG refueling station and conversion kits and providing installation and maintenance services to power plants. EPGL has established a plant to assemble gas and diesel based generators. EPGL has achieved a new milestone this year in its business arena by adding Steelpac brand to provide designing, manufacturing and erecting of pre-engineered steel buildings, aiming to provide complete steel constructions to industrial, commercial and residential steel buildings. In addition of that, EPGL has successfully entered in LPG market branding as G-GAS. The LPG bottling & distribution plant is located near Mongla sea port.

This is to certify that Md Shamsuzzoha Sarker is an employee of Energypac Power Generation Limited & has been employed since January 10, 2019. His current designation is Assistant Manager (Maintenance).He is doing research on Optimization of maintenance management framework of LPG cylinder manufacturing. The company does not have any objection on his research work for educational purpose.

This certificate is issued on his request.

Your's Faithfully,

Mizan-Ur-Rahman Chowdhury
Head of Admin (Plant)
Energypac Power Generation Limited (G Gas LPG)

AGM, Admin
G GAS LPG PLANT