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Enhancing Overall Equipment Effectiveness in Battery Industries through Total Productive Maintenance

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***Abstract*:-- :- Frequent machine breakdowns, low plant availability, increased rejection are a great threat to increase operating cost and lower productivity. The objective of the work is to enhance the overall equipment effectiveness (OEE) in battery industry through the implementation of total productive maintenance (TPM). The company has to suffer due to lower availability of machines as a result of breakdowns. Comparison of OEE between before and after implementation of TPM can provide the much needed force to improve the maintenance policy.**

Index Terms- Total Productive Maintenance, Availability, Performance, Quality, Overall Equipment Effectiveness

1. INTRODUCTION

Effectiveness of equipment plays a major role in modern manufacturing industries to achieve their goals. Total productive maintenance (TPM) is a methodology to increase the availability of the existing equipment hence it reduces the further capital investment. The TPM results in maximum effectiveness of equipment, tidier, and clean work place. Maintenance has been largely considered as a support function which is none productive since it does not generate cash directly. However for industry to produce goods of the right quality and quantity for the customers and be able to deliver them at the right time its plant or equipment must operate efficiently and accurately. For every manufacturing industry, the objective is to produce goods at a profit and this is only achieved by using an effective maintenance system that helps maximize availability by minimizing machine downtime due to unwarranted stoppages. Without an effective and economically viable maintenance system, equipment reliability suffers, and the plant pays the price with poor availability and increased downtime. All these mentioned poor key performance indicators could be a result of poor machine condition and sometimes low employee morale. Low plant availability and overtime costs will negatively affect an industry's operational efficiency. Plant Engineers must therefore design an effective maintenance system for the plant and its equipment. The aim of this paper is to measure the Overall Equipment Effectiveness (OEE) of the existing plant and there by develop a maintenance policy to enhance the OEE.

II. IMPLEMENTATION OF TPM

Implementation of TPM is based on systematic implementation of its pillars. The pillars of TPM are shown in below figure. Many companies struggle today to implement TPM due to two main reasons. First is having insufficient knowledge and skills especially in understanding the linkages between the pillar activities in TPM. The second reason is that TPM requires time, resources and efforts than most of these companies believe they can afford. 5S forms the base and is the starting point for TPM implementation. The TPM pillars are explained below.

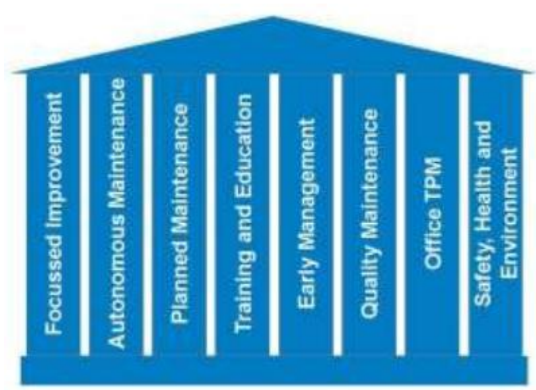

Figure 1: Eight Pillars of TPM

5S CONCEPT:

TPM starts with 5S. It is a systematic process of housekeeping to achieve a serene environment in the work

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place involving the employees with a commitment to sincerely implement and practice housekeeping. Problems cannot be clearly seen when the work place is unorganized. Cleaning and organizing the workplace helps the team to uncover problems. Making problems visible is the first step of improvement. 5S is a foundation program before the implementation of TPM. 5S is the name of a workplace organization method that uses a list of five Japanese words: seiri, seiton, seiso, seiketsu, and shitsuke. There are five primary 5S phases: sorting, set in order, systematic cleaning, standardizing, and sustaining. Refer to the Figure 2 for 5S meaning.

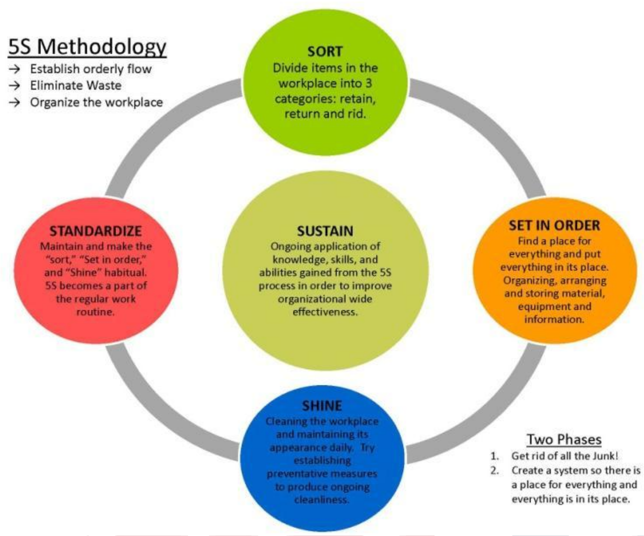

Figure2: 5's Meanings

PILLAR 1: FOCUSED IMPROVEMENT:

Focused improvement includes all activities that maximize the overall effectiveness of equipment, processes, and plants through uncompromising elimination of losses* and improvement of performance. The objective of Focused Improvement is for equipment to perform as well every day as it does on its best day. The better our machines run, the more productive our shop floor, and the more successful our business. The driving concept behind Focused Improvement is Zero Losses. Maximizing equipment effectiveness requires the complete elimination of failures, defects, and other negative phenomena – in other words, the wastes and losses incurred in equipment operation. (Nakajima 1988). Overall Equipment Effectiveness (OEE) is the key metric of Focused Improvement. Focused Improvement is characterized by a drive for Zero Losses, meaning a continuous improvement effort to eliminate any effectiveness loss. Equipment losses may be either chronic (the recurring gap between the equipment's actual effectiveness and its optimal value) or sporadic (the sudden or unusual variation or increase in efficiency loss beyond the typical and expected range), (Tajiri and Gotoh 1992).

PILLAR2. AUTONOMOUS MAINTENANCE:

Autonomous Maintenance follows a structured approach to increase the skill levels of personnel so that they can understand, manage and improve their equipment and processes. The goal is to change operators from being reactive to working in a more proactive way, to achieve optimal conditions that eliminate minor equipment stops as well as reducing defects and breakdowns. The Autonomous Maintenance pillar activity is broken down into three phases and is owned by the team who use the equipment on a daily basis.

The first phase establishes and maintains basic equipment conditions through restoration and eliminating causes of forced deterioration and sources of contamination. Standards are introduced for cleaning, inspection, tightening and lubrication to ensure the conditions are sustained.

The second phase increases the capabilities of the team by training them in the detailed operating principles of the equipment and then improving the standard basic condition.

During the third phase, the operators take total ownership of the equipment as self-directed teams, continuously improving equipment condition and performance to further reduce losses.

PILLAR 3: PLANNED MAINTENANCE:

Planned Maintenance aims to achieve zero breakdowns. It follows a structured approach to establish a management system that extends the equipment reliability at optimum cost.

It is aimed to have trouble free machines and equipment producing defects free products for total customer satisfaction. The Planned Maintenance pillar activities are normally led by the maintenance team. The initial phase prioritizes equipment and involves evaluating current maintenance performance and costs to set the focus for the pillar activity. Support is provided to the Autonomous Maintenance pillar to establish a sustainable standard basic condition and the team focuses on eliminating the causes of breakdowns.

PILLAR 4: EDUCATION AND TRAINING:

It is aimed to have multi-skilled revitalized employees whose morale is high and who has eager to come to work and perform all required functions effectively and independently. Education is given to operators to upgrade their skill. It is not sufficient know only Know-How by they should also learn

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Know-why. By experience they gain, Know-How to overcome a problem what to be done.

This they do without knowing the root cause of the problem and why they are doing so. Hence it become necessary to train them on knowing Know-why. The employees should be trained to achieve the four phases of skill. The goal is to create a factory full of experts. The different phase of skills is:-

1. Do not know
2. Know the theory but cannot do
3. Can do but cannot teach
4. Can do and also teach

PILLAR 5: EARLY MANAGEMENT:

Early Management is the fifth pillar of TPM and aims to implement new products and processes with vertical ramp up and minimized development lead time. It is usually deployed after the first four pillars as it builds on the learning captured from other pillar teams, incorporating improvements into the next generation of product and equipment design. There are two parts to the Early Management pillar: Early Equipment Management and Early Product Management. Both approaches focus on using the lessons from previous experiences to eliminate the potential for losses through the planning, development and design stages.

For Early Equipment Management, the goal is to introduce a loss and defect free process so that equipment downtime is minimal (zero breakdowns), and maintenance costs are all considered and optimized, from commissioning onwards.

Early Product Management aims to shorten development lead times, with teams working on simultaneous activities so that vertical start up can be achieved with zero quality loss (zero defects).

PILLAR 6: QUALITY MAINTENANCE:

Quality Maintenance aims to assure zero defect conditions. It does this by understanding and controlling the process interactions between manpower, material, machines and methods that could enable defects to occur. The key is to prevent defects from being produced in the first place, rather than installing rigorous inspection systems to detect the defect after it has been produced. Quality Maintenance is implemented in two phases. The first phase aims to eliminate quality issues by analyzing the defects, so that optimum conditions can be defined that prevent defects occurring. Then, the current state is investigated and improvements are implemented. The second phase ensures that quality is sustained, by standardizing the parameters and methods to achieve a zero defect system.

PILLAR 7: OFFICE TPM:

Office TPM should be started after activating four other pillars of TPM (Autonomous Maintenance, Focused Improvement, Planned Maintenance and Quality Maintenance).Office TPM concentrates on all areas that provide administrative and support functions in the organization. The pillar applies the key TPM principles in eliminating waste and losses from these departments. The pillar ensures that all processes support the optimization of manufacturing processes and that they are completed at optimal cost. Office TPM benefits organizations by eliminating losses in the administrative systems across the whole organization and into the extended supply chain. This delivers cost reductions in the organization’s overheads as well as supporting improvement and sustainability of the manufacturing process efficiency.

PILLAR 8: SAFETY, HEALTH AND ENVIRONMENT:

Safety, Health and Environment (SHE) implements a methodology to drive towards the achievement of zero accidents. It is important to note that this is not just safety related but covers zero accidents, zero overburden (physical and mental stress and strain on employees) and zero pollution. SHE pillar activities aim to reactively eliminate the root causes of incidents that have occurred, to prevent reoccurrence, and proactively reduce the risk of future potential incidents by targeting near misses and potential hazards. The pillar team target three key areas: people’s behaviors, machine conditions and the management system. All SHE pillar activities should be aligned to relevant external quality standards and certifications. The immediate benefits of implementing the SHE pillar are to prevent reoccurrence of lost time accidents and reduce the number of minor accidents as well as preventing environmental system failure. This has a direct financial saving in the cost of containment, investigation and compensation as well as reputational impact.

III. OVERALL EQUIPMENT EFFECTIVENESS (OEE)

The goal of the TPM is to maximize equipment effectiveness. OEE provides an effective way of measuring and analyzing the efficiency of a single machine/cell or an integrated manufacturing system. The Six major losses that can result from faulty equipment or operation, whose elimination is the major objective of the TPM, are as shown in Table 1, can

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results in a dramatic improvement in the Overall Equipment Efficiency (OEE).
The calculation of OEE is performed by obtaining he product of availability of the equipment, performance efficiency of the process and rate of quality products.

OEE= Availability (A)*Performance (P)*Quality (Q)

AVAILABILITY (A):
Availability takes into account Availability Loss, which includes any events that stop planned production for an appreciable length of time (usually several minutes; long enough for an operator to log a reason).
Examples of things that create Availability Loss include Unplanned Stops (such as equipment failures and material shortages), and Planned Stops (such as changeover time). Changeover time is included in OEE analysis, since it is time that could otherwise be used for manufacturing. While it may not be possible to eliminate changeover time, in most cases it can be significantly reduced. Reducing changeover time is the goal of SMED (Single-Minute Exchange of Dies).

The remaining time after Availability Loss is subtracted is called Run Time.

Run Time = Planned Production Time − Stop Time

Availability is calculated as the ratio of Run Time to Planned Production Time:

$$\text{Availability (A)} = \frac{\text{Plant operating time} - \text{Break Down time}}{\text{Plant operating time}}$$

PERFORMANCE (P):
Performance takes into account Performance Loss, which accounts for anything that causes the manufacturing process to run at less than the maximum possible speed when it is running (including both Slow Cycles and Small Stops).
Examples of things that create Performance Loss include machine wear, substandard materials, misfeeds, and jams. The remaining time after Performance Loss is subtracted is called Net Run Time.
Performance is the ratio of Net Run Time to Run Time. It is calculated as:

$$Performance\ (P) = \frac{Actual\ Production}{Shift\ target\ production}$$

QUALITY (Q):
Quality takes into account Quality Loss, which accounts for manufactured parts that do not meet quality standards. Examples of things that create Quality Loss include scrap and parts that need rework. OEE Quality is similar to First Pass Yield, in that it defines Good Parts as parts that successfully pass through the manufacturing process the first time without needing any rework.
The remaining time after Quality Loss is subtracted is called Fully Productive Time. Quality is calculated as:

$$Quality\ (Q) = \frac{No.of\ good\ batteries\ produced}{Total\ no.of\ batteries\ produced}$$

SIX BIG LOSSES:
The three categories of loss are further divided into what is referred to as the Six Big Losses, illustrated in figure. One of the main aims of any TPM/OEE program is to focus on the elimination of these Six Big Losses.

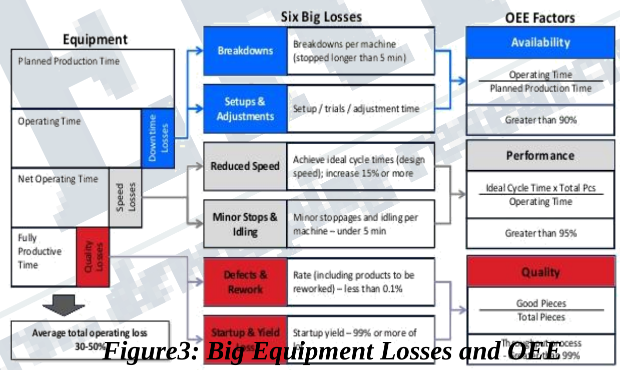

Figure3: Big Equipment Losses and OEE

WORLD CLASS OEE:
World class OEE is a standard which is used to compare the OEE of the firm. The percentage of World Class OEE is given in Table (Kailas, 2009).

OEE Factor	World Class
Availability	90.0%
Performance	95.0%
Quality	99.9%
Overall OEE	**85.0%**

Table1: Percentage of World Class OEE

IV. CASE STUDY IN BATTERY MANUFACTURING INDUSTRY

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The method used for the work is analyzing the present OEE and compare it with world class OEE in manufacturing and thereby develop a maintenance plan to improve the OEE. These are done by collecting the production data from company and calculating the OEE in terms of Availability, Performance of machines, and also the quality of the product. In company there are three shifts, the shift length of 8hrs. The data collected for this study is in month of May 2017, .this study is done in the battery manufacturing sector at Andhra Pradesh, India. The values chosen are meant for justifying the research initiatives only. “Table 2” contains the shift data, to be used for complete the OEE calculation.

A. OEE CALCULATIONS BEFORE IMPLEMENTATIONS:

Item	Data
No. of shifts per day	3
Shift length	8hrs
Planned Break’s time	60 min =60*3 =180 min/day 180 * 30 days= 5400 min/month
Unplanned down time	8385 min month
Targeted Production	60,000 Nos./month
No. of batteries produced	43, 789 Nos. /month
No. of batteries Rejected	683 Nos. /month

Table 2: Production Data before Implantations

$$Availability\ (A) = \frac{Plant\ operating\ time - Break\ Down\ time}{Plant\ operating\ time}$$

Where,

Planned Production time = Shift length – planned break time = 24-3 hrs = 21 hrs (per day) =21*60*30 = 37800 min/month

Plant operating time = Planned production time – down time =37800-8385 = 29415 min/month

Availability =29415 / 37800

= 0.7782

$$Performance\ (P) = \frac{Actual\ Production}{Shift\ target\ production}$$

= 43789 /60000

= 0.7298

$$Quality\ (Q) = \frac{No.of\ good\ batteries\ produced}{Total\ no.of\ batteries\ produced}$$

= (43789-683) / 43789

= 0.9844

OEE= Availability * Performance * Quality

= 0.7782 * 0.7298 * 0.9844

= 55.91 %

OEE Factor	World Class	Obtained
Availability	90.0%	77.82%
Performance	95.0%	72.98%
Quality	99.9%	98.44%
Overall OEE	**85.0%**	**55.91%**

Table 3: Comparisons between world class and obtained

From above “Table 3” we can conclude that actual obtained OEE is less than the World class OEE 85% (world class manufacturing performance for continuous manufacturing industry). So it indicates that improvements are required.

Losses occur in assembly line more because of cast on strap machine (availability loss), heat sealing machine (performance loss) and inter-cell welding machine (quality loss). To reduce this losses effect on OEE I implemented some solution. Those are discussed below.

B. DURING THE STUDY THE FOLLOWING PROBLEMS WERE IDENTIFIED:

1. During the case study the major problem was identified that, because of breakdown losses in Cast on Straps (COS) machine the availability rate is 70.98%. Major cause of breakdown of machine is cooling water flow rate is not sufficient because of dust piratical in flowing water and some other problems observed those are hot cut, mould height adjustment etc. in Cast On Straps Machine. Because of this problem the availability rate is affected in OEE.

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2. During the case study another major problem was identified that the production rate was low because of the larger cycle time in heat sealing machine and post burning machine. Because of this problem the performance rate is affected in OEE.

C. SOLUTIONS FOR THE ABOVE PROBLEMS:

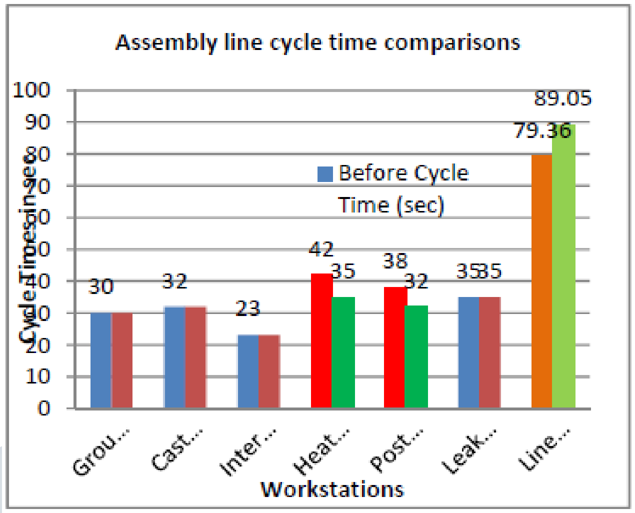
Solution for problem 1:
Jishu Hozen also called autonomous maintenance is a team-based approach to maintenance activities. The goal of autonomous maintenance is to prepare operators to do some equipment care independently of the maintenance staff. Jishu Hozen implementation lays the foundation for other maintenance activities by establishing the basic conditions for a machine's operation. Various tentative standards for cleaning, inspection and lubrication are set for Cast On Straps machine. These standards are shown in "Table 4"

STANDARDS FOR INSPECTION OF CAST ON STRAPS (COS) MACHINE:

DEFECTS	LOCATION	METHOD OF INSPECTION	STANDARD	TIME (min)	FREQUENCY	ACTION TAKEN IF NOT OK
Mould water flow error	Mould water pipe	Venturimeter	Use Water filter to remove dust	3-4	Weekly	Change the circulating water
Lug to strap Bounding	Strapping section	Visual	Chains adjustment	5-7	Daily once	Adjust the chain length
Hot cut	Mould	Visual	Mould height	6-7	Staring of shift	Adjust mould height
Low or High mounting Height	Groups insertion	Visual	Place wood to adjust height	2-4	If type changes occur	Place wood to adjust height
Post Appearance not good	Mould	Visual	Dust free Mould	2-3 min	Staring of the shift	Clean the dust in mould

Table 4: standards for inspection of cast on straps (COS) machine:

Solution for problem 2:
During the second stage of the TPM implementation the importance is given to increase the production rate. For the study, the Heat Sealing (HS) machine has been selected. During the study it was found that the major causes for the low production rate was the larger cycle time for each operations. By using line balance heat sealing machine time are reduced. Heat sealing machine is bottleneck in that assemble line i.e. 42 sec. After ling balance we get cycle time shown in below graph.



Graph 1: cycle time before after line balancing

D. Oee calculations before implementations:

Item	Data
No. of shifts per day	3
Shift length	8hrs
Planned Break's time	60 min =60*3 =180 min/day 180 * 30 days= 5400 min/month
Unplanned down time	3925 min/ month
Targeted Production	60,000 Nos. /month
No. of batteries produced	52,789 Nos. /month
No. of batteries Rejected	473 Nos. /month

Table 2: Production Data after Implantations

$$Availability\ (A) = \frac{Plant\ operating\ time - Break\ Down\ time}{Plant\ operating\ time}$$

Where,
Planned Production time = Shift length – planned break time = 24-3 hrs = 21 hrs (per day)
=21*60*30 = 37800 min/month

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Plant operating time = Planned production time – down time =37800-3925 = 33875 min/month

Availability = 33875 / 37800

= 0.8962

$$Performance\ (P) = \frac{Actual\ Production}{Shift\ target\ production}$$

= 52789 /60000

= **0.8798**

=

$$Quality\ (Q) = \frac{No.of\ good\ batteries\ produced}{Total\ no.of\ batteries\ produced}$$

= **(**52789-473) / 52789

= **0.9910**

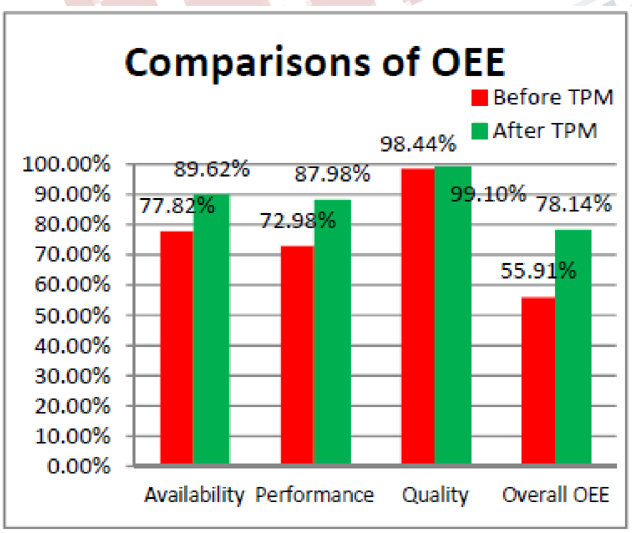
OEE= Availability * Performance * Quality

= 0.8962 * 0.8798 * 0.9910

= **78.14 %**

V. CONCLUSION

After a small implementation of TPM in industry, it is found that the Overall equipment effectiveness is increased by 22.23%. It should be noted that the change in maintenance policy in the company changed their availability, performance and quality. In below graph the improvement in availability, performance, quality and OEE has shown



Graph 2: OEE before and after implementation

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