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Enhancement of Overall Equipment Effectiveness using Total Productive Maintenance in a Manufacturing Industry

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Abstract: The current levels of competition makes the organizations to continually strive to meet the customer demand but it has been observed that due to problems like machine breakdown, machining and setting process delays it has become difficult in meeting this on time. The objective of this article is to inspect the manufacturing losses arising on account of such problems by prioritizing the root causes with the help of a pareto diagram and finally suggesting the solution to overcome these problems. A case study was carried out to improve the utilization of machine tool and manpower by initiating the practices through, TPM that would also form as a base for lean manufacturing. TPM helps to adopt a systematic work inside the shop floor which reduces the losses in production activity, increases the equipment life, ensures effective utilization of equipments and organized employee behavior. Introduction of new fixture reduces the idle time of machine during component setting and achieving cycle time reduction by analyzing cutting tool and its parameters which helps to increase the output to meet the customer demand. From the final results, it was observed that there was reduction in setup time, cycle time, breakdown losses and rework time, while the overall equipment effectiveness was also found to have increased by about 15%.

Keywords: *Manufacturing, TPM, OEE, Cycle Time, Setup Time*

1. Introduction

As the industries have been trying to minimize their operational costs, there has been maximization of usage of their assets. Production efficiency and effectiveness of these industries depends more on the equipment effectiveness employed. Overall equipment effectiveness (OEE) is seen to be the fundamental way of measuring performance efficiency. An attempt was made to find out the OEE of all the machines and equipment during April 2016 in a CNC manufacturing industry located at Chennai, India. The observed OEE showed various time losses that occurred in the equipment during different processes and the recurring reduction in overall output. In order to meet the customer demand, the OEE metrics were analyzed and solutions were found out for all major losses. Total Productive Maintenance (TPM) being a continual improvement on effectiveness of equipment and processes where all employees are involved, the autonomous maintenance concept being a part of TPM was introduced for maintaining equipment and to follow a systematic procedure in shop floor activity. As the component size being huge it was observed that, the setting takes more time. Therefore, in order to reduce the component setup time by stopping the machine, a new fixture was introduced to do the setup activity

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outside of the machine using FARO instrument. This helped the component to be kept ready for loading once the running component got completed. Similarly, since cycle time also plays a major role in component output, a common tool for drilling, chamfering and counter boring operations which reduces the cycle time considerably was also introduced. From OEE metrics, as it was found that the rework also creates a major time loss. Hence, all the reworks that had happened during April 2016 were studied and analyzed and also appropriate preventive actions for improving the quality performance were taken to reduce this time loss.

2. Literature Review

The concept of TPM provides quantitative metric OEE for measuring the effectiveness of equipment in production line. TPM is an exceptional method which is developed from preventive maintenance concept for plant maintenance and management. The actions of TPM eliminate the equipment related losses and improve availability, performance rate and quality rate. Through proper implementation of TPM the OEE value gets increased [1-3]. Just in Time (JIT) and Total Quality Management (TQM) is closely tied and is an extension of Preventive Maintenance (PM) where the machines work at high productivity and efficiency. The fundamental concept of TPM is, if you properly maintain plant machinery there will be a sharp decline in machine breakdowns, safety and quality problems. It needs the development of a preventative maintenance program for the life-cycle of equipment and involvement of operators in maintaining the equipment in order to maximize its overall efficiency and effectiveness [4, 5]. Also it is closely related to the maintenance of all employee responsibility and focus to take necessary preventive action for the expected problem before it occurs [6, 7]. There is emerging need for TPM implementation in Indian manufacturing industries and need to develop TPM implementation practice and procedures. A new definition of performance ratio was introduced to reduce the limitation of cycle time and hence the OEE has been improved [8]. The OEE was improved with low machine breakdown, less idling and minor stop time, less quality defects, reduced accident in plants, increased productivity rate, optimized process parameters, worker involvement, improved profits through cost saving method, increased customer satisfaction and increased sales and also improved employee morale and confidence [9,10]. TPM is widely used to measure the efficiency of a manufacturing plant in terms of availability, performance and quality to identify the major productivity losses [11]. An analysis was carried out in CNC shop to calculate the OEE percentage and necessary recommendations were given to enhance the efficiency of the CNC shop floor by eliminating three OEE losses such as downtime, speed loss and quality loss [12, 13]. The successful applications of motion and time study in manufacturing industries are dependent on the training of the individual employees, who apply it and also highlight the OEE improvement of the autoclave process through the implementation corrective actions [14-16]. Overall Performance Effectiveness (OPE) measurement was an effective way to analyze the efficiency of a single setup process [17, 18]. The influences of flexible and rigid TQM practices in small and medium scale industries were investigated and broad overviews of how TQM practices were constructed for various quality improvements were studied. Productivity improvement is achieved through eliminating un-necessary movements by use of standard operating procedure, reducing

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cycle time and providing appropriate solutions to various problems during the assembly of components to improve productivity and OEE [19-22]. Various theoretical models were proposed to facilitate the industries for having better understanding about TPM techniques and step by step implementation to improve their productivity [23, 24]. Based on the above literature, an attempt was made to implement the TPM techniques in a windmill component manufacturing industry specifically in the CNC machine shop of Star Engineering located at Chennai. This TPM implementation is to improve the level of quality and reduce the manufacturing cost of the product there by increasing the overall equipment effectiveness of the industry.

3. Problem Definition and Methodology

The Industry chosen for the study does the job of machining operations of windmill parts such as rotor hub and bedplates and hence the study specifically focuses on issues in CNC machining operations. In the existing process it was found that the machining cost and cycle time of component to be moderately high. The company was found facing many problems through unexpected machine breakdown and more often they were not able to achieve the customer demand of 6 components per day. In order to correct the systems that were followed in the existing production line TPM practices were suggested for better productivity and OEE. A TPM tool was used to measure performance before and after TPM implementation. OEE when measured was found to be less than 65%. As OEE helps in monitoring and improving the efficiency of a manufacturing process, this article presents a systematic way to identify the root causes for the low OEE and arrives at a solution in tackling the bottleneck problems by implementing TPM practices.

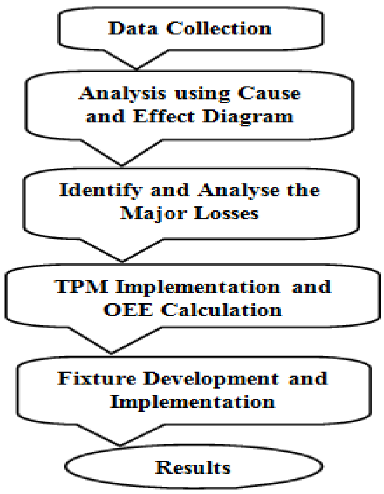

Figure 1: Methodology Flow Chart

The methodology flow chart for the research is shown in Figure 1. The case company found difficulty in competing with other players in the industry but did not know the exact reasons. Hence the study started with detailed collection of data of as existing and a further analysis of the problems were studied. Based on the existing data, the analysis was carried out using cause and effect diagram. The major losses were located through Pareto chart for identifying opportunities to change. As the industry had not been practicing any of the TPM techniques, it was suggested to implement the same and was implemented to mitigate the issues in the existing system. A new fixture and tool was developed to reduce the setup time as well. After implementing the TPM technique the results were collected and compared with the existing data.

4. Data Collection and Analysis

All the production activity in the CNC machine shop was closely monitored for the month of April 2016. The everyday output was recorded and is shown in Figure 2. The individual machine losses were also identified and noted down.

$$\text{OEE} = \text{Availability (A)} \times \text{Performance (P)} \times \text{Quality (Q)}$$

Where,

$$\text{Availability} = \frac{\text{(Planned production time - Unscheduled downtime)}}{\text{Planned production time}}$$

$$\text{Performance (Speed)} = \frac{\text{(Cycle time x Number of products processed)}}{\text{Production time}}$$

$$\text{Quality (Yield)} = \frac{\text{(No. of products processed - No. of products rejected)}}{\text{Number of products processed}}$$

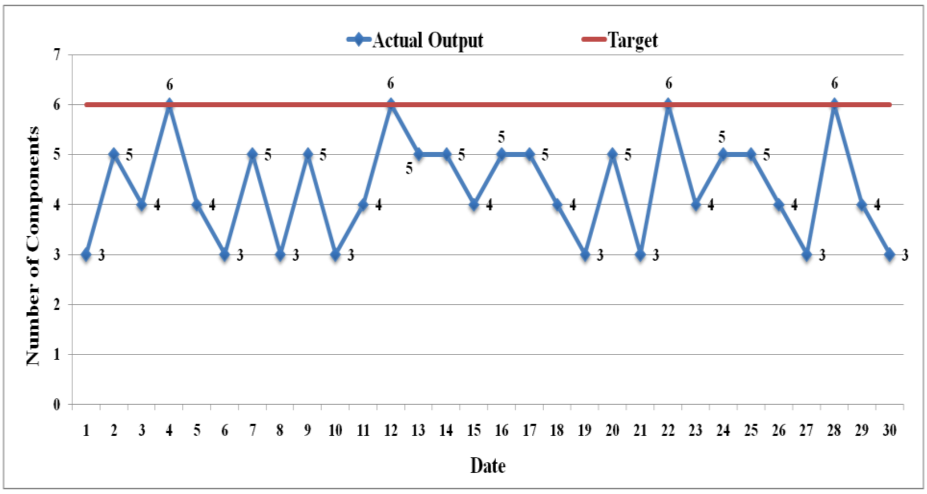

Figure 2: Output for the Month of April 2016

Based on the collected data OEE was calculated for all the individual VMC and HMC machines for the Month of April 2016 and their measurement is shown in Figure 3. From the calculated value it was found that the maximum OEE was around 60% only.

4.1 Component Cycle Time

The component cycle time was noted using stop watch for every operation. It starts from loading the component in the machine and till unloading of the component from the machine. The total cycle time for each component and respective operation is shown in Table 1.

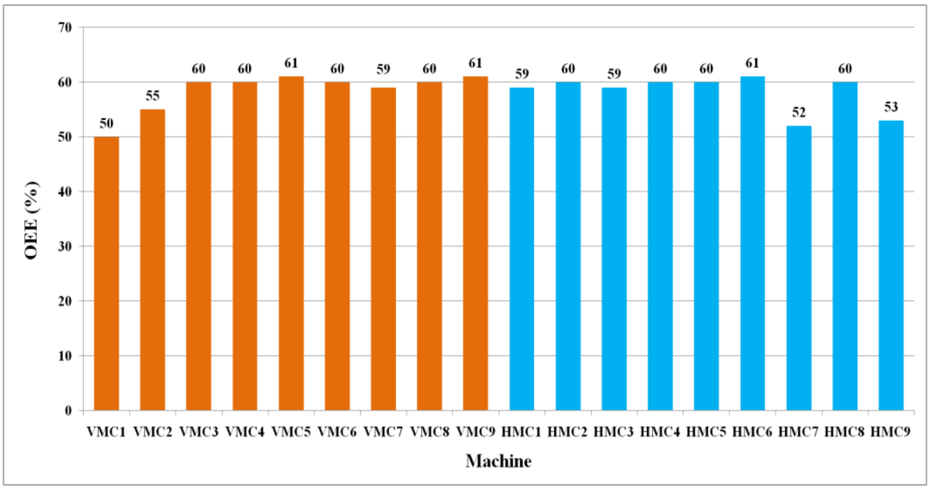

Figure 3: OEE of VMC and HMC for the Month of April 2016

Table 1: Cycle Time for Individual Component

Name of the Component	Operation	Total Cycle Time in Hours
Mainframe	First	35
Mainframe	Second	27
Hub	First	33
Hub	Second	14
E Hub	First	43
E Hub	Second	11
Bedplate	First	29
Bedplate	Second	35

4.2 VMC and HMC Machine Setup

Based on the cycle time of every component the VMC machine was allocated for the first operation and the second operation to meet customer requirement. The machine allocated for first and second operation and the output of each machine is shown in Table 2. Similarly based on the component cycle time, the HMC machine was allocated for first operation and second operation to meet the customer demand. The machine allocated for first and second operation and the output of each machine is shown in Table 3.

Table 2: VMC Machine Setup and Output

Machine	First Operation	Second Operation	Output (Pieces)
VMC 1		MF	1
VMC 2		E BP	1
VMC 3		MF	1
VMC 4	MF		1
VMC 5	MF		1
VMC 6	MF		1
VMC 7		MF	1
VMC 8	E BP		1
VMC 9	MF		1

Table 3: HMC Machine Setup and Output

Machine	First Operation	Second Operation	Output (Pieces)
HMC 1		Hub	2
HMC 2	Hub		1
HMC 3	Hub		1
HMC 4	Hub		1
HMC 5	E Hub		1
HMC 6	E Hub		1
HMC 7		E Hub	2
HMC 8	Hub		1
HMC 9		Hub	2

4.3 Component Output per Day in VMC and HMC

The component output is based on number of machines allocated for each operation (first operation and second operation) and the output of Mainframe and E Bedplate in VMC machines and the output of Hub and E Hub in HMC machines are shown in Table 4.

Table 4: VMC and HMC Machine Output per Day

Machine	Component	First Operation	Second Operation
VMC	Mainframe	3	2
	E Bedplate	1	1
HMC	Hub	3	3
	E Hub	1	2

4.4 Sample OEE Analysis

From the collected data, the OEE analysis was carried out for all the machines of VMC and HMC for the month of April 2016. The model graphical representation of OEE for fifth VMC machine is shown in Figure 4.

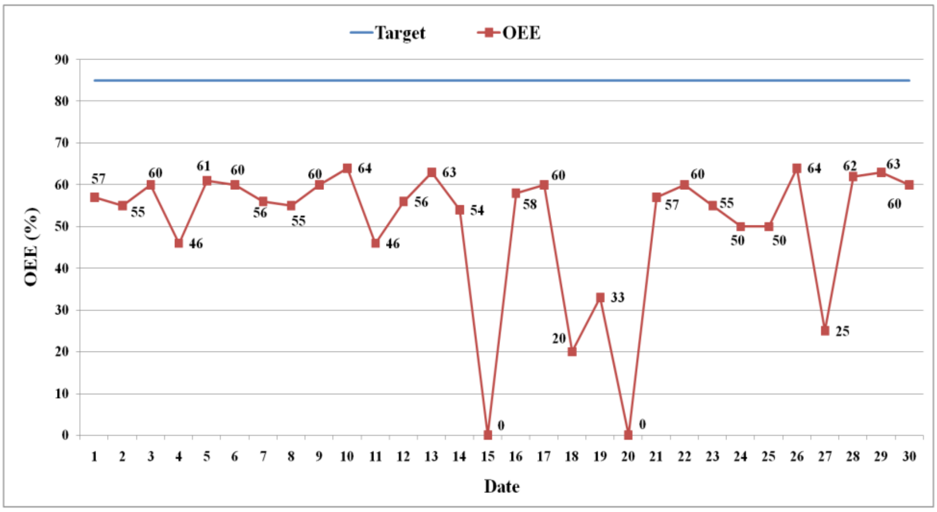

Figure 4: OEE of Fifth Machine

4.5 Fishbone Diagram

The development of cause and effect diagram is to highlight the problem occurred during the OEE measurement. The cause and effect diagram for low OEE is shown in the above Figure 5.

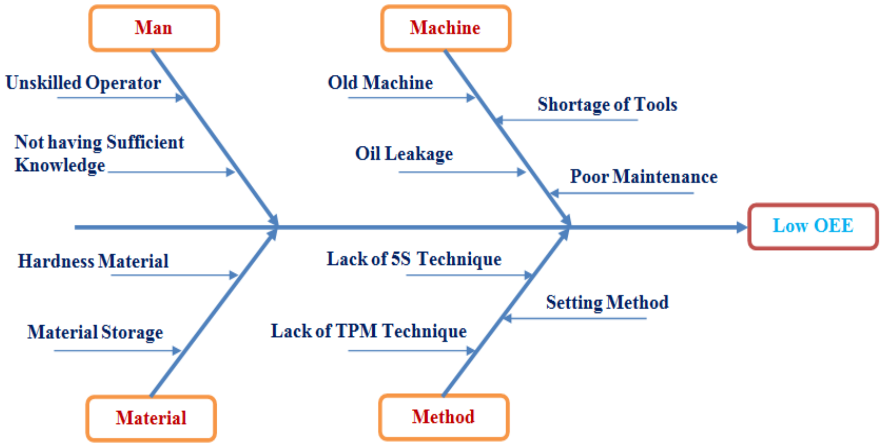

Figure 5: Cause and Effect Diagram for Low OEE

4.6 Identification of Major Losses

During the measurement of OEE it was found that various losses had occurred and among these the major losses were identified by using Pareto diagram. Pareto principle says 80% of the problem is caused by 20% of the cause. The Pareto chart for various time losses during different operations are shown in Figure 6. From the Pareto chart, it was found that the machining delay, machine breakdown, setup delay and rework were the major losses.

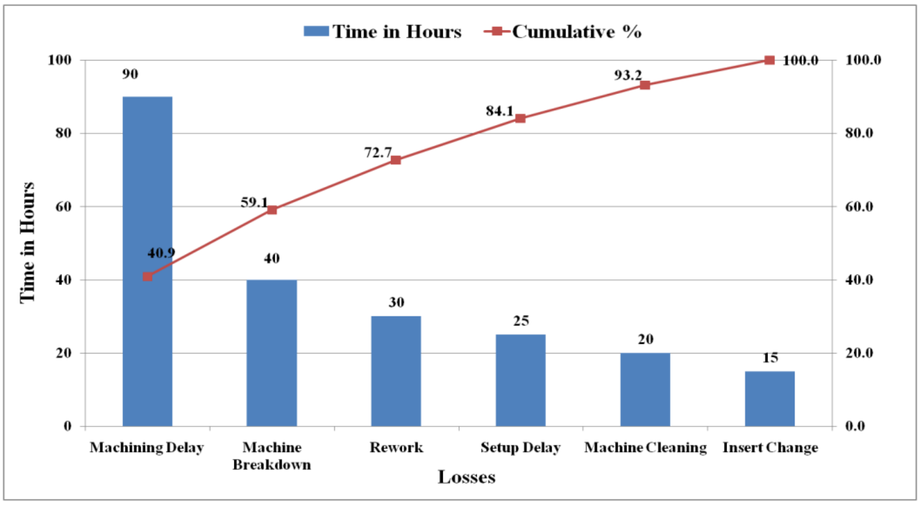

Figure 6: Pareto Chart for Time Losses

4.7 Total Productive Maintenance

The fifth machine of VMC was selected as model machine for TPM activities. Initially all the problematic areas like oil leakage, wire lose connection, rotating component not having guards, coolant tank not having guards were noted. The oil leakage problem was arrested through maintenance. Similarly, guards were provided for uncovered area of rotating parts. Then cleaning started by TPM team coordinator and TPM activities were handed over to operators to carryout individually. The operators were initially trained in autonomous maintenance for implementation of TPM. A check list was prepared for follow up of the daily activities which include points like coolant level checking, hydraulic oil level checking, abnormal noise in motor, telescopic cover cleaning and Cathode Ray Tube (CRT) screen cleaning.

After implementation of TPM, the management observed changes in shop floor and employee activities towards discipline. For example, the KAIZEN activity implemented for TPM implementation in coolant tank is shown in Figure 7. Initially the machine did not have guard for coolant tank and after thorough cleaning guard has been provided. It was also observed that the coolant life had increased and rust forming in the component was eliminated after providing the guard for the coolant tank. Through autonomous maintenance the machine breakdown time was reduced by about 25% in the fifth VMC machine and it was found that there was an improvement in the machine availability after implementing the autonomous maintenance system. The actual breakdown time and the reduction of breakdown time through TPM are shown in Figure 8. It was found that the breakdown time after implementation of TPM was reduced and it was even lesser than the actual target time as was fixed for breakdown.

KAIZEN			
Team Member	L. Perumal and S. Murugan	Location/Equipment	Fifth Machine
Problem Identified	Machine breakdown due to contamination of coolent	Remedial Action	Coolent oil was Covered
BEFORE 		AFTER 	
Benefit Category	☐ EHS ☐ Quality ☐ Cost ■ Delivery	Benefit Summary: Life of coolent increased	
Execution Date	04.05.2016		

Figure 7: Kaizen for TPM Implementation

4.8 Setup Time Reduction

As per the existing study, the setup of component makes the aligning and clamping of component by stopping the machine using plunger dial of 0.01mm. For this aligning and clamping it took more than 150 minutes. A new fixture was designed for aligning and clamping the component outside of the machine and is shown in Figure 9. Introduction of new fixture makes the component to align and clamp outside of the machine itself and kept ready for loading once the running component got completed. The fixture was kept over the surface Table with flatness of 0.2mm.The component was loaded over the fixture and top, front and side alignment measurements were taken by faro instrument.

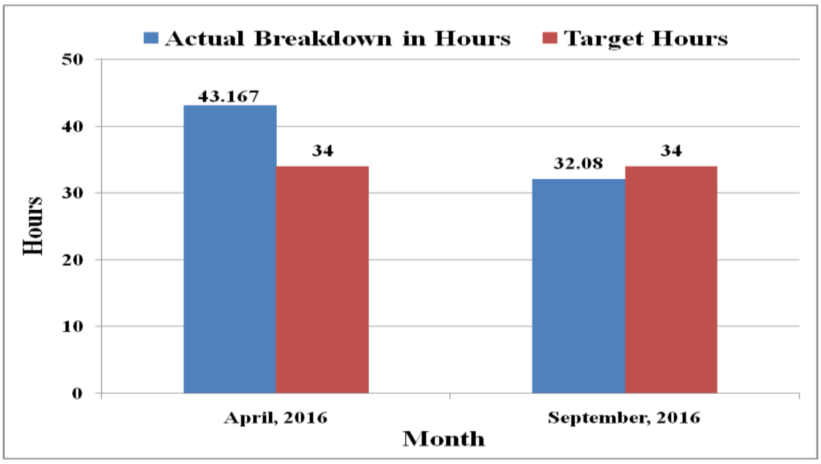

Figure 8: Breakdown Time using TPM

Top alignment was to be within 5mm and front was to be kept within 2mm. When the alignment did not measure up to the required level then repeated measurements were done to bring the alignment within the required value. The setup time observed after implementation of new fixture is given in Table 5. The observation was made for 10 consecutive components in the fifth machine to find out the setup time and found that the possible set up time was about 36 minutes and the offset was being taken for each component. The setup time for fifth VMC machine was observed and is given in Figure 10 with the target time.

Table 5: Setup Time Observation for Fifth VMC Machine

Date	Machine	Component	Operation	Shift	Operator Name	Start Time	End Time	Total Time	Remark
16-04-16	V	Mainframe	First	I	K. Vivek	9:15 AM	10:05 AM	56 min	Feasibility Checking
18-04-16	V	Mainframe	First	II	S. Baskar	10:10 PM	11:45 PM	35 min	
20-04-16	V	Mainframe	First	I	K. Vivek	2:37 PM	3:23 PM	47 min	
22-04-16	V	Mainframe	First	III	J. Ashok	4:20 PM	5:05 PM	46 min	
23-04-16	V	Mainframe	First	II	S. Baskar	7:15 PM	8:45 PM	85 min	Crane Breakdown
25-04-16	V	Mainframe	First	I	K. Vivek	11:07 AM	11:42 AM	36 min	
27-04-16	V	Bedplate	First	III	J. Ashok	3:22 AM	3:54 AM	33 min	
28-04-16	V	Bedplate	First	III	J. Ashok	5:47 AM	6:21 AM	35 min	
30-04-16	V	Bedplate	First	III	J. Ashok	4:15 AM	4:47 AM	33 min	
02-05-16	V	Bedplate	First	I	K. Vivek	8:11 AM	8:48 AM	38 min	

Due to aligning of the component outside of the machine using faro instrument, time taken for aligning the curved components was completely eliminated. The cost of the setup time was calculated before and after implementation of new fixture which is given below.

Cost for setup time for 150 minutes	= Rs 5500
Cost for setup time with new fixture (36 minutes)	= Rs 1320
Cost saving during setup time with new fixture	= Rs 4180

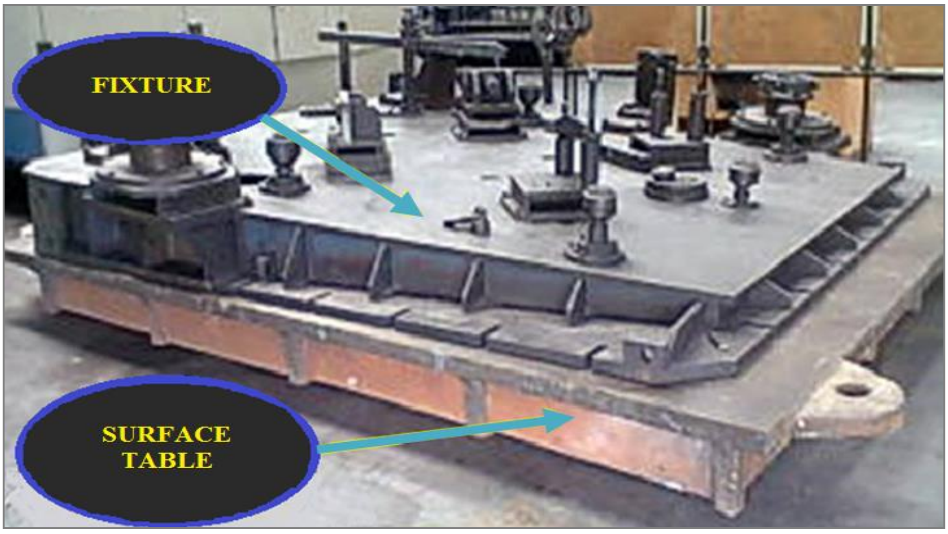

Figure 9: Proposed New Fixture

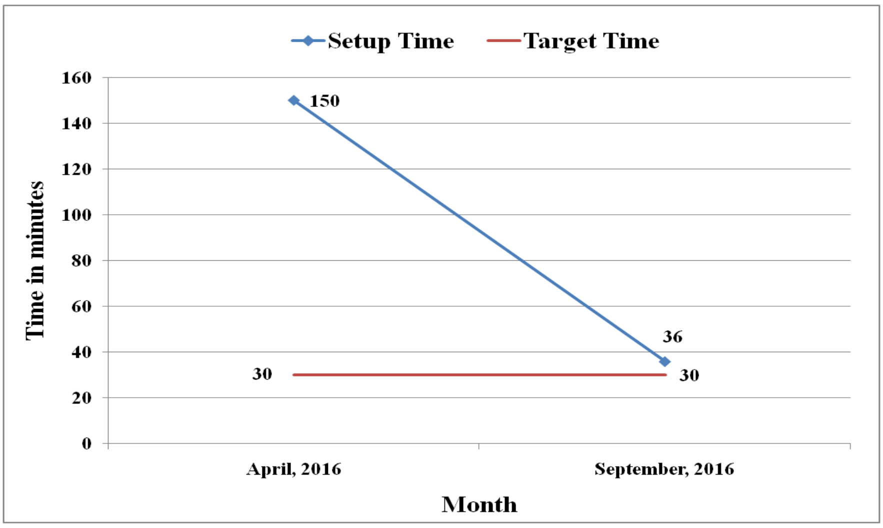

Figure 10: Setup Time for fifth VMC Machine

4.9 Cycle Time Reduction

In the existing operation, the drilling, counter boring and chamfering were carried out with separate tools and after introduction of common tool all the operations were done in a single tool hence the cycle time was reduced. Similarly, by selecting appropriate parameters on speed, feed and depth of cut and tools the cycle time got reduced. Due to aligning done by faro instrument, it was enough to keep raw casting stock of 20 mm in all machined area in the place 30 mm thus a saving of 10 mm was made possible. The operations of drilling, counter boring and chamfering were made through a common tool in single plunge made in solid carbide material up to 18mm diameter. Above 18mm diameter, the insert type cutter body could be used. Figure 11 shows the common tool for 35mm diameter drill size and 42mm diameter counter bore. The cycle time after incorporation of common tool was reduced and all the values for each operation were observed and are given in Table 6.

Figure 11: Common Tool for Drilling, Counter Boring and Chamfering Operations

Table 6: Cycle Time after Setting New Fixture

Component	Operation	Cycle Time in Hrs		Remarks
		Before	After	
Mainframe	First	35	30	New fixture and Common tool were introduced and Stock reduced from 30 to 20mm
Mainframe	Second	27	25	Common tool introduced and stock reduced from 30mm to 20mm
Hub	First	33	32	New fixture was introduced
Hub	Second	14	14	Common tool were introduced
E Hub	First	43	43	Common tool were introduced
E Hub	Second	11	11	Nil
Bedplate	First	29	27	Common tool introduced and stock reduced from 30mm to 20mm
Bedplate	Second	35	32	Common tool introduced and stock reduced from 30mm to 20mm

Cycle time was reduced due to introduction of new fixture, common tools and reduction of raw material stock due to faro measurement used for alignment. Figure 12 shows the cycle time reduction for mainframe.

Cycle time of mainframe before introduction of new fixture	= 62 hrs
After cycle time reduction after introduction of new fixture	= 55 hrs
The total saving in cycle time after introduction of new fixture	= 07 hrs

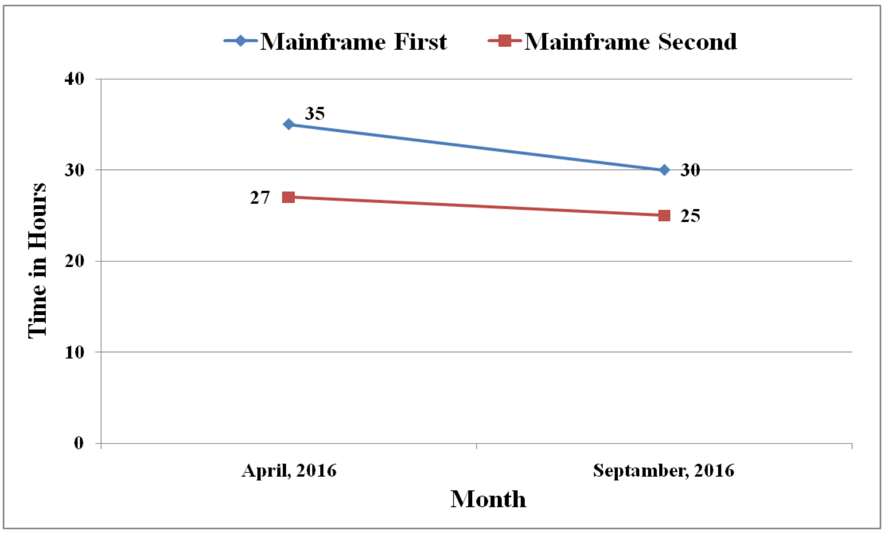

Figure 12: Mainframe Cycle Time

Table 7: Preventive Action Chart for Rework

					Date: 24/08/2016
Nature of Defect	**Nos**	**Rework Time**	**Rework Cost (Rs.)**	**Reason**	**Preventive Action Taken**
M36 Tab broken, hance counter bore damage	2	650 mins	24500	Worn out tab used	Tool life monitoring chart implemented and recommented to change at regular interval of 80 minutes
Chamfering operation was not done	1	300 mins	11000	Chamfering program made as sub program, hence operator missed the operation	Program operation sequence was modified
Surface finishing was not as per drawing	1	220 mins	8500	Due to vibration mark was found in back face operation	Final inspection checklist was provided
Thickness was measured as 30mm instead of 31mm	2	1000 mins	38500	Crack found in 140mm diameter back face cutter	Dimension added in Process Inspection Report
M36 Tab operation missing	1	450 mins	17500	M36 tab operation was carried out with length tab and short tab	Program changed to do the M36 tab with single tab
Finishing problem in counter bore operation	3	1300 mins	36500	Selected parameter not suitable for tool	Common tool provided with correct parameter
25mm dia drill with depth of 25+2mm was	2	220 mins	8500	Due to measurement was taken from raw casting area	Before drilling operation component facing operation done in program

					Date: 24/08/2016
Nature of Defect	**Nos**	**Rework Time**	**Rework Cost (Rs.)**	**Reason**	**Preventive Action Taken**
measured as 24.5mm					
244+0.2mm slot GO gauge not entered	2	400 mins	15000	Operator was not checked the slot size	Dimension was added in In-Process Inspection Report
110mm thickness face found unwash	1	300 mins	11000	Stock problem in raw casting	Advised to check during offset
Due to wrong tool used 12mm dia counter bore damaged	1	220 mins	9000	unskilled operator	Advised to give proper training to the operator
Total		**5060**	**180000**		

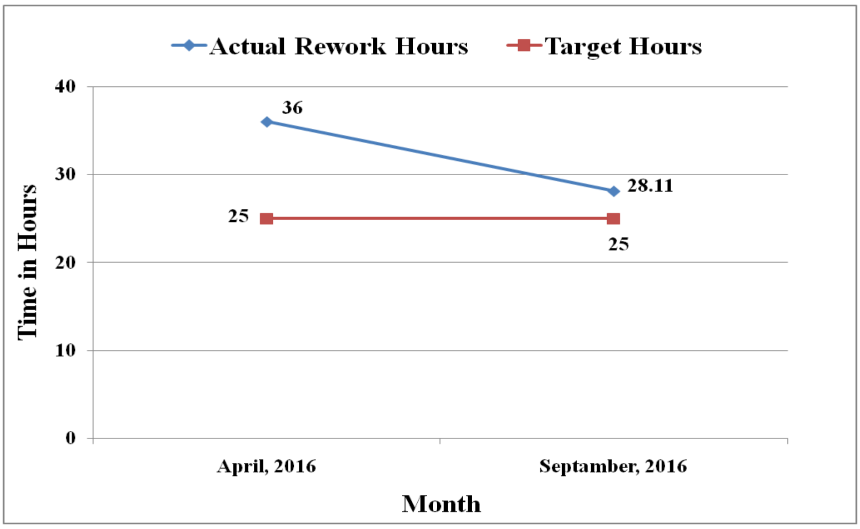

Figure 13: Reduction of Rework Time

After implementing the necessary preventive action to reduce the rework, the time taken was calculated. The rework time taken after the preventive actions was only 28.11 hours as compared to 36 hours earlier and against the target rework time of 25 hours per month/shift. On account of the preventive action, rework time was reduced by about 29% and hence this increased the quality rate of OEE. The reduction of rework time before and after implementation of preventive action is given in Figure 13.

5. Results and Discussion

From the existing data and analysis, it was observed that the OEE for the month of April 2016 was about 60%, which required to be improved through adopting some of the best practices. For this TPM techniques were suggested and implemented in the selected CNC line. After implementation of TPM practices with autonomous and preventive maintenance actions the OEE was increased to 75% during the month of September 2016.

The breakdown loss also got reduced by about 25% through the autonomous and preventive maintenance actions and with the introduction of a new fixture the setup time was reduced to 36 minutes from 150 minutes which was nearer to the target time. Similarly, the cycle time was reduced by about 13.5% by introduction of a common tool and also the size of the raw material stock was reduced by about 10 mm. It was also observed that the rework time was reduced to 28.11 hours from 36 hours nearly by about 29% due to the preventive action taken at the right time. The comparative analysis of OEE for the fifth VMC machine is shown in the following Figure 14. It was clearly found that the OEE increased during September 2016 as compared to April 2016. Ultimately it was observed that the Overall Equipment Effectiveness has increased by about 15% after the suggested implementation of TPM practices.

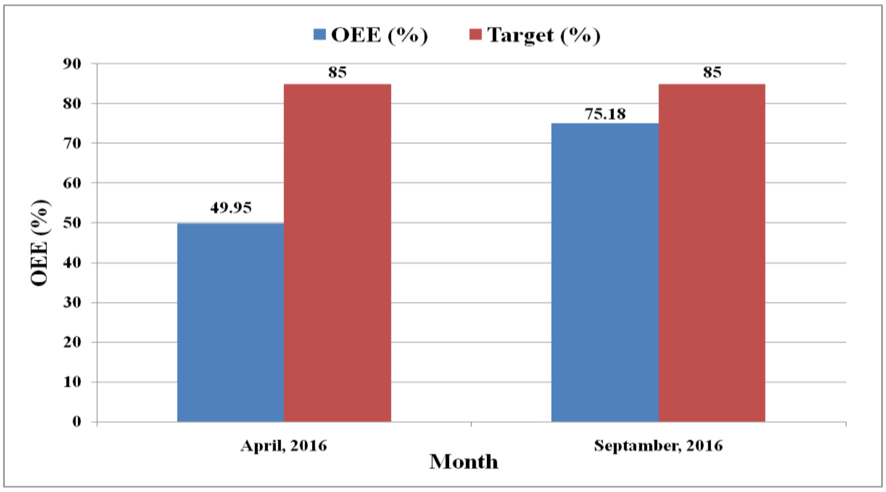

Figure 14: Comparison of OEE (%)

From the above study and analysis made it can be clearly stated that, on implementing the TPM practices many benefits such as reduction of setup time, cycle time, machine idle time and reduction of rework time were achieved. The increase in OEE ultimately helped the company in gaining competitive edge in the industry. The TPM practices provide better work system among employees and increases the involvement of individual persons. Also it reduces the equipment deterioration and failure, maximizing production.

6. Conclusions

The following conclusions were arrived from the observed results of the above case study.

- Through the autonomous maintenance concept, the breakdown loss was reduced by about 25%.
- The total setup time was reduced by about 75% through the introduction of new fixture.
- Through the introduction of common tool, the size of the raw material stock was reduced by about 10 mm which in turn reduced the cycle time by about 13.5%.
- Due to the preventive actions taken based on the defects, the rework time was reduced by about 29%, hence the rate of OEE also increased.

- Finally, it was clear that through the implementation of TPM the OEE increased by about 15% and helped in meeting the customer demand.

The present work is focused to improve the effectiveness of machines which have low OEE by implementing the TPM technique and setup time reduction. It would be beneficial for future projects to find out the root causes of machine related issues and to improve the performance levels of machines and their productivity through TPM methodology and also by using TPM metrics like MTBF, MTTR, etc.

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