Optimization of Overall Equipment Effectiveness Through Total Productive Maintenance Perspective – A Case Study

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***Abstract*—The world class Overall Equipment Effectiveness (OEE) is termed to be 95% at least for an equipment under standard operating conditions. To achieve this performance to the assets needs major attention from the root level to the final production stages. The Total Productive Maintenance (TPM) concept can bring the equipment to this world class performance level with detailed analysis for all the TPM components. A case study has been carried out in an industry which uses CNC lathe machine in the production line to optimize the OEE to world class level. Presently it is observed that the CNC lathe machine was working with 31.21% OEE which is very low to the required level. The detailed analysis through all the TPM components brought out the key ineffectiveness throughout the processes. On implementation of TPM with detailed analysis and suggestions the OEE of CNC lathe machine improves from 31.21% to 74.47% which is still far less than the world class requirements. Further monitoring and improvement in the process, the equipment may improve the OEE level into world class OEE level.**

***Keywords*—CNC Lathe, OEE, TPM and Availability**

I. INTRODUCTION

The Total Productive Maintenance (TPM) is a comprehensive strategy that supports equipment improvement to maximize its efficiency and the quality of the product it produces. TPM is a World Class Enabling Tool which is process and result orientated. It provides methods for data collection, analyses, problem solving and process control. It also involves other departments, such as design, quality, production control, finance and purchasing who are concerned with equipment, and this of course, includes management and supervision [1]. TPM is also part of the process of continuous improvement and total quality management [2]. It is about the continuous improvement of equipment and therefore makes extensive use of standardization, workplace organization, visual management and problem solving [3]. TPM not only takes care of the basic maintenance matters, but also consider the impact on productivity, quality and people related items. This will make the management to utilize the equipment in its designed performance as well as quality management. TPM is an Asset Care Process which covers that broad range of issues [4].

OEE is an abbreviation of Overall Equipment Effectiveness which gives a measure of production performance with an industrial asset. OEE is a ratio of actual productive time to the planned productive time of that equipment. Practically OEE is product of availability, performance and quality [5]. In this paper an attempt has been made to conduct a case study on CNC Lathe machine which is used as one of the production machine in a precision industry.

II. COMPUTER NUMERICAL CONTROL (CNC) LATHE

A Computer Numerical Control (CNC) lathe is intended for turning operations on complex parts and specifically used for batch productions. A part program is prepared according to the object to machine with respect to the operating system of the CNC machine. This part program can feed into control system of the machine accordingly the controller will control all the machine elements as per the part program. The work piece is fixed in the rotating chuck and the required tools are using for turning from the tool turret. A feedback system will also be provided to ensure the positional accuracy of the turning operations.

CNC machines are used in different circumstances such as small and medium batch production, industrial special request parts, die making industry etc. A production unit required steady state of running where as a die making unit requires concentrated performance and profile accuracy. Accordingly the maintenance strategy also changes.

III. CASE STUDY

The Ray Precision is a well-known industry in Muscat fabricating and manufacturing products, on request from industries. The CNC lathe in the production line is used for

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small batch production of industrial seals. These seals are produced in batches. These seals are required for own use for fabricating units and as well as for the external requested productions. The dimensional features are varying according to the batches, but it is very easy to produce in CNC lathe machine. Different part programs are used for each batch of productions. A long history of maintenance activities was not available since the core process of the establishment would be other than the CNC machining. All the observations and historical inputs given in this study have been collected with detail discussion with the staffs of the company those who are concentrating CNC Lathe related maintenance and production activities.

There are many sophisticated equipments in the company which are fully functional throughout the process. By priority ranking, a CNC lathe machine shown in Figure.1 is chosen for this case study to analyze OEE and optimize its use because huge amount of money is invested on this machine to produce very precise products.

Fig. 1. Initial observation on CNC Lathe machine

A. Study on Existing OEE Rating

The systematic approach for an OEE needs through investigation of the existing system in its performance, availability and quality. This is to be investigated for a predetermined period of time. Many times the engineers are conducting this study for different time scheduling such as three or four particular duration of time over a period of time. This schedule strictly depends on the process nature and its specialties.

The accuracy of the historical data depends on the system which the establishment follows and the related personals those who handling it. Many of the cases, we need to collect information and experience from the concerned operators.

B. Existing OEE Rating for Present Condition

The OEE formula is:
OEE = Availability * Performance Rate * Quality Rate

$$Availability = \frac{total\ available\ time - actual\ down\ time}{total\ available\ time} X\ 100\ \%$$

$$Performance = \frac{ideal\ cycle\ time\ X\ total\ units\ produced}{actual\ working\ time} X\ 100\ \%$$

$$Quality\ Rate = \frac{total\ units\ produced - number\ of\ defects}{total\ units\ produced} X\ 100\ \%$$

Availability of a machine is the ratio of actually available time out of the time scheduled to be available.

Total available time is the time scheduled for operations. Actual down time is the time for planned and unplanned down times. Panned down time includes startup time, shift changes, coffee and lunch break time, planned maintenance time etc. Unplanned down time includes equipment break down, changeovers, lack of materials etc.

Performance factor represents the difference between ideal speed (based upon equipment capacity as per design specifications) and actual operating speed of the equipment. This includes speed losses, small stops, idling time etc which is not producing the quantity intended to provide.

Quality rate represents the ratio of the good production over the scheduled time period and to the defected production. Defected production includes reworks required, rejections and scraps etc [6]. As per Nakajima's text, an OEE of 85 percent is considered as being world class and a benchmark to be established for a typical manufacturing capability [7].

Initial data were collected from shop floor for CNC Lathe machine and is tabulated in Table 1.

Table 1: OEE calculations for the existing conditions

	Description	Duration	
1	No. of setups per day	2	nos
2	Setup time per setup	30	min
3	Break time per day	60	min
4	Preventive maintenance per year - 4 days	3840	min
5	No. of failures per month	6	nos
6	Time to cover each failure - 2 hrs	120	min
7	Shift hr loss due to failure - 1 hrs	60	min
8	Short stoppage per year	45	
9	Time for one short stoppage	30	min
10	Machine designed cutting capacity in	600	m/min
11	Machine actual speed of cutting	200	m/min
12	No. of goods per day	35	nos
13	Rejected goods per month	4	nos
14	Operating hours per day - 16 hrs	960	min
15	Number of working days per year - 325 days		
16	Working days per month - 24 days		
a.	Total working time per day	960	min

	Set up time per day	60	min
	Break time per day	60	min
	Preventive maintenance per day	11.82	min
b.	Total planned down time	131.82	min
	Unplanned down time due to failures per day	45	min
	Unplanned down time due to short stoppages per day	4.15	min
c.	Total unplanned down time	49.15	min
d.	Actual down time = b + c	180.97	min
e.	Total available time = a - b	828.18	min
f.	Actual operating time = a - d	779.03	min
g.	Availability = f / e	0.9406	
h.	Actual cycle time at actual cutting speed = f / (12)	22.26	min
i.	Number of actual products at unit cutting speed = (12) / (11)	0.175	Nos
j.	Number of products at designed cutting speed = i x (10)	105	Nos
k.	Ideal cycle time at designed cutting speed = f / j	7.42	min
l.	Performance rate = k x (12) / f	0.3333	
m.	Number of goods per day	35	Nos
n.	Number of goods per month	840	Nos
o.	Rejected goods per month	4	Nos
p.	Quality Rate = (n - o)/n	0.9952	
	OEE = Availability x Performance rate x Quality rate =	0.3121	
	OEE =	31.21%	

IV. RESULT AND DISCUSSION

The OEE calculated for CNC lathe machine is 31.21% against desired 85% to achieve a world class performance. On a worldwide survey, average OEE gets above 65% in manufacturing industries.

On a detail analysis of the obtained data and the OEE calculation steps, it is understood that the CNC lathe machine's performance efficiency effecting greatly on OEE. The estimated performance efficiency is 33.33% which drags all other positive things. Whereas, the quality rate is getting 99.52 % which is very much appreciable and the Availability of the CNC lathe also not bad, getting as 94.06%. This means the company procured a good class of machine and all the related process concentrated in Quality. All these two factors are giving more mileage on market competency on customer satisfaction. But, of course, will have dangerous hit in profitability.

A. Identification of area for OEE Improvement

The important points coming out from the fishbone diagram are:

1. Lack of knowledge about the machine or operator awareness: the equipment performance is directly proportional to the operator's awareness of proper and optimum use of that equipment.
2. Vibration: performance rate can improve by using the CNC lathe machine in its standard surrounding conditions. Vibration leads to reduce the cutting speed from the rated values.
3. Coolant: Another important factor affecting cutting speed is coolant. Proper application of coolant improves the surface quality and provides easy metal removal.
4. Lack of standardized procedure: Proper documentation about the procedures will assist the operators and related support staffs to perform well and in organized manners. This will reduce the speed loss of the CNC machines.
5. Maintenance frequency: Re planning of maintenance strategy will reduce the down time of the machines.

A through restructuring on these areas will provide drastic improvements in OEE.

B. 5 Why Analysis

The 5 Whys is a question-asking method used to explore the cause/effect relationships underlying a particular problem. Ultimately, the goal of applying the 5 Whys method is to determine a root cause of a defect or problem.

By repeatedly asking "Why" (five is a good rule), we can peel away the layers of symptoms that can lead to the root cause of a problem. Often the reason for the first "Why" will lead to another "Why" and then to another [8].

Benefits of the 5 Whys:

- Helps to quickly identify the root cause of a problem.
- Helps to determine the relationship between different root causes of a problem.
- Can be learned quickly and doesn't require statistical analysis to be used.

With 5why analysis, following benefits can achieve

- Number of production can increase from 35 to 50 per day
- Rejection of produced goods can reduced from 4 to 1 per month.

The 5 Why analysis applied to CNC lathe machine and answer, comments and final action are tabulated in Table.2.

C. Fishbone Diagram

The Fishbone diagram and also called cause-and-effect diagram identifies many possible cause for an effect or problem. It can be used to structure a brainstorming session. It immediately sorts ideas into useful categories.

The low value of the OEE can be analyzed further through the fishbone diagram shown in Fig. 2.

Out comes from the fish bone diagram for low OEE percentage is as follows:

- Man: Lack of knowledge about the machine.
- Machine: Vibration, coolant leakage
- Material: Not identified any problem since it is specific requests from customer.
- Method: No standardized procedure, maintenance frequency, lack of keeping check list and area determination

Table 2: 5 Why analysis applied to CNC Lathe machine

Date	24/12/2014	Machine	CNC lathe	
Problem description		Machine operates in reduced cutting speed which creates drastic reduction in number of products per day. This creates less performance efficiency and overall OEE getting very less.		
Step	Why	Answer	Comment	Final Action
1.	Why machine runs in reduced cutting speed	Because; creates vibration	Vibration created many related problems for machine	Check foundation of machine and any other loose fittings
2.	Why machine creates vibration	Because; improper work holding method	Colet chucks are suitable than the soft jaws	Periodic re-boring needed for soft jaws
3.	Why improper work holding method	Because; lack of operator knowledge	Spot knowledge and experience of operator is a key factor	Better supervision and recruit experienced operators
4.	Why the lack of operator knowledge	Because; no periodic and customized trainings	Customized trainings is more vital for specific batch productions	Improve customized training schedules
5.	Why not periodic and customized trainings	Because; no training schedules and shop floor supervision.	Strategy change required for a continued training programs	Implement training schedule

D. Autonomous Maintenance

In a TPM, Autonomous Maintenance (AM) is one of the most important basic building blocks. Autonomous Maintenance is predominately a production based activity [9]. The goals of an Autonomous Maintenance Program are:

1) Prevent equipment deterioration through correct operation and daily checks.
2) Bring equipment to its ideal state through restoration and proper management.
3) Establish the basic conditions needed to keep equipment well maintained.
4) Use the AM process and equipment as a means of teaching operators new ways of thinking and working.

Proposed 7 steps autonomous maintenance activity is as shown in Table 3.

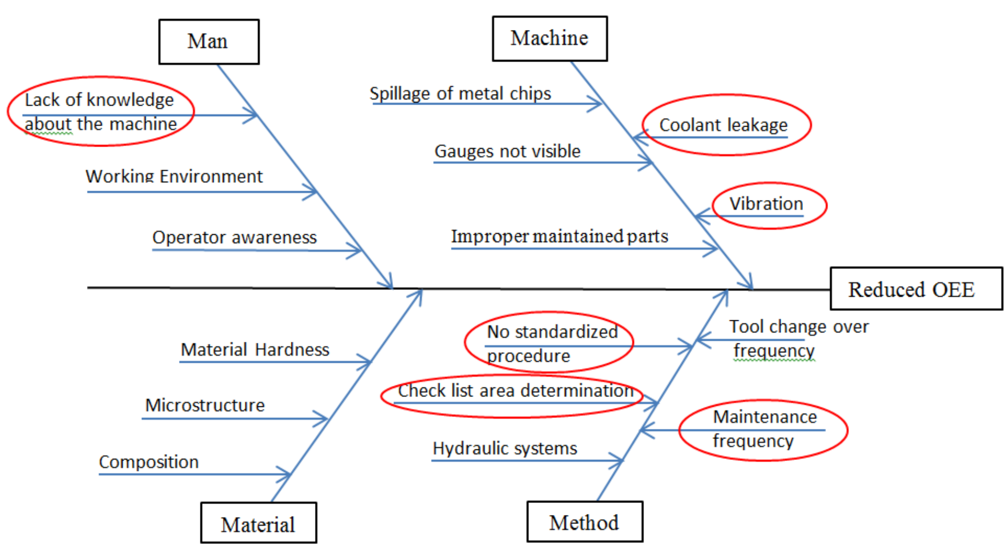

Fig. 2. Fishbone diagram

Table 3: 7 Step Autonomous maintenance

7	Full Autonomous Maintenance.	Gives the accuracy and optimum performance Finally the product quality achieves without compromising performance rating
6	Organisation and Tidiness.	
5	Autonomous Inspection	
4	General Inspection.	Knows the function and structure of the equipment
3	Cleaning and Lubrication Standards.	
2	Counter-measures at the source of problems	These steps detects the problems and clarifies procedures f the equipment
1	Initial cleaning.	

With this activity, following benefits can achieve

- Preventive maintenance can reduce from 4 days to 2 days per year.
- Number of short stoppages can reduce from 45 to 15 per year.
- Cutting speed can increased from 200 m/min to 450 m/min.

E. Planned Maintenance

TPM has a specific tool: Physical Phenomenon and the Mechanism Analysis (normally referred to as P-M Analysis) to deal with losses. P-M Analysis provides the ability to exactly identify the real causes behind each minor stops and quality defects each time [10]. This would thereby eliminate totally the minor stops and quality defects in the operation of CNC lathe.

The Fig. 3 shows the computer system used for planned maintenance activities using built in software diagnosis tools and Fig. 4 shown the block diagram of planned maintenance.

Fig. 3. Computer Assistance for Planned Maintenance

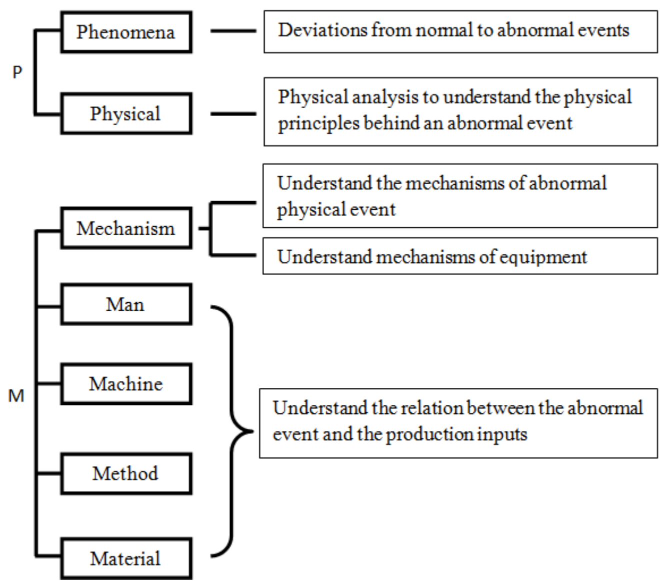

Fig. 4. Block diagram of Planned Maintenance

With planned maintenance activity, following benefits can achieve

- The number of preventive maintenance reduced from 4 to 2 per year.
- The number of failure reduced from 6 to 1 per month.
- Time to cover each failure can reduce from 120 min to 60 min.

F. SMED Analysis

The SMED system is a set of techniques that make it possible to perform equipment setups or changeover operations in fewer than 10 minutes. This improves the Overall Equipment Effectiveness (OEE) vastly.

In this case study, the work holding devices shown in Fig. 5 is to be revised thoroughly as well as tool holding devices. Another major area is setup sequences.

Instead of soft jaw chucks, collets chuck is giving more benefits and the CNC machine can be set to its optimum cutting speed.

Fig. 5. Study on work holding and tool holding system

Other area of this SMED analysis is tool fixing and setting management. Better rework on tooling procedure gives advantages in short stoppages

There are seven basic steps to reduce setup/changeover time by using the SMED system:

1) Observe the current methodology (stage A).
2) Separate the internal and external activities (stage B).
3) Convert (where possible) Internal activities into External ones (stage C) (pre-setting of tools is a good example of this).
4) Streamline the remaining internal activities, by simplifying them (stage D). Focus on fixings - Shigeo Shingo rightly observed that only the last turn of a bolt that tightens it - the rest is just movement.
5) Streamline the External activities; so that they are of a similar scale to the Internal ones (stage D).
6) Document the new procedures, and actions; yet to be completed.
7) Do it all again: For each iteration of the above process, improvement in set-up times should be expected, so it may take several iterations to cross the below ten minute line.

With this activity, following benefits can achieve

- The number of setup can reduced from 2 to 1 per day.
- Setup time can reduced from 30 min to 8 min
- Short stoppages time can reduced from 30 min to 5 min

Table 3**:** Calculations on improved OEE rating

	Description	Duration	
1	No. of setups per day	1	nos
2	Setup time per setup	8	min
3	Break time per day	60	min
4	Preventive maintenance per year - 2 days	1920	min
5	No. of failures per month	1	nos
6	Time to cover each failure -1 hrs	60	min
7	Shift hr loss due to failure - 1 hrs	60	min
8	Short stoppage per year	15	
9	Time for one short stoppage	5	min
10	Machine designed cutting capacity in	600	m/min
11	Machine actual speed of cutting	450	m/min
12	No. of goods per day	35	nos
13	Rejected goods per month	1	nos
14	Operating hours per day - 16 hrs	960	min
15	Number of working days per year - 325 days		
16	Working days per month - 24 days		
a.	Total working time per day	960	min
	Set up time per day	8	min
	Break time per day	60	min
	Preventive maintenance per day	5.91	min
b.	Total planned down time	73.91	min
	Unplanned down time due to failures per day	5	min
	Unplanned down time due to short stoppages per day	0.23	min
c.	Total unplanned down time	5.23	min
d.	Actual down time = b + c	79.14	min
e.	Total available time = a - b	886.09	min
f.	Actual operating time = a - d	880.86	min
g.	Availability = f / e	0.9941	
h.	Actual cycle time at actual cutting speed = f / (12)	25.17	min
i.	Number of actual products at unit cutting speed = (12) / (11)	0.0778	Nos
j.	Number of products at designed cutting speed = i x (10)	46.6667	Nos
k.	Ideal cycle time at designed cutting speed = f / j	18.88	min
l.	Performance rate = k x (12) / f	0.75	
m.	Number of goods per day	35	Nos
n.	Number of goods per month	840	Nos
o.	Rejected goods per month	1	Nos
p.	Quality Rate = (n - o)/n	0.9988	
	OEE = Availability x Performance rate x Quality rate =	0.7447	

V. CONCLUSION

The present condition of the company is not up to the world class expected level. It is running in very low OEE as 31.21%.

As we seen in the existing analysis the availability and quality rate is getting high values. It means the company invested in getting good quality machine. At the same time they are well concentrated in quality of the product. This is very well reflects as availability is 94.06% and the quality rate is getting 99.52%. Problem lies in the performance efficiency. It is getting only 33.33%.

By applying TPM to the entire functions of this CNC Lathe machine, the performance efficiency can bring to 75.00%. At the same time the availability coming as 99.41% and the quality coming to 99.88%. All together OEE is getting as 74.47%.

Improvement of OEE from 33.33% to 74.47% is a remarkable achievement. Even though, the expected world class performance is not reaching. By further detailed study and iterations in the TPM application, the company can achieve the world class OEE performance for this CNC lathe.

ACKNOWLEDGMENT

The management of the company and the floor level supervisors cooperated well with me in this case study. The authors wish to express sincere thanks to all those staffs from the Ray Precision, Muscat, Oman

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