Analysing Cost – Effective Maintenance Policy and Profitability Case- Study[1]

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Abstract

There are many different maintenance approaches; philosophies, strategies, methodologies and policies, described in the literature. One common way to classify maintenance is based on the technique used and its main purpose: Failure Based Maintenance, Preventive Maintenance, Condition Based Maintenance, Total Productive Maintenance and Reliability Centred Maintenance and another's. A decision was to be taken about the replacement of an old line with a new one for the production of the stators for the electric motors. As the line was old production targets were fixed based on the past experience. Therefore, before a decision was taken, whether to replace the line or not it was decided to investigate the productivity of the line. The line consisted of three machines with operators and the rest were simple manual work stations, where operators worked with just tools. It was decided to measure the overall equipment effectiveness (OEE) of the machines. It showed that while the availability of the machines were high, performance efficiency were low. The bottleneck in the productivity was the performance efficiency of the winding machine. The reason for the low efficiency of the machines was management of the operators. Furthermore, it was shown that by raising the OEE to the international level, productivity and hence the profitability of the company can be dramatically increased.

Keywords: Overall Equipment Effectiveness, Performance Efficiency, Failure Based Maintenance, Total Productive Maintenance.

[1] For the abstract in Arabic see pages (225- 226).

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Introduction

Many different maintenance approaches described in the literature, see for example [6, 1, 13 15]. One common way to classify maintenance is based on the technique used with main purpose: Failure Based Maintenance (FBM), where maintenance actions are initiated by failures and the main objective is to put the equipment back to working conditions as fast as possible. FBM.may be motivated in some cases, but usually the costs associated with this approach are considered to be high [1, 10]. Preventive Maintenance (PM), where maintenance is planned and optimised using statistical methods with the main objective of reducing the number of failures and their economic consequences. Several authors have written papers on different methods for optimising PM see [6], for a discussion about different optimisation models and their application. There have been reported problems also associated with this type of model, [11, 6, 1]. Condition Based Maintenance (CBM), where the objective is to determine the best time for intervention by monitoring the condition of the component, thereby utilising as much as possible of its life and at the same time avoiding unnecessary stops because of maintenance [14, 2]. There are also other approaches to planning and organising maintenance work, of which two of the best known are Total Productive Maintenance (TPM) and Reliability Centred Maintenance (RCM). TPM, introduced by Nakajima [12], is a concept for maximising the effectiveness of equipment by reducing production cost and increasing productivity. Working in small groups for solving problems and operator-based maintenance are key features in TPM. There are many implementations of TPM see [9, 7, 4]. RCM used in maintenance with the aim of finding the best maintenance for each significant component and of scheduling maintenance activities [8]. To improve the performance of the next generation of equipment British Standard Institute and others [5, 13, 10] describe an approach for developing maintenance strategies based on the company's business objectives. In Total Quality Maintenance (TQMain) the role of maintenance is defined as: " a means for detecting and controlling the deviations in the condition of a production process, such as damage causes and initiation, damage developing mechanisms and potential failures, production costs, working environment and product quality in order to interfere when it is possible to arrest or reduce equipment/ component deterioration rate before the process condition and product characteristics are intolerably affected and to perform the required action to restore the equipment/ process or a particular part of it to as good as new "[3, 13].

Maintenance Case

In an electric motor manufacturing shop, there were eight ordinary production lines for the manufacturing of the stators. Out of these, one line was sixteen years old and had lived its life of thirteen years. It was targeted to produce 7951 stators in the year 2007. It was 18.8% of the total production of the stators from the ordinary lines. As it was an old line the production targets were fixed based on the past experience. There was no planned maintenance for the line and only corrective maintenance was being done whenever it was required. Guided by the age of the line, the management was toying with the idea of replacing this line with a new one. Before a decision was taken, it was decided to investigate the productivity of the line.

Process Flow Of The Line

There were three different machines in the line. A winding machine, an inserting machine and a lacing machine. There were one operator at the winding machine, two operators at the inserting machine and one operator at the lacing machine. The total number of operators on the line per shift was eight. The buffer between the machines managed of how large the order was. The order fluctuated between 1 to 48 stators, but the median was 20 stators.

Figure 1 shows the process flow of the line.

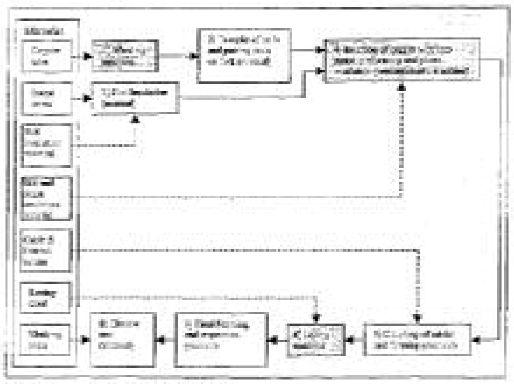

Figure 1. Process flow of the line.

In this figure, number (1) is the winding machine, number (4) is the insertion machine and number (6) is the lacing machine. These machines are involved in the calculation of the overall equipment effectiveness. All the other stages in Fig. 1 are only manual processes. The process starts with the winding of the copper wire and making of coils on the winding machine from the rolls. The length of the wire in a coil and the number of coils made at a time on the winding machine depends upon the stator for which it is made. These coils are transferred manually to another workstation where the coils are put into the fork manually (2). Parallel with this process, an operator does slot insulation on the stator cores, (3) which he receives from the store. Slot insulation means that the operator puts into the insulating paper, in the splints of the stator cores.

Next is the insertion process. In this process, an operator puts the fork with coils into the machine (4) and another brings the stator core into the contact with the fork with coils. The machine is put on and it inserts the coils into the splints of the stator core. It is followed by the insertion of the insulating paper from below. In this way, the coils are insulated from the core from all the sides. The stator core is then taken to another position on the machine, where pre-forming operation is done to give the coils the required shape. After pre-forming, phases are insulated manually. This means that the operator puts insulating paper between the phases to insulate them from each other.

From this station, the stator core is transported to the coupling and forming station (5). Here the operator connects manually the cables and the thermal sensors to the coils. The operator also does a quick test on the resistance. If it is within the prescribed limit, the stator core is transported to the lacing machine (6), were the coils are laced on both sides of the stator with lacing cord. In the final forming (7), the stator is inspected with a gauge for the width dimension of the coil and, if needed, final forming is done. The last step in the process is the final electric tests (8). The final test includes test of resistance, earthing and isolation between phases, phase sequence, and test for the defect, if any, in the phases. Next, a marking plate is fixed to the stator.

Analysis

Effectiveness is related to the process outputs and it could be defined as the ratio of the actual output over the expected output [16]. To be able to maximize the output, an ideal operation condition and effective utilization of the equipment is a prerequisite. To achieve total effectiveness of the equipment there are "six big losses", which have to be eliminated. These are divided into three groups with two losses in each [12]:

- Down times, (availability):

- Machine stoppages due to machine failures and breakdowns

-Set up and adjustment times due to, for example tool exchanges.

- Speed losses, (performance efficiency):

- Idle times and smaller stoppages due to, for example un normal functioning of sensors

-Decreased operation speed due to differences in the equipments planned speed and the actual speed.

- Quality losses, (quality rate):

- Process errors due to the equipment is marred by shortcomings which means waste and quality failures which in its turn results in adjustments or cassations

- Reduced exchange from machine start to stable production.

Due to the impact of the "six big losses" on the total equipments effectiveness these factors should be considered in the calculations of the equipment effectiveness, to give a value more accordance to the reality. In the total overall equipment effectiveness, OEE, the six big losses are considered, [12].

An OEE – value of equation (1) is the maximum output and means that everything is working perfect and functioning to 100%. In other words, the machine or equipment is working non-stop with right speed without producing any defect products or products that have to be reworked, [17, and 15]. When a company wants to increase their overall equipment efficiency, the OEE can help the company to put their focus on the right issue by seeing which one that has the lowest value, [17].

The OEE is given by formula (1), [12, 17]

*OEE = availability * performance efficiency * quality rate.* …. (1)

Availability gives the utilization rate of the equipment or operation and this calculation considers the two losses in the category down times, (see formula 2),[12].

$$\text{Availability} = \frac{\text{Utilized time}}{\text{Loading time}} = \frac{\text{total available time} - \text{planned idle time} - \text{down time}}{\text{total available time} - \text{planned idle time}} \quad \ldots(2)$$

The planned idle time, in the calculation, is the time, which is planned into the schedule from start including for example morning meetings and maintenance, [12].

Performance efficiency is a measure of how efficient the machine is performing. This calculation considers the two losses in the category speed losses, see formula (3), [12].

*Performance efficiency = operating speed rate * net operating rate* ….(3)

This parameter consists of two parts, operating speed rate and net operation speed rate. The operation speed rate measures losses due to the machines are running with decreased speed. The net operating speed measures losses due to idle time and short stoppages, [12 and 17].

$$\text{Operating speed rate} = \frac{\text{Theoretical cycle time}}{\text{Actual cycle time}} \quad \ldots(4) \text{ It could be} > 1$$

$$\text{Net operating rate} = \frac{\text{Actual processing time}}{\text{Operating time}} = \frac{\text{processed amount} * \text{actual cycle time}}{\text{operating time}} \quad \ldots(5)$$

Quality rate is a measure of the amount of non-defect products out of the total amount produced and it includes the two losses from the category quality losses. The formula for quality rate is given by [12 and 17]. (See formula 6)

$$\text{Quality rate} = \frac{\text{Processed amount} - \text{defective amount}}{\text{Processed amount}} \quad \ldots(6)$$

To investigate the productivity the Overall Equipment Effectiveness was calculated for the whole year, 2007. The total number of stators produced was 7954, out of which 105 stators were scrapped. The scheduled number of working hours per shift for the whole year of 2007 was taken from the company and it was 1655 hours. As the line was working in 2 shifts/day, the total working hours for the year was (1655 x 2) 3310 hours. The loading time for the year was calculated from it by subtracting the 2 pauses of 15 minutes each in every shift and 12 minutes meant for handing over the charge to the next person, coming for the second shift. Thus, the loading time was 3050, 8 hours. The number of hours the machines was not Available for production during the year for different reasons were taken from the factory records. The downtimes for the winding, inserting and lacing machines are given in Table 1.

Table 1, Data for the Overall Equipment Effectiveness measurement

	Winding machine	Inserting machine	Lacing machine
Produced amount	7 954 pcs	7 954 pcs	7 954 pcs
Scrapped	11 pcs	81 pcs	13 pcs
Loading time	3 050,8 h	3 050,8 h	3 050,8 h
Downtime	41,5 h	118,55 h	80,8 h
Theoretical cycle time	0,0705 h	0,1833 h	0,0408 h
Operating time	2 879,7 h	2 808,41 h	2 934 h

Calculation of the theoretical cycle time, listed in Table 1, is done from the data gathered from the shop floor. The nominal speed of the winding machine is 560 RPM and is obtained from the machine manual. The winding machine winds the copper wire into coils for different types of stators. There are 11 types of stators, for which the machine makes complete set of coils. The number of coils and the length of the wire in a coil differs by stator type. Theoretical cycle time of the winding machine for each type of stator is obtained by multiplying the number of coils by the number of phases for which coils are made and multiplying it further by the number of revolutions the winding machine makes to produce the coils. The obtained number is then divided by the RPS of the machine. Each time a set of coils are ready, the position is changed manually. This figure has been clocked and found to be 90 sec. Since there are 3 phases, to get a complete set of coils for one stator, this change of position occurs 2 times. Therefore, the total time to change the position is 180 sec. All these figures are summed up and divided by the number of types of stators and the theoretical cycle time of the winding machine, 0.0705 hours, is obtained.

On the inserting machine, it takes 30 sec. to insert copper coils and insulating paper into the stator core and to bring it to the pre-fanning-operation position. The pre-forming operation takes 70 sec. Since 3 phases are inserted, it takes 30 x 3 = 90 sec. for insertion and 70 x 3 = 210 sec. for pre-forming. This time is common to all types of stators. The insertion and performing are done on the same machine. The operator has to move the stator from one position to another. Then the manual operation with the movement and phase insulation takes another 360 sec. Thus, the total theoretical cycle time of the inserting machine is 660 sec. or 0.I 833 hours.

The lacing machine does 150 strokes/minute or 75 stitches/minute (1.25 stitches/sec.). Different types of stators require different number of stitches. It takes 60 sec. to change stator position to get it stitched on both the sides. The total time required for the stitching operation on each stator type is calculated. Since there are I types of stators, all these are summed up and divided by the number of types of stators to get an average theoretical cycle time, 0.0408 hours of the lacing machine. The setup time for winding machine, inserting machine and lacing machine is calculated based on the fact that they do two kinds of setups, "large" and "small". A large setup means that the operator does a setup for change to another stator type and a small setup means that the operator does a setup for change to another variant of the same stator type. An amount of 60% of the setups are large setups and 40% are the small setups. It is approximately 1.5 days between two set-ups and the number of working days during the year 2007 were 216. This gives a total of 144 set-ups during this period. To obtain the set-up time, the set-up activity was closely observed and clocked. The percentage of large and small set-ups and the time between the set-ups was obtained from the company. From these data, the set-up time for the whole year was calculated and is given in Table 2.

Table 2. Time for the change of setups at the different machines

	Winding machine	Inserting machine	Lacing machine
Large. (86 setups)	1,3 h	1,1 h	0,25 h
Small (58 setups)	0,3 h	0,5 h	0,25 h
Setup time per year	129,6 h	123,8 h	36 h

Following Nakajima [12], OEE of different machines were calculated. Before OEE is calculated, availability, performance efficiency and quality rates need to be known which were calculated utilizing the data given in Tables 1 and 2. Their values are given below:

For the winding machine:
Availability…………………..94, 4 %
Performance efficiency, …….19 %
Quality rate…………………..99, 9 %
And the OEE…………………18% …. (7)

For the inserting machine:
Availability…………………..92 %
Performance efficiency………52 %
Quality rate……………………99 %
And the OEE………………….47 % … (8)

For the lacing machine:
Availability…………………..96 %
Performance efficiency ………11 %
Quality rate …………………..99,8 %
And the OEE …………………11 % …. (9)

The motors produced are assembled with the mixer manufactured by the same company. The market price of the motor-mixer assembly is € 6,300. The production cost of the motor mixer assembly is € 1,910. Thus the profit is €

4,390. The production cost of the motor (excluding rotor and assembly of the rotor into the motor) is € 174,4 (the production costs quoted above include only the overheads at the plant) and 7954 stators were produced in the year 2007. Assuming that the profit is divided between the motor and the mixer in the same proportion as the cost of production, profit on the motor can be calculated by the following equation,

(19100 / 1744) = (43900 /PM) …. (10)

Where PM is the profit on the motor and:

PM = 400, 8 €.

The production cost/stator at the *OEE* value of the inserting machine of 47% is € 174, 4. If this *OEE* value is increased to 85%, the production cost/stator would be € 150,8 as the number of stators produced would be 14385, i.e., 643I more stators. Assuming that everything else remains the same, the profit would increase by € 2,577,544,8 /year.

Results And Discussion

According to Nakajima [12], when a company has implemented TPM, it is usual to expect That, the *OEE* of a machine would be 85%. It means that the availability would be higher than 90%, performance efficiency would be higher than 95% and the quality rate would be higher than 99%. These criteria can be used to judge if the *OEE,* availability, performance efficiency and quality rate of the machines involved in the production are satisfactory or not The *OEE* of the winding, inserting and lacing machines are 18%,47% and 11%, respectively and are not satisfactory. The availability of the winding, inserting and lacing machines is 94.4%, 92% and 96% respectively and are satisfactory. The quality rate of the winding, inserting and lacing machines are 99.9%, 99% and 99.8% respectively and are also satisfactory. The performance efficiency of the winding, inserting and lacing machines are 19%, 52% and 11%, respectively, and are not satisfactory.

The OEE-values of the three machines show that the inserting machine is the bottleneck in the line. It is because of the fact that the machine has the highest OEE - value (47%), and this means that this machine is most sensitive to the disturbances. Moreover, if the *OEE* of the inserting machine could be increased to 85%, immense increase in the profit could be expected. The machines have good availability, because they are all over the goal of 90 %. The machines have also a good quality rate. This shows that the electric motor shop has a good and well functioning organisation and work procedure to handle quality issues.

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The performance efficiency of the winding and lacing machines are low as compared to the inserting machine. It shows that much of the capacity of the winding and lacing machines as compared to the inserting machine remain unutilized. That they do not use more capacity ofthe inserting machine depends on idling and minor stoppages. From another point of view, alarge overcapacity of the winding and lacing machines means that the production disturbances do not disturb the lead-time and production .

Finally, TPM, introduced by Nakajjma, is a concept for maximizing the effectiveness of equipment by reducing production east and increasing pracluetivity.

Working in small groups for salving problems and operator - based maintenance are key furfures in TPM.

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