Performance augmentation of machining centers by improving the overall equipment effectiveness in subsystems

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Abstract. The demand for increase in performance of the manufacturing units is increasing day by day. This project work aims at improving the Overall Equipment Effectiveness (OEE) of a Hardinge 600 II series Vertical Machining Centre (VMC) machine by modification of its subsystems. The problems related to higher power consumption and decreases in the units produced per unit hour were taken for analysis. By analyzing the earlier conditions it was found that the productivity of the VMC machine was found to be limited because of low OEE. The installation of an accumulator in the hydraulic system of work holding device and a simplification of the chip removal mechanism was proposed on the VMC subsystem. Also these changes were only possible to be done effectively by removing the existing conveyer belt and introducing tray disposal system. After the suggested changes were made the machine was again investigated to check for any possible increase in the OEE. An increase of 40% in OEE was achieved after implementation of the suggested changes. The improvement in OEE could be followed in similar machines such as HMC machines, FMS setups and other machines through proper steps for better productivity of the manufacturing facility.

Keywords: Vertical Machining Centre, Overall Equipment Effectiveness, performance

1. Introduction

The OEE is a standard for analyzing the effectiveness of the sub systems of the machine; it is used for increasing effectiveness of a machine. The productivity of the machine can be improved, so measures are taken to increase the productivity. Due to use of separate conveyer belt to transfer chips to filter tank, a motor has to be used for conveyer operations. Hence more power is consumed eventually leading to high electric bill. Due to delay in cleaning of burr from filter tank there is a decrease in productivity because the operator has to periodically clean the burr from the filter tank which is tedious and time consuming. Due to usage of separate motor for conveyer belt and continuous usage of hydraulic pump motor the power consumption increases and this will result in increase in overall cost.

Bamber et al. (2003) grouped a cross-functional team to work for OEE. Their research has shown that the most successful method of employing OEE is to use cross-functional teams aimed at improving the competitiveness of business. Raja and Kannan (2007) have done evolutionary programming to improve yield and OEE of casting industry. They optimized the parameters causing problems using Total Productive Maintenance (TPM) and evolutionary programming. Hedge, Mahesh and Doss (2009) have carried out a review on impact on OEE by Total Preventive Maintenance (TPM) and 5S techniques in a CNC machine shop. They increased the total saving per annum around Rs. 4,53,000/- by increasing the OEE from 43% to 72%. OEE was improved by applying Pokayoka and Kaizen effectively on the machine.
Taisir and Almeanazel (2010) have carried out a review on the on Total Productive Maintenance (TPM) and stressed the importance of measuring the OEE. By daily maintenance they reported to have achieved 99% of quality factor, 76% of availability and 72% of performance. They also suggested a computer maintenance system and active production planning to increase the productivity.

Fore and Zuze (2010) have shown improved OEE through TPM. They recommended implementing Computerized Maintenance Management System (CMMS) for large plants, since preventive maintenance cannot be handled manually.

Samad, Hossain, and Asrafuzzaman (2012) have done an analysis of performance by OEE of CNC cutting section of a shipyard. They reported that, by increase in performance by eliminating certain factors which affect the down time, speed loss and quality loss.

Afefy (2013) has made detailed report on implementation of TPM and evaluated the OEE. An increase in OEE was attributed to increase in the quality by 93% and availability by 87% and the performance by 87.5%, all using TPM technique.

Vijayakumar and Gajendran (2014) reported Improvement of OEE in injection molding process industry. They reported to have increased the OEE from 61% to 81% through implementation of availability, better utilization of resources the all of which have also raised levels of employee morale and confidence also improved.

Vivekprabhu, Karthick and Kumar (2014) have optimized the OEE in a manufacturing system. They said that decreasing the Mean-Time-Between-Failure (MTBF) and Mean-Time-To-Repair (MTTR) OEE can be improved and also said that maintaining the performance level above 95% would result in effective utilization of the considered manufacturing system.

Lahri and Pathak (2015) has made a case study of implementing OEE to CNC table type boring and milling machine (Make: Juaristi) of a heavy machinery manufacturing industry. The researchers reported that OEE extracts all the reason for delay of the job and after carrying out OEE by finding out the bottle necks and hidden losses. They concluded that the productivity increased to a significant level.

Suryawanshi and Karmarkar (2015) have carried out investigations on improvement of the OEE of a wire cut CNC through the implementation of TPM. They reported an increase of OEE from 43% to 65% by using autonomous maintenance and planned maintenance.

Salim and Rameshkumar (2016) have made a case study on the OEE for CNC lathe machine using TPM. They reported that an improvement in OEE can be as high as 74% and also availability of machine tools increased soon after implementing of TPM.

Lande, Sirsat and Tupkar (2017) have done a case study on the predictive maintenance of QJ/5522 DT-40CNC milling machine. They designed a predictive maintenance technique to determine the condition of a machine in order to predict when maintenance should be performed.

2. Objectives
The primary goal of this investigation is to eliminate the losses and to increase its OEE of the VMC 600 CNC machine through detailed analysis of the operating conditions and performance of the machine.

The performance analysis of the machine is carried out by using OEE methodology for the proposed work. The modifications are carried out in a VMC machine with objectives to identify of the problems in existing VMC setup, to determine the parts of existing VMC setup to be eliminated, to identify time required to complete the modifications in VMC system, to decide on the evaluation methods used in analyzing the performance of the machine and to propose a feasible solutions to the VMC system.

3. Preliminary study of VMC system
The details of electrical specifications of the machine VMC 600 (Make: Hardinge) manufactured by Taiwan Precision Machinery Limited are given in table 1.

Table 1. Electrical specifications of machine - VMC 600

| Parameter                          | Value         |
|------------------------------------|---------------|
| Machine power consumption          | 25 kW         |
| Frequency of the machine           | 50 Hz         |
| Supply Voltage                     | 220 V         |
| Phase                              | 3 Φ           |
| Spindle Drive                      | 69 A          |
| Control Unit                       | AC 110V       |
| Short circuit interrupting capacity of the over current | 25,000 A |

As the process related information is vital to calculate the time, material and other requirements the production related figures are collected from the existing conditions. The observations made during the primary investigation are given in table 2.

Table 2. Production Parameters for VMC machine

| Parameter                          | Value         |
|------------------------------------|---------------|
| Component machined                 | Fly wheel housing for Cummins |
| No of shifts per day               | 3             |
| No of units manufactured per shift | 70            |
| No of Tools                        | 24            |

Feasibility analysis was carried out to verify whether the logical and technical output can be finished or not. All problems are studied and analyzed completely and are noted down. The secondary investigation aims at analyzing the problems thoroughly by a fish bone diagram. The performance of the machine depends on various factors like operator, type of material machined, number of units to be produced per shift, Quality required, efficiency and skill of the operating personnel, etc., The fish bone diagram for the analysis of the performance of the machine is shown in the figure 1.

![Fish Bone Diagram for analysis of a CNC machine](image)

It was observed that conveyer belt setup has to be replaced first because it occupies more space and consumes electricity due to running of motor which is used to rotate the conveyer belt. Secondly Hydraulic Motor setup has to be replaced the continuous running of the motor to supply adequate pressure for the work holding devices eventually leads to increase in power consumption, to reduce the cleaning time of the filter tank which will increase the productivity. The power utility cost of the total setup should be also reduced.

The prioritized problems are thus, Replacement of conveyer belt, Inclusion of an accumulator for hydraulic pump unit, reduction of the cleaning time of the filter tank, and reduction of the
power utility cost for the entire machine.

4. Detailed study about OEE
The literature survey helped us in arriving at the solutions easily and we gained sufficient knowledge about various maintenance techniques and principles they used in establishing OEE.

4.1. Alternate Solution for Conveyer
Removal of conveyer setup and installation of pneumatic setup for cleaning the burr will occupy less space compared to existing setup. Cleaning burr using push and flush coolant methods is a another alternative solutions for removal of the burr from the machining area and the burrs will be removed effectively using this technique when compared to conveyer setup because the force of the coolant is higher so that the burrs will be transferred easily from the machining area to collection area. Running the conveyer belt motor by using other sources like solar power, etc.
Use of accumulator as a pressure storage device is the best remedy for the above mentioned problem. Use of solar power to run electric motor may be one of the alternative solution for using solar power as a source for running the motor instead of electric power.
Usage of vacuum cleaner to clean the burr in the filter tank is one of the proposed alternatives for the specified problem. Usage of single mesh tray and a larger tank than the existing one is considered. Usage of solar power to run electric motors to reduce the power utility bill to a considerable level and increases the efficiency of the unit since no power is taken from outside. Hence equipping with power efficient components is considered as one of the alternate solutions for the specified problem.

4.2. Reducing Power Consumed by Hydraulic Pump
Usage of accumulator as a pressure storage device reduces the power consumption for the hydraulic unit, since the accumulator does not require continuous running of electric motor, sufficient pressure is stored in the accumulator for clamping the work holding devices.

4.3. Replacement of double layered tray
By replacement of double layered mesh with single layered tray easier cleaning of burr is enabled. This helps in decreasing the cleaning time of the tray. Hence It helps in the improvement in productivity as well as reduction of operator fatigue.

4.4. Reduction in Power Consumption Bill
To reduce the power consumption, in house power generation through solar panels was considered before considering modification of existing components. But solar panels don’t work efficiently if the panel layer is surrounded by dusts as smoke is raised in the industry while melting aluminum. So the option of using solar powered motors is neglected. Also, solar panels are ineffective on a cloudy day due to this productivity will decrease. Hence taking all considerations into account the modifications of the subsystems is selected as the best alternative solution.

5. Result - Implementation of solution
Implementation of the proposed solution is critical one because the modification of the sub systems should not disturb other components and should work effectively and efficiently. It should bring in the expected results in terms of OEE. Every modification is analyzed thoroughly before implementing. They are implemented according to their prioritization as mentioned earlier and the performance before and after implementing the modifications are noted down.

The OEE is a function of availability, performance and quality, expressed in general as,
OEE=(Cycle time x Good count)/ (Planned time x Total count)

The above relation clearly explains that the OEE is directly proportional to cycle time and number of good count in total count, and inversely proportional to the planned time. So, as the planned time is decreased the OEE can be increased.
5.1. **Conveyor Replacement**

Existing Setup Power Consumption:

- **Drive Motor Specification:**
  - **Volt:** 400VAC
  - **Current:** 5 Amps
  - **Power:** 4KW

  
  **Working hours per shift** = 7 hrs

  **No of shifts per day** = 3

  **Total working hours per day** = Working hours per shift * No of shifts per day

  **Total working hours per month** = Total working hours per day * 30

  **Total working hours per month** = 21 x 30 = 630 hrs

  **Power consumed in a month** = 4 x 630

  **Power consumed in a month** = 2520 kW hr

  **Cost per month** = Rs. 24,642

Extra Coolant Pump Specification:

- **Volt:** 415 V
- **Current:** 5.43 A
- **Power:** 2.25 kW
- **Rpm:** 3000

  
  **Total working hours per month** = 630 hrs

  **Power consumed per month** = Total working hours per month * power

  **Power consumed per month** = 2.25 x 630

  **Power consumed per month** = 1417.5 kW hr

  **The monthly cost due to usage of coolant pump** = Rs. 17288

  **Cost saved per month due to replacement of Conveyor belt** = 24642 – 17288

  **Cost saved per month due to replacement of Conveyor belt** = Rs. 7354

  **No of coolant motors used** = 2

  **Type of coolant used:** WS 5050

  **Previous capacity of coolant tank** = 100 lit

  **Modified coolant capacity** = 2 x 100

  **Modified coolant capacity** = 200 lit.

  **Tray of 300 micron and 800 micron are used in filtering the chips formed during the operation.**

  **This is chosen based on the chip size.**

  **Tank size was chosen based on the opening of the work table. Size chosen: 80*55 cm**

5.3. **Maintenance Improvement**

- **Previous time taken for cleaning** = 3 min
- **Current time taken for cleaning** = 1 min
- **Time saved per cleaning** = 3-1 = 2 min
- **No. of cleaning cycles per shift** = 4
- **No. of cleaning shifts per day** = 4 x number of shift = 4 x 3 = 12
- **Time saved per day** = Time saved per cleaning x No. of cleaning shifts per day
- **Time saved per day** = 12 x 2 min = 24 min

  **Parts produced per shift** = 70 parts

  **Number of working hours per shift** = 7 hrs

  **Parts produced per hour** = Parts produced per shift / working hours per shift

  **Parts produced per hour** = 70/7

  **Parts produced per hour** = 10 parts

  **Parts produced per 24 minutes** = Parts produced per hour x 24/60

  **Parts produced per 24 minutes** = 10 x (24/60)

  **Parts produced per 24 minutes** = 4 parts.

  **So in average for every day the time is saved for the production of extra 4 parts. It doesn’t mean**
that for every day extra 4 parts can be produced excess, it means that in case of defects in parts machined this will compensate the target to be achieved by the production. It may also be helpful to increase overall productivity.

5.4. Selection of Accumulator in Hydraulic System:

Uniform pressure required = 50 bar

The pressure requirement varies according to the weight of the work piece and the rotation speed of the machine. In this case of Hardinge VMC 600 machine the pressure required for clamping and jacking is 50 bar

From design table for working pressure of 50 bar

Type of Accumulator chosen is: EBV0.5-50/00-A25KD-200

Effective gas volume = 0.5 lit

Maximum flow rate = 450 lit/min

Maximum weight = 3 kg

The symbols mentioned below can be identified from the image of the accumulator shown in figure 2.

Maximum height,

A = 245 mm
B = 52 mm
C = 28 mm
D = 90 mm
e = 68 mm

d = 16 mm

Fig.2. Accumulator Dimensions

Previous running time of motor = 21 hrs
Current running time of motor = Parts per day * running time
Parts per day * running time = 210 x 10
Parts per day * running time = 2100 sec
Current running time of motor in minutes = 2100 sec / 60
Current running time of motor = 35 minutes

Take 1 hr approximately considering other allowance

Current running time = 21 - 1 hr
Difference in time = 20 hr
Power saved by using accumulator = 2.3 kW x 20 hr
Power saved by using accumulator = 46 kW hr
Power saved per month = 46 x 30
Power saved per month = 1380 kW hr/month

We save Rs 16,822 a month by using accumulator.

Overall equipment effectiveness (OEE) = A x P x Q
Where A = Availability = Run time / Planned time
P = Performance = (cycle time x total count)/Run time
Q = Good count / Total count
Run time = Planned time – Stop time
Good count = Total count – Rejection count

So by substituting all the corresponding factors in its position
OEE = Cycle time * (Total count – Rejection count)/Planned time x Total count
OEE = (Cycle time x Good count) /(Planned time x Total count)

By the modifications done in the subsystems of these machine there is a reduction in planned time of about 24 minutes. By this reduction in the planned time the OEE gets increased.
By the calculations shown, for each day 10 extra parts can be machined, by this the ratio of good count to total count is increased
Therefore by decreasing the time factor about 24 minutes and increasing the count factor by giving an allowance of 10 parts the OEE of this machine is increased.
Previously the OEE is given by means of Availability=78%, Quality=76% and performance=84%
So, OEE = 0.78 x 0.76 x 0.84
OEE = 0.498
OEE (before) = 49.8%

After the modification is implemented there is an increase in the factors of the OEE as given below,
Availability = 93%, Quality= 87%, Performance = 96%
Therefore, OEE = 0.93 x 0.87 x 0.96
OEE = 0.776
OEE (after) = 77.6%

Therefore it is seen that by the implementation of the modifications the OEE of the machine is increased from 49.8% to 77.6%.
Parameters of OEE before and after modification is given in Table 3

| Parameters                          | Before  | After  |
|------------------------------------|---------|--------|
| Productivity (units/hr)            | 10      | 12     |
| Power consumption cost (Rs)        | 24,642  | 17,282 |
| Cleaning time (minutes)            | 3       | 1      |
| Availability (%)                   | 78      | 93     |
| Quality (%)                        | 76      | 87     |
| Performance (%)                    | 84      | 96     |
| Overall Equipment Effectiveness (%)| 49.8    | 77.6   |

Figure 3 shows the factors of OEE before and after modification. The increase in all the parameters of the OEE of the machine can be observed.

Fig.3 Comparison of parameters before and after modifications
6. Conclusion
One of the major losses in the equipment is due to the large electricity consumption. This problem is solved by removing of the conveyor set up. Another is the disposal of the wastes produced from the equipment. The time taken is reduced to a large extent by fixing up a trash removal method. This helps to increase the productivity. Work holding set up losses is also have been removed by using an accumulator set up which in turns reduces the power of the motor. Upon the modifications which had been subjected to change and set up, OEE is increased from 49.8% to 77.6%. Thus it has been seen that OEE has a significant performance measurement tool which considers cumulative impact of all its components. The losses were identified using fish bone diagram method. The factors responsible for lowering the OEE were identified and suitable modifications were carried out which resulted in considerable improvement in availability, quality, performance and OEE.

References
[1] Afefy I H 2013 Implementation of Total Productive Maintenance and Overall Equipment Effectiveness Evaluation Inter J Mech Mechatronics Eng 13 231
[2] Taisir O and Almeanozal R, 2010, Total Productive Maintenance Review and Overall Equipment Effectiveness Measurement Jordan J Mech indus Eng 4 24
[3] Bamber C J et al 2003 Cross-functional team working for overall equipment effectiveness (OEE) J Quality Maintenance Eng, 9 94
[4] Fore S and Zuze L 2010 Improvement of Overall Equipment Effectiveness through Total Productive Maintenance Int.Journal of Manufacturing Engineering, 4 64
[5] Hedge H G et al 2009 Overall Equipment Effectiveness Improvement by TPM and 5S Techniques in a CNC Machine Shop SuxTech 8 45
[6] Lahri V and Pathak P 2015 A Case Study of Implementation of Overall Equipment Effectiveness on CNC Table type boring & milling machine of a Heavy Machinery Manufacturing Industry J Mech Civil Eng 12 24
[7] Lande M S et.al. 2017 A Case Study on Predictive Maintenance of OJ-5522-Dt-40 CNC Milling Machine. Int J Adv Res Pub, 1 45
[8] Levitt and Joel 2009 The Hand Book of Maintenance Management 2 ed New York: Industrial Press
[9] Willmott P and McCarthy D 2014 TPM a route to world class performance 2 ed Delhi: Butterworth Heinemann.
[10] Raja N P and Kannan S M 2007 Evolutionary programming to improve yield and OEE of casting industry J Eng app sci 2 45
[11] Salim R K Rameshkumar G R 2016 Optimization of Overall Equipment Effectiveness through Total Productive Maintenance Perspective- A Case Study Int J Multidisciplinary Sci Eng 7 1
[12] Samad M A et al 2012 Analysis of Performance by Overall Equipment Effectiveness of the CNC Cutting Section of a Shipyard ARPN J Sci Tech 2 24
[13] Sarfraz M S 2018 Implementing a Preventive Maintenance Planning Model for Computer Numerical Control (CNC) Milling Machine American J Embedded System and Applications 2 23
[14] Sinhal A and Kulshreshtha A 2016 Overall equipment effectiveness improvement by reducing non value adding activities using lean tools Int Adv Res Innovative Ideas in Education 2 45-51
[15] Suryawanshi V and Karmarkar.G 2015 Improvement in the Overall Equipment and Effectiveness of wire cut CNC machine through the implementation of TPM Int J Sci Res 6