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Retrofit of two way holding chuck to improve process efficiency and resource management

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ABSTRACT

In today’s industrial scenarios, having continuous improvement to increase the process efficiency is one of the key measures. Especially manufacturing and automotive industries are putting forth a lot of resource and time to improve the efficiency of the process without compromising the current production capacity and improve the quality rate. This paper deals with a case study of retrofitting a two-way chuck in a vertical lathe machine and thereby calculating the overall equipment effectiveness of the entire automated process in piston manufacturing. The current automated production line of piston manufacturing is being analysed with the help of value stream mapping (VSM). Value stream mapping is widely used by the industrial persons to identify the wastes i.e., non-value-added time in the process line. The Critical to Quality (CTQ) parameters in an efficient production line such as lead time, value added time, transfer time and take time have taken into account for identifying the places of improvement. A new retrofitted design has been suggested which can increase the production efficiency of the current system with effective utilization of available resources. After implementing the modified retrofit design, the subsequent changes in the process line have also been stated through Future state VSM, which clearly indicates the reduction in drop to drop time between the cells which has been considered as the non value added time in the current system. Studies like these shows that effective utilisation of available resources through retrofitting can greatly assist the manufacturers to reduce their cost of additional investment and be sustainable among the growing competitors in the market.

1. Introduction

A company’s efficiency and competitiveness are the most challenging aspects in the fast-growing global market which have motivated the firms to plan manufacturing management strategies. The critical issue addressed by them are, delivery of the product at the earliest to the customer, and at low cost without compromising the quality of the product [14]. One of the well-established systems is lean manufacturing which involves transformation of existing process manufacturing system into a system with elimination of waste i.e., eliminating non-value-added time/activities existing in the process [11]. One of the lean manufacturing techniques called value stream mapping helps to identify the places wherever improvements are possible with the help of other lean tools. Value Stream mapping is simple and visual process-based tool, enabling documentation, visualisation, comprises materials and flow of the process [2]. In order to find waste within the process and assist in elimination of the waste, in the last few years organisations around the globe have used the value stream mapping which enabled them to achieve higher efficiency within the system [6]. A case of automated piston manufacturing line has been taken into study and for further continuous improvement and better resource allocation by analysing current state of the process. The technology has been growing at a higher growth rate and new equipment coming into the manufacturing markets is growing exponentially. Thus, for the companies to stay in the competitive market, it is imperative for them to adapt to the latest technology and machinery which are currently trend [7]. In many industries, the resources within a system have been increasing and without any acquaintance, the excessive resources are either being idle or scraped. The available resources could be utilised, redesigned, retrofitted or used for different application [10]. This way the resources can be effectively utilized without wastages. Various researchers have proven that optimization with retrofitting has shown considerable increase in the efficiency of operation. Chen, Ting-Yu, et al. show that optimisation of the headstock with
redesign or new parts would be great performance enhancers [4]. Alquraan, T, et al., said that the chuck designs can be used for high speed cutting and it is apt for CNC lathes [1]. Dimitrov, Dimitar, et al., in their study suggested that retrofitting of tool holder with multiple tool holder with standard setup will be very helpful and reduce the non-value-added time [5]. The automated piston production line for the piston have been taken as a case study to reuse the existing vertical lathe machine in the existing automated production line which includes four cells comprising of horizontal lathe machine. The new redesigning of the existing process line with the available resource using a two-way holding pull back chuck in a vertical lathe machine replacing horizontal lathe machine could demonstrate that sustainability of process line also can be achieved by excellent resource management [3].

### 2. Value stream mapping

This is a method of using symbols, metrics and arrows to show the flow of inventory and information required to produce a product. A visual presentation of the current process, delivery system and inventory management can be plotted [11]. It helps to identify the wastages within a production system or in the logistics. Enabling us to map the production system by value-added time and non-value added time [2].

Initially Pistons are produced for the domestic market in batch production methodology and have been supplied to the customers in monthly batches. The current production rate is 1692 per day of three shifts (8 h/shift) which brings about 40,000 pistons for one month inclusive of products rejected in quality check which is 2300. The process of piston manufacturing starts initially with casting of pistons and then removing the crown plug which is in excess during the casting process. Thus the process of crown plug removal is made mandatory after the casting process. The current value stream mapping below shows the number of cells being operated with horizontal CNC lathe machine with number of employees being used.

A current state VSM is prepared for the existing setup as shown in above Fig. 1. The mapping clearly shows the number of cells involved in the production of pistons and number of process in each cell. It starts with plunging, Outer Edge (OE) crown boring and Oil Hole (OH) drilling then it is moved to next cell with the help of robotic arm. The cell 2 consists of rough grooving, semi finish boring and dishing and later moved to the next cell. The cell 3 consists of finish grooving, circlip grooving and finish Outer Diameter (OD) turning. Then it moves on to the last cell 4 comprising accurcising, washing and End –of-Line (EOL) gauge. The drop to drop time for robotic arm is fifty-one seconds inclusive of unlocking the work piece, picking the other work piece and then to place it in the horizontal lathe machine. The above picture indicates that three employees are assigned to this automated line. The Mapping of the new process line clearly shows the improvement after retrofit and its impact on resource management Figs. 2 and 3.

### 2.1. Chuck adapter design

The production line implemented is an autonomous production line which utilizes the help of CNC coding predefined earlier to run the system, thereby eliminating the wastages in the basic areas. Thus, the concept of retrofitting was incorporated, i.e., any new parts or new design to an existing machine. In our case we are considering through resource management, vertical CNC lathe machines were available thus retrofitting them with the help of push back two-way holding chuck. In order to do so, the chuck holder of the existing vertical CNC lathe has to be considered for redesigning and produced in order to hold the new chuck. After considering different alternative designs for the adapter, it was narrowed down to one design which would be a single part adapter which can restrict the other unwanted degree of freedom except the rotational axis effectively.

A master adapter and a corresponding centre slide was modelled which has threads for mating with the adapter, and a centre nut which aids in fixing the push back two-way holding chuck adapter with it. The centre slide is screwed with the draw bar directly and controls the jaw movement. During the rotary motion all other degrees of freedom are arrested and the parts are safe and secure during production.

Adding to that, the existing face plate was also modified which had 12 nuts, 6 nuts for fixing the face plate with the a2 6 spindle and other 6 nuts for arresting the relative motion of the adapter with respect to the face plate.

The 6 nuts which were used for arresting the relative motion of the face plate were deleted and the other 6 nuts are retained on the face plate. It consists of the master adapter and the Sinkang adapter. The master adapter is fixed directly with the spindle thus eliminating the presence of the face plate. The Sinkang adapter is used for mounting the master adapter with the chuck. The functions rendered by the three parts of the adapter are done by the single master adapter and thus the weight is considerably reduced and the purpose of the adapter is also served.

### 3. Vertical lathe machine

While horizontal lathes are very versatile and easily adapted to perform a very wide range of different operations, generally they do not meet the demand for turning parts in large quantities and at high production rates. This demand is met by other types of high production turning machines such as vertical turning lathes. These lathes are designed with a vertical spindle [9]. They can be controlled manually or automatically by mechanical mechanisms or electronic controls [4].

The vertical lathe, commonly referred to as a vertical boring mill, has a circular table which revolves around a vertical axis so that the work holding surface is horizontal, thus making it comparatively easy to place and hold large circular parts in position [1].

There is a class of medium sized to very large vertical spindle lathes that are not intended for high production manufacturing.

### Table 1

Current state process time in four cells.

| Operation          | Seconds | Operation          | Seconds | Operation          | Seconds | Operation          | Seconds |
|--------------------|---------|--------------------|---------|--------------------|---------|--------------------|---------|
| CELL 1             |         | CELL 2             |         | CELL 3             |         | CELL 4             |         |
| Operation          | Seconds | Operation          | Seconds | Operation          | Seconds | Operation          | Seconds |
| Plunging           | 34      | Rough Grooving     | 28      | Finish Grooving    | 32      | Accurring          | 38      |
| OE Boring          | 31      | Semi Finish Boring | 28      | Circlip Grooving   | 35      | Washing            | 26      |
| OH Drilling        | 26      | Dishing            | 30      | Finish Od Turning  | 28      | EOL Gauge          | 28      |
| Robot Drop to Drop | 51      |                   | 51      |                    | 51      |                   | 51      |
| Total              | 142     |                   | 137     |                    | 146     |                   | 143     |
These machine tools, usually called vertical boring mills, are designed to perform turning type operations on work pieces that are more convenient to be laid down and held on a horizontal face plate surface than on the vertical face plate surface of a conventional lathe [5]. Many medium and large sized parts are machined more conveniently in this manner. Often these machine tools are required to bore large deep holes, in which case the boring bars or long tool holding slides are attached in a vertical position. Held in a horizontal position, these bars or slides would bend or sag appreciably under their own weight, which would make it difficult to bore an accurate hole. Many of these machines are operated by numeric control, which enables them to machine complex contoured surfaces in addition to performing other more conventional operations [13]. The vertical turning lathe has specific advantage when it comes to tool holders as it can hold more number of tools as in this case it needs room for four different tools in a single vertical lathe [12].

4. Process modification

With respect to the literatures mentioned earlier, the place of holding the piston by the robotic arm is going to be changed, and the transfer time with respect to holding of piston will be reduced by 9 s. The robotic arm moving horizontally by holding the work piece needs certain precision as there is stress developed during the movement and holding of the work piece. Hence, this movement has to be optimised and was fixed as fifty-one seconds. The work piece is initially held at the body of the piston and after implementing the new design, the piston is held at the top. In this perspective, the position of holding the piston reduces the stress implicated while fitting precisely in the vertical CNC lathe, as the robotic arm moves and holds the work piece vertical. Thus the optimum transfer time was calculated to be nine seconds lesser than the previous process design. The new proposed process line operation is given below in Tables 2–4.

With respect to the new process design the total numbers of cells were reduced to 3 with each performing 4 operation within them. The new process flow is given in the below arrangement. Starting with plunging operation, OH drilling, OE boring and surface finish boring in cell 1, it is then transferred to cell 2 with robotic arm of forty-two seconds. In cell 2 finish grooving, dishing, OH drill and circlip grooving are done and finally at the cell 3, finishing OD turning, accurcusing, washing and EOL gauge are performed.

The absence of the centre slide prohibits the movement of the jaw due to the fact that the adapter cannot move in the vertical direction. A master adapter and a corresponding centre slide was modelled which has threads for mating with the adapter and a centre nut, which aids in fixing the Sankang adapter with it.

With the new proposed design, the future state value stream mapping is done which is shown below in Figure: 3. It clearly shows, with 3 work cells in the system and with the same 3 workers who were working earlier, there is a reduction in total lead time as the drop to drop time of robotic arm in between the work cells has been considerably reduced approximately to nine seconds. The future state mapping also shows the increase in effective use of the resources available in the organisation.
5. Overall equipment effectiveness

Calculating the Overall Equipment effectiveness for the current state and future state have clearly shown the difference that retrofitting has shown good improvement within the system, the table below gives the overall equipment effectiveness of both existing and new process design. The below formula shows how overall equipment effectiveness calculated.

1. Planned Production Time = Shift length – breaks
2. Operating Time = Planned Production Time – downtime
3. Good Pieces = Total no of Pieces – rejected pieces
4. Availability = \[
\frac{\text{Operating Time}}{\text{Planned Production Time}} \times 100
\]
5. Performance = \[
\left(\frac{\text{Total Pieces}}{\text{Operating Time}}\right) \times \text{Run rate}
\]
6. Quality = \[
\frac{\text{Good Pieces}}{\text{Total no of pieces}} \times 100
\]
7. Overall Equipment Effectiveness (OEE) = \[
(\text{Availability} \times \text{Performance} \times \text{Quality})
\]

6. Results and discussion

The present work which has been optimised to show that the retrofitting i.e., redesigning, replacing a component or adding a different component is done to increase the advantage of the machine utilisation which in turn also increases the effectiveness of production line. The calculation of overall equipment effectiveness gives the perspective of advantage over the new process line as the drop to drop time between the cells has been reduced from 51 s in the current state to 42 s in future state. Elimination of wastages by using value stream mapping is a thorough well sort within the manufacturing sector, and as for this case, it shows that retrofitting of a vertical CNC lathe with a two way holding chuck has increased the effectiveness. The number of cells required for total operation has been decreased from four to three, which gives the current system an edge to adapt or increase the production with the help of available resources. This not only helps the machines, but also assists in effective usage of available man power. It has been predicted that, with the current setup of three cells, the company can expect its production capacity to have a higher production rate.
as; number of pistons produced per day of three shifts (8 h/shift) to be 2057 which brings about 49,125 pistons for one month excluding rejection rate. Though, it is hard to forecast the rejection rate, the rate of 49,125 still shows an increased percentage from its earlier capacity of 42,300 excluding rejection.

7. Conclusion

With the industries currently looking to adapt Industry 4.0 and to move forward, the system has to be clearly sustainable not by just having plans and costs for future technologies, but also have to make use of the available resources effectively. Thus, our case shows that the industry can make its production phase sustainable by not only adapting new technology and huge investment; it can also be achieved through effective usage of available resources. Certain study also comes up with a solution that when the conventional lathe machine has been retrofitted with numerical stepper-based method, the machine works as a CNC trainer kit, which can aid the company to improve its overall productivity [8]. The above study can be used as a case, to show the effective management of available resources for industries to be sustainable amidst the economic crunch situation, which has become unpredictable post pandemics like Covid-19 and other external factors.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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