Line Balancing and Lean Line Design for Common Rail Pump Housing Manufacturing

Vivek. Koppal and Arunkumar. N S

Abstract — In this paper, the post process operations of the housing manufacturing of common rail pump and line balancing and lean line design concepts are discussed. Line balancing process is performed by plotting Man – Machine charts to improve the productivity of the line by reducing the input of man power and maintaining the product output. The post process operations of the housing manufacturing consists of 12 associates working on various machines. The required data was collected from a leading manufacturing company. The Line Balancing process resulted in elimination of 2 associates out of 12 in the manufacturing area which resulted in the improvement of the productivity. An attempt was also made in converting the manufacturing line of housing into a lean line and an area of 150sqmtr was saved. Converting the layout into a lean line also increased the productivity of the plant.

Keywords — Customer Takt Time, Cycle Time, Line Balancing, Lean Line, Planned Cycle Time.

I. INTRODUCTION

The primary function of the common rail pump is to pump the fuel into the rail at a very high pressure of 1600 bars. The figure of the common rail pumps produced by leading manufacturing companies is as shown in the figure below.

Fig. 1 Common Rail Pump Housing. [5]

The working principle of the common rail systems is briefed with the help of the figure as shown in figure 2. The fuel from the tank is pumped into the filter where the fuel undergoes the filtration process then the fuel is sent to the high pressure fuel pump where the fuel is pumped into the common rail with a very high pressure of 1600 bars. The external cover of the high pressure pump is called the Housing. Then the fuel in the common rail is pumped into the cylinders with the help of the injectors. Then the wasted or unused fuel is pumped back into the fuel tank.

Fig. 2 Working procedure of the Common Rail Systems. [5]

A detailed labelling of the Common rail pump is as shown in the figure below.

Fig. 3 Detailed labeling of the Common Rail Pump. [5]
The pump fixtures are covered by housing. This paper concentrates on the post processes performed on the CP1 and CP1H type housings. The post process operations consist of 10 operations for CP1 Housing and 6 operations for CP1H Housing type. A few of the operations are common for both CP1 and CP1H housings. The generalized layout with the material and man movement is as shown in the figure below.

**Fig. 4 Current layout with man and material movements.**

The above figure explains the movement of CP1 and CP1H type housings. The blue arrow indicates the flow of CP1H housing and the red arrow indicates the flow of CP1 housing. The green arrow indicates walk path of the associates in the layout. The green circle at each station indicates the station number in the order of process. The plain blue circle and the solid blue circle indicate the number of parts entering and exiting the station at an instant of time.

The paper explains the process of working of common rail systems and the working procedure of housings. Further, it explains the post process manufacturing operations of housings. The layout of the post process operations is explained and line balancing process is performed to improve the productivity of the layout by the elimination of associates. Lean principles are also applied to the layout which results in the reduction of area of the layout which in turn results in productivity improvement.

In the last decade, most of the European car companies have reorganized the projects comprehensively due the inspiration of lean manufacturing principles [1]. Lean manufacturing majorly concentrates in eliminating the wastes in the production system and majorly facilitates in the streamlining of the process [2-4]. The application of Lean Manufacturing and Line Balancing principles to the common rail pump housing manufacturing process is not reported in the published literature. This paper addresses the challenges in the design of production line with lean manufacturing principles.

**II. LINE BALANCING PROCESS**

The line balancing process is performed first by plotting the operator line balancing chart. To plot the operator line balancing, **Customer Takt Time**, **Planned Cycle Time** and **Operator Cycle Time** is calculated.

**A. Customer Takt Time**

Customer Takt is defined as the ratio between the planned operating time per day to the customer demand per day.

\[
\text{Customer Takt Time} = \frac{\text{Planned Operating Time per day}}{\text{Customer Demand per day}}
\]

\[\text{Customer Takt Time} = \frac{3 \text{ Shifts} \times 435 \text{ Minutes} \times 60 \text{ Seconds}}{1000 \text{ Pieces per day}} = 78.3 \text{ seconds/piece} \quad (1)\]

**B. Planned Cycle Time**

The planned cycle time is the customer takt time taking into accounts all influencing parameters and losses included in Overall Equipment Efficiency (OEE) at maximum capacity of the line.

\[
\text{Planned Cycle Time} = \text{Customer Takt Time} \times \text{OEE}
\]

\[
\text{Planned Cycle Time} = 78.3 \times 0.85
\]

\[
\text{Planned Cycle Time} = 66.5 \text{ seconds / piece} \quad (2)
\]

The number of associates working in the current layout is 12. The Current condition of the layout with the cycle times of all the operations is plotted in the Operator balance chart. The Operator Balance Chart plotted is as shown in the figure below.

**Fig. 5 Operator Line Balance chart of the current status.**

The operator line balancing chart plotted for the current condition has one bottleneck station whose cycle time is more than the **Customer Takt Time** i.e. the WMS Robotic arm station. The cycle times of other operations are less than the **Planned Cycle Time**, but this can be a liability which results in the danger of over production. Hence the line balancing process is performed to reduce the idle time of the operators working on the stations. The line balancing process is performed by plotting man – machine charts and the idle time of the operators is reduced.

---

**International Conference on Mechanical and Industrial Engineering (ICMIE’2013) August 28-29, 2013 Penang (Malaysia)**
Further, the line balancing process was performed on the associates and 2 associates were eliminated. The elimination of the associates was performed due to the results obtained from the associate utilization study. Man – machine charts were plotted for the associates whose percentage of utilization was less in the plant. The associates were provided to handle the operations of two machines. The pattern of operations to handle these machines based on the manual cycle times were plotted in to the man – machine charts. The cycle time of the complete operation was aimed to be equal or a little less than the planned cycle time. Thus one associate was provided to handle TEM CP1H and DURR machines, another associate was provided to handle the operations of TEM CP1 and Brushing machine and two operators were provided to handle three machines in the inspection area i.e. the Ball and Screw inspection station, 8 diameter inspection station and visual inspection station. Therefore, The Operator Line Balancing Chart with the Layout after the line balancing process with the elimination of two associates is as shown in the figure below.

Fig. 6 Operator Line Balance Chart after Line Balancing Process

The figure 6 shows the Operator line balancing chart after the line balancing process and the operator cycle times have been increased by providing the associates with extra operations and the idle times of the associates was reduced and the productivity was improved. Thus the operations in the plant which was handled by 12 associates is now converted to 10 associates.

The figure 7 indicates the layout with 10 associates and the walk paths for all the 10 associates. The associates eliminated as a result of the line balancing process as colored as red.

III. LEAN LINE DESIGN

The Lean Line Design (LLD) is a concept obtained from the lean manufacturing domain. In the lean line design concept the manufacturing line is redesigned to form a lean line with an optimum layout which results primarily in the productivity improvement. An attempt was also made to convert the layout of the housing manufacturing into a lean line. The current area of the layout was measured and calculated as 475sqmtr. This layout was converted to a lean line. The primary intentions of were to reduce the area of the layout which would reduce the walking distance of the associates between machine and with these results the productivity could also be improved. The area of the current layout was determined and the rearrangement of the machines in the layout so that there is a decrease in the area and decrease in the walk paths of the associates was achieved. Various combinations of the lean layouts were determined and the ideal layout with 325sqmtr was obtained and the walk paths of the associates were reduced to the maximum level. With this process the productivity increase was also achieved and savings of 150sqmtrs of area was achieved. The layouts of the current and the proposed lean line are as shown below in the figures.

Fig. 8 Current Layout with Area.

Fig. 9 Layout after Lean Line Design with Area.
IV. EXTENDED ANALYSIS USING PLANT SIMULATION

Extended analysis of the common rail pump housing manufacturing was conducted using plant simulation software supplied by Siemens. Tecnomatix Plant Simulation 9 was used to achieve extended analysis.

The layout of the post process operations of the housing manufacturing was created. The layout created using the Tecnomatix plant simulation is as shown in the figure below.

![Fig. 10 Layout using Plant Simulation Software](image)

In the layout created all the processing stations are provided with the cycle times and buffers are added as predecessors to the processing stations. Using discrete event controller, we can simulate the working model of the layout. With the simulation software it is possible to obtain the throughput of the product at any instant of time. The products to be manufactured are created as entities and the flow of the products through the machines are also set. Since the study was on CP1 and CP1H type housings, two entities are created and the product flow of the two entities are set according to their specifications. There is also an option to view the simulation in 3D in the software. The figure 11 shows the layout with the flow of entities and workers during simulation using discrete event controller.

![Fig. 11 Layout during simulation.](image)

Further analysis is being carried on using the plant simulation software to maximize the productivity of the layout by reducing the number of associates to 6. Man – machine charts for these 6 associates will be generated with the help of the plant simulation software. The utilization of all the associates can also be found out using the simulation software.

### TABLE I

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Status</th>
<th>Present</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>No. of Operators</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>Total Length</td>
<td>25mtr</td>
<td>25mtr</td>
</tr>
<tr>
<td>3</td>
<td>Total Width</td>
<td>19mtr</td>
<td>13mtr</td>
</tr>
<tr>
<td>4</td>
<td>Total Area</td>
<td>475sqmtr</td>
<td>325sqmtr</td>
</tr>
</tbody>
</table>

V. CONCLUSION

The work reported in this paper is in the manufacturing field of the common rail diesel injection systems. The work was concentrated on the housing manufacturing section of the common rail pump. The production layout of the housing was studied and lean manufacturing principles were applied to result in productivity improvement. The productivity of the layout was increased by eliminating 2 associates out of 12 using the line balancing process by using man – machine chart as a tool. The productivity was further increased by converting the current layout into a lean line. 150sqmtrs of area was saved by converting the layout into a lean layout. Extended analysis is also being carried on using plant simulation software which aims at maximizing the productivity of the plant by reducing the number of associates working in the plant to 6.

REFERENCES


