Lead Time Reduction of Component Manufacturing Through Quick Changeover (QCO)

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Abstract

Rapid changeover capability is a key pre-requisite for satisfying market demands in today’s customer-driven mass customization paradigm, which places emphasis on increased flexibility, lead time reduction and responsive manufacturing. Companies have to be able to adapt swiftly to market turbulence and at the same time avoid the traditionally high unit costs associated with custom made or small volume products. To achieve these goals, manufacturers are working to streamline their operations by application of lean production techniques such as QCO.

This paper discusses the background of QCO relating to the manufacturing industry and presents an actual application on the bottleneck machine of a leading machine tool manufacturer. The approach involved reviewing the present changeover procedures and tackling the causes for large changeover times in four stages - Mixed Phase, Separating Phase, Transferring Phase and Improving Phase. These phases included preparation of activity breakdown and time observation lists, classification of activities, preparation of standardized parallel operations schedules, and design of a dedicated component fixture.

The results showed that employing parallel operations can provide a significant reduction in set-up times, with an average reduction of 30 percent. Using the dedicated component fixture can enable the changeover process to be more systematic, with a drastic reduction in set-up time of about 55 percent. Investing in the fixture can enable the production capacity to be dramatically increased without addition of an extra machine or a negative impact upon quality, and with a very short payback period of two months. Based on these results, a few recommendations have been made towards continuous improvement, in alignment with the strategic objectives of a lean manufacturing organization.

Key Words: Lead time, Quick Changeover, Manufacturing

Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>QCO</td>
<td>Quick Changeover</td>
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<tr>
<td>OEE</td>
<td>Overall Equipment Effectiveness</td>
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<td>SMED</td>
<td>Single Minute Exchange of Dies</td>
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<td>SUR</td>
<td>Set-up Reduction</td>
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<td>BFW</td>
<td>Bharat Fritz Werner Ltd.</td>
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1. INTRODUCTION

For the last two decades, there has been an increasing need for reduction of setup times across all types of industries. Transition is taking place from a sellers’ to a buyers’ market. Several factors such as globalization of the markets, changing market demands towards more product variants and smaller order series are forcing manufacturing organizations to reduce setup times. Short set-ups are the key to both flexible and lean manufacturing. This requires a culture of continuous improvement in which the company is continuously trying to find ways to reduce times. Three key reasons for reducing the setup times can be identified, which are flexibility and inventory reduction, bottleneck capacity and cost minimization. The real challenge for companies is to manufacture customized products in combination with short delivery times and high delivery reliability. The most efficient way to accomplish these is to have shorter lead times in production. The need for flexibility directly corresponds to lot sizes with a key factor being the smallest lot size that can be produced in an economic way. The shorter the setup time, the smaller the lot size that can be produced in an efficient way [1]. As lot sizes are decreased, inventory levels will decrease. Also the replenishment cycle time can be drastically reduced due to the decreased lead times in production. Further, every manufacturing plant has its bottleneck capacities that barely can, or cannot meet market demand. When production needs to be increased, instead of taking decisions like buying additional machines or running additional shifts, a better approach would be to find ways to ensure that the available capacity is being fully utilized. Since a large amount of production time is lost due to changeovers typically, if setup times can be reduced then extra production capacity can be created. Therefore bottlenecks need to be the first priority for setup time reduction [2]. Also in today’s markets, the only thing that companies can work on to maximize profits is cost reduction. Since a major portion of the cost of a product is determined by the manufacturing cost, especially the equipment cost, it is critical that equipment performance is monitored well. Overall Equipment Effectiveness calculations show that reducing setup times provides substantial improvement of OEE [3]. To get an understanding of QCO, first the changeover process needs to be understood. A changeover is the complete process of changing between the manufacture of one product to the manufacture of an alternative product, to the point of meeting specified production and quality rates. The changeover time consists of Run-down period, Set-up period and Run-up period. QCO is a process through which the total changeover or setup time is dramatically reduced through a systematic, waste-eliminating approach, to support
the movement toward small lot size runs. By using a QCO strategy, the velocity of production is increased as well as the inventory turnover, both having positive results on the cash flow in a company. Through a faster response to customer demand, value adding activities can be carried out more efficiently within an organization and also greater number of customers can be served as a result of more flexibility. Instead of losing orders due to a lack of capacity, market shares can be gained by a high velocity and faster response to customer demand. QCO positively affects many aspects of a business and makes it more competitive. When smaller batches can be run cost effectively, inventory is reduced and thus costs for inventory are saved and tied up cash can be freed [4]. Thus the effort put into the QCO strategy pays back by the reduced cost of carrying inventory, reduced part shortages, less lead time and the smoother overall flow of production. For these reasons, QCO is a key principle in a lean production system to enable small lot production and to achieve a leveled production.

This study has been undertaken in Bharat Fritz Werner (BFW), which is one of the largest machine tool manufacturers in the private sector in India. BFW produces a range of products that encompasses the diverse needs of the engineering industry. The Slideway and Surface Grinding Machine was identified as the bottleneck machine in Heavy Parts Section of Manufacturing Division, considering aspects such as extremely high initial cost of the machine and its unique ability to grind large sized components. Therefore this particular machine was selected for QCO and further, of all the components on this machine, BMV-60 cross slide was identified to be the most frequent component with long lead times around 4 to 6 hours. Hence an attempt was made to bring down the lead time of BMV-60 cross slide by reducing its setup time.

Studies on setup reduction methods, design aspects for quick changeover and relationships between setup costs-set up reduction investments, have been carried out by several researchers over the last decade. S. Patel et al. [5] examined setup time reduction methods being used by four companies and found that the critical success factors for effective setup time reduction were operator training, employee participation, management support and undertaking cost-benefit analysis. They also identified that the main barriers to the application of QCO include undertaking cost-benefit analysis. They also identified that the main barriers to the application of QCO include setup procedure is being followed. Operators are spending considerable amount of time making adjustments and settings, and the setup times are mainly dependent on the individual operator skills.

2. MODEL CONSTRUCTION AND SOLUTION

The present study involved observing and analyzing the current changeover process by manual means employing time study, using activity breakdown and time observation sheets. Next step was identifying and separating the Internal and External activities by re-examining the true function of each step; and developing parallel operation schedules using activity predecessors. A dedicated cross slide fixture was designed for converting some of the internal activities into external and eliminating certain operations.

To begin with, the current setup process and operating procedures were observed and studied. Set-up time during changeover from other components to cross slide was recorded to be around 76 minutes and set-up time for changeover from cross slide to the next cross slides was found to be around 70 minutes.

2.1 Causes for Large Setup Times

After evaluating six complete setups and several partial setups, the causes for current large setup times were identified and presented pictorially using a ‘Cause and Effect Diagram’. Some of the major causes which were identified are:

- The setup method is highly unsystematic and varying from operator to operator as no standard setup procedure is being followed.
- Operators are spending considerable amount of time making adjustments and settings, and the setup times are mainly dependent on the individual operator skills.

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The tools, blocks, stoppers and bolts are not being stored in an organized manner, causing a lot of time to be wasted on searching.

Conventional lengthy threaded bolts are being used as fasteners, thus requiring a lot of time for tightening and loosening them.

The setup times are not being recorded and parallel activities are not being employed.

Thus, an attempt was made to bring down the changeover time by focusing on these causes in 4 stages: Mixed Phase, Separating Phase, Transferring Phase and Improving Phase, shown in Fig 1.

2.2 Stage One: Mixed Phase

The first step was to observe the tasks performed during the changeover and measure the time taken to complete these activities. The observations were undertaken using manual means employing standardized activity breakdown and time observation lists. After getting measurements from four changeovers, activity breakdown lists were developed to organize the activities performed during the two changeovers involved, which are: changeover from other components to cross slide and changeover from cross slide to the next cross slides.

It was identified that the present method being followed is in the preliminary stage of setup reduction, where in the internal and external setup elements have not been effectively distinguished, causing very large changeover times.

Next, the detailed setup activities were broadly categorized into four types to study the portion of total setup time each type is consuming as:

- Type 1 - Gathering and preparing
- Type 2 - Mounting the setup
- Type 3 - Measuring, calibrating and adjusting
- Type 4 - Un-mounting and cleaning

For both the changeovers, it was observed that a major portion of the setup time was consumed by Type 3 activities, (i.e. measuring, calibrating, adjusting), followed by Type 2 activities (i.e. mounting the setup).

2.3 Stage Two: Separating Internal and External Setup Elements

During this classification phase, the activities recorded in the activity lists were reviewed and every task in the changeover process was challenged in a brainstorming and task evaluation activity to categorize them as Internal, External and Eliminate. The six questions of Kipling were used as a guide to help categorize the activities.

2.3.1 Parallel Operations

The primary purpose of this parallel operations schedule building phase was to develop a standardized method for performing the changeover with two operating personnel by strategically organizing the activities among them. To develop these schedules, activity dependency charts were constructed for both changeovers indicating predecessor operations for each activity. Gantt charts and network diagrams were generated using MS-PROJECT and emphasis while designing the schedule was placed on the critical path. Then the parallel operations schedules were prepared having two columns, with operations to be carried out by one operator on each column. This eliminates any chance of redundancy and helps to coordinate tasks to perform a standardized changeover.

2.4 Stage Three: Shifting Internal Setup Elements to External

This stage consisted of the analysis of the current setup operations and determining means for converting activities being conducted as internal setup to external, wherever possible. The idea was to move as many tasks as possible from internal time to external time because fewer tasks within internal time will reduce the setup time.

In the present method of setup being followed, the cross slide is directly mounted on to the machine table making use of individual support blocks, butting blocks, stoppers, support jacks and conventional threaded bolts as shown in Fig 2.
not being done in an organized manner, causing
time to be wasted on searching during setups.
• Due to defective support blocks being used,
operators are wedging the component by using
thin pieces of paper in order to make the
component lie flat. Also additional packing plates
are being used to compensate for the mismatch
between the component width and machine table
slots. These operations have been found to be time
consuming and fatigue causing.
• The setup times are not consistent and varying
from operator to operator, depending on the
individual operator skills and motivation.

In order to address these above mentioned problems,
having a dedicated fixture for the cross slide has been
proposed as the solution, as it enables the component to be
attached and un-attached quickly and more effectively.
Hence a dedicated cross slide fixture was designed to meet
these requirements.

2.4.1 Solid Modeling
Engineering drawing of the BMV-60 cross slide was
procured from the design department and a solid model was
created using CATIA V5 R16, shown in Fig 3.

![Fig. 3 Solid Model of BMV-60 Cross Slide](image)

Next, a dedicated cross slide fixture was designed and
modeled. The design of the fixture is such that, all the four
support blocks, six butting blocks, four support jacks and
two stoppers which are needed for the setup, are clamped on
to the fixture base as shown in the Fig 4.

![Fig. 4 Dedicated BMV-60 Cross Slide Fixture](image)

Using Weighted Ranking Method, Alloy Steel - AISI 4042
was selected as the best material for this fixture from among
the short listed materials, which were carbon steel, grey cast
iron and alloy steel. One of the views of the fixture-cross
slide assemble is shown in Fig 5.

![Fig. 5 Assembly of the Cross Slide and Fixture](image)

2.4.2 Features of the Dedicated Cross slide Fixture
• By considering this fixture for changeovers,
operations such as positioning, adjusting,
tightening blocks and stoppers, and undertaking
necessary checks, can straight away be eliminated.
The times being spent on these activities can be
saved and set-ups can be made systematic.
• The need for adjusting additional packing plates
and fastening lengthy bolts on all sides of the cross
slide is eliminated through this fixture design. The
fixture design is such that bolts are needed to be
fastened only on three of the six butting blocks and
only on one of the two stoppers.
• Using the fixture also eliminates the need for
separate storage of all the individual support
blocks, butting blocks, stoppers and support jacks.
The time wasted on searching and gathering these
during the setups can be eliminated.
• All steps related to wedging the cross slide by
using pieces of paper can be eliminated by surface
hardening the upper surfaces of support blocks
provided on the fixture. Thus the grinding finish
and accuracy can be improved and made more
consistent along with saving in setup times.
• The design of the fixture has been made foolproof;
the positions of the butting blocks have been
arranged such that it does not permit the cross
slide to be inserted in any position other than the
correct one.
• Tenons have been provided at the fixture bottom to
enable quick positioning of the fixture on to the
machine table, thus reducing downtime.
• The changeover thus becomes simple to perform,
with no special skills required and makes possible
the use of lower skilled labor.

Exploded view of the cross slide, fixture and table
surface is shown in Fig 6.
The total cost on the fixture implementation was estimated to be Rs 57,425/- considering various costs such as design cost, material cost, machining cost, labor cost, cost of fasteners, and heat treatment cost, shown in Table 1.

**Table 1: Costs on Fixture Implementation**

<table>
<thead>
<tr>
<th>Type of Cost</th>
<th>Cost (Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design cost</td>
<td>3,750</td>
</tr>
<tr>
<td>Material cost</td>
<td>9,000</td>
</tr>
<tr>
<td>Machining cost</td>
<td>41,275</td>
</tr>
<tr>
<td>Cost of fasteners</td>
<td>1,200</td>
</tr>
<tr>
<td>Flame hardening and blackening cost</td>
<td>2,200</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>Rs 57,425/-</strong></td>
</tr>
</tbody>
</table>

Using this fixture eliminates the need for parallel operations using an additional operator, as the tasks become simple enough to be performed by a single operator. The final stage involves streamlining further the internal and external setup elements through continuous improvements i.e. kaizen.

**3. RESULTS AND DISCUSSIONS**

**3.1 Stage One: Mixed Phase**

The present method being followed was found to be in the mixed phase of setup reduction, where in the internal and external setup elements have not been effectively distinguished, causing an increase in the setup time. It was recorded that the present setup time during changeover from other components to cross slide is around 76 minutes and setup time during changeover from cross slide to the next cross slides is around 70 minutes.

**3.2 Stage Two: Separating Internal and External Setup Elements**

In this stage, analysis of the current setup operations was reviewed and categorized under eliminate, external or internal. Parallel operations schedules were prepared to develop a standardized method for performing the changeover with two operating personnel. From the schedules, a possible setup time saving of 33.4 percent has been estimated for changeover from other components to cross slide and a saving of 25.8 percent for changeover from cross slide to the next cross slides, shown in Table 2.

**Table 2: Savings with parallel operations**

<table>
<thead>
<tr>
<th>Changeover</th>
<th>Current Setup Time</th>
<th>Setup Time with Parallel Operations</th>
<th>Percentage Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Others components to cross slide</td>
<td>76 mins 02 secs</td>
<td>50 mins 38 secs</td>
<td>33.40%</td>
</tr>
<tr>
<td>Cross slide to the next cross slides</td>
<td>70 mins 10 secs</td>
<td>52 mins 04 secs</td>
<td>25.80%</td>
</tr>
</tbody>
</table>

After stage two i.e. segregating internal and external setup elements and performing parallel operations, the average setup time can be brought down from the existing 73 minutes to around 51 minutes as shown in Fig 7.

**3.3 Stage Three: Shifting Internal Setup Elements to External**

In this stage, analysis of the current setup operations was carried out and certain flaws were identified in the current method, which were responsible for increase in the setup times. In order to address these problems, a dedicated cross slide fixture was designed with an idea to eliminate certain operations, and to move as many tasks as possible from internal time to external time. This fixture design enables the cross slide to be attached and un-attached quickly and more effectively, thus providing a significant reduction in the setup times.

Activity breakdown lists were prepared to identify the activities that can be eliminated and those that can be made external. From these charts, a possible setup time saving of 57.1 percent has been estimated for changeover from other components to cross slide and a saving of 52.76 percent for changeover from cross slide to the next cross slides, shown in table 3.
Table 3 Savings Considering Fixture

<table>
<thead>
<tr>
<th>Changeover</th>
<th>Current Setup Time</th>
<th>Setup Time Considering Fixture</th>
<th>Percentage Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other components to cross slide</td>
<td>76 mins 02 secs</td>
<td>32 mins 40 secs</td>
<td>57.10%</td>
</tr>
<tr>
<td>Cross slide to the next cross slide</td>
<td>70 mins 10 secs</td>
<td>32 mins 55 secs</td>
<td>52.76%</td>
</tr>
</tbody>
</table>

From Fig 8, it can be seen that by implementing stage three (i.e. dedicated fixture) after stage two (i.e. parallel operations), the average setup time can be brought down from 51 minutes to 32 minutes. But if the company is ready to invest in the fixture straight away after stage one; the average setup time can be directly brought down from 73 minutes to around 32 minutes, shown in Fig 9. This is because implementing the dedicated fixture eliminates the need for parallel operations using an additional operator, as the tasks become simple enough to be performed by a single operator.

In addition to these direct benefits, there are also certain other benefits from the setup reduction program such as:

- Increased capacity on bottleneck machine
- Improved flexibility and responsiveness to customers
- Improved quality and less process variability
- Reduction in inventory and stock holding costs
- Reduction in Economic Batch Quantity
- Increased operator safety and reduced fatigue

3.4 Calculation of Payback Period

- Business earned in rupees by running the grinding machine for one hour = Rs 2,700/hour
- Average number of minutes reduced per cross slide setup = 40 minutes
- Number of cross slide setups per year = 200
- Total reduction in setup time per year = 8000 minutes = 133.33 hours
- Expected additional business in the time saved on each setup = Rs 1,800/-
- Annual additional business estimated in rupees = Rs 3,60,000/-

Investment

Payback Period for the fixture = \[ \frac{57,425}{1,800} \] = 31.90 changeovers

Thus, the payback period has been calculated to be around 32 changeovers i.e. if the company invests in the dedicated cross slide fixture, the investment will be recovered within the first two months considering an average of 16 cross slide setups per month (200 setups per year).

4. CONCLUSIONS

Solutions have been proposed to address the problems faced during cross slide setups on the Slideway and Surface Grinding Machine, through the application of Quick Changeover methods. The study has shown that it is possible to improve the machine capacity without having to make large investments in new equipment, with just nominal investments in fixture having a short payback of two months or by adding an extra operator during the setups.
Japanese lean techniques such as setup reduction are applicable well outside their traditional domains such as stamping and metal-working, and can be transplanted to machine tool production as well.

Setup processes become accretive and grow over time, thus operations need to be reviewed regularly to check if they are still relevant and required. Applying lean production tools like SMED can greatly reduce the number of tasks performed during planned downtime.

Better machine utilization results in additional production capacity and can reduce the costs per product produced on that machine. Implementation of setup reduction programs on bottleneck machines of all divisions of the company will translate into significant increase in production capacity, cost savings, production flexibility and profit.

Operator involvement during QCO programs results in sharing of knowledge and awareness regarding the competitive environment facing the company and the pressures involved. The value of these indirect benefits of QCO is harder to quantify, but they play a significant part in contributing to the direct benefits and are likely to serve the company well for sustaining the improvements in the long run.

Being able to sustain an improvement is as important as the improvement itself. Companies must be conscious of the difficulties in sustaining rigorous setup practices for there is always a natural tendency to revert back to the previous less efficient practices.

By using design to aim at reducing physical effort and adjustment, some changeover procedures can be eliminated and others can be deskilled, thus making them far easier to sustain. The remaining setup operations can be tackled by conducting evaluations and audits on a regular basis, through a continuous improvement process to ensure that planned results are obtained.

Leadership and management support at every level is critical to the success of a setup reduction program. Management needs to recognize that significant benefits can be achieved by prioritizing setup reduction investments in an effective manner.

Thus the changes proposed can bring the company’s manufacturing capability into closer alignment with market conditions.

The changes proposed for the changeover process should not be viewed by the company as a one off program, but rather as the beginning of a general movement towards adapting to more demanding market conditions. This is going to be the only effective solution to survive in the ever changing conditions with globalization of the markets, changing customer demands towards more product variants and smaller order series. This project serves as the beginning of a cultural change of what is possible not only on a particular grinding machine, but on all other machines and divisions as well.

REFERENCES