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

R. Bharath [1], A.C. Lokesh[2]

[1]M.Sc. (Engg.) Student, [2]Assistant Professor
Centre for Manufacturing
M.S. Ramaiah School of Advanced Studies, Bangalore 560 054

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

QCO	Quick Changeover
OEE	Overall Equipment Effectiveness
SMED	Single Minute Exchange of Dies
SUR	Set-up Reduction
BFW	Bharat Fritz Werner Ltd.

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 is 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-setup 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 traditional methods of working, resistance to change, justification of investments needed and large time scale involved. Dirk Van Goubergen [6] focused on the increasing need for short setup times and an integrated approach combining SMED method with additional Industrial Engineering techniques to make the setup reduction effort more effective. S. Patel et al. [7] identified flaws such as lack of planning, organization and structure in the identification and implementation of setup time reduction in traditional companies, and addressed these through SMED principles. Dirk Van Goubergen [2] discussed the need for short setup times and concluded that all functional areas should be involved with improving setup times, since their direct and indirect influence can be significant. A.R. Mileham et al. [8] described a set of 'design for changeover' rules from their action research and found that improvements to existing equipment that are based on a combination of both design and methodology typically result in lower changeover times than can be achieved through improvements based on methodology alone. They also concluded that improvements which are design based are permanent as compared to organizational only improvements, since they tend to lack sustainability in the long term. Dirk Van Goubergen and Hendrik Van Landeghem [9] looked into aspects such as responsibility of the equipment design engineer to go beyond the technical aspects in order to design an efficient and effective setup method, and to ensure no special skills are needed to perform setups. John P. Leschke and Elliott N. Weiss [10] & [11] examined the best way to prioritize investments during the stage that emphasizes standardizing setups across a work center discussing the various Investment-Allocation Rules in detail.

The literature reveals that there is a lack of empirical research on the application of setup reduction methods in manufacturing industries and that more research is needed in several SMED areas. It provided an understanding of the critical success factors and main barriers for setup reduction in traditional companies. It provided an insight into certain design for changeover rules and the role of equipment design engineer to design an effective setup method. It showed that relationships between setup reduction investments-setup costs are more complex than generally assumed and that significant benefits can be achieved by prioritizing setup reduction investments in an effective manner.

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 represented 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.

- 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.

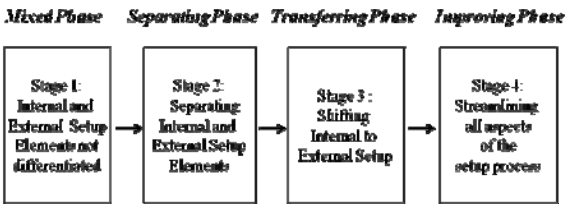

Fig. 1 Stages in Setup Reduction

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.

Fig. 2 Current work-holding method

From examining the recorded setups, certain flaws in the current method have been identified, which are as listed:

- Operators spend considerable time positioning, adjusting, tightening the various blocks and stoppers, and undertaking necessary checks. These operations are unsystematic, with no standard procedures being followed.
- The storage of these individual support blocks, butting blocks, stoppers, support jacks and bolts is

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.

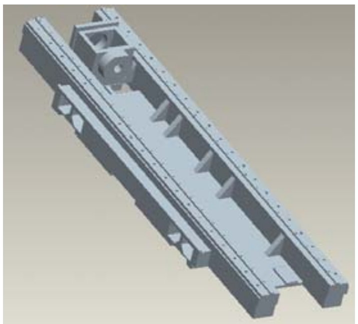

Fig. 3 Solid Model of BMV-60 Cross Slide

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.

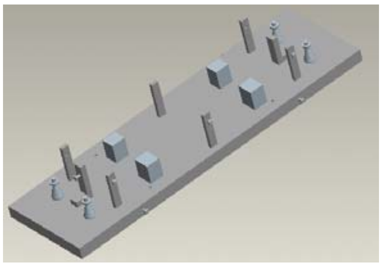

Fig. 4 Dedicated BMV-60 Cross Slide Fixture

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.

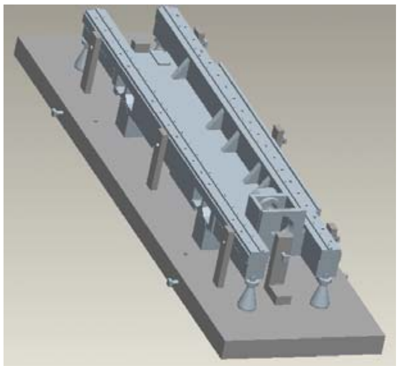

Fig. 5 Assembly of the Cross Slide and Fixture

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.

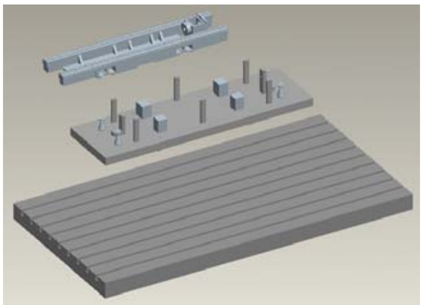

Fig. 6 Exploded View Showing the Cross Slide, Fixture and Machine Table Surface

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

Type of Cost	Cost (Rs)
Design cost	3,750
Material cost	9,000
Machining cost	41,275
Cost of fasteners	1,200
Flame hardening and blackening cost	2,200
Total	**Rs 57,425/-**

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 the classification phase, each setup activity 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

Changeover	Current Setup Time	Setup Time with Parallel Operations	Percentage Saving
Others components to cross slide	76 mins 02 secs	50 mins 38 secs	33.40%
Cross slide to the next cross slides	70 mins 10 secs	52 mins 04 secs	25.80%

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.

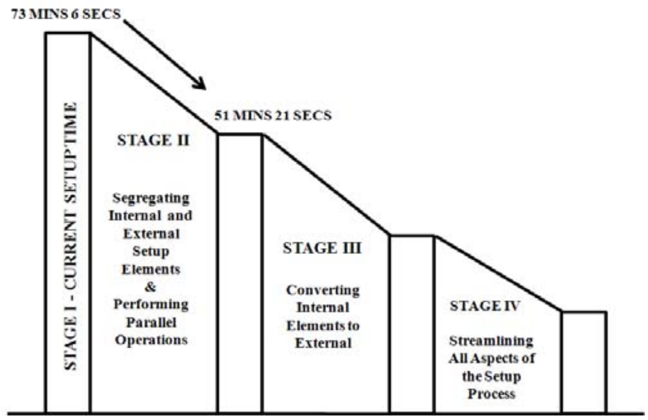

Fig. 7 Reduction in Average Setup Time After Stage 2

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

Changeover	Current Setup Time	Setup Time Considering Fixture	Percentage Saving
Other components to cross slide	76 mins 02 secs	32 mins 40 secs	57.10%
Cross slide to the next cross slide	70 mins 10 secs	32 mins 55 secs	52.76%

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.

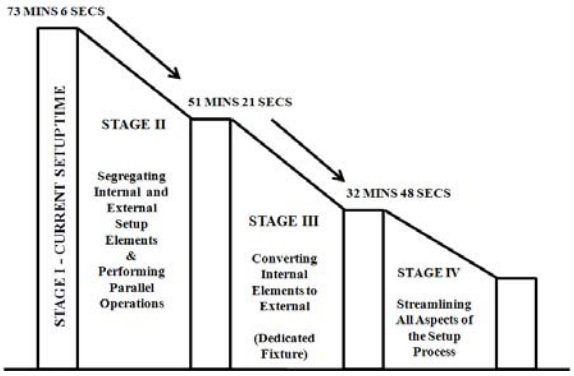

Fig. 8 Reduction in Average Setup Time After Stage 3 - Option 1

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/-

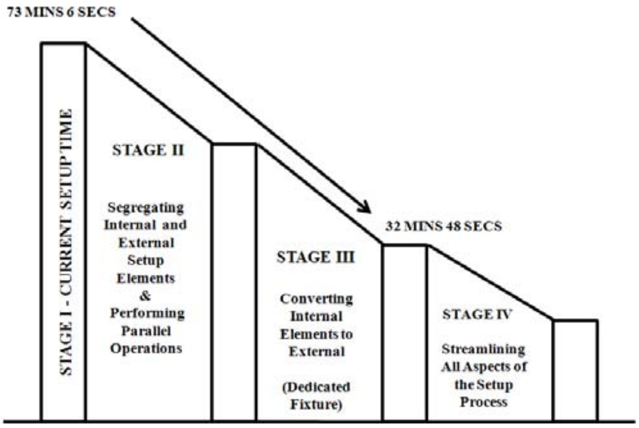

Fig. 9 Reduction in Average Setup Time After Stage 3 - Option 2

$$\text{Payback Period for the fixture} = \frac{\text{Investment}}{\text{Expected additional business}}$$

$$\text{Payback Period} = \frac{57{,}425}{1{,}800} = 31.90 \text{ changeovers}$$

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

[1] Shigeo Shingo, A Revolution in Manufacturing: The SMED System, Productivity Press, 1985

[2] Dirk Van Goubergen, Set-Up Reduction As An Organization-Wide Problem, Solutions 2000 Conference, Organized by the Institute of Industrial Engineers, Cleveland, Ohio, May 22-24, 2000, http://www.vangoubergen.com/pdf/IIE2000%20paper.PDF

[3] Seiichi Nakajima, Introduction to TPM, Productivity Press, 1988 http://www.gfse.de/se/edu/award/sp2007/downloads/Zusammenfassung_Bang.pdf

[4] http://www.gfse.de/se/edu/award/sp2007/downloads/Zusammenfassung_Bang.pdf

[5] S. Patel, B.G. Dale and P. Shaw, Set-up time reduction and mistake proofing methods: an examination in precision component manufacturing, The TQM Magazine, Vol. 13, No. 3, 2001, pp.175-179

[6] Dirk Van Goubergen and Hendrik Van Landeghem, An Integrated Methodology for More Effective Set-up Reduction, IIE Solutions 2001 Conference, Organized by the Institute of Industrial Engineers, Dallas, TX, 21-23 May, 2001, http://www.vangoubergen.com/pdf/IIE%202001%20A4.pdf

[7] S. Patel, P. Shaw and B.G. Dale, Set-up time reduction and mistake proofing methods, Business Process Management Journal, Vol. 7, No. 1, 2001, pp. 65-75

[8] A.R. Mileham, S.J. Culley, G.W. Owen and R.I. McIntosh, Rapid changeover - a pre-requisite for responsive manufacture, International Journal of Operations and Production Management, Vol. 19, No. 8, 1999, pp.785-796

[9] Dirk Van Goubergen and Hendrik Van Landeghem, Role and Responsibility of the Equipment Design Engineer in the Setup Reduction Effort, FAIM 2001- Flexible Automation and Intelligent Manufacturing Conference, Dublin, Ireland, 16-18 July, 2001, http://www.vangoubergen.com/pdf/FAIM2001_paper.PDF

[10] John P. Leschke and Elliott N. Weiss, A Comparison of Rules for Allocating Setup-Reduction Investments in a Capacitated Environment, Production and Operations Management, Vol. 6, No. 4, 1997, pp.329-340

[11] John P. Leschke, An Empirical Study of the Setup-Reduction Process, Production And Operations Management, Vol. 5, No. 2, 1996, pp.122-131