DEVICES TO REDUCE SETUP TIME OF TOE LASTING MACHINES

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Abstract. *Globalization has a direct effect on the competitiveness of the footwear market, forcing companies to increasingly invest to improve performance and reduce setup time in order to remain competitive. Therefore, the objective of the present study was to suggest an alternative method to reduce the setup time of toe lasting machines at a footwear factory. We evaluated the times required to change the tools (setup) and determined the most critical adjustment points of toe lasting machines. Based on our findings, we suggest alternative methods of adjustment optimization. We also present a project and suggest the design of devices to significantly reduce setup times without raising equipment prices by more than 30%. Our reults were tested using prototype devices. These devices will be tested and improved in the future. The improvement and evolution of the footwear industry equipment is strategic and necessary in order to preserve the high level of productivity and profitability of the footwear industry, which are crucial aspects for its survival.*

Keywords*: Manufacturing of machines. Footwear industry.*

1. INTRODUCTION

Brazilian footwear manufacturers are currently undergoing a series of profound changes that are essential if they are to remain viable in a market in which competition is ever more fierce. One of these changes is a tendency for production batches to reduce in size and increase in diversity, which in turn means that a business' ability to rapidly reset its production lines between batches has become a decisive factor in maintaining market share (Fensterseifer, 1995).

The demands of the modern market have forced manufacturers to redesign their production lines to offer rapid setup times without unduly increasing their production costs. In a shoe production line, the rhythm is dictated by the toe lasting machine because it has to be adjusted to fit the shape and type of shoe that is being produced (Borba and Schnorr, 2010). The result of smaller batch sizes is an increase in the number of times that the toe lasting machine has to be set up. In this situation, any improvement that offers increased flexibility and reduced setup times would be of strategic importance to footwear manufacturers (Renner and Trein, 2003).

This article describes the most important factors that affect the time taken to change tools on a brand of toe lasting machines manufactured in the Vale dos Sinos region in Brazil (*Máquinas ERPS*) and then describes the design of a number of devices for reducing the time taken to set up a production line. The project objective was to reduce the setup time of *Máquinas ERPS* toe lasting machines by 50% without increasing their price by more than 30%.

2. METHODOLOGY

An initial analysis was performed of the setup times for the toe lasting machines at a footwear factory, broken down into times for each of the separate stages involved and based on timing ten repetitions. The total setup time was calculated by summing the shortest time taken to complete each step.

The most critical points in the process were identified on the basis of the setup time analysis and new devices were designed to deal with each one. The design stage comprised conceptualization, specification and simulation. Prototype devices were then produced and tested. The prototypes were tested by timing each step of the setup process again, using the same methodology as had been used for the unmodified machine.

3. BOTTLENECKS IN FOOTWEAR MANUFACTURING

When Brazil began to export footwear in 1970, the average price of a pair of shoes was US$2.19. The footwear industry worked with large production batches and enjoyed a period of unparalleled growth. By 2002 the average price was US$ 8.83 in Brazil as a whole and US$ 10.16 in the state of Rio Grande do Sul (ABICALÇADOS, 2003). Large-scale orders began to be filled by factories in Asia because of the low production costs (Henriques, 1999). This caused Brazilian footwear manufacturers to instigate significant changes, because they were forced to move to small batches and focus on diversifying their products in order to survive (Renner and Trein 2003). These manufacturers need more versatile production lines to enable them to remain competitive while producing a wide variety of products in many different shapes and sizes. Production lines must be set up as quickly as possible between different batches. There are certain processes in the production of shoes that are considered bottlenecks, in particularly stitching and, to a lesser extent, the assembly sector (Humann, 2001). While assembly is not considered to be the most critical operation, it deserves the greatest attention because it involves machines and processes that must be adjusted depending on the models and sizes being produced. The toe lasting machines are considered the most critical element when setting up the assembly line for different models. The majority of the footwear manufacturers in the Vale dos Sinos area have daily production figures in the range of 750 to 1250 pairs (Borba and Schnorr, 2010).

4. TOE LASTING MACHINES

Shoe assembly normally follows a predefined sequence of processes. This article will not describe all of the stages involved in shoe manufacture, but will focus specifically on the toe assembly process. The material from which the shoe is to be made is cut, prepared and stitched to form the upper. The upper is then sent to the assembly area where it will be molded over a form, called a "last", which will determine its principal characteristics, which in turn depend on whether the type will be women's, men's, children's, sporting, round-toed, square-toed, narrow, wide etc. The first part of the upper to be "lasted" is the toe, which is basically a process of stretching the upper around the last and gluing it to an insole held on the underside of the last. The resulting toe is the same shape as the last (Ruas, 2010).

Currently, toe lasting machines are the most significant bottleneck in a shoe assembly line. (Borba and Schnorr, 2010). These machines have undergone a great deal of development in terms of their electrical and electronic components, but their mechanical parts still present the same adjustment difficulties as the machines of earlier decades did. Irrespective of where they are made, all toe lasting machines function according to the same basic principles, respecting their different constructions, and use the same toolsets to assemble the toe. The majority of the shoe manufacturers in the Vale dos Sinos area use semiautomatic machines. Figure 1 below shows a toe lasting machine that is typical of those used by the majority of manufacturers (ERPS 2010).

Figure 1 – Shoe lasting machine, model MAP. (ERPS 2010).

The final quality of the shoe is dependent on the machine being fitted with a toolset that is manufactured and adjusted to fit the shape of shoe that is being lasted. Figure 2 illustrates the work area of a toe lasting machine that has been set up for a women's, narrow-toed shoe. The work area denotes the part of the machine where the operations take place.

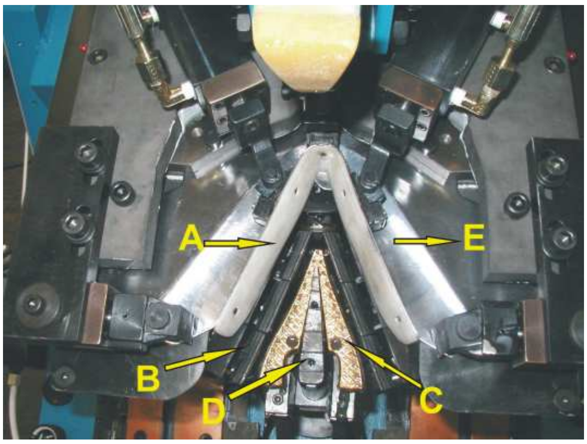


Figure 2 – Work area of a toe lasting machine set up for a narrow-toed shoe.
Detail of moving and/or adjustable parts.

Figure 2 shows the parts that must be adjusted or substituted when the model of shoe is changed. The operations performed by this machine are as follows: the upper is positioned into the pincers (B) which close and grip it. Next the last support (D) rises and stretches the upper to the desired height. With the upper gripped and stretched, the teflon® belt (A) holds the upper. Next the adhesive gun (C) rises and applies adhesive to the insole which is on the bottom of the last. The adhesive gun then drops away, leaving the area free once more.

The pincers (B) then release the upper which is still held by the teflon belt® (A) and then the wiper plates (E) move downwards, bringing the edge of the upper into contact with the edge of the insole that has been prepared with hot melt adhesive. The wipers remain below the last, compressing the upper against the insole while the glue dries. Once the preset gluing time has elapsed, the wipers (E) and the teflon belt® (A) release the last with the toe molded in place around it.

A single toe lasting machine can last the toes of an average of 120 to 140 pairs of shoes per hour and can achieve daily production volumes of 1000 to 1200 pairs. A single tool-change operation takes an average of 15 minutes. The tool change begins with substitution of the hot melt adhesive gun because it needs an additional ten minutes to heat the adhesive to its operating temperature of 225° C (with room temperature of 25° C and assuming that the base to which the gun is attached is already at the desired temperature). The heat is needed to melt the adhesive so that it can be applied to the different parts of the shoe. (AMAZONAS, 2010).

While the adhesive gun is warming up, the pincers are adjusted (there are seven on this machine) Each pincer is fixed in place with a screw. Each screw is loosened and each pincer moved into the position that most closely contours the shape of the last. To enable this movement, each pincer is fitted to a slotted base plate along which they slide to reach their correct positions. The teflon belt® and the wiper plates are specific for each last and they snap in and out of place in a few seconds. The total time taken for a trained technician to complete the entire tool change operation is about 15 minutes. Approximately 2 minutes of this time is spent changing the wipers and the teflon belt®, while the remaining 13 minutes are spent on changing the adhesive gun and adjusting the pincers.

These times were recorded during tests performed at the shoe lasting machine factory (*Máquinas ERPS*). Each step was timed ten times and the total setup time was defined as the sum of the shortest time for each operation. These times are subject to minor variations.

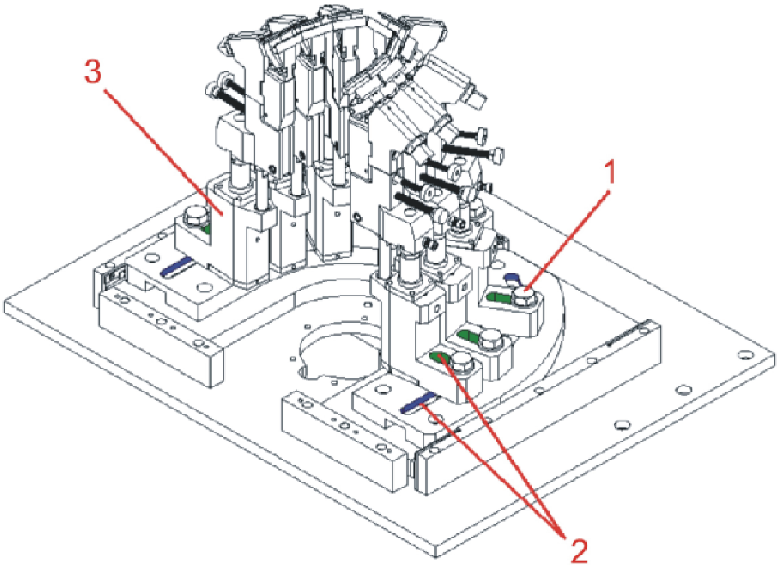
When the model of shoe changes, the toe lasting machine needs a full toolset change, which is a highly complex process that requires trained personnel. The toe lasting machine setup time can be defined as the time needed to complete the following steps: change the teflon belt®, 1 minute, change the plates (wipers), 1 minute, change the adhesive gun, 2 minutes (although another 10 minutes are needed to heat the adhesive to its 225° C operating temperature), change the last support, optional item. Adjust the pincers, 11 minutes. Since the adhesive gun requires the longest time, tool changes always start with the gun and while it heats up all the other adjustments are made.

It will be observed that the greatest problem is changing the hot melt adhesive gun, followed by setting the pincers, which are the parts that take longest to change and adjust. In a shoe factory that works with small batches and has to change models daily, with a daily production volume of 1056 pairs, the time spent on setup can translate into a considerable reduction in production and, consequently, earnings (ABICOURO, 1998).

The setup steps that demand the greatest expenditure of time, of those analyzed here, were changing the adhesive gun, which took 2 minutes plus 10 minutes heat-up time, and setting the pincers, which took 11 minutes. As a result, the project to develop devices to reduce setup time was restricted to the pincers and the adhesive gun, since they are responsible for approximately 86.7% of the setup time. These devices are presented below.

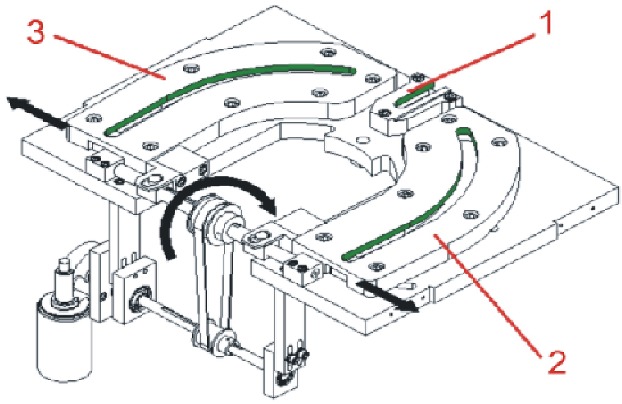
5. PINCER BASE PLATES

The first item to be studied was the pincer system. Figure 3 illustrates the system of seven pincers and the manner in which the pincer bodies are fitted to their base plates. A screw (1) secures the body of each pincer (3) and must be loosened in order to adjust it. Each pincer body can move along slots (2), highlighted in green and blue in the diagram. Each pincer must be adjusted separately. The pincer bodies are fixed to one of three base plates, shown in Figure 4, the front pincer is attached to one plate (1), pincers 2R, 3R, 4R to another (2) and pincers 2L, 3L, 4L are fixed to the third (3). The three base plates are fixed to the machine. On the unmodified machine all pincer adjustment is done manually and an experienced technician can complete the pincer setup operation in 11 minutes.



1 – Pincer attachment screw
2 – Slots for pincer movement
3 – Pincer body

Figure 3 – Pincer system showing method of fixation to the machine.



1 – Front pincer plate
2 – Plate for pincer 2R, 3R, 4R
3 – Plate for pincer 2L, 3L, 4L

Figure 4 – The pincer bodies are fixed to one of three base plates

One possible solution proposed was to move the pincer base plates laterally. However, this proposal was rejected because simple lateral movement resulted in the last four pincers becoming overly displaced from the outline of the last. Figure 5 shows what would have occurred if simple lateral movement had been used and also shows a feasible solution to correct the excessive gap to the last four pincers (shown in red).

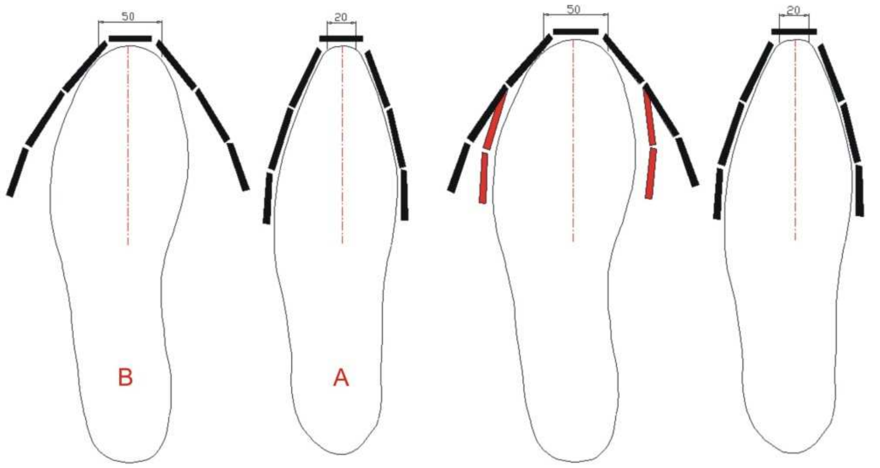
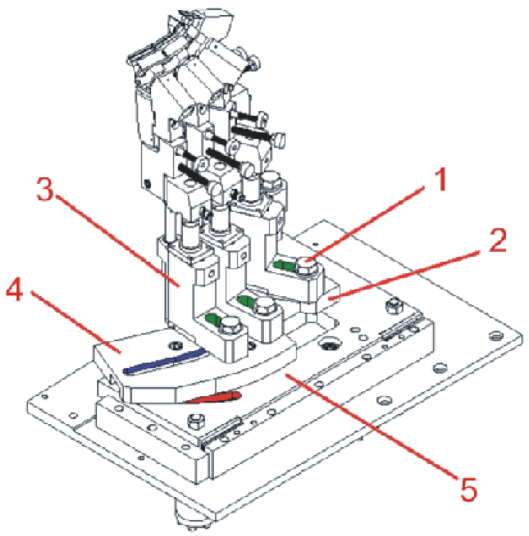


Figure 5 – Plan view of pincer positions with lateral movement for two types of last (A- narrow toe, B- round toe) and the possible solution for the problem caused by lateral movement.

The solution actually chosen for the problem was therefore to fix the seven pincers on a total of five base plates. Using this new configuration, with the pincers on five plates with independent movement, a large number of movements are possible and the machine can be set up for different lasts more quickly.

The system of plates is as follows: A) pincer 1, the front pincer, remains attached to a fixed plate in the center (1), B) pincers 2 right (R) and 2 left (L) are fixed to individual movable plates (2 & 3), C) while pincers 3 and 4 right (R) and 3 and 4 left (L) are attached to their own movable plates (4 & 5,) as shown in Figure 6.

It will be observed that with the pincers fixed to individual plates it is no longer necessary to move the pincer bodies. The new system can therefore be fitted both to new machines and also to those that are already on the market.



1 – Pincer attachment screw
2 – Plate for pincer 2R
3 – Pincer body
4 – Plate for pincers 3R & 4R
5 – Master base plate

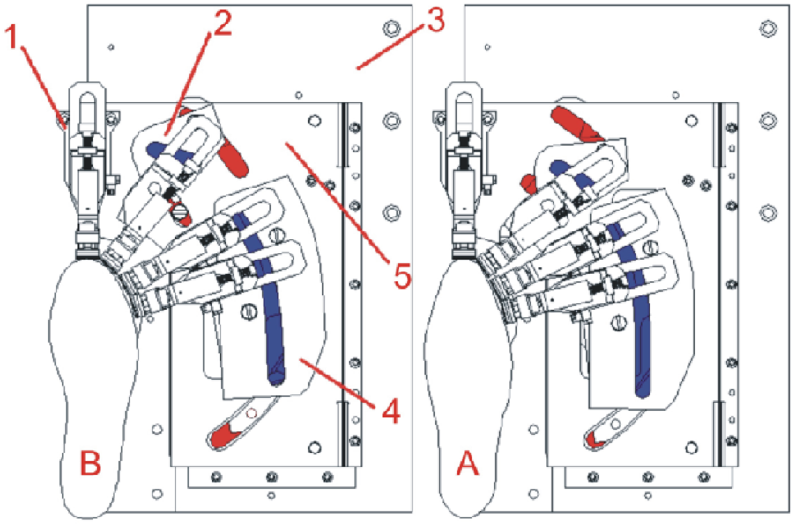
Figure 6 – Detail of movable plates for new system.

The movements were based on the plan shown in Figure 5 which illustrates exactly what will be done on the machine. When the pincers are moved to change the last for a different model, the last four pincers also need to be adjusted to correct for the excessive gap. The plan was also used to define the positions of the slots along which the adjustable plates will slide.

Certain limits were imposed on the physical space available by the decision to design a device that could be fitted both to new machines and to those already on the market. The solution chosen was to move the plates using motors and rack and pinion gears (Melconian, 2008). The plates slide along slots. Direct current (24 Vcc) motors coupled to reduction gearboxes to increase torque and reduce velocity were chosen because they are more compact than alternating current motors for the same torque and because they meet the safety requirements of the applicable Brazilian standard (NR12, 2010). Also in order to save space, crown wheel and pinion type reduction gearboxes were chosen.

Once these variables had been defined, CAD 3D software was used to simulate the way the pincers would adapt to different models of last. This was done as a final check. Figure 7 illustrates a simulation of the way the new system adjusts to fit two different lasts, on the right for a narrow shoe (A) and on the left for a more rounded one (B).

It can be observed that the pincers are correctly aligned to the narrow last (A) and that by moving the pincer base plates they can be adjusted to the shape of the rounded last (B) without having to move the pincer bodies. The new pincer movement system allows the operator of the toe lasting machine to change the profile of the pincers to fit a large variety of types of shoe lasts.



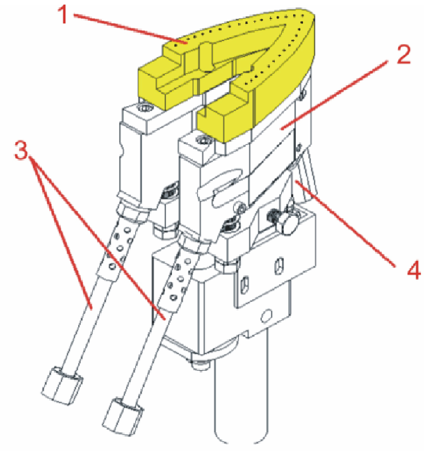
1 – Front pincer plate (fixed)
2 – Plate for pincer 2R
3 – Machine body
4 – Plate for pincers 3R & 4R
2 – Master base plate

Figure 7 - Simulation of new system adjusted for a round-toed last (B) and a narrow-toed last (A).

6. ADHESIVE GUN

The second part of the machine to be analyzed was the adhesive gun. Until this project was completed, adhesive guns were always custom fabricated for each last. A generic gun would perform poorly, applying hot melt adhesive outside of the desired area, which in turn would interfere with subsequent assembly processes and/or waste adhesive. The adhesive guns are fabricated from carbon steel (SAE 1020) or brass, with brass being preferred because it conducts heat better (Callister, 2008). This is a useful property because the adhesive is applied at around 225° C and better heat conductivity reduces time lost while the gun heats up. Each manufacturer must have an adhesive gun specially made for every model of shoe it produces. Figure 8 illustrates the traditional design of the adhesive gun and its heater base.

In Figure 8, the adhesive gun (1) is attached to its base (2) by two screws. The base is responsible for heating the entire assembly and contains two resistance elements that are powered by an electric cable (4). The hot melt adhesive is fed in through two Teflon ducts (3).

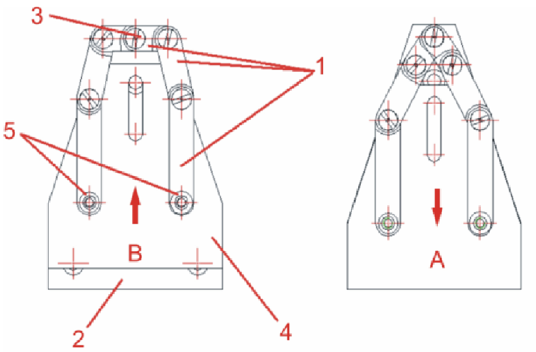


1 – Adhesive gun
2 – Heater base
3 – Teflon ducts
4 – Power cable entry point

Figure 8 - Adhesive gun and heater base.

The time taken to change the adhesive gun was approximately 2 minutes. After the new gun had been fitted and assuming the base was already at 225° C, it was still necessary to wait 10 minutes for the adhesive gun to reach its operating temperature.

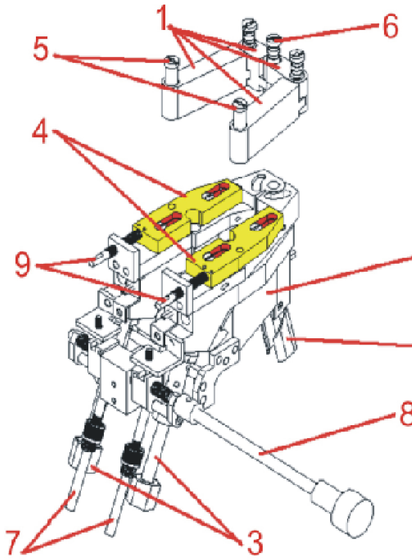
The second part of the project to reduce setup time was to conceive a new adhesive gun design, which is shown in Figure 9. The new concept shown in the figure is to segment the gun so it can be moved into different shapes. Figure 8 shows a segmented adhesive gun set for a narrow-toed shoe (A) and the same adhesive gun reset for a wide toed shoe (B). The device includes the heater base (2), to which the front hinge pin for the adhesive gun is attached (3). The base also supports a sliding plate (4), to which the adhesive gun's rear hinge pins are fixed (5). As can be observed in the figure, the gun is made up of six parts that are joined together with hinge pins. As the sliding plate (4) is brought forward, the shape of the adhesive gun widens, and vice versa. The arrows in Figure 9 indicate these movements.



1 – Adhesive gun segments
2 – Heater base
3 – Adhesive gun front hinge pin
4 – Sliding plate
5 – Adhesive gun rear hinge pins

Figure 9 – Preliminary design of new adhesive gun.

Figure 10 illustrates the detailed design of the segmented adhesive gun and its components.



1 – Adhesive gun segments
2 – Heater base
3 – Teflon ducts
4 – Sliding plates
5 – Adhesive gun rear hinge pins
6 – Adhesive gun front hinge pin
7 – Power cable entry points
8 – Lateral movement adjustment
9 – Screws to adjust sliding plates

Figure 10 - Segmented adhesive gun and its components.

During the conceptualization stage it was found that a six-segment design would not be feasible because two of the parts would have been too small, making them difficult to fabricate and also running the risk of compromising the flow of adhesive, which must be as smooth and regular as possible. As can be seen in Figure 10, the final design is made up of four segments rather than six.

7. PRODUCTION OF PROTOTYPES

As has been explained above, the final proposal to reduce the setup time of toe lasting machines comprises modification of the pincer mounting plates, which are now one fixed plate and four movable plates controlled by DC motors, and segmentation of the adhesive gun in order to make new adjustments possible.

Based on these specifications, certain adaptations were made to ensure that the two devices could be mounted together on the toe lasting machine. With a view to future commercial production, the following steps were carried out: fabrication designs were drawn up, tolerances were calculated, the equipment to be used for fabrication, thermal and surface treatments and the bill of materials were all specified. One prototype of each device was fabricated and tested separately.

Once the prototypes had been tested, they were fitted to a toe lasting machine (an ERPS MAP model) and were adjusted to their final setup positions. Figure 11 shows the work area of the machine with the new devices fitted and set for two different lasts.

Figure 11 – work area of the toe lasting machine with the new devices fitted and set for narrow toe (left) and wide toe (right).

8. TESTING THE NEW SETUP TIME

Once all of the preliminary tests had been completed and passed, the prototype machine was set up for shoe lasting. The setup times for a variety of last shapes were then measured. Fifty pairs of toes were produced for each type of last, as shown in Figure 12. The quality of the assembled product was also checked during these tests.

Figure 12 – Contour followed by pincers around a narrow-toed last.

Figure 13 shows the same machine set up for a wide toe, illustrating the contour followed by the pincers around the last. The adjustments were made without using any tools whatsoever and without changing any parts, using only the setup possibilities offered by the new devices.

Figure 13 **-** Contour followed by the pincers around a wide-toed last.

The unmodified MAP toe lasting machine has an average setup time of 15 minutes, according to the measurements taken previously, whereas with the new devices fitted setup time was reduced to an average of 3 minutes 30 seconds. This time was measured using the machine fitted with the new setup devices. The reduction in setup time was 76% of the time previously taken to change the toolset for one last for the toolset for another last. The cost of the modifications was initially 26% of the average price of the machine. These results were considered extremely satisfactory.

9. CONCLUSIONS

The changes that footwear manufacturers have been forced to make by both their domestic and international markets have meant that they now work with very small batches that are very often personalized too. These factors, in turn, have meant that these manufacturers are seeking methods to reduce the setup times of their production lines.

It is within this context that this paper has proposed two news devices to be fitted to toe lasting machines, which, at a reasonable cost, reduce setup time by 76%. In order to achieve this, the first step was to identify those areas that could be changed to affect the machine's setup time. The most critical steps were adjustment of the pincers and substitution of the adhesive gun. These results were used to define the focus of the project. With these objectives set, a design ptoject was undertaken to create new devices that could be fitted to current machines and also to those already in the market.

The two modifications proposed were: automation of the process of adjusting the pincers that grip the upper and segmentation of the adhesive gun to allow it to be set for a range of lasts without being substituted.

The new devices were designed and tested and resulted in a 26% increase in the machine's retail price.

It cannot be claimed that the toe lasting machine with the new devices is capable of lasting all shapes of shoe without needing to change the gun or adjust the pincer bodies. Even with the new devices fitted there are still limits to the adjustments that were possible. What has been achieved is a considerable increase in the number of different lasts the machine is capable of adapting to with the same toolset. The devices designed to be fitted to the MAP toe lasting machines increase their speed and so make them more competitive.

What can be stated is that this project can be considered a success in terms of coming closer to meeting the demands of the market, but does not exhaust the possibilities for reducing the setup time of MAP toe lasting machines.

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