IMPROVING FEEDING EFFICIENCY OF A SEWING MACHINE BY ON-LINE CONTROL OF THE PRESSER FOOT

Dr. Luís F. Silva	Dr. Helder Carvalho	Dr. Filomena Soares
Dep. of Mechanical Eng.	Dep. of Textile Eng.	Dep. of Ind. Electronics
School of Engineering	School of Engineering	School of Engineering
University of Minho	University of Minho	University of Minho
Campus de Azurém	Campus de Azurém	Campus de Azurém
4800-058 Guimarães	4800-058 Guimarães	4800-058 Guimarães
Portugal	Portugal	Portugal
Tel.: +351-253-510253	Tel.: +351-253-510280	Tel.: +351-253-510190
Fax: +351-253-516007	Fax: +351-253-510293	Fax: +351-253-510189
Email:lffsilva@dem.uminho.pt	Email: helder@det.uminho.pt	Email: fsoares@dei.uminho.pt

ABSTRACT
This paper presents a contribution towards the development of a new generation of sewing equipment integrating auxiliary add-on kits to improve performance and flexibility in the production of high-quality garments. An overview of all the recent developments concerning the redesign of the first PC-based controller developed for a novel electromagnetically actuated presser foot on an industrial overlock sewing machine will be presented. Other software modules, developed to ease the establishment of control references and the tuning of the controller parameters, as well as a brief discussion and analysis of the obtained results, will also be described in this paper. According to the latest results here reported, the presser foot firmly controls the fabric plies for a wide range of materials and situations.

KEYWORDS
Overlock sewing machine, fabric feeding system, electromagnetically actuated presser foot, presser foot closed-loop control

1. INTRODUCTION

Market requirements for high quality products, produced from an increasing variety of materials and small-batch order sizes, stress the need for flexible and reconfigurable machines, which can be quickly set-up and/or self-adjusted. This is especially true for the garment and leather industries in European countries. To fulfil these needs, new control devices and process-engineering tools for sewing machines are required.

However, due to the complexity of the sewing process itself, commercial machines are not yet fully controlled or monitored. The sewing parameters are still being adjusted by "*trial-and-error*" at the beginning of the operation, as average values. Therefore, new generation of industrial sewing machines need to offer a pre-setting stage, adaptation, and self-adjustment to each situation.

In this sense, the research efforts undertaken by several researchers, from three different R&D Centres of the University of Minho, have been directed to avoid empirical machine settings, reduce set-up times and improve sewing machine performance and flexibility. Important contributions and achievements have been reported elsewhere (Rocha [1], Silva [2], Carvalho [3] and Carvalho [4]).

Two "sewability" testers, based on industrial overlock sewing machines instrumented with different types of transducers and with dedicated signal acquisition hardware, display and analysis tools (developed using LabView graphical programming language), have been used to assess and evaluate:

1 - Stitch formation,
2 - Needle penetration (and withdrawal), and
3 - Material feeding.

For the feeding system, two variables were evaluated: the presser foot bar compression force and displacement, using, respectively, a piezoelectric force transducer and a LVDT attached to the presser foot bar.

This led to the development of an electromagnetically actuated presser foot to replace the standard spring actuated presser foot system, proving to be reliable, effective, and able to control the movement of the fabric plies, according to material characteristics and sewing speed.

Figure 1 shows the transducer's arrangement and the adopted actuation set-up, using a proportional force solenoid placed sideways to the presser foot bar. (On this same figure it is possible to observe a new thread-tensioning device, another new add-on kit currently under development. It uses a low-cost transducer device - developed specifically for this application - with an actuator for controlling the adjustment and/or readjustment of the sewing thread tensions, as briefly reported in [5], at the beginning of operation or during the course of sewing.)

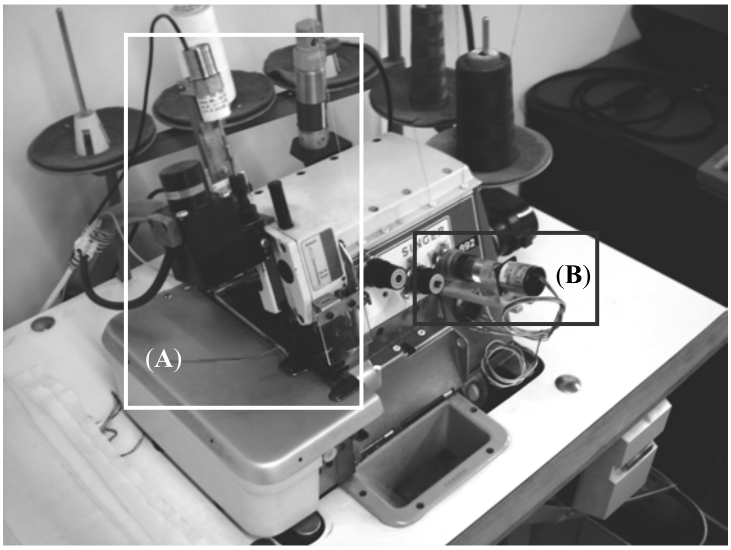

Figure 1 - The overlock sewing machine including two add-on kits: (A) The electromagnetic actuated presser foot, using a proportional force solenoid placed sideways to the presser foot bar, and (B) a new thread-tensioning device.

2. THE PRESSER FOOT CONTROLLER

The approach towards the development of a presser foot controller to accomplish the main objectives mentioned previously has already been published [6]. For the sake of completeness, it must be referred that this study began with the development of a software module to ease the setting of force according to the properties of the fabric being sewn. Two control strategies were implemented:

1 - An open-loop control, according to the control curves determined for each tested fabric, as a function of the imposed seam quality, and knowing that the force applied by the electromagnetic actuator should be proportional to the measured sewing speed, and

2 - A closed-loop control, using a PID PC-based module and computing the presser foot bar maximum displacement peak, above the throat plate level, as the feedback variable, to be compared with a reference defined within the admissible displacement values found to assure good feeding performance and seam quality.

All the software modules for these control schemes have been developed in LabView, with specific routines to acquire, process, actuate, display, analyse, and store all data to enable the assessment of process behaviour. The PID parameters were determined and initialised to those obtained using the Ziegler-Nichols criteria.

Figure 2 shows one of the presser foot bar displacement waveforms obtained with the PID closed-loop control, sewing two plies of a rib 1×1 fabric while varying the machine speed between a minimum of 2000 stitches per minute (spm) to a maximum of 4700spm, which corresponds to the most critical operating mode.

Although the presser foot is controlled and the fabric plies are firmly in place, being the total variation of the maximum displacement peak ±0.05mm around the established set point of 0.9mm, this controller has been further improved and other modules have been designed and included in the overall package to ease flexibility and machine set-up.

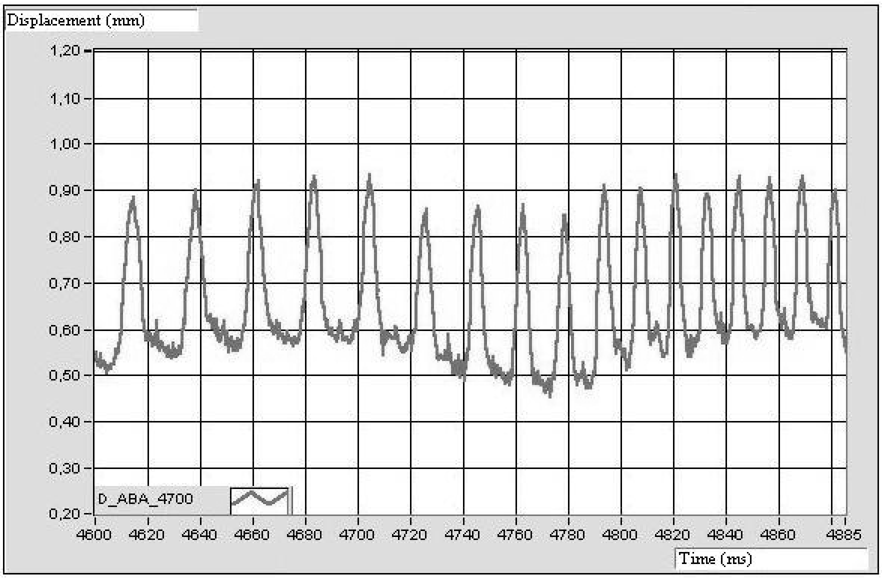

Figure 2 - Presser foot bar displacement waveforms obtained from low-to-high speed transitions using the first developed PID PC-based controller.

Therefore, over the next topics the redesign of the PID PC-based controller as well as the new modules for computing the displacement reference and the controller parameters will be presented and analysed.

3. RECENT IMPROVEMENTS

3.1. THE CONTROLLER

The current PID controller was redesigned and improved from the previous one, showing. Figure 3 shows part of the software-module's front panel. The graphs plot (from top to bottom) the displacement error, the presser foot bar maximum displacement peak and the force applied to the presser foot. The other five bottom graphs plot each of the three PID outputs, as well as the controller output to the electromagnetic actuator and the time interval between acquired samples. All this information (along with the presser foot bar compression force and displacement waveforms acquired, that are also are plotted in the main front panel, however not shown in figure 3) were extremely important to assess not only the performance of the fabrics feeding system but also the performance of the designed controller.

All the improvements were basically carried out evaluating the previous controller, reprogramming the PID equations and improving the extraction of the critical displacement values from the acquired signal. The equation for the proportional controller was implemented as:

$$S_p = K \cdot e(n) + S_{offset} \qquad (1)$$

being S_p the proportional output, K the proportional gain, e(n) the error and S_{offset} the force offset value, to guarantee a force output when the displacement error is null.

A practical test result obtained with the measurement and control system can be observed in figure 3. In this test, two plies of a rib 1×1 fabric were sewn keeping the machine speed unchanged. The displacement set point was set to 0.9mm, being the controller switched to work just as a proportional controller. (A switch on the front panel allows the user to select the operating mode for the controller, as can be seen in figure 3).

According to the plotted values, each of them representing a stitch cycle, it can be observed that the maximum displacement peaks measured are all around the established displacement reference of 0.9mm, being the computed displacement error very small, At stitch 115, the change to one ply of fabric can be clearly noticed. Shortly after, the fabric sample has ended and the displacement value returns to zero, as the presser-foot touches the stitch plate. The actuator's control values have reduced to minimum force since the first fabric thickness change.

The fabrics seem to be safely under control, which has also been observed for the other rib samples, sewn using the proportional controller and keeping the sewing speed constant.

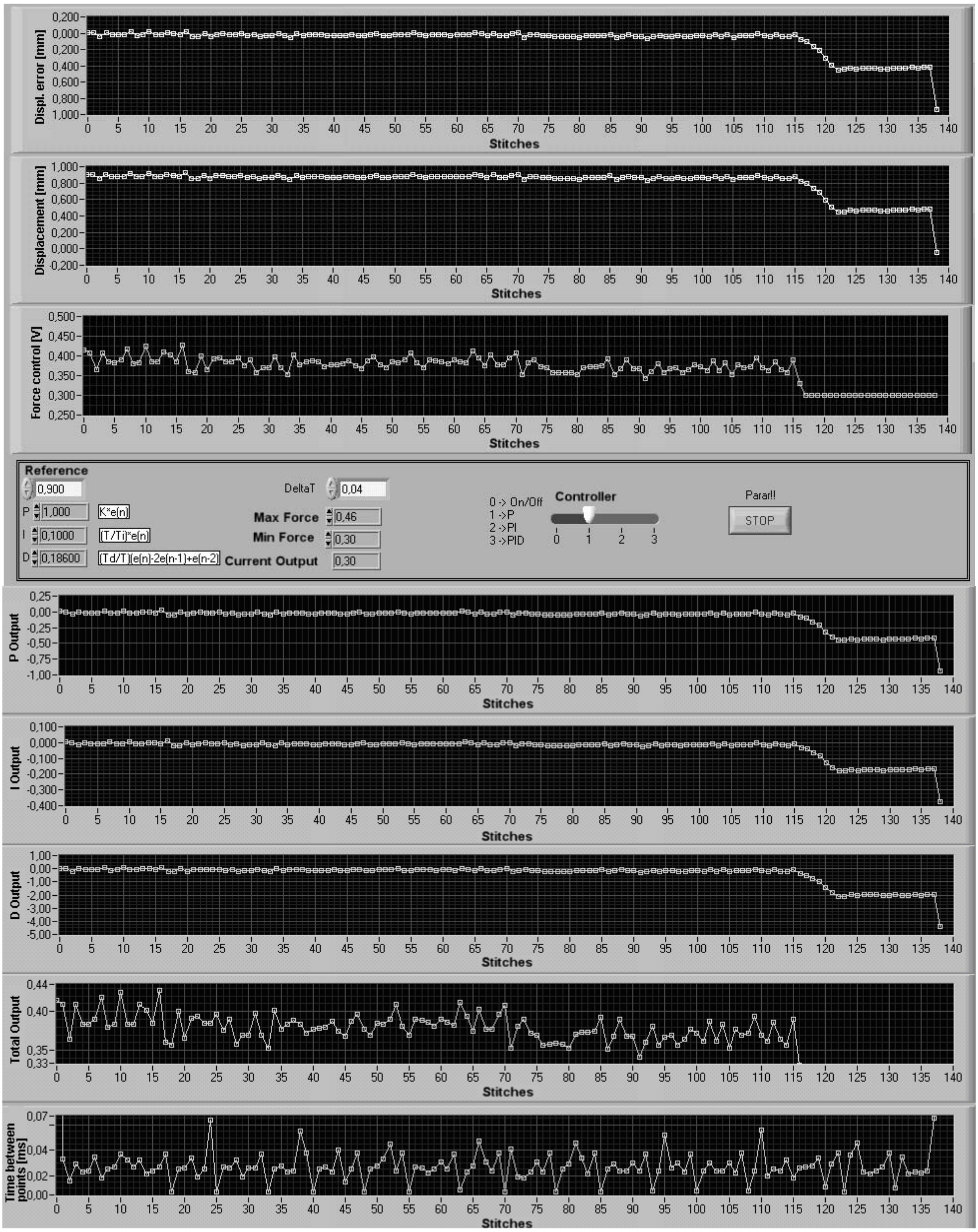

Figure 3 - Main front panel of the second developed PID PC-based controller, ploting some results after sewing two plies of a rib 1×1 fabric and keeping the machine speed constant.

It is interesting to observe the result obtained varying the displacement set point and the sewing speed. Figure 4 displays a new set of results, this time using a reference of 0.8mm, in which the maximum displacement peaks are found again varying closely around the displacement reference.

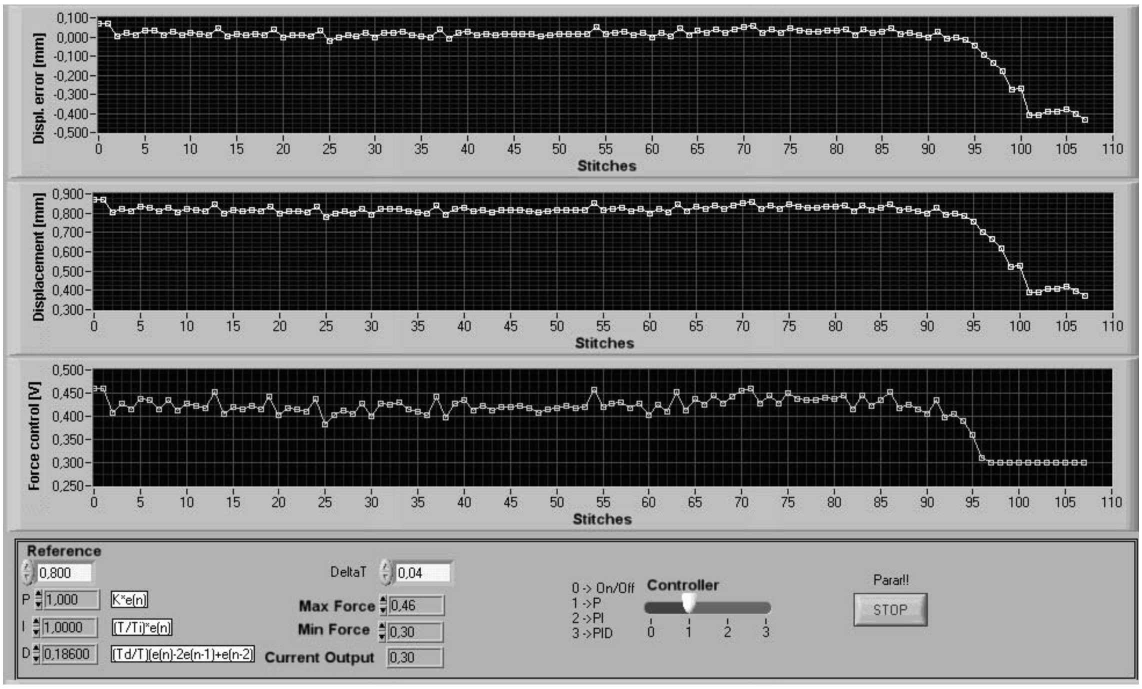

Figure 4 - Other results using just the proportional controller in which the maximum presser foot displacement peaks measured are around the displacement reference of 0.8mm.

A last observation worthy of note is shown in figure 5. Near the end of the seam, a huge increase of the presser foot bar maximum displacement peaks was noticed. This increase is due to a defect that resulted of a small piece of fabric that curled at the machine's knife and was pushed under the presser-foot, being included in the seam. At this point, an increase of the force applied by the actuator was observed, since the controller was set to keep the presser foot at a maximum height of 0.9mm, precisely responding to this displacement variation.

Testing the controller as a proportional-integral-derivative (PID) controller, the same performance has been observed as the one presented in figure 2. Although other tests have revealed that the PI controller is also a good solution for the electromagnetic actuated presser foot, more comprehensive and systematic tests are still needed and should be undertaken to obtain the most suitable controller for this application. This study can also lead to the development of an adaptive controller, able to adjust the presser foot force at the beginning or during operation, as the sewing parameters change.

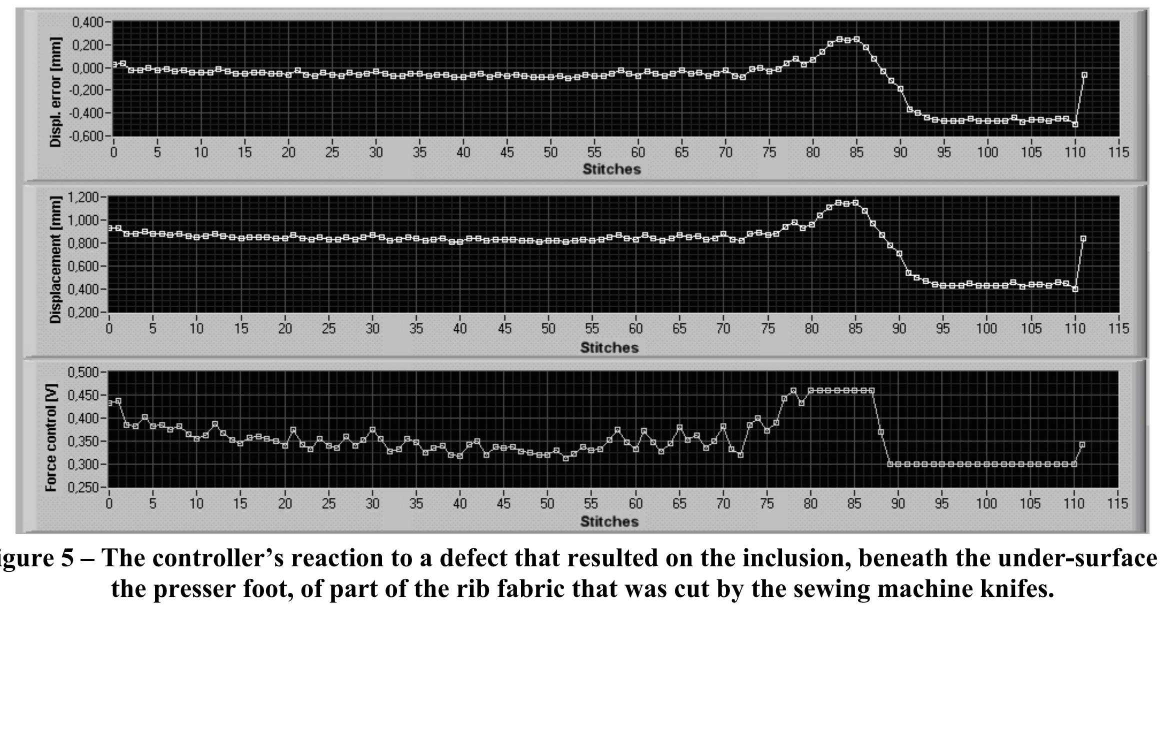

Figure 5 – The controller's reaction to a defect that resulted on the inclusion, beneath the under-surface of the presser foot, of part of the rib fabric that was cut by the sewing machine knifes.

An initial approach towards a more “intelligent” and flexible procedure for machine set-up has been established by developing two software modules to ease the setting of the displacement reference and the P-gain for the proportional controller, as described next.

3.2. THE DISPLACEMENT REFERENCE MODULE

Figure 6 shows the front panel of the module used for computing the displacement reference to set the PID controller.

After adjusting the force applied to the presser foot (using the button placed on the upper left hand side of the front panel) and calibrating the zero point of the LVDT, the operator/technician sews the number of plies required at a low speed.

The measured maximum displacement peaks are plotted on the graphs shown in figure 6, and the displacement reference (computed as the mean value of all peaks), the maximum and minimum displacement peaks (their values as well as in which stitch cycle have they occurred) and the variance are displayed.

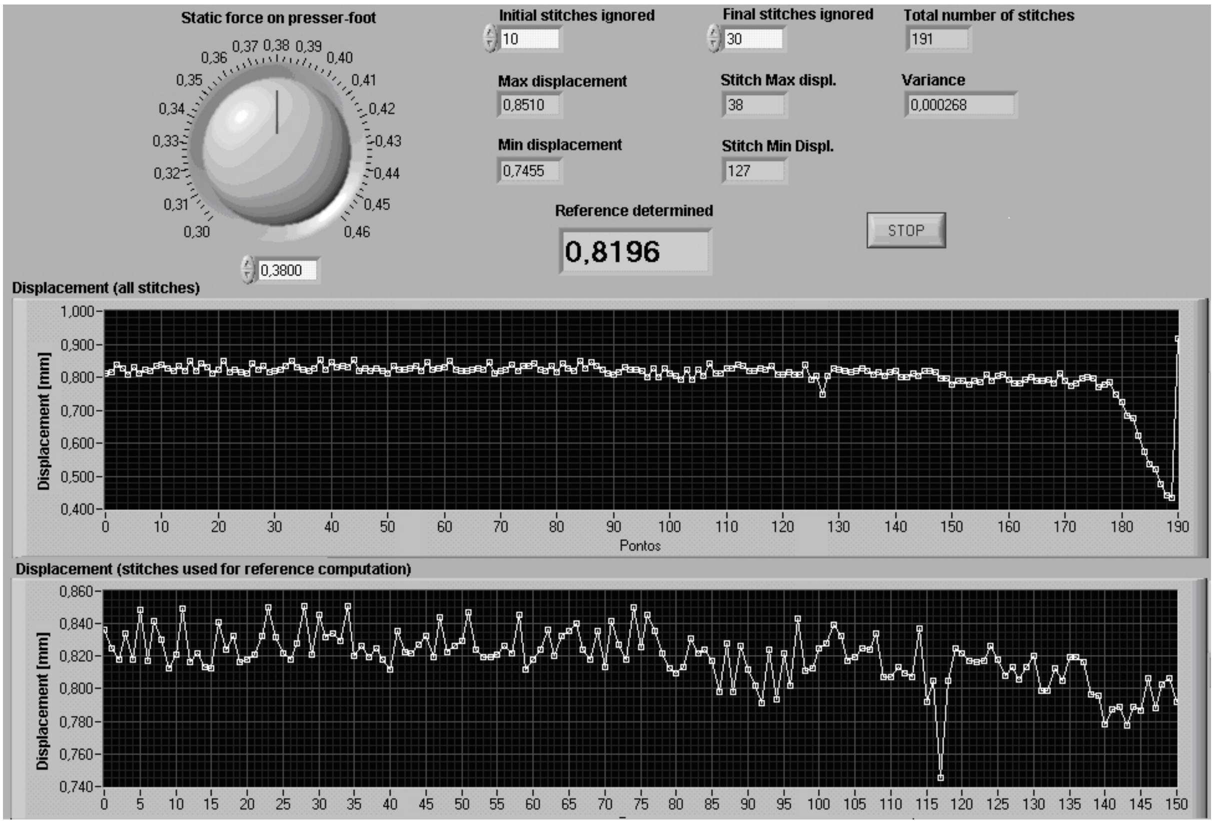

Figure 6 – Front panel of the module to compute the displacement reference for the PID controller.

3.3. THE CONTROLLER TUNING MODULE

Another important function is the computation of the P-gain for the proportional controller, which is performed by the software module whose front panel is shown in figure 7. Its determination is carried out by varying/increasing the gain and evaluating the performance of each gain according to the plotted data and statistic analysis.

The user must set the displacement reference, determined using the previous module, the gain increment and the number of stitch cycles over which each gain will be tested.

The length of the fabric samples and a good manipulation of the plies should be considered to obtain a reliable evaluation of the overall testing procedure and the "best" gain for a given sewing operation.

The displacement tolerance range [defined as (max-min)/2] and mean value, standard deviation and variance are computed for each gain. Figure 7 displays the first set of results using a different fabric from the one tested in previous sections.

On the other hand, this module can also be improved to determine and set the I-gain for the PI controller, if this will be the final adopted controller for the presser foot.

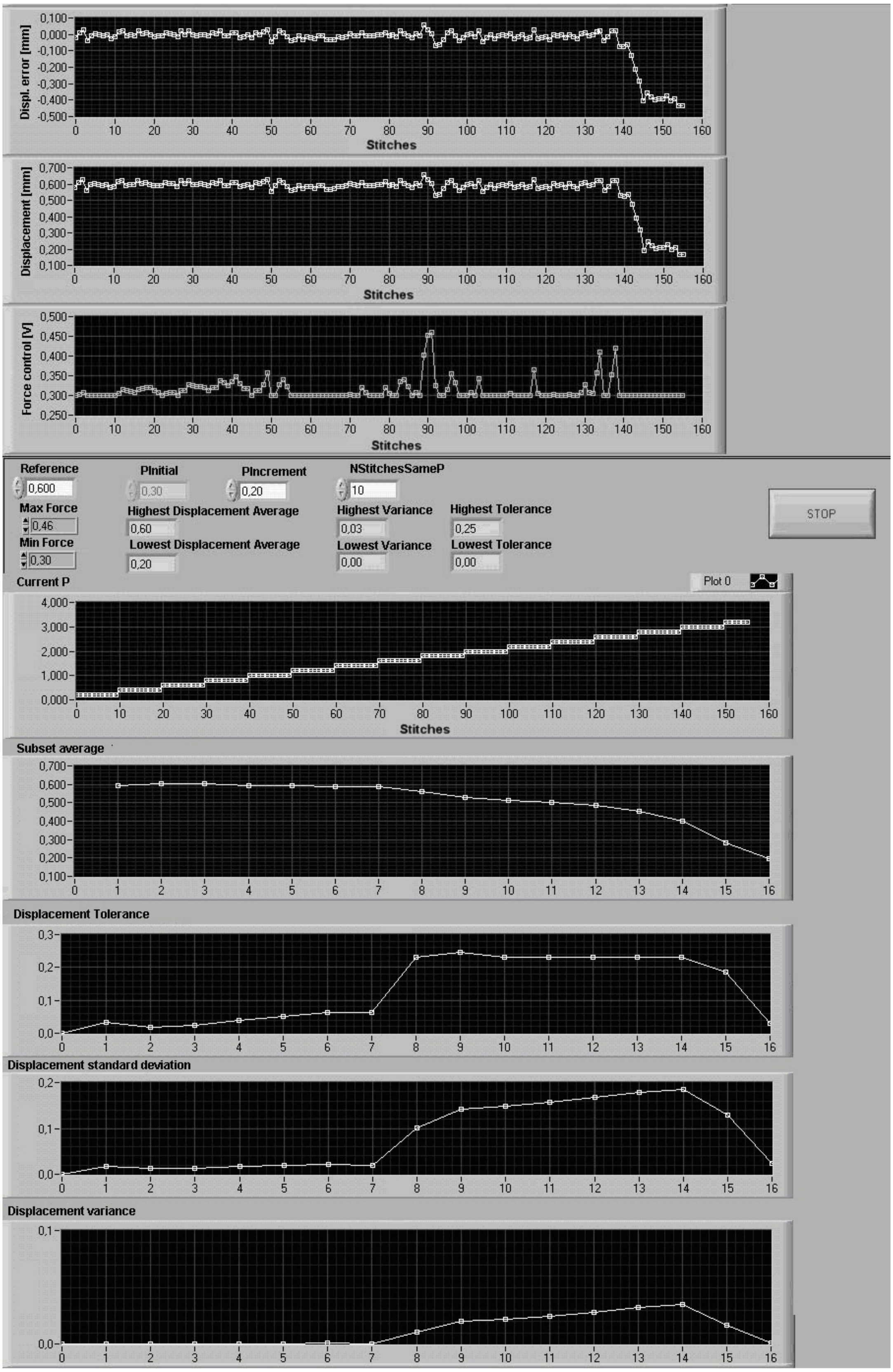

Figure 7 - Front panel of the tuning module for setting the P-gain to the controller.

4. CONCLUSIONS AND FUTURE WORK

The knowledge and control of sewing technology is an important aspect to consider by textile and apparel manufacturers in order to produce high-quality garments and other sewn textile end products.

Based on the experience of the multidisciplinary research team, considering the purposes already mentioned, this paper reviews some of the latest improvements carried out on the development of a controller for the electromagnetic presser foot. According to the results here presented, two controllers (P and PI) seem to be a good solution after the first developed PID PC-based controller. Other two modules have also been developed for setting the controller, enabling the determination of the displacement reference and the P controller gain. Future work will be focused on carrying out more comprehensive tests, to obtain the most efficient controller to accomplish the objectives defined by the authors.

The introduction of sensors and actuators in the machine's tuning mechanisms, as presented, has opened a wide area of applications of diverse complexity. It is now possible to measure and reproduce the settings of presser-foot force and thread tensions, which allows the sewing technician in the factory more control over the machine's tuning. In fact, one of the end-products envisaged for this project is the assisted setting of sewing machines. Instead of the traditional trial-and-error process, the technician would use offline support software to engineer the process, establishing the ideal controller parameters, or simply recall the settings of a previous manufacturing order, stored in a database. The setting of the machines can then occur in several ways, for instance by network (if the machine is equipped with the sensors and actuators), or with a portable (for example PDA-based) sensing/actuation system that can be quickly connected to the machine to perform the tuning. Another possible application is the transmission of process data from the machine controllers to a central quality management system.

The actual implementation of these functionalities will, in practice, depend on a cost/benefit analysis to be performed for each of the devices proposed. Currently, the effort within the project is the development of modular, low-cost systems for each of the functions proposed, allowing an adaptation of the complexity of the system to each specific situation.

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