Actuation, monitoring and control of fabrics feeding during high-speed sewing

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SYNOPSIS

For some years now the fabrics feeding system of an industrial overlock sewing machine has been studied at the University of Minho, gathering different background researchers at the Laboratory of Process Research. Following the findings reported in previous stages, briefly summarised in this paper, a new research programme was established to enable a PC-based open and closed-loop control of the presser foot system. This paper highlights all this recent developments, presenting and discussing, in detail, the PID closed-loop control strategy implemented. The results show that the presser foot closed-loop control has improved performance for a wide speed variation range.

1 INTRODUCTION AND PREVIOUS RESEARCH MILESTONES

This investigation is part of a broader research work that began in the early 90's at the University of Minho. The sewing process, namely needle penetration, stitch formation and fabrics feeding dynamics, have been studied using a "*sewability*" tester based on an industrial overlock sewing machine, where the performance of needle penetration, fabric feeding and stitch formation can be assessed during sewing. The authors (1-4), and other researchers that also supported this project, instrumented this machine with miniature piezoelectric force transducers on the presser foot and needle bars, encoders and semiconductor strain gauge transducers on the threads' path. A dedicated signal acquisition and analysis equipment was also developed for measuring, respectively, the presser foot bar compression force, the needle penetration and withdrawal forces and the needle and loopers threads consumption and tension.

With this system, the performance of the sewing machine feeding system (made up by a standard presser foot, with a helical compression spring on the presser foot bar, a throat plate and a differential feed dog) was studied. A LVDT was also attached to the sewing machine to measure the presser foot bar displacement and, along with the kinematic analysis, enabled a better understanding of the feeding system dynamics. The "*critical*" points in the stitch cycle, that greatly influence the quality of the produced seams, were identified and correspond to the contact losses occurring between the presser foot and the fabric plies.

After this analysis, and to avoid the lack of fabrics' control, especially at high sewing speeds, different actuation technologies were studied and two presser foot actuation set-ups based on a proportional force solenoid were developed: *(1) Using the solenoid placed sideways* and *(2) Aligned with the presser foot bar*.

The presser foot bar displacement and compression force waveforms acquired and the differences between the actual obtained stitch density and the one established with nominal machine settings indicated that an effective control of the fabric plies, for all tested speeds, has been achieved with the proportional force solenoid attached sideways to the presser foot bar.

The spectral analysis on the acquired waveforms (Fast Fourier Transform – FFT) and the computation of harmonic distortion parameters revealed itself as an important technique to characterise and differentiate the performance of the standard presser foot and the developed actuation system.

Finally, the approach taken to implement an adequate (*on* and *off-line*) monitoring system, based on a new concept for the assessment of the seams quality, was named *Admissible Displacement Limits* (ADL). In this technique, the presser foot displacement is supervised directly, and it is possible to automatically detect loss of feeding efficiency.

Some of these research milestones are displayed on figure 1, which especially focuses the electromagnetic actuated presser foot, the displacement waveforms acquired and the feeding efficiency monitoring system. All of them are described in more detail in reference (5) as a preparation for the automatic control. After this stage, further research efforts were directed for designing two PC-based presser foot control schemes, presented and discussed over the next topics.

2 RECENT DEVELOPMENTS

This study began with the development of a software driver, in LabView, for applying a constant force to the presser foot bar. Instead of manually adjusting the forces using a potentiometer available on the actuator drive-circuit, this PC driver eases force setting according to user/technician need to sew a certain type of fabric.

2.1 Open-loop Control

The PC-based open-loop control was established knowing that the force applied by the electromagnetic actuator should be proportional to the measured sewing speed, according to the control curves determined earlier for each knitted fabric tested as a function of the imposed seam quality – see reference (5) for further details. After computing the sewing speed using a specifically designed routine, the force intended to provide a controlled movement of the fabric plies is converted into an electric output by the controller to drive the proportional force solenoid. The presser foot displacement waveforms obtained during experiments showed, as expected, no contact losses between the presser foot itself and the fabrics running at constant speed, stitching two plies of the rib1×1 fabric. During quick speed transitions, from lower to higher speeds, the presser foot bar displacements tend to increase. Nevertheless, the displacements reach the same top values observed at constant speed shortly after this transition period (that relates to the dynamic response of the actuator).

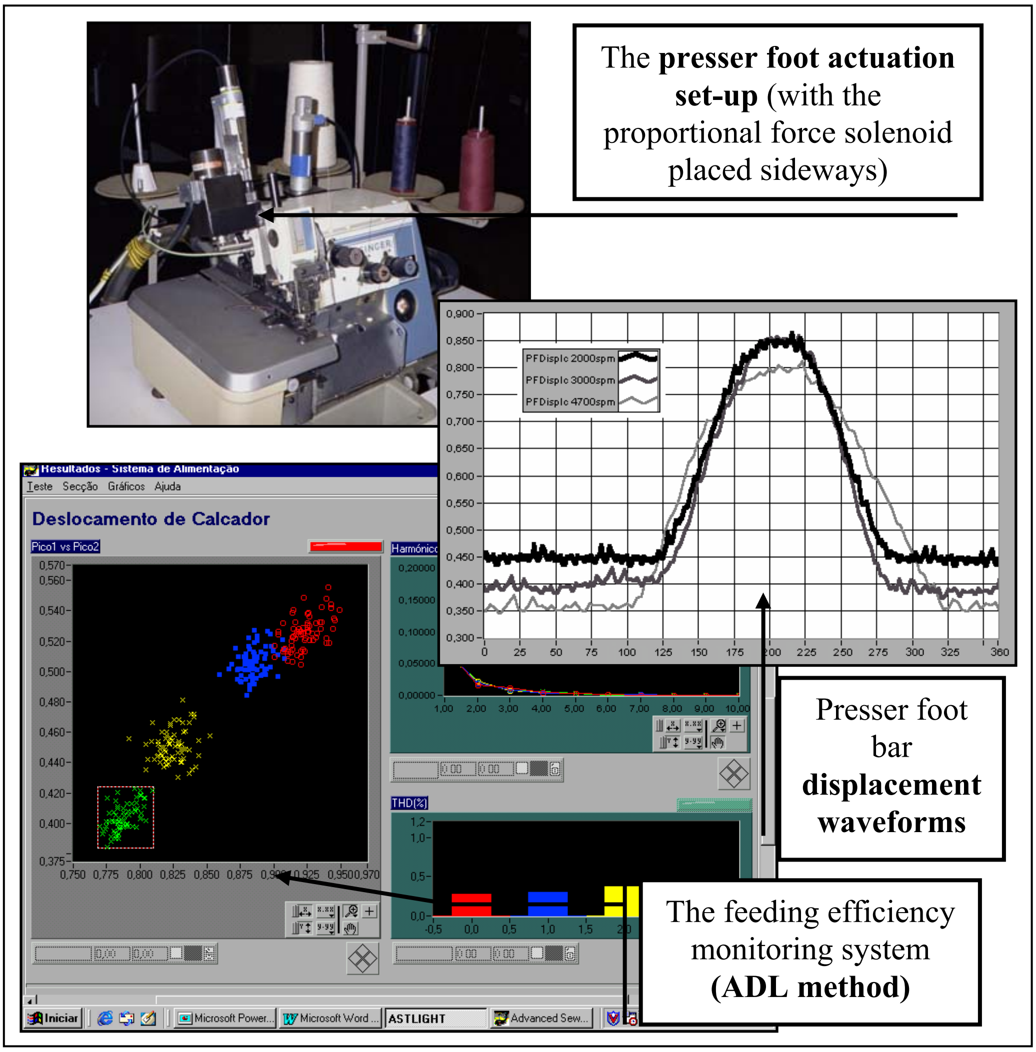

Figure 1. Overview of previous studies

2.2 Closed-loop Control

A closed-loop control was developed computing the presser foot bar maximum displacement peaks as the feedback variable to be compared with the defined admissible displacement references that guarantees good feeding performance (and seam quality) under any circumstances.

2.2.1 The Controller

This PC-based closed-loop was implemented using a PID controller, programmed in LabView, with specific routines to acquire, process, actuate, display and analyse all the information (waveforms and numerical parameters) to access feeding behaviour and its performance. The front panel of software driver developed for this purpose is shown in figure 2 and the PID gains were determined and initialised according to the Ziegler-Nichols rules, after placing the presser foot system (including the fabric plies) to oscillate.

2.2.2 Results and Discussion

The following figures (3, 4 and 5) display the first set of waveforms obtained with the developed PID controller while sewing two plies of a rib 1×1 fabric. The succession of all figures highlights the performance of the presser foot bar displacement; quickly varying the sewing speeds between 4700spm to a minimum of 2000spm, with the PID displacement reference set to 0.9mm (which is the material thickness measured by the LVDT).

Figure 2. Front panel of the PC-based closed-loop control

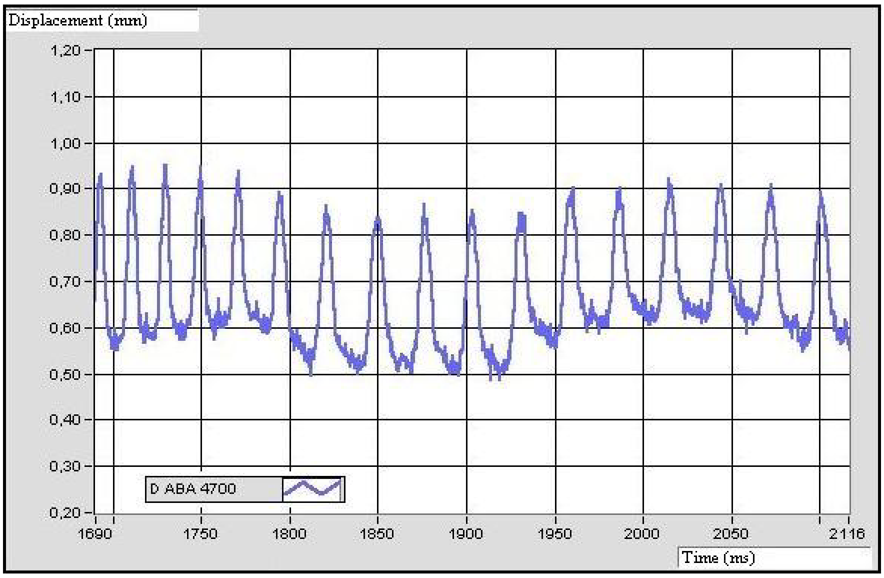

Figure 3. Displacement waveforms obtained from high-to-low speed transitions

All the maximum displacements computed off-line in a stitch-to-stitch analysis, above the throat plate level, showed to be consistently around the established set point of 0.9mm, within a tolerance margin of ±0.05mm. This presser foot bar displacement variation is perfectly inside the admissible limits determined earlier for this knitted fabric to obtain good quality seams (in terms of stitch regularity) in order to on-line monitor the feeding efficiency. (It must be emphasized that similar results were also observed when the displacement reference was set to 1mm, using again two plies of the same rib fabric.)

The presser foot appears to be under control during all speed variations tested (from high-to-low and also from low-to-high speeds, being the latest variation the most "*critical*" operative mode). The visual inspection of all samples revealed that the produced seams are quite regular, without any defects that could be addressed to the feeding system, and with an expected stitch density variation of ±1%.

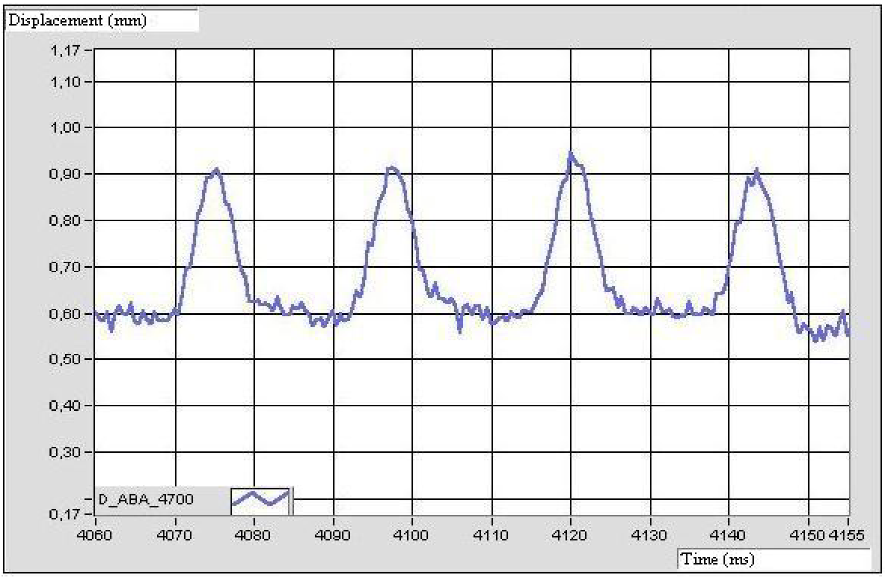

Figure 4. Displacement waveforms obtained at lower, constant speed

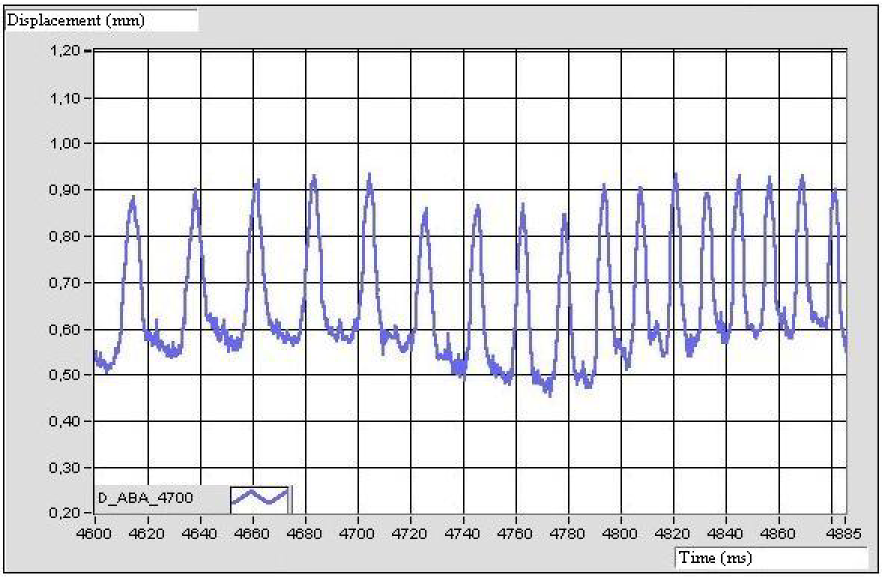

Figure 5. Displacement waveforms obtained from low-to-high speed transitions

According to our best knowledge and common agreement, it is possible to improve this closed-loop control even further. A more precise fine-tuning of the PID gains and force ranges involved, to sew this type of fabric, will probably increase the performance and reliability of the proposed PID PC-based control.

Therefore, further research will be directed to these aspects and a different approach will also be considered in future work, using specially designed fuzzy logic or neuro-fuzzy control schemes according to our application needs. The advantages and disadvantages of different control strategies studied will then be analysed and discussed in order to reach (and implement) an adequate self-adaptive controller, enabling the presser foot to dynamically adapt to current process conditions (like the change of number of plies that might occur during sewing).

3. CONCLUDING REMARKS AND FUTURE WORK

Using the presser foot actuation set-up developed earlier and the principles stated for monitoring the fabrics feeding efficiency, a software driver was designed for applying a constant force to the presser foot bar and a PC-based open-loop and closed-loop control (PID) systems were proposed and implemented. As the first approach towards the design of an adequate presser foot closed-loop control for high-speed sewing machines, the displacement waveforms obtained showed that it is possible to control this feeding component for a wide range of speeds (up to a total variation of 2700spm), firmly securing the fabric plies during the whole stitch cycle. The next research stage will be focussed to achieve even better presser foot control performance, improving the closed-loop controller here proposed, and to test other control strategies, in order to reach the implementation of a totally self-adaptive controller.

ACKNOWLEDGEMENTS

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