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Monitoring and control of industrial sewing machines

Research on thread tension behavior in lockstitch machines

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Abstract—**Processing textile materials is generally very difficult due to the flexible nature of the material. In industries using sewing as assembly process, most processes rely on human labor, being difficult or even impossible to automate. The relations between machine configuration and adjustment, material properties, and the resulting product quality are also complex. This paper describes current work using an instrumented lockstitch sewing machine to study the dynamics and variations of one of the important process parameters during high-speed sewing of shirts: thread tensions. The objective is study the principles that may allow for an automatic setting of the machines, quality control and for real-time process control. It has been found that differences in material properties result in measurable features of the thread tension signals acquired.**

Keywords— monitoring and control, sewing, thread tensions, lockstitch, garment manufacturing

I. INTRODUCTION

The processing of textile products by sewing them together is a very complicated process. This may not be apparent at first glance, but a closer look at the process reveals that, due to the flexible, often extensible nature of the materials, their handling is a procedure that in almost all cases requires human hand. Another important aspect is setting the machines for the great variety of materials used currently. This can only be accomplished by experienced sewing technicians. Machine configuration and adjustment is an empirical, time-consuming process that is more and more significant considering that textile industry has been constantly moving away from mass-production to small orders with varying materials and styles.

Machines should be able to set themselves up when the data regarding material properties and desired process parameters is known. During the process, it would be ideal if they could adapt themselves and detect defects or malfunction automatically. This would reduce set-up times, increase flexibility of the machines and increase product quality and process reliability, avoiding defects and rejected products.

Research in this direction has been carried out by several investigators, such as Clapp [1], who studied the interface between the machine and the material feeding system, Stylios

[2] who proposed the principles of intelligent sewing machines, amongst others. Within our team, previous work has been carried out on thread tensions, material feeding and needle penetration forces in overlock machines [3-5]. Other studies targeted needle and bobbin thread tension measurement on lockstitch machines [8-10].

The sewing process is a cyclic process in which several occurrences take place. The objective is to interlace thread(s) with each other and through a fabric, for the purpose of joining, finishing, protecting or decorating. Three main "sub"-processes can be identified that ideally should be monitored and/or controlled automatically:

-Material feeding. Seams are produced on the fabric with a certain pattern, which is, in the simplest case, a straight line, but may also be a complicated form such as the ones used in embroidery operations. To form these patterns, the material has to be transported-"fed" by a distance that is called the stitch length. Given that industrial machines operate at very high speeds (some of them attaining 10 000 stitches per minute), the dynamics involved is complex and there are very often problems with material deformation and irregular stitch length. Some of these aspects have been addressed in [1-3, 5];

-Needle penetration. Considering again the high sewing speeds that occur, problems with needle penetration can arise due to the mechanical and thermal interaction between needle and fabric. Fabric yarns may be torn by the forces acting during needle penetration or they may fuse due to the high needle penetration produced by friction. Systems to monitor needle penetration forces during the process to detect defects and off-line systems to support the choice of needles and fine-tune fabric structures and finishing to avoid these problems, would be of high value to the industry. This kind of approach has been studies by several authors, such as in [4-8].

-Stitch formation/Thread tensions. The interlacing of the threads itself, which constitutes the actual stitch formation, cannot be dissociated from the processes of material feeding and needle penetration. However, there are two variables directly linked to the thread that most intimately represent it: Thread tensions and thread consumption. The relationships between fabrics, machine set-up and stitch formation in lockstitch machines have already been studied in [9-15]. Methods for defect detection have been developed for overlock machines and presented in [3]. However, an automatic system for setting

thread tensions online is still missing. Wang and Ma [15] describe thread tension control in embroidery machines, but the work only tackles the issues associated to the control of the actuator. Setting of the correct references for the controllers to produce a high-quality product in varying conditions is the key issue, and this has to be further tackled.

This paper describes current work on the behavior of thread tensions in an industrial lockstitch sewing machine using a new measurement set-up. Methods previously investigated for monitoring of thread tensions and establishing the correct variable references are being ported and/or re-evaluated. The first step is the study of the relations between material properties and thread tensions. Some aspects are still not clear in this regard. In [13], for instance, the authors state that the thickness of fabric plies does not affect the needle thread tension. This is one of the aspects to be studied in this work.

The paper will describe the measurement set-up and experimental design in chapter II, present and discuss results in chapter III, and summarize conclusions and future work in chapter IV.

II. MATERIALS AND METHODS

An industrial PFAFF 1183 lockstitch (stitch 301 according to ISO 4915) machine (Fig.1) has been instrumented with a thread tension sensor (Fig.2) connected to a signal conditioning circuit which in turn plugs to a National Instruments PCI-MIO-16E-1 data acquisition board (although often called thread tension, the parameter measured is actually a thread pulling force). The machine's "synchronizer" (a rotary optical encoder) provides 512 pulses per rotation of the machine, which is used as sample clock for signal acquisition. It is thus possible to determine the exact angle at which each signal sample is acquired, allowing relating the signal directly with the events during the stitch cycle. Signals are thus represented on a continuous angle rather than a time scale, in which the rotation N of the machine corresponds to the angles between 360º·(N-1) and 360º·N.

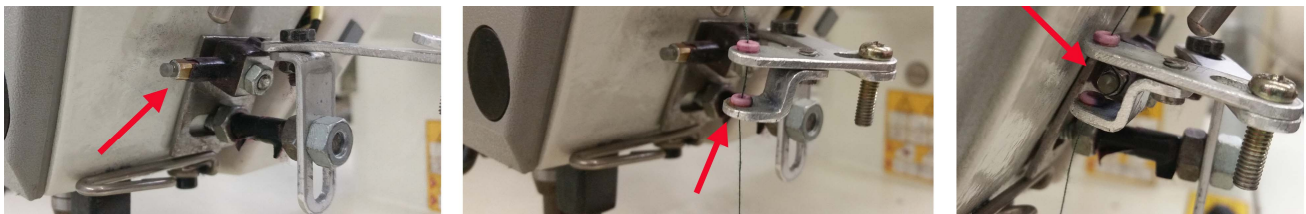Fig. 1. Pfaff 1183 lockstitch machine (left) with signal conditioning hardware for sensors (right)

Fig. 2. Set-up of the thread tension sensor: Attachment of the sensor (left), thread guide (middle), sensor with thread in the guide (right)

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The sensor (custom-designed by Petr Skop) is a cantilever beam with semiconductor strain gauges at the base, configured as a complete Wheatstone bridge. A glass sphere with a rounded slot allows a low-friction interface with the sewing thread. A thread guide with two ceramic O-rings has been designed to guide the thread around the thread sensor. The thread pulling force produces deformation on the cantilever sensor that is picked up by the strain gauges.

Thread tension is imposed to sewing threads by a device called a tensioner (partially visible in Fig.2). This device consists of two disks between which the thread passes. A spring holds the two disks together. The pre-tension of this spring can be adjusted and is called in this context static thread tension.

A software application has been developed in Labview allowing the acquisition and processing of the resulting signals. The signal processing functions of this software have been reported elsewhere [3]. The most important one is splitting the thread tension signals into stitch cycles (each cycle corresponding to one rotation of the machine's main shaft) and in turn dividing each stitch cycle into phases, which are associated to specific events of stitch formation. For each one of these phases, that will be described later, features such as peak values, power, energy or average of the signal is computed.

In the current experimental work, thread force waveforms throughout the stitch cycle are being analysed when varying parameters such as static thread tension adjustment, number of fabric layers, mass per unit area and thickness of fabric, needle size and sewing speed. Both the effect of the machine settings and process variables on the thread tensions, as well as the effect of the material properties are investigated. In this paper, the effect of static thread tension and the influence of the fabric on the dynamic tension signals are analysed.

The first step was to observe the resulting thread tension signals and interpret their relation to the stitch formation process. Some trials with the adjustment of the needle thread pre-tensions were made.

Afterwards, a more comprehensive experiment was set up to investigate on the influence of the material being sewn.

Three similar shirt fabrics with different mass per unit area were used, namely

- Fabric 1 : 1x1 plain weave ; 100% cotton; 102 g/m^2; thickness 0,22 mm

- Fabric 2 : 2x1 twill fabric; 100% cotton; 127 g/m^2; thickness 0,23 mm

- Fabric 3 : Mixed structure; 100% cotton; 118 $g/m2$; thickness 0,23 mm

The machine was set-up as following:

- Groz-Beckert 134 needle with round point and size 8;

- 100% corespun polyester thread with ticket number 120;

- Constant sewing speed of 2000 stitches per minute;

- Stitch length 3,5 mm

- Static thread tensions were adjusted empirically for the fabric with average weight; no difference in stitch balance and tightness could be observed sewing the three fabrics with this adjustment. Adjustment was maintained unchanged throughout the experiment.

For each fabric, strips of fabric of 10 cm width and 30 cm length were cut. Specimens with two and four layers of these strips were prepared. On each one of them, 10 seams with 20 stitches each were performed.

Peak values for each of the three defined stitch cycle phases (see next section) were extracted by the developed software. Results were compared between specimens of two and four layers. For this purpose, the Statistical Package for the Social Sciences (SPSS 20.0) was used.

For each experiment a MANOVA (one-way between-groups multivariate analysis of variance) was performed. Three dependent values were used: Peak values of thread force in phase 1, 2 and 3. The independent variable was the number of layers: 2 or 4. The analysis was carried out following the recommendations of Pallant [16].

Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multicollinearity, with no serious violations noted.

The results of the MANOVA analysis include the F-statistic value, average (M), standard deviation (SD), Wilks' Lambda, significance level p and partial eta squared. Wilks' Lambda is one of the most reported statistics. If the associated significance level p is less than 0.05, then it can be concluded that there is a significant difference between groups. Partial eta squared, also known as effect size, shows the proportion of the variance in the dependent variable than can be explained by the independent variable. The guidelines proposed by Cohen [17] have been used in this work: 0.01=small effect, 0.06=moderate effect, 0.14=large effect.

When the results for the dependent variables were considered separately, a Bonferroni adjusted alpha level of 0.017 was used. In this case, a significance level p smaller than 0.017 represents a significant difference.

III. RESULTS

A typical sewing waveform of thread tension is represented in Fig.3.

The waveform has been obtained by averaging 20 stitch cycles.

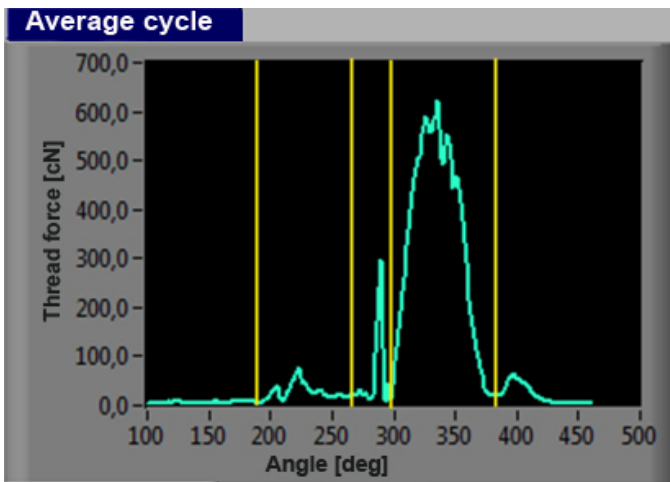Although several peaks are observed, the phases described in Table 1 are considered the most important:

Fig. 3. Typical waveform of dynamic thread force and its division in phases

TABLE 1: Thread tension signal phases for measurement of peaks [10]

Phase	Approx. angles	Event
1	190º-270º	Needle thread is being guided around the bobbin by the hook. At approximately 260 degrees, take-up lever is in its lowest position.
2	270º-295º	Needle is approaching highest position; thread take-up lever initiates its upward movement.
3	295º-380º	Thread take-up lever pulls thread up. In this phase, the highest thread tensions are observed.

Zero degrees is the angle at which the needle is at its lowest point. This moment is very close to the point at which thread tensions are at its highest. For the definitions of the stitch cycle phases, it is more convenient to split the stitch cycles from 100 to 460 degrees, as can be observed in Fig.3.

The software was set up to extract the peak values of the measured thread force signals in these three phases, for all stitches performed on the specimens.
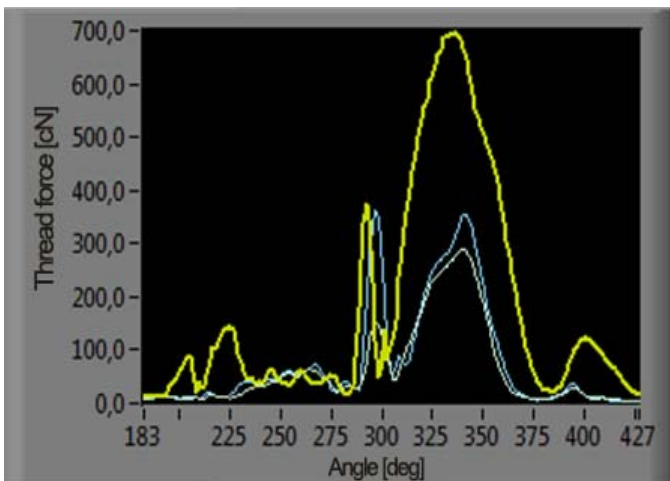

Fig. 4. Thread force over one stitch cycle with low, normal and high static thread tension adjustment. Amplitude of main peak reflects the adjustment

A preliminary trial to observe the influence of static thread tension was performed to compare this effect with the variation of the number of layers. The result is presented in Fig.4.

As can be observed, the static thread tension has a significant influence on the thread tension signals, both in the amplitude of the attained peaks as well as in the shape of the signals.

A. Fabric 1

There was a statistically significant difference between 2 and 4 fabric layers on the combined dependent variables: F= 52.632, p=0.000; Wilks' Lambda = 0.714; partial eta squared=0.286.

When the results for the dependent variables were considered separately, a difference with statistical significance was found using a Bonferroni adjusted alpha level of 0.017 - PEAK1: F=20.082, p= 0.000, partial eta squared=0.048; PEAK2: F= 7.456, p = 0.007, partial eta squared = 0.018; PEAK3: F=66.817, p = 0.000, partial eta squared = 0.144.

An inspection of the mean scores indicates that 4 layers reported slightly higher levels of thread tension on PEAK1 (M=84.541, SD=11.142) and PEAK2 (M= 435.727, SD = 122.458) than 2 layers (PEAK1, M= 79.238, SD=12.488; PEAK2, M= 402.227, SD= 122.322).

However, mean scores indicate that 4 layers report lower levels of thread tension on PEAK3 (M = 637.114, SD = 29.439) than 2 layers (M = 661.973, SD = 31.299).

B. Fabric 2

There was a statistically significant difference between 2 and 4 fabric layers on the combined dependent variables: F= 114.106, p=0.000; Wilks' Lambda = 0.547; partial eta squared=0.453.

When the results for the dependent variables were considered separately, two variables showed differences with statistical significance using a Bonferroni adjusted alpha level of 0.017, namely PEAK1: F=17.709, p= 0.000, partial eta squared=0.041, and PEAK3: F=191.105, p = 0.000, partial eta squared = 0.315. The difference without statistical significance was found for PEAK2: F= 2.139, p = 0.144 partial eta squared = 0.005.

An inspection of the mean scores indicates that 4 layers reported slightly higher levels of thread tension on PEAK1 (M=85.100, SD=11.385) than 2 layers (M= 80.311, SD=111.878). Instead, mean scores indicate that 4 layers report lower levels of thread tension on PEAK3 (M = 632.397, SD = 27.617) than 2 layers (M = 675.105, SD = 35.100).

C. Fabric 3

There was a statistically significant difference between 2 and 4 fabric layers on the combined dependent variables: F= 92.637, p=0.000; Wilks' Lambda =0.587; partial eta squared=0.413.

When the results for the dependent variables were considered separately, differences with statistical significance, using a Bonferroni adjusted alpha level of 0.017, were found for PEAK1: F=8.930, p= 0.003, partial eta squared=0.022, PEAK2: F= 24.193, p = 0.000 partial eta squared = 0.057, and PEAK3: F=153.822, p = 0.000, partial eta squared = 0.292.