Measurement and analysis of needle penetration forces in industrial high-speed sewing machine

1. Introduction

The industrial manufacturing of sewn products has always been one of the critical processes of the textile chain concerning quality assurance. Assuring the appropriate set-up and operation of all the machines, and thus the final seam quality, is a very complex task. Traditionally, this task is accomplished through–empirical methods, with the machine setting and quality control relying on the skills of operators and technicians.

This work presents an approach to a more knowledge-based and integrated process planning and control. A system was developed to measure and analyze the most important mechanical effects occurring during high-speed sewing. The paper will focus mainly on the measurement and evaluation of needle penetration and withdrawal force.

After an overview of the system, the most important experimental results obtained in a series of experiments will be described.

2. Objectives

2.1 General objectives of the research project

In general, the result expected in the research project in which this work is integrated is the development of:

- devices for real-time monitoring and control of the sewing process;
- tools for offline process planning.

Several sewing variables are studied, namely variables related to stitch formation, fabric feeding and to needle penetration.

2.2 Needle penetration force measurement

The work described in this paper focuses on the measurement of needle penetration in real time, with a sensor integrated into an industrial sewing machine. The main objective is to evaluate the feasibility of real-time measurement of the needle penetration forces, in an actual industrial situation. This involves not only an examination of the measured values and its relation to the sewing conditions in hand, but also an assessment of the accuracy of the measurement process itself, as it is influenced by several disturbing factors.

The expected outcomes of this work are techniques

a) to monitor the process in order to detect needle wear, needle damage, excessive penetration forces, changes in penetration forces due to needle heating, damage or other abnormal situations;

b) to create process planning and sewability testing tools, with which it is possible to support needle choice, definition of maximum sewing speeds, test sewability problems of fabrics prior to production, etc.

2.3 Approach

To achieve these objectives, a series of experiments was carried out in which situations with predictable results were produced. These were based on previous work by the authors and of other researchers. The data resulting from these experiments was then analysed with the objective of finding trends that can help distinguishing normal from defect situations. Rather than concentrating on numeric results, a more qualitative examination was carried out. The sheer numerical values of penetration forces are not expected to be clear defect indicators, considering that materials, sewing speeds and other sewing conditions vary drastically from one situation to another.

The final objective is to create algorithms able to compute and classify the trends and qualitative information of the data, enabling not only real-time monitoring but also pre-industrial testing, even if limited to comparative analysis.

3 Previous work

The subject of needle penetration force measurement has been studied by several researchers since the 1960's. The work focuses on two aspects: the development of instruments to measure penetration forces, and studies to relate the material, machine and needle variables to the penetration forces, needle heating and resulting seam damage.

In the 1970's, Hurt and Tyler have carried out extensive research work on this subject. The findings most relevant for this work have been

- Finishing processes applied after manufacture modify the frictional properties of fabrics. Lubricants decrease the needle penetration forces required. Frictional properties have an influence on seam damage (the example given is for acrylic fibre that presents high inter-yarn friction, being thus prone to damage) (Hurt and Tyler, 1975).
- Needle size is the main variable affecting mechanical damage (Hurt and Tyler, 1976)

According to Blackwood and Chamberlain (1970), the damage produced on a fabric does not change significantly with thread in the needle, when comparing with a situation in which the fabric is stitched without thread.

Regarding fabric finishing, Leeming and Munden (1978) have found that the force of penetration is critically affected by the use of lubricant or softener. The fabrics exhibiting high penetration values were also the fabrics which exhibited sewing damage when sewn using standard sewing tests. These authors contributed decisively with the *L&M sewability tester (*US Patent 3979951, 1976), a device used in many studies on needle penetration force. This equipment simulates a sewing machine by penetrating the tested fabric with an unthreaded needle, at a rate of 100 penetrations per minute. A force measurement is taken and the device counts the number of times the value is higher than a preset threshold. Although this situation is quite different from industrial operation, it allowed many laboratorial studies to be developed.

In recent work, Gurarda and Meric (2005) conclude that both pre-setting temperature and the finishing process have significant effects on the seam performance, needle penetration force and elastane fibre damage during the sewing of cotton/elastane woven fabrics.

Rocha (1996) related material and machine variables to the needle penetration forces. Among other parameters, bending rigidity and drape factor were found to influence needle penetration forces. The findings of other authors regarding the influence of fabric finishing on needle penetration forces were confirmed on a sewing machine, sewing at medium to high speeds.

The phenomenon of needle heating during high-speed sewing, particularly important in the sewing of synthetic materials, is also a subject that has been studied by several researchers, e.g by Hurt and Tyler (1971). Recently Liasi *et al* (1999, 2001) presented a series of publications concerning the problems arising from this occurence.

Concerning the development of measurement instruments, there is also relevant research work to consider.

S.Simmons (1979) equipped a milling machine (for easier speed control) with a piezoelectric sensor and measured force during needle penetration into fabrics. The needle penetration force waveform obtained is depicted in Figure 1.

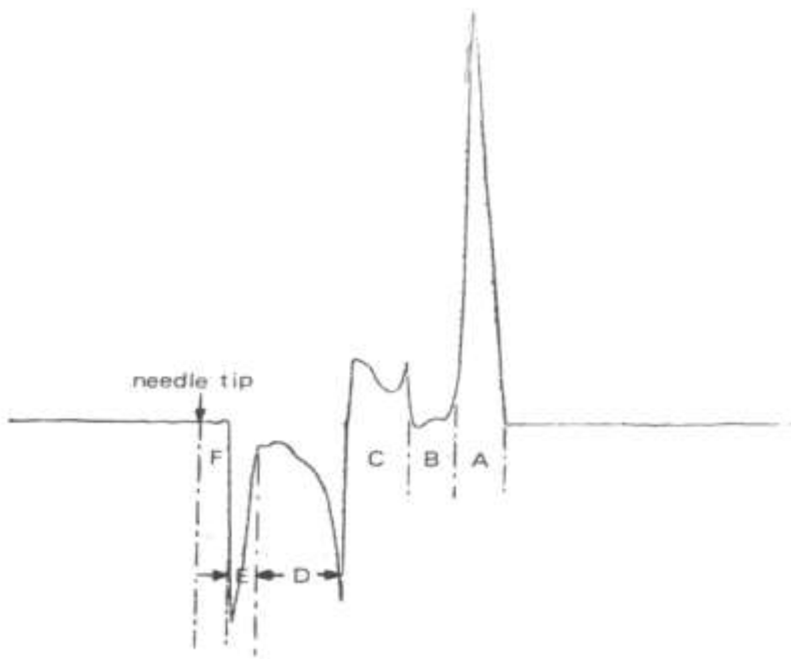

Figure 1: Needle penetration force waveforms found by Simmons (1970). Time-scale is inverted, penetration occurs from A to F.

As we shall see, this waveform is consistent with the results presented in this paper. Simmons made a detailed description of the whole penetration. Regarding needle withdrawal, he stated: “Needle shoulder is encountered [phase F] and a rapid increase of force ensues. Force is not as large as in zone A [penetration of eye] because a hole is already formed”. This statement is very important in the current work since it indicated that there may be some relation between the force values in the individual penetration phases.

Matthews and Little (1988) devised a sewing machine with sensors to measure force on the needle and presser-foot bar. The studies focused mainly on the study of the feeding system.

Bühler and Hennrich (1993) developed measurement methods for thread tension and needle penetration force. The sensor for needle penetration force was integrated in the needle plate, measuring the force with which the needle compressed the fabric against the plate. This method does not allow the measurement of needle withdrawal force. The authors mainly presented the results of the thread tension measurements; little is said about needle penetration.

Chmielowiec and Lloyd (1995) equipped a Pfaff lockstitch machine with sensors measuring presser-foot force and displacement, thread tension and needle penetration force. They were able to detect the effect of “presser-foot bouncing”, and some correlation between presser-foot compression force and seam pucker. Some experiments with very limited results were carried out concerning needle penetration force.

Rocha (1996) developed the sensor setups for needle-bar and presser foot force measurement used in this work. With a very simple acquisition setup it was possible to evaluate the behaviour of needle penetration and withdrawal forces.

Lomov (1998) presented a mathematical model for needle penetration force in woven fabrics resulting in a "*qualitatively accurate and quantitatively reasonable*" model for prediction of needle penetration force depending on several factors. The model is formulated for the "static penetration force", when the needle is moving at about 1 mm/s. This condition is far different from that occurring in industrial high-speed sewing.

Stjepanovic and Strah (1998) proposed an expert system for supporting the choice of an adequate needle size for a specific seam. Fabric composition, mass per unit area and density (ends and picks /cm) as well as sewing thread linear density, composition and stitch type were used as inputs for a "learn-by-example" regression tree. 193 examples were used to train the machine-learning technique implemented on *Retis* software. The application was found to present answers with an error margin of ±5 Nm, a good value, although the authors indicate a margin of ±1 Nm as a required error.[1]

Mallet and Du (1999) proposed the use of finite element modelling techniques to predict penetration forces into fabrics. Some success was achieved with this numerical technique, being the values within an 11% margin of those measured by a strain gauge applied to the needle. The simulation used simplified models of the needle and a plain weave fabric. Figure 2 shows the typical profile of needle penetration forces predicted by Mallet. It is

[1] Nm: Metric numbering system, needle shaft diameter x 100

interesting to note that this is close to the shape of the needle penetration force waveforms that have been observed by Simmons and also in this work.

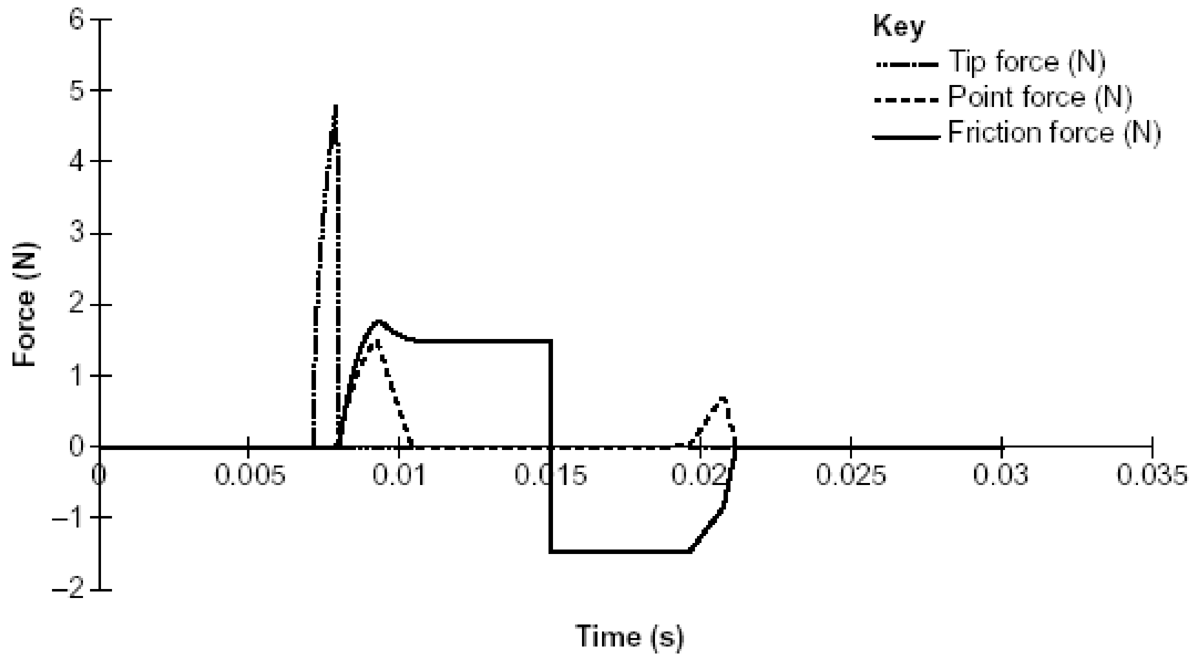

Figure 2: Needle penetration force profile predicted by Mallet with its FEM

The work herein presented is different from other work because it intends to develop systems that can be used in real industrial situations, during actual sewing, with thread and varying sewing speed. The presence of thread (producing forces on the needle that are largely unrelated to the penetration itself) and variable sewing speed, are two aspects of industrial operation that have only partially been analysed in other research. The L&M sewability tester, used in much of the referenced work, produces measurements at 100 penetrations/minute. This is a single, constant speed that is also very low when compared to industrial speeds. Other work developed on sewing machines has focused mainly other aspects (thread forces, fabric feeding).

4. The measurement system

The developed measurement system is based on a Singer 882 overedge machine configured to produce the three-thread stitch type 504. Several sensors measuring the relevant process parameters have been applied to the machine. Thread forces are measured by strain-gauges at the base of cantilever bars deflected by the threads, thread consumption is measured by rotative encoders at each thread, needle-bar and presser-foot bar forces are picked up by piezoelectric sensors and presser-foot bar displacement is sensed by a LVDT. The sensors' signals are conditioned by custom-developed hardware and are, then, connected to a data acquisition board plugged to the PC. A software package developed in LabView acquires, stores, displays and analyses the signals (Carvalho et al 1997; Carvalho 2004)

The test rig measures sewing process variables related to three different sub-functions of the machine: needle penetration, fabric feeding and thread interlacing or stitch formation.

5. Measurement of needle penetration and withdrawal forces

The pick-up of the forces acting on the needle-bar is achieved by a commercial piezoelectric sensor (Kistler type 9001) that is inserted into the bar, as shown in Figure 3.

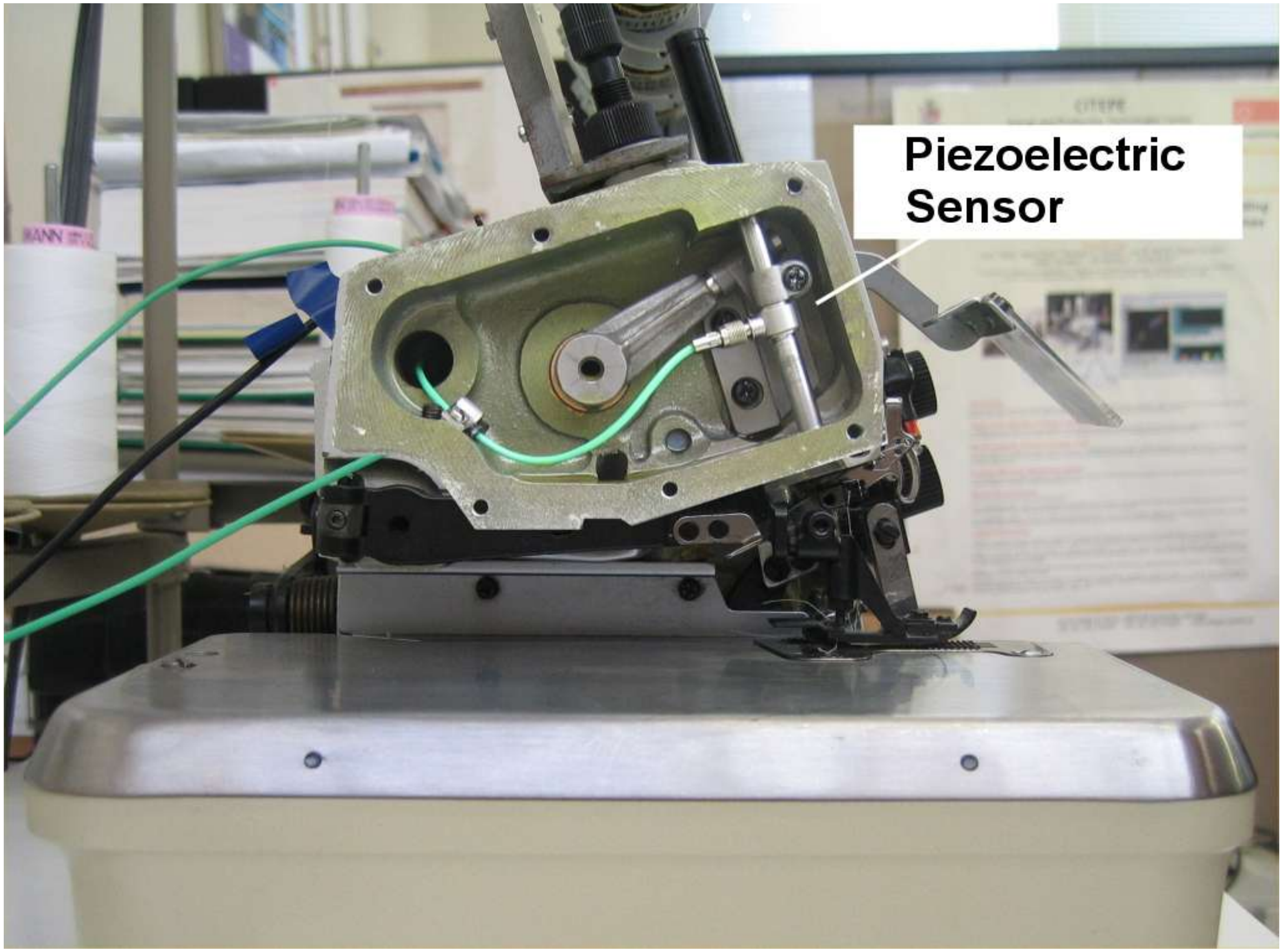

Figure 3: Set-up of the sensor for needle penetration force measurement

Measuring needle penetration and withdrawal forces is very difficult. Sensing penetration and withdrawal forces with a single sensor is only possible by inserting a sensor into the needle bar. The possible mechanical set-up in the machine used is the one represented in Figure 3.

In this configuration, the signal picked up by the sensor contains three distinct components:

-Forces necessary for needle bar motion;

-Forces produced by the interaction between needle/thread and fabric;

-Forces produced on the needle bar by thread motion;

Of these three components, only the one related to penetration and withdrawal forces is interesting for the measurement. The remaining can be considered parasitic. To extract the relevant component of the signal, a special technique was developed and optimized. This technique, described by Carvalho et al (2003) and Carvalho (2004, p. IV.3 – IV.36) involves some error, but it is sufficient for comparative analysis and approximate indication of actual force values. This issue will be addressed later in this section.

After this measurement process, still presenting some side effects that corrupt the aimed waveform, a signal is obtained that depicts the forces occurring during penetration and withdrawal.

Figure 4 shows a typical needle bar signal after filtering, over one complete penetration.

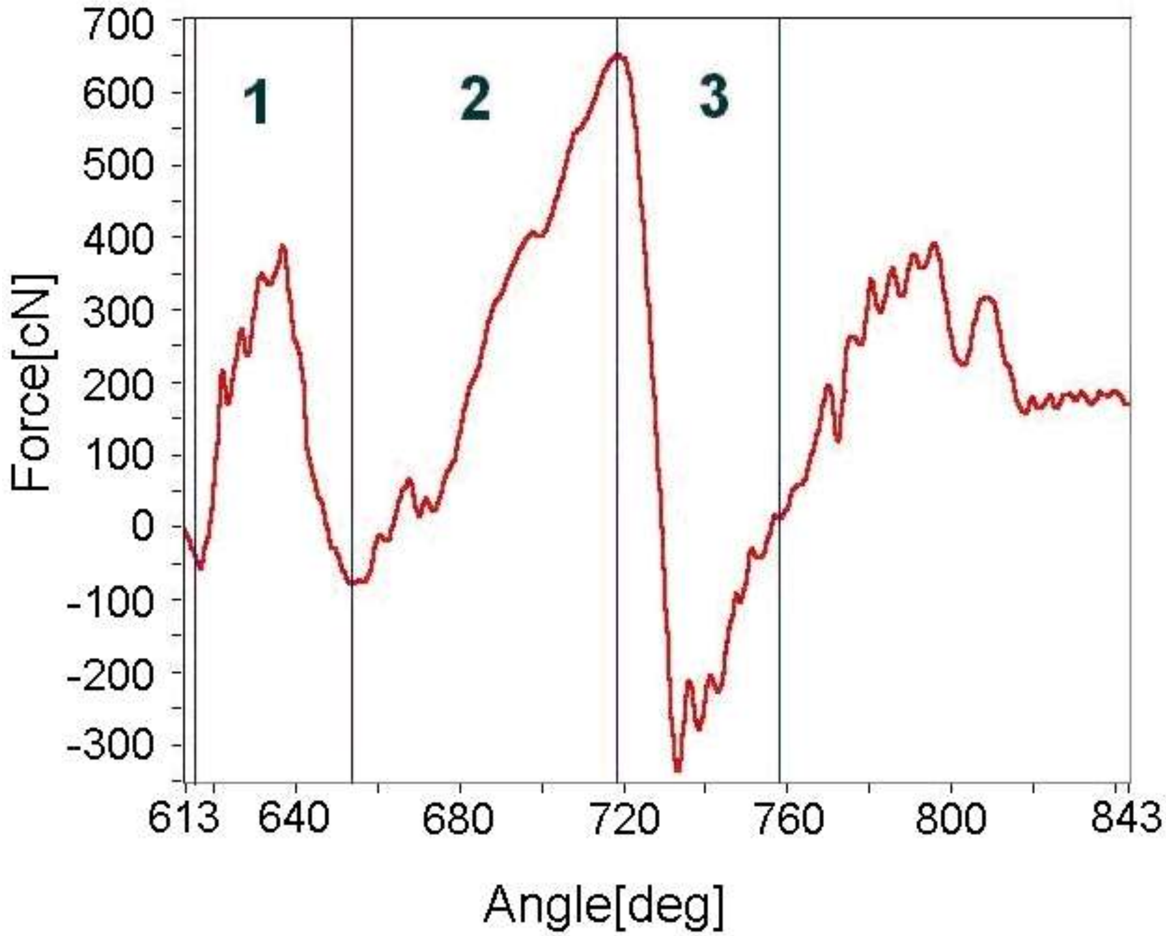

Figure 4: Typical needle penetration force waveform, division into penetration phases

The shape of this signal is different according to fabric, needle tip and size and sewing speed, among other factors and it is also highly variable from one stitch to another. It is also consistent with the waveforms found by Simmons (1979) and predicted by Mallet and Du (1999) .In most penetration waveforms, three distinct phases can be observed:

- Phase 1: First contact of the needle tip with the fabric, and penetration of the eye, producing a first force peak;
- Phase 2: The needle passes through the fabric. The shaft penetrates and produces a second peak;
- Phase 3: The needle reverses its movement and the fabric holds the needle, producing a third, inverted force peak (a *valley*).

The bounds of these phases are straightforward to define, combining the observation of the signals with the knowledge of the angles at which penetration and withdrawal occur.

In each of the three phases described, the analysis software calculates several features of the signal, the most representative being the peaks/valley and power. The latter describes the signal for the whole phase interval, whilst the peak measurement delivers a value that is measured on a single sample (where the peak has occurred).

After this processing, the extracted feature values may be represented in two ways:

-A graph in which the values for each feature are plotted according to their chronological order;

-A 3-dimensional graph, in which a point is plotted for each stitch, being its coordinates the 3 feature values extracted from the stitch.

These two representations are complementary. The latter normally gives a clearer and wider overview of the needle penetration behaviour for a first analysis, and it is very useful when comparing different situations.

As previously described, accuracy is affected by residual mechanical noise still present in the signal after the filtering process. To approximately quantify the amount of noise present in the measurements, a series of acquisitions was performed in which signals were obtained without fabric being present in the machine. Figure 5 presents peaks in phase 1, peaks in phase 2 and valleys in phase 3 extracted from the signals.

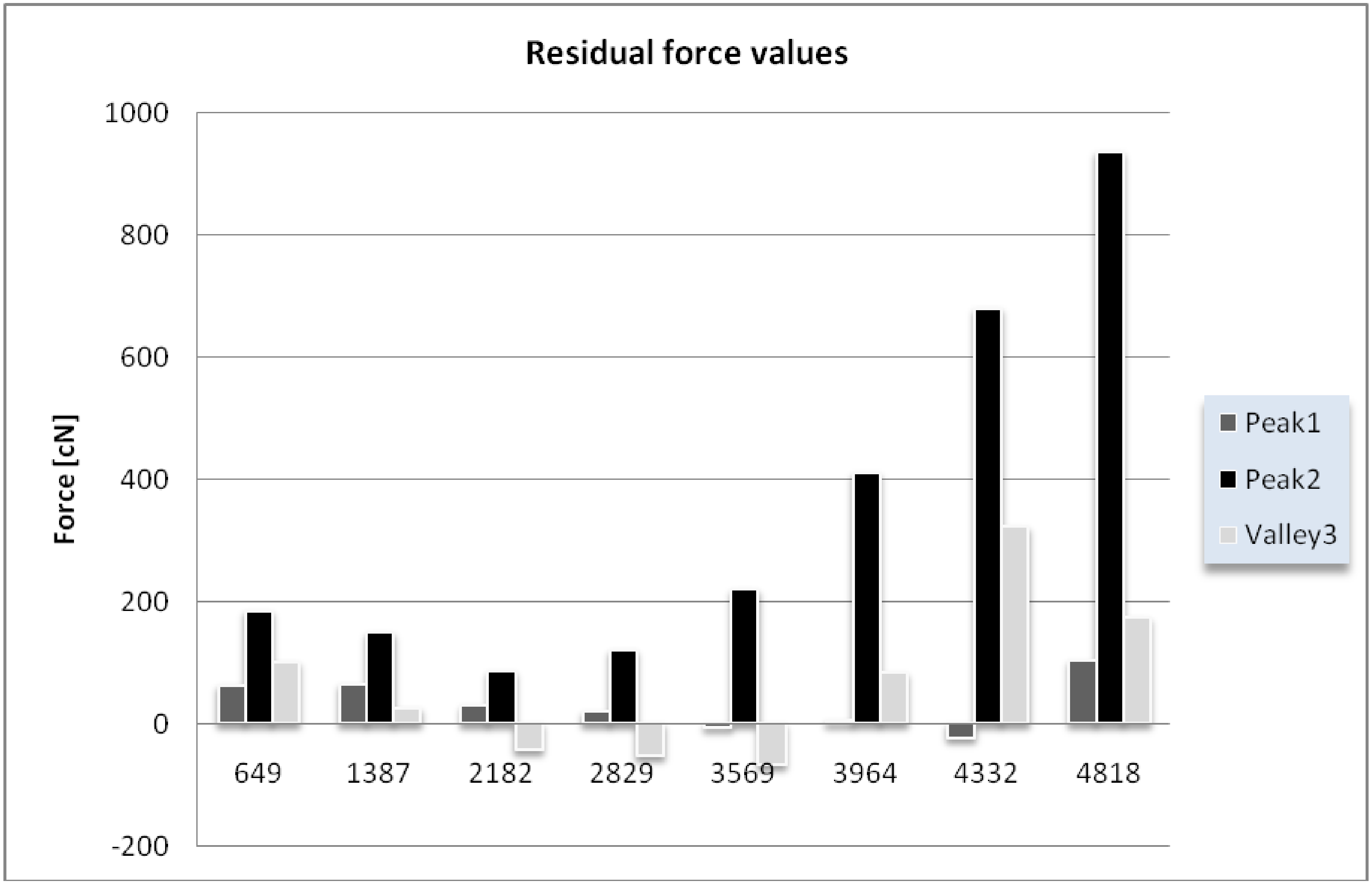

Figure 5: Feature values [cN] extracted from signal acquired without fabric and thread being present in the machine. The values represent residual mechanical noise present in the signal, after the filtering process

The value of peak 2 is the most affected by noise; however, in most situations the final measured values are significantly higher than the residual values.

6. Experimental results

6.1. General experimental setup

The experimental work carried out has pursued the main purpose of defining the needle penetration signal features that are most adequate for implementation of real-time monitoring algorithms.

Previous work, described in section 3, allows a prediction of some of the results of the experiment, such as the influence of needle size and fabric finishing. Still, the new method adds new measurement parameters worthy of examination, such as separate values of force by penetration phases. Besides any new data obtained, the effectiveness of the measurement system in depicting different situations was examined.

Above all, the analysis sought-to find features of the needle-bar force signals that could be potential indicators of problems due to needle-fabric interaction. Depending on fabric or needles, the values of the forces may be numerically different. However, when a normal sewing condition changes into a defect situation, the modifications in these values should follow the same trends. The fundamental aim was to define indicators that can be generally applied, regardless of the fabric or machine type.

The same single jersey knitted fabric in three different states was used:

1-Loom state, designated in this work as “raw”,

2-Dyed and calandered, designated as “dyed”,

3-Thermoseted and softened designated as “finished”.

Table 1 shows the technical characteristics and properties of the fabric used.

Table 1: Technical characteristics and properties of the fabric

	Raw	**Dyed**	**Finished**	
Property	**Mean (CV)**	**Mean (CV)**	**Mean (CV)**	**Test method**
Structure	Single jersey			
Composition	96% Polyamide / 4% Elasthane			
Courses /cm	17,0 (0,00%)	15,0 (0,00%)	16,0 (0,0%)	NP EN 1049-2
Wales /cm	27,6 (1,9%)	26,4 (2,0%)	25,6 (2,1)%	NP EN 1049-2
Yarn Linear density (dtex)	16,7 (0,87%)	17,66 (0,95)	16,58 (1,67%)	NP EN 4105
Mass per unit area (g/m2)	241,10(0,99)	221,7 (0,91%)	220,59 (1,93%)	NP EN 12127
Drape factor	*	0,26 (10,50%)	0,20 (9,83%)	AFNOR G07-109
Bending rigidity-Courses	*	25,62 (5,56%)	13,25 (13,79%)	BS 3356
Bending rigidity - Wales	*	25,03(5,48%)	13,04 (15,13%)	BS 3356
Thickness [mm]	0,83 (1,08%)	0,69 (1,21%)	0,69 (0,65%)	SDL Thickness Tester, ISO 5084
Loop length [cm]	0,31 (1,32%)	0,30 (1,06%)	0,29 (1,41%)	AFNOR G07 101

*Not measured due to excessive curling of fabric edge

The experiment was divided into three groups. Table 2 describes the variations of each variable produced in the individual groups of experiments

Table 2: Overview of the set-up of the experiment

Group of Experiments	**Fabric Finishing**	**Needle**	**Sewing speed [stitches per minute]**	**Needle threading**
1	Dyed	60,70,80,100,120 Nm	1000, 3500	Threaded, unthreaded
2	Raw, Dyed, Finished	Adequate (70 Nm), Inadequate (120 Nm)	1000, 3500	Threaded, unthreaded
3	Dyed	70 Nm, 120 Nm, Damaged tip, new tip	1000, 3500	Threaded, unthreaded

For each situation, a minimum of 250 stitches was acquired. The number of stitches was chosen with the objective of assuring that the confidence interval of the mean would have a width of less than 2,5% of the average, in each situation, for a significance level of 1%. The confidence interval was calculated on basis of the Student t-test for one variable. This confidence interval was chosen to enable comparison between very similar sewing situations, as is the increase of just 0,1 mm in needle diameter.

Initial tests showed that at high speeds the spread of values was quite high. To assure the above mentioned conditions, more than 200 stitches were needed. The number of 250 was defined for all experiments, which corresponds to 5 seams of about 10 cm each (with a 2 mm stitch length). At low speeds this number of samples would not have been necessary, but in this way procedures were normalised for the whole experiment.

Comparison between values of different tests was performed computing intervals of confidence using a function included in the software, for a significance level of 1%.

Seams were produced at different speeds. In each seam, speed was maintained constant. To control speed, an analogue speed limiter at the machine motor was set to the required speed and then the seams were performed at this maximum (limited) speed. The software computes the exact average sewing speed of the seams performed, being simple to tune the speed limit to the required speed.

The thread used was 100% spun polyester Nm120 (Amann SABA), and needles were Groz-Beckert system B-27 with an R point (round point).

6.2. Part 1: Influence of needle size

In the first group of experiments, the aim was to examine sewing process behaviour when needle size is varied between adequate and very inadequate values. In this way, defect situations should be more easily generated, allowing the identification of defect indicators.

Figure 6 shows an overview of the results obtained.

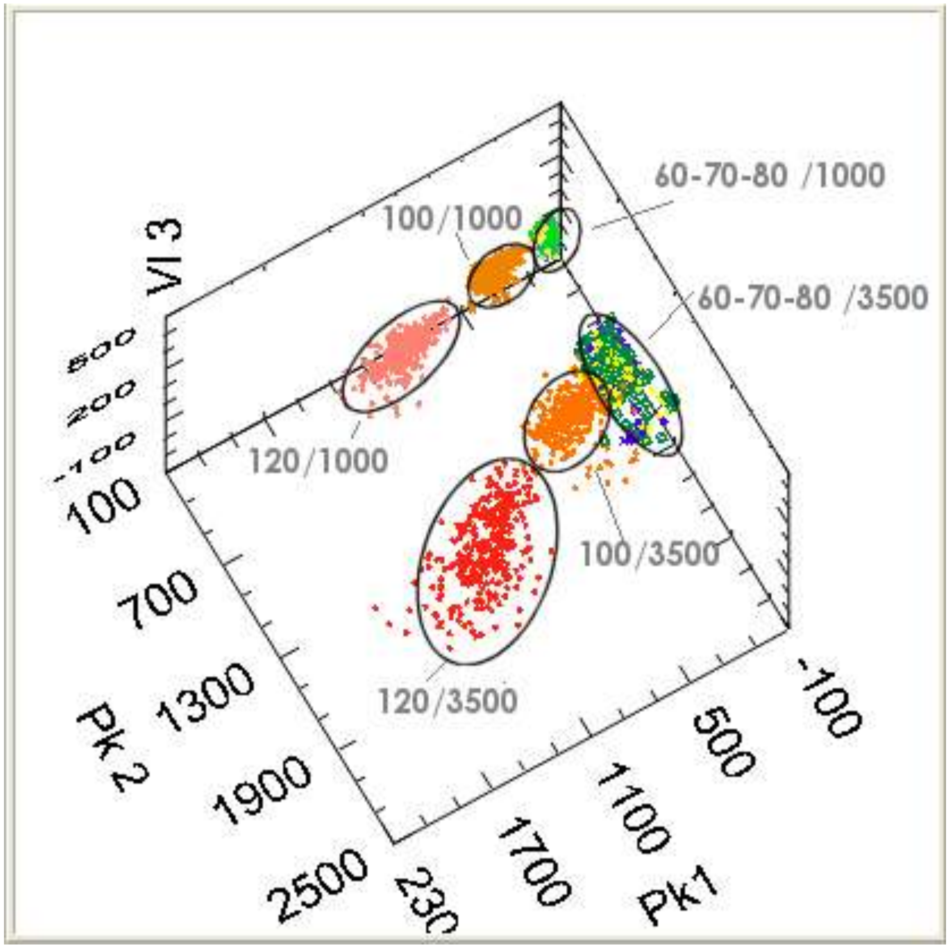

Figure 6: Overview of results, 1st group of experiments. 3-D representation of peaks and valleys of penetration force [cN] for 250 stitches each, for 60, 70, 80, 100 and 120 needle, at 1000 and 3500 spm, machine unthreaded

The first important observation is that the main parameter influencing needle penetration and withdrawal forces is sewing speed. This is an expected result from the point of view of the penetration process itself, and implies that comparative analyses of different sewing situations (damaged versus new needles, for instance) should only be done at the same sewing speed.

The second observation is that for needle sizes of 60, 70 and 80, penetration and withdrawal forces are not significantly different. However, higher needle sizes (100 and 120) show a significant difference in force values and penetration is more visible on the fabric. There was no actual disruptive damage produced to the fabric - yarns were not broken, but they were pulled out of the fabric's structure, producing a localized distortion of the fabric.

The graph represented in Figure 7 shows the average values of peak 1, peak 2 and valley 3 of needle penetration and withdrawal forces obtained in this experiment, with the machine threaded and unthreaded, compared to the residual noise levels previously presented:

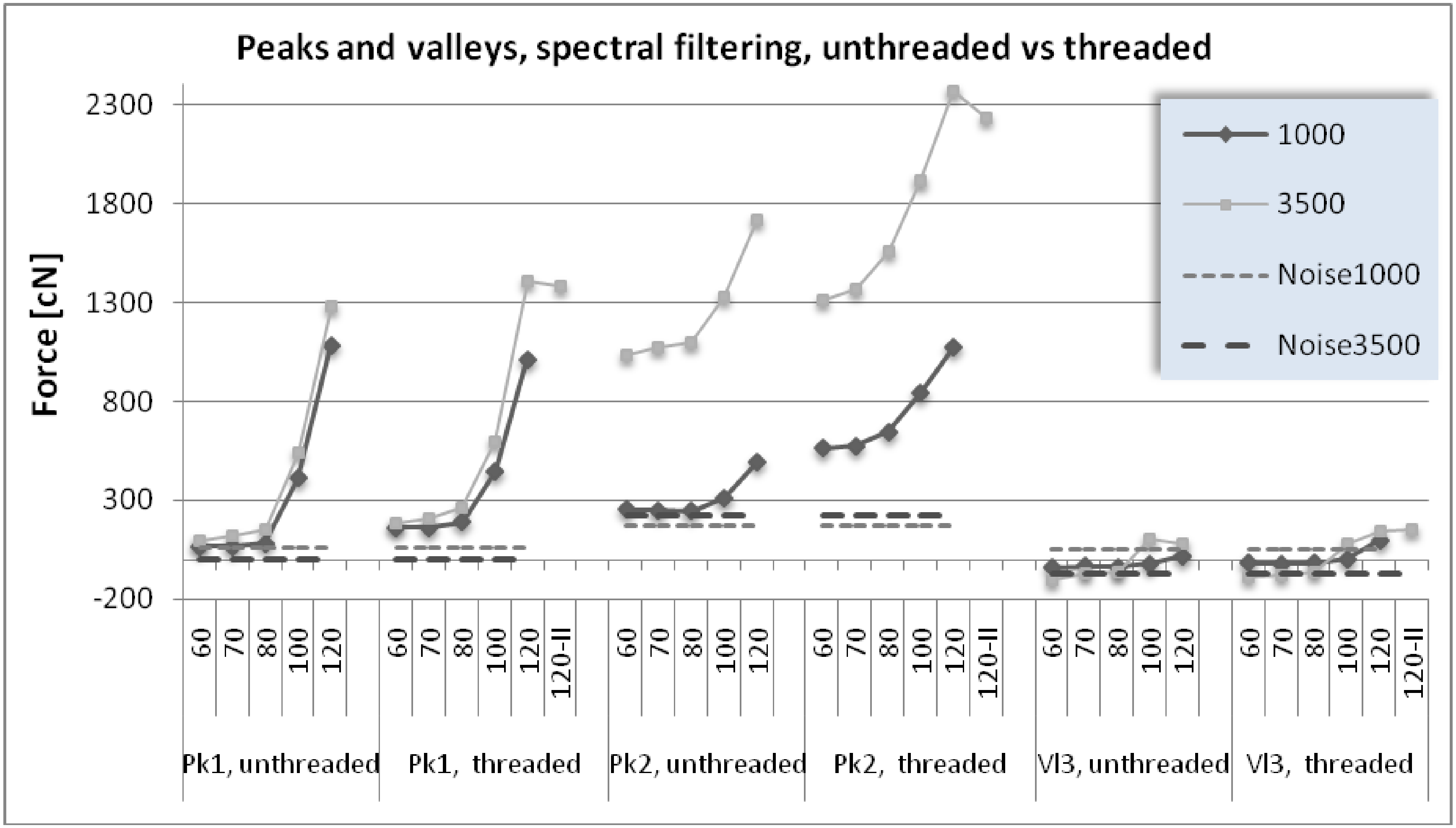

Figure 7: Results of the 1st group of experiments: Average values of penetration force [cN] peaks and valleys for 60, 70, 80,100 and 120 needles, at 1000 and 3500 spm, machine unthreaded and threaded. Residual noise values depicted as dashed lines, obtained by interpolation from data presented in Figure 5

It is possible to confirm the evolution of penetration forces with needle size, just as reported by Hurt and Tyler (1976), and here confirmed for force in both phase 1 and phase 2 of penetration. The progression of the forces can be fit by an exponential or quadratic law, explaining the detachment of values for the higher-sized needles (thicker).

Regarding the measurement error, we can see that for needle sizes up to 80, values are very close to the expected residual noise levels, although they follow a clear trend of increase. This suggests that needle penetration forces are not significant for these needle sizes and this fabric. Even so, the values obtained for sizes 60 to 80 are statistically different.

The values of withdrawal force (valley 3), in turn, do not vary significantly with needle size and sewing speed. They are also very close to the residual noise values, thus highly affected by the described disturbing factors. Nevertheless, they evolve from negative to positive values in all cases. Positive values are the result of a measurement error explained by the distortion caused to the signal in the filtering stage, causing an offset of the values. The general trend, though, seems to be a decrease of force necessary to pull out the needle, which can be explained by the larger opening of the fabric caused by the thicker needles upon penetration.

Finally, when comparing the values obtained with and without thread, the progression is very similar; they seem to be separated by an offset, which is much higher for peak 2. It has been observed that a thread force peak occurs at about the same angle as peak 2, which may be the cause of the increase. However, it is also important to mention that the presence of thread is expected to produce an increase of penetration forces in phase 2, when the shaft is penetrating, and not in phase 1, when there is merely a contact of the needle tip. Anyhow, experiments have shown that a change in needle thread pre-tension adjustment is reflected in the measured penetration values, as expected. This influence has to be considered in practice, especially for real-time monitoring applications.

6.3. Part 2: Influence of fabric state

In this group of experiments, the influence of fabric state was examined.

Two needle sizes were used: the 70-needle, considered the most adequate for the fabric, and the 120 needle, the one that produced the highest penetration forces as well as the worst appearance of the seams. The results are depicted in Figure 8.

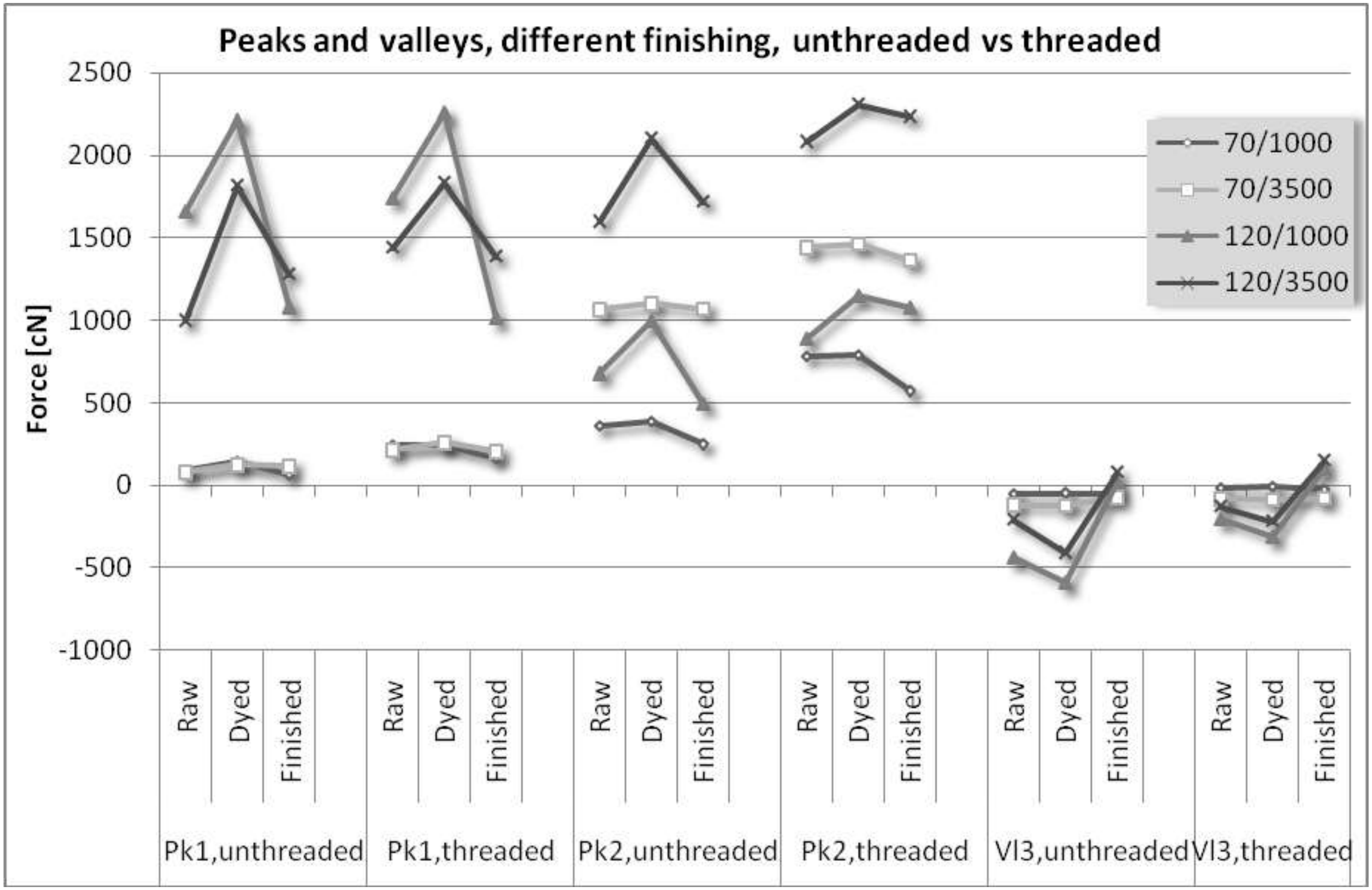

Figure 8: Results of 2nd group of experiments: Average values of penetration force [cN] peaks and valleys for raw, dyed and finished fabric, at 1000 and 3500 spm, machine unthreaded and threaded

The plots show that peak 1 is mostly influenced by needle size, whilst the highest values of peak 2 are produced according to sewing speed. This shows once again the sensitivity of peak 2 measurement to motion forces.

The effect of fabric state is more evident with the thicker needle. Generally, the dyed fabric produced the highest forces in the three phases (the most negative in the case of Valley 3). This is in accordance with fabric properties reflected by the higher bending rigidity and drape factor of the dyed fabric, and is consistent with previous work already described.

6.4. Part 3: Damaged needles

In the third group of experiments, an evident defect situation was created using a needle with a damaged tip. To enhance the defect situation, the dyed fabric was selected. It was found to be the one producing the highest penetration forces and thus expected to cause the most penetration problems.

Damage was caused to the needle by rubbing its tip against a hard surface. The defective needles of both sizes produced damage to the fabric, but the damage was clearer when using the damaged 120 needle. The 3-D graph depicted in Figure 9 shows a comprehensive overview of the results obtained with damaged and new needles.

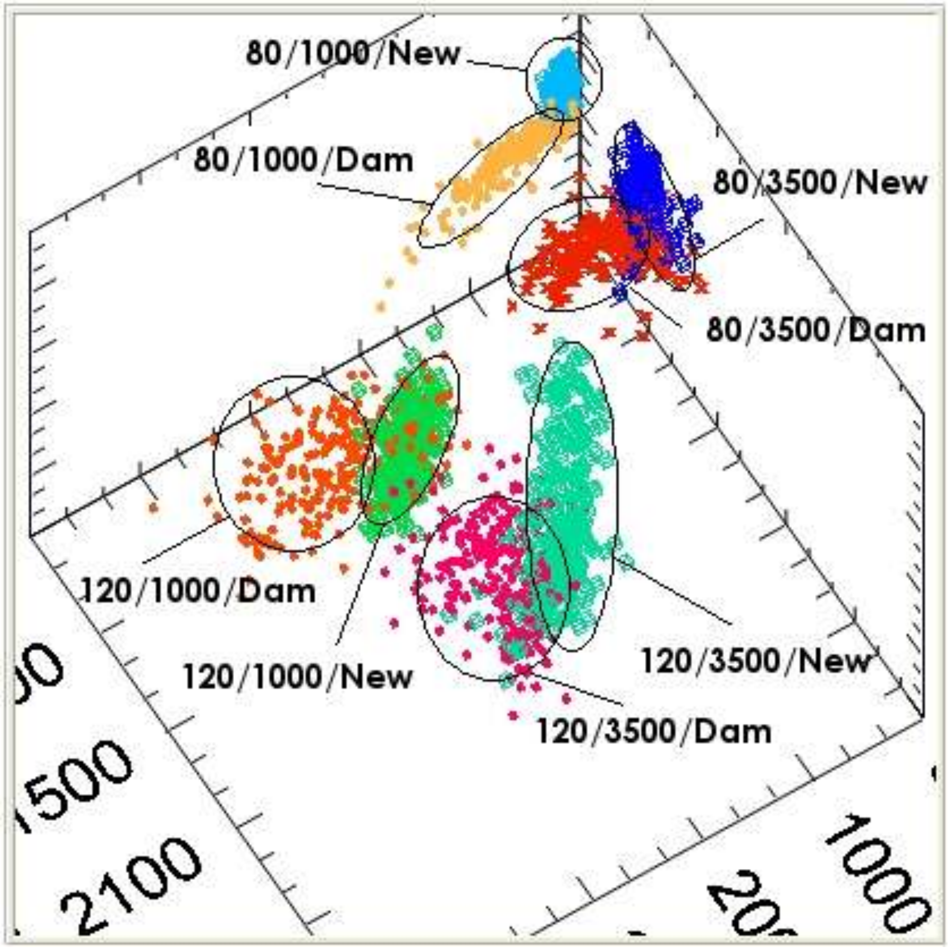

Figure 9: Overview of results, 3rd group of experiments. 3-D representation of peaks and valleys of penetration force [cN] for damaged and new needles of sizes 80 and 120, at 1000 and 3500 spm, machine unthreaded

This graph characterizes the behaviour of measured needle penetration forces quite insightfully. The clustering of needle penetration values depends mainly on needle size and sewing speed. Four main clusters are found, each one corresponding to one of the 4 needle size/speed combinations tested. Within each of these clusters, the values form “sub-clusters” according to needle tip condition.

It can be concluded that the detection of defects, based on needle penetration measurement, is very difficult due to the strong dependency of the values on sewing speed. This limits the use of this parameter because many sewing operations are performed at variable speed, rendering the detection of needle wear or damage very tricky. However, in constant-speed operations or for sewability testing purposes, the results demonstrate the ability of the system to clearly separate different sewing situations.

An additional approach to find an indicator for defect detection was based on the relation between the values in the individual penetration phases already described (Figure 4, section 3).

When a needle penetrates without affecting the fabric’s structure, the fabric will oppose resistance to the needle during the whole penetration and withdrawal process. On the other hand, if the needle breaks one or more yarns at first contact, lower values are expected in the remaining phases of the penetration. This line of reasoning has also been followed by Simmons (1970) to explain why forces are lower during withdrawal than during penetration; some relation between the peak forces or power of the penetration signal in the different penetration phases should thus be expectable and should vary when normal situations turn into defect situations.

An evaluation of this behaviour has been carried out, defining a feature ratio used as a shape factor for the penetration signal:

$$R_{mn} = \frac{F_m}{\overline{F_n}} \tag{1}$$

where

F_m: Feature Value in phase *m*

F_n: Feature Value in phase *n*

Example: Peak2/Peak1 ratio

F_m=Peak2; F_n=Peak 1; $R_{21} = \frac{F_2}{\overline{F_1}} = \frac{Peak_2}{Peak_1}$

The results of the ratios peak2/peak1, valley3/peak 1 and valley 3/peak2 can be observed in figure 10.

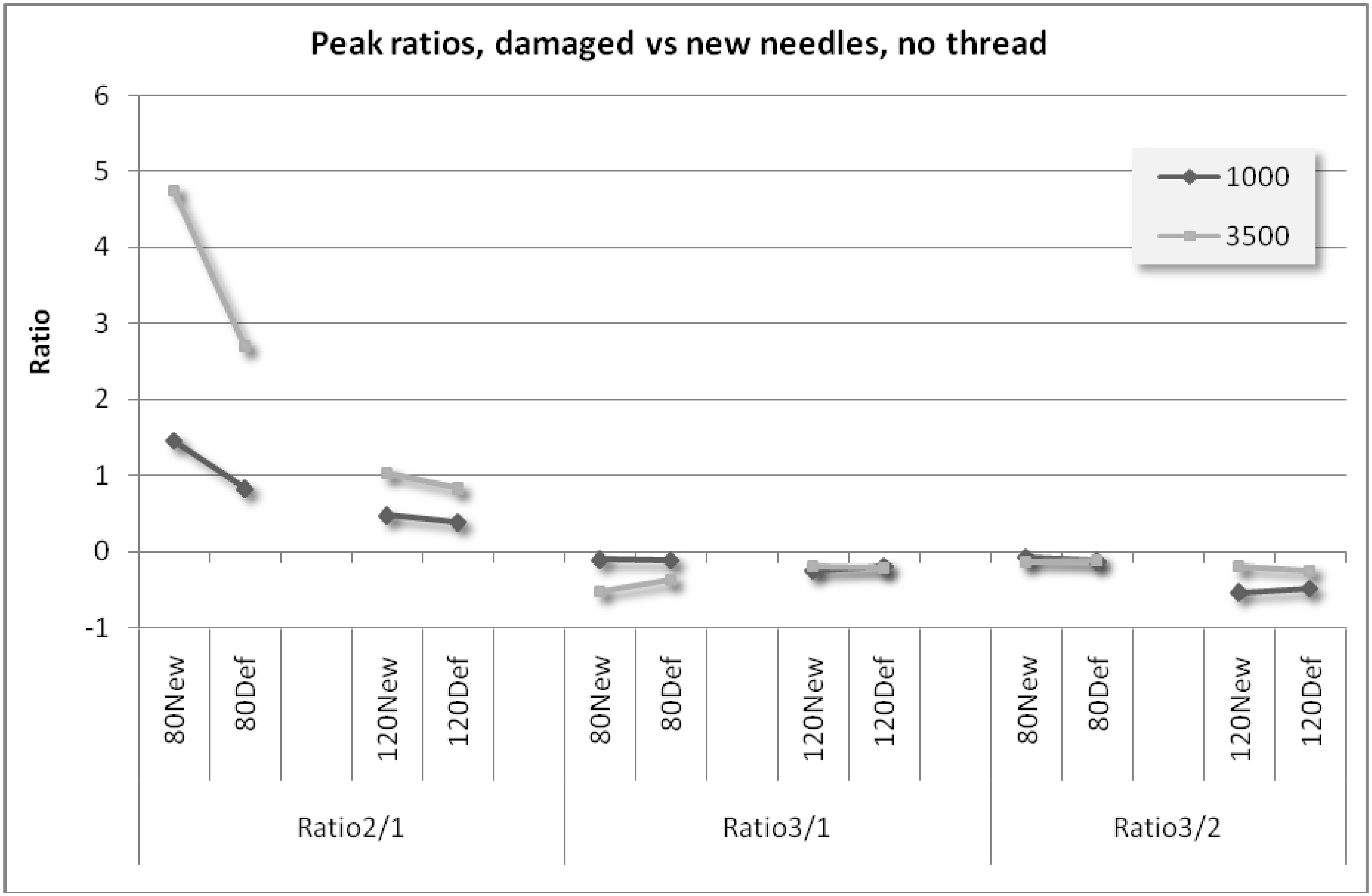

Figure 10: Average peak ratios 2/1, 3/1 and 3/2 for new and damaged needles of sizes 80 and 120, at 1000 and 3500 spm, machine unthreaded

The graph shows that ratio 2/1 is in fact lower in those cases where the damaged needle is compared with a new needle of the same size. This suggests that damage is caused to the fabric on first contact, thus reducing penetration force in phase 2. The same effect is likely to occur when needle size is increased. This has been confirmed in the 1st group of experiments, where the average of peak2/peak1 ratios were consistently found to decrease with increasing needle size. However, no such trend was observed in the 2nd group of experiments, when fabric finishing state varied.

The ratio 2/1 seems thus a potential indicator for fabric damage, but unfortunately it also reveals a strong dependency on sewing speed.

The remaining peak ratios were found to vary rather randomly, although the authors expected the relation between phase 3 (withdrawal) and phases 1 and 2 to reflect the defect situation. This may be due to the measurement error present in the measurement of valley 3. A different mechanical set-up of the measurement, with the sensor closer to the needle, may reduce this error and provide more interesting results.

7. Conclusions

7.1 Summary of results

The forces related to needle penetration are the most demanding parameters to measure in a sewing machine, being partially affected by some parasitic effects, noise and inaccuracies due to the measurement setup. Nonetheless, the results display some trends that can be considered effective for the analysis of needle-fabric interaction.

It has been shown that with this system it is possible to detect different needle sizes, and draw the relation of penetration forces to needle size for a particular fabric, in a comparative analysis. This relation is different from fabric to fabric, and is linked to its sewability.

It is also possible to perform comparative analyses to evaluate fabrics in different states, different needles or other sewing conditions.

The factor most influencing the penetration values has been found to be sewing speed.

The computation of peak ratios was an approach for a speed-independent indicator of penetration efficiency. As a result, it has been found that the value of the ratio peak2/peak1 tends to decrease when sewing conditions get worse (thicker or damaged needles). However, this peak ratio also varies with sewing speed, meaning that a comparative analysis of different sewing situations should only be done at the same sewing speed.

7.2 Real-time monitoring and pre-screening analysis

The results obtained demonstrate the feasibility of the monitoring system for constant-speed operations. However, defect situations can only be detected as a general trend. The detection of individual penetrations in which damage has occurred does not seem to be feasible. Measurement differences found when comparing damaged with new needles seem small considering that the needles tested were strongly damaged, still, they are clearly detectable.

As an offline application the system can be used as test equipment to study process parameters regarding fabric characteristics (including finishing) and sewing conditions (needles and speed of operation) considering research, textile testing and pre-production screening purposes. An interesting application is its use for determination of limits for sewing speed, needle diameter and for support in needle choice (e.g: for needle point choice), prior to production.

References

1. Hurt, F.N and Tyler, D.J., 1971, ‘ An investigation on needle heating and associated problems in machine sewing-I’, *HATRA Research Report*, No 19
2. Hurt, F.N and Tyler, D.J., 1975, ‘Seam damage in the sewing of knitted fabrics’.II – Material Variables. *HATRA Research Report*, No 36
3. Hurt, F.N and Tyler, D.J., 1976, ‘Seam damage in the sewing of knitted fabrics’.III – The mechanism of damage. *HATRA Research Report*, No 39
4. Carol A.Leeming and D.L.Munden, 1978, ‘Investigations into the factors affecting the penetration force of a sewing needle in a knitted fabric and its relationship with fabric sewability’, Clothing Research Journal, vol.6, no3, pp91-118
5. Carol A.Leeming and D.L.Munden, 1976,’ Testing fabric sewing properties’, US Patent 3979951
6. Matthews, B. N., Little, T. J., 1988, ‘Sewing Dynamics, Part I: Measuring Sewing Machine Forces at High Speeds’, Textile Research Journal, 58, pp. 383-391.
7. Bühler, G., Hennrich, L., 1993, ‘Control "On-Line" de la Formación de las Costuras’, Punto Técnica y Moda, 11, Nº. 4, pp. 239-242 and 244
8. Bühler, G., Hennrich, L., 1994, ‘Control "On-Line" de la Formación de las Costuras’, Punto Técnica y Moda, 12, Nº. 1, pp. 42-46 and 51

9. Chmielowiec, R., Lloyd, D. W., 1995, 'The Measurement of Dynamic Effects in Commercial Sewing Machines', Proceedings of The 3rd Asian Textile Conference, Vol. II, pp. 814-828

10. Rocha, A. M., 1996, 'Contribuição para o Controlo Automático dos Parâmetros de Costura: Estudo da Dinâmica da Penetração da Agulha e da Alimentação do Tecido' (Contribution to automatic control of sewing parameters: Study of needle penetration and fabric feeding dynamics) , PhD diss., University of Minho, Portugal

11. Lomov, S.V., 1998, 'A predictive model for the penetration force of a woven fabric by a needle', International Journal of Clothing Science and Technology, Vol. 10 No. 2, pp. 91-103

12. Stjepanovic, Z., Strah,H., 1998, 'Selection of suitable sewing needle using machine learning techniques', International Journal of Clothing Science and Technology, Vol. 10 No. 3/4, pp. 209-218

13. Mallet, E.,Du, R., 1999, 'Finite element analysis of sewing process', International Journal of Clothing Science and Technology, Vol. 11 Nº 1, pp. 19-364

14. Simmons, S., 1979, "An analysis of forces in a fabric-needle sewing system", Clothing Research Journal, Vol. 1 pp.51-59

15. Liasi, E., Du,R., Bujas-Dimitrejevic,J., Liburdi,F., 1999, 'An experimental study of needle heating in sewing heavy materials using infrared radiometry', International Journal of Clothing Science and Technology, Vol. 11 Nº 5, pp. 300-314

16. Li, Q., Liasi, E., Zou, H., Du,R., 'A study on the needle heating in heavy industrial sewing: Part 2: finite element analysis and experiment verification', International Journal of Clothing Science and Technology, Volume 13, No. 2, 2001

17. Li, Q., Liasi,E., Simon,D., Du,R., A study on the needle heating in heavy industrial sewing: Part 2: Finite element analysis and experiment verification, International Journal of Clothing Science and Technology, Volume 13 No. 5; 2001
18. Carvalho, H., Monteiro,J, Ferreira, F.N. 1997, 'Measurements and Feature Extraction in High-Speed Sewing', Proceedings of the IEEE International Symposium on Industrial Electronics, University of Minho, Guimarães, Vol.3, 961-966
19. Carvalho, H 2004, 'Optimisation and Control of processes in Apparel Manufacturing.' PhD diss., School of Engineering, University of Minho, Portugal, available at http://hdl.handle.net/1822/59
20. Carvalho, H, Ferreira, P, Rocha, A, Monteiro,J, 2003, 'Signal Feature Extraction for Sewing Analysis using Non-Linear Techniques', Proceedings of the IEEE International Symposium on Industrial Electronics, Rio de Janeiro, Brazil, Article available at http://hdl.handle.net/1822/4792
21. A.Gurarda, B.Meric, 2005, 'Sewing Needle Penetration Forces and Elastane Fiber Damage during the Sewing of Cotton/Elastane Woven Fabrics', Textile Research Journal, Vol. 75, No. 8, 628-633 (2005)