TECHNICAL UNIVERSITY OF LIBEREC
Faculty of Textile Engineering

A Study on the Needle Heating of Industrial Lockstitch Sewing Machine

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SUMMARY OF THE THESIS

Title of the thesis: A study on the needle heating of industrial lockstitch sewing machine
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Field of study: Textile Technics and Materials Engineering
Mode of study: Full time
Department : Department of Clothing Technology
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The dissertation is available at the Dean's Office FT TUL.

Liberec 2015

Abstract

Sewing process is one of the most important operations in the clothing industry. It is also an important part of assembling some technical textile products. Every day, millions of products ranging from shirts to automotive airbags are sewn. Hence, even a minor improvement may result in significant commercial and performance benefits. The biggest issue with high speed sewing is the damage caused by heating of the needle on the sewing thread and the fabric. Sewing thread undergoes repeated abrasion and passes through the needle eye resulting in a friction with the needle; on the other hand the friction between the needle and the fabric during its penetration through the fabric layer(s) causes an increase in the needle temperature. This hot needle causes damage to the thread, the fabric and finally a loss in productivity. This work described in this dissertation aims at understanding the various processes causing a heating of the needle, with the needle's temperature measurement and prediction. It also explores certain methods which may possibly improve the productivity of the sewing operation by reducing the needle temperature without compromising the sewing speed.

This work covers the experimental techniques to measure the sewing needle temperature. Three methods (thermal camera, inserted thermocouple and thermocouple touch method) are compared under different sewing conditions. It was found that the thermal camera got influenced by the low emissivity of the needle and it is very difficult to measure at speeds higher than 3000r/min. Inserted thermocouple method showed repeatable results with the lowest deviation. On the other hand, the thermocouple touch method could be used to provide an estimation of the needle temperature since the delay in contact between the needle and the thermocouple provides lower values of needle temperature as compared to the inserted thermocouple method.

It was observed that the sewing speed, the thread count, the sewing time, the fabric structure and thickness had major impact on sewing needle temperature. On the other hand, ambient humidity, ambient temperature, stitch density and needle parameters played a minor role in heating of the sewing needle.

Cooling of hot needle by a vortex stream of cold air is the common method in industry to decrease the needle temperature. In this research, a 10 second of cooling time was suggested at the time of machine stoppage or deceleration. This technique provides similar results as compared to the continuous vortex cooling, but significantly saves the energy consumption.

Lubrication is the second most common technique in industry for decreasing the needle temperature after the cooling air. Results of this research show that, to decrease needle temperature, it's not productive to use lubricants if the machine speed is less than 2500 r/min; whereas for higher machine speeds, it's recommended to add 3-4% of lubricant to the sewing thread.

It was observed that the tensile properties of the used sewing threads decreased dramatically for machine speeds higher than 3000r/min; where about 40% loss of tensile strength was recorded for sewing threads at machine speed of 4000 r/min. The tensile properties of the sewing threads were also measured at different sections of the sewing machine to examine the effect of the needle temperature as well as the abrasion by the tension devices.

This research presents the methodology for evenly coating the sewing needle with a diamond like carbon (DLC) layer. DLC coatings are well known for decreasing the friction properties of heavy machine parts like engines and pistons. In this research, the sewing needle (a very thin metal) was coated evenly with the DLC layer. There were minor differences observed in the properties of stitched thread after sewing using a DLC coated needle.

Finally, a simple analytical model was developed to calculate the needle temperature at its steady state from a set of parameters that includes: friction coefficients, friction forces and thread tension. A linear equation was obtained for the temperature of the needle related to the machine speed as an independent variable. It was found that the model could predict the maximum needle temperature that can be attained during a continuous sewing process of more than 12 seconds with a reasonable accuracy. The important role of the sewing thread in contributing towards the needle temperature was also established by this simple theory which corroborates with the experimental observations.

Keywords: Needle heating, sewing machine, needle cooling, needle temperature prediction, sewing thread, needle coating.

Anotace

Šicí proces je jednou z nejdůležitějších operací v oděvním průmyslu. Je také důležitou součástí při sestavování některých technických textilních produktů. Každý den se ušijí miliony produktů od košil až po airbagy. Proto i malé vylepšení může mít za následek významné obchodní a výkonnostní výhody. Největším problémem při vysokorychlostním šití je poškození způsobeno zahříváním jehly na niti a materiálu. Šicí nit podléhá opakovanému oděru a prochází očkem jehly, což vede k tření s jehlou; na druhé straně tření mezi jehlou a materiálem během pronikání přes vrstvu materiálu způsobuje nárůst teploty jehly. Tato horká jehla způsobuje poškození nitě, materiálu a nakonec i ztrátu produktivity.

Tato disertační práce se zaměřuje na pochopení různých procesů způsobujících zahřívání jehly, s měřeními a predikcí teploty jehly. Práce také zkoumá určité metody, které by mohly zlepšit produktivitu šicího procesu snížením teploty jehly bez ohrožení rychlosti šití.

Tato práce zahrnuje experimentální techniky pro měření teploty šicí jehly. Tři metody (termo kamera, vložený termočlánek a dotyková metoda pomocí termočlánku) jsou porovnávány při různých podmínkách šití. Bylo zjištěno, že termo kamera byla ovlivněna nízkou emisivitou jehly a je velmi obtížné provádět měření při rychlosti vyšší než 3000 ot / min. Metoda s vloženým termočlánkem ukazuje opakovatelné výsledky s nejnižší odchylkou. Na druhé straně by dotyková metoda s termočlánkem mohla být použita pro poskytnutí odhadu teploty jehly, protože zpoždění v kontaktu mezi jehlou a termočlánkem poskytuje nižší hodnoty teploty jehly ve srovnání se způsobem vloženého termočlánku.

Bylo zjištěno, že rychlost šití, počet nití, čas šití, struktura materiálu a tloušťka měly hlavní vliv na teplotu šicí jehly. Na druhé straně, parametry jako okolní vlhkost, okolní teplota, hustota stehu a parametry jehly hrály menší roli v zahřívání šicí jehly.

Chlazení horké jehly ve vířivém proudu studeného vzduchu je běžný postup používaný v průmyslu ke snížení teploty jehly. V tomto výzkumu byla navržena doba chlazení 10 sekund v okamžiku zastavení stroje nebo jeho zpomalení. Tato technika poskytuje podobné výsledky při porovnávání s kontinuálním vírovým chlazením, ale výrazně šetří spotřebu energie.

Mazání je druhou nejčastější technikou v průmyslu pro snížení teploty jehly po chlazení vzduchem. Výsledky tohoto výzkumu ukazují, že ke snížení teploty jehly není produktivní používat lubrikanty, pokud je rychlost stroje nižší než 2500 ot / min vzhledem k tomu, že pro vyšší rychlosti stroje je doporučeno přidat 3-4% maziva do šicích nití.

Bylo pozorováno, že tahové vlastnosti použitých šicích nití se dramaticky snížily při rychlostech stroje vyšších než 3000 ot / min; kde asi 40% ztráta pevnosti v tahu pro šicí nitě byla zaznamenána při otáčkách stroje 4000 ot / min. Tahové vlastnosti šicích nití byly také měřeny v různých částech šicího stroje kvůli zkoumání vlivu teploty jehly, jakož i oděru pomocí napínacích zařízení.

Tento výzkum představuje metodiku pro rovnoměrné potažení šicí jehly s tzv. "Diamond like carbon" (DLC) vrstvou. DLC povlaky jsou dobře známé pro snížení třecích vlastností různých částí těžkých strojů, jako jsou motory a písty. V tomto výzkumu, šicí jehla (velmi tenký kov) byla potažena rovnoměrně DLC vrstvou. Byly pozorovány drobné rozdíly ve vlastnostech nití v stehu, po šití s jehlou s DLC povlakem.

Na závěr byl vyvinut jednoduchý analytický model pro výpočet teploty jehly ve svém ustáleném stavu ze souboru parametrů, který obsahuje koeficienty tření, třecí síly a napětí nitě. Lineární rovnice byla získána pro teplotu jehly vztahující se k rychlosti stroje jako nezávislá proměnná. Bylo zjištěno, že model by mohl predikovat maximální teplotu jehly, která může být dosažena v průběhu kontinuálního procesu šití při více než 12 vteřinách s dostatečnou přesností. Pomocí této jednoduché teorie byla prokázána důležitá role nitě v přispívání k teplotě jehly, což potvrzuje experimentální pozorování.

Klíčová slova: Zahřívání jehly, šicí stroj, chlazení jehly, predikce teploty jehly, šicí nit, povlak jehly

Summary

1 Introduction

Industrial sewing is one of the most common operations in the manufacturing of garments, shoes, upholstery and technical fabrics for automobiles. Every day, millions of products ranging from shirts to automotive airbags are sewn using industrial sewing machines. Heavy industrial sewing, such as that used in the manufacture of automobile seat cushions, backs and airbags, requires not only high production but also high sewing quality (i.e. better appearance and seam strength). Typically, the material being sewn includes single and multiple plies of fabric or leather, sometimes backed with plastics, and needle heat-up is a major problem on the sewing floor. In recent years, in order to increase production, high-speed sewing has been extensively used. Currently, sewing speeds range from 1000-6000r/min. In heavy industrial sewing, typical sewing speeds range from 1000-3000r/min.

Depending on the sewing conditions, maximum needle temperatures range from 100°C~300°C [1]. This high temperature weakens the thread, since thread tensile strength is a function of temperature, resulting in decreased production [2]. In addition, the final stitched thread has 30–40% less strength than the parent threads [3]. Very high temperature of the needle can also damage the materials such as some synthetic fabrics or plastics which come in direct contact with the needle during sewing process. Since generally an increase in the machine speed is accompanied by an increase in the needle temperature, an optimization is often required. Therefore, it is important to understand the causes of the heating of needle in a sewing machine and to be able to predict the maximum needle temperature from the various parameters of the machine, process and material.

However, the temperature of the needle of a sewing machine during its operation is a difficult thing to measure since the needle moves at a very high speed and its size is generally not very big [4]. Nevertheless various methods for measuring needle temperature, such as infrared pyrometer, thermocouple and temperature sensitive waxes, have been used. Sondhelm [5] used a lacquer painted in the needle groove to observe a change of colour with temperature. Laughlin [6] tried to measure needle temperature through infrared measurement from the needle using a lead-sulphide photocell. Recently Yukseloglu et al [7] have observed the needle temperature by thermal camera for polyester blend fabrics for sewing speed of 3000r/min using chromium needle and the emissivity was considered as 0.07. For infrared temperature measurement, there is a problem in calibration because the amount of radiation emitted at higher temperature depends on the surface characteristics [8]. The emissivity of each needle must be determined individually and, indeed, the emissivity might change during high speed sewing process. Another technique using thermocouples was later developed by Dorkin and Chamberlain [9]. There are few theoretical models available to predict sewing needle temperature [4, 8, 10, 11]. Trung et al [10] used Finite Element Analysis (FEA) model, Q. Li et al and Howard [4,11] have used analytical as well as FEA models and reported that the FEA approach gives much better accuracy compared to their analytical models which had an average error of 25%. As a result of such variety of measuring methods used by various researchers, it is sometimes difficult to compare the results reported in literature. Nevertheless, as a result of improved understanding of the causes of sewing damage, many technical developments such as improved needle design [12,13] fabric finishes [14], thread lubrication and needle coolers [15,16] have taken place over the years.

2 Purpose and aims of the thesis

The aim of the research is to;

- Develop an experimental technique to measure the sewing needle temperature.
- Determine the factors affecting the needle temperature.
- Evaluate the effectiveness of common methods used for industrial needle cooling.
- Examine the effects of needle heat on sewing thread.
- Analyze theoretically the sewing needle temperature.

2.1 Develop an experimental technique to measure the sewing needle temperature

- Apply the three described measuring methods (thermal camera, inserted thermocouple method and thermocouple touch method)**.**
- Study the effectiveness of each method**.**
- Compare mentioned methods at different conditions**.**
- Recommend the optimum and limiting operating conditions for each method.

2.2 Determine the factors affecting the needle temperature.

- Select affecting parameters based on the available literature and the practical experience.
- Design experimental procedure for studying the effect of each parameter.
- Analyze the significance effect of each factor and the interaction between them.

2.3 Evaluate the effectiveness of common methods used for industrial needle cooling.

- Applying the cooling methods**.**
- Measuring the dynamic needle’s temperature as well as the tensile properties of the sewing thread**.**
- Optimize the operating cooling conditions**.**

2.4 Examine the effects of needle heat on sewing thread.

- Study the factors affecting the tensile properties of sewing thread (heat and abrasion).
- Evaluate the tensile properties at different sections of the sewing machine.
- Examine the indirect effect of the machine speed on the tensile properties.

2.5 Analysing theoretically the sewing needle temperature

- Develop an analytical model for predicting the needle temperature.
- Conduct experimental verification for the model.
- Compare the model’s results with literature values.

3 Overview of the current state of the problem

3.1 The role of sewing thread

There are two different school of thoughts for the cause of sewing needle heating. Some researcher [2, 9, 16, 23] believe sewing thread as a heat sink taking heat away from the hot needle. It is reported that needle decreases when sewing thread is used, friction between needle and fabric is considered as the major source of the needle heating.

On the other hand the researchers [7, 8, 31] report the increase in needle temperature when sewing thread is used, showing the sewing thread as heat source and applies the friction heat to the needle. It is reported that the needle temperature rises before the needle punctures the fabric.

- **Therefore, it's necessary to examine the role of sewing thread in needle heating.**

3.2 Experimental techniques

The experimental verification by most of the researchers is done by the infrared or pyrometer method, which get influenced by the low emissivity of needle, changing emissivity of needle during the process and bigger measurement spot of the infrared heat measurement devices. First of all, it's necessary to experimentally verify the needle temperature using different techniques and observe the major factors that cause the increase of needle temperature.

- **Therefore, emissivity with contactless and discontinuity of measurement with the contact method is an unavoidable limitation.**

3.3 Effectiveness of cooling techniques

The effect of forced air cooling on needle temperature needs more investigation in terms of the required temperature of air and the time of exposure. Similarly, the amount of lubricant to decrease the needle temperature should be studied as this amount might affect the tensile properties of the sewing thread.

- **Therefore, the effect of cooling by air and lubrication needs more investigation.**

4 Used methods, study material

There are multiple efforts in the past to experimentally observe the sewing needle heating. The experimental techniques to measure sewing needle temperature can be classifies as;

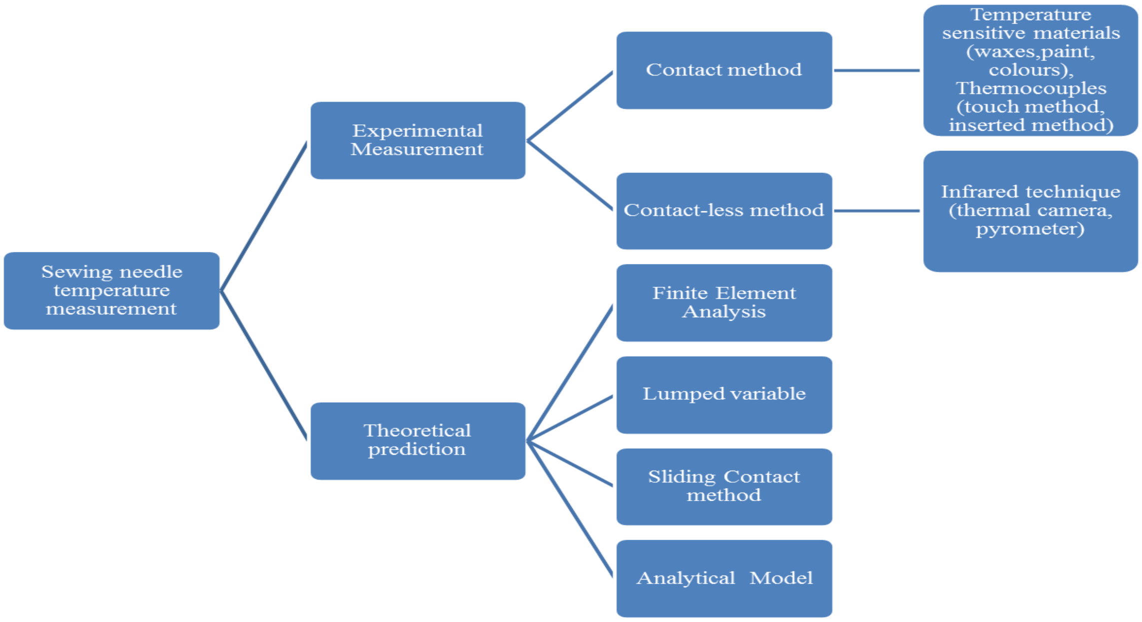


Figure 1 Classification of Sewing needle temperature measurement

In our research we measured needle temperature at high speed sewing by three methods (thermal camera, inserted thermocouple method and thermocouple touch method). Conditions for all experiments were kept constant at 26°C and 65% RH. The devices used for the experiments are listed below:

- Lockstitch machine (Brother Company, DD7100-905).
- Thermal camera P60 and X6450 from the FLIR Company.
- Thermocouple by Omega (K type 5SC-TT-(K)-36-(36)) for the inserted method.
- Thermocouple by Omega (5SC-GG-(K)-30-36) for the touch method.
- Thermocouple by Omega -wireless device and receiver (MWTC-D-K-868).
- Needles (Groz-Becker 100/16) R- type.
- Relevant parameters of the sewing thread are shown in Table 1.
- Relevant parameters of the denim fabric are shown in Table 2.

Table 1 Sewing thread used for the experiments

Thread type	Company name	Fineness (Tex)	Twist (t/m)	Twist direction (ply/single)	Coefficient of friction µ
Polyester–polyester core spun	AMANN-Saba C-80	20*2	660	Z/S	0.13

Table 2 Fabric used for the experiments

Fabric type	Weave	Weight	Ends/cm	Picks/cm	Fabric thickness
100%cotton Denim	2/1 Twill	257 g/m^2	25	20	0.035cm

All methods were tested 20 times each and the results were statistically analysed. Maximum sewing time was 60 seconds for all techniques. The stitch density was kept constant at 5 stitches/cm and the sewing process was done both with and without thread to determine the temperature difference caused by the sewing thread. All three methods are compared to determine the suitable method of needle temperature measurement.

4.1 Thermal camera

The FLIR P60 is a manual thermal camera that measure temperature as triggered by the operator, whereas the FLIR X6450 is a continuous filming camera. Therefore, the FLIR P60 was used for the emissivity measurement for the sewing process. All thermal cameras work on the principal of emissivity of the object. For this test, the emissivity of the needle was calculated by ASTM standard E 1933 – 99a [19] by painting a portion of needle with known emissivity as shown in figure 2, and determined to be 0.08 for a chromium polished needle at 37^{o}C. As the needle is thin and shiny, it is complicated to determine the exact emissivity, and most researchers adopt the emissivity of the needle as that for polished chromium, which is 0.06 [7]. Even with knowing the emissivity of the needle, measurement is extremely difficult, as the sewing process is fast and the needle moves at a rate of 1000-6000r/min. Another problem is that the emission of the needle changes during the sewing process, as the surface characteristics change [8]. Therefore, the FLIR P60 was used for the emissivity measurement for the sewing process, and the X6450 was used for measuring the needle temperature during the sewing process.

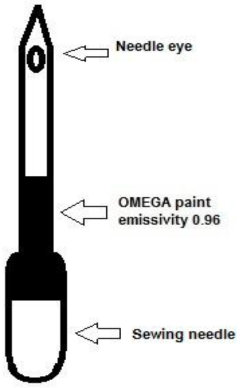


Figure 2 Needle temperature/emissivity measurement

The first experiment was conducted without thread at speeds of 1000-3000r/min; the standard deviation increased sharply at 3000r/min. It is not possible to use the camera at speeds higher than that as the needle is moving more than 3500r/min, which makes it impossible to focus the camera on the needle. When the experiment was performed with thread even at 2,000 r/m, it was difficult to measure the needle temperature, as the thread, which has an emissivity of nearly 0.95 [20], significantly affects the needle measurement, which has extremely low emissivity, as shown in Figure 4.

Figure 3 Thermal camera FLIR P60 with Lockstitch machine

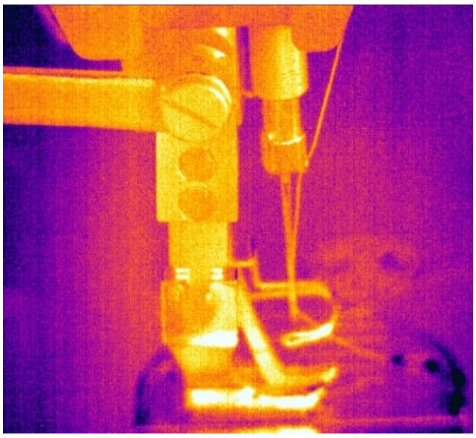


Figure 4 Needle eye temperature measured by camera

Figure 5 shows the needle temperature measured by the thermal camera with an increase of sewing speed. The maximum machine speed used was 3000 r/min, as after this speed, it was not possible to focus on the needle. Even at 3000 r/min the standard deviation was much higher than at slower speeds. It can be seen that after 15 seconds of sewing, there was not much difference in the needle temperature as the process stabilizes with the surroundings. The needle temperature was higher compared to that measured when sewing without thread. The mean needle temperature reached 135^{o}C at speed of 3000 r/min, with thread after 60 seconds of sewing.

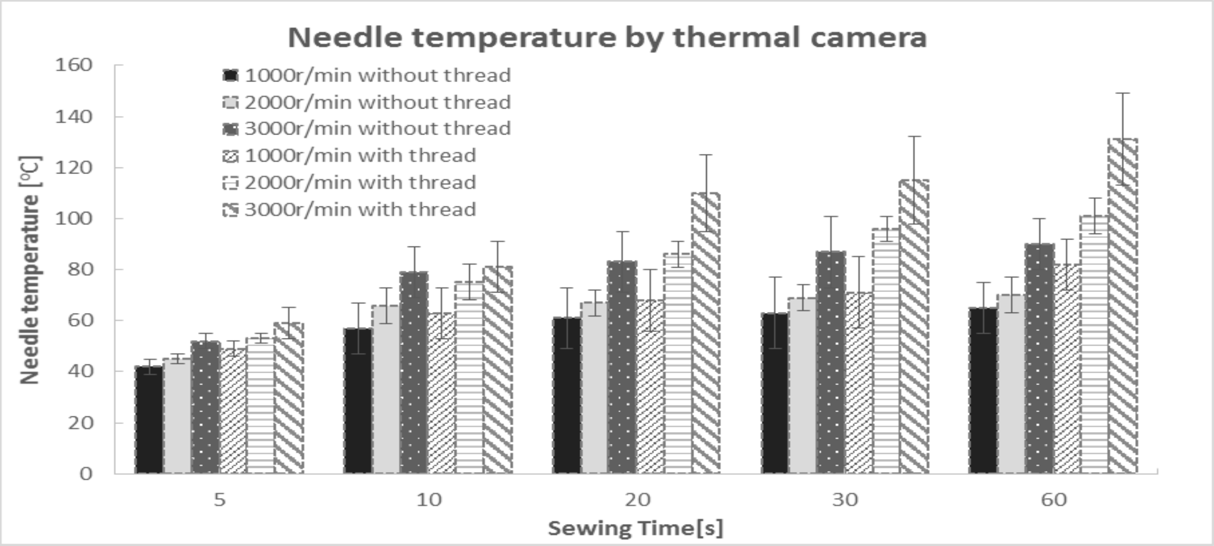


Figure 5 Needle temperature measured by thermal camera

The thermal camera was placed at position B, as shown in Figure 6. Even changing the position from A or C caused a significant change in the recorded needle temperature; this might be attributed to the surrounding energy sources, which receive reflection from the shiny needle. These energy sources are quiet hard to omit, and performing the sewing process under an enclosed black box is not suitable for determining the exact needle temperature as the surrounding conditions will not be same as those on the sewing floor. In our research we covered the surrounding with black fabric to minimise the energy sources from other object to get reflected from sewing needle.

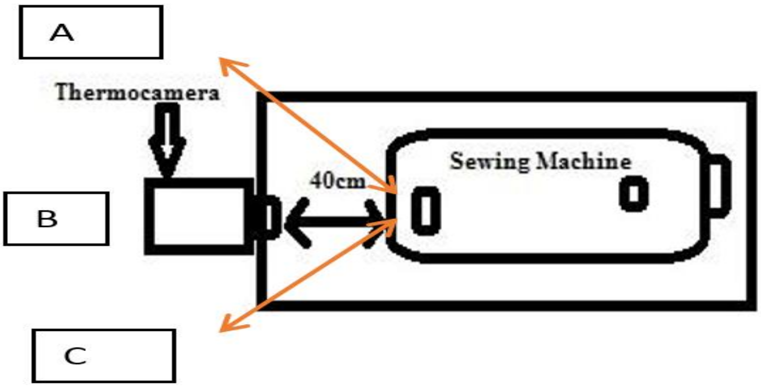


Figure 1 Placement of thermal camera

4.2 Thermocouple touch method

In this method, a thermocouple by Omega (5SC-GG-(K)-30-36) was used to measure the sewing needle temperature. The sewing process was done for 10-, 20-, 30- and 60-second time periods, and the thermocouple was manually touched to the eye of the needle to measure its temperature. This method involved a degree of human error, as the thermocouple was applied to the needle just after the sewing process finished. Being quick when applying the thermocouple and taking multiple observations for each time period reduces the percentage of error, however, the needle temperature results were still much lower when compared with the other methods, as the needle dropped heat very quickly. Figure 7 shows the thermocouple and the placement of the thermocouple after each sewing process interval.

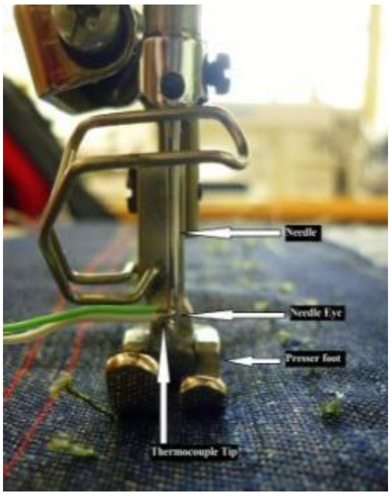


Figure 2 Thermocouple placement for thermocouple touch method

Figure 8 shows the needle temperature at the different sewing speeds; the maximum machine speed was 4000 r/min, which shows a mean temperature of 98^{o}C after 60 seconds of sewing without thread, whereas the needle temperature of 122^{o}C is recorded for sewing with thread under same conditions. It is observed that the needle temperature rises with higher sewing speed and sewing time .The needle temperature with thread is higher as compared to dry sewing (without thread).

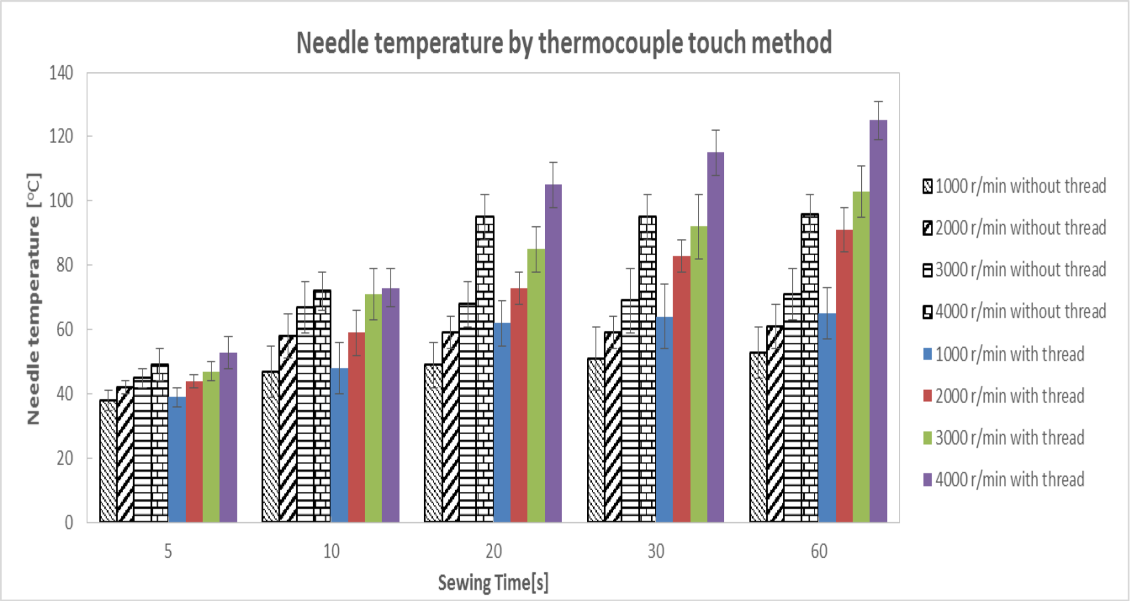


Figure 8 Needle temperature measured by the thermocouple touch method

4.3 Inserted thermocouple method

In this method for measuring sewing needle temperature, technique of inserting thermocouple inside needle groove patent by Hes [18] still remains a novel approach to practically measure the sewing needle temperature. A thermocouple by Omega (K type 5SC-TT-(K)-36-(36)) was inserted into the groove of the sewing needle and soldered. The thermocouple was located near the eye of the needle to measure the exact needle temperature, and the temperature was measured at different sewing speeds. This method proved to be very efficient as it provided continuous changes in needle temperature every second and it had a low standard deviation. Figures 9 show the placement of the thermocouple inside the needle groove. The thermocouple remained inside the needle groove during the sewing process and measurements were recorded wirelessly on a computer through a wireless end device (MWTC-D-K-868).The Figure 10 shows the inserted thermocouple measurement method during the sewing process the legend 1 is thermocouple wire, 2 is needle groove, 3 is sewing thread and 4 is the needle eye.

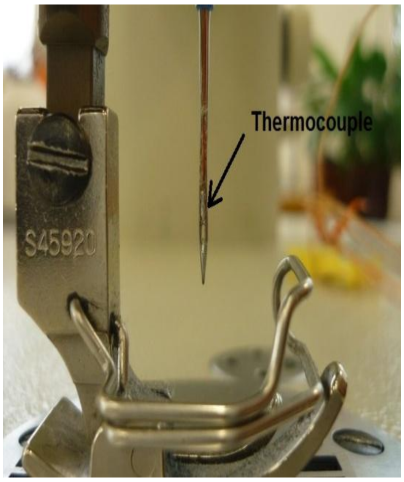


Figure 3 Sewing needle with thermocouple

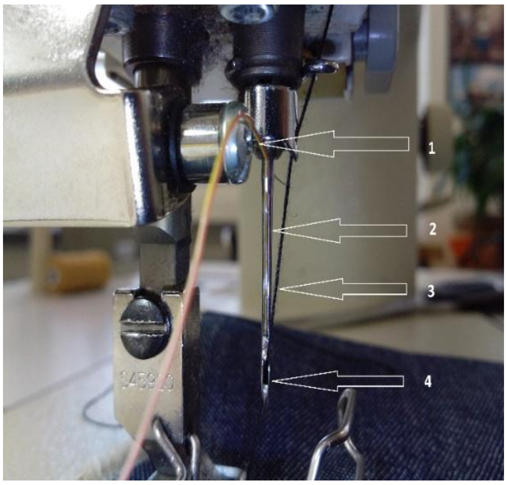


Figure 10 Placement of the thermocouple

Figure 11 shows the needle temperature measured by the inserted thermocouple at sewing machine speed 1000-4000 r/min for both sewing with and without thread. This method proved to be efficient for the different machine speeds and had a lower standard deviation as compared to the other methods of measurement.

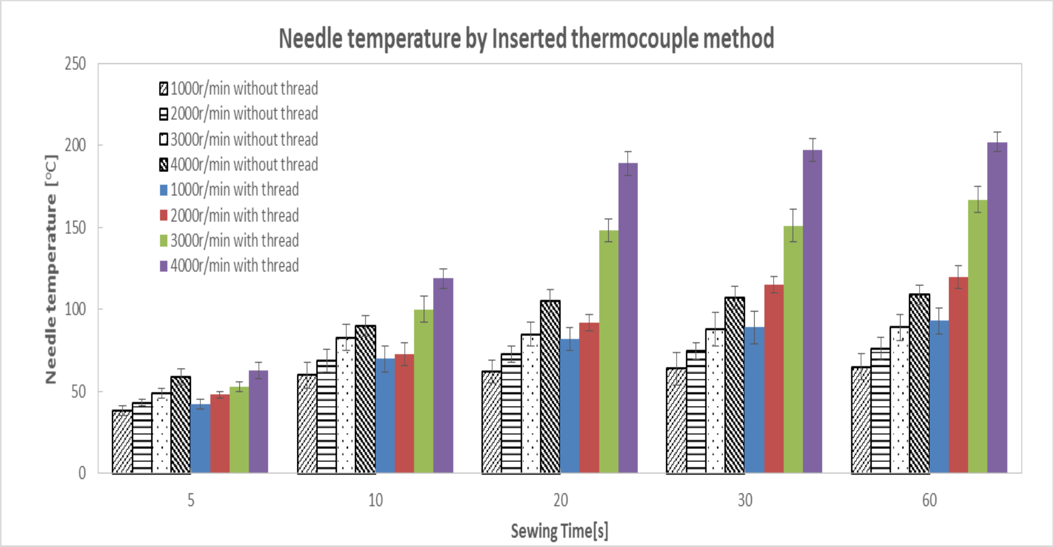


Figure 11 Needle temperature measured by the inserted thermocouple method

Figure 12 shows the needle temperature (with thread) comparison for the different methods of measurement at a machine speed of 3000 r/min. The inserted thermocouple method shows the highest needle temperature after 60 seconds of sewing with the lowest standard deviation, followed by the thermal camera measurement, which had the highest standard deviation. The thermocouple touch method shows the lowest temperature of the three methods of measurement. It was impossible to measure the needle temperature with the thermal camera at speeds higher than 3000 r/min; therefore, the thermocouple touch method and the inserted thermocouple method were used to measure needle temperatures at sewing speeds of 4000 r/min, both with and without thread. The inserted thermocouple method shows significant temperature differences between the tests performed with and without thread. Each experiment was repeated for 30 times.

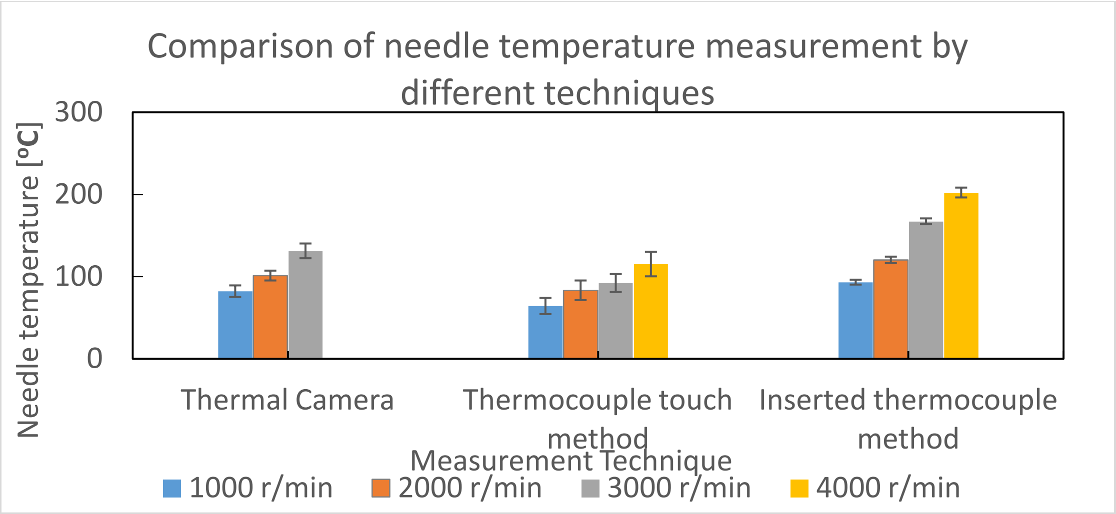


Figure 12 Comparison of the needle (with thread) temperature measurement methods

Thermal cameras was not a suitable method for measurement of sewing needle temperature. The emissivity of the needle posed a major problem and changed the surface properties [8]; during the normal sewing process, surrounding energy sources reflected off the needle surface. Keeping the same emissivity caused a large standard deviation in the needle temperature measurement, and it was even higher when sewing was done with thread. The thermal camera works on emissivity, and a needle with low emissivity and thread with high emissivity are too close differentiate by the thermal camera. All three methods of needle temperature measurement shows that the needle temperature was higher when sewing with thread as compared to dry sewing.The thermocouple touch method resulted in the lowest measured needle temperature, which was most likely due to measurement time delays.The inserted thermocouple appeared to be an efficient method of measurement. Wireless data transfer makes it possible to record needle temperatures each second at all sewing speeds.

All three methods of needle temperature measurement shows that the needle temperature was higher when sewing with thread as compared to dry sewing.

5 Summary of the results achieved

5.1 Factors affecting needle temperature

The inserted thermocouple method showed repeatable results with minimum deviation, so this method is used to examine the effect of different factors on sewing needle temperature. Some of the factors are also reported by previous researchers [4, 7, 8], but there are many factors which influences the needle temperature and not been discussed before. In this research some very common industrial sewing thread as shown in table 3 were tested under different sewing conditions to observe the effects of different factors on sewing needle temperature.

Table 3 Common industrial sewing threads used for the experiment

Thread Name	Composition	Thread count tex	Coef. of friction µ
Merciful 24/2	long-staple mercerised cotton	70	0.40
Mercifil 40	long-staple mercerised cotton	50	0.20
Mercifil 50	long-staple mercerised cotton	40	0.14
Rasant 35	Polyester-cotton corespun	80	0.30
Rasant 50	Polyester-cotton corespun	60	0.18
Rasant 75	Polyester-cotton corespun	40	0.14
Saba C35	Polyester-Polyester corespun thread	80	0.30
Saba C50	Polyester-Polyester corespun thread	60	0.17
Sabab C80	Polyester-Polyester corespun thread	40	0.13
Ctech 80	polyester filament +Carbon	35	0.11

Figure 13 shows that needle temperature rises with longer time of sewing but the increase is dramatic till 10 s of sewing, as after this time the needle system get stabilize with the environment temperature. The needle temperature also rises with the increase of sewing speed. The maximum needle temperature was recorded for the sewing threads made from cotton, as cotton has higher hairiness to cause more friction at the needle eye, which causes higher frictional heat. This needle heat is dissipated to surrounding through conduction to needle holder and also by convection through airflow (surrounding airflow and air forced at the needle eye with the sewing thread), whereas the heat dissipation through radiation might be very low as needle is thin and shiny with emissivity of less than 0.08 [8].

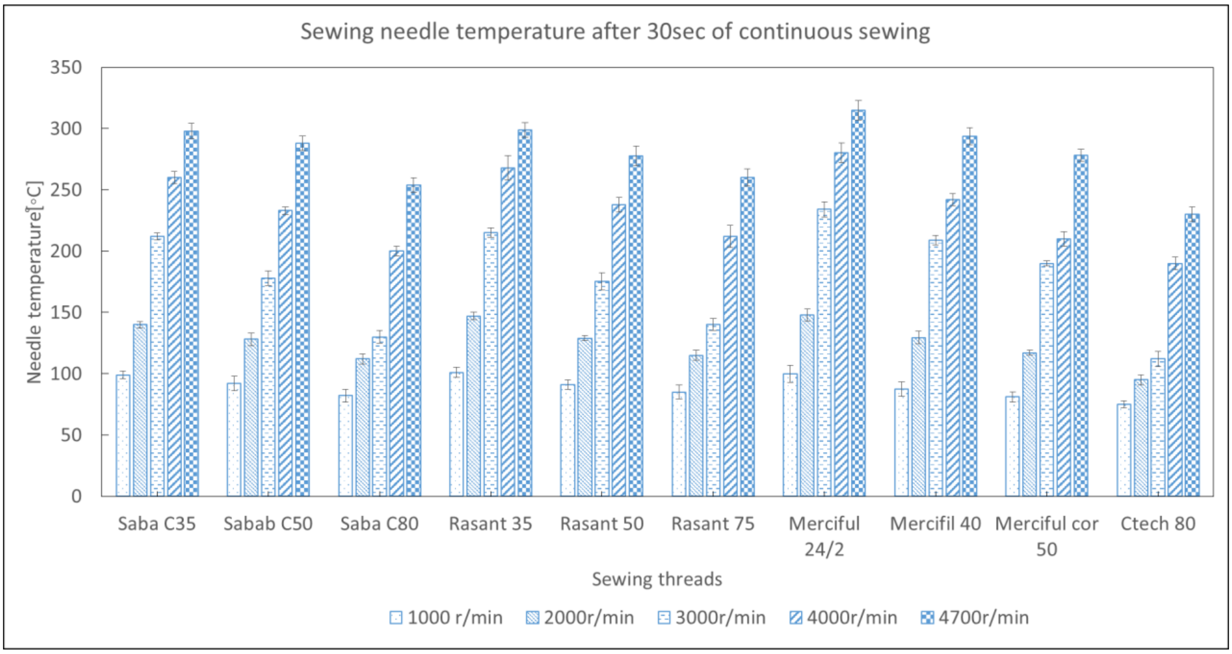


Figure 13 Needle temperature under different sewing conditions

The SEM images of each type of sewing thread after 4700r/min of sewing is shown in Figure 14.The broken and protruding fibers are visible on each thread, the melting of the fibers can be observed for the polyester based threads.

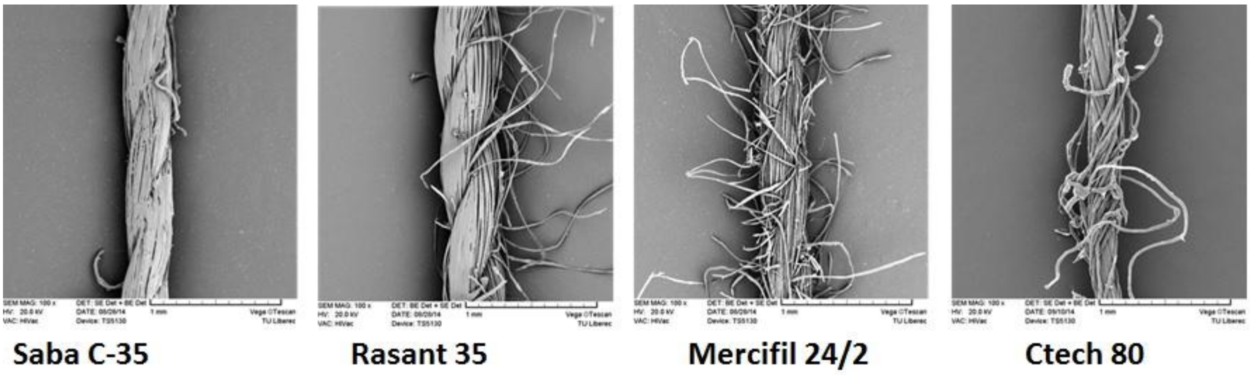


Figure 14 SEM images of the threads after sewing (machine speed 4700r/min)

This research work presents a discussion on the effect of different factors on the sewing needle temperature; it was observed that the sewing speed, the thread count, the sewing time, the fabric thickness had major impact on sewing needle temperature. On the other hand, ambient humidity, ambient temperature, stitch density and needle parameters played a minor role in heating of the sewing needle. Needle temperature for denim fabric is also measured at different speeds of sewing, sewing time, stitch density and number of fabric layers. A multiple regression analysis is done to obtain the coefficients, and the derived equation was used to predict the needle temperature.

5.2 Influence of cooling time on tensile properties of thread

Hot needle greatly influences the tensile properties of sewing thread. To measure the impact the needle thread is pulled out of the seam by precisely cutting the bobbin thread. Tensile properties like tenacity, initial modulus and breaking elongation of the thread were tested 20 times each to observe the effect of the cooling time on the thread strength. It was seen that sewing without cooling showed the weakest thread, where the tenacity was decreased to 26% at 4700 r/min for the sewing thread (Saba C-80); however, the sewing with continuous cooling and partial cooling (10 sec) showed almost the same tenacity of the seam thread. Figure 15 shows the tenacity of the thread for the Saba c-80 at different speeds and cooling times. The effect of the needle heat is quite visible at speeds higher than 3000 r/min.

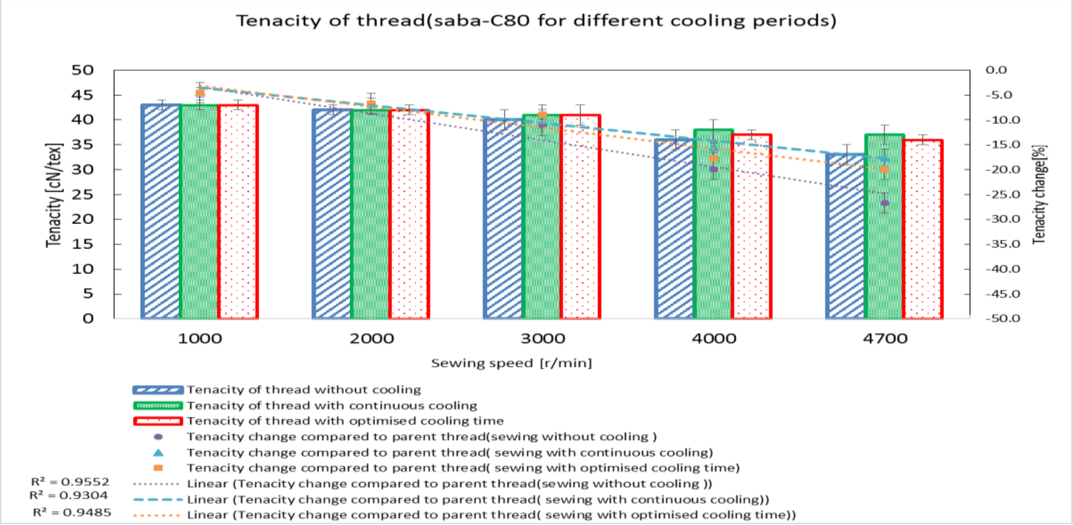


Figure 15 Tenacity of thread (Saba C-80) at different speeds and cooling times.

Figure 16 shows the tenacity of the thread (Sabac-35), sewing without cooling shows the weakest thread, where the tenacity of the thread is decreased to 30% at 4700 r/min, which is 4% higher than the thread Saba C-80; however, sewing with continuous cooling and partial cooling (10 sec) shows a minor difference in tenacity of the seam thread. The effect of the needle heat is quite visible for 3000 r/min and higher.

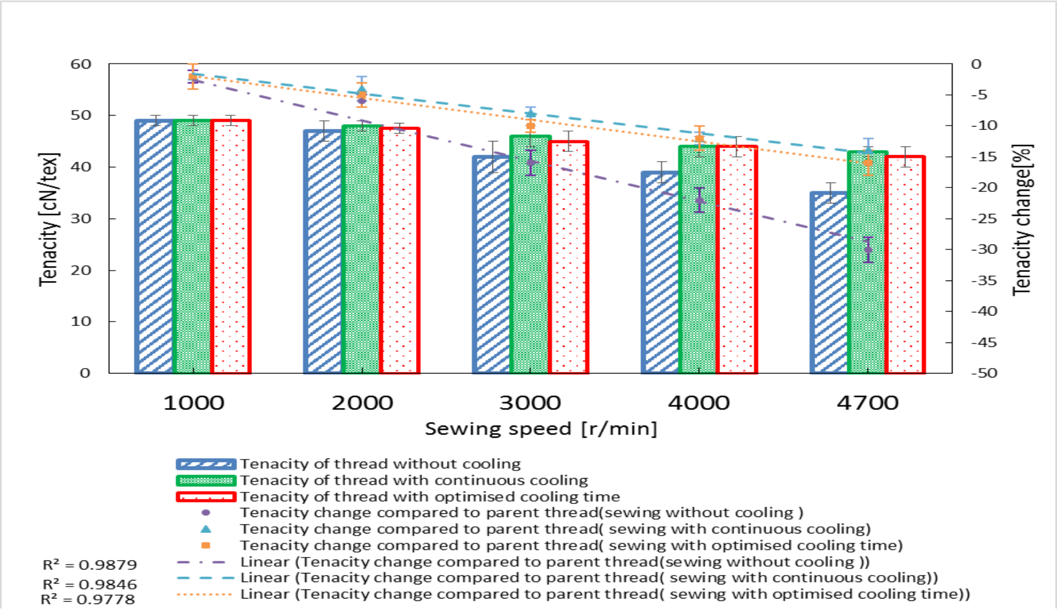


Figure 16 Tenacity of thread (Saba c-35) at different speeds and cooling times.

The major outcomes from this part are highlighted below:

- Air cooling (Vortex) is an effective way of decreasing needle temperature, and the continuous cooling method decreases the needle temperature by nearly 100°C at

4000 r/min and 4700 r/min; whereas the 10 sec cooling at the time of machine stoppage decreases the needle temperature by 92°C at 4000 r/min and 4700 r/min.

- At high speed sewing, the contact time between the thread and needle is very low, but as the machine comes to a complete stop, the contact time of the thread and needle is relatively higher, which causes damage to the sewing thread. The results represents that cooling at the time of machine stoppage and continuous cooling show the same results in terms of thread tensile properties.
- Cooling only at the time of machine stoppage can also cause decrease in energy consumption at sewing industry due to low usage of compressed air.
- Industrial sewing machine producers must operate the air cooling device with the machine speed pedal, which operates at 3000r/min and higher, and at the time of machine deceleration.
- Cooling only at time of machine stoppage can be used for sewing operations like on bed sheets, curtain or long length stitches, where a straight long time sewing is made and cooling at time of machine stoppage can save energy consumption.

5.3 Effect of lubricant on sewing needle temperature

Lubricants cause the decrease in friction coefficient of sewing threads and are commonly used in sewing industries [21-22]. The lubricant improves the surface finish which causes the decrease of friction between yarn and the metal object and most lubrication is intended to decrease yarn to metal friction. In recent publication, it was reported that the amount of lubricant used have a profound effect on friction, and lubricants linearly decreases the coefficient of friction in sewing threads [26]. Sewing thread lubricant always contains silicon, because silicon provides the heat protection and friction reduction in sewing threads. It is accepted that silicones are poor conductor of heat but good release agent and causes reduction in coefficient of friction for sewing threads [25].

Due to high strength and durability of polyester-polyester (PET-PET) core-spun thread, it is the most common sewing thread used in apparel industry. High amount of lubricant are applied to decrease friction and needle temperature [26]. In our research we measured the effect of different amount of lubricant on needle temperature, coefficient of friction and breaking tenacity of PET-PET core-spun thread.

Figure 20 shows the effect of lubricant amount on breaking tenacity of sewing thread before sewing.

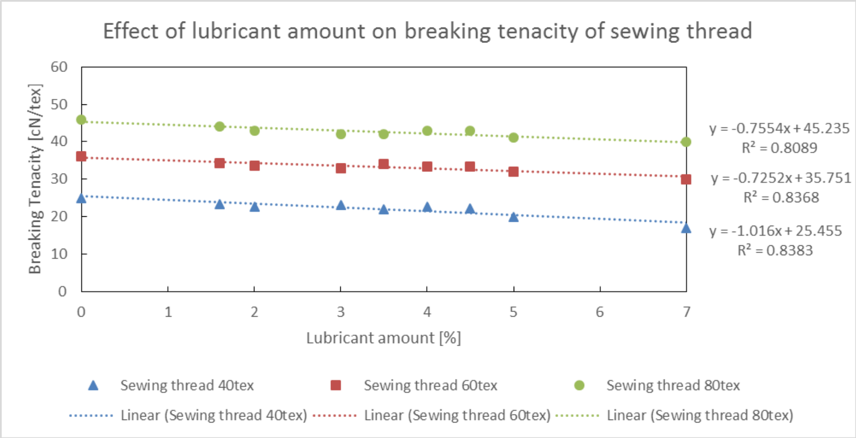


Figure 17 Effect of lubricant amount on breaking tenacity of sewing thread (before sewing).

Figure 18 shows the contour plots of needle temperature, breaking tenacity and extension at break of stitched thread laid one above each other. This graphical representation shows the effect of lubricant amount and sewing speed on needle temperature, thread tenacity and extension at break. It is visible from the contour plots that it's not economical to use lubricant if sewing speed is less than 2000r/min, whereas for sewing speed of 2500r/min and higher the most feasible region of sewing is for lubricant amount of 2-4%(feasible region of sewing is shown by purple colour lines in contour plots).The higher amount of lubricant decreases the needle temperature and thread tenacity. To obtain highest tensile properties and maximum sewing speed it is recommended to use 2-4% of lubricant amount, but if it's necessary to achieve lower needle temperature due to synthetic fabrics then lubricant amount of more than 3% can be used. The effect is same for all three counts of PET-PET cores-pun thread.

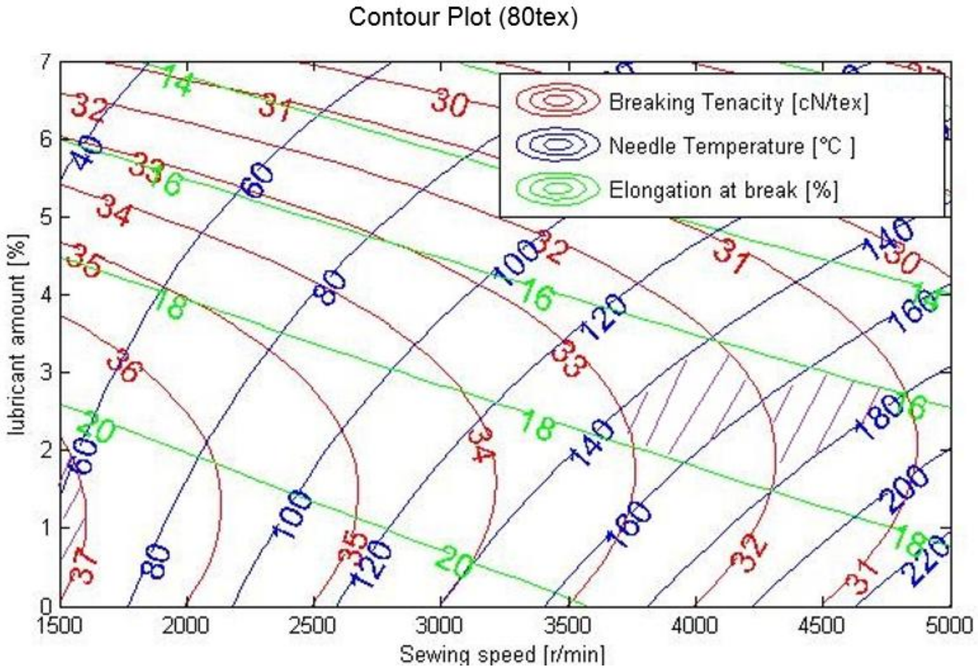


Figure 18 Effect of lubricant amount and sewing speed on needle temperature, tenacity and breaking extension of sewing thread (80 tex)

Figure 19-20 shows the SEM images of 80tex (Saba-C35) lubricated and non-lubricated thread after 4000 r/min of sewing speed. The lubricated thread fibers are more intact with the thread body whereas the non-lubricated thread shows broken and protruding fibers.

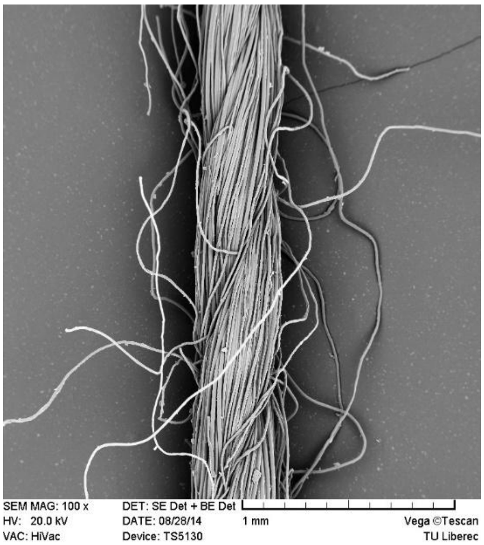


Figure 19 Saba c-35 with 0% lubricant

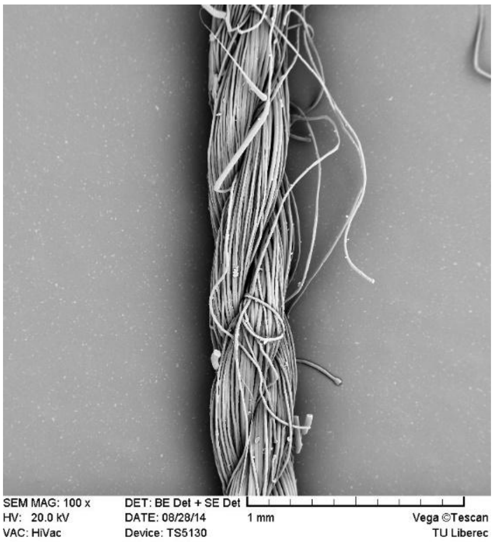


Figure 20 Saba c-35 with 4% lubricant

- It is visible that breaking tenacity decreases with the amount of lubricant. As the lubricant might penetrates inside the yarn, it might decreases the fiber to fiber friction and make it slippery for the fibers to hold each other. As shown in figure 20 the breaking tenacity of thread is decreases by nearly 4-7% when the lubricant amount is 7%.There is a linear decrease in breaking tenacity of thread for all thread counts with increase of lubricant amount
- Lubricants are mainly used for reduction of coefficient of friction for sewing thread. It is true that the coefficient of friction of sewing threads and needle temperature decreases with the increase of lubricant amount, It might be possible that higher amount of lubricant decrease the friction between fiber to fiber inside the thread, this slippery condition between fiber to fiber causes the decrease of breaking tenacity of sewing thread.
- In this work, it is visible that there is minor decrease in breaking tenacity of stitched thread with the addition of lubricant for sewing speeds till 2500r/min. From economical point of view it’s not wise to use lubricant if sewing speed is less than 2000r/min whereas for sewing speed of 2500r/min and higher the most feasible condition of sewing is for lubricant amount of 2-4%.The needle temperature is less than 130^{o}C at this sewing speed and has insignificant effect on the sewing thread.
- It is advised to use the lubricant when sewing speed is 2500r/min and higher. The higher amount of lubricant decreases the needle temperature and thread tenacity .To obtain highest tensile properties and maximum sewing speed it is recommended to use 2-4% of lubricant amount, but if it’s necessary to achieve lower needle temperature due to synthetic fabrics then lubricant amount of more than 3% can be used.
- It is observed that coefficient of friction decreases with the increase in lubricant amount. There is nearly 35% decrease in coefficient of friction when the lubricant amount is 7%.
- Needle temperature decreases linearly with the increase of lubricant amount, there is nearly 30% reduction in needle temperature when lubricant amount is 7% as compared to needle temperature without lubricant on sewing thread.

5.4 Effect of the needle heat on tensile properties of sewing thread

The tensile properties of sewing threads are the key parameter at sewing floor is. In our research we measured the breaking tenacity and elongation at break of the sewing thread using INSTRON Tensile strength tester according to standard ASTM 2256 [24]. All sewing threads are tested before sewing and after sewing process, the stitched thread is carefully removed from the seam by cutting the bobbin thread for tensile testing. Each thread is measured 30 times each for all speeds of sewing respectively

Figure 21 shows that there is a strong linear relation between needle temperature and speed of machine, experimental result also shows a strong negative linear relationship between speed of machine and tenacity of sewing thread, at 4700 rpm of machine the sewing thread exhibit nearly 50% decrease in tenacity.

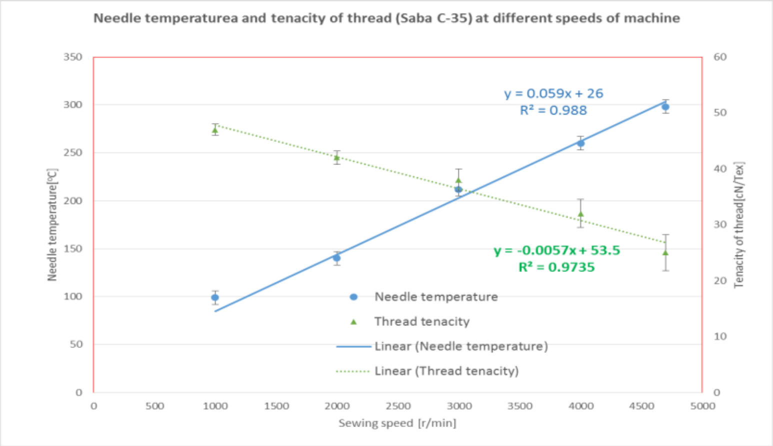
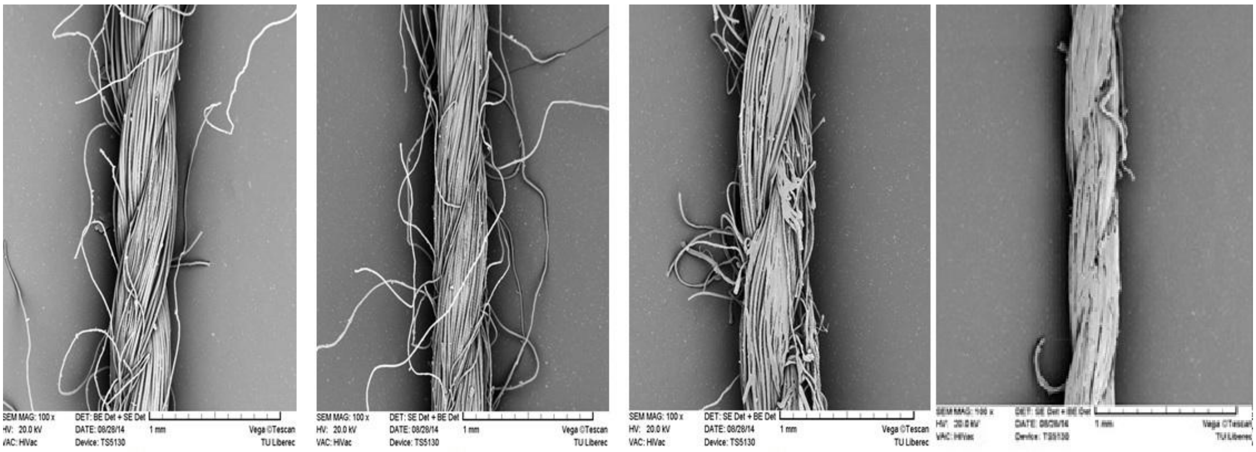


Figure 21 Needle temperature and Tenacity of sewing thread

Figure 22 shows the images of sewing thread (Saba c-35) after continuous sewing of 15 seconds for different sewing speeds, the melted fibers can be easily seen In the SEM image of sewing speed of 4700r/min.



3000r/min 4000r/min 4200r/min 4700r/min

- Figure 22 SEM images of sewing thread (Saba c-35) at different machine speeds at S3

5.5 Analytical model to predict the needle temperature

Analytical models offer simplicity and less computational demands with reasonable accuracy, on the other hand, numerical simulation gives better accuracy but is complicated and time consuming. In this study, unlike the previous models, two sources of frictional heating have been considered as a general case. The two sources are one due to contact friction between the needle surface with fabric and the other due to the contact friction between the inner edge of the needle's eye and the sewing thread.

In this model, the following assumptions are used:

- Needle, sewing thread and fabric are all at room temperature T_i initially before the sewing starts.
- The needle has uniform material properties throughout its length and can be assumed as a cylinder
- The thermal conductivity of needle material λ_n is much higher than the thermal conductivity of the sewing thread λ_y as well as than the thermal conductivity of the fabric λ_F. Here it is implicitly assumed that both the yarn and fabric can be assumed to have lumped thermal properties, i.e., each has uniform thermal conductivities, represented by single values.
- Since the total needle surface area is small, radiation heat loss is neglected.
- In this model, it is approximated that the friction heat is given as $\boldsymbol{Q = F.v}$ [1] where F is friction force and v is the relative velocity of the rubbing surfaces. The needle gains heat energy due to frictional rubbing with the fabric. The needle also gains heat due to frictional rubbing between the sewing thread and the needle eye.
- In case of the heat generated due to frictional rubbing between two materials, part of the generated heat will go to one and the rest will go to the other material. Here it is assumed that there is no other way of heat loss at the points of friction. A partition ratio, γ is considered to calculate the heat distribution between the rubbing surfaces. In this study, the partition ratio is calculated using the Charron's relation [27] as

$$\boldsymbol{\gamma = \frac{1}{1+\xi_N}} \qquad (1)$$

Where $\xi_N = \frac{b_i}{b_N}$, N denotes the needle and i denotes the other rubbing material in contact, and b is the thermal absorptivity of the respective materials the calculated value given as $b = \sqrt{(\rho \times C \times \lambda)}$, where ρ is the density of the material, C is the specific heat of the material and λ is the thermal conductivity.

- The heat partition ratio between needle and fabric is γ_{FN} and between needle and sewing thread is γ_{YN}.

Heat is generated during the sewing process as a result of friction between the needle-fabric and needle-yarn. In this analysis, a steady-state condition is considered in which the amount of heat generated by friction exactly equals the amount of heat loss by the needle .The complex shape of needle is neglected, and it is treated as a uniform cylinder.

The heat generated due to rubbing between the surface of needle and the fabric can be expressed as

$$Q_{FN} = \gamma_{FN} \times \mu_{FN} \times F_{FN} \times v_{FN} \qquad (2)$$

The heat generated due to rubbing between the sewing yarn and the needle can be expressed as

$$Q_{YN} = \gamma_{YN} \times \mu_{YN} \times T_y \times \cos\theta \times v_{YN} \qquad \ldots (3)$$

Where

γ_{NY} = Partition ratio of heat gain between needle and yarn using Charron's relation

γ_{FN} = Partition ratio of heat gain between needle and fabric using Charron's relation

μ_{YN} = coefficient of friction between needle and sewing thread

μ_{FN}= coefficient of friction between fabric yarn and sewing thread

F_{FN}= needle penetration force with the fabric

T_y= maximum tension of sewing thread during sewing cycle

θ= the angle of sewing thread with needle

v_{FN}= velocity of needle with respect to fabric

Maximum needle speed is linear function of machine speed with multiplier constant C_{FN}=0.0008

v_{YN}= velocity of thread with the needle

The total heat gain by the needle is therefore,

$$Q_N = Q_{FN} + Q_{YN} \qquad \dots (4)$$

From 1st law of thermodynamics in a closed system,

$$Q = m \times C_N \times (T - T_i) \qquad \dots (5)$$

Where

m = Mass of needle

C_N = Specific heat of needle

T =Final temperature of needle

T_i =Initial temperature of needle

Using equations 2, 3, 4 and 5

$$m \times c_N \times (T - T_i) = \gamma_{FN} \times \mu_{FN} \times F_{FN} \times v_{FN} + \gamma_{YN} \times \mu_{YN} \times T_y \times \cos\theta \times v_{YN} \dots (6)$$

The above equation, for a more precise result, should be solved by evaluating it numerically over time as many of the variables present in equation (6) are complicated functions of time. However, in order to simplify the calculations, the maximum value of F_{FN} and T will be considered here for the prediction of maximum temperature of the needle, these values can also be obtained from literature [28,29,30] . Similarly, the maximum relative speed between the sewing yarn and the needle will be used as v_{YN}. As a further approximation, both v_{FN} and v_{YN} can be expressed as proportional to the machine speed v_M. If C_{FN} and C_{YN} are the two coefficients of these proportionalities respectively, then it can be obtained from equation (6) that

$$T - T_i = B \times v_M \qquad \dots (7)$$

Where

$$B = \frac{1}{m \times c_N} \times \{\gamma_{FN} \times \mu_{FN} \times F_{FN} \times C_{FN} + \gamma_{YN} \times \mu_{YN} \times T \times \cos\theta \times C_{YN}\} \quad \dots (8)$$

Thus, equation (7) indicates that the maximum needle temperature is a linear function of machine speed. The prediction of maximum temperature of needle from the machine speed is possible if the parameter *B* can be evaluated using equation (8).

This simple approach may be more useful for shop floor compared to the complicated numerical methods.

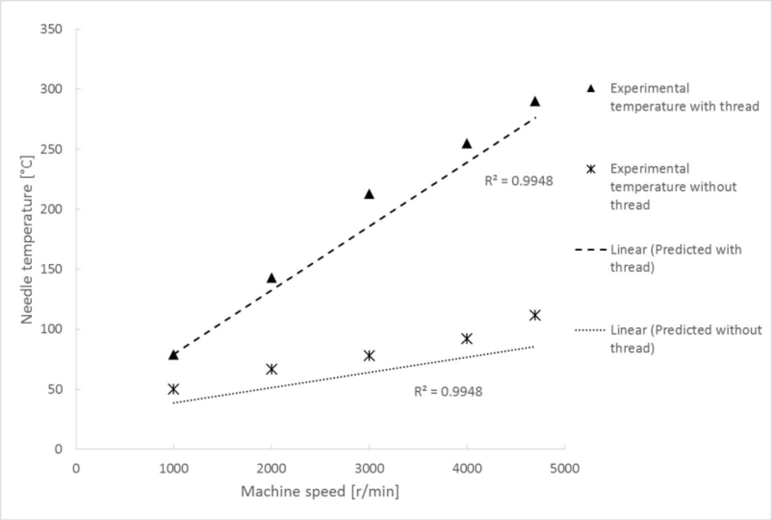


Figure *23* Comparison between theoretical prediction and experimental observation

6 Evaluation of results and new findings

Needle heating is a serious issue for sewing industries and understanding the causes of heating and applying this knowledge for reducing needle temperature during high speed sewing can bring greater corporate benefits. It can be concluded from the present research that:

- Needle temperature can be precisely measured with inserted thermocouple method which shows minimum standard deviation and higher repeatability as compared to thermal camera or Thermocouple touch method. The thermal camera works on emissivity, and a needle with low emissivity and thread with high emissivity are too close to be differentiated by the thermal camera. All three methods of needle temperature measurement showed that the needle temperature was higher when sewing with thread as compared to dry sewing (without thread).
- Multiple factors were considered in this research to determine their impact on sewing needle temperature. It was observed that the sewing speed, the thread count, the sewing time and the fabric thickness had significant impact on sewing needle temperature. On the other hand, ambient humidity, ambient temperature, stitch density and needle parameters played a minor role in heating of the sewing needle.
- Air cooling (Vortex) is an effective way of decreasing needle temperature, and the continuous cooling method decreases the needle temperature significantly. At high speed sewing, the contact time between the thread and needle is very low, but as the machine comes to a complete stop, the contact time of the thread and needle is relatively higher, which causes the major damage to the sewing thread. The results reflect this that cooling at the time of machine stoppage and continuous cooling show the same results in terms of thread tensile properties. Cooling only at the time of machine stoppage can save 60-80% on energy consumption. Industrial sewing machine producers must operate the air cooling device with the machine speed pedal, which operates at 3000r/min and higher, and at the time of machine deceleration.
- The effect of lubricant amount on tensile properties of thread should always be considered for sewing process. It is advised to use the lubricant when sewing speed is 2500r/min and higher. The higher amount of lubricant decreases the needle temperature and thread tenacity. To obtain highest tensile properties and maximum sewing speed it is recommended to use 2-4% of lubricant amount, but if it’s necessary to achieve lower needle temperature due to synthetic fabrics then lubricant amount of more than 3% can be used.

- This research shows that needle temperature has a dominant influence on the strength of sewing thread. Seam thread was considered as the thread with the weakest tensile properties as compared to the parent thread but the research shows that the hot needle also damages the thread when the machine stops after sewing and needle is in direct contact with the thread. This needle-heat damaged thread eventually becomes part of the next seam and causes loss in seam strength. It is recommended to waste 20 cm of the thread after one complete sewing, so that the thread damaged at the needle eye after machine stoppage should not be part of the next seam. As thread moves from cone to the seam, it undergoes various stresses, there is a marginal decrease in tensile strength for thread at 1000 and 2000 r/m of machine, whereas loss of tensile strength of thread is much significant from 3000 r/m of machine and higher. Bobbin thread interaction and needle heat are the two main causes of reduction of tensile strength, breaking elongation and initial modulus of thread. In this section the loss of tensile strength is mainly due to bobbin thread interaction and friction of guides and tension devices on machine, but due to high speed of machine the contact time between thread and needle is much less to impact. That is why the thread at seam shows higher tensile properties as compared to section of thread that stay in the hot needle after machine stoppage.

- It’s possible to cover the needle with DLC coating but the complex shape of the needle eye makes it impossible to determine if the coating is evenly applied at the inside part of the needle’s eye. DLC-coated needles along length shows better roughness property as compared to normal needles by AFM measurement. Diamond polish is also important step in bringing better surface properties of martial but the needle eye could not be diamond polished due to the complex shape of the needle eye. There was a small improvement noted in terms of tensile properties and needle temperature for DLC coated needles.
- In this work a simple analytical model was developed to calculate the needle temperature at steady state from a set of parameters including friction coefficients, friction forces, thread tension and a linear equation was obtained for the temperature of the needle related to the machine speed as an independent variable. It was found that the model could predict the maximum needle temperature that can be attained during a continuous sewing process of more than 12 seconds with a reasonable accuracy. The important role of the sewing thread in contributing towards the needle temperature was also established both theoretically and experimentally. The presented analytical model does not require extensive computation. As a result, it can be used to estimate the needle temperature at sewing floor and provide valuable information for optimizing the industrial sewing operation.

7 References

[1] Qinwen, Li., and Liasi, E. A study on the needle heating in heavy industrial sewing part-1. International Journal of Clothing Science and Technology, 2001, 13(5), 351-367.

[2] Hersh, S., and Grady, P. Needle heating during high speed sewing. Textile Research Journal 1969, 39, 101-120.

[3] Midha, V., Mukhopadhyay, A, Chatopadhyay R., et al. Studies on the changes in tensile properties of sewing thread at different sewing stages. Textile Res Journal 2009; 79: 1155–1167.

[4] Qinwen, Li., and Liasi, E. A study on the needle heating in heavy industrial sewing-part II. International Journal of Clothing Science and Technology, 2001, 13(2), 87-105.

[5] Sondhelm, W. Causes of seam damage: Needle heating. Journal of Textile Institute, 1953, 44, 580-585.

[6] Laughlin, R. Needle temperature measurement by infrared pyrometry. Textile Research Journal, 1963, 33(1), 35-39.

[7] Yukseloglu, M., Citoglu, F., and Catinkaya B. A study on the needle heating in polyester blend upholstery fabrics. Industria Textila, 2013, 63(5), 246-253.

[8] Li, Q., Liasi, E., Simon, D., and Du, R. Heating of industrial sewing machine needles: FEA model and verification using IR radiometry. In: Thermosense XXI, Proc. SPIE, R.N. Wurzbach,D.D. Burleigh eds. 1999, 3700, 347-357.

[9] Dorkin, C., and Chamberlain, H. The facts about needle heating. Clothing Institute Technical, 1963, Report no.13.

[10] Trung, N., and Kùs, Z. Computer Simulation of Sewing Needle Heating. CSCC'99 Proceedings. CzechRepublic 1999, 1991-1994.

[11] Howard, G., and Parsons, D. Sewing needle temperature Part1: Theoretical analysis and experimental methods. Textile Research Journal, 1968, 1, 606-614.

[12] Fan, J. The Effect of Throat Plate Design on Sewing Damage on an Overlock Sewing Machine. Research Journal of Textile and Apparel, 1977, 1, 112-116.

[13] Schmetz needle guide. Published by: Schmetz Company. http://www.schmetzneedles.com /learning/pdf/schmetz-needle-chart.pdf (2013, accessed 19 October 2014).

[14] Lewis, J. Clothing finishing procedure for preventing sewing damage in wool and wool/synthetic fiber double jersey fabrics. Clothing Research Journal, 1973, 1(3), 3-19.

[15] Poppinswimmer, K. Sewing damage in knit goods-What can be done. Melliand and Textilberichte, 1980, 9, 1556-1559.

[16] Infrared needle temperature measurement. Published by: TEXTILCHEMIE DR. PETRY GMBH. http://www.drpetry.de/file

[17] Dal, V., Kayar, M. and Akçagün E. Examination of the Effects of the Physical Properties of Woven Fabrics on the Heating of Sewing Machine Needles. FIBRES & TEXTILES in Eastern Europe, 2014, 22, 6(108), 113-117.

[18] HES, L. Method for measuring needle temperature by thermocouple, CzechRepublic Patent No.255597. http://spisy.upv.cz/Patents/FullDocuments/255/255597.pdf

[19] ASTM E1933–99a, Standard Test Methods for Measuring and Compensating for Emissivity Using Infrared Imaging Radiometers.

[20] Emissivity of different materials, (accessed 2014: http://www.optotherm.com/emiss-table. html)

[21] Bupta, B. Friction in textile materials,1st edn.The textile Institute, Cambridge, England, 2008

[22] Meric, B., and Durmaz, A. Effect of thread structure and lubrication ratio on seam properties, Indian journal of Fiber and Textile Research, 2005, 30, 273-277.

[23] Khan, R., Hersh, S., and Grady, P. Simulation of needle–fabric interaction in sewing operation. Textile Research Journal, 1970, 41, 489-497.

[24] ASTM D204-97, International Standard Test Methods for Sewing Threads.

[25] Gurada, A., Kaplangiray, B., and Kanik, M. The effects of lubricantion on properties and seam performance of sewing threads, Tekstil ve Muhendis, 2011, 18, 19-25.

[26] Eryuruk, S., Kalaoglu, F. The effects of different amounts of lubricant application on sewing thread performance properties. Textile Research Journal, 2010, 80(12), 1232-1242.

[27] Charron, F. Partage de la chaleur entre deux corps frottants, Publ. scient. et techn. Ministere air, article 182.1943.

[28] Haghighat, E., Etrati, S., and Shaikhzadeh, N. S. Modeling of needle penetration force in denim fabric. International Journal of Clothing Science and Technology,2013, 25(5), 361-379.

[29] Haghigat, E., Etrati, S., and Najar, S. Evaluation of woven denim fabric sew ability based on needle penetration force. Journal of Engineered Fibers and Fabrics, 2014, 9(2), 48-60.

[30] Gurarda, A. and Meric, B. Sewing needle penetration forces and elastane fiber damage during the sewing of cotton/elastane woven fabrics. Textile Res. J., 2005, 75(8), 628-633.

[31] Liasi, E., et al. An experimental study of needle heating in sewing heavy materials using infrared radiometry. International Journal of Clothing Science and Technology, 1999, 11(5), 300 – 314.

8 List of papers published by the author

8.1 Publications in journals

[1] Mazari, A. and Havelka, A. Tensile properties of sewing thread and sewing needle temperature at different speed of sewing machine. Advanced Materials Research, 2013, 627, 456-460.

[2] Mazari, A., Havelka, A. and Mazari, F. Needle eye temperature measurement at different speeds of sewing. IEEE, 2012. Available from: doi:10.1109/ICEngTechnol.2012. 6396164.

[3] Mazari A., Havelka A. and Hes L. Experimental techniques for measuring sewing needle temperature, Tekstil ve Konfesiyon, 2014,1, 111-118.

[4] Mazari, A., Havelka, A. and Mazari, F. Effect of sewing speed on sewing process. Textile Today, 2012, 11, 1-8.

[5] Mazari, A. and Havelka, A. Impact of stitch length on sewing needle temperature. World Journal of Engineering, 2014, 11(2), 187-192.

[6] Mazari, A. and Havelka, A. Optimising Vortex Cooling Time for Industrial Lockstitch Sewing Machines. International Journal of Textile and Fashion Technology, 2014, 4(1), 25-34.

[7] Mazari, A. and Havelka, A. Effect of ambient temperature and humidity on sewing needle temperature. Textiles and fibers, 2013, 4, 20-27.

[8] Mazari, A. and Havelka, A. Influence of needle heat during sewing process on the tensile properties of sewing thread. Tekstilec, 2013, 6, 345-352.

[9] Mazari, A. and Havelka, A. Sewing needle temperature of an Industrial lockstitch machine. Industria Textila, 2014, 65(6), 335-339.

[10] Mazari A., Havelka A., Kus Z. The effects of Lubricant amount on sewing needle temperature and tensile properties of Polyester-polyester core-spun thread. Industria Textila, 2015, 66(2), (Accepted-In press).

[11] Mazari, A., Havelka, A., Wiener, J. and Zbigniew, R. A study on DLC-coated industrial lockstitch sewing needle. Industria Textila, 2015, 66(1), (Accepted-In press).

[12] Mazari, A., Bal, K. and Havelka A. Prediction of needle heating in an industrial sewing machine. Textile research journal, 2014, under review.

8.2 Contribution in conference proceeding

[1] Mazari, A., Havelka, A. and Mazari, F. Needle eye temperature measurement at different speeds of sewing. In: ICET, Egypt, 2012.

[2] Mazari, A. and Havelka, A. Methods for sewing needle temperature measurement. In: 19th International Conference Strutex, ISBN: 978-80-7372-913-4, Czech Republic, 2012.

[3] Mazari, A., Havelka, A. and Mazari, F. Impact of ambient humidity on sewing needle temperature. In: ITC-2013, Istanbul, May 30-May 31, 2013.

[4] Mazari, A. and Havelka, A. Effect of ambient humidity and temperature on sewing needle temperature. In: ATC-12, Shanghai, 2013.

[5] Mazari, A. and Havelka, A. Experimental techniques for measuring sewing needle temperature.In: Workshop Chata Pod Lipami, Czech Republic, ISBN: 978-80-7372-987-5, 2013.

[6] Mazari, A., Havelka, A. and Mazari, F. Tensile properties of sewing thread at different speed of sewing machine"International conference on innovation in textile. In: Covitex, Pakistan, 2013.

[7] Mazari, A., Havelka, A. and Mazari, F. Optimisation of lubricant amount for pet-pet corespun thread on industrial lockstitch machine. In: FIYEC, Lahore, 2014.

[8] Mazari, A. and Havelka, A. Impact of needle size on sewing needle temperature.IN: Texsci conference, ISBN: 978-80-7372-989-9, Liberec, September 23-25, 2013

[9] Mazari, A. and Havelka, A. Effect of fabric layer on needle temperature. In: Autex, ISBN: 978-3-86780-343-4, Dresden, 2013.

[10] Mazari, A. and Havelka, A. Stitch length impact on sewing needle temperature"19th International Conference Strutex, ISBN: 978-80-7372-913-4, Czech Republic, 2012.

[11] Mazari, A. and Havelka, A. Optimizing Lubricant Amount for Sewing Threads, In: Fiber Society, Liberec, May 2014.

[12] Mazari, A. and Havelka, A. effect of DLC-coated needle on sewing performance.In: Texco, ISSN: 1335-0617, Slovakia, 2014.

[13] Mazari, A., Havelka, A. and Mazari, F. Impact of different factors on sewing needle temperature for industrial lockstitch machine. In: Autex, ISBN: 978-605-63112-4-6, Turkey, 2014.

[14] Mazari, A., Havelka, A. and Mazari, F. Optimising vortex cooling time for industrial lockstitch sewing machines, In: Autex, ISBN: 978-605-63112-4-6, Turkey, 2014.

[15] Mazari, A., Havelka, A. and Mazari, F. The effects of sewing needle heat on stitched thread. In: ITC&DC ISSN: 1847-7275, 294-299, Croatia, 2014.

[16] Mazari, A., Bal, K. and Havelka, A. Temperature distribution on sewing needle at high speed industrial sewing lockstitch machine. In: Strutex, ISBN: 978-80-7494-139-9, Liberec, 2014.

8.3 Quotation

10 articles are available in the database of Scopus, 5 articles are published in Impact factor journals (Web of Science/Thompsons Reuters) and the articles are cited 5 times by foreign researchers.

Curriculum Vitae

Adnan Ahmed Mazari
Block A, Koleje Harcov,
460 15, Liberec, Czech Republic
Telephone: 00420-773068803
E-Mail: adnanmazari86@gmail.com ; adnan.ahmed.mazari@tul.cz

Objective

A prospect to work in a research based environment to use my technical skills and offers ample learning opportunities to enhance my knowledge and to develop creative research for the textile field.

Personal Details

Passport Details	AB0825742 [Pakistan]
Marital status	Married
Date of Birth	24 April 1986
Languages	Fluently speaks English and Urdu, intermediate Turkish
Qualifications	Excellent academic records with all education in English, Master with Distinction in Textile technology from Technical University of Liberec ,Czech Republic

Educational Qualifications

Degree	University	percentage	Year
Ph.D. in progress	Technical University of Liberec ,Czech Republic	In progress	2015
Master in Textile Technology	Technical University of Liberec ,Czech Republic	Distinction (Red diploma)	2011
Bachelors of Textile Engineering	National Textile University, Faisalabad Pakistan	70%	2008

Projects

Nanotechnology in Clothing under Doc. Havelka, TUL, Czech Republic.
Projects at Pakistan textile companies related to lead time and manufacturing cost.
Parameters of needle and needle less spinning under prof. Jirsak, TUL, Czech Republic
Student grant competition. (2012, 2013, 2014)
Erasmus student's bachelor projects and lectures (2013 and 2014)

Expertise

Electron Microscope
Industrial clothing machinery.
Needle-less electrospinning (patent prof. Jirsak TUL, Czech republic)
Alambeta and Permabeta (patent by prof. Hes ,TUL, Czech Republic)
Non-Woven technology and machinery (meltblown, spunbond, needle punching)
High-speed camera
Image analysis (NIS software)

IT Knowledge

Gerber accumark
V-stitcher
SPSS(software for statistical evaluation)
Matlab
Macromedia flash

Honours & Awards

Master with Distinction from Technical University of Liberec.
Best poster presentation award Fibre Society, 1st place 2014.
Best paper award International journal of textile and fashion technology, 2014.

Research Interest

My keen interest is to research in the fields of textile clothing, clothing machinery, nano textile, technical textile and car-seat comfort.

Additional Information available on request

References , Credentials to support the claims made in this CV.

Brief description of the current expertise, research and scientific activities

I am actively involved at research related to clothing production, sewing machines, clothing comfort, car-seat comfort and designing special testing equipment for the testing of car seat comfort under dynamic loads. I have successfully passed all exams related to my PhD studies.

Doktorské studium

Studium	Doctoral study programme Textile Engineering in a full-time form at the Faculty of Textile Engineering, Technical University of Liberec.	
Seznam zkoušek		
	Heat and Mass Transfer in Porous Media	13.12.2011
	Structure and Properties of Textile Fibe	18.05.2012
	Mathematical Statistics and Data Analysi	20.08.2012
	Specialization in Field	24.09.2012
	Experimental Technology	27.05.2013
SDZ	Comprehensive Doctoral Exam, passed on	11.07.2014

Pedagogická činnost

Taught multiple courses for the international Erasmus students like

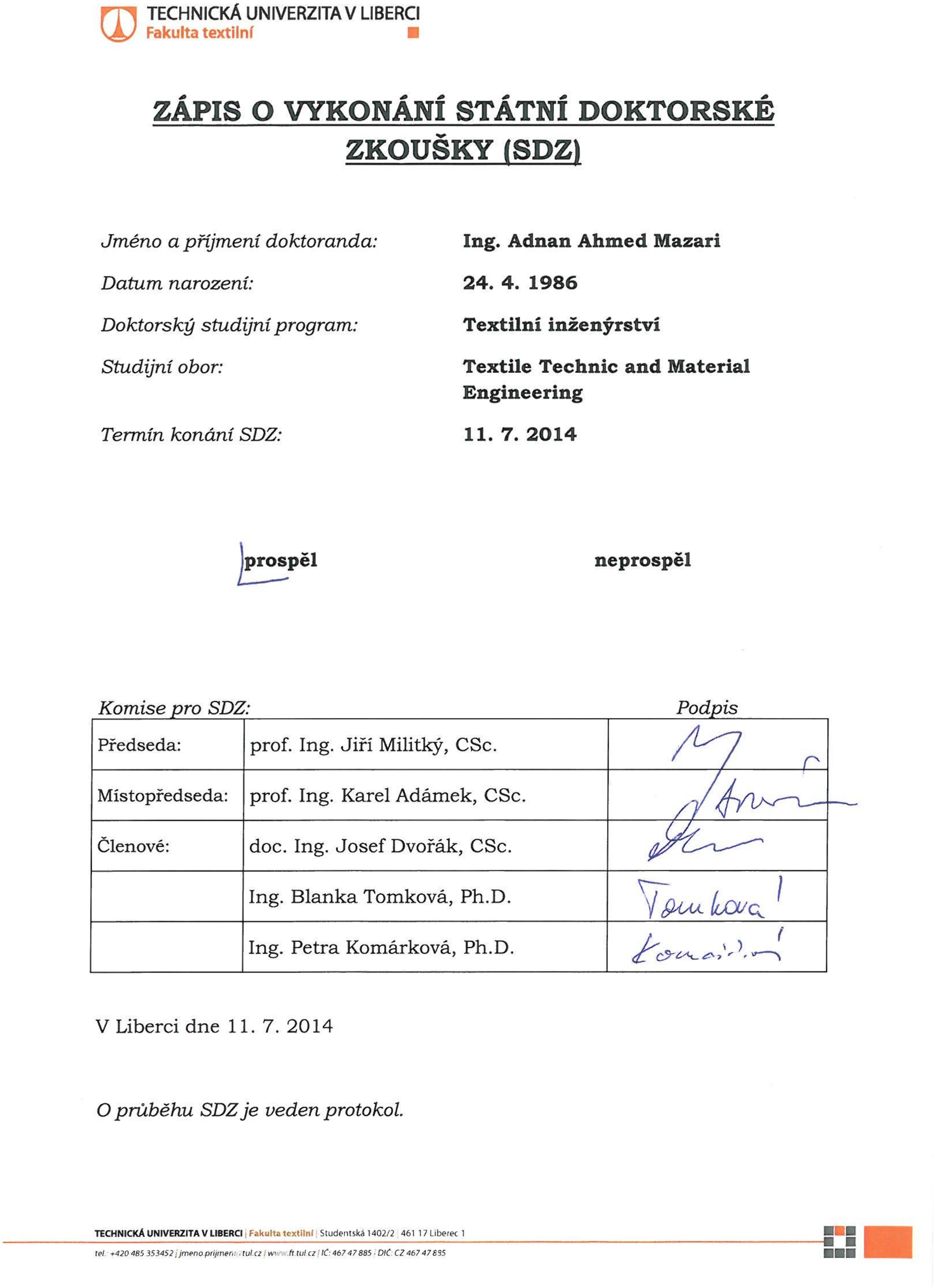
- **Textile technology**
- **Clothing production**
- **Sewing Machines**

Výzkumné projekty

Research Leader for three SGS projects for year 2012. 2013 and 2014.

Project Alfa from Department of Clothing, TUL, Czech Republic.

Record of the state doctoral exam



TECHNICKÁ UNIVERZITA V LIBERCI
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ZÁPIS O VYKONÁNÍ STÁTNÍ DOKTORSKÉ ZKOUŠKY (SDZ)

Jméno a příjmení doktoranda:	**Ing. Adnan Ahmed Mazari**
Datum narození:	**24. 4. 1986**
Doktorský studijní program:	**Textilní inženýrství**
Studijní obor:	**Textile Technic and Material Engineering**
Termín konání SDZ:	**11. 7. 2014**

[✓ **prospěl**]   **neprospěl**

Komise pro SDZ:		*Podpis*
Předseda:	prof. Ing. Jiří Militký, CSc.	
Místopředseda:	prof. Ing. Karel Adámek, CSc.	
Členové:	doc. Ing. Josef Dvořák, CSc.	
	Ing. Blanka Tomková, Ph.D.	Tomková
	Ing. Petra Komárková, Ph.D.	Komárková

V Liberci dne 11. 7. 2014

O průběhu SDZ je veden protokol.

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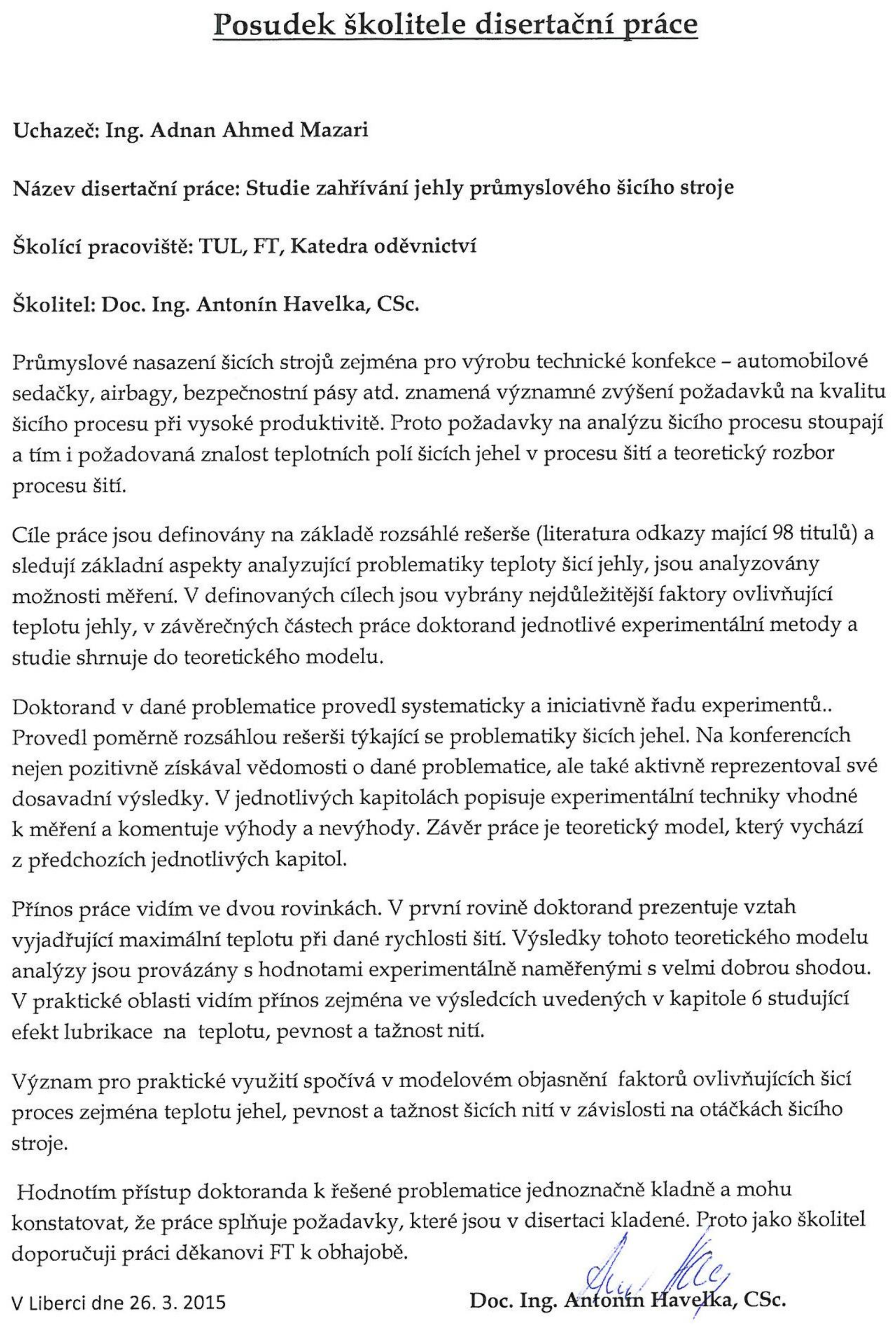
Recommendation of the supervisor



Posudek školitele disertační práce

Uchazeč: Ing. Adnan Ahmed Mazari

Název disertační práce: Studie zahřívání jehly průmyslového šicího stroje

Školící pracoviště: TUL, FT, Katedra oděvnictví

Školitel: Doc. Ing. Antonín Havelka, CSc.

Průmyslové nasazení šicích strojů zejména pro výrobu technické konfekce – automobilové sedačky, airbagy, bezpečnostní pásy atd. znamená významné zvýšení požadavků na kvalitu šicího procesu při vysoké produktivitě. Proto požadavky na analýzu šicího procesu stoupají a tím i požadovaná znalost teplotních polí šicích jehel v procesu šití a teoretický rozbor procesu šití.

Cíle práce jsou definovány na základě rozsáhlé rešerše (literatura odkazy mající 98 titulů) a sledují základní aspekty analyzující problematiky teploty šicí jehly, jsou analyzovány možnosti měření. V definovaných cílech jsou vybrány nejdůležitější faktory ovlivňující teplotu jehly, v závěrečných částech práce doktorand jednotlivé experimentální metody a studie shrnuje do teoretického modelu.

Doktorand v dané problematice provedl systematicky a iniciativně řadu experimentů.. Provedl poměrně rozsáhlou rešerši týkající se problematiky šicích jehel. Na konferencích nejen pozitivně získával vědomosti o dané problematice, ale také aktivně reprezentoval své dosavadní výsledky. V jednotlivých kapitolách popisuje experimentální techniky vhodné k měření a komentuje výhody a nevýhody. Závěr práce je teoretický model, který vychází z předchozích jednotlivých kapitol.

Přínos práce vidím ve dvou rovinkách. V první rovině doktorand prezentuje vztah vyjadřující maximální teplotu při dané rychlosti šití. Výsledky tohoto teoretického modelu analýzy jsou provázány s hodnotami experimentálně naměřenými s velmi dobrou shodou. V praktické oblasti vidím přínos zejména ve výsledcích uvedených v kapitole 6 studující efekt lubrikace na teplotu, pevnost a tažnost nití.

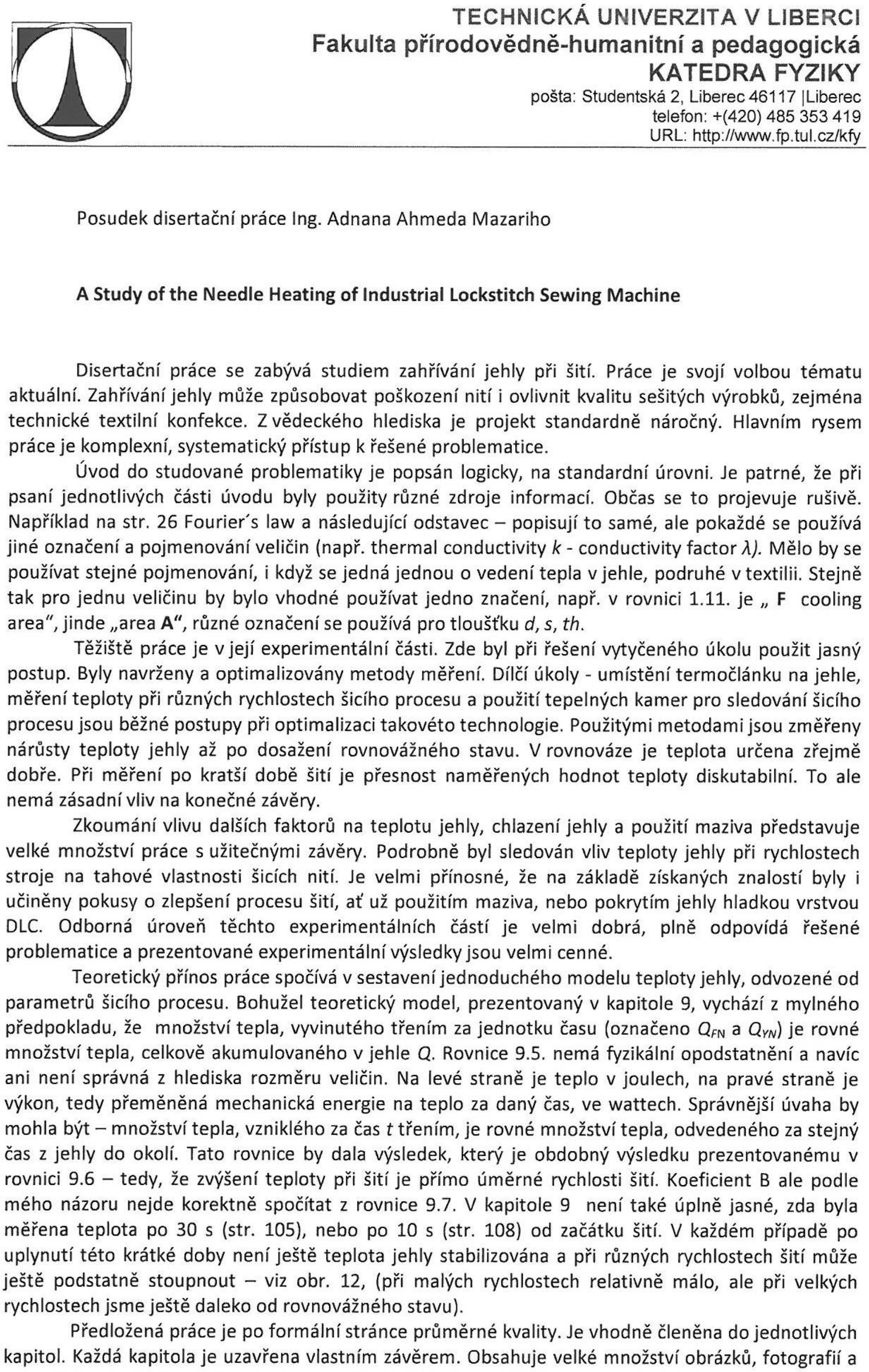
Význam pro praktické využití spočívá v modelovém objasnění faktorů ovlivňujících šicí proces zejména teplotu jehel, pevnost a tažnost šicích nití v závislosti na otáčkách šicího stroje.

Hodnotím přístup doktoranda k řešené problematice jednoznačně kladně a mohu konstatovat, že práce splňuje požadavky, které jsou v disertaci kladené. Proto jako školitel doporučuji práci děkanovi FT k obhajobě.

V Liberci dne 26. 3. 2015

Doc. Ing. Antonín Havelka, CSc.

Reviews of the opponents



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Posudek disertační práce Ing. Adnana Ahmeda Mazariho

A Study of the Needle Heating of Industrial Lockstitch Sewing Machine

Disertační práce se zabývá studiem zahřívání jehly při šití. Práce je svojí volbou tématu aktuální. Zahřívání jehly může způsobovat poškození nití i ovlivnit kvalitu sešitých výrobků, zejména technické textilní konfekce. Z vědeckého hlediska je projekt standardně náročný. Hlavním rysem práce je komplexní, systematický přístup k řešené problematice.

Úvod do studované problematiky je popsán logicky, na standardní úrovni. Je patrné, že při psaní jednotlivých části úvodu byly použity různé zdroje informací. Občas se to projevuje rušivě. Například na str. 26 Fourier´s law a následující odstavec – popisují to samé, ale pokaždé se používá jiné označení a pojmenování veličin (např. thermal conductivity k - conductivity factor λ). Mělo by se používat stejné pojmenování, i když se jedná jednou o vedení tepla v jehle, podruhé v textilii. Stejně tak pro jednu veličinu by bylo vhodné používat jedno značení, např. v rovnici 1.11. je „ **F** cooling area“, jinde „area **A**“, různé označení se používá pro tloušťku *d*, *s*, *th*.

Těžiště práce je v její experimentální části. Zde byl při řešení vytyčeného úkolu použit jasný postup. Byly navrženy a optimalizovány metody měření. Dílčí úkoly - umístění termočlánku na jehle, měření teploty při různých rychlostech šicího procesu a použití tepelných kamer pro sledování šicího procesu jsou běžné postupy při optimalizaci takovéto technologie. Použitými metodami jsou změřeny nárůsty teploty jehly až po dosažení rovnovážného stavu. V rovnováze je teplota určena zřejmě dobře. Při měření po kratší době šití je přesnost naměřených hodnot teploty diskutabilní. To ale nemá zásadní vliv na konečné závěry.

Zkoumání vlivu dalších faktorů na teplotu jehly, chlazení jehly a použití maziva představuje velké množství práce s užitečnými závěry. Podrobně byl sledován vliv teploty jehly při rychlostech stroje na tahové vlastnosti šicích nití. Je velmi přínosné, že na základě získaných znalostí byly i učiněny pokusy o zlepšení procesu šití, ať už použitím maziva, nebo pokrytím jehly hladkou vrstvou DLC. Odborná úroveň těchto experimentálních částí je velmi dobrá, plně odpovídá řešené problematice a prezentované experimentální výsledky jsou velmi cenné.

Teoretický přínos práce spočívá v sestavení jednoduchého modelu teploty jehly, odvozené od parametrů šicího procesu. Bohužel teoretický model, prezentovaný v kapitole 9, vychází z mylného předpokladu, že množství tepla, vyvinutého třením za jednotku času (označeno Q_{FN} a Q_{YN}) je rovné množství tepla, celkově akumulovaného v jehle Q. Rovnice 9.5. nemá fyzikální opodstatnění a navíc ani není správná z hlediska rozměru veličin. Na levé straně je teplo v joulech, na pravé straně je výkon, tedy přeměněná mechanická energie na teplo za daný čas, ve wattech. Správnější úvaha by mohla být – množství tepla, vzniklého za čas t třením, je rovné množství tepla, odvedeného za stejný čas z jehly do okolí. Tato rovnice by dala výsledek, který je obdobný výsledku prezentovanému v rovnici 9.6 – tedy, že zvýšení teploty při šití je přímo úměrné rychlosti šití. Koeficient B ale podle mého názoru nejde korektně spočítat z rovnice 9.7. V kapitole 9 není také úplně jasné, zda byla měřena teplota po 30 s (str. 105), nebo po 10 s (str. 108) od začátku šití. V každém případě po uplynutí této krátké doby není ještě teplota jehly stabilizována a při různých rychlostech šití může ještě podstatně stoupnout – viz obr. 12, (při malých rychlostech relativně málo, ale při velkých rychlostech jsme ještě daleko od rovnovážného stavu).

Předložená práce je po formální stránce průměrné kvality. Je vhodně členěna do jednotlivých kapitol. Každá kapitola je uzavřena vlastním závěrem. Obsahuje velké množství obrázků, fotografií a grafů, které vhodně doplňují text. Všechny obrázky jsou přehledně a ilustrativní. Popisky obrázků jsou dostatečné a přesné, odkazy na obrázky jsou správně umístěny v textu, pouze je zaměněno číslování obr. 13 a obr. 14 na straně 48. Rovnice nejsou vysázeny moc přehledně. V rovnicích se používají fonty „tučné", nepoužívají se dobře mezery, znak násobení se vyjadřuje pomocí znaménka *, někde i x (str. 98, 99), zlomková čára ve zlomku se píše pomocí lomítka, a čtenář neví, kde končí zlomek. Pravopisné chyby a překlepy se vyskytují v malém počtu, např. v List of Symbols - Stefan´s constant w namísto W. Někdy jsou špatně umístěné mezery před interpunkční znaménka, někde chybí za interpunkčními znaménky. V tabulce 19 na str. 105 jsou standardní odchylky udávány s nadbytečnou přesností. Odborná terminologie je používána dobře, pouze občas jsou špatně zaměněny veličiny teplo a tepelný tok, nebo teplota - např. str. 32 "T is heat gained by needle". Seznam literatury je obsáhlý a obsahuje důležité publikace oboru, práce jsou citovány korektně. Anotace je výstižná.

Na doktoranda mám tento dotaz:

Nezvýšil vložený termočlánek tření při šití a tím i výslednou teplotu?

Z předložené práce je vidět, že autor si studovanou problematiku plně osvojil, a že vykonal velký kus experimentální práce. Autor zároveň aktivně přispěl k rozvoji tohoto oboru, o čemž svědčí i uvedený seznam publikací, kde je autorem, nebo spoluautorem. Přiložené publikace autora jsou dobře sepsané.

Předložená disertační práce Ing. Adnana Ahmeda Mazariho je bezesporu kvalitní. Autor prokázal předpoklady k samostatné vědecké práci. Práce přispívá k analýze teplotních polí šicích jehel.

Doporučuji přijetí předložená práce k obhajobě.

v Liberci, dne 12.4.2015

doc. RNDr. Miroslav Šulc, PhD.

Posudek doktorské disertační práce

Řešitel:	**Ing. Adnan Ahmed Mazzari**
Název disertační práce:	**Studie zahřívání jehly průmyslového šicího stroje**
Oponent:	**Prof. Ing. Karel Adámek, CSc.**

Aktuálnost zvoleného tématu

Šicí proces je jednou z nejdůležitějších operací v oděvním průmyslu. Se zvyšujícími se výkony průmyslových šicích strojů (otáčky, šité materiály atd.) se zvětšuje i problém poškození šicí nitě v důsledku různých jevů během šití – ohřev šicí nitě, její poškození oděrem atd. Ovlivňování šicí jehly a nitě je vzájemné – třením nitě se ohřívá jehla, vyšší teplotou jehly se zvyšuje poškození nitě. Tedy i malé zlepšení v této oblasti může vést k významnému obchodnímu i výkonovému přínosu.

Cíl práce

Hlavním cílem práce je porozumět různým procesům, které vedou k ohřátí šicí jehly a prozkoumat určité metody, které vedou ke zvýšení produktivity šicích operací snížením teploty jehly, ale bez snížení šicí rychlosti.

Zvolené metody zpracování a postup řešení

Postup řešení je logický a je přehledně popsaný v jednotlivých kapitolách.

Kap. 1 obsahuje literární rešerši, v závěru práce je uvedeno na 100 referencí. Z nich vycházejí definice hlavních problémů k řešení, jak jsou shrnuté v odst. 1.6 – vliv šicí nitě v jehle na teplotu jehly při šití, problematika bezkontaktního a diskontinuálního měření teploty, efektivita chlazení a mazání. Z výsledků rešerše byl stanoven další postup práce.

V kap. 2 jsou definované hlavní cíle řešení, jak vyplynuly z uvedené rešerše – vyvinout experimentální techniku k měření teploty šicí jehly, definovat vlivy působící na teplotu jehly, vyhodnotit účinnost metod chlazení šicí jehly, stanovit vliv teploty jehly na šicí nit a teoreticky analyzovat teplotu šicí jehly.

Kap. 3 popisuje experimentální techniky k měření teploty jehly – termokamera, dotykový termočlánek, zabudovaný miniaturní termočlánek a uvádí výhody a nevýhody jednotlivých metod. Nejvhodnější je zabudovaný termočlánek, obecně se ukazuje, že při šití s nití jsou teploty vyšší, tj. že vliv tření nitě v jehle má svůj vliv.

Kap. 4 uvádí celkem 10 vlivů, které ovlivňují teplotu šicí jehly. Z nich jsou vybrané 4 hlavní nezávislé parametry, které jsou pak dále sledovány a další analýzou je stanoven jejich účinek.

Kap. 5 popisuje příznivý účinek chlazení šicí jehly vírovou trubicí. Je potvrzeno, že chlazením se výrazně sníží teplota jehly, takže po skončení šití se nit nepřeruší (nepřetaví).
Dotaz: Z hlediska celkové spotřeby energie je nějaká zásadní výhoda při použití vírové trubice (ofukování „studeným koncem", přičemž „teplá" část vzduchu není využita) proti jednoduchému ofukování přímo vzduchem (tj. o vyšší teplotě než z vírové trubice, ale celé množství)?

Kap. 6 studuje vliv mazání šicí jehly na její teplotu, na druhou stranu snížené tření mezi vlákny v šicí niti vede ke snížení její pevnosti v tahu. Z výsledků experimentu a následující analýzy vychází doporučený rozsah otáček pro aplikaci maziva a jeho vliv na součinitel tření a na teplotu jehly.

Kap. 7 popisuje vliv teploty jehly na pevnost nitě. Podrobně je popsané namáhání nitě při průchodu jednotlivými místy šicího stroje a snižování její pevnosti v důsledku postupného poškozování nitě otěrem.

Kap. 8 studuje vliv tvrdého povlaku na jehle na snížení součinitele tření a na vysokou odolnost proti opotřebení. Správně je poznamenáno, že takový obecně výhodný povlak lze obtížně aplikovat v okolí složitého tvaru oka jehly, zatímco na válcovém tvaru jehly bez problémů.

Kap. 9 uvádí teoretický fyzikální model vzájemné interakce nitě a jehly během šití – silové účinky, třecí účinky, vývin a odvod tepla. Je otázka, zda by takový model neměl být vytvořen a diskutován na začátku řešení, ale na druhé straně právě provedené předchozí experimenty umožní vytvoření modelu, který bude odpovídat realitě.
Dotaz: Jsou k dispozici naměřené závislosti pohybu nitě očkem jehly nebo síly v dříku jehly v průběhu šití (otáčky stroje)?

Zhodnocení výsledků dosažených disertantem

Složitá problematika ohřevu šicí jehly a poškození šicí nitě při procesu šití je vhodně rozdělena na dílčí problémy, ty jsou postupně řešeny v jednotlivých kapitolách a v závěru kapitol je vždy uveden stručný souhrn výsledků. Z mnoha parametrů jsou vytipované ty nejdůležitější, kterým je třeba se věnovat především.

Význam pro praxi nebo rozvoj vědního oboru

Práce odpověděla na některé protichůdné předpoklady různých autorů (např. zda šicí nit ochlazuje nebo ohřívá jehlu) a dává řadu podnětných výsledků pro praktickou aplikaci i pro další výzkum, jak je uvedeno v jednotlivých kapitolách. V závěru je naznačeno, že závěry získané v laboratorních podmínkách na určitém stroji a s určitými materiály by nyní bylo možné použít i v různých provozních podmínkách různých průmyslových šicích dílen.

Publikační aktivita disertanta

Publikační aktivitu disertanta lze označit za významnou, v práci je uvedeno spoluautorství 12 publikací v mezinárodních časopisech a 16 publikací na mezinárodních konferencích.

Formální úprava a jazyková úroveň

Práce je předložena v angličtině. Má dobrou formální úroveň, je přehledně a logicky členěná podle průběhu postupu řešení, které končí dosaženými závěry. Rovněž použitá vyobrazení jsou přehledná a přispívají k celkové srozumitelnosti textu.

Připomínky k disertační práci

Připomínky k práci nemám, dotazy pro diskusi jsou uvedeny v textu u jednotlivých kapitol. Snad by základní fyzikální rozbor v kap. 9 mohl být na začátku výzkumu, aby se teoreticky stanovily hlavní příčiny ohřevu jehly a následně vliv její teploty na sledovaný proces. Na druhou stranu, k takové teoretické úvaze jsou potřebné nějaké výchozí podklady, které byly nejprve stanoveny experimentálně, jak je uvedeno v předchozích kapitolách.

Závěrečné hodnocení

Konstatuji, že předložená práce splňuje požadavky kladené na disertační práce, a proto ji doporučuji k obhajobě.

Po úspěšné obhajobě disertační práce doporučuji udělení titulu Ph.D.

V Liberci dne 6.3.2015

Prof. Ing. Karel Adámek, CSc.
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