Investigating the heat measurement techniques of sewing needle

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ABSTRACT – REZUMAT

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Industrial lockstitch sewing machines have an unavoidable issue with the heat generated by the sewing needle during high-speed sewing. This needle heat causes thread breakage, burn spots on fabric and poor seam strength. Garment manufacturers and technical textile producers are forced to slow down production or use expensive cooling techniques, such as needle coating, thread lubrication, and forced cooling. In this research, the techniques used in needle heat measurement are summarised and show why the classical technique of thermal camera shows false readings. The research work shows repeatable results from a unique technique of embedded thermocouple technique to measure sewing needle temperature and compares with other techniques. The overall setup of this technique, including the types of thermocouples and receiver, is deeply explained in the article. This technique shows significant improvement in the needle temperature measurement methodology, which is tested at different sewing speeds and with the most common sewing threads used in the market. The article is useful for researchers and also for the industry to know exactly the needle heat before sewing and consider the machine parameters accordingly for better seam quality.

Keywords: *needle heat, garment, heat transfer, sewing, lock stich*

Investigarea tehnicilor de măsurare a efectului de încălzire a acului de cusut

Mașinile industriale de cusut au o problemă inevitabilă legată de încălzirea acului de cusut în timpul coaserii la viteză mare. Încălzirea acului provoacă ruperea firului, apariția de pete de arsuri pe materialul textil și rezistența slabă a cusăturii. Producătorii de îmbrăcăminte și de textile tehnice sunt obligați să încetinească producția sau să utilizeze tehnici de răcire costisitoare, cum ar fi tratarea acului, lubrifierea firului și răcirea forțată. În această cercetare, sunt rezumate tehnicile utilizate pentru măsurarea efectului de încălzire a acului și se prezintă de ce tehnica clasică a camerei termice afișează valori eronate. Cercetarea prezintă rezultate repetabile obținute cu ajutorul unei tehnici unice de termocuplu încorporat pentru măsurarea temperaturii acului de cusut și le compară cu alte tehnici. Configurația generală a acestei tehnici, inclusiv tipurile de termocuplu și receptor, este explicată în detaliu în articol. Această tehnică prezintă o îmbunătățire semnificativă a metodologiei de măsurare a temperaturii acului, fiind testată la diferite viteze de coasere și cu cele mai utilizate fire de cusut de pe piață. Articolul este util pentru cercetători, dar și pentru industria de profil, pentru a cunoaște cu exactitate temperatura acului înainte de coasere și pentru a lua în considerare parametrii mașinii în consecință, pentru o calitate superioară a cusăturii.

Cuvinte-cheie*: încălzirea acului, îmbrăcăminte, transfer de căldură, coasere, cusătură simplă*

INTRODUCTION

Over the last 2 decades, there has been a huge demand for the sewing of garments, technical textiles, and highly functional apparel. This forces the garment producers to run the sewing machine at the maximum possible sewing speed, but a key issue of needle heat forces the producers to decrease overall production. A classic lock stitch machine, which is commonly used for sewing in the apparel industry, can easily run at a speed of 5000–6000 r/min, but just because of unavoidable needle heat, it is recommended to run the machine at 2500 r/min or lower. Many of the producers use expensive techniques of forced air cooling or thread lubrications, but still the exact needle temperature is unknown because it depends on multiple factors, including speed, ambient conditions and material properties. Knowing the needle temperature range, considering classical textiles will still provide useful information for the producer, but unfortunately, there is no trustworthy technique to provide repeatable results.

Depending on the sewing conditions, the maximum needle temperature ranges from 100°C – 300°C [1]. This high temperature weakens the thread because the tensile strength of the thread is a function of temperature [1] and leads to a decrease in production [2]. Furthermore, the final sewn thread has 30–40% less strength than the comprehensive thread [3]. Various methods were used to measure needle temperatures, such as infrared thermometers, thermocouples, and temperature-sensitive waxes. The needle moves very quickly during the sewing process, making it extremely difficult to measure accurate temperatures [4]. Although only a few theoretical models are available to predict sewing needle temperatures [4, 5], the experiments conducted by thermal cameras are affected by emission as well [7]. Sondhelm [8] used paint applied to the needle to observe colour changes over temperature. Laughlin [9] attempted to measure needle temperature by infrared measurements from needles using Lead-Sulfide cells. Another technique with a thermal element was later developed by Dorkin and Chamberlain [10]. Many technological developments have been undertaken over the years, including needle design [11, 12], fabric conductors, thread lubricants [13], needle coolers [14] to cool down the needle at speed sewing, but knowing the exact needle temperature still needs a more research and technological advancement.

Experimental techniques of measurement

A flow chart of the needle heating approach by multiple researchers is shown in figure 1. The collection of techniques is mainly divided into experimental and theoretical approaches. In all the fields, multiple research studies have been performed in the last decade. The chart gives a general overview of what researchers have worked on in the last years and how it will be improved in the author's work [15]. Generally, the contactless techniques of thermal cameras are very famous for experimental techniques; on the other hand, the finite element method using simulation software like Ansys is popular to obtain the prediction of needle temperature with respect to time.

It is briefly explained below how the needle temperature is measured and how it is used.

Contact method

This technique involves any method of needle temperature in which there is physical contact of the measuring device to the needle, like thermocouple and heat-sensitive colours, etc. [16]. The sewing process goes through enormous roughness between the needle, fabric and the sewing thread, and any attachment of colour, waxes and coatings does not last long. Touching the needle with the measurement device after finishing the sewing process brings human error and time delay. The needle with a small mass and thin size can cool down before the measuring device can be touched. Inserting a thermocouple inside the needle groove has been tested in the past, but due to the thick size of the sensor, low fragility and slow response measurement, it was never practical. But now with the new K and C type thermocouple, it's possible to measure with a very thin wire with better fragility and quick response measurement by wireless data loggers.

Contactless method of needle temperature measurement

These methods include techniques in which the temperature of the needle is measured without contact with the needle. Thermal camera, pyrometers and infrared techniques can be used for this approach. Most of the researchers have either used this technique or they have used the results from this method to compare with their theoretical models. The principle of contactless measurement depends on the emissivity of the object. Generally, for a stationary object with high emissivity, like a wall, human body or rigid structure, this technique is an excellent choice, but in the case of thin shining metal moving at high speed, like a sewing needle, there are complications to achieve repeatable results.

The main goal of the article is to measure the needle temperature with the latest thermal camera and see if it's really possible to measure needle temperature at high speeds of sewing speeds. Later, a unique technique of embedding the thermocouple in the needle groove will be experimented with to see if this technique is practical for measuring needle heat under different sewing conditions. A variety of sewing threads will be tested to see the overall change in needle heat during the sewing process and the performance of the thermocouple.

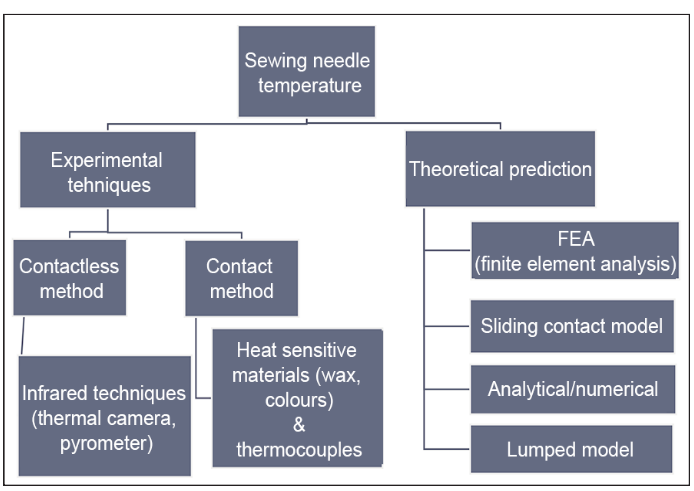

Fig. 1. Techniques to measure needle of sewing needle

Experimental part

In this research latest thermal camera, "Infratec 9400", and the embedded thermocouple technique will be used to determine the sewing needle temperature at high speeds. The 9 most commonly used sewing threads are selected to sew denim fabric at high speeds of sewing on an industrial lockstitch machine. The properties of denim fabric are shown in table 1, followed by the thread details in table 2.

The testing is performed on an industrial Lock stitch machine at different speeds of sewing with 100% Cotton, Denim fabric of 290 g/m^2 and two layers of fabric. Each stitch is performed for 15 seconds of time. The Lock stitch machine "Brother Company, DD7100-905" is run at different sewing speeds. The sewing needle of size 100/16 from the company Groz-Beckert is selected for all experiments.

Thermal camera setup

In this research, the high-speed thermal camera "Infratec 9400" is used to measure the needle temperature at different speeds of sewing speeds. To start the measurement process, it's important to know the exact emissivity of the sewing needle. All thermal cameras work on the principle of the emissivity of the object. For this

Table 1

FABRIC USED FOR THE EXPERIMENTS					
Fabric type	**Weave**	**Weight (g/m²)**	**Ends/cm**	**Picks/cm**	**Fabric thickness (cm)**
100% cotton Denim	2/1 Twill	290	26	18	0.035

Table 2

SEWING THREAD USED FOR THE EXPERIMENTS			
Trade name	**Composition**	**Thread (density) count (tex)**	**Coef. of friction, μ**
(C80) Saba	PET-PET corespun (CS) thread	40	0.13
(C50) Saba	PET-PET corespun (CS) thread	60	0.16
(C35) Saba	PET-PETcorespun (CS) thread	80	0.31
(75) Rasant	PET-COTTON corespun(CS)	40	0.14
(50) Rasant	COTTON-PET corespun(CS)	60	0.17
(35) Rasant	PET-COTTON corespun (CS)	80	0.31
(24/2) Merciful	Mercerised cotton (long staple)	70	0.4
(40) Mercifil	Mercerised cotton (long staple)	50	0.2
(50) Mercifil	Mercerised cotton (long staple)	40	0.13

test, the emissivity of the needle was calculated by ASTM standard E 1933-99a and determined to be 0.08 for a chromium-polished needle. 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 [9]. All the tests are performed in a dark room to avoid external heat sources reflecting from the shining needle. The "InfraTec 9400" high-speed thermal imaging camera is intended for recording fast events during which temperature excitation occurs on the observed object. The camera is set up as shown in figure 2, with a Basic lens 100 mm FOV (Field of View): 7.3 × 5.9° and a 20 mm Macro lens NWIR f/3.0 with a maximum frame rate binning mode: 622 Hz. The camera is placed 20 cm away from the needle tip on a separate vibration-free tripod to avoid focus change during high-speed sewing. Firstly, sewing is performed without thread and later with different thread types. The experiments are repeated 10 times, and each sewing is performed for 15 seconds.

Embedded thermocouple setup

This technique involves the technique of needle temperature in which there is physical contact of the measuring device to the needle, like a thermocouple and heat-sensitive colours, etc. The sewing process goes through enormous roughness between the needle, fabric and the sewing thread, and any attachment of colour, waxes and coatings does not last long. Touching the needle with the measurement device after finishing the sewing process brings human error and time delay. The needle with a small mass and thin size can cool down before the measuring device can be touched. The scientific idea by Prof. Hes [15] is modified to use the K type and C type thermocouple (Company: Omega®) which is soldered near the eye of the needle in the groove, the groove is designed for the thread to hide itself during needle insertion time but has enough space of a thin needle to be embedded K type thermocouple was used which are relatively slower in measurement and are more rigid with bigger thickness, the thermocouple was replaced with C type with much quick response, size of 0.076 mm shown in figure 3 and connected to fast wireless device for obtaining the temperature

Fig. 2. Thermal camera setup

Fig. 3. The thermocouple is attached by soldering and welding techniques

each second wirelessly. The thermo-couple is selected according to as thinnest available with the measurement range. In thin size, the range of the K type is less than 300°C, whereas the C type can measure a much higher range in the same thinness. The other important property required was better flexibility to not break the thermocouple during high-speed sewing, and also the remote connectivity with the data receiving unit. After multiple tries, the whole system from Omega® Company was useful for this technique. The tip is soldered in the groove of the needle (the space is enough for the wire to sit inside the groove during the insertion of the needle in the fabric), just next to the needle eye, as this is possibly the maximum hot point of the needle.

The collector is connected to a sewing machine, which remotely sends the temperature measurement to the computer via Bluetooth. This is accepted that these kind of sensor attachments causes a possible change in the thermal disturbance. It was made to keep this impact to a minimum, and comparing the results with other techniques, this method shows better accuracy, and the results were repeatable and reproducible.

The needle size of 100 or above is most suitable for this kind of measurement (normally size 90–140 is used for Denim or technical apparel), as the groove is big enough for the thermocouple to easily be fixed. The thermocouple is soldered, firstly precleaning with HCl solution and later attached with Sn-Ag-Cu-Zn using a soldering rod at 480°C. To achieve a higher range of melting, later spot welding and Tungeten Inert Gas (TiG) is used to attach the needle next to the needle eye. TiG welding showed excellent attachment properties. Argon gas is used during welding to avoid oxidation. A fine electrode tip of 0.5 mm was used for the welding. The attachment of the thermocouple to the needle eye by TiG welding is shown in figure 4.

After multiple experiments and optimisations, for low speed of sewing speeds, the soldering technique worked perfectly and for higher sewing speeds, the TiG welding performed perfectly. Both techniques can be used to solder the thermocouple inside the needle groove. The needle with attached thermocouple can be seen in figure 5.

The classical communication of the thermocouple sensors provided a slow response, in which it's possible to have the peak temperature, but overall gain and loss of needle temperature is very important with respect to short time intervals. As the needle gains above 200°C within the first 3 seconds of sewing, and similarly, the trend of heat loss gives us better knowledge of the heat loss when the machine is decelerating. For this experiment, the special wireless connector from the company Omega® was ordered. Initially the MWTC wireless device with K type thermocouple (5SC-TT-(K)-36-(36)) is used, with the improvement in the thermocouple technology the latest device of wireless connectivity UWTC-2 from Omega® company can work with thermocouple of type C (W5%Re-W26%Re) which are finer, around 0.076 mm and can

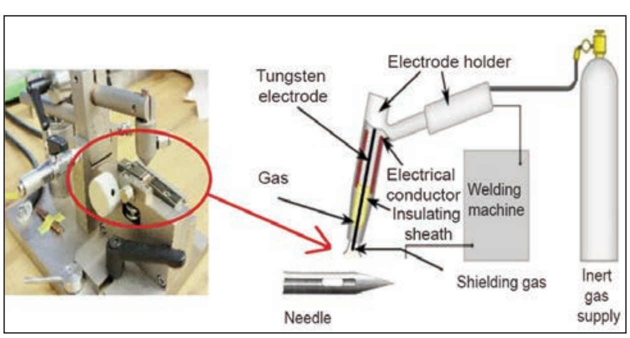

Fig. 4. Thermocouple attachment by the TiG welding technique

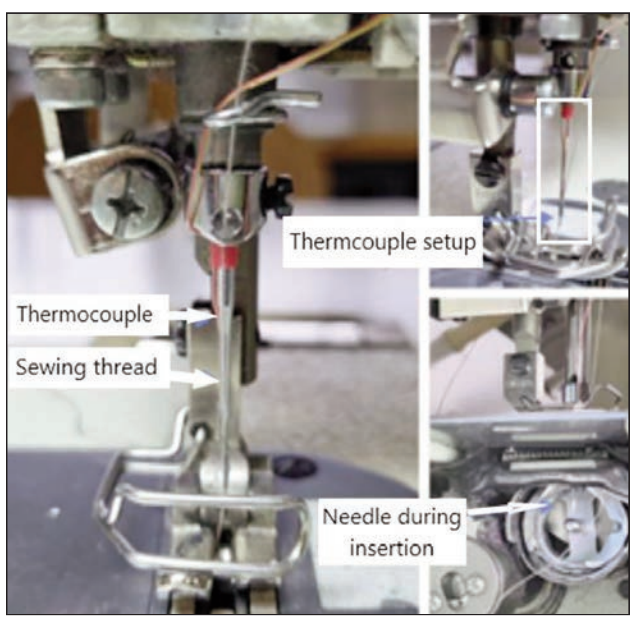

Fig. 5. A thermocouple attached to the sewing needle of an industrial lock stitch machine

Fig. 6. Data logger and wireless connection device for K and C type thermocouple

work till range of 2300ºC, special connector OSTW-C-M-S were used for the connectivity of the thermocouple to the sender device.
The testing is performed on an industrial Lock stitch machine at different speeds of sewing with 100% Cotton, Denim fabric of 290 g/m^2 and two layers of fabric. Each stitch is performed for 15 seconds of time.

RESULTS AND DISCUSSION

Firstly, testing is performed at different speeds of sewing with a classical Chrome needle of size 100; the thread Saba C80 is used for the experiments. The results are shown in table 3. At a lower speed of sewing of 250 r/min, the thermal cameras showed repeatable results, whereas at a higher speed, there was a huge standard deviation, which is mainly due to error in the exact needle temperature. The experiment is performed only with Polyester core spun thread of 80 tex, due to high variability in the results and poor repeatability, other threads were not tested as the thermal camera technique was not suitable.
It is observed that the thermal cameras, even at their fastest frame rate and optimum lens, it was able to measure the needle temperature with acceptable deviation only till 500 r/min or lower speeds. In the case of a needle with thread, even speeds of 500 r/min bring a significant change in the mean temperature of the needle. This is mainly due to the focus point being larger than the needle size, and impossible to avoid the thread's impact on the measurement of sewing needle temperature. Another issue is the change of emissivity of metals with the rise of temperature. This change is still insignificant for temperatures less than 100ºC but later on, there must be a dynamic change of emissivity level according to the material surface properties at different temperatures. Whereas when the classic thread of 40 tex is used during sewing, the error percentage was much higher, and the main reason was that the thread's emissivity was much larger compared to the shining needle, which causes error in the measurement.

Table 3

SEWING NEEDLE TEMPERATURE MEASURED WITH THERMAL CAMERA

Object	Sewing speed (r/min)				
	250	500	1000	2000	3000
Needle without thread	32	44	59	81	87
Standard Deviation (±)	3.8	4.2	5.8	12.7	18.4
Needle with thread (40 Tex)	38	59	76	125	158
Standard Deviation (±)	4.8	5.9	13.9	22.1	41.2

Secondly, the thermocouple setup is prepared to measure the needle at a vast range of sewing speeds from 1000 r/min to 4700 r/min. This technique showed an error of 5–7% but overall, it is the only technique in which needle temperature can be measured at such a high speed. The results of different threads at different speeds of sewing are shown in figure 7.
Results show that above 4000 r/min the needle temperature ranges to nearly 300ºC, which is not possible to measure using any other technique, and secondly, the repeatability of the results makes it a good choice to know needle temperature considering a defined set of parameters like sewing thread, machine speed and textile fabric. The needle temperature was the highest of the cotton-based thread, which is also connected to a higher coefficient of friction and directly causes more needle heat. The gain and loss of the needle heat are shown in the figure below for the speed of 4700 r/min. It is obvious that the needle reaches the maximum temperature within

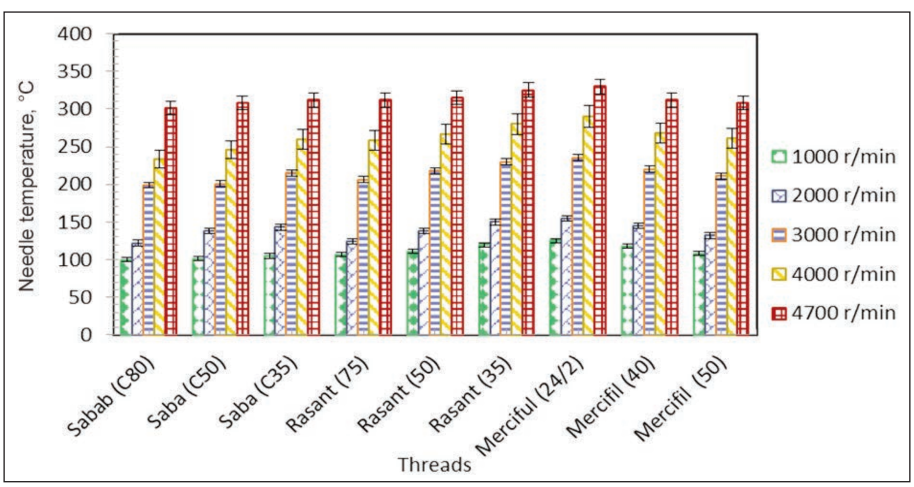

Fig. 7. Needle temperature by the embedded thermocouple approach

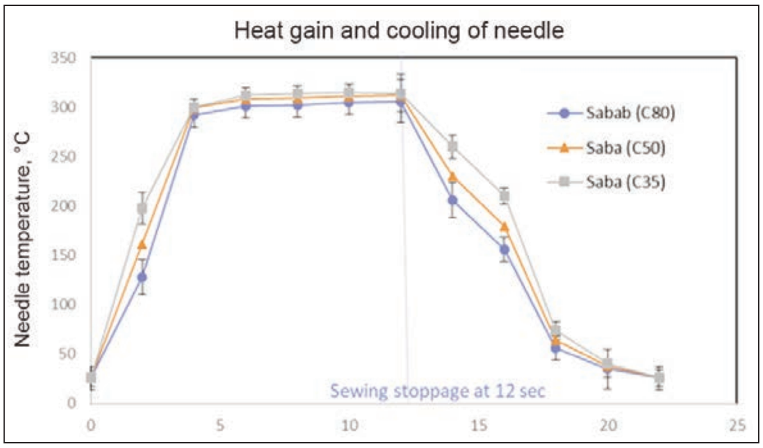

Fig. 8. Needle heat gain and loss

in first few seconds of sewing and takes nearly 10 seconds to cool down to room temperature.
The heat gain and loss at very small intervals of time were not possible with a K K-type thermocouple and a manual data logging approach; the wireless connectivity and C-type thermocouple provided much more reliable results, as shown in figure 8. It is seen that the rise of needle temperature is within the first 3–5 seconds of sewing, and after stoppage, the needle cools down within in few seconds.

CONCLUSIONS

It is concluded that a thermal camera or contactless approach that works with emissivity is not a practical solution for the sewing needle temperature measurement. The small size of the needle, low emissivity and high frequency make it impossible to measure needle temperature. The needle temperature with thread was even more complicated because of the high emissivity level of the thread as compared to a thin, shiny needle. There was more than 30% error at even speeds of 500 r/min. Whereas the inserted thermocouple approach showed repeatable results and even with 5–7% of error, this technique is the only method to measure needle temperature at the speed of sewing of 4000 r/min. The needle temperature at this speed is around 300ºC which is much more than the melting temperature of polymeric threads. The research provided the latest knowledge of the thermocouple attachment setup with the sewing needle and how to measure needle temperature at higher speeds for sewing. The technique provided unique information for the industrial partners as well, to know the exact needle temperature before the sewing process to obtain high-quality seams. In future, with better, thinner and more flexible thermocouples, it might be possible to decrease this error of measurement. But still, this technique shows one of the lowest standard deviations as compared to other techniques.

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