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# Assessment of Knitting Process Dynamics Using Computer Thermovision Method

**Abstract**
*The research aim of this work was to assess the usefulness of the thermovisual method in the qualitative and quantitative analysis of tension changes in warp threads during the technological process of manufacture anisostructural warp knitted fabrics. Research carried out with the use of warp-knitting machines shows that significant temperature changes occur in the region of the knitting zone and its surroundings. One characteristic of temperature changes in the knitting zone is the identical frequency of pulsation as an oscillatory input function of warp thread tensions which equal 0.15 Hz. The periodic characteristics of thread forces and temperature changes differ, which is rooted in the dissimilarity of the methods used. At the present stage of research, there is a lack of unequivocal correlation between instantaneous force values in threads measured by the tensometric method and temperature values measured with the use of a thermovision camera.*

**Key words:** *knitting, warp knitting, anisostructural knitted fabrics, tension, thread temperature, thermovision, strain gauges.*

## Introduction

The identification of the technological process carried out with the use of warp-knitting machines, based on active experiments, includes the measurement of tension in warp threads during feeding, among other elements. Having the information about the character and values of experimental forces in threads enables the prediction of possible disturbances to the knitting process (e.g. thread breakage), as well as of deformation and errors of the knitted fabric's structure during its creation.

Tensometric sensors are most commonly used for measurements of tensions in warp threads. In these sensors the change in the resistance of strain gauges, embedded in an elastic element touching the tested thread, is transduced by means of an electric system into an output signal in the form of force changes over time. The construction of the strain gauge allows force measurement in a single thread.

In the case of producing isostructural warp knitted fabrics, which are characterised by the repeat of the structure in the width and the length of the fabric (in the plane), identical conditions occur for all warp threads fed in the component stitch. This leads to the repeatability of the character and force values in threads which are unwound from the warp beam.

Therefore, making representative measurements of tension in a single selected thread is sufficient, because the rest of the measurements for this group of threads, fed into the entire machine's width, will be identical.

In the case of the identification process of anisostructural knitted fabric production, the analysis of tension in threads is extremely complicated. The basic cause lies in the structure of the knitted fabric.

Anisostructural warp-knitted fabrics are constructed from structural elements, which differ in the thread's length [1]. During the knitting process, when threads are unwound from warp beams, differences in length of knitted fabric's threads appear. The differences of knitting-in inside each thread lead to different characters and various values of thread tensions.

In this case, using the measurement method by use of strain gauges is unsuitable, because of the significant force sizes of those sensors in relation to the small distances between neighbouring threads, as well as the great number of sensors required for the measurement.

The best method to estimate the force in the group of neighbouring threads would be one which illustrates the spectrum of the tension characteristics of all threads.

On the basis of the results obtained hitherto, considering the use of the thermovisual technique in the identification of knitting processes, and an analysis of the literature [2,3], reasons exist for undertaking research, the aim of which could be to estimate the usefulness of the thermovisual method in the qualitative and quantitative analysis of tension changes in warp threads on warp-knitting machines. Such tests have not yet been carried out. To justify selection of the above-mentioned method, the following reasons can be listed:

- the thermovisual method of tension measuring is a passive method (non-contact), which does not interfere with the state of the object measured;
- in the feeding zone of threads and in the region of knitting the loop, a passive friction effect appears between the threads and frictional barriers such as guides, needles, needle bars, and knock-over sinkers, the result of which is the conversion of mechanical energy into heat (emitted in the form of thermal radiation) generated by the friction of bodies;
- thermograms of the knitting zone on warp-knitting machines record the variability of temperature in the operational width of the machine, for different conditions of thread feeding and take-up of the knitted fabric, and also illustrate the thread breakage by the resolution of a single thread in the temperature field;
- the observation field of the thermovision camera encloses from several to tens of threads, which means that changes of temperature of thread groups are recorded simultaneously.
- threads from natural or synthetic raw material (cotton, wool, polyester, polyamide) used in knitting technologies with the use of warp-knitting machines have a high emissivity value ($\varepsilon_\lambda$=0.82-0.93), which means that they are good infra-red emitters.

## Research Programme

The research presented in this paper concerns the analysis of dynamic tension changes in warp threads and the take-up forces of the knitted fabric manufactured on warp knitting machines. Analyses of

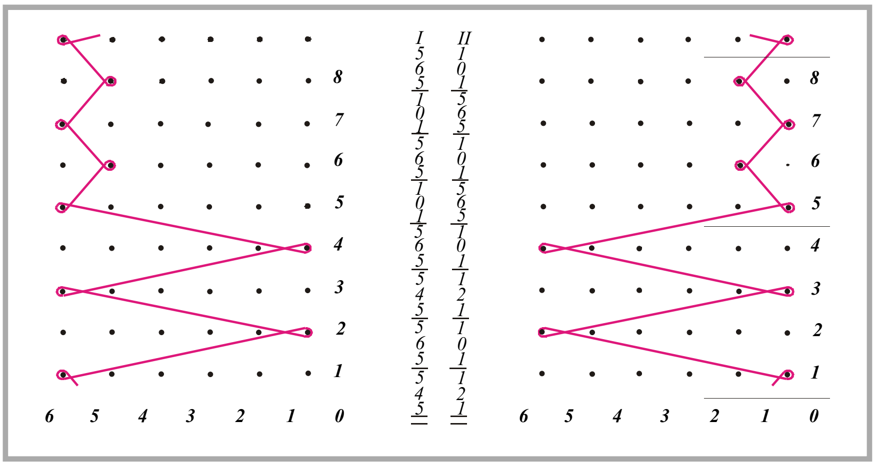

*Figure 1. Simplified draught of stitch I and II for guide bar.*

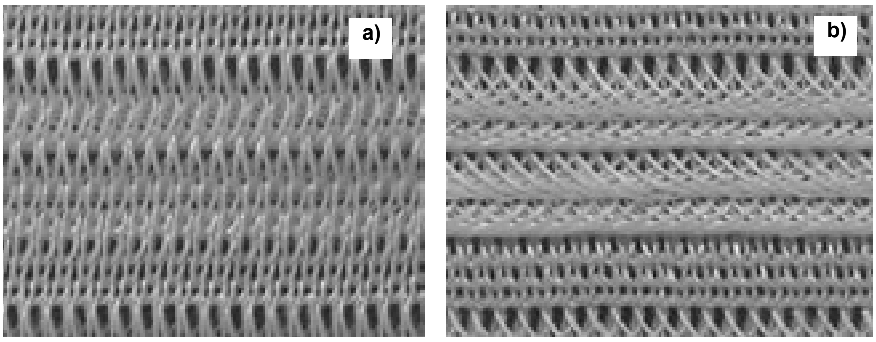


*Figure 2. Picture of double guided knitted fabric: a - right face, b - left face.*

the above-mentioned parameters during the production process of knitted fabrics were carried out using two measuring methods:

- the measurement of tension with tensometric transducers (the contact method), and
- the temperature measurement by the computer thermovision technique (the non-contact method).

In these investigations, periodic excitations of tension in warp and in the knitted fabric threads were assumed to occur. The measuring conditions which

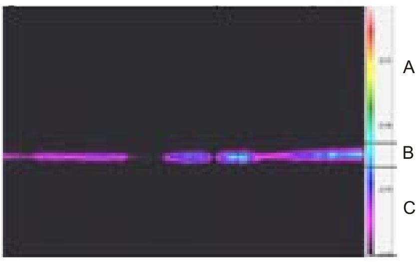


*Figure 3. Thermogram with separated warp feeding, knitting and fabric take-up zone: A - warp feeding zone, B - knitting zone, C - take-up zone of the knitted fabric.* ***Remark:*** *This figure is presented in colour in the internet - edition of the journal (www.fibtex.lodz.pl)*

we present in this paper are based on the changing differences between the thread requirement and the quantity of the thread delivered by applying different structures of the anisotropic knitted fabric (Figures 1 and 2).

The knitted fabric was produced on a warp-knitting machine (K. Mayer Company, type K2, E20). The knitted fabric was made of polyester thread with a linear density of 84 dtex. Two values of knitting speed and two of loop length were chosen. The knitting velocities $n_i$ are nominal velocities. In our research program, average knitting velocities of $n_1$=320 courses per min and of $n_2$=420 courses per min were assumed, while the average loop length was selected as $l_1$=5.5 mm and $l_2$=6 mm.

The thread tensions for guide bars I and II were monitored during the manufacture of the knitted fabric structure with the use of an on-line computer system equipped with a tensometric transducer working at high frequency (20 kHz). In addition, the take-up force was measured by the same system.

Simultaneously, the sequence of thermal images showing the temperature distribution in the knitting zone was recorded at a rate of 10 frames/s with an Inframetrics ThermaCam SC1000 system. While carrying out the thermogram measurement series, the camera was located 1 m from the knitting zone being photographed. The thermovision photos obtained enclosed a surface of 15×15 cm. The emissivity of the polyester yarn used was ε=0.83.

During testing, the environmental conditions were kept as stable as possible (the air temperature within 20±0.5°C, and the humidity within 60±2%).

## Research Results and Analysis

**Results and analysis of preliminary tests**

Our initial research concerned the analysis of temperature changes on the threads' surface in the knitting zone, with the warp-knitting machine working at the velocity of 600 courses/min. While knitting the fabric, the creation of tension oscillations in threads was forced to a frequency of 0.15 Hz, which corresponds to a vibration period of T=6.0 s.

During normal operation of the machine, the system was prepared to measure temperature changes in the warp feeding, knitting, and knitted fabric take-up zones, as presented in Figure 3.

As a result of these theoretical considerations, an increase in temperature was expected in every zone. However, the above assumption was not confirmed by the experiment. The analysis of a sequence with 300 thermal images revealed a temperature increase only in the knitting zones where threads, needles, and holding-down-knocking-over sinkers were placed. However, we had stated that the temperature variations would be negligible in the thread feeding and the knitted fabric take-up zones. Additionally, a discontinuity of temperature pulsation was noticed along the whole width of the knitted fabric, occurring over time, and changing its position along the fabric's width. This phenomenon was not the subject of the analysis carried out in this paper.

The proper choice of the areas of interest is important considering the thermogram analysis. It may lead indirectly to a working performance monitoring of the knitting machine, in order to determine when it should be tested or repaired. Finally, we confined our interest to those areas where the temperature increase was clearly visible, would be significant for further analysis, and where the temperature spectrum was uniform. The analysis results are visible in Figure 4 as 'hot spots' of determined time frequency. It was confirmed that temperature changes occur periodically with a period equal to the excitation period of the knitting process.

### Tension in warp threads and knitted fabric

Diagrams of the forces in threads and in the knitted fabric show that these forces change periodically (Figures 5 and 6). The periodical character of tensions in threads depends on the varying quantity of thread required in loops of the stitch.

We carried out many experiments, during which we found different tension amplitudes in each of them. We concluded that the values of tension amplitudes depend on the length of the take-up thread. For the length l=5.5 mm, we found tension amplitudes ranging from 30.2 cN at a knitting speed of n=342 courses/min to 21.7cN at n=420 courses/min. At a length l=6 mm, however, the tension amplitudes ranged between 10.6 cN at n=342 courses/min and 17.2 cN at n=420 courses/min. The relative difference of thread tension varies between 105% and 526%.

### Results and analysis of thermograms

The investigations were carried out for different excitation levels. An example diagram for the temperature variation in the knitting zone of the K2 knitting machine (at n=318 courses/min and l=5.5 mm) is presented in Figure 7.

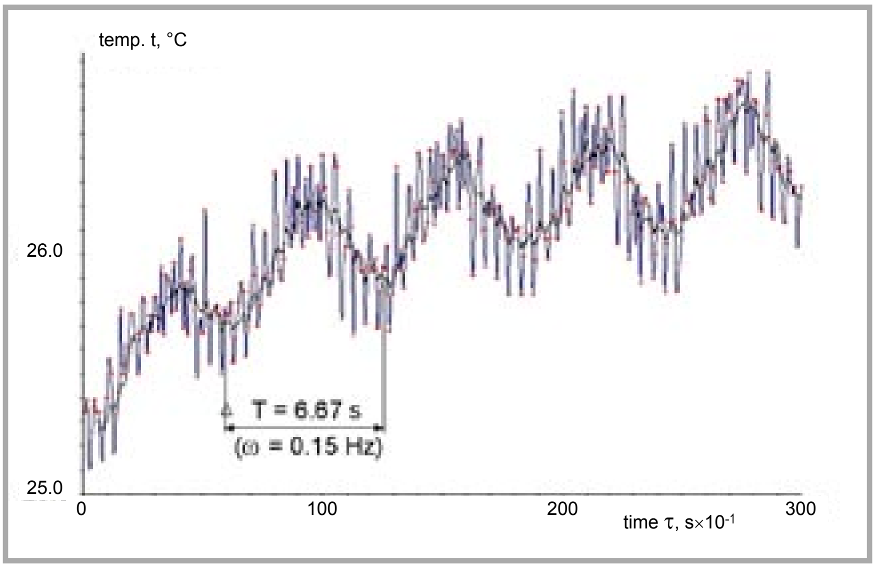


*Figure 4. Temperature oscillation in the region analysed - the knitting zone of the warp knitting machine.*

A periodical variation of temperature with a periodicity of 1.51 s could be noted, which was synchronous with the excitation. The difference between periods due to the measuring error is below 0.1 s (Figures 5, 6, and 7).

As examples, some thermograms are presented in Figure 8. Below each image, the mean temperature in the area of interest is indicated.

The analysis we carried out enabled us to state that on the basis of the thermograms, it is impossible to measure the force quantitatively. However, this can be done by using the contact method based on tensometric transducers. Thermograms can only be used to evaluate the frequency of temperature and force variation. For a more precise mathematical analysis a special program, ORIGIN 6.0, was applied in the next step of our investigation, in order to analyse the frequency at which the measured parameters change periodically. In this analysis, we determined the force amplitude ΔP and the frequency of the spectral components.

The frequency changes proceeding in the knitting process were marked on the frequency characteristic graph. Thus, in Figure 9a, $\omega_i$=0.712 Hz determines the frequency changes of forces in threads at the repeat of weave under a knitting velocity of n=342 courses/min, whereas in Figure 9b, $\omega_i$=0.625 Hz determines the frequency changes of temperature in the knitting zone under a velocity of n=313 courses/min. These frequencies

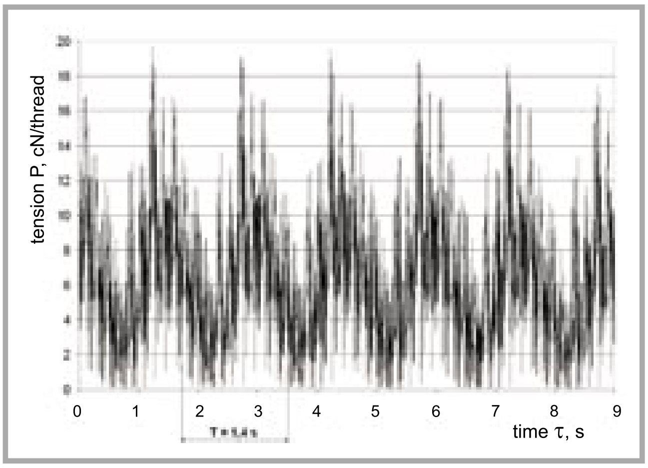


*Figure 5. Tensions in warp threads, guide bar for n=342 courses/ min, l=5.5 mm.*

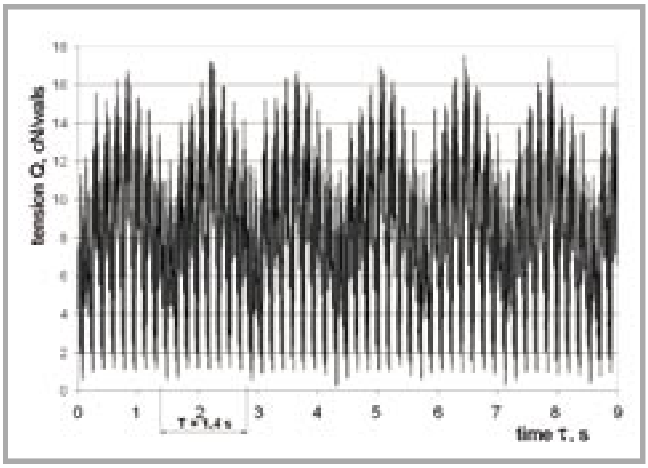


*Figure 6. Tensions in knitted fabric for n=342 courses/min, l=5.5 mm.*

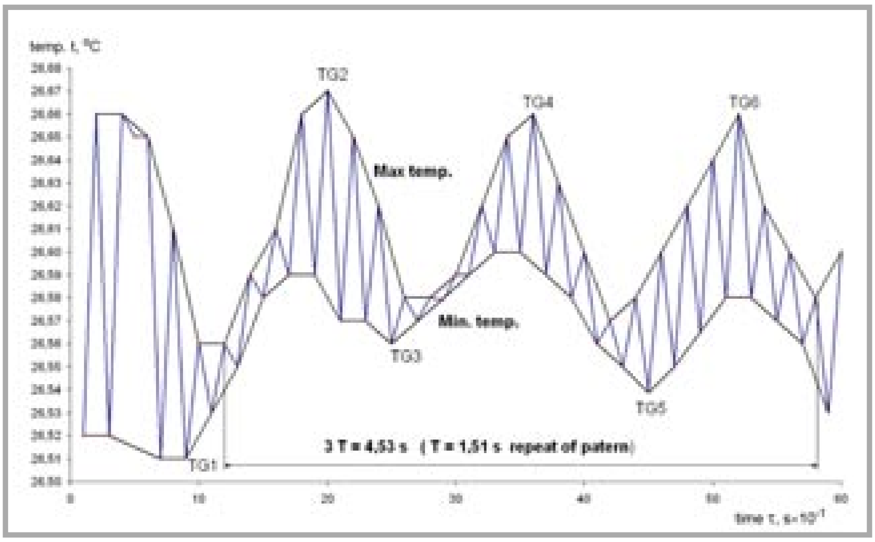


*Figure 7. Temperature in the knitting zone at n=318 courses/min, l=5.5 mm.*

unequivocally determine the period of the repeat of weave creation in the knitted fabric. Some frequency differences arise from changes in the knitting velocity between the particular measurements. Firstly the temperature measurements were carried out (10 minutes after the machine's start), and then (after half an hour, when the machine was 'heated up', and the velocity had increased to 342 courses/min) measurements of thread tensions were made with strain gauges. The corresponding thread tensions and temperatures of the knitting zone were measured for eight variants, which differed in knitting velocity, the average length of knitted-in threads and the guide bar's order. In the case of two variants, it was impossible to determine cyclic tem-

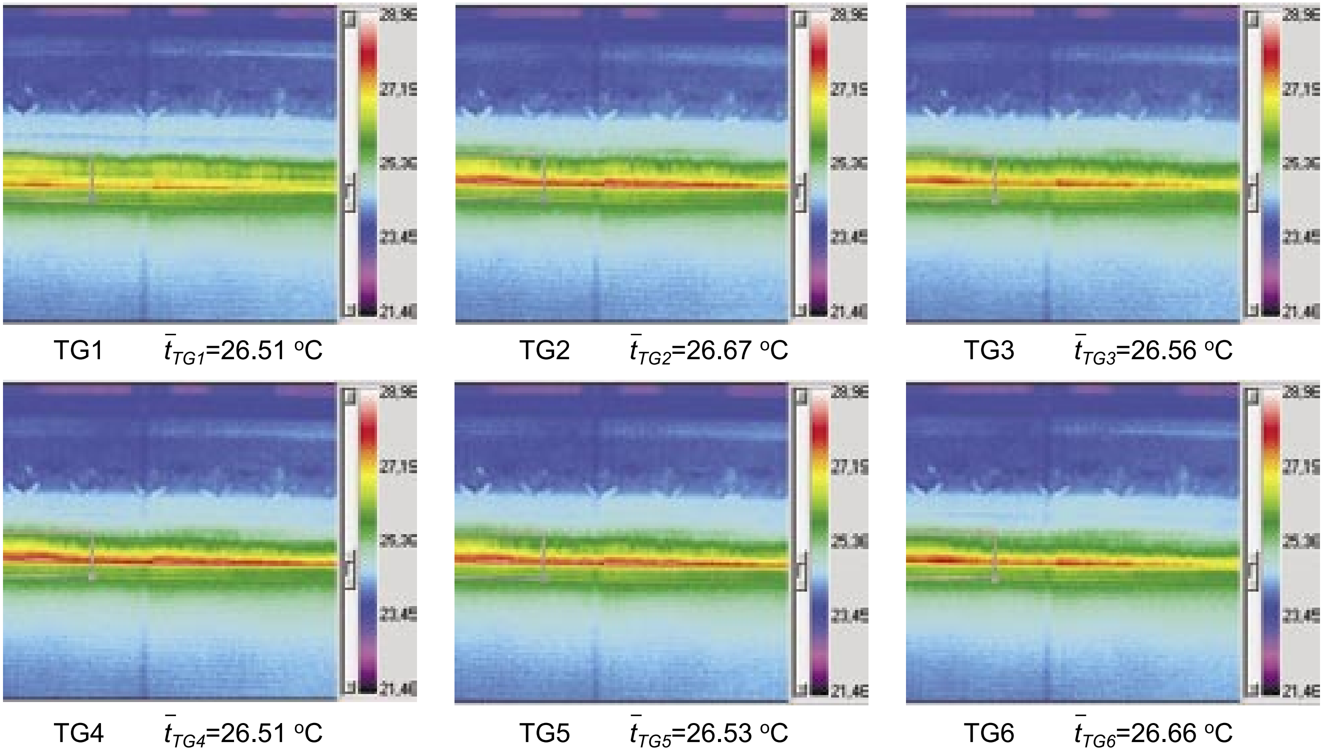


***Figure 8.** Selected thermograms of the knitting zone for variant K2-318 max, l=5.5 mm. **Remark:** This Figure is presented in colour in the internet - edition of the journal (www.fibtex.lodz.pl).*

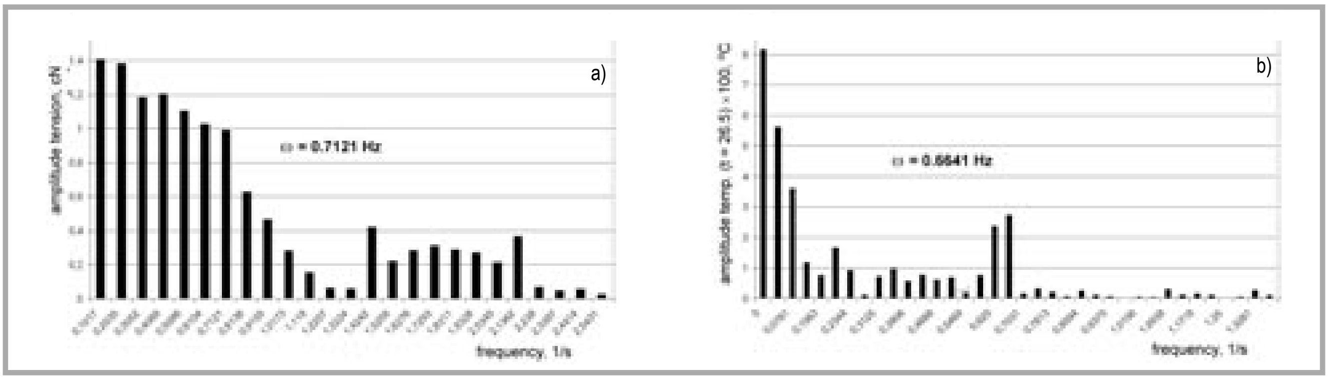


***Figure 9.** Frequency spectrum for: a - tension in threads; b - temperature.*

perature changes. In the remaining six variants in the FFT-frequency analysis of temperature changes, records of all temperature values as a function of time, as well as selected extreme values (minimum and maximum), were taken into consideration. The analysis carried out demonstrates that there is a compatibility of force vibration frequency in threads measured by the tensometric method with oscillatory temperature changes of the knitting zone, measured with the use of a thermovision camera. In this phase of the present research, it has been impossible to find univocal quantitative correlation between the values of thread forces and the temperature changes of the knitting zone.

## Summary


- When analysing the parameters of threads fed during production of wale anisostructural knitted fabrics of medium and large weave repeat widths, the method of measuring thread tensions with use of strain gauges is useless and practically impossible to apply, because of the need to use a large number of sensors, as well as sensors of considerable sizes, in relation to the small distances between warp threads, several times smaller than the sensor's dimensions. This makes it impossible to place them in the warp thread feeding zone. In the context of these statements, it seemed right to search for a method which would simultaneously enable tension measurements in group of several or several tens of threads. On the basis of experience acquired concerning the use of the thermovisual technique in the knitting process analysis, the following research aim was accepted: 'Identification of warp thread tensions on warp-knitting machines based on thermograms of selected, determined zones during knitted fabric creation.'
- Preliminary research carried out with the use of a warp-knitting machine with E 28 needling number, and a knitting velocity of n=600 courses/min, have shown that significant temperature changes appear in the region of the knitting zone. Records of temperature changes in the knitting zone have an identical frequency of pulsation to the oscillatory input function of warp threads' tensions, which equal 0.15 Hz. The remaining thermal regions of the knitting-in and the knitted fabric take-up zone did not react to changes in the thread tensions.
- As a result of the main research stage carried out with use of the warp-knitting machine with the E 20 needling number, and at two kinds of knitting velocity (n=340 courses/min and 420 courses/min), a compatibility of the force frequency changes in threads with the temperature changes in the knitting zone could be stated for six of the eight variants planned. The periodic characteristics of thread forces and temperature changes are different, which is caused by the dissimilarity of the methods used, based on measuring different physical values, as well as different time intervals of the measurements carried out (for thread tensions $\Delta\tau$=0.0006 s, and for temperature $\Delta\tau$=0.1 s).


## Conclusions

At the present stage of research, there is a lack of unequivocal correlation between the instantaneous force values in threads measured by the tensometric method and the temperature values measured with the use of a thermovision camera. That is why the thermovisual method cannot be used for the quantitative identification of thread forces. However, it may serve as a method for estimating thread tension changes (e.g. upward or downward trends), which may practically lead to a determination of extreme tension levels. The thermovisual method, together with the FFT harmonic components analysis of vibration, can be used to determine the frequency changes of the tension in threads.

### References


1. *Mikołajczyk Z., Model of Spatial Structure of Anisotropic Warp Knitted Fabrics, Fibres & Textiles in Eastern Europe, Vol. 9. No 2 (33), 2001, pp. 23-27.*
2. *Mikołajczyk Z., Thermovision - Verfahren im Einsatz bei der Fehleranalyse - Teil 1. Maschen - Industrie No. 2, 1999, pp. 12-17; Thermovision - Verfahren im Einsatz bei der Fehleranalyse - Teil 2. Maschen - Industrie No. 3, 1999, pp. 20-22.*
3. *Mikołajczyk Z., Michalak M., Więcek B., Analyse von Zugbeanspruchungen an textilen Materialien mit der Thermovisionmethode, Melliand. No. 11/12, 199, pp. 960-963.*



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