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Analysis of Values of Punching Forces in the Process of Web Needling in Dynamic Conditions

Abstract

In this article, a method for testing the technological needling resistance of a textile web in dependence on the type of elementary fibres and the needling frequency is presented. A testing and measuring stand used in this investigation is described. Exemplary measurement results of the needling forces' values are shown in the form of curves in dependence of time.

Key words: *needling, needling machine, fibres, technological needling resistance, dynamic process, dynamic measurements.*

Introduction

The results of measurements of the punching forces' values in quasi-static conditions, i.e. at very low velocities of the needle penetrating the web as underlay, does not give a full representation of the phenomena which occurs in real manufacturing conditions. However, preliminary conclusions considered with the test stand, raw material, work performed by the needles etc. can be drawn, as was shown in [1].

The elementary fibres lying generally in the web plane are pulled in the direction perpendicular to the web surface under the action of the punching needle's indentations. This reorientation of fibre directions runs in a slightly different way depending on the needling conditions.

Scientific investigations into the branch of needling technology and needling machines have mostly been carried out by research and development centres related to companies which manufacture needling machines. The competition between manufacturers means that up-to-date research results have not yet been published. The papers [2-5] are connected with technological aspects of needling. The work described in [4] also includes measurement results of values of the punching force, but these are related only to small needling frequencies up to 350 cycles/min.

The course of inertia forces of the plate and of needling forces was separated in a difference amplifier from the total signal, as presented in [6]. An example of an oscilloscope record of the course of forces in dependence of time is presented in Figure 1. Such a system can be used for small needling frequencies up to about 300 cycles/min.

Testing and Measuring Stand

The stand described in detail in [7] and presented in Figure 2 is equipped with a frame (2) on which an electrical motor (1) with regulated revolutions is mounted. The motor drives a crank connecting rod with slider (3) through a belt-transmission (8). The slider to which is assembled a bar (5) with punching needles is guided in a cylinder (4); 19 needles are fixed in the bar (5). The web to be needled is guided between two perforated plates, the upper (9) and the bottom plate (10). The bottom perforated plate (10) is fixed to the rail (11) mounted on piezo-electric force gauges (6) which rested on a bracket. A schema of the measuring system is presented in Figure 3.

The piezo-electric force gauges are connected to a multi-channel data acquisition station by means of amplifiers, and then to a PC with software including specialised programmes. The measuring system is a 'PULSE' standard set produced by Bruel & Kjaer, and designed to measure and analyse vibration, force, noise etc. It is equipped with a system for accurate measurement and recording of the r.p.m. number of a crank connecting rod, which means that it allows us to measure the needling frequencies.

The bottom perforated plate (10) together with the rail (11) which rests on the piezo-electric gauges No. 551459 and No. 1948756 together constitute an integrated part of the force transducer.

The free frequency of the basic vibrations of the force transducer is 1.3 kHz, whereas the second frequency is about 3.9 kHz. It is thus evident that the signals from the transducer of up to 130 Hz will be transmitted without any distortions.

The parameters of the crank connecting rod with slider which was used in the research stand are the same as those for an industrial experimental model, with crank length r=0.03, and connecting rod length l=0.27. Thus, the distribution of the needle's velocity over the time of inserting into the web is identical as regards manufacturing needling conditions. A view of the testing and measuring stand is shown in Figure 4.

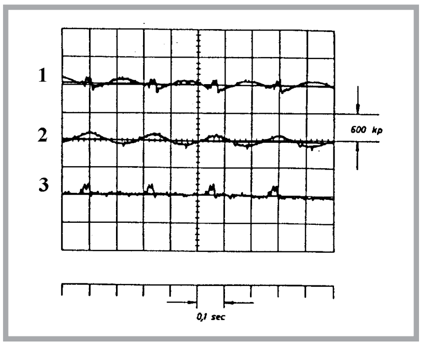

Figure 1. *Example of an oscilloscope record of the forces' course in dependence of time according to [6], where: 1 - total course of inertia and punching forces, 2 - mass forces, 3 - punching forces.*

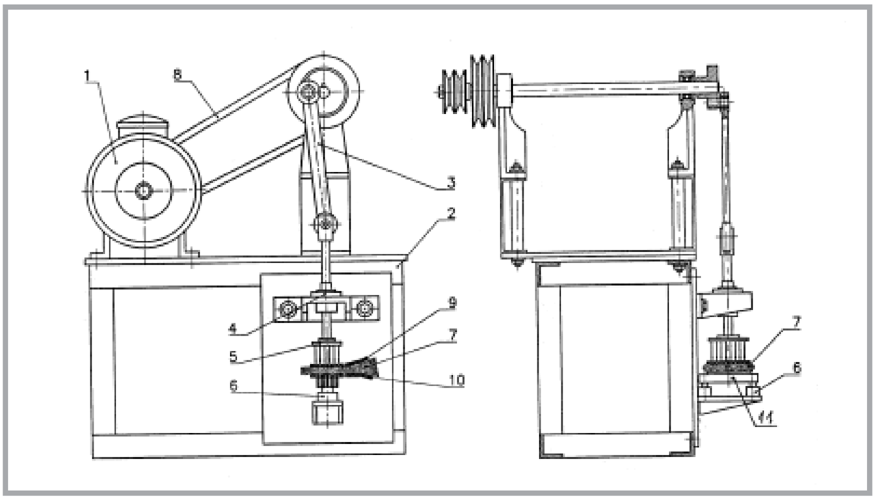

Figure 2. Testing and measuring stand for measurement of punching resistance; 1 - motor, 2 - frame, 3 - crank connecting rod with slider, 4 - guiding cylinder, 5 - bar with punching needles, 6 - piezo-electric force measurement gauge, 7 - needled web, 8 - belt transmission, 9 - upper perforated plate, 10 - bottom perforated plate., 11 - rail.

Measurement Results

The tests in dynamic conditions were carried out for viscose fibres (Argona), polyacrylonitrile fibres (Anilana), polyolefine fibres (Polypropylene PP), phenol fibres (Kynol), and their blends. The plots of forces with time presented as examples in this article consider the total force when needling with the use of the rail with 19 needles fixed in it and numbered 15 x 18 x 36 3.5RB, which corresponds to the No. 77/8 needles in the 'Famid' catalogue. Such needles as those mentioned above are most frequently used in the domestic industry.

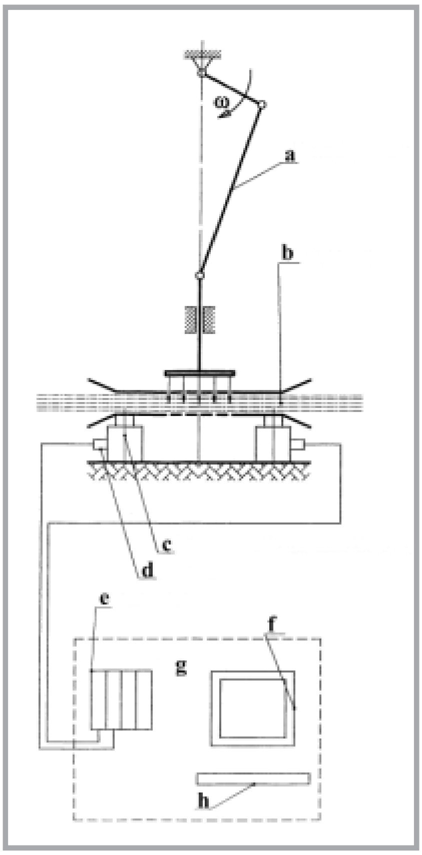

Figure 3. Schema of the measuring system; a - crank connecting rod with slider, b - nonwoven, c - piezo-electric transducers, d - amplifier, e - modulus of data acquisition No. 2816, f - PC with Windows NT, g - PULSE analyser by Bruel & Kjaer, h - keyboard.

Figures 5, 6, and 7 include time plots of punching a web of aerial mass m_a=480 g/m^2 manufactured from the elementary fibres 3.3 dtex/87 elana, elana HS, and 6.7 dtex/90 mm PP fibres of fibre contents in the web corresponding to 50%, 20%, and 30%. The needling frequency, i.e. the number of strokes of the needling bar per minute or r.p.m. of the main shaft of the crank connecting rod, is given in min^{-1}.

Analysis and Discussion of Measurement Results

Only the fresh web was needled over all tests using the research stand. The configuration of needles fixed in the needling assembly served non-repetition of the needling points. The take-up velocity of the web was selected in such a way that the punching number would equal about 30 cm^{-2} every time. According to [2], an increase in punching number from 50 cm^{-2} up to 300 cm^{-2} results in a decrease in the web thickness on average of 15%. Thus, preserving an approximately constant number of needling punches per cm^2 at different needling frequencies serves to maintain constant damping properties of the needled web layer. This in turn secures constant conditions for transmitting the force pulses created by the web's resistance to the measuring system transducer.

The values of punching forces when needling with different frequencies were determined for selected webs prepared by the carding system. Every first measurement for the selected web given was performed at a very small needling frequency which could be related to the quasi-static needling. The statement that forces transmitted through needles do not increase with the increase in needling frequency is very important for designer and operational staff, including textile technologists. Our tests performed with needling at different frequencies could demonstrate that the needling forces indeed do not increase with needling frequency.

Figures 5, 6, and 7 show the time plots for punching a web of aerial mass m_a=480 g/m^2. As can be seen, the punching forces

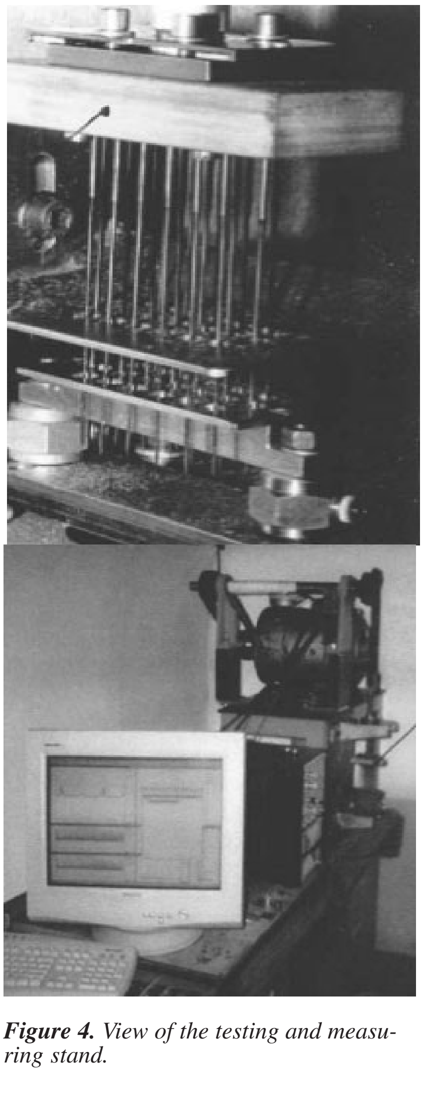

Figure 4. View of the testing and measuring stand.

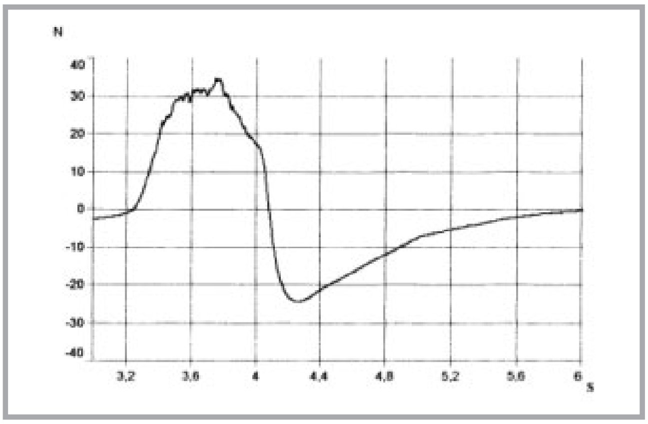

Figure 5. *Time plot of needling force, quasi-static needling, total forces, web of aerial mass m_a=480 g/m^2; 3.3 dtex/87 mm elana, elana HS, and 6.7dtex/90 mm fibres; contents 50%, 20%, and 30%.*

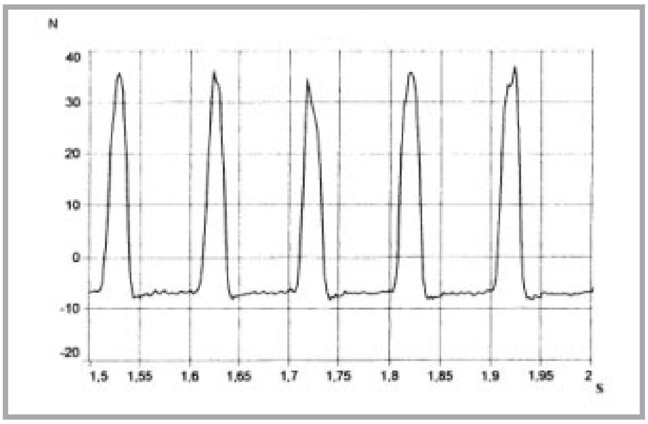

Figure 6. *Time plot of needling force at needling frequency n=604.72 min^{-1}.*

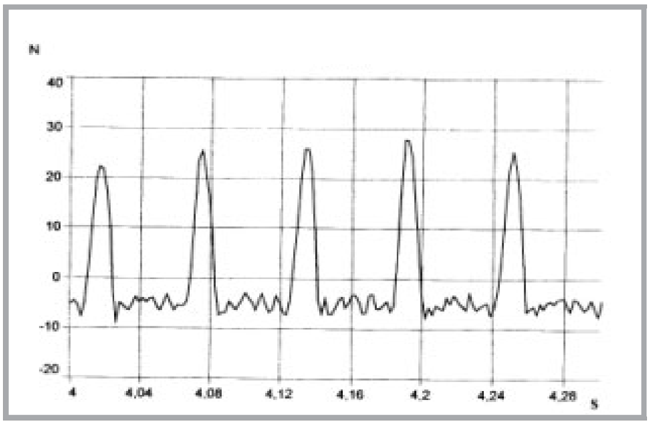

Figure 7. *Time plot of needling force at needling frequency n=1024.00 min^{-1}.*

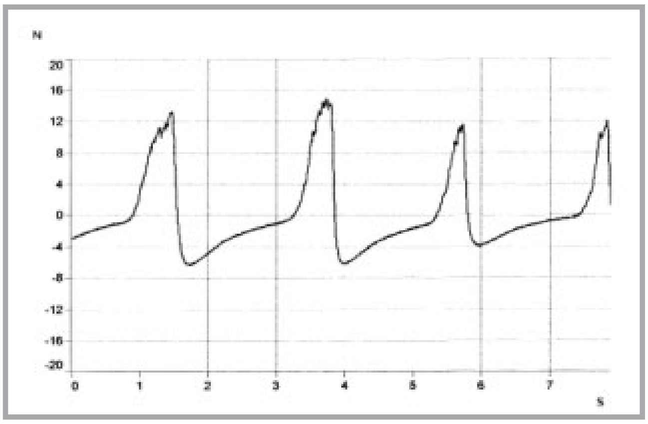

Figure 8. *Time plot of needling force, quasi-static needling; two-layer polypropylene web: m_a=230 g/m^2, 6.6 dtex/60mm fibres, and m_a=225 g/m^2, 3.3 dtex/40 mm fibre.*

in quasi-static conditions and at low needling frequencies have similar values, whereas those resistance values already beginning with a needling frequency of 17.06 Hz are evidently smaller.

By an analysis of the example plots presented in Figures 8, 9, and 10, a similar conclusion can be drawn that the technological resistance forces decrease with the increase in needling frequency.

Web temperature measurements at the output of the needling zone were performed with the aim of clearing the phenomenon of punching resistance decrease with an increase in needling frequency. A measuring system with a Fe-Konst thermocouple as temperature gauge was applied. The gauge wire diameters were equal to 0.2 mm, and a system of reference temperature compensation together with an amplifier was used. A digital voltmeter served as a measuring instrument. All these arrangements served as indication accuracy of 0.1°C. However, as temperature measurements of such structures as textile webs are very difficult, it was agreed that additional temperature measurements with the use of a thermovision camera should be carried out to obtain standard temperature distributions. These measurements were performed with the use of the AGEMA 489 thermovision system.

14 gauge needles from the Grossbecker company with indentations of the projection height = zero (soft) were used for needling with the aim of measuring temperature. The needling depth was 8 mm. The temperature of the web surface taken from the thermovision thermogram was about 23.5°C. It can thus be assumed that in the needling zone the temperature is evidently higher. At the same time, the measurements performed with the use of the thermocouple measuring system yielded a temperature of 23.6°C, which allows us to draw the conclusion that both measurements are credible. Measurements carried out by both methods and repeated several times yielded identical results. Thus, a conclusion can be drawn that the web temperature depends on the needling frequency, the aerial mass, the raw material structure of the web, and the type of elementary fibres.

A series of temperature measurements of the web at the exit of the needling zone was carried out. The measurements were carried out at the 'Filtex' company. As examples of the measurements performed, the following can be cited:

- web formed from PP/60 mm fibres of aerial mass m_a=300 g/m^2 needled at a frequency of 15 Hz; surface temperature: 38.3°C; and
- web formed from PP/60 mm and 3.3 dtex/87 mm Elana fibre of aerial mass m_a=400 g/m^2 with different content needled at a frequency of 15 Hz; surface temperature: 43.1°C.

The temperature of the punching needles is essentially higher than the web temperature. The measurement of the needle temperature was not included in the au-

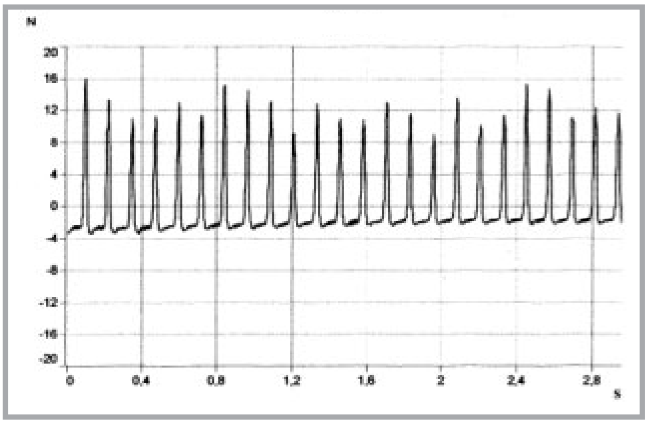

***Figure 9.** Time plot of needling force at needling frequency n=500 min^{-1}.*

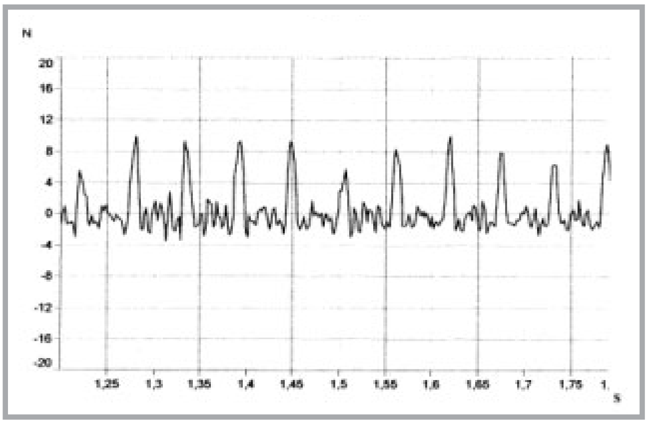

***Figure 10.** Time plot of needling force at needling frequency n=1100 min^{-1}.*

thor's research programme. But it is known from works published [6, 8, and 9] that the temperature of a punching needle achieves values of up to 100°C depending on the kind of web, type of needle, and needling frequency. With the aim of stressing the influence of temperature on the values of needling forces, the mechanism of pulling the fibres through the web in the direction perpendicular to the web surface should be discussed. The elementary fibres in the web lie in planes approximately parallel to the web surface. The fibres in the upper layers are loosely arranged during the initial needling phase, and

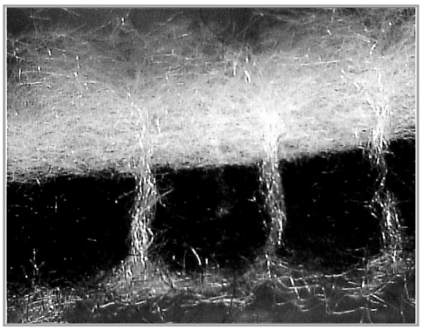

***Figure 11.** Cross-section of two-layer nonwoven needled at a frequency of n=4981 min^{-1}.*

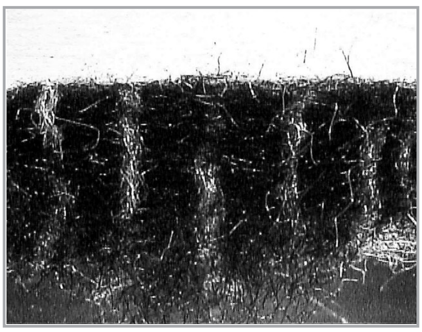

***Figure 12.** Cross-section of two-layer nonwoven needled at a frequency of n=10,801 min^{-1}.*

the needle's hooks (indentations) principally pluck these fibres out. The loops of fibres taken by the particular hook have their ends in the horizontal plane, and in this way a connection between horizontal and vertical structure is maintained. The fibres held directly by the needles' hooks pull other fibres from the vertical planes and generate a chain reaction as a result of the action of friction forces and adhesion. These actions caused the fibres to be continually displaced from horizontal to vertical planes, and at the same time some of the fibres are placed in both planes. The majority of the fibres pulled through have their origin in the upper layers, because the bottom layers are pressed as the needles immersed in the web, and higher resistance exists when these fibres are pulled out. Apart from this, the majority of needle hooks are filled with fibre loops from the upper layers.

As was demonstrated, the web temperature in dependence on the type of elementary fibres, aerial mass, and needling frequency can reach up to several tens of degrees Centigrade. The temperature of needles is a little higher. As fibre loops pulled by the needle hooks fit close to the needle along the whole way of immersing the needle into the web and on the return path, these fibres can reach a temperature similar to the needle temperature. As is already known, e.g. from [10], the melting temperature of the fibres used ranges from about 150°C for polypropylene fibres to up to 220-250°C for the other fibres used in this investigation. This means that an essential drop of the elasticity of these fibres which are pulled by the needles and of fibres surrounding the needle hooks occurs as a result of temperature increase. The lateral pressures of these fibres are lower, as are the friction and adhesion forces at the same time. This is the reason for the significant decrease in the values of punching forces.

Another cause of the drop in punching force values is the increase of fibre inertia forces, and as a result of this, the fibre's cutting and breaking. These phenomena occur mainly in polypropylene which constitute a significant content in the majority of the nonwovens tested, which means that the elasticity change of this component has significant influence on the decrease in the values of punching forces. It can also be assumed that a small decrease in the friction coefficient takes place.

A part of the needle's blade is surrounded by fibres taken by its hooks, but a part of the needle exists (up to the first hook) which fits directly with the needled web. However, the friction forces depend not only on the friction coefficient, but also on the lateral pressure on the needle. Considering the web structure, the friction forces which are the basic cause of temperature increase are small. The basic punching (needling) resistance is generated by pulling and drawing of fibres, as well as by their cutting and breaking.

Figures 11 and 12 present the cross-section of a two-layer nonwoven which was formed from a polyester web. The upper, white layer of aerial mass m_a=230 g/m^2 consists of 6.6 dtex/60 mm fibres, whereas the bottom, black layer of aerial mass m_a=225 g/m^2 consists of 3.3 dtex/40 mm fibres. The time plots of punching forces are shown in Figures 9 and 10 correspondingly at needling frequencies of n=4981 min^{-1} and n=10801 min^{-1}.

As can be seen from the photos presented in Figures 9 and 10, more fibres have changed their orientation and lie more regularly at the lower needling frequency. At the higher frequency, a smaller amount of fibres from the upper layer are pre-oriented, which can be the result of fibre breakage or fibre sliding from the hooks. The irregular shape of the pre-oriented fibre bundle indicates damage to the pulled fibres.

Conclusions

The results of the investigations carried out allow us to formulate the following conclusions:

- The values of forces for punching needled webs at high frequencies (higher than 15 Hz) are lower than the forces' values which occur by quasi-static needling.
- The decrease in punching resistance is the effect of:
  * cutting and breaking of elementary fibres by the punching needles' hooks,
  * temperature increase of the elementary fibres which results in their drop of elasticity, and which in turn facilitates their pulling through the web and causes a decrease in the lateral pressure of the fibres on the needles with fibres jammed on the needles' hooks,
  * decrease in the friction resistance as result of an easier strengthening of the crimped fibres.

References

1. Cisło R., Kapusta H., 'Analysis of Forces Transmitted by Needles in the Process of Web Needling in Quasi-Static Conditions', Fibres & Textiles in Eastern Europe, vol. 10, No.1 (36), 2002, p. 76-80.
2. Gądor W., Heinze K., 'Dependencies of some properties of needled nonwovens on selected manufacturing parameters' (in Polish), Przegląd Włókienniczy, 1989, p. 458-460.
3. Lünenschloss J., Janitza I., 'Die Untersuchung des Vernadelungsvorganges bei der Nadelfilzherstellung und die Eigenschaften der Nadelfilze', Textilpraxis, July, August 1972, p. 407-409, 471-473.
4. Lünenschloss J., Janitza I., 'Der Einfluss verschiedener Nadelformen auf die Grösse der Nadeleinstichkräfte und die Eigenschaften der Nadelfilze', Melliand Textilberichte 4/1972, p. 395-400.
5. Szałkowski Z., Nowak R., Dawid D., 'The value of the punching force in the process of web needling as a criterion of punching needle selection' (in Polish), Zeszyty Naukowe PŁ - Włókiennictwo (Scientific Bulletin of the Technical University of Łódź - Textile Science), 38, 1979.
6. Lünenschloss J., 'Die mechanische Verfestigung von Vliessen aus Chemiefasern durch Vernadeln, einige neuere Erkentnisse', Melliand Textilberichte, 11/1973, p. 1163-1171.
7. Kapusta H., 'Measurements of the punching forces at needling in dynamic conditions' (in Polish), Proceedings of the 4th Scientific Conference of the Faculty of Textile Engineering and Marketing, Technical University of Łódź, 2001.
8. Szałkowski Z., collective work, ed. WNT, Warsaw, 1971.
9. Jędrzejewski W., Karolak J., Mrożewska H., 'Machines and equipment for manufacturing nonwovens', ed. WNT, Warsaw, 1978.
10. Włodarski G., 'Włókna Chemiczne. Poradnik inżyniera i technika' (in Polish - 'Chemical fibres. Hand book for engineers and technicians'), ed. WNT, Warsaw, 1977.

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The Rights and Duties of the Engineer in an Integrated Europe Considering the Available Knowledge about the European Union

In March 2003 a council of the Chief Technical Organisation of Poland' - the Federation of Polish technical branch organisations (NOT - Naczelna Organizacja Techniczna) accepted a project which aim is to acquaint Poland's technical communities with knowledge about the rights and duties of engineers in the European Union, especially with regard to the problems concerning the recognition of engineering diplomas and engineer's rights to practise their learned profession.

This project is directed to Polish engineers and students. Realisation of two main tasks is provided within the framework of this project.

An All-Polish Conference 'The Rights and Duties of the Engineer in an Integrated Europe' which will be organised by NOT will be the first task. The organiser predicts that the representatives of Polish engineering communities and students of Technical Universities will take part in the conference. Their expectations and possible doubts will be the subject of discussion. Outstanding, competent representatives of the Government, the Technical Universities, and the Scientific-Technical Associations will present plenary lectures. The representatives of the Ministry of National Education and Sport, the Ministry of Economy, Labour and Social Policy, and the government's Office for European Integration have been invited to take part in the Conference. Efforts have been made to ensure that the Conference will be organised under the honourable patronage the Polish Prime Minister Mr Leszek Miller.

The dissemination and promotion of the Conference's results and achievements will include not only the distribution of the conference proceedings but also special publications of the statements, theses and conclusions formulated during the Conference. This will be printed in journals edited by SIGMA NOT, in informational bulletins of the universities and included in the Internet web pages of the NOT Federation.

A cycle of courses based on conference materials and discussion conclusions, which will be organised for technical communities, is provided as the second task of the project under consideration. The courses will be organised in co-operation with the Technical Universities and Scientific-Technical Associations which are active in the Łódź region About thirty courses will be organised in the period from April to June 2003 according to the preliminary project planes. The conference materials will be distributed free of charge to Technical Universities (the main centres where future engineers are taught), to Provincial Councils of the Scientific-Technical Associations of the NOT Federation, and to the Boards of Scientific-Technical Associations in which engineers are organised.

The Conference as proposed would allow discussion of the problems which pervade the technical communities, whereas the cycle of courses will ensure that the problems discussed will reach a broad circle of those interested in the future conditions of the practice of engineer's profession.