DEVELOPMENT OF THE MEASURING SYSTEM FOR ANALYSING THE THERMAL PROPERTIES OF CLOTHING

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Abstract: The measuring system for assessing static and dynamic thermal properties of textile composites and clothing is described in this paper. The measuring system consists of a guarded hot plate for measuring thermal insulation values of textile composites, and segmented metal mould, so called thermal manikin, anatomically designed to simulate human body for the determination of static and dynamic measurements in accordance with human walking simulation. Both measuring systems are located simultaneously in the joint climate-controlled chamber. The associated measuring software, whose development and general features are described in this paper, enables related measuring system control, measuring process and acquiring normative measuring specifications.

Key words: thermal manikin, guarded hot plate, measuring and control software, thermal properties, clothing, material composites

1. Introduction

While shopping clothing, whose primary objective is protection against cold stress (garments such as coats, wind jackets, cloaks, pullovers and other similar types of protective clothing against cold), there is still lack of exact assessment ability of clothing ensemble with regard to accurately defined degree of thermal protection. The only thing for the customer to do is to buy according his ability to estimate garments upon the visual impression and experience assessment of garment construction, fabric thickness and material structure composition, without even knowing their actual thermal protective characteristics. Similarly, in the process of designing new garments it is impossible to accomplish an exact clothing technical design without the basic knowledge on thermal parameters of built-in textile composites (one or more layers of composed and/or built-in different textile and/or other materials) and efficacy of composite mounting, material selection, thickness, bonding properties, density, finishing and other properties of proposed materials, as well as the efficacy of general clothing construction and garment cut on the final thermal properties of a newly designed and produced garment [1].

2. Measuring system for analysing the thermal properties of material composites and clothing

The measurement of thermal insulation properties of textile composites and clothing is a demanding test method depending on the measuring technique and equipment used to conduct those measurements. Patent protection was registered and acquired for engineered and installed measuring system for static and dynamic estimation of thermal properties of textile composites and clothing ensembles at the Laboratory for Process Parameters of the Department of Clothing Technology at the University of Zagreb, Faculty of Textile Technology, as shown in Figure 1. The measuring system for assessing static and dynamic thermal properties of textile composites and clothing combines: measuring system for assessment of the thermal properties of material composites, measuring system for assessing the static and dynamic thermal properties of clothing, joint climate-controlled chamber and associated software solutions. The measuring system has a developed software that enables the process of measuring and calculating the thermal properties of composites and/or clothing to be repeated several times at defined intervals after which the measuring system automatically stops running, carries out the required statistical analysis, presents the results and prints out a protocol and the determined results of thermal properties by the computer printer.

The guarded hot plate consists of the measuring system and the temperature regulation system for the measuring area of the measuring device which is based on the electronic power regulation called PMW technique (Pulse-width modulation). The measuring unit is a rectangular 10 mm thick aluminium plate, which is connected to the metal block containing electrical heating elements. The measuring area (0.4×0.6 m) is surrounded with the protective isolation thermal guard, whose aim is to prevent
lateral heat leakages from the sides of the measuring unit and fabric edges. The heating elements of the measuring device placed below the measuring area conduct heat to the measuring area and simultaneously prevent heat leakages from the bottom of the measuring unit. This device construction only conducts heat upwards along the direction of the test specimen thickness [2]. Using the guarded hot plate is a standard measuring technique for measuring thermal properties of material composites, as well as for measuring the impact of different combinations of high tech materials for clothing ensembles, the impact of material layers and also the impact of conventional and intelligent thermal insulation spacers on thermal clothing properties in the process of technical garment design itself to produce desirable thermal properties. The specimen to be tested in a size of 0.4×0.6 m is placed on an electrically heated rectangular plate with constant temperature which corresponds to the skin temperature of the human body (i.e. 34°C). It should be noted that this measuring device is designed so that temperature values could be set on any given value supported by the heating elements [2].

A segmented metal mould, anatomically constructed to simulate human body, so called thermal manikin consists of 24 human body segments with installed electrical heaters, temperature sensors, 14 microcontroller interfaces and pneumatic system for arms and legs movements, Figure 2. Determining the thermal properties of clothing in dynamic conditions is performed in a way that the mentioned casting starts with the garment put on and simulates the walk of the garment wearer whereby both arms and legs move in counter-phase. The limbs are moved using a pneumatic-bar linkage system built in the body of the casting. Limb movement speed can be varied over a wide range and accurately adjusted by the air damper so that a motion speed of 45 ± 2 double steps / min and 45 ± 2 double arm movements / min for walking, which corresponds to ISO 1583. The method of control, regulation, measurement and calculation of thermal systems on the garment was introduced using a segmented metal casting shaped to the human body with the possibility of activation and deactivation of all segments (entire casting) or any segment group of the casting and the possibility of introducing and setting measurement parameters in accordance with the standards for experimental research. The measuring system is designed in such a way that thermal properties are measured simultaneously at the moment when thermal comfort occurs by using the sensory system and known data and with the help of a specially constructed internal microcomputer interface for each measuring panel. The usage of a large number of conventional electrical power measuring devices is avoided with this kind of solution. Also, the estimation of dynamic thermal properties is enabled by means of a pneumatic system built inside the segmented metal mould shaped like a human body. This actuating system allows avoiding the heavy-handed external actuating mechanisms and their negative effect on measuring accuracy [3]. The measurements of values of thermal insulation properties of material composites and clothing are performed, unlike all the other systems, in the same environmental conditions and inside the same unique environment, according to the International standard ISO 15831:2004 [4]. The total heating power supplied to the measuring system is measured within ±1 % of the total range. When studying the results acquired by measurements of thermal resistance by means of the measuring equipment described in this paper, there is a noticeable dependence of results upon the working conditions of the measuring equipment and well established reproducibility.

The measuring system consists of several different software packages:
• Software for thermal manikin control, anatomically constructed to simulate human body (there is a possibility to choose segments and to define temperature values for individual manikin segments), Figure 3;
• Software for measuring clothing thermal properties by means of the thermal manikin with the results given in [m$^2$K/W] and in [Clo], Figure 3;
• Software for controlling the climate-controlled chamber (control of environmental temperature and air speed including relative humidity control of ambient air) shown in Figure 5 and
• Software for controlling and measuring the thermal properties of material composites by means of the guarded hot plate with the results given in [m$^2$K/W] and in [Clo], Figure 6.

The display of the computer monitor for controlling the thermal manikin is shown in Figure 3. It has several functional units. It was designed in such a way that all communicational parameters to connect the thermal manikin and PC are displayed in the left part of the display. In the centre of the display the thermal manikin segments are marked and shown. For each segment the set temperature value is presented. If the current temperature value occurs in the range $\pm 0.2\,^{\circ}C$, then the green light will be on, but if the temperature value exceeds this range, the red light will switch on. A special button to turn on/off each segment is also built in. The right part of the display presents the active measuring field in which all of the measuring parameters are shown such as mean temperature and heating supply for all active segments. In the lower part of the display all diagrams of mean values are drawn.

The display of the computer monitor for measuring of thermal manikin, Figure 4, has two functional units. In left side of the display the thermal manikin segments are marked and shown. For each segment the surface area is displayed, and also the current heating power supplied to each of the segments so that temperature value could be set, current temperature value and thermal resistance are presented for each segment. The right side of the display shown on the computer monitor presents the active measuring field in which all of the measuring parameters are shown, such as mean temperature, heating power supplied to each of the segments and all diagrams of mean temperature values, mean heating power values supplied and mean values of thermal resistance are shown. In the lower part of the screen all diagrams of mean values are rendered in the way that mean value of temperature and heating power is measured after every 5 seconds for all active (heated) segments, and mean values are drawn for each minute of measuring. The testing procedure takes 20 minutes in which 240 mean values are obtained. Beneath the diagrams all recorded data, mean temperature value of all segments, mean power supplied to segments and total thermal resistance are automatically entered. Also all of the important measuring information (measurement description) could be entered in the lower part of the display.

The display of the computer monitor for controlling the climate-controlled chamber shown in Figure 5 has three functional units. In the left side a temperature regulation for the chamber temperature is placed. The central part has the air speed regulation system and the third measuring segment monitors the air humidity inside the climate-controlled chamber.

The display of the computer monitor for controlling and measuring the guarded hot plate, Figure 6 has several functional units. In left side of the display, all communicational parameters for establishing a connection between the guarded hot plate and PC are displayed and also the heater control and the part for activating the set temperature. In the lower part of the screen, there is a calculator so that the resultant total thermal resistance of the measuring device can be calculated. The central part of the display shows the current values of measuring parameters. Beneath the analogue measuring indicators all diagrams of hot plate temperature and required power supply values are rendered (in
accordance with the measuring time span). The right side of the display shown on the computer monitor presents the active measuring field in which all of the measuring parameters are shown, such as mean hot plate temperature, heating power supplied to each part of the hot plate and thermal resistance calculated for each minute of measuring. All diagrams of mean temperature values, mean heating power values and mean values of thermal resistance are rendered.

**Figure 3.** The display of the computer monitor for controlling the thermal manikin

**Figure 4:** The display of the computer monitor for measuring the thermal manikin

Beneath the diagrams all recorded data set for a time period of 20 minutes, such as mean temperature value, mean power supplied to the hot plate and total thermal resistance are
automatically entered. Also all of the important measuring information (measurement description) could be entered in the lower part of the display.

Figure 5: The display of the computer monitor for controlling the climate chamber

Figure 6: The display of the computer monitor for controlling and measuring on the hot plate

When stable environmental conditions are reached (temperature, relative humidity and air speed) inside the climate-controlled chamber, the value of the apparatus constant of the guarded hot plate and/or thermal manikin $R_{ct0}$ should be determined, which is determined according to the equation (1). The composite specimen to be tested is placed on an measuring unit of electrically heated plate after resultant total thermal resistance of measuring device is determined and the heat flux through the test specimen is measured after new stable conditions have been reached. The assessment of thermal properties of clothing by means of the thermal manikin is conducted in such a way that the chosen garment or ensemble is placed around the body of the thermal manikin in the static or dynamic.
operational mode. The dynamic measurement is performed with the manikin simulating wearer’s walking, in the way that both thermal manikin legs and arms are phase-reversal moving, with a defined number of movements per minute and a defined stride length. The measurements could be made in static or dynamic environmental conditions which are simulated in the climate-controlled chamber. After thermal comfort has been established, which can be detected from the stabilisation of parameter values (shown numerically and in diagrams), measurements are performed and thermal resistance, $R_{ct}$ is calculated from equation (2).

$$R_{ct} = \frac{(T_a - T_s) \cdot A}{H_0}$$  \hspace{1cm} (1)

$$R_{ct} = \frac{(T_a - T_s) \cdot A - R_{ct0}}{H_0}$$  \hspace{1cm} (2)

Where: $R_{ct0}$ – resultant total thermal resistance of the measuring device including the thermal insulation of the boundary air layer [$m^2 \cdot K \cdot W^{-1}$]; $A$ – total body surface area of the manikin, [$m^2$]; $T_s$ – mean skin surface temperature of the manikin, [$^\circ C$]; $T_a$ – air temperature within the climate-controlled chamber, [$^\circ C$] and $H_0$ – total heating power supplied to the manikin, [W].

The created thermal manikin and the climate-controlled chamber allow determining thermal properties of the garment according to the so-called series and parallel model [4].

3. Conclusion

The measuring system for testing static and dynamic thermal properties of textile composites and clothing is used to measure values of thermal protection intensity of material composites, conventional, protective and intelligent clothing during the technical engineering process and construction of new garments with desirable thermal properties. This system could also be used to select the warmest clothing article among several of the similar kind. Hardware components of the described system and all described software packages were developed at the Faculty of Textile Technology of the University of Zagreb. The patent protection was acquired because this measuring solution has many original elements. The software packages are also unique and an original intellectual solution made by a group of authors, and they are designed in such a way that they provide measuring system control, monitoring and functional control, measuring activities and statistical analysis. The software concept was designed to meet all of the requirements of international standards, but it also enables parameter adjustments to various ranges of values. This kind of solution enables routine standardised measurements, as well as the possibility of scientific experimenting with the help of the measuring equipment described in this paper and associated software solutions.

4. Reference


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