DESIGNING OF CONDUCTIVE YARN KNITTED THERMAL COMFORTABLE SHIRT USING BATTERY OPERATED HEATING SYSTEM

İLETKEN LİF İLE ÖRÜLMÜŞ PORTATİF BATARYA İLE ÇALIŞABİLEN ISIL KONFORLU GİYSİ TASARIMI

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ABSTRACT

With electric conductive yarns, an electric resistor has been inserted into a shirt in order to heat the shirt. This might have possible use for medical applications or energy savings. The heating properties were investigated with infrared thermography and the possibilities for portable battery operation have been studied.

Key Words: Garment heating, Thermography, Thermal resistance, Battery operation.

ÖZET

Isıtma amaçlı olarak, bir gömleğin içerisine direnç meydana getirebilen iletken iplikler yerleştirilmiştir. Bu uygulamanın tıbbi veya enerji tasarrufu amacıyla kullanılabilmesi mümkündür. Isıtma özellikleri kızılötesi termografi ile incelenmiş olup sistemin portatif batarya ile çalışma olasılığı araştırılmıştır.

Anahtar Kelimeler: Isıtma sistemi, Termografi, Isıl direnç, Batarya çalışması.

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INTRODUCTION

In recent years a lot of research is going on in the field of electroconductive textile materials for a wide range of applications (1)(2). Several electric or electronic components have been made using textile materials: conductors and resistors (3)(4), capacitors and batteries (5)(6)(7)(8), transistors (9)(10) and antennas (11). Application fields for these textiles include automotive industry, biomedical materials, and flexible electronic substrates (12)(13)(14).

As an illustrative example, we mention sensors for heart beat rate measurements. These sensors require electrodes in direct contact with the human skin which can be made out of textile materials. For electrotherapeutic treatments one also needs electrodes firmly attached to the human skin. For all these kinds of applications electric conductors have to be inserted into the garments. Obviously, it will be an advantage if not only the electrodes but also other electronic components can be integrated in the garment.

The fabrication of electric conductive layers can be done using several technologies. First of all electric conductive yarns (made from stainless steel e.g.) can be used (15)(16). Other possibilities are coating (17)(18)(19) or screen printing conductive pastes on a fabric (20).

As fabrics are flexible, one has to pay attention to the mechanical and physical properties of the electric conductive materials integrated into textiles (21)(22). Mechanical aspects are important for textiles applied to the human skin in order to insure a tight contact. Especially for textiles, washability turns out to be a particular issue (23). Due to their flexibility and the texture of the textile fabrics, the measurement of the electric properties require special adapted techniques (24)(25)(26)(27).

In this paper a thermal application of conductive yarns is investigated (28)(29). Kayacan *et al*. predicts that conductive yarn integrated textiles will be utilized as heating garment effectively in the future (30). An electrically conductive yarn made from stainless steel fibres was sewn into a fabric. The stainless steel yarn was connected to an electric power supply and the resulting temperature rise of the fabric was measured with an infrared thermographic camera. The electrical resistance of the yarn was designed in such a way that it can be operated with a battery at a low voltage (typ. 10 volt) in order to get a wearable system. Normally a heating element is characterised by its thermal resistance, being the ratio of the temperature rise to the applied power. This value will be measured experimentally using a thermographic camera (31).

The efficacy of the activated heating effect of stainless steel yarn knitted fabric has been assessed by AGEMA 900 infrared thermographic camera. The camera was placed approximately 2 m away from the heated samples and the examinations were carried out at 20 ±2°C, RH 50 ±5%. The emissivity of white cotton fabric was adjusted at 0.55 (32).

A possible application of this research can be found in the medical field. A local heating of the human body can be help a patient for quicker recovery. The purpose of this research can also be related to energy saving. If a person is sitting in a room, the room is heated to the normal room temperature which is usually 20 °C. If the person is wearing a shirt with a heated element, it might be possible to keep the room temperature to a lower level say 17 °C. A lot of energy is then saved because it is more efficient to warm up a single person than an entire room, still keeping the thermal comfort at the same level.

Of course these applications can only be of any practical use if the system is fully portable. It means that the electrical power must be delivered by a battery which can be operational for several hours and which may not be too heavy.

2. THERMAL RESISTANCE OF A STAND ALONE SHIRT WITH HEATING ELEMENT

A shirt with a heating element has been designed. A possible way is to insert an electroconductive yarn into a textile as shown in Figure 1.

Electroconductive yarns can be made from stainless steel fibres or polymer yarns which have been coated with silver or copper. Conductive layers can also be screen printed on a textile fabric as mentioned in the previous section. The wearers' thermal comfort using this undershirt is optimised by heating the lumbar region. For the heating element, a silver based yarn was used with a total length of 1544.4 cm. Taking into account the yarn resistance per unit length being 0.057 Ω/cm we get a theoretical resistance of 88 Ω.

A picture of the shirt equipped with an electrical heating element is shown in Figure 2. The left image shows the front part with a small pocket to store the battery. Note that the resistive heating yarn was knitted into the shirt.

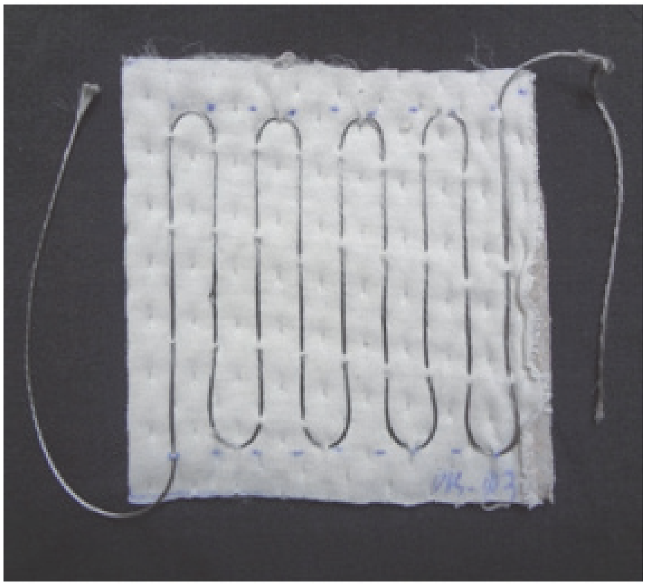

Figure 1. Typical layout of conductive yarns sewn into a fabric.

Figure 2. Photograph of a shirt with battery operated heating elements. Left: battery holder on the front side. Right: knitted heating element

The right part of Figure 2 shows the backside with the integrated resistive heating element.

A more detailed picture of the heating element is shown in Figure 3.

Figure 3. Detailed photograph of the shirt with battery and knitted heating elements.

The temperature of the heating element has been measured with infrared thermography. A typical thermographic image is displayed in Figure 4.

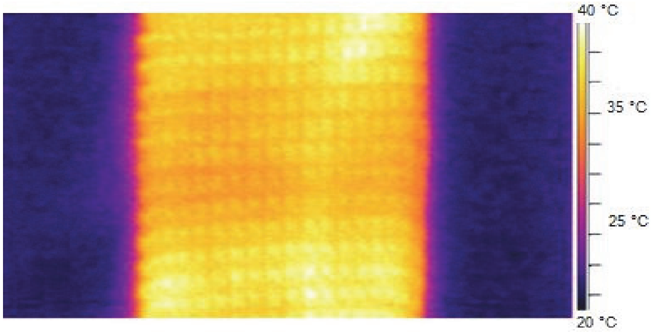

Figure 4. Thermographic image of the heated shirt.

As one can see, the temperature distribution is far from being homogeneous. This is due to the fact that textile yarns are not good thermal conductors and the resistive heating yarn is not very dense. Also the unevenness of the silver based yarns can be easily observed from the thermographic image. For the temperature measurements the average temperature of a region of interest was taken. Figure 5 shows the recorded temperature as a function of the applied electric power. From the slope of the trendline, the thermal resistance of the shirt heating element is then found to be 2.4 °C/W. During the experiment, the shirt was placed above a wooden table with the heating element on top and the camera installed in front of the heating zone. The gap between the fabric and the plate is around 2 mm. Consequently, the heating element was cooled by natural convection with the ambient air and by radiation towards the sealink of the laboratory. Taking into account that the shirt has a low thermal conductivity and it provides a good thermal insulation between the heating element and the wooden table. Hence, we can reasonably assume that natural convection of both side are practically the only way of cooling. The theoretical thermal resistance is then given by:

$$R_{th} = \frac{1}{hS} + \frac{0.002}{k} \qquad (1)$$

where h is the heat transfer coefficient, S is the heated area and k is the thermal conductivity of air. Taking the area S = 8 x 45 cm^2 of the heating element and k = 0.026 W/m^2K (33) into account we find a heat transfer coefficient of about h = 11.95 W/m^2K.

In practical situations, the heat transfer coefficient h is the sum of two components: h_c and h_r. h_c describes the convective heat losses to the ambient air whereas h_r gives us the heat transfer only due to radiation. For a horizontally placed flat rectangular heat source, the following formula for h_c can be used (34):

$$h_c = 1.36 \left(\frac{\Delta T}{\alpha}\right)^{0.25} \qquad (2)$$

Where ΔT is the temperature difference between the heat source and the ambient air and α the ratio between the area and the circumference of the heat source. The area being S = 8 x 45 cm^2, one gets α = 3.39 cm. Using ΔT = 12 K as the average temperature drop during our experiments (Figure 5), we obtained from (2) that h_c = 5.89 W/m^2K. The radiation heat transfer coefficient is h_r = 6 W/m^2K at room temperature (35). Hence the global heat transfer coefficient turns out to be h = 5.89 + 6 = 11.89 W/m^2K, which is closer the experimental value h = 11.95 W/m^2K. Textile shirts have a rather rough surface which enhances the heat transfer by convection due to the fact that the area in contact with the ambient air is higher than for a perfectly flat surface.

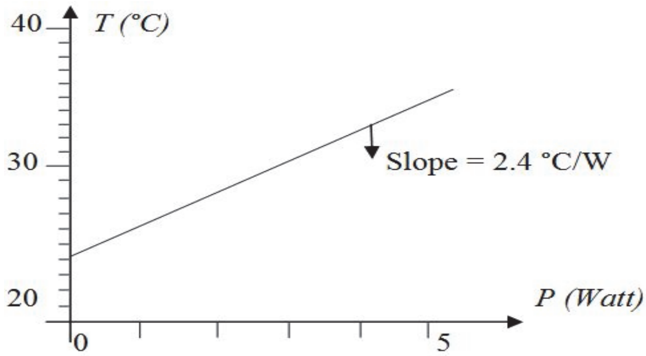

Figure 5. Recorded temperature versus the applied power

3. BATTERY OPERATION

Portable batteries should not be too heavy but on the other hand, they should provide electric power for a sufficiently long period of time. For our application a battery providing an output voltage of 10 *V* was used. The capacity of the battery was 6000 *mAh which* means that 6 *A* can be delivered during one hour or 1 *A* during 6 hours. The energy stored in such a battery is then given by:

This is a rather small amount of energy but for our applications, it will turn out to be quite enough. Such a battery can provide 60 *W* of power during one hour or 6 *W* during 10 hours. From Figure 5 we learn that 5 *W* is enough to give a sufficient temperature rise (from 24°*C* to 36°C), so that the shirt can be used during one working day without being recharged.

It should be noted that a 6000 *mAh* is a typical battery for a netbook portable computer. These small computers consume approximately 10 -12 *W* so that they can be operated for about 6 hours without recharging. Such a battery has a weight around 160 g, so that the portability is not a problem.

4. CONCLUSION

It has been shown in this contribution that a heating element with an area of 8 *cm* 45 *cm* inserted in a shirt can be heated up to approximately 12-14°*C* above ambient temperature with a limited amount of electric power around 5*W*. It has also been demonstrated that this amount of energy can be supplied by a portable battery for 8 – 10 hours.

As pointed out in the introduction the practical applications of this research can be found in the medical domain and a new way of energy saving.

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