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Harvesting voltage using knitted structures

Abstract. *This article presents methods of harvesting voltage from knitted fabrics. In these samples of fabric, thermocouples were developed in main knitted structures. These thermocouples incorporated a range of filament yarns. Diverse materials mostly enriched these filament yarns. The ensuing sample fabric were tested for the response of thermocouples with regard to voltage generation due to change in temperature.*

Streszczenie. *W artykule przedstawiono metody pozyskiwania napięcia z dzianin. W tych próbkach tkanin opracowano termopary w głównych strukturach dzianych. Te termopary zawierały szereg włókien ciągłych. Różnorodne materiały w większości wzbogacały te przędze z włókna ciągłego. Powstała próbka tkaniny została przetestowana pod kątem reakcji termopar w odniesieniu do generowania napięcia w wyniku zmiany temperatury. (**Zbieranie napięcia za pomocą struktur dzianych**)*

Keywords: knitted fabric, technical textiles, thermocouple, temperature sensing.
Słowa kluczowe: dzianina, tekstylia techniczne, termopara, czujnik temperatury.

Introduction

We developed flexible samples of knitted fabric for voltage harvesting. These samples are washable and reusable fabric has been developed, identical efforts has emerged in the form of either embedded sensors or by a combination of embedded and printed electrodes[1,2,3]. These fabrics possess advantages of customization and compliance to change in ambient conditions. These characteristics are useful in situations which are normally in relation to post operation, athletics, firefighting and law enforcement [4]. An approach for temperature measurement fabric has been tried by [5], by capturing an industrial thermistor in to the knitting process. Another scientific approach was taken by [5, 6] with the help of implanting temperature sensing devices in to the knitted fabrics. The setup was applied to quantify thermal behavior of human skin [7]. This effort was the part of a series of production of fabrics, which could sense temperature. The products included a flexible band to go arm, a pair of socks and a knitted glove having knitted electrodes. These were manufactured by [8] to test the samples under diverse loading mechanisms of the form stressed or compressed. Researchers have reported a great number of development in the area regularly. These development efforts cover up a number of areas in the technical textiles. [9] Reported a built in sensor into a piece of sensing fabric, which was capable of measuring variations in parameters of the form, force, physical pressure, water contents and thermal variations. However, these applications required remained customized. However, a trade off to its sturdiness as compared to classical sensors has emerged as necessity. Chatterjee et al. [10] discussed in detail about the materials which are used in developing technical textiles for the applications in the area of temperature sensing while considering the See beck effect. Also, they discussed advantages of using such constituents in textiles so that the general setup rests good to follow the norms of Peltier effect. Kexia [11] et al. presented a set of wearable computer textile by incorporating silver-coated conductive filaments, yet having mixed specifications in terms of doping and concentrations. They reported the behavior of impedance that are developed in knitted textile as a result of using such yarns. By virtue of this investigation, the performance of the fabric was calculated in relation to electro thermal, which is capable of suggesting the use of optimum fabric style for use in such applications. Kizilcay et al [12] used a variety of metal doped filament yarns to knit a fabric, which was tested good to act as a shield against electro-magnetic radiations. Atalay et al. [13] developed a weft knitted fabric structure using silver doped yarn in conjunction with lycra. The study was mainly based upon observations to variation in impedance values for samples of knitted fabrics. Hudec et al. [14] developed temperature sensing fabric for temperature measurement with regard to human body. However, the fabric had buried standard temperature sensors. Seulah et al. [15] worked on a knitted glove which incorporated implanted sensors. The glove used metal coated yarns having a base of non-conducting yarn, to act as a strain gauge. The glove was tested for hand posture pattern recognition. The experimentation was mainly based upon impedance change of the developed sensor. Which is the principle of standard strain gauge. Bouamara et al [16] developed an antenna which was low profile and tested for wireless body area network purposes. This effort catered for a bandwidth range of 1.4 GHz. Yutian et al. [17] constructed flexible strain sensors within a knitted structure and tested those for human motion detection in 3D setup. The test was found to be very close to realistic human motion sensing while the wearable sensors are worn. Peng et al. [18] used knitted sensors for monitoring body and its surrounding temperatures. After monitoring thermal conditions, the temperature was also maintained using the same set of sensors.

Peltier in 1834 [8, 19, 20] narrated that a junction between two unalike metals give rise to flow of current when the junction is exposed to a thermal situation. Such junction normally also known as a thermocouple. Figure 1 shows a standard basic set up of a thermocouple. The equation presenting such a plan is given by

$$\Delta U = \alpha \Delta T$$

Where ΔU is the difference in Seebeck coefficient of two metals and ΔT is the temperature difference of hot and cold junctions.

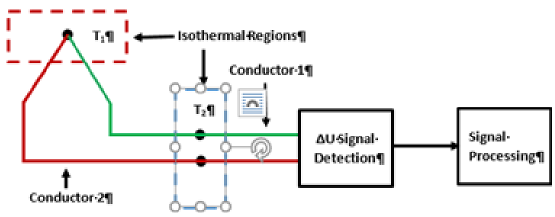

Fig. 1. Thermocouple model and signal conditioning.

The fabric under contemplation was developed by making use of conduction doped yarns, which in turn act as basic Thermo Couple (TC) in a knitted structure. These TCs act as array of temperature sensing elements at each junction of knitted stitches. Therefore, the array is capable of sensing temperature variations at each junction or in its vicinity or in the surface to which the TC is subjected. The two basic yarns used for such structure act as a scaffold to such knitting. These yarns have different level of enrichment for doping. Therefore, when these yarns are assimilated in a knitted structure, they start acting rather as a slack form of a thermocouple junction. This does give a look of disparity in impedance at the output terminals of the TC. This disparity in impedance appears to be a function of change in temperature. The change can be linear or exponential which depends upon the choice of the yarns filaments used. Apart from basic developments in technical textile, a high number of applied fields have been explored in this area.

Description

Basic knitted structures are more often utilized in various combinations and in other beneficial ways. This is achieved by making use of a variety of conducting and semi conducting material in the form of enriched filament yarns. In basic categories of knitting, there exists weft and warp knitting methods. Fig. 2. shows the simplest weft knitted structure. Whereas, **Błąd! Nie można odnaleźć źródła odwołania.** shows a tuck loop within a weft knit. This is the very loop used for the realization of knitting under discussion.

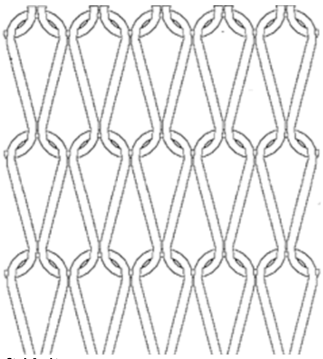

Fig. 2. Basic Weft Knit.

Fig. 3. A tuck loop within weft knit.

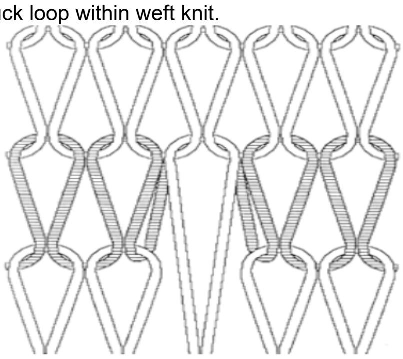

Fig. 4. Flatbed machine with side feed arrangement.

There is a possibility of using a range of platforms in order to insert conducting wires and filament yarns in a knitted structure. The ranges of platforms ranges from single layer to multiple layer fabrics that depends upon the purpose and type of application in target. However, as this particular case was the first of its type in our research lab, therefore, a decision for single layer setup was taken up to be on the safe side. A number of samples were knitted on a flat bed machine which was fitted with a modified feed arrangement as shown in Błąd! Nie można odnaleźć źródła odwołania..

A range of metal yarns and ordinary filaments yarns was used to knit fabric samples. These materials were procured from various manufacturing resources and were supplied in the form of small spools or reels. Therefore, it was not viable to use them as such on the knitting machine due to various reasons. These reasons include repeated wire breaks due to friction with flanges of spools and also failure to maintain tension in the wire. Each sample has been developed in such a way that combination of wire/filament was sufficient to withstand Seebeck effect.

The Seebeck effect works very well, if there exists a strong connection/conductive bonding between two dissimilar metals. However, in this experiment, two metals had a loose connection at the junction between two metals which was inevitable due to the knitting process. However, this led to a number of promising results, whereas, the connection between the two yarns has been in the loose form. The idea was incorporated into knitted structures by using a few combinations of metal and metal enriched yarns. These yarns were used as a part of knitted structures figures 5 and 6.

Fig. 5. Sample using tungsten rich yarns.

Fig. 6. Stainless steel and silver enriched yarns.

Due to the nature of knitted pattern both the metal yarns could only make loose junction with each other, so that each crossing of two yarns acted as a loose junction thermocouple. These wobbly connections thus are capable to behave as if a large number of thermocouples were connected to each other in a series connection arrangement. Therefore, even a small change in impedance of each junction of the arrangement adds up to show a substantial adjustment in reading at the output terminals of the fabric. As a result a potential difference was observed at the two terminals of the TC. This gives rise to a number of advantages of this type of knitted fabric over the conventional thermocouple. The resulting fabric in turn is washable, wearable, durable and flexible. Therefore, opening more avenues for TC applications for harvesting voltage. The range of applications includes from very basic to sophisticated applications such as battery charge up, in the fields of medical and sports etc.

The Experiment

Various knitted fabric samples were prepared in the laboratory. The major dissimilarity between these knitted samples was the in terms of parameter variation in metal yarns, which were used in the knitted patterns. The output terminals of each piece of sample fabric were attached directly to a digital volt meter. A hot plate made by Fisher Scientific Company was used for steady heating up of each sample one by one. Each piece of fabric as it was placed on the hot plate was covered up with a plane piece of ceramic. This helped to attain rigidity and uniform thermal environment for the sample. The setup is shown in **Błąd! Nie można odnaleźć źródła odwołania.**7.

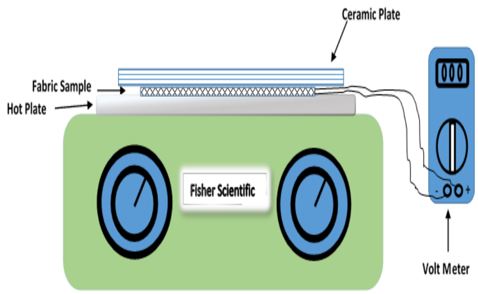

Fig. 7. Experimental arrangement for fabric heating up.

Based upon the kind of metal used in knitted samples, some samples showed direct generation of voltage between the two conducting filaments. This is mainly due to a change observed in the overall impedance of metal junctions which in response to changes in the temperature to which the sample was exposed.

Results and Discussion

i). **Błąd! Nie można odnaleźć źródła odwołania.**Figure 8, shows plot for observations obtained due to use of same metal yarns as filament for two conductors, which was Tungsten. However, the cross section range used for both the electrodes was dissimilar; this is declared in the title of **Błąd! Nie można odnaleźć źródła odwołania.**9. The result in this case has shown a linear behavior towards the change in impedance with the change in temperature. It shows more linearity in impedance variation with respect to the changes in temperature. The temperature range covered in this case was from 35 to 90 ^{o}C.

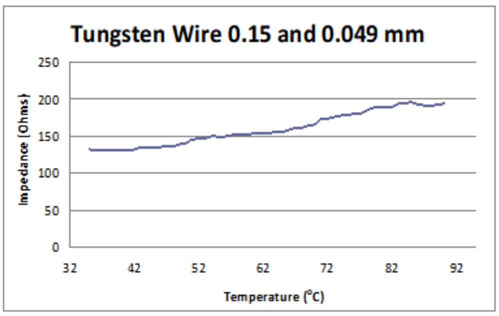

Fig. 8. Impedance observation from Tungsten wires used for both the conductors.

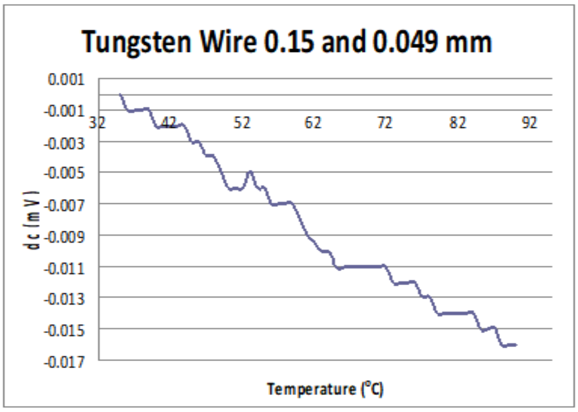

Fig. 9. Voltage harvest observation from Tungsten wires used for both the conductors.

Figure 9, shows a plot between temperature variations and harvesting of dc voltage. The relationship between the increase in temperature and the development of potential difference between the two terminals shows a liner trend. However, the harvesting of the voltage as result of this setup has been negative. This is due to the negative temperature coefficient between the two filaments used in knitting this particular sample.

ii). **Błąd! Nie można odnaleźć źródła odwołania.**0, shows a graph for the data which was obtained from a knitted sample. This sample was developed by using two type of yarns having enrichment from Stainless Steel and Silver. In order to run the experiment, 50% of the junctions in the fabric were bonded with the help of conductive adhesive. The disparity in the overall impedance of the sample depicts a linear behaviour. The dips in the profile may have appeared due to the inevitable flexibility of the two filament yarns at the intersection.

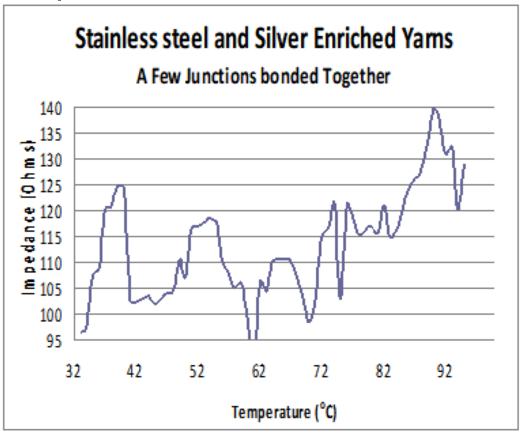

Fig. 10. Impedance observation from combination of Stainless Steel and Silver enriched yarns.

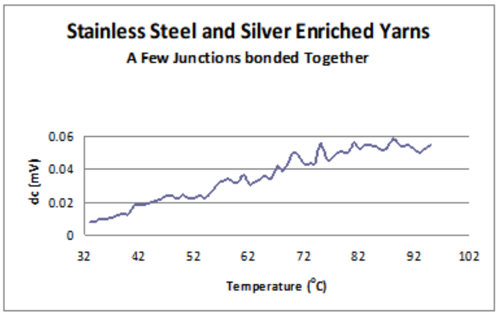

Fig. 11. Voltage harvest from combination of Stainless Steel and Silver enriched yarns.

Błąd! Nie można odnaleźć źródła odwołania.1, depicts a linear relationship between temperature variation and the dc voltage at the output terminals of the fabric. Thetrend shows a voltage harvest from 0.001 to 0.06 mV was possible against a temperature rise from 32 to 93^{o}C

Conclusions

Voltage harvesting results from knitted fabric samples have considered reasonable and reported here. The present research acts as a guideline for development of sensor electro textile structures. The developed sensor fabrics are long lasting and can be utilized in various applications. Especially, in situations which are having access complications. These applications may include the reas such as medical, sports and other high tech applications.

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