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Design and Development of a Pressure Sensing Device for Analysing the Pressure Comfort of Elastic Garments

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Abstract
In this paper, a pressure sensing device for analysing pressure comfort on elastic garments was designed and developed. The device was calibrated and tested on different compression garments for its reliability. This pressure comfort measurement device is used to measure the pressure between the human body and garments. The fabric resistance due to each and every body movement is noted to evaluate the effect of fabric compression on body muscles in order to assess the pressure comfort for sports persons. The new device proved that elastic garments certainly improve stamina and speed through its quick recovery and lower stress with higher elongation. There is a good correlation found between the pressure values given by the new sensing device and the Instron tester.

Key words: *compression garment, muscle fatigue, pressure comfort, pressure sensing device, sportswear.*

Introduction

Elastic fabrics are an important route to achieving fit comfort through freedom of body movement by way of reducing fabric resistance to body stretching. Elastic garments have been mostly used in athletics to improve the performance of athletes. Simple body movement may extend the body's skin by about 50%, and fabric should also respond by stretching with the body's extension and recovering on relaxation. The strenuous movements involved in active sports may require even greater garment extension and fabric stretch. A significant difference between the skin and fabric movement will result in the restriction of the wearer's movements. The most outstanding properties of elastic sports garments are body fit, moisture management and durability. Furthermore, fabric elastic recovery is also as important as fabric stretch. Fabric with high elasticity is preferable for good sportswear. The degree and direction of elastic properties determine the end use of stretch garments [1]. Generally fabric elasticity is measured using ASTM – 2594 standards [2], which are normally used to measure a fabric's elastic stretch and its recovery. This is a static measurement which helps to analyse the dimensional stability of the fabric and garment during field trials and to study the laundering effect. The dynamic elastic stretch and recovery of the fabric helps to analyse the garment's response to instant body movements [3].

Although there are some standard methods available to evaluate the elastic performance of fabrics, it is difficult to incorporate the results in product development when it is converted into a garment. Elastic garment stretch is mainly due to body skin strain, which depends upon garment fit and slip during body movements. Thus the performance analysis of fabric at the garment stage is more useful than at the fabric stage. So far few attempts have been made to evaluate compression garments using new testing methods. In this direction, an attempt was made by Salim M Ibrahim (1968), who developed a new test method to provide a quantitative definition for the performance of form persuasive fabrics and garments. The new test methods are as follows: (i) the Pressure indicator technique, which continuously measures garment pressure on the body; (ii) the Contour meter measure, developed to measure the static response with the help of a contour gauge to provide quantitative and qualitative measurement of the change in body geometry due to pressure, and finally (iii) the Accelerometer (two accelerometer probe with associated equipment), measuring the extent of dynamic control or the control of seat vibration during walking, afforded by foundation garments [4].

William J Kraemer et al [5] (1996) studied the compression performance of shorts during the vertical jump of volleyball players. The vertical jump test was performed on an AMTI force plate interfaced to a computer with customised software so as to determine the jump force and power. It was found that the compression of shorts had a significant effect on the mean jumping power. However, it had an insignificant effect on the highest jump power. Jill A Bush et al (1998) also found the same trend [6]. Brandon et al (2003) analysed the performance of compression garments using track and field sprinters and jumpers, measured with a Celesco cable transducer attached to the person's waist. Skin temperature and force data (between the body and garment) were also recorded during the study [7].

Michael I Trenell et al (2006) investigated the benefit of a compression garment using P-Magnetic Resonance Spectroscopy on a walking person who wore a compression garment on one leg and none on the other . They have reported that the results support the beneficial aspects of these garments [8]. Elzbieta Maklewska et al (2007) designed a new measuring device for recording the pressure exerted by the garments or bandages used in the healing therapy of hypertrophic scars. These garments are used to provide constant pressure over the healed burn. This compression minimises the development of scarring and deformity caused by serious burn injury [9]. This can be used in the field of sports for analysis of a sports person's garment fit and performance enhancement.

Antonius Hubertus et al patented a tight-fitting garment comprising a dipole resonator, which is adapted to vary its shape in accordance with the shape variations of the person wearing the garment. The shape of the resonator determines the resonance frequency which can be detected

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by a reflection analyser [10]. Compression garment performance can also be evaluated by the measurement of oxygen consumption, heart rates, body mass change and skin temperature, as well as by a venous blood test for the determination of lactate and hematocrit levels in sports persons [11]. Kraemer et al (2001) studied the performance of these garments using a compression sleeve around the elbow and reported that the swelling, perceived muscle soreness and impact on the elbow joint's range of motion were all reduced due to the use of the compression sleeve [12].

Although the benefits of compression garments have been positively highlighted in a lot of literature, there have been some contradictory views on the effect of compression garments on sports performance. For example, Bernhardt (2005) found no difference in the balance, agility, proprioception and endurance of muscular power in a person wearing and one not wearing elasticised compression shorts [13].

Similarly, Rob Duffield et al (2007) studied the effects of three types of full-body compression garments on the repeat-sprint and throwing performance of cricket players. It was found that no significant differences were evident in the repeat-sprint performance or throwing performance when measuring the person's heart rate, body mass change or blood measures during exercise [14]. Another study carried out by Rob Duffield et al (2008) showed that the effects of compression garments on the recovery of muscle performance following high-intensity sprinting and plyometric exercise were negligible [15]. Ali et al (2007) analysed the effect of wearing graduated compression stockings on physiological and perceptual variables during and after intermittent and continuous running exercise. It was found that there was no performance difference found between normal and compression stockings [16].

Contradictory opinions were expressed regarding the benefits of wearing elastic garments, which may be due to the nature of test methods, their repeatability and reliability. The effect of compression garments on sports performance could be explored by way of defining a test method, machine calibration, the procedure of performing the experiments and defining the number of samples and their variances. Compression garment performance can be assessed by measuring body muscle pressure during any sports activity. The pressure should be maintained for every stroke of body movement. The garment's resistance to the body during every stroke should be as low as possible in order to avoid skin irritation and muscle fatigue, as a too tight fitting compression garment makes the person feel discomfort due to the reasons aforementioned. Inversely, a too loose fitting garment will not be beneficial to the wearer in terms of speed, power and stamina. Hence optimum pressure should be maintained when constructing a garment for a particular sports activity in order to enhance the performance of the sports person.

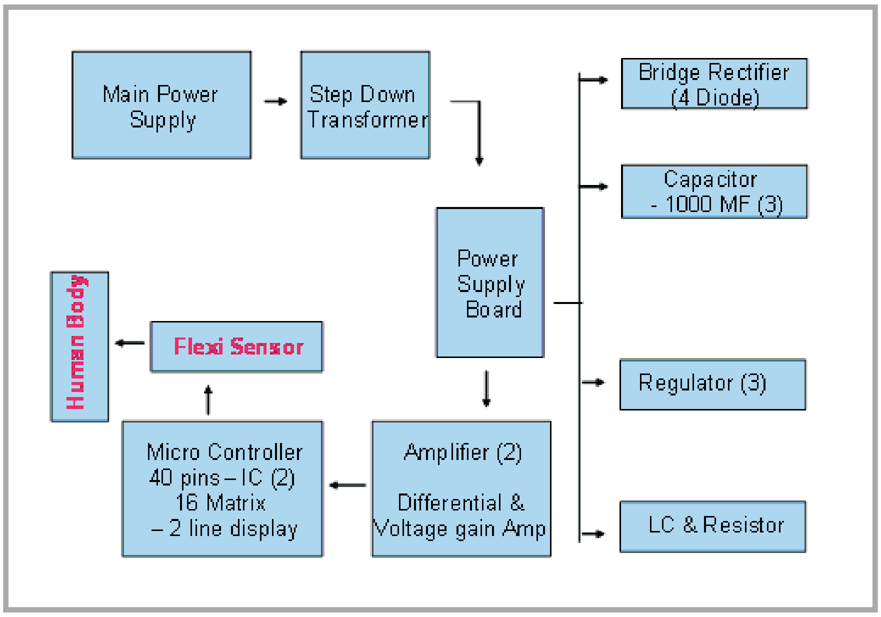


***Figure 1.** Block diagram of elastic garment performance evaluation using the pressure sensing device.*

Objective

The present work was to design and develop a new pressure sensing device which would be used to assess the dynamic pressure comfort of a garment by measuring the pressure acting on it during each and every body movement. This will help to evaluate the pressure comfort of any elastic garment assigned to a sports person, in order to develop tight fitting sportswear products.

Design of the pressure sensing device

Concept

A block diagram of the working principle of the dynamic pressure measurement is shown in ***Figure 1***. This instrument is used to assess the dynamic pressure comfort of a fabric or garment by measuring the force acting on the fabric due to body movement. The new pressure sensing device consists of a sensor placed between the body (the place to be measured) and garment.

A highly sensitive sensor (12 V minimum ground output) is used to measure the force acting on a body in the range of 0 N to 10,000 N, placed between the elastic garment and human skin. A step down transformer is used to convert 230 V to 15 V for the power supply board, consisting of four diode bridge rectifiers to convert AC to DC, as well as 1000 μF and 10 μF capacitors for filtering purposes. The power supply board supplies 15 V DC to a PIC16F877 microcontroller.

The sensor is interfaced with the microcontroller, which acts as a measuring and control unit. The sensing and control unit is used to sense the dynamic pressure value and store the information, presenting it in a readable format. The information is displayed by a 2 × 16 LCD unit. Moreover the pressure value measured can be transferred to a computer through serial communication protocol. The data values stored in voltage are converted to Newtons per square millimeter and displayed in a graphical format using dedicated Lab VIEW based Dynamic Stretch Measurement Software.

Working principle

A pictorial view of the pressure sensing device for elastic garment perform-

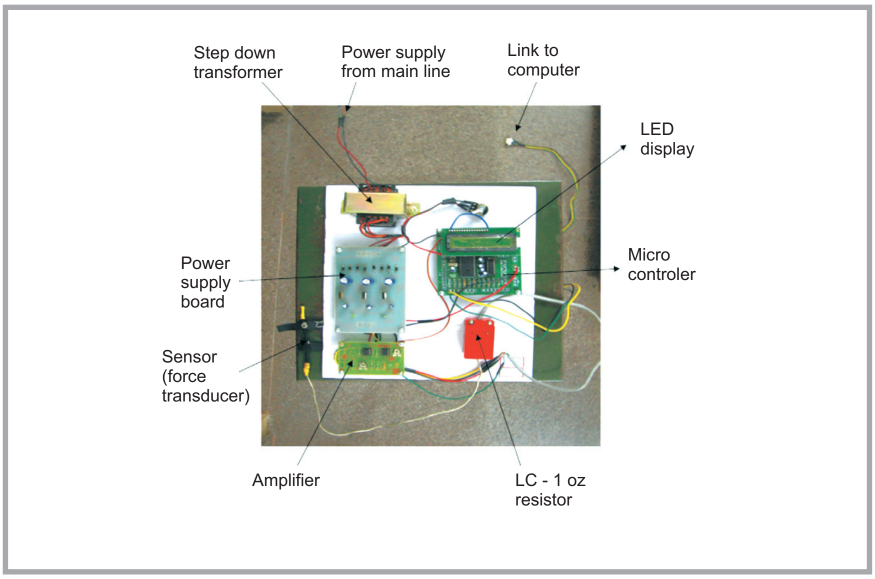
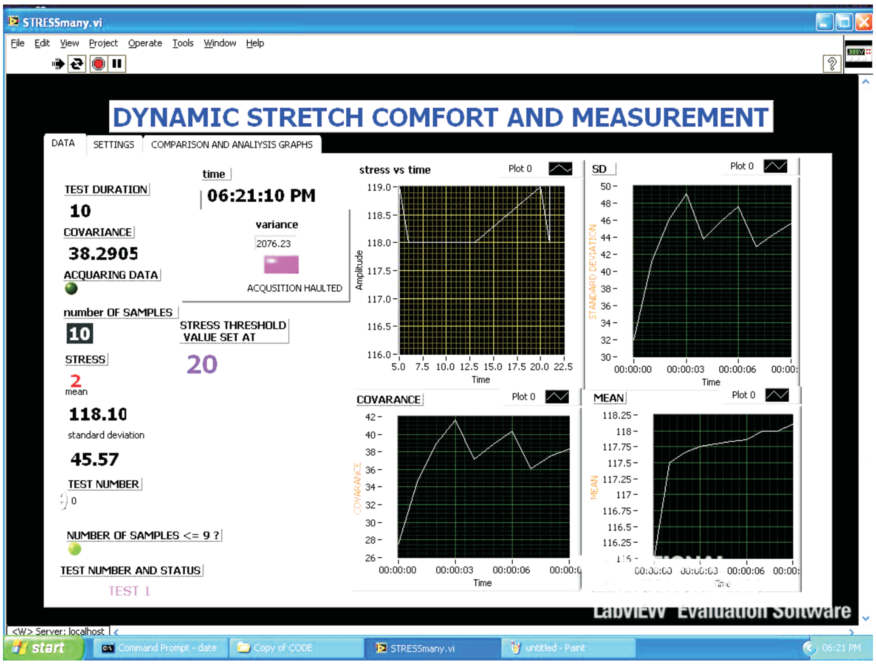


Figure 2. Pressure sensing device for elastic garment performance evaluation.



TEST DURATION
10
time
06:21:10 PM
COVARIANCE
38.2905
variance
2076.23
ACQUARING DATA
ACQUSITION HAULTED
number OF SAMPLES
10
STRESS THRESHOLD VALUE SET AT
20
STRESS
2
mean
118.10
standard deviation
45.57
TEST NUMBER
0
NUMBER OF SAMPLES <= 9 ?
TEST NUMBER AND STATUS
TEST 1
<W> Server: localhost

Figure 3. LabVIEW Software - Home page.

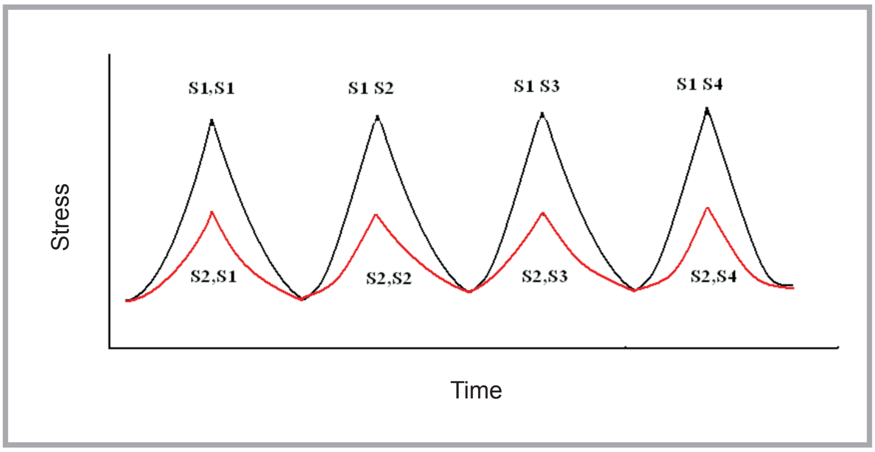


Figure 4. Computation of garment pressure using lab view software.

ance evaluation is shown in ***Figure 2***. The working principle of the device can be explained in three steps: i) Function of the pressure sensing device, ii) Garment with dynamic movement, and iii) Pressure output display. The pressure sensor is interfaced with the garment to be sensed. The sensor is flexible and can be placed between the body and garment; it is specifically designed to be placed at the arm elbow joint. For every arm stroke, the elastic garment expands and contracts due to muscle movement. The pressure value will be higher when the garment resists expansion and will be lower when the garment relaxes and recovers. Too high or too low garment pressure will lead to the pressure discomfort of the wearer. Fabric with low stress at higher elongation is always preferable. The elastic garment should expand and contract along with body movement in order to provide the benefits of compression during sports activity.

The sensor senses the arm pressure of every stoke, and the pressure values are continuously stored by the microcontroller and recorded on the computer with the help of Lab VIEW software. The display unit shows the pressure value continuously. The data can be logged for future use or it can be accessible in print out format.

Lab VIEW software is used to record and display a graphical representation of each performance, which is shown in ***Figure 3***. The software gives information about the input and output data of the compression garment performance evaluation. The input data consist of the total number of samples to be tested, the time duration for each test, the mean stress value and its standard deviation, and the allowable error. The output data show mean stress values of each stroke of the test sample, its standard deviation, its covariance and the mean stress value of all test samples graphically as well as numerically.

The pressure sensing device measures the stress value of the garment for each stroke of the arm; a hypothetical condition is shown in ***Figure 4***. The mean stress value, standard deviation and coefficient of variation of samples were calculated using the following formulas.

Mean stress value of sample 1

$$(S_1) = (S_1S_1 + S_1S_2 + S_1S_3 + \ldots + S_1S_n)/N_1 \quad (1)$$

Mean stress value of sample 2

$$(S_2) = (S_2S_1 + S_2S_2 + + S_2S_3 + \ldots + S_2S_n)/N_2 \quad (2)$$

Mean stress value of ‘n’ sample

$$(S_n) = (S_nS_1 + S_nS_2 + + S_nS_3 + \ldots + S_nS_n)/N_n \quad (3)$$

Overall mean stress value of all the samples

$$(S) = (S_1 + S_2 + S_3 + \ldots + S_n)/n \quad (4)$$

$$\text{Standard deviation of the samples} = (SD(S_1) + SD(S_2) + + SD(S_3) + \ldots + SD(S_n))/n \quad (5)$$

$$\text{Coefficient of variation of the samples} = (CV\%(S_1) + + CV\%(S_2) + \ldots + CV\%(S_n))/n \quad (6)$$

where:
S_1 S_1 - Stress value of first sample for 1st stroke of the arm
S_1 S_2 - Stress value of first sample for 2nd stroke of the arm
S_1 S_n - Stress value of first sample for nth stroke of the arm
N_1 - No of strokes by 1st sample
N_2 - No of strokes by 2nd sample
N_n - ‘N’ number of strokes by ‘n’ number of samples
SD (S_1) - Standard deviation of 1st sample
SD (S_n) - Standard deviation of ‘nth’ sample
n - Total number of samples

Pressure comfort measurement

Pressure Comfort is a complex phenomenon which involves a number of synthetic sensations, such as snugness, looseness, tightness, light-weightiness, softness and stiffness. It mainly corresponds to the pressure receptors in skin and may come from a combination of a number of simple sensory responses, depending on fabric elastic characteristics and elastic recovery properties [17]. A fabric or garment requires high stretch with low pressure, which will lead to better comfort. The pressure comfort zone is where the pressure sensation is less than 0.4 N/mm^2.

$$\text{The pressure applied on the fabric } (P) = (TH/\gamma H) + (TV/\gamma V)$$

where:
TH - Tensile stress in horizontal direcion
TV - Tensile stress in vertical direction

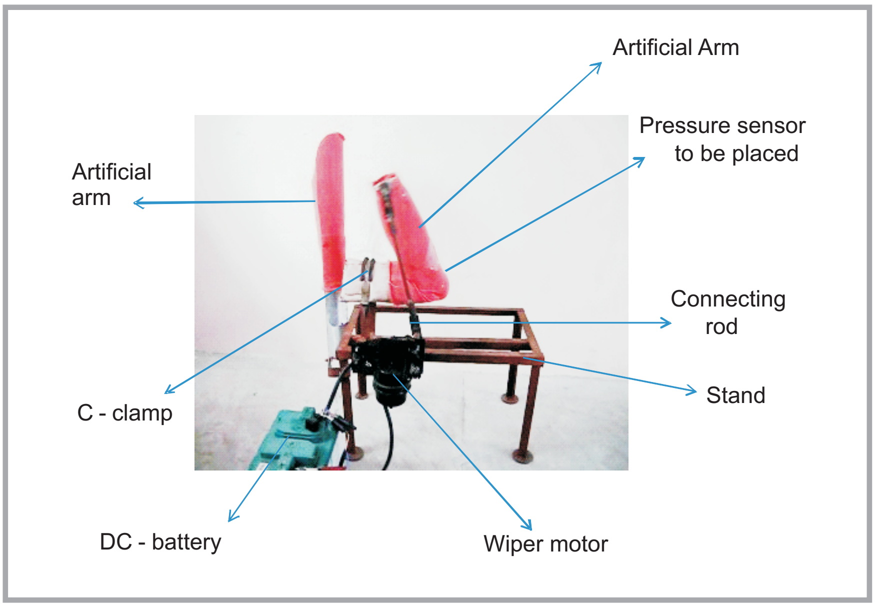


Figure 5. *Design of the dynamic artificial arm.*

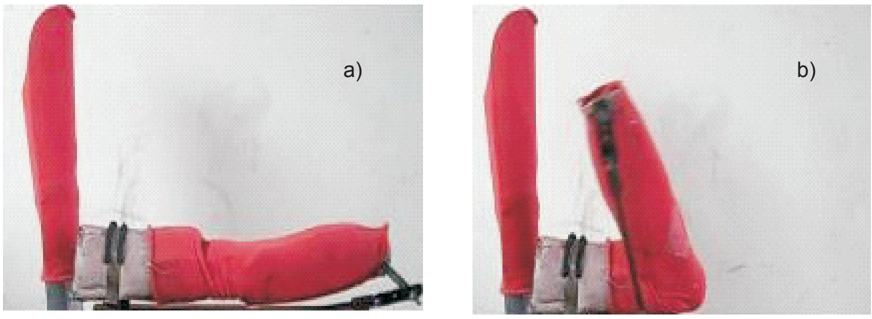


Figure 6. *Artificial arm movements; position 1 (a) and 2 (b).*

γH - Radius of curvature in horizontal direction
γV - Radius of curvature in vertical direction

A pressure sensing device is used to measure the garment resistance developed due to dynamic movements. A sports person’s each and every body movement may not be the same during real time performance. For example, an athlete’s performance while running starts with a slow run, then consistency of movement is maintained, and in the final phase maximum speed is gained. The body movements and muscle oscillations of performers vary . In order to eliminate these variations, an artificial arm was designed, developed and used in the study. ***Figures 5*** and ***6*** show the newly designed artificial arm for controlling variation in the strokes of the person’s movements.

The artificial arm was designed using Plaster of Paris, a cement mixture was then applied on steel rods, and finally a Polypropylene cloth was wrapped around the mixture. The forearm and biceps are joined with an elbow arrangement. A C-Clamp is used to connect the arm with the stand. A wiper motor is connected to the arm with the help of a connecting rod in order to give cyclic movement to the arm. A 12 V DC battery is used to give power to the wiper motor. The test specimen is gripped at both ends of the arm by an elastic band. A pressure sensor is placed in the garment to exert the pressure developed on the body due to garment resistance during body movement. The pressure developed between the body and garment during each movement can be seen with the aid of the LED display in the device, which is continuously recorded by the computer.

Interpretation of pressure measurement

The pressure sensor senses fabric resistance in terms of voltage. The voltage measured is converted into force. For example, 1 V = 100 N and 2.5 V = 250 N.

Table 1. *Standard deviation of primary test samples.*

Measurement	Single sample	Multiple sample
Standard deviation, %	17.44	29.36

Table 2. *Critical differences at 95% confidence level with t = 2.1315.*

No. of trials	Single sample	Multiple sample
2	18.12	18.53
4	15.24	15.72
6	13.33	14.97
8	10.56	11.62
10	07.25	09.35

The values converted are displayed in the LCD display in Newtons.

$$P = T / R \quad \text{Laplace law}$$

where:
P = Pressure in N / mm^2,
T = Tension expressed as the force per length of the cloth ($T = f/L$) and
R = radius of the arm.

Supposing the pressure output measured is 20 V (force is 2000 N).
Then, T = Force (2000 N)/arm length (500 mm) = 4 N/mm.
Pressure = Tension/Radius of the arm (80 mm) = 0.05 N/mm^2

The critical difference at a 95 % confidence level was analysed for selected samples, given in ***Tables 1*** & ***2***. Analysis of the performance evaluation can be done by the analytical and graphical methods. When the mean stress value is low and with high garment elasticity, the garment will be highly suitable for sports events (the standard deviation and coefficient of variation of the sample should be as low as possible). This measurement follows the principles of the relative grading method, used to compare two or more samples.

Validation of the new test method

In order to validate the reliability of the device, three types of fabrics were produced from 24 gauge using a Mayer and Cie knitting machine of 20 inch diameter, with 72 feeders and 1800 needles. A cotton yarn count of 40^s Ne and spandex yarn of 200 denier were used for manufacturing the fabrics. The fabrics were a) normal cotton fabric (no spandex feed fabric), b) alternate spandex-cotton fabric c) and all spandex-cotton fabric. Spandex yarn was fed only in alternate feeders and all feeder cotton fabrics. The knitted fabrics were heat set in an Askme model machine at 200 °C for 38 seconds and then treated with reactive dye at 60 °C temperature, maintaining the pH at 7.5. Then these fabrics were washed twice at the same temperature.

The geometrical properties of the fabrics selected are given ***Table 3***. The spandex content in the fabrics increases with an increase in the number of courses and wales per centimeter thereof, which is due to its lateral compression of yarn loops. The compression of loops due to the inter yarn space, which increases with the fabric thickness, further increases with the fabric areal density.

These fabrics were tested in the new device, the results of which are shown in ***Figure 7***. The mean, standard deviation and coefficient of variation of the samples selected were calculated using ***Equations 4, 5*** and ***6***, respectively.

It is very clearly seen that all spandex-cotton fabric has lower stress or a lower pressure value, followed by alternate spandex-cotton fabric, than that of normal cotton fabric. When the amount of spandex in the fabric was increased, the stress or pressure value of the fabric decreased. The standard deviation of the test results also decreases in the case of all spandex-cotton fabric, followed by alternate spandex-cotton fabric and normal cotton fabrics. This simple experiment carried out on the new device helps to understand the behaviour of garment response thoroughly.

Table 3. *Geometrical properties of the three knitted fabrics.*

Sample	Wales per centimeter	Courses per centimeter	Loop length, mm	Thickness, mm	Areal density, g/m^2
No spandex fabric	15.75	15.35	2.9	0.40	104.56
Alternate spandex feed fabric	17.32	18.50	3.1	0.49	144.32
All spandex feed fabric	17.72	22.05	3.2	0.57	216.12

Table 4*. Pressure values of selected fabrics.*

Sample	Fabric stress, N/mm^2		PSD – Stress, N/mm^2	PSD – Coefficient of variation, %
	Instron (W - 50%)	Instron (C - 50%)		
No spandex fabric	1.75	2.30	2.01	12.55
Alternate spandex fabric	0.94	1.35	0.75	17.28
All spandex fabric	0.08	0.20	0.14	16.28

The stress (or pressure) values of all three fabrics were compared with those of the fabrics tested using an Instron tester (dynamic tensile test – CRE principle) at a 50% extension in both the wale wise and course wise direction, the data of which are given in ***Table 4***.

It is very clearly seen that the all spandex-cotton fabric has a lower stress or lower pressure value, followed by alternate spandex-cotton fabric, than that of normal cotton fabric. When the amount of spandex in the fabric was increased, the stress or pressure value of the fabrics decreased due to yarn loop compression. Elastic garments have a really beneficial effect on the wearer/sports person due to lower stress with higher elongation and also quick recovery. The beneficial effects on sports persons were proved by comparing the test results of the new pressure sensing device with the Instron results. The new test results have good correlation (R = 0.95) with the Instron test results.

Conclusions

A pressure sensing device for analysing the pressure comfort of elastic garments was designed and developed. The device was calibrated and tested with different elastic garments for its reliability. This pressure measurement device is used to measure the pressure comfort between the human body and garments. The new device proves that elastic garments really improve the stamina and speed of the sports person through its quick recovery and lower stress with higher elongation, which enhances the performance of the sports person in terms of stamina, speed and power. There is a good correlation found between the pressure values obtained from the new sensing device and those from the Instron tester.

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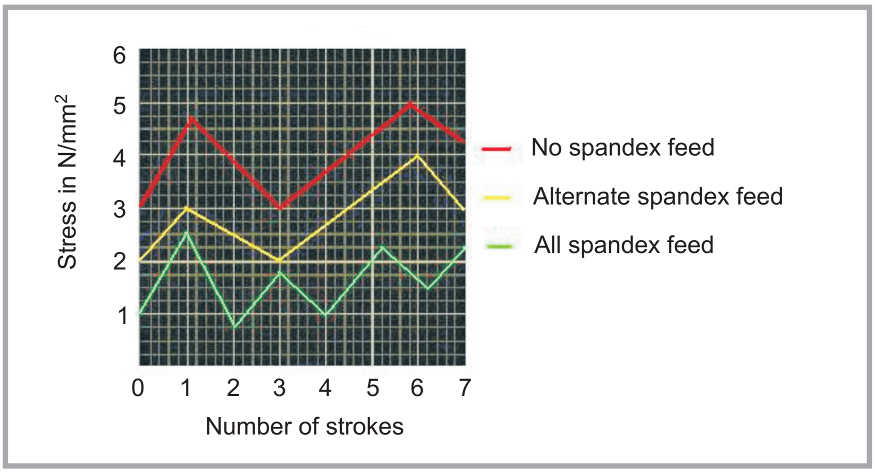

Figure 7. *Graphical representation of experimental results for selected fabrics (X axis : Number of strokes, Y axis : Stress or pressure value in N/mm^2).*

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