STUDIES ON THE CHARACTERISTICS OF ELASTIC KNITTED FABRIC TUBES AND THEIR INFLUENCE ON PRESSURE GENERATION

by

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Dedicated to my mother

Tripti Bera

CERTIFICATE

This is to certify that the thesis titled '**Studies on the Characteristics of Elastic Knitted Fabric Tubes and their Influence on Pressure Generation',** being submitted by **Ms. Moumita Bera** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy,** is a record of bonafide research work carried out by her. She has worked under our guidance and supervision and fulfilled the requirements for submission of the thesis which has attained the standard required for a Ph.D. degree of this Institute.

The results contained in this thesis have not been submitted, in part or in full, to any other university or institute for the award of any degree or diploma.

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ABSTRACT

Pressure garments are used to generate positive pressure over human body parts. They are produced from elastic knitted fabrics. Their size is deliberately kept smaller than the size of the body part they enclose so that they remain in stretched state. Pressure garments are used in various medical conditions, such as, scar management, venous and lymphatic disorders, bone and muscle problems. In each of these applications, the therapeutic pressure required is different. Application of precise amount of pressure on the body requires an understanding of the factors affecting the generation of pressure. The important factors include the tension generated in the fabric per unit width, fit of the garment, and curvature and compressibility of the body part on which it is worn.

Fit of the garment is decided by reduction factor (R_F) which is the percentage difference between body and garment circumference. 10, 15 or 20% reduction factor is normally applied to the patient's circumferential measurements without considering the nature of fabric and body characteristics. The curvature of the body depends on the limb shape and size. More pressure is generated on low circumferential body parts and vice versa. Further, compressibility of the body tissues also matters. Low and high pressure can be found on soft tissue part (like thigh) and bony part (like ankle), respectively. The body compressibility is a complex factor and varies over a wide range between subjects for the same body part. To reduce the variability in the experiment, researchers use rigid body, such as wooden leg or rigid cylinder. But pressure generated on rigid body may not correctly estimate the pressure generated on soft human body.

Tension generation in the elastic fabric is dependent on the extent of extension the fabric experiences at the wearing condition known as the fit of the garment. Higher the tension higher is the exerted pressure. In this respect the tensile behaviour of the constituent yarns and fabric construction has an important role. The fabrics used in pressure garments are

warp or weft knitted structures containing in-laid elastic yarns. Power net fabrics produced on raschel warp knitting machine are also used. In case of weft knitted structures, rib and single jersey structures have been used. Nylon filament yarn (50- 400 denier) is used along with a fine spandex yarn for loop formation. Spandex yarns of 280 – 560 denier or rubber threads (1500-3000 denier) are inlaid (6 to 16 per cm) in the structure to impart elasticity. Hence, there exists a wide range of fabric types for production of pressure garments. The structure property relationship of elastic knitted fabric is of great interest.

Bare spandex filaments are generally not used in the fabric for tactile discomfort. They are first covered with nylon or polyester filament and the covered yarns are subsequently used in fabrics. The effect of covering by nylon on the properties of spandex filament has been investigated. Load extension and stress strain behaviour of bare and covered spandex filaments were graphically plotted and discussed. It was found that covering of spandex increased its linear density and diameter. Covering changes the load extension behaviour of yarns. Covered spandex yarn showed less stress at a given strain than bare spandex filament.

The elastic yarns are always inserted in the fabric at a fixed input tension. Variation in input tension needs to be avoided to uniformly maintain the stretch characteristics of the fabric. The effect of level of input tension of elastic inlay yarn on the characteristics of fabrics has been studied. Input tension of inlay yarns were kept at four levels and fabric samples were prepared. Constructional, physical and mechanical properties of fabrics were tested and analyzed. It was found that with the increase in input tension in inlay yarn, loops became narrow in width and longer in height. This caused the change in dimension of fabric tubes. The circumference of the fabric tube decreased with the increase in input tension. However the effect of input tension of inlay yarn on tensile properties of the fabrics was marginal especially up to initial 100% extension level.

In order to study the effect of linear density of inlay yarn on characteristics of elastic fabrics several fabric tube samples were prepared at fixed input tension by varying linear density of inlay yarns. The samples were characterized in terms of their constructional, physical and mechanical properties. It was found that with the increase in linear density of inlay yarn, the loops became wider and shorter in height. Fabric thickness and weight increased with the increase in linear density of inlay yarn. At any given extension, tension in coursewise direction of fabric increased as linear density of inlay yarn increased. Hence, varying the linear density of inlay yarn could be an easy way to change the level of tension development in the fabric.

It has been found that, the change in input tension of inlay yarn affect the dimension of fabric tubes. The question arises whether this change in dimension makes any difference in the pressure generated by the fabric tube on rigid cylindrical body? It was found that, at fixed reduction factor and body curvature there is no effect of input tension of inlay yarn on pressure development.

To understand the effect of linear density of inlay yarn, reduction factor of the fabric tube and curvature of body on pressure generation, a set of experiments based on mixed level factorial design was carried out. The main and interaction effects of the parameters were also studied by response surface methodology. In order of importance the factors affecting the pressure generated on a cylindrical body was found to be the linear density of inlay yarn followed by reduction factor, and curvature of the cylinder.

To understand the relationship between body compressibility and pressure generation, pressure was measured on both rigid and soft cylinder. A PVC cylinder was covered by foam to make the surface soft. The compressibility of the foam was characterized. The knitted fabric tubes with varying reduction factor were mounted on the same keeping the pressure sensor in between. The pressure was found to decrease on foam covered cylinder. A model based on energy consideration was developed to predict the pressure on soft cylinder. The predicted pressure showed good fit with experimental data.

The pressure generated by fabric tubes on human subjects was also studied. Ten males and ten females were selected. Pressure was measured on upper arm of right hand. The variation in amount of pressure on male and female bodies was also noted. The deviation from theoretical pressure calculated from Laplace's Law and actual measured pressure was analyzed. It was found that, under identical conditions, pressure generated was less in females as compared to that in males. Laplace's law was found to be unsuitable for predicting the pressure generated on human body.

As the pressure garments are used next to skin, the comfort aspect of the fabric becomes a critical issue. Patients stop using pressure garments because of perspiration, itching, rashes, warmth. It was found in the literature that, comfort properties are dependent on the fibre type and fabric structure. Mostly nylon fibre is used for construction (50-85%). But it is hydrophobic in nature. Some amount of hydrophilic fibre can be incorporated in the fabric. It is interesting to investigate the effect of fibre content on comfort behaviour. Fabric tube samples were produced varying the nylon and cotton proportion. Thermal property, water vapour permeability, air permeability, in-plane wicking and surface friction properties were found out and analyzed. It was found that, water vapour permeability increased and wicking property decreased as cotton percentage increased in the fabric.

Fabric in a pressure garment remains in an extended state during use. As a result, the loop shape, stitch density and thickness of the fabric changes. The comfort characteristics of the fabric are expected to be totally changed during use. Available information on this aspect is not enough. Thermophysiological properties of an elastic knitted fabric were tested in various extended state. The extension of the fabric was varied from 10-60%. Results suggested that, in extended state, permeability improved and thermal resistance decreased

thereby indicating that actual comfort during wear was enhanced compared with fabric in relaxed state.

From this study it could be concluded that there are three important parameters - intrinsic properties of elastic yarn, its physical dimensions and the reduction factor of the garment, that have a strong bearing on the tension development in the fabric and consequently the pressure. It was also seen that addition of cotton to the fabric can be used to improve its comfort characteristics.

Findings of the study provide useful insight into the structure- property relationships of elastic knitted fabrics and tubes made from them. These findings can be used to “engineer” pressure garments to regulate the exact amount of pressure exerted on the human body. Comfort properties can also be controlled as per requirement.

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