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MEASUREMENT OF STRESS IN CLOTHING: A LITERATURE REVIEW AND METHODS SELECTED

by

Rita M. Crow and Malcolm M. Dewar

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ABSTRACT

This paper is a literature review of the methods to determine the magnitude and location of stresses which occur in clothing, as well as what stances cause the maximum stress. It describes various methods tried by the authors and their final selection of methods used both qualitatively and quantitatively to measure stress in clothing.

RÉSUMÉ

Cet exposé est une étude documentaire des méthodes utilisées pour déterminer la force des contraintes auxquelles sont soumis les vêtements lorsqu'ils sont portés, sur quelles parties de ceux-ci elles sont exercées et les positions qui causent les plus grandes tensions sur les tissus. On y décrit les diverses méthodes essayées par les auteurs et celles qu'ils ont choisies pour mesurer les contraintes qualitatives et quantitatives auxquelles sont soumis les vêtements.

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INTRODUCTION

In a DCGEM-sponsored task to determine if alternative seam types could replace the commonly-used double lap seams in Canadian Forces (CF) clothing, the question was raised as to how strong seams have to be in clothing. In a 1952 study, Frederick at Natick, had stated that the seam strength, for the end uses he was considering, should be 80% of the fabric strength. The recommendation arising from the DCGEM-sponsored task (Crow and Dewar, 1983), was that the criteria of 80% seam efficiency be re-validated because of the progress made in technology since Frederick's work, resulting in stronger, more durable sewing threads, seams and fabrics.

Therefore this study was undertaken to find a technique to determine where maximum stresses in clothing, and thus, in seams, occur; to find a reliable method to measure these maximum stresses; and to determine the maximum stresses which would occur in the seams of various CF garments which presently have double lap seams.

This paper will review the literature for methods to determine where stresses occur in clothing, what stances cause maximum stress and how to measure these stresses. It will describe various approaches we tried and our final selection of methods used to both qualitatively and quantitatively measure stress in clothing.

TECHNIQUES TO DETERMINE WHERE MAXIMUM STRESSES OCCUR IN CLOTHING

A REVIEW OF LITERATURE

A review of literature turned up only one pertinent reference for a method to identify where maximum stresses occur in clothing. The original paper, presumably outlining the actual method, is a German

'dissertation' which was unobtainable. Nestler and Schlegel's (1978) paper which referenced this dissertation, briefly described the method as "circular pieces of paper which are stuck to an article of clothing in a scale-like pattern; the distance between these pieces change as a result of the movements performed by the wearer. This method gives a very clear picture of the various stress zones on the garment".

Attempts to reproduce this method by glueing 3.5 cm circular paper discs onto rubber dam or sheeting did give some indication of where stresses occurred, but it was found that very large increases in the percent elongation of the rubber sheeting were required to get visibly discernible movements of the paper discs. Presumably if the paper discs were put on less extensible fabrics which are used for clothing, there would be even less discernible movements of the paper discs.

A indirect approach by Kirk and Ibrahim (1966) was to measure the increase in body dimensions on bending, stretching, etc. in order to establish where maximum local strain areas should occur in clothing. To define the location of the maximum horizontal strain of the skin at the knee, they drew a series of lines on the skin at regular intervals and then measured the changes in skin dimensions which took place with critical body movements, such as bending the knee. They then carried out subsequent experiments using similar techniques on clothed subjects, trying to match the lines on the skin with those put on the clothing. They found that the measured stretch of the skin was always considerably higher than the actual garment stretch. They said this was due to the "taking up of garment volume slack by the body or local fabric slippage and/or over-all constraint of the body".

Emanuel and Barter (1957) also took measurements of various parts of the body in 'neutral' and then selected postures. They marked reference lines on the body and then measured the change in distance between various points or lines.

Since we could not successfully duplicate the technique used by Nestler and Schegel (1978) and found the skin measurement method more applicable to determining what stances cause maximum stress, we tried various approaches to the problem, some of which were successful, and some not. The approaches investigated will now be described.

EXPLORATORY EFFORTS

One of the approaches tried was to thread a low-twist nylon yarn through a highly weft-extensible net fabric. The ends of the yarn were marked with ink so that they could be re-positioned in the net to ensure

that the same amount of yarn was in the net from test to test. For the test, the net fabric was made into a tube to fit the arm. When the arm, with the net on it, was bent, the yarns pulled through the net to accommodate the curvature of the elbow and remained there when the elbow was straightened out, and the net was removed from the arm. A picture of the resulting pattern of the yarn in the net is shown in Figure 1.

In some areas of the body, there will be vertical components of stress as well as the horizontal ones, so the ideal method would detect both. Therefore, the net tube was made with the extensible-weft direction running the length of the arm to detect lengthwise, or vertical stress. This was relatively unsuccessful because there was very little extension of the net in the warp direction, i.e. around the arm, so the arm could barely be bent. This resulted in very little pull-back of the yarns through the net. Although some pattern of stress could be seen using this technique, it was discarded, not only because of its unidirectional drawback, which is common for nets, but because too many variables were involved: the amount of yarn which pulls back through the net depends on the amount of friction between the yarn and the net and the amount of contact of the net on the skin which tends to trap the yarn in the net and not let it move freely through the net.

Another technique of determining where maximum stresses occurring is to mark squares of known size on an extensible fabric and then to measure the distortion of the squares on stressing. This was not attempted in any great detail since the tedious work involved for questionable results was not deemed worthwhile.

The final unsuccessful effort was to make a shirt from a relatively extensible 'eyelet' weft knit whose oval holes became circular when stretched in the weft direction and slit-like when stretched in the warp direction. Figure 2 shows a test subject wearing this shirt. It was found that the size of the holes were just too small to clearly identify areas of maximum stress since relatively small stresses made the holes circular or slit-like.

THE METHOD SELECTED

We realized that an exaggeration of the 'eyelet' weft knit would be the best method of identifying areas of stress in clothing.

The first attempt was to cut alternating slits in a gingham fabric, using the checks as a guide. When the slit fabric was made up into a shirt and evaluated on a test subject (Figure 3), it was found that the slits fell open too readily and had to be eased shut manually on donning

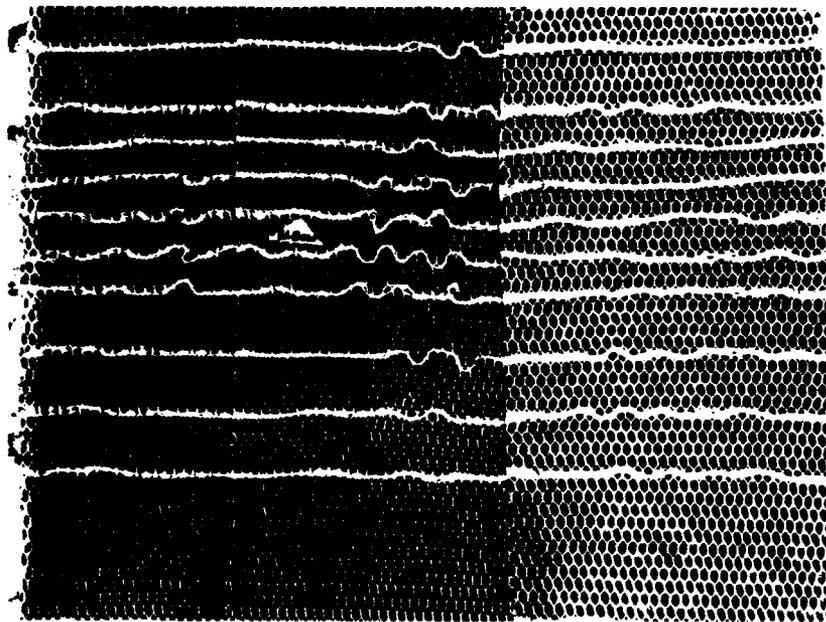


Figure 1: Stress Pattern Indicated by Yarn in a Net Tube After being Stressed Over the Elbow.

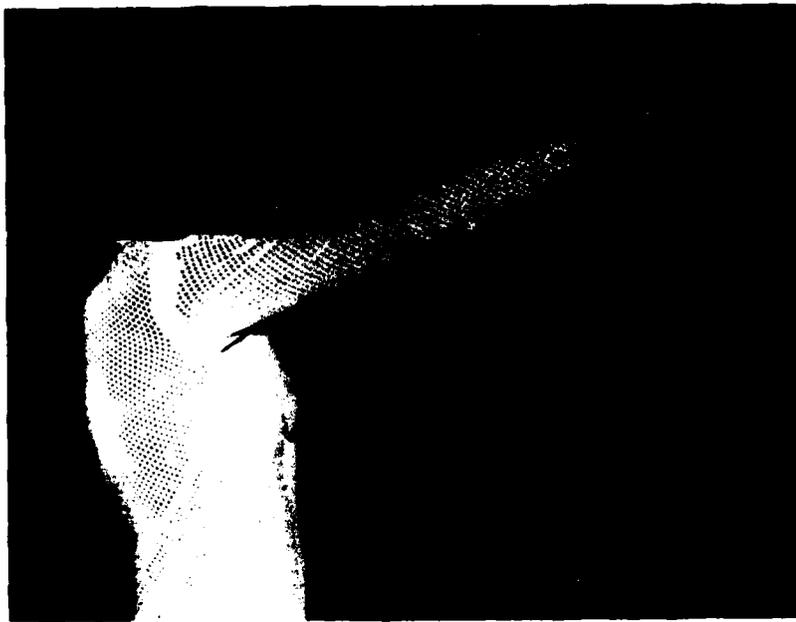


Figure 2: Subject Wearing 'Eyelet' Weft Knit Shirt.

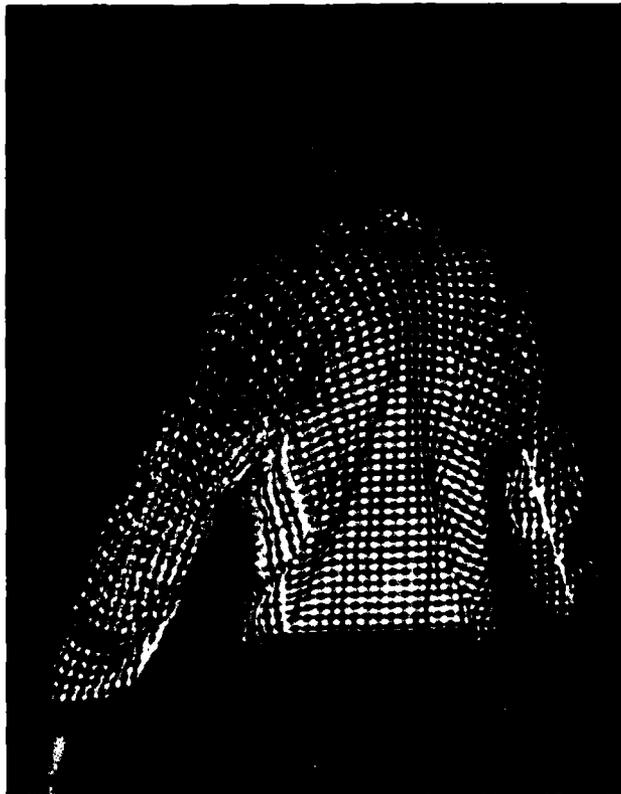


Figure 3: Subject Wearing Slit Gingham Shirt.

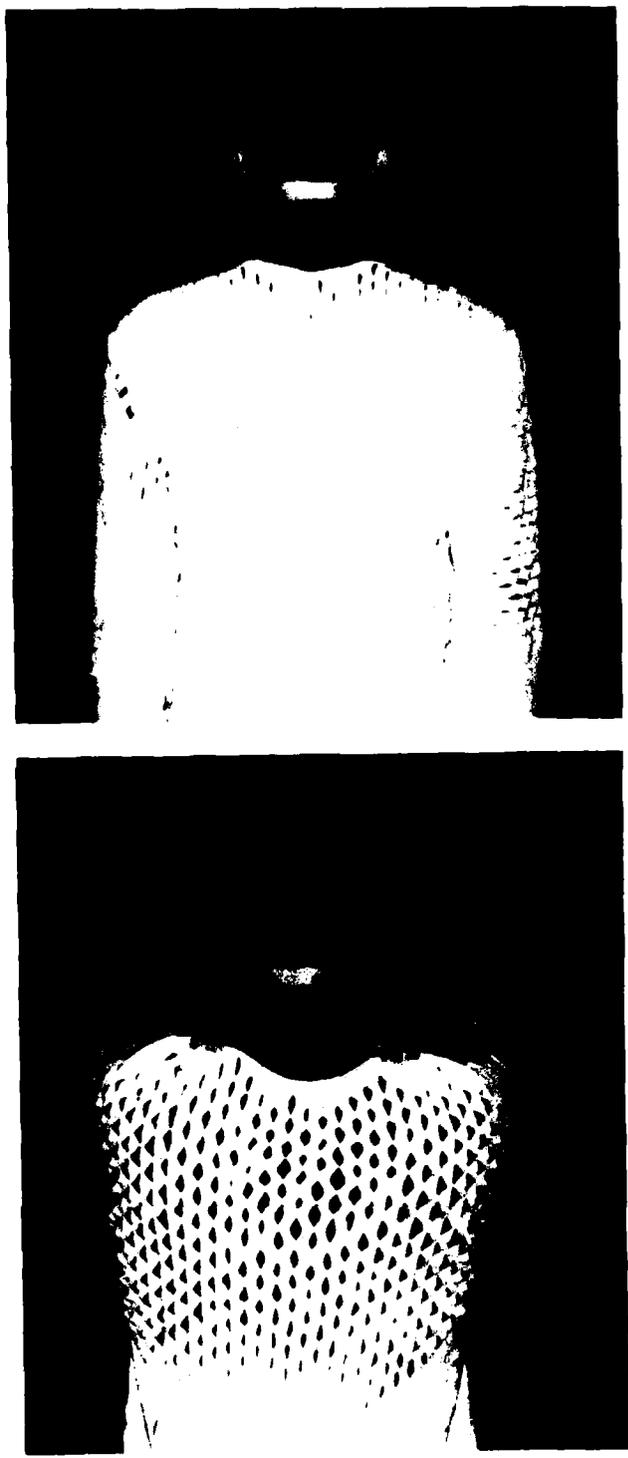


Figure 4: Subject Wearing Slit-Rubber Sheeting Shirt; Unstressed and Stressed.

and after each movement trial. This was mainly due to the relative softness of the fabric which allowed it to drape. Therefore, the final product was made by cutting alternating slits in a highly extensible rubber dam or rubber sheeting. The slits were 1.9 cm long, separated by a space of 0.64 cm, in rows 1.3 cm apart. A T-shirt with set-in sleeves and a pair of trousers were made from the rubber sheeting, the slits being cut in the component pieces before they were sewn together. A non-woven fabric was used as a carrier for handling the pieces as they were being slit and sewn. It was cut away from the seams after sewing. Since the back and the front of the T-shirt were almost identical in shape and size, and so reversible, slits were cut horizontally in one piece and vertically in the other. One sleeve and one side of the trousers had horizontal slits, the other sleeve and side of the trouser, vertical slits. In this way, vertical and horizontal stresses could be detected. Preliminary work showed that this method worked very well (Figure 4), although it was difficult to see stress patterns which occurred at the back of the upper leg when a test subject was in a squatting position, with the calf of the leg touching the back of the upper leg.

STANCES WHICH IMPOSE MAXIMUM GARMENT STRESS

As well as having a method to determine where stresses occur in clothing, it is necessary to know what stances or postures cause maximum stresses. It is primarily the nature of the garment which will determine what stance(s) will impose these maximum stresses, and this is largely determined by the number of 'tie points' the garment has. For instance, a one-piece coverall cannot separate at the waist as a shirt and trousers can. Therefore, when one wears a coverall and bends over, tie points occur at the shoulder and the crotch. When one is wearing a shirt and trousers and bends over, the shirt tail comes out of the trousers and the back waist line of the trousers moves down to accommodate the extra length which is required in the buttock and back area. This movement of the shirt and trousers eliminates the tie points at the shoulder and crotch which the coverall had. Other tie points which can occur are at the elbow for long-sleeved garments when the elbow is bent, at the wrist for a buttoned cuff on a long sleeve shirt when the arm is outstretched and at the knee and buttocks for trousers when squatting.

REVIEW OF LITERATURE

Only one reference was found for determining the stances which impose stress. Nestler and Schlegel (1978) say that they selected

appropriate movements based on detailed observations made while subjects were wearing different garments, and on the qualitative analysis of the results of the paper disc method, as described earlier. We have summarized the stances they used and the area of maximum stress for various garments in Table 1. These authors also mention that considerable stresses can occur in the donning and doffing of clothing.

Worthington (1974), in his study of stresses in seams, did not determine where the maximum stresses occurred, but rather measured the stresses at selected seam areas while subjects performed "common body movements". For trousers, stress was measured across the centre back seam 19 to 24 cm below the waistband for 4 postures: sitting down onto upright and easy chairs; sitting relaxed on chairs; rising to the feet from a sitting position on chairs; the stooping, bending, crouching and sitting on the floor or on the heels. Sitting relaxed on chairs was the least stressful posture of the four types of trousers tested on 3 to 5 wearers. For men's jackets, stress was measured across the armhole seams at 19 to 24 cm below the shoulder and/or across the centre-back seam 15 to 20 cm below the neck as the subject bent, stretched and folded arms while standing and sitting. For one of the jackets an added posture was that of thrusting the hands into side pockets of the jacket both while standing and while sitting. This posture did add slightly more stress to the centre-back seam than the other postures. For men's shirts, stress was measured across the centre back armhole seam and across centre back (not on a seam). For women's frocks, stress was measured across the back armhole seam 20 cm below the shoulder and across the side seam in line with the bust when the wearers bent, stretched and folded their arms while standing and sitting. The author noted that stresses across the back yoke of the men's shirts larger than those recorded for the above postures can occur if the shirt is pulled off over the head without fully unbuttoning the shirt first. Stress in a woman's pantie girdle was measured across the centre back seam 14 cm below the waist edge in bending and stretching of the trunk in standing postures as well as when putting on and taking off the girdle.

Limited work has been done to find out how much the nude body stretches between arbitrary points in order to design tight-fitting garments or stretch fabrics, such as those which arrived on the consumer market in the sixties. The results of these skin measurements will be briefly summarized here as they do give a good indication of what stances cause the body, and by implication the clothing, to stretch the most. Kirk and Ibrahim (1966) found that the greatest local skin strain occurred at the knee when going from standing to a deep bend, and at the elbow when going from straight to full bend, as measured in the vertical direction. In the seat, the greatest local body strain occurred in the vertical direction in the 'local buttocks' when going from standing to bending. In the back the greatest local skin strain was found going from standing erect to bending over frontwards to tie shoes.

Interpreting the results of Emanuel and Barter (1957), which we have selectively summarized in Table 2, we find that bending the elbow, holding the arm to the back or to the front, sitting with knees up,

TABLE 1
 Stances Which Impose Maximum Stress on Clothing
 (Nestler and Schlegel, 1978)

<u>Garment</u>	<u>Stance</u>	<u>Area of Maximum Stress</u>
Sports Jackets	"Bend forward until your fingers touch the floor".	At the waist at centre back seam.
Ladies Pullover	"Cross your arms and lay your hands on your elbows".	Under the armpit.
Ladies Slip	"As sports jackets".	Armpit region.
Swimwear	"Crouch with knees spread apart".	Hip area.
Track Suit - Jacket	"Various movements".	Armscye*
Trousers	"Various Movements".	Seat seam.

* Point of smallest radius of an armhole.

TABLE 2

Selected Summary of Results of Emanuel and Barter (1957)

Part of the Body	Measurement Limits	Movement	Increase in Dimension (cm)
Elbow	Mid-arm to Mid-forearm	Straight to bent	8.5
Chest	Sternum-at-Scye Level to Anterior Scye Point	Arm at side to arm held (i) to back (ii) straight out at side	2.8 2.5
Arm	Anterior Scye Point to Mid-arm line	As for chest (i) to back (ii) to side	1.8 1.5
Back	Posterior Scye Point to Mid-arm line	Arm at side to arm held (i) to front (ii) straight out at side (iii) above head	4.8 1.5 4.6
	Vertebra-at-Scye Level to Posterior Scye Level	As above (i) to front (ii) to side (iii) above head	9.1 2.0 5.8
	Cervicale (back of neck) to tip of coccyx	Sitting to bending over for maximum spinal curvature	10.1
Trunk	Iliac Spine (just below waist) to Mid-thigh line	Standing to (i) sitting (ii) sitting with knees up	8.6 15.2
Knee	Mid-thigh to Mid-leg	Standing to (i) sitting (ii) knee bent forcibly	6.0 10.4

forcibly bending the knee and bending over to get maximum spinal curvature, all gave the maximum increases in local body measurements.

THE STANCES SELECTED

The clothing which will be used in our study will be CF clothing and generally, will be either long-sleeve shirts and trousers or coveralls. From the literature review, the stances which will probably stress the CF clothing the most are fully bending the elbow (sleeve), forcibly bending the knee (trouser leg), crossing one's arms in the front (shirt back), bending over for maximum spinal curvature (back of coverall) and sitting with the knees up (seat of trousers).

THE MEASUREMENT OF STRESS IN CLOTHING

There are many methods for measuring the stress in materials, especially rigid materials such as metals and plastics. The main methods are outlined in depth by Dally and Riley (1978) and include brittle-coating methods, strain-measurement methods as well as optical methods of stress analysis such as moiré, photoelasticity and birefringent coating techniques. A brief review in a Hewlett-Packard Application Note (1981) adds the measurement of gauge length and the use of mechanical devices to this list of ways to measure strain in materials. A review of the literature showed that the most popular method of measuring stresses in clothing or textile-like materials is with strain-measurement methods, using strain gauges mounted on metal 'carriers' (Worthington (1974), Rand (1983), Garrard and Carey (1982)). Nestler and Schlegel (1978) used 'extensible measuring strips' or 'extensometers' mounted on a textile carrier, to measure stress in clothing.

This section will describe our evaluation of various methods of measuring stress or strain as applied to textiles and clothing.

METHODS OF MEASURING STRESS EXCLUDING STRAIN-MEASUREMENT METHODS

The methods for measuring stress, as outlined above, are typically used on materials such as metals and plastics. We thought that of these, brittle-coating methods and gauge length techniques could be applied successfully to measuring stresses in clothing. Optical methods of stress analysis were not tried since the equipment required was usually complex and costly. Also a great amount of expertise was required in operating this equipment. For some of the techniques, the non-translucent, highly-flexible and expansive human body just does not lend itself to them. Mechanical devices, such as the extensometer used by Nestler and Schlegel (1978), were not evaluated since none could be found commercially.

This section will discuss our evaluation of brittle coatings, our attempts to use gauge-length measurements in clothing and some 'go-no-go' techniques.

BRITTLE COATINGS

A commercially-available brittle coating, "STRESSCOAT", manufactured by Magnaflux Corporation, was sprayed on a woven fabric, a weft-knit fabric, a 0.08 cm thick metal sheet and a 0.15 cm thick plastic sheet. An undercoat was first sprayed on the surfaces of these materials, then the strain-indicating coating. The STRESSCOAT performed well on the metal and plastic, cracking and crazing in areas of stress when these materials were slightly bent. When the coatings were applied to the textile materials, the materials stiffened considerably, altering their basic physical properties. When the fabrics were stressed, the coating tended to flake rather than crack. This was probably due to the relatively high elasticity of the fabrics which caused the brittle coating to break in many places.

Limited attempts to coat the fabrics with some compatible coatings such as starches produced the same results as with the STRESSCOAT when the fabrics were stressed.

It was concluded that for brittle coatings to work successfully on textiles, they would have to be made with an elasticity closer to that of the textile substrate to which they were to be applied. Because of the wide range of elastic properties of textiles used in clothing, a wide range

of coatings would be required. It was concluded that the use of brittle coatings is not a practical or expedient method of measuring stress in textile materials.

GAUGE LENGTH

At the beginning of this study, it was thought that the measurement of strain by measuring the displacement between two points some distance apart (called the gauge length) would be appropriate for clothing because any such device which would do this would probably be lightweight, easily attached to clothing and could be flexible enough to conform to the curves of the body. The general concept of such a device was that if it initially had a fixed length, l , when stressed it would extend Δl and remain in this extended state upon removal of the stress. Δl could then be measured and correlated to a previously-determined stress versus Δl curve. It was considered that the advantage of a simple gauge-length measuring method over strain gauges with their traditional umbilical electrical wires is that stress could be readily measured during normal donning and doffing of clothing or during wear under field conditions.

Various ideas of ways to measure gauge length were tried. For instance, it is known that undrawn textile fibres extend readily when stress is applied, and remain more or less in the extended state when the stress is removed. However, examination of typical stress-strain (Figure 5) of drawn fibres showed that a very large stress was required to initiate extension, after which high extension occurred at a constant load. Therefore, this approach was discarded.

The next device which was tried was the plastic-molded cable tie (Figure 6). This device has a ratchet-type tongue which, once it has passed through the head, is prevented from passing back through the head by an anti-ratchet locking device in the head. Two heads and a tongue were used as shown in Figure 6. Thumb tacks into the heads held the device to the fabric. It was found that, as with the undrawn textile fibre, a relatively large load was required to start the tongue through the head. The fabric on which the device was mounted had to be quite extensible to give any movement of the tongue through the heads. At low stresses, the heads tended to bend towards each other rather than remaining upright with the tongue passing through one.

The next attempt was to extend the idea, described earlier, of threading the low-twist nylon yarn through the extensible net, but this time to use the yarn as a gauge length. Cords were threaded through a highly extensible material, in this case, the honeycomb knitted fabric of an underwear top. To exaggerate the extension on stressing this fabric,

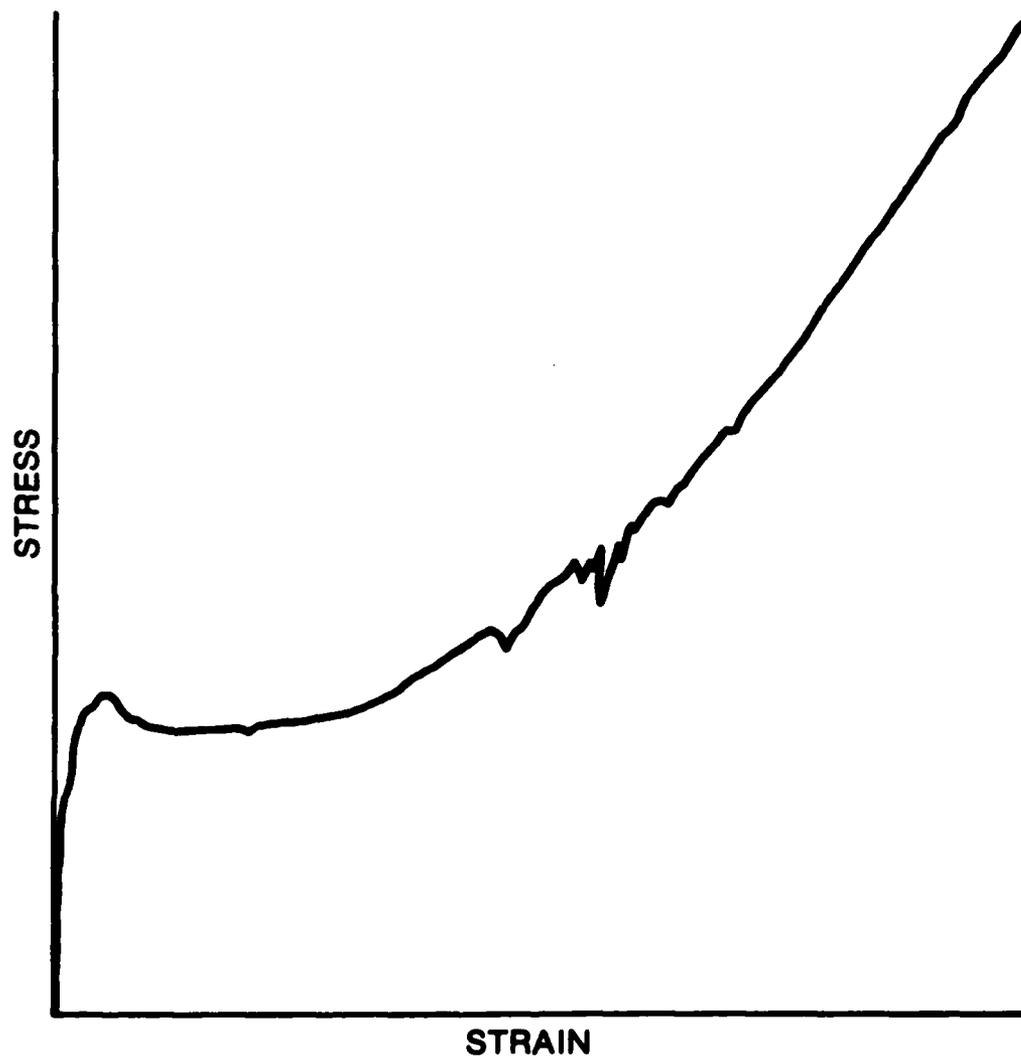


Figure 5: Typical Stress-Strain Curve of Previously Undrawn Textile Fibre.

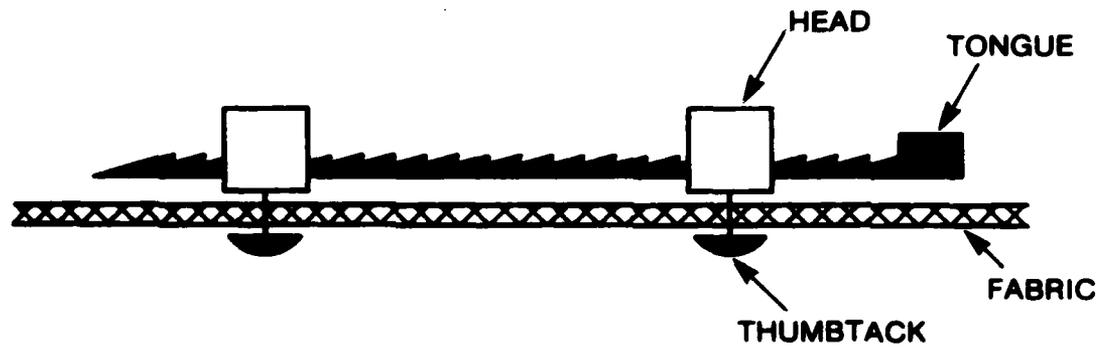


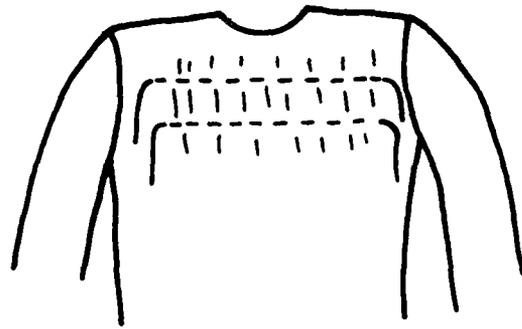
Figure 6: Schematic Drawing of Cable Tie, Adapted to Member Gauge Length.

the gauge length of the cord was made slightly less than that of the fabric through which it was threaded, as shown in Figure 7a. The gauge length was marked on the cord with red ink. When the underwear was donned and then stressed by various movements, the cords moved through the fabric to accommodate the stretched length of the fabric (Figure 7b). When the stress was removed, the fabric returned to its relaxed state, but the cord did not, leaving a portion of the cord in the fabric (Figure 7c). Although this method did give some indication of the areas of highest stress the extension of the underwear and the body was not large across the back. Therefore, a long gauge length of cord was needed to obtain any discernible movement of the cord into the fabric. It would have been extremely difficult to calibrate the actual amount of stress which caused the extension of the underwear and the accompanying run-back of the cord since the fabric and the cord were not free-stressed, but stressed against the surface of the human body. Reproducing the many curvatures of the human body for such a calibration would have been extremely tedious and probably not very accurate.

A linear variable differential transformer, a LVDT, was evaluated. It is shown schematically in Figure 8. The core is made of a magnetic material, supported on a shaft of non-magnetic material. When the core is displaced and it moves relative to the coils, an electrical output is produced across the coils in proportion to the distance moved by the core. The evaluation showed that the LVDT performed as it should, with a high sensitivity, but its overall length of 2.5 to 3 cm made it too long to conform to the curves of the body, such as at the back scye of the armhole. Further, some type of mounting device would have to be made to attach it to clothing, and this would increase the bulk of the device. Of course, umbilical electrical leads are required. The LVDT would be probably suitable for measurement of stresses of flat surfaces such as those in tents.

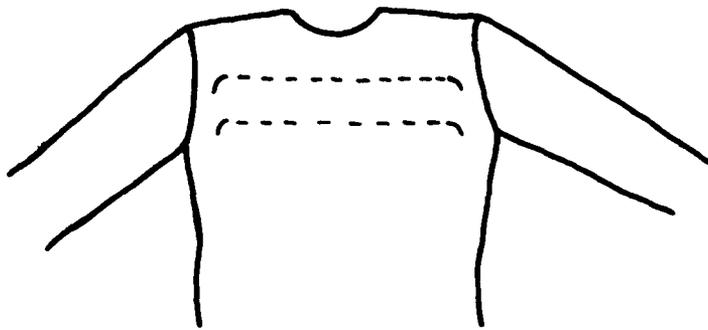
GO-NO-GO TECHNIQUES

One go-no-go technique would be to make seams of a range of known strengths in clothing. When a particular seam broke, the approximate force required to do this, the part of the seam where this occurred and the movement of the body which caused this breakage would all be known. The great advantage of this method is that it imitates exactly what actually happens in normal wearing of clothing, and would simultaneously give the results required in this research project. The problem with this method is to find sewing threads, or equivalent material weak enough to readily break over a range of 0 to 30N, and still be strong enough to be made into a seam. To evaluate the idea, strips of hook Velcro were sewn to either side of an unpicked back armhole seam of a laboratory coat. Various widths of



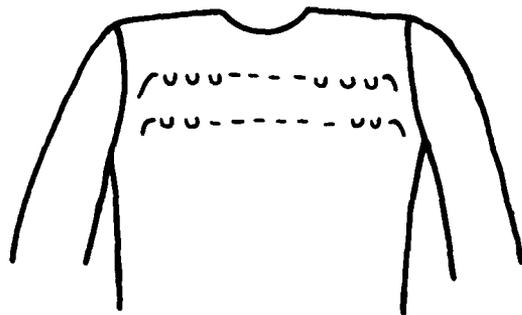
(a)

UNEXTENDED STATE



(b)

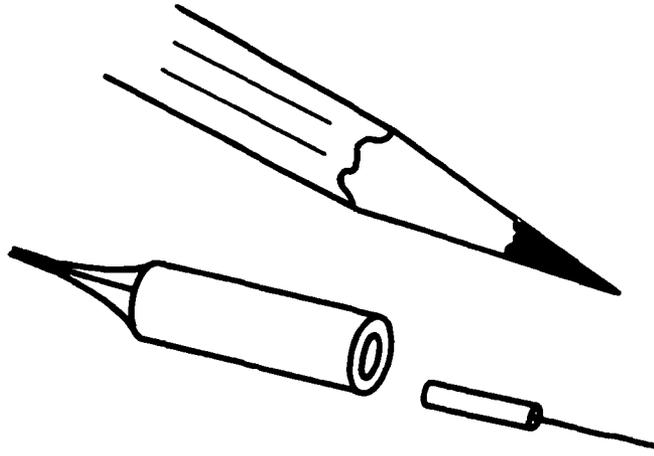
EXTENDED STATE



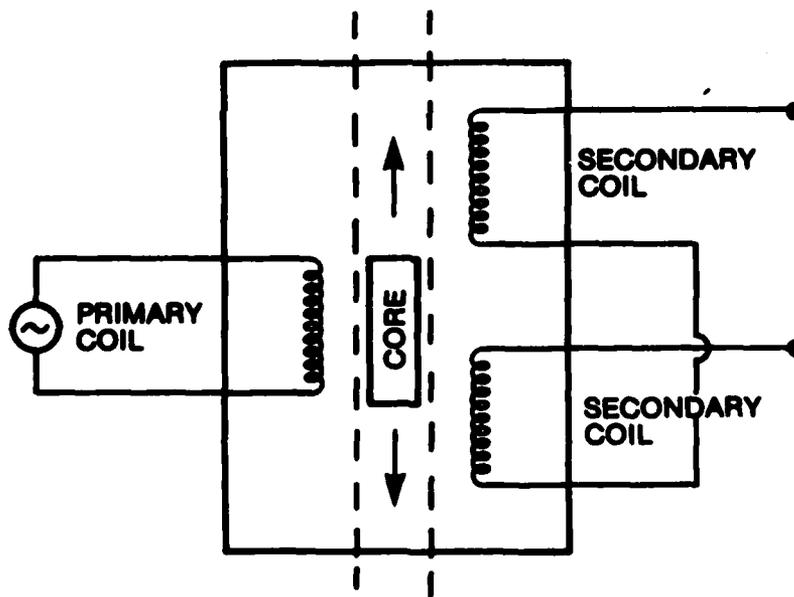
(c)

RELAXED STATE

Figure 7: The Use of Cord in an Extensible Fabric to Measure Increase in Gauge Length on Stressing.



Schematic Drawing of a Sub-Miniature Linear Variable Differential Transformer.



Schematic Diagram of a LVDT

Figure 8

pile Velcro were placed across the armhole to close it up. The wider the pile Velcro, the more force was required to detach it from the hook Velcro. This worked well for very crude measurements, but much refining of the method would be required to control variables such as area of contact of the hook and pile Velcro and the degree of attachment of the two Velcro strips.

MEASURING STRESS WITH STRAIN GAUGES

As mentioned earlier, the most common technique for measuring stress in clothing or textile-like materials (e.g. polyethylene film for high-altitude balloons) is with strain gauges. The problem with using strain gauges on such materials is that the gauge itself cannot be glued directly onto the material since this alters the elastic properties of the materials immediately around as well as under the strain gauge. The relatively large extensions which occur in such materials are incompatible with the small amount of extension of the strain gauges which are designed to be attached to much more rigid, inextensible materials. Therefore, the approach by other workers has been to attach strain gauges to metal 'carriers' which in turn are attached to the material. Large changes in material strain are thus 'stepped down' by the metal carrier to which the gauge is attached. Repeatable and reproducible measurements can then be made.

REVIEW OF LITERATURE

The differences in the three references found which use strain gauges for measuring stress in clothing, parachutes and high altitude balloons is the shape of the metal carrier to which the strain gauge is attached. Worthington (1974) developed a bridge clip (Figure 9a) to measure stress in seams. When stress is applied to the fabric, to which the bridge clip is attached by means of a central staple, the centre of the bridge is deflected downward and the strain gauges on the bridge register a resistance in proportion to this strain. Worthington found some difficulties with this bridge clip when the fabric on which it was mounted formed furrows when the fabric was stressed. No entirely satisfactory way to overcome this problem was found.

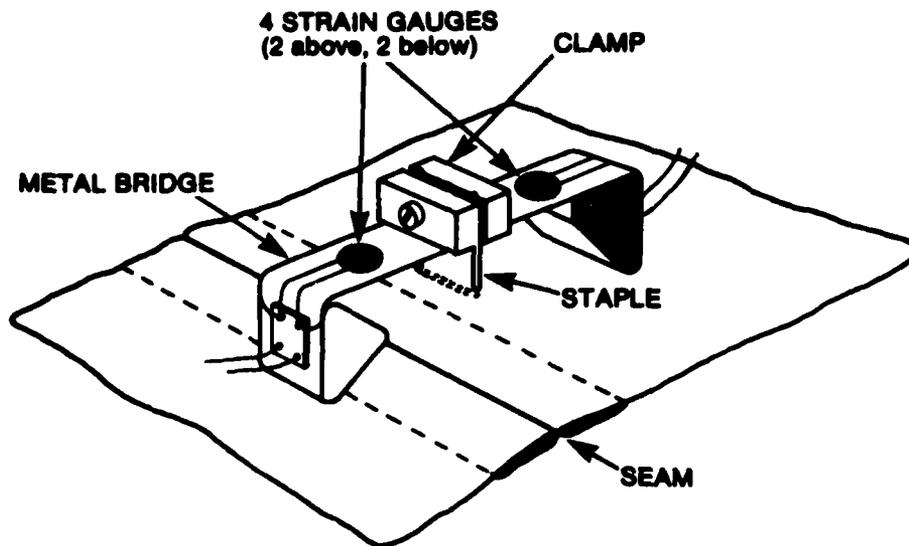


Figure 9a. Worthington's Bridge Clip.

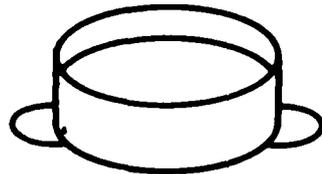


Figure 9b. Rand's Circular Metal Carrier.

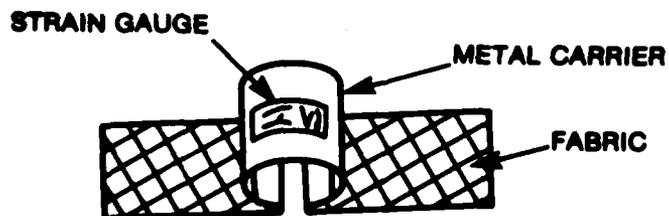


Figure 9c. Garrard and Carey's Omega Sensor.

Rand (1981) has developed a circular metal carrier (Figure 9b) for measuring strain on the thin polyethylene-film high-altitude balloons. Any distortion or strain of the film translates into a distortion of the circle which has strain gauges mounted on it.

Garrard and Carey (1982) report an Omega sensor or bridge carrier (Figure 9c) for measuring stresses on model parachute canopies. The Omega sensor is so named because of its shape and acts in much the same way as the circular carrier; any distortion or strain of the material to which it is attached translate into the separation of the 'feet' of the Omega carrier, causing distortion of the circular part of the carrier, and thus of the strain gauge on it.

The latter two metal carriers were attached by gluing the lobes of the circular carrier or the feet of the Omega carrier to their respective materials.

THE METHOD SELECTED

The requirement for our particular application was that the carrier be able to be attached and detached easily from clothing so that strain measurements could be taken at a variety of locations on several types of clothing. Worthington's bridge clip filled this requirement, but some means of temporarily attaching the sensor to the fabric had to be devised for Rand's circular carrier and the Omega sensor. The original Omega sensor had its feet made of fabric which was glued onto the circular portion of it. We modified this slightly so that the whole sensor was made from one piece of metal, and bent to give a similar Omega shape. The feet of the Omega sensor provided a good site for fabric attachment by simply drilling a small hole in each foot, putting a thumb tack through the hole and fabric, and then capping the thumb tack with a small plastic cap to hold the sensor on the fabric. Finding a means to attach Rand's circular carrier proved more difficult, and no satisfactory way for temporarily attaching it to fabric was found. Therefore only the Worthington bridge clip and the Omega sensor were evaluated. A strain gauge was placed on each, and it was found that the sensitivity of the bridge clip was three times that of the Omega sensor. Subsequent calibration of the Worthington bridge clip showed that it performed well, and would be suitable for measurement of stress in clothing; thus, it was selected for use in this project.

CONCLUSIONS

The literature review and the various approaches tried have shown that:

(1) The areas of maximum stress in clothing can be best identified by having a subject wear clothing made of slit rubber-sheeting, the slits opening up in the areas of high stress for the various stances taken by the subject.

(2) The stances which will probably stress CF clothing the most are fully bending the elbow (sleeve), forcibly bending the knee (trouser leg), crossing one's arms in the front (shirt back), bending over for maximum spinal curvature (back of coveralls), and sitting with the knees up (seat of trousers).

(3) The optimum method for measuring stress in clothing is with the Worthington bridge clip on which a strain gauge is mounted.

REFERENCES

Rita M. Crow and Malcolm M. Dewar. Comparison of Seam Types. Defence Research Establishment Ottawa Technical Note 83-21, September 1983.

James W. Dally and William E. Riley. Experimental Stress Analysis, Second Edition, McGraw-Hill Inc., New York, 1978.

I. Emanuel and J.T. Barter. Linear Distance Changes Over Body Joints. WADC Technical Report 56-364, Wright-Patterson Air Force Base, Ohio, February 1957.

E.B. Frederick. Development of a Sewability Test for Cotton Fabrics. Tech. Res. J., 1952, 22, pp 687-692.

W.L. Garrard and D.G. Carey. Properties, Construction and Use of the Omega Sensor for Stress Measurement, Dept. of Aerospace Engineering and Mechanics, University of Minnesota, June 1982.

Hewlett-packard Co., Application Note 290-1 Practical Strain Gage Measurement. Hewlett-Packard Co., Palo Alto, CA, September 1981.

W. Kirk and S.M. Ibrahim. Fundamental Relationship of Fabric Extensibility to Anthropometric Requirements and Garment Performance. Text. Res. J. 36, No. 1, pp 37-47, 1966.

R. Nestler and W. Schlegel. Determining the Stresses to Which Wearing Apparel is Subjected. Textiltechnik, 28, No. 2, pp 113-117, 1978 (Unedited translation).

James L. Rand. A Balloon Strain Gage. AIAA-81-1946, AIAA 7th Aerodynamic Decelerator and Balloon Technology Conference, Oct 21-23, 1981, San Diego, CA.

A.P. Worthington. Stresses in Seams. Shirley Institute Bulletin, 47, No. 5, pp 131-136, 1974.

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13. ABSTRACT This paper is a literature review of the methods to determine the magnitude and location of stresses which occur in clothing, as well as what stances cause the maximum stress. It describes various methods tried by the authors and their final selection of methods used both qualitatively and quantitatively to measure stress in clothing.		

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