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Estimation of Differential Fiber Hooking by Fibrograph

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ABSTRACT

The fibrogram shapes of clamped fiber beards have been deduced under a range of conditions. For constant staple length material and for fibers with low length variability, the maximum span length difference between the fibrograms in the two directions becomes equal to the differential hook extent in the sliver. When length variability is more, the maximum span length difference is found to be different but is still closely related to the differential hook extent.

Introduction

Disorientation and presence of hooks in fiber are characteristic features of card slivers. In addition there is also an asymmetry in the amount of hooking in the two directions of the sliver. Not only are hooks more numerous, but also their extents are larger in the trailing direction as the material leaves the card. Since the direction of presentation of hooks has a marked effect upon the quality of combing and drafting, considerable interest is evinced in evolving methods for measuring the differential hooking in a sliver. Lindsley [5] and others [8, 9] have used measures like combing and cutting ratios for this purpose, but the usefulness of these measures was found to be limited because of their dependence upon the clamp length and the fiber length [11]. Foster, Gregory, and Womersley [3] employed a much simpler and more direct method for determining the disorientation in a sliver. Tallant, Pittman, and Patureau [10] extended this method to obtain differential hooking. The theoretical basis for this method is given by Pittman and Tallant [7]. A similar method was also suggested earlier by Nakagawa and Nagashima [6]. Basically the method consists in clamping the sliver across a section and combing out the loose fibers not held by the clamp. If there is differential fiber hooking, the beard projecting from the clamp will be heavier in one direction than in the other, depending upon the direction of lie of the majority hooks. Tallant *et al.* [10] showed that the difference in weights could be used to estimate differential hooking under certain conditions.

Jain [4] and Audivert [1] also employed the same method of clamping the sliver and combing out the fibers for getting the fiber beard, but they used the fibrograph to determine the length distribution or fibrogram of the projecting beard. The span length (at a given frequency) of the fibrogram was found to be dependent upon the direction of lie of the majority hooks, and span length difference was therefore used to determine differential hook length. An interesting finding emerging from these studies is that the span length differences are more marked at 50% and 67% than at 2.5% frequency. In an earlier paper [2] a theoretical explanation for this finding was provided. This work was later extended to obtain the shapes of fibrograms under a variety of conditions and to find out if the differential hooking can be estimated from the fibrograms. The results of these studies are discussed in this paper.

Results and Discussion

It is assumed that all fibers are straight and parallel to the sliver axis. The sliver is clamped across a section and the fibers that are not held by the clamp are combed out. The fibrogram profile projecting from the clamp is dependent upon the proportion of hooked fibers, the hook extent, and the direction of lie of the hooks. From these profiles, projecting to the left and right of the clamp, useful information can be obtained in regard to the amount of differential hooking present in the sliver.

CONSTANT FIBER LENGTH WITH CONSTANT HOOK EXTENTS. We will first consider the case when all fibers are of the same length l. Fractional hook extent is also assumed as constant, being u in one direction and v in the opposite direction; p denotes the proportion of fibers with u hooks, and q, with v hooks. We take u greater than v and p greater than q. Obviously, the differential hook extent in the sliver is given by $l(pu - qv)$. This measure has been used because of its simplicity, even though it may not fully quantify differential hooking.

Consider the fiber beard projecting to the right of the clamp. Let $r_1(x)$ denote the proportion of fibers with span length x when u hooks are at the left. Then $r_1(x)$ gives the fraction of fibers (held by the clamp) which project to a length equal to or greater than x from the clamp to the right. In actual practice the number of fibers crossing a section of sliver varies from place to place, and $r_1(x)$ denotes an average fraction obtained in the following manner. If $N(x,w)$ is the number of fibers crossing the section at distance x from the clamp in the sample w, then $N(x,w)$ is a stochastic process. If the total number of fibers held by the clamp is $N(o,w)$, $r_1(x)$ is given by:

$$r_1(x) = \int \frac{N(x,w)\mathrm{d}p(w)}{N(o,w)}.$$

Contribution to $r_1(x)$ comes from

a) straight fibers,
b) fibers with hooks at left, and
c) fibers with hooks at right.

The fibrogram profiles for these three categories of fibers are illustrated in Figures 1a, b, and c.

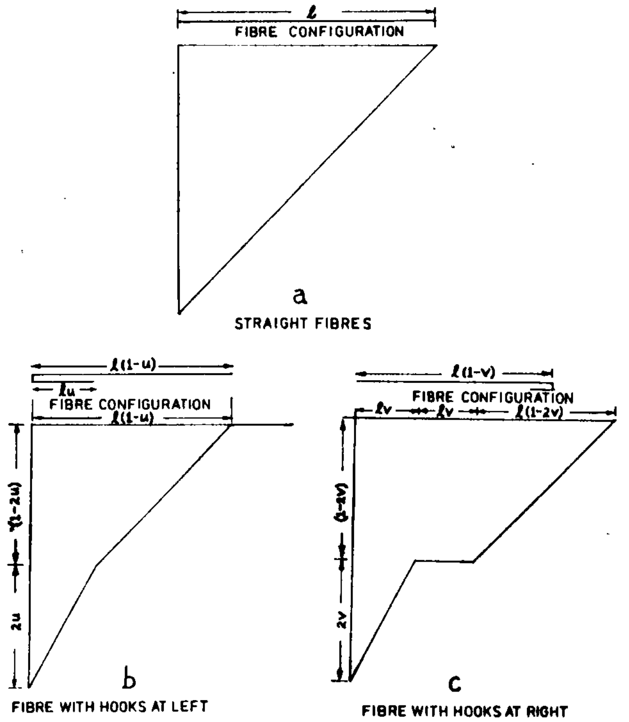

FIG. 1. Fibrograms with constant staple length and constant hook extent (all fibers of the same type). a) straight fibers; b) fibers with hooks at left; c) fibers with hooks at right.

It is easy to see that the contribution to $r_1(x)$ from the straight fibers is

$$\frac{(l-x)}{l}(1-p-q).$$

The contribution from fibers with hooks on the left is

$$= 0, \qquad \text{when } l(1-u) < x \leqslant l,$$

$$= \frac{p}{l}[l(1-u)-x], \qquad lu < x \leqslant l(1-u),$$

$$= \frac{p}{l}[l(1-u)-x] + \frac{p}{l}[lu-x], \quad 0 < x \leqslant lu.$$

The contribution from fibers with hooks at right is

$$= \frac{q}{l}[l-x], \qquad 2lv < x \leqslant l,$$

$$= q[1-2v], \qquad lv < x \leqslant 2lv,$$

$$= q[1-2v] + \frac{2q}{l}[lv-x], \quad 0 < x \leqslant lv.$$

(The last equations in both of these sets admit of a simpler presentation, *viz.*, $p(1-2x/l)$ and $q(1-2x/l)$ exhibiting a symmetry; however, the present form brings out the contributions from the hooked and straight parts more clearly.)

The fibrogram profile is obtained by the superposition of these three; it consists of a number of straight segments forming a chain. In general, the points of discontinuities will be at distances lv, lu, $2lv$, $l(1-u)$, perpendicular to the direction of the clamp. As the order of these points is determined by u and v, we will get distinct profiles when $u \geqslant 2v$, and $u < 2v$.

In the case of the first alternative, when $u \geqslant 2v$, the analytical expressions of $r_1(x)$ are

$$r_1(x)$$

$$= -\frac{(1-p)}{l}x + (1-p), \quad l(1-u) < x \leqslant l,$$

$$= -\frac{x}{l} + (1-pu), \qquad lu < x \leqslant l(1-u),$$

$$= -\frac{(1+p)x}{l} + 1, \qquad 2lv < x \leqslant lu,$$

$$= -\frac{(1+p-q)}{l}x + (1-2qv), \quad lv < x \leqslant 2lv,$$

$$= -\frac{(1+p+q)}{l}x + 1, \qquad 0 < x \leqslant lv.$$

In the latter event, when $u < 2v$, the first and the last relations continue to hold, but the middle equalities change to

$$r_1(x) = -\frac{x}{l} + (1-pu), \qquad 2lv < x \leqslant l(1-u),$$

$$= -\frac{(1-q)}{l}x + (1-pu-2qv), \qquad lu < x \leqslant 2lv,$$

$$= -\frac{(1+p-q)}{l}x + (1-2qv), \qquad lv < x \leqslant lu.$$

The fibrogram when u hooks are at right ($r_2(x)$ *vs.* x) can be determinted in a like manner; it is also obtained from the above set of equations on interchanging u and p by v and q, respectively. Fibrograms thus obtained are shown in Figure 2 for an arbitrary selection of values of u, v, p, and q.

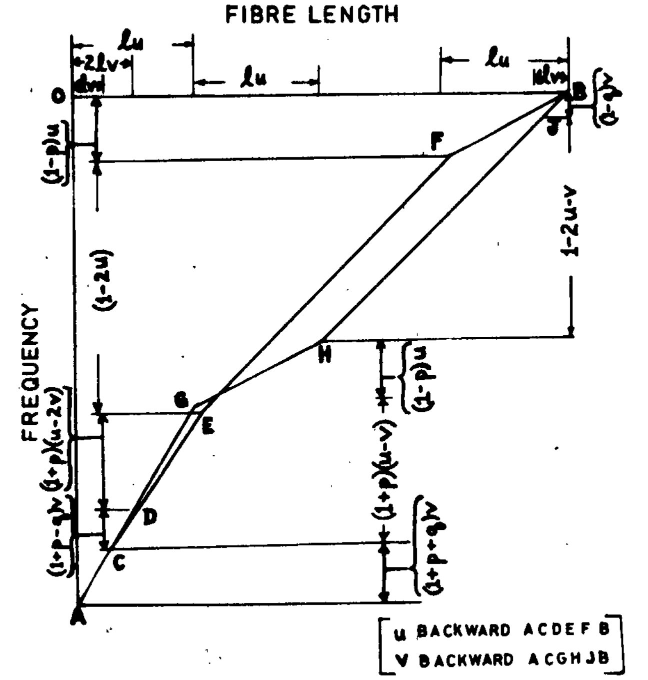

FIG. 2. Fibrograms with constant fiber length and hook extent (proportion of fibers with u hooks is p, and proportion with v hooks is q).

It will be noticed that the difference in span lengths between the fibrograms increases, attains a maximum, and then diminishes again. This is a characteristic feature of fibrograms obtained from slivers having differential hooking; it arises because the sliver is made up of hooks in either direction as well as straight fibers. This serves to explain the findings of Jain and Audivert, who found that the span length differences are more prominent at 50% and 67% frequency than at 2.5% frequency.

If $(1-2u-qv) > (1-p)u$, the fibrograms contain parallel segments with a common slope $-1/l$; these are displaced by a distance $l(pu-qv)$ measured parallel to the length axis over the length region $2lu$ to $l(1-u)$. The span length difference is also maximum in this region unless $(pu-qv) > (u-v)$.

When $(pu-qv) > (u-v)$, the span length difference reaches a maximum at the relative frequency $u(1-p)$ and has a value

$$u\left[\frac{p-q}{1-q}\right].$$

Reverting to the case $(pu-qv) \leqslant (u-v)$, we see that the maximum span length difference is $l(pu-qv)$, provided $(1-2u-qv) > (1-p)u$. As a numerical illustration, if $p=0.5$, $q=0.25$, $v=0.1$ the above condition holds for values of u as high as 0.39.

CONSTANT FIBER LENGTH AND VARIABLE HOOK EXTENT. Let us suppose that the fibers are of constant length l, but that the fractional hook extent is variable. For the u hooks the fractional hook extent varies from u_1 to u_m with a mean $\bar{u}$; and for v hooks, from v_1 to v_m with a mean $\bar{v}$. Let $f(u)$ and $g(v)$ be the corresponding density functions for u and v. The function $r_1(x)$ is given by:

$$\begin{aligned} r_1(x) = {} & \frac{l-x}{l}(1-p-q) \\ & + \frac{p}{l}\int_{u_1}^{(l-x)/l}[l(1-u)-x]f(u)\mathrm{d}u \\ & + \frac{p}{l}\int_{x/l}^{u_m}[lu-x]f(u)\mathrm{d}u \\ & + \frac{q}{l}\int_{v_1}^{x/2l}[l-x]g(v)\mathrm{d}v \\ & + \frac{q}{l}\int_{x/2l}^{v_m}l[1-2v]g(v)\mathrm{d}v \\ & + \frac{q}{l}\int_{x/l}^{v_m}2[lv-x]g(v)\mathrm{d}v. \end{aligned}$$

It is easy to see that in the above equation the first term represents the contribution from the straight fibers, the terms in the second and third lines represent those from fibers with u hooks, and the remaining terms, with v hooks. When u hooks are at right, the fibrogram can be calculated in a similar manner. Shapes of fibrograms calculated from the above equation are given in Figure 3. When u hooks are at left, the part of the fibrogram between Max $(lu_m, 2lv_m)$ and $l(1-u_m)$ (*i.e.* GF) is a straight line and is given by

$$r_1(x) = -\frac{x}{l} + (1-p\bar{u}).$$

Similarly, if u hooks are at right, the fibrogram is a straight line between $2lu_m$ and $l(1-v_m)$ (*i.e.* HJ) and is given by

$$r_2(x) = -\frac{x}{l} + (1-q\bar{v}).$$

The difference in span length is constant and it is at a maximum, being equal to $l(p\bar{u}-q\bar{v})$ in the relative frequency range $(u_m - p\bar{u})$ to $(1-2u_m-q\bar{v})$ (*i.e.* F

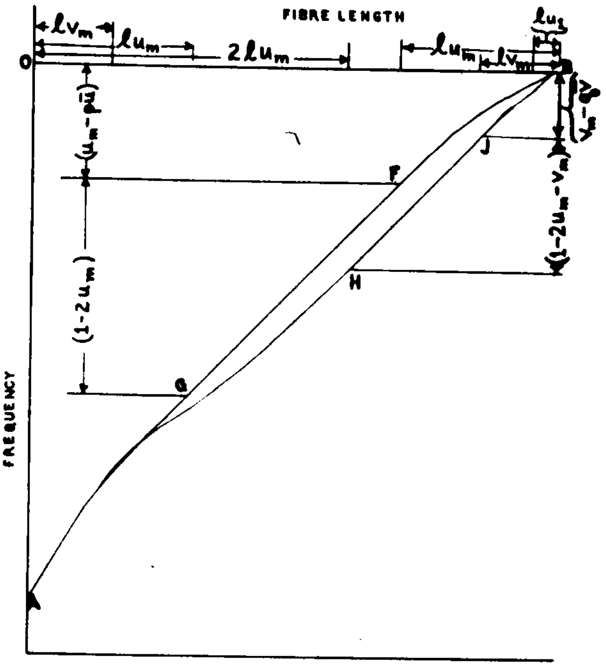

FIG. 3. Fibrograms with constant fiber length and variable hook extent (u hooks vary from u_1 to u_m with mean $= \bar{u}$, and v hooks vary from v_1 to v_m with mean $= \bar{v}$); u backward—AGFB, v backward—AHJB.

to H), provided the former is the smaller of the two. As this condition is normally fulfilled for the textile slivers, the maximum span difference can be used to estimate differential hook length for constant staple fibers. Calculations show (Table I) that the maximum span difference is close to $(p\bar{u} - q\bar{v})l$, even if $(u_m - p\bar{u}) > (1 - 2u_m - q\bar{v})$, provided the difference is not too large. Hook extent is assumed to follow a truncated normal distribution (varying between mean $\pm 3\sigma$) and $l = 1$.

TABLE I. Relation between maximum span length difference and differential hook extent (when $(u_m - p\bar{u}) > (1 - 2u_m - q\bar{v})$).

$\bar{u}$	$cv(u)$, %	$\bar{v}$	$cv(v)$, %	u_m	v_m	$(u_m - p\bar{u})$	$(1 - 2u_m - q\bar{v})$	$p\bar{u} - q\bar{v}$	Maximum span length difference (actual)
0.25	20.0	0.10	20	0.40	0.16	0.275	0.175	0.100	0.096
0.30	16.7	0.10	20	0.45	0.16	0.300	0.075	0.125	0.120
0.30	20.0	0.10	20	0.48	0.16	0.330	0.015	0.125	0.119

VARIABLE FIBER LENGTH AND CONSTANT HOOK EXTENT. We consider next the case where fibers are of variable length with a distribution density $n(l)$ ranging between l_1 and l_m with a mean $\bar{l}$. Fractional hook extent is assumed as constant (u and v with proportion p and q, respectively) and is independent of length variation. The fibrogram profile with u hooks at left is given by

$$r_1(x) = \frac{(1-p-q)}{\bar{l}} \int_x^{l_m} (l - x)n(l)\mathrm{d}l + \frac{p}{\bar{l}}\left[\int_{x/(1-u)}^{l_m} \{l(1-u) - x\}n(l)\mathrm{d}l + \int_{x/u}^{l_m} \{lu - x\}n(l)\mathrm{d}l\right] + \frac{q}{\bar{l}}\left[\int_x^{x/2v} (l-x)n(l)\mathrm{d}l + \int_{x/2v}^{l_m} l(1-2v)n(l)\mathrm{d}l + 2\int_{x/v}^{l_m} (lv - x)n(l)\mathrm{d}l\right].$$

As in the preceding case, the expression for $r_2(x)$ is obtained from the foregoing by interchange of u and p by v and q, respectively.

In the present case the differential hook extent can be estimated by the maximum span difference only when

$$l_1 \geqslant \frac{2l_m u}{(1-u)}.$$

It has been shown in the Appendix that under this condition the graphs of $r_1(x)$, (u hooks on left) and $r_2(x)$ (u hooks on right) have straight and parallel portions as expressed in the equations:

$$r_1(x) = -\frac{x}{\bar{l}} + (1 - pu), \quad ul_m < x \leqslant 2ul_m$$

$$r_2(x) = -\frac{x}{\bar{l}} + (1 - qv), \quad 2ul_m < x \leqslant \frac{2u(1-v)}{1-u} l_m.$$

(Incidentally, the stipulated condition implies that $u < \frac{1}{3}$.)

(The maximum span difference is found at $r_1(x) = (2ul_m)/\bar{l} + (1 - qv) = r_2(x)$ and has a value equal to $\bar{l}(pu - qv)$, which is, once again, the differential hook extent for the sample.

For $l_1 < (2ul_m)/(1-u)$ (*i.e.*, when length variability is high) the maximum span difference, in general, will be different from the differential hook length.

This will be made clear from the following. From the fibrograms the differential hooking can be estimated either by the maximum span length difference or by the maximum difference in frequencies at a given span length. When length is variable and $l_1 < (2l_m u)/(1-u)$, the maximum frequency difference will be found to be less than $(pu - qv)$, since the maxima for the different length groups do not lie at the same span length. But the maximum span length difference is found to be greater than the frequency difference (multiplied by mean length). This is so because the maximum frequency difference occurs at a span length much higher than the minimum fiber length, where the tangent to the fibrogram makes an angle greater than 45° to the length axis. Under the circumstances it is difficult to obtain an analytical expression for the maximum span length difference. If $n(l)$ is taken to be a polynomial of kth degree in l, $r_1(x)$ becomes a polynomial of degree $k+2$. Thus the problem reduces to inversion of such an expression and is impossible theoretically for $k > 2$. But even for $k = 0$ (a rectangular distribution), the inversion, though less difficult, leads to unwieldy expressions. Under these circumstances a recourse can be had to representative numerical computations with a hypothetical length distribution. Such calculations were made for the case of a truncated normal distribution.

$$n(l) = \frac{1}{\sigma\sqrt{2\pi}}\exp[-(l-\bar{l})^2/2\sigma^2] \quad \text{for } \bar{l}-3\sigma \leqslant l \leqslant \bar{l}+3\sigma$$

$$= 0 \quad \text{otherwise.}$$

Using the function

$$N(x) = \frac{1}{\sigma\sqrt{2\pi}}\int_x^{\bar{l}+3\sigma} n(l)\mathrm{d}l,$$

we find:

$$r_1(x) = (1-p-q)[\sigma^2 n(\bar{l}) + (\bar{l}-x)N(x)]$$
$$+ p\Big[(1-u)\sigma^2 n\left(\frac{x}{1-u}\right) + \{\bar{l}(1-u)-x\}N\left(\frac{x}{1-u}\right) + u\sigma^2 n\left(\frac{x}{u}\right) + (\bar{l}u-x)N\left(\frac{x}{u}\right)\Big]$$
$$+ q\Big[\sigma^2\left\{n(x) - n\left(\frac{x}{2v}\right)\right\} + (\bar{l}-x)\left\{N(x) - N\left(\frac{x}{2v}\right)\right\} + \sigma^2(1-2v)n\left(\frac{x}{2v}\right) + \bar{l}(1-2v)N\left(\frac{x}{2v}\right) + \sigma^2 2vn\left(\frac{x}{v}\right) + 2(\bar{l}v-x)N\left(\frac{x}{v}\right)\Big].$$

$r_2(x)$ can be determined likewise. Tables of $n(x)$ and $N(x)$ are available; utilizing these tables, $r_1(x)$ and $r_2(x)$ can be obtained for any desired values of u, v, x, and σ. In Table II the maximum span difference is given for a selection of values of u and v. For the chosen illustration $\bar{l} = 5$, $l_1 = 0$, and $l_m = 10$; thus the cv of fiber length 33.3%. Two fibrogram profiles corresponding to $u = 0.25$, $v = 0.10$, and $u = 0.15$, $v = 0.10$ are shown in Figures 4(a) and (b).

TABLE II. Relation between differential hook extent and maximum span length difference and maximum frequency difference.

(For a normal distribution truncated beyond $\pm 3\sigma$; $\bar{l} = 5$ (arbitrary units); $\sigma = \bar{l}/3$; $p = 0.5$; $q = 0.25$.)

u	v	$pu - qv$	$(pu - qv)\bar{l}$	Max. Span Length Difference (Calculated)	Max. Frequency Difference $\times \bar{l}$ (Calculated)
0.25	0.05	0.1125	0.562	0.594	0.454
0.25	0.10	0.1000	0.500	0.495	0.394
0.25	0.15	0.0875	0.437	0.471	0.337
0.25	0.20	0.0750	0.375	0.415	0.286
0.25	0.25	0.0625	0.312	0.350	0.254
0.20	0.05	0.0875	0.437	0.494	0.390
0.20	0.10	0.0750	0.375	0.403	0.338
0.20	0.15	0.0625	0.312	0.337	0.277
0.20	0.20	0.0500	0.250	0.349	0.225
0.20	0.25	0.0375	0.187	0.273	0.221
0.15	0.05	0.0625	0.312	0.327	0.299
0.15	0.10	0.0500	0.250	0.287	0.239
0.15	0.15	0.0375	0.187	0.232	0.180
0.15	0.20	0.0250	0.125	0.288	0.178
0.15	0.25	0.0125	0.062	0.334	0.207

It will be seen that the maximum span difference is greater than the differential hook length, as expected. But there is a close relationship between the two quantities, which means that the maximum span length difference can be used for getting relative estimates of differential hooking in slivers. The maximum frequency difference will be found to be lower than the maximum span length difference but closely related to the differential hook extent. An estimate of differential hooking can, therefore, be obtained by either maximum span length difference or frequency difference (see Figure 5 and Table II).

VARIABLE FIBER LENGTH AND HOOK EXTENT. Finally, we consider the general case when fiber length as well as fractional hook extent are variable. Let $f(u)$, $g(v)$, and $n(l)$ have the same meanings as the earlier ones, and we will suppose that these distributions are independent. With the same notation as before we have

$$r_1(x) = \frac{(1-p-q)}{\bar{l}}\int_x^{l_m}(l-x)n(l)\mathrm{d}l$$
$$+ \frac{p}{\bar{l}}\int_{x/(1-u_1)}^{l_m}\int_{u_1}^{(l-x)/l}[l(1-u)-x]f(u)\mathrm{d}u\cdot n(l)\mathrm{d}l$$

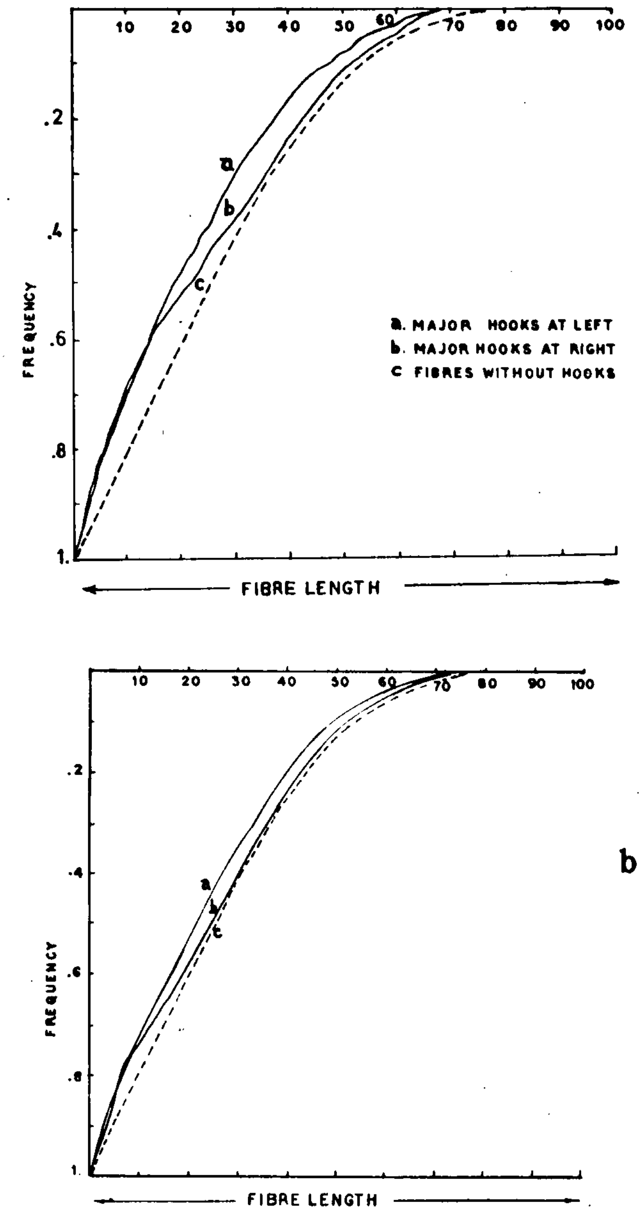

FIG. 4. Fibrograms with variable fiber length but constant hook extent. a) $u = 0.25$ and $v = 0.10$; b) $u = 0.15$ and $v = 0.10$.

$$+\frac{p}{l}\int_{x/u_m}^{l_m}\int_{u/l}^{u_m}[lu - x]f(u)\mathrm{d}u\cdot n(l)\mathrm{d}l$$

$$+\frac{q}{l}\int_{x}^{x/2v_1}\int_{v_1}^{x/2l}(l - x)g(v)\mathrm{d}v\cdot n(l)\mathrm{d}l$$

$$+\frac{q}{l}\int_{x/2v_m}^{l_m}\int_{x/2l}^{v_m}l(1 - 2v)g(v)\mathrm{d}v\cdot n(l)\mathrm{d}l$$

$$+\frac{q}{l}\int_{x/v_m}^{l_m}\int_{x/l}^{v_m}2(lv - x)g(v)\mathrm{d}v\cdot n(l)\mathrm{d}l.$$

$r_2(x)$ can be obtained from this equation by interchanging p and u with q and v.

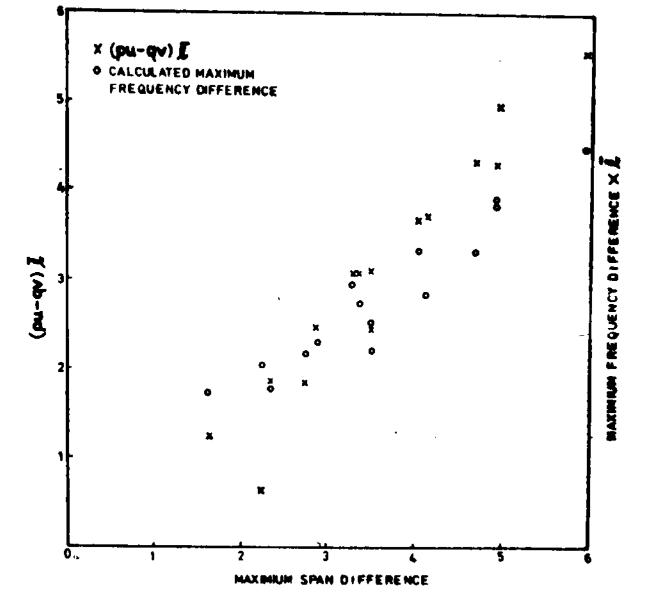

FIG. 5. Relationship between differential hook extent and maximum span length difference and maximum frequency difference.

Figure 6 shows the fibrogram profiles for the combination when $n(l)$ is a truncated normal distribution with mean 0.8 and coefficient of variation 20%; $f(u)$ and $g(v)$ are also similar distributions with $\bar{u} = 0.25$ and $\bar{v} = 0.15$, distributed independently of l and of each other, $p = 0.5$ and $q = 0.25$.

The calculated $(p\bar{u} = q\bar{v})\bar{l} = 0.07$.

Actual maximum span length difference is $= 0.09$ approx.

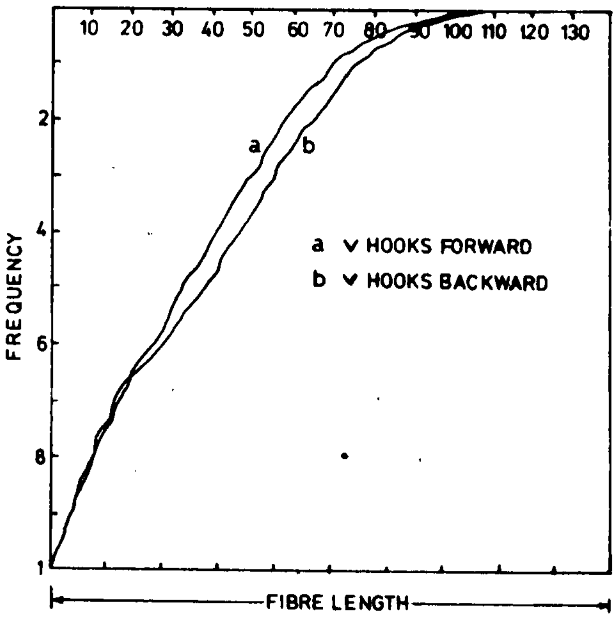

FIG. 6. Fibrograms with variable fiber length and variable hook extent.

Summary and Conclusions

The fibrogram shapes of fiber beards that are obtained by clamping a sliver across a section and combing out the loose fibers have been examined for constant as well as variable hook extent and fiber length materials. The fibrogram shape is dependent upon the number and extent of hooks in the two directions. The difference in span length between the two fibrograms increases with frequency, reaches a maximum, and again diminishes. For constant staple length material and for fibers with less length variability, the maximum span length difference between the two fibrograms is equal to the differential hook extent in the sliver for the hook lengths normally found in slivers. When length variability is more, the maximum span length difference though not equal to the differential hook extent is still closely related to it.

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APPENDIX

Let u hook be at left. l_1 is taken as $= (2l_m u)/(1-u)$.

For $2l_m u > x > \max(2l_m v, l_m u)$

$$r_1(x) = \frac{(1-p-q)}{l}\int_{l_1}^{l_m}(l-x)n(l)\mathrm{d}l + \frac{p}{l}\int_{l_1}^{l_m}[l(1-u)-x]n(l)\mathrm{d}l + \frac{q}{l}\int_{l_1}^{l_m}(l-x)n(l)\mathrm{d}l$$

$$= \frac{(1-p-q)}{l}(l-x) + \frac{p}{l}[l(1-u)-x] + \frac{q}{l}(l-x)$$

$$= -\frac{x}{l} + (1-pu).$$

Let u hooks be at right.

For $2l_m u(1-v)/(1-u) > x > 2l_m u$

$$r_2(x) = \frac{(1-p-q)}{l}\int_{l_1}^{l_m}(l-x)n(l)\mathrm{d}l + \frac{q}{l}\int_{l_1}^{l_m}[l(1-v)-x]n(l)\mathrm{d}l + \frac{p}{l}\int_{l_1}^{l_m}[l-x]n(l)\mathrm{d}l$$

$$= -\frac{x}{l} + (1-qv).$$

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