THE YARN FORMATION IN FRICTION SPINNING

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September 1988

SEPTEMBER 1988

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ABSTRACT

A novel approach explaining the yarn forming process in friction spinning is presented. The factors, determining the yarn build-up, are the conditions at landing of the fibers on the surface of the suction drum, the speed relation of the drum surface speed to the yarn speed and the size of the temporarily formed rotating sleeve in the gap between the two drums. An explanation is given for the seeming discrepancy between expected and measured yarn twist.

1. INTRODUCTION

The principle of friction spinning was introduced on industrial basis by the "DREF"-Spinners from Fehrer, Austria. It has found some interesting fields of applications, mainly for producing novelty type yarns of rather heavy yarn counts. On the other hand, the "Masterspinner" from Hollingsworth-Platt suggests some potential for spinning medium count cotton yarns as well. Yarn strength and yarn uniformity however still need to be improved in order to reach broader acceptance.

The basic idea of OE-friction spinning is to feed fibers in suitable form and direction onto a moving surface and to withdraw the formed yarn perpendicular to the direction of the moving surface. In practice, the fibers are deposited in the gap of two cylinders rotating in the same direction, whereby at least one of the cylinders is acting as suction drum. The yarn is formed by friction forces acting between the fibers and the moving surfaces and then withdrawn in axial direction. The working principle has already been described in earlier papers [1,2] and detailed knowledge is available on the various influencing factors and processing parameters [3,4,5,6]. With respect to the twist insertion mechanism, most authors describe the observance of a so called "twist slippage". By this, one refers to the apparent discrepancy between the observed twist and a calculated twist level (based on the ratio of the yarn tail rotational speed to the drum surface speed). The following analysis presents a new concept for the yarn formation process, explaining also the apparent twist deficiency.

2. FIBER LANDING

The first major step in the friction-yarn formation process is the phase of the fiber landing in the gap between the two friction drums. It is assumed that the fibers, coming from a suitable opening device, are being transported by aerodynamic means through a channel, tilted at an angle γ with respect to the drum axis (fig.1).

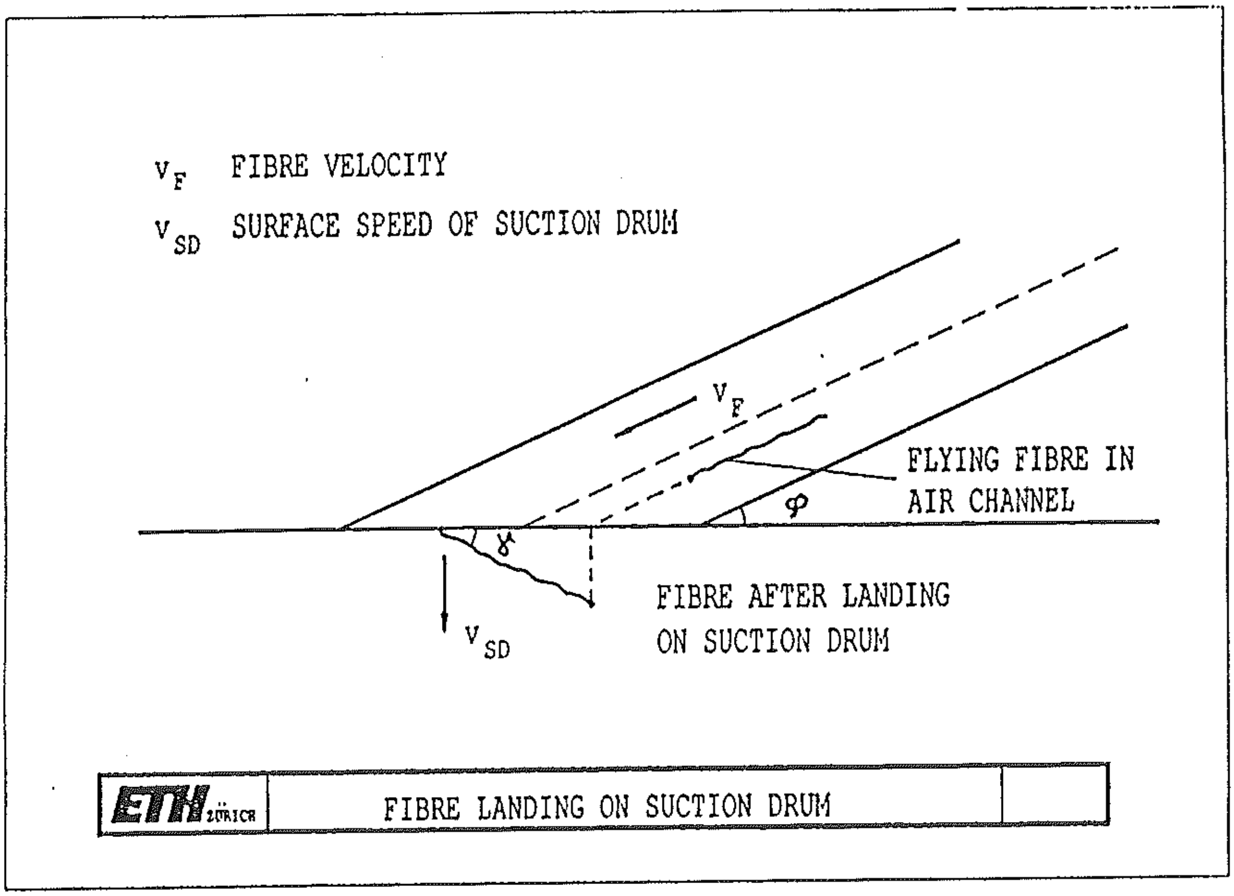

FIG 1 FIBRE LANDING ON SUCTION DRUM

the fully extended fiber shall be flying towards the drum at the same angle φ with a velocity v_F which is n times greater than the drum surface speed v_{SD}:

$$v_F = n * v_{SD}$$

The fiber tip then is caught on the drum surface (photos and high-speed films reveal that indeed most fiber tips are actually pulled into the suction holes of the drum) whilst the fiber tail continues its travel in the original direction and at the same velocity. Due to the decelerating effect upon landing and due to the prevailing air flow conditions, the fiber will perform a "somersault" and finally be deposited on the drum surface essentially in reversed direction at an angle γ [7].

In order to obtain a mathematical expression for the determining parameters, namely the channel angle φ, the speed ratio n and the fiber depositing angle γ, the fiber landing geometry at time t, when the fiber tip touches the drum surface, is compared with the situation at time (t+ Δt), when the drum surface has moved along the distance y (fig.2).

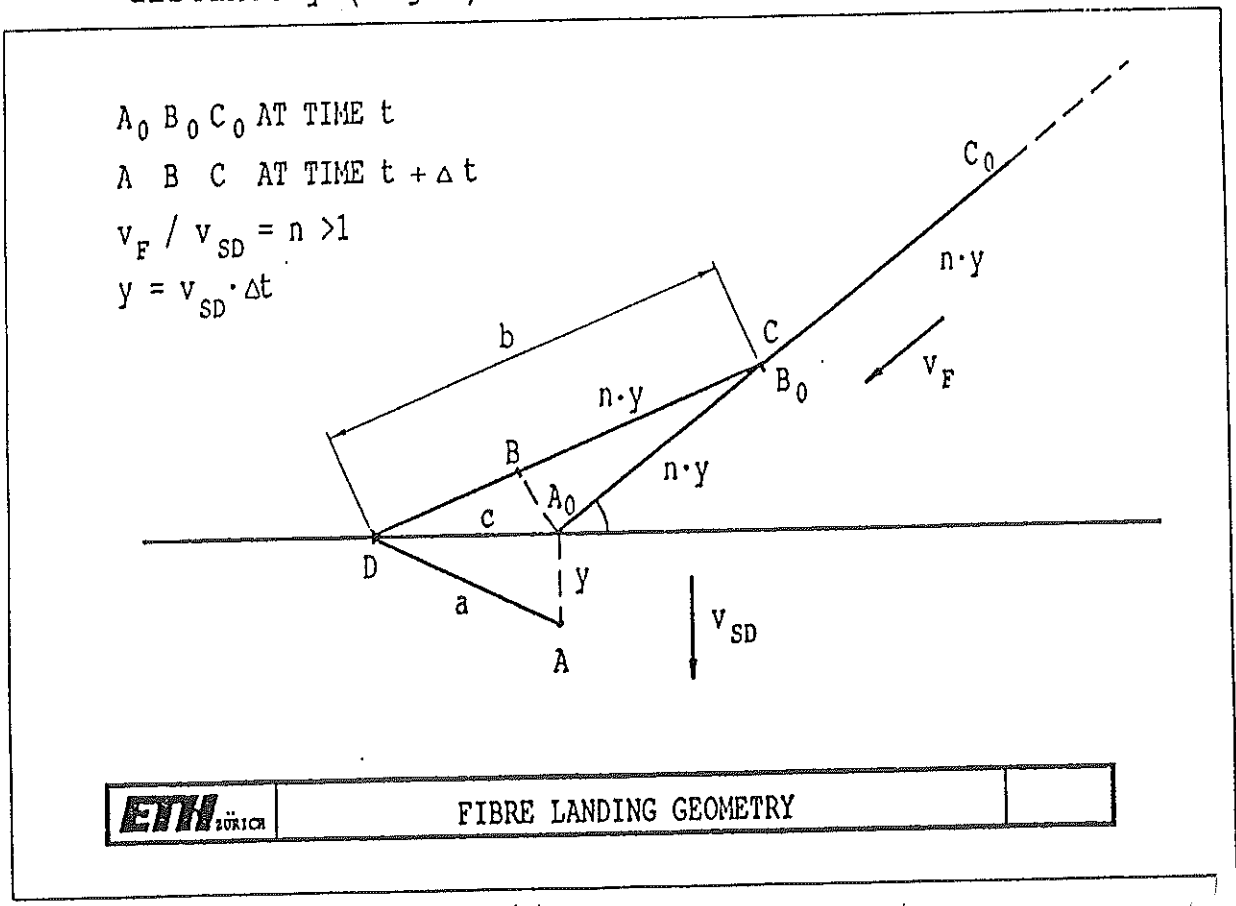

FIG 2 FIBRE LANDING GEOMETRY

For convenience, the distances along the fiber from A_0 to B_0 as well as from B_0 to C_0 are considered to correspond exactly to the travelling distance within the time interval Δt. Furthermore, the bending rigidity of the fibers is assumed to be negligible. At time $t + \Delta t$, A_0 has moved to A, B_0 to B and C_0 to C. Because there exists an overfeed of fiber material, the fiber will overshoot and the former fiber portion from A_0 to C_0 will be branching into the section AD on the drum surface and the section DC which is still in the air stream.

With the four equations

$$a+b=2*n*y\ ,$$

$$y/a=\sin\gamma,$$

$$c/a=\cos\gamma$$

$$\text{and } b^2=c^2+n^2*y^2+2*c*n*y*\cos\varphi$$

one obtains the following expression combining n, φ and γ:

$$(3n^2 + 1)/(2*n) = (\cos\gamma*\cos\varphi + 2)/\sin\gamma \quad (1)$$

The solution with respect to the landing angle γ may be easily computed for varying channel angles φ and varying speed ratios n.

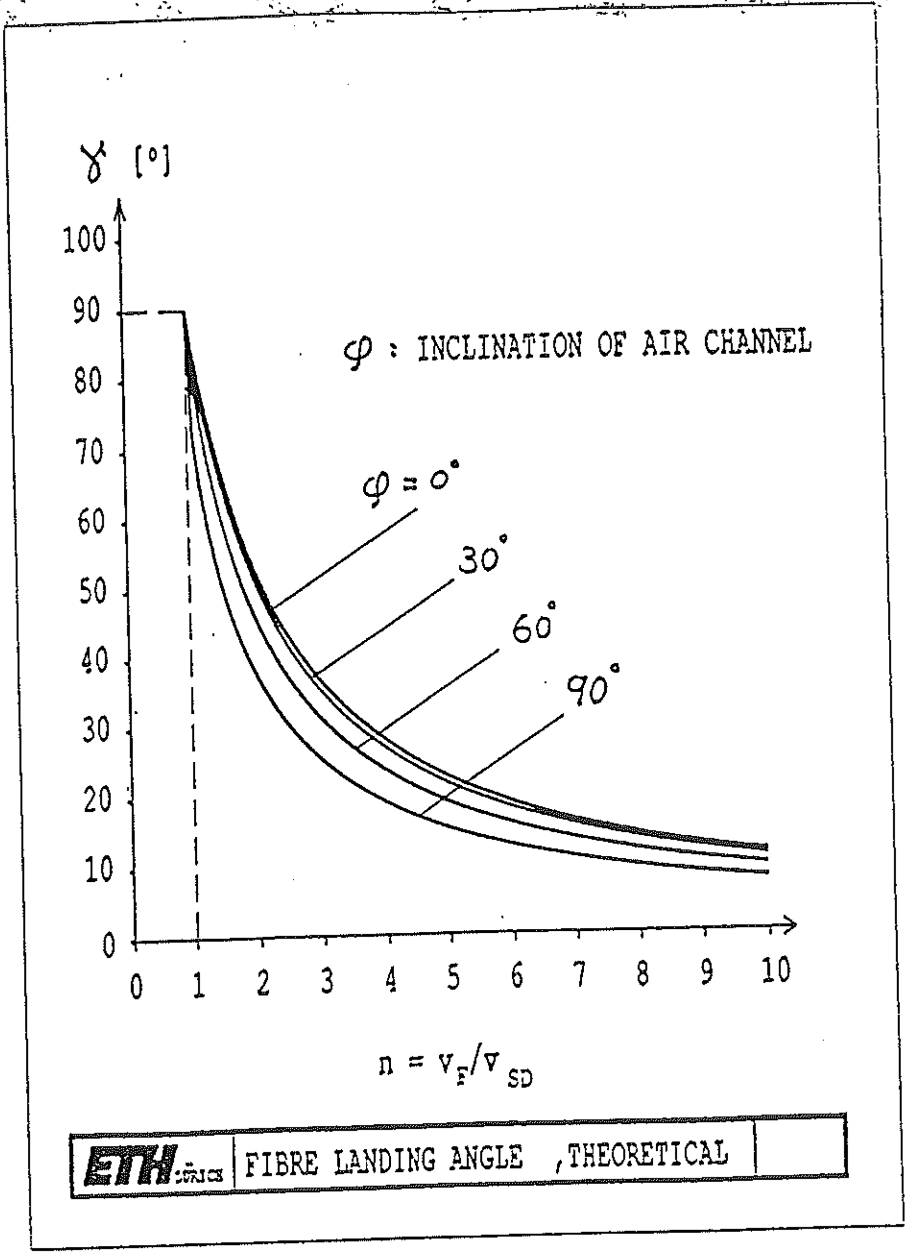

FIG 3 FIBRE LANDING ANGLE, THEORETICAL

Fig.3 depicts such results showing clearly the strong effect of the ratio n, which is the fiber transport velocity to the drum surface speed. In analysing high-speed photographs such as fig.4, taken from the drum surface during spinning, the fiber landing angle was determined experimentally for different conditions of speed ratios at a given channel angle. As fig.5 indicates, there exists a good agreement between the theoretical and experimental results, thus proving the validity of the theory based upon the somersaulting of the fibers during landing on the suction drum.

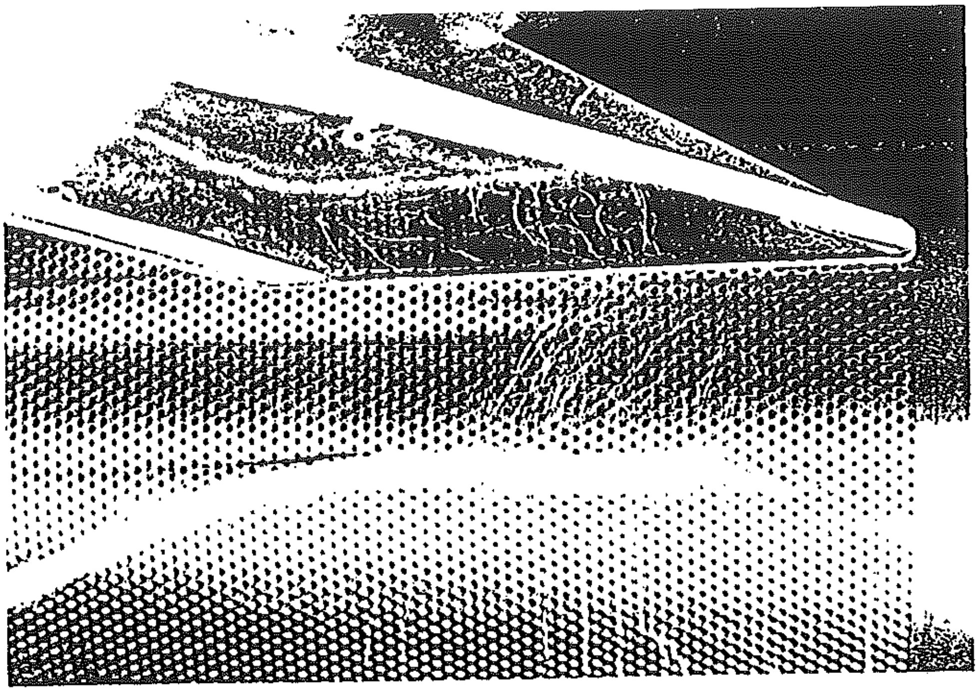

FIG 4 PHOTOGRAPHY OF FIBER LANDING ON SUCTION DRUM

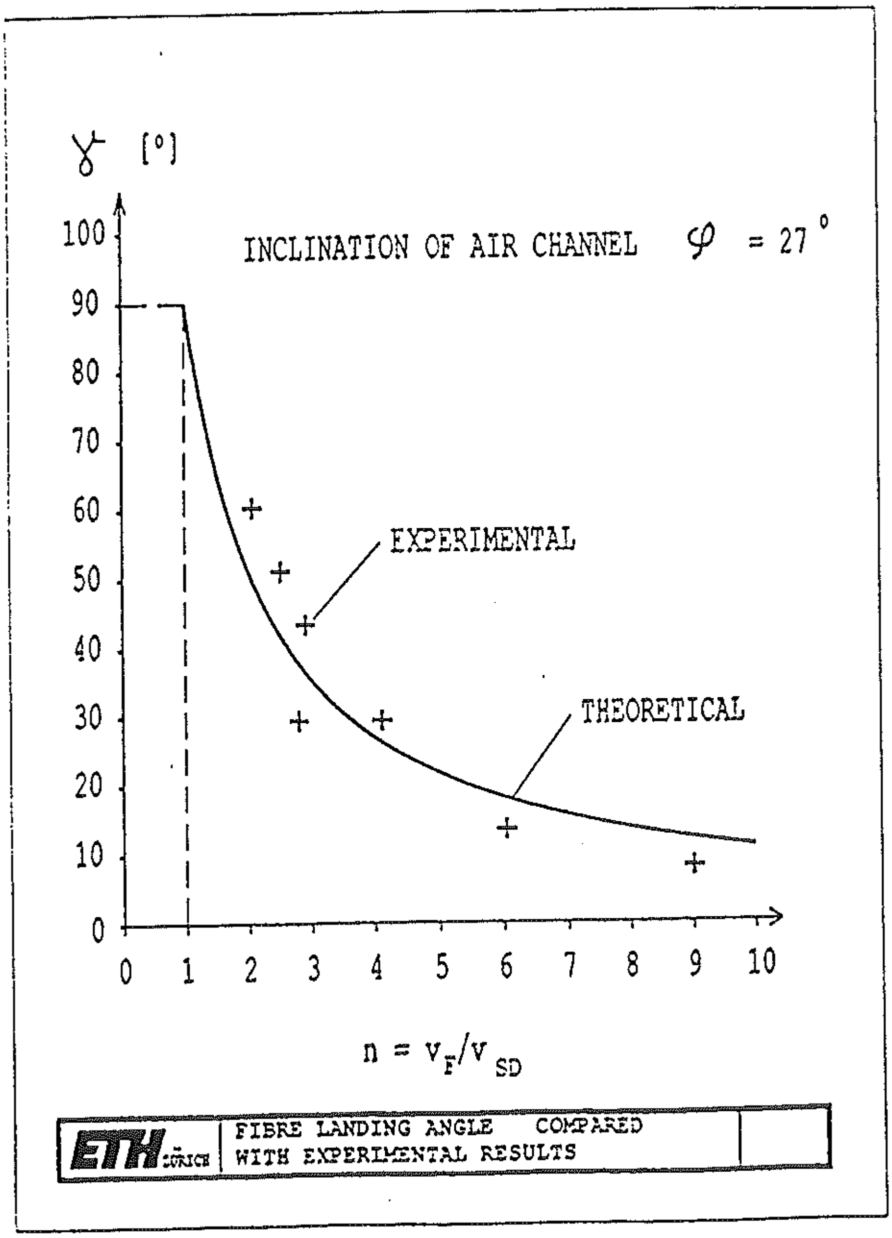

FIG 5 FIBRE LANDING ANGLE
COMPARED WITH EXPERIMENTAL
RESULTS

3. FIBER TRANSFER AND FIBER ASSEMBLY

The next step involves the fiber transfer and final fiber assembly into the open yarn end. According to the oversimplified hypothesis, the fibers are wrapped-in by the rotating yarn tail. This certainly is incorrect, since any rotation of a finished yarn section would only produce false-twist. A close inspection however reveals the conditions indicated in fig.6. Initially, the arriving fibers are temporarily collected in a rotating sleeve around the yarn and only in a second step, will transfer from the inside of this sleeve onto the (non-rotating) yarn core, which is withdrawn in axial direction.

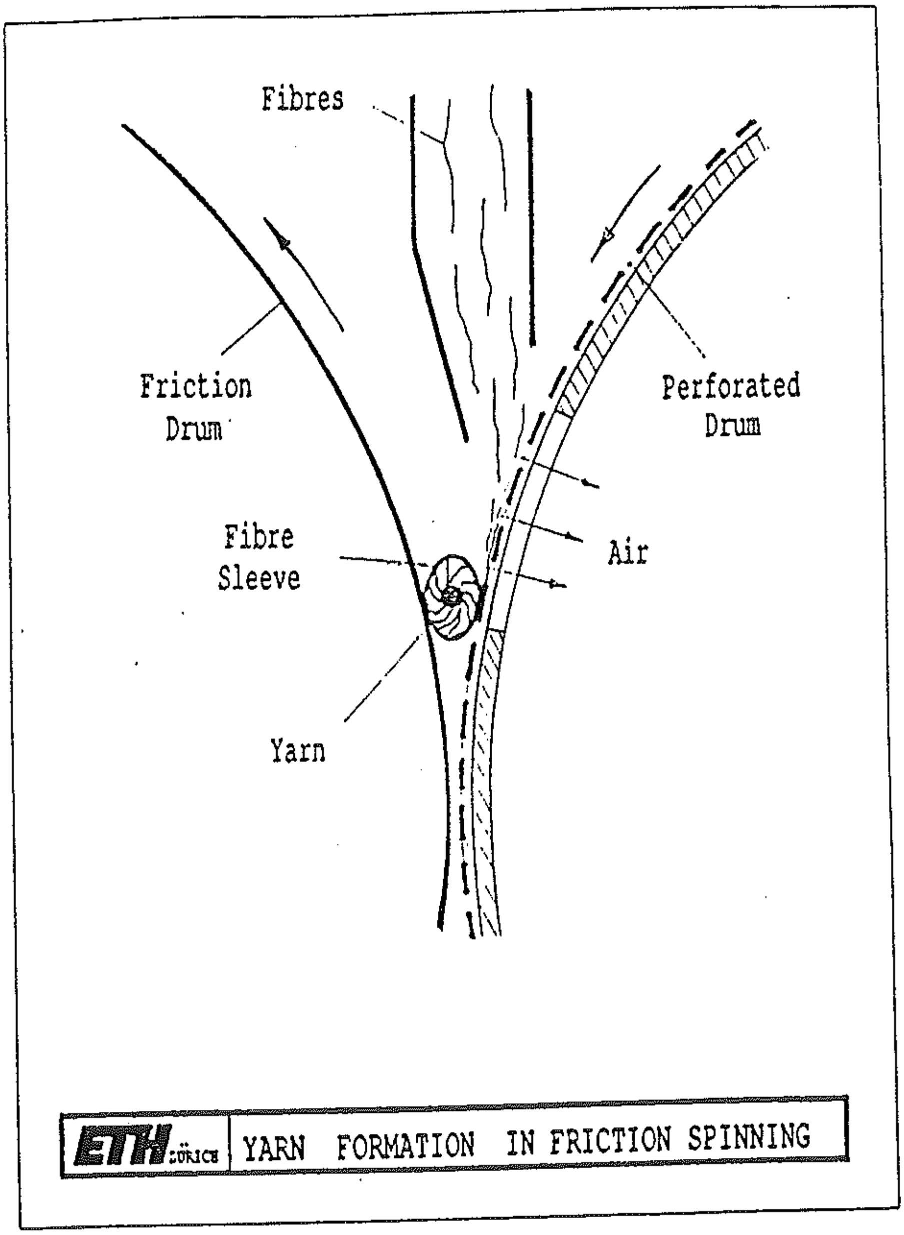

FIG 6 YARN FORMATION IN FRICTION SPINNING

This fact is not generally known, similar observations however have also recently been reported elsewhere [8,9]. With this geometrical configuration in mind, the theoretical twist structure of a friction can be calculated as follows.

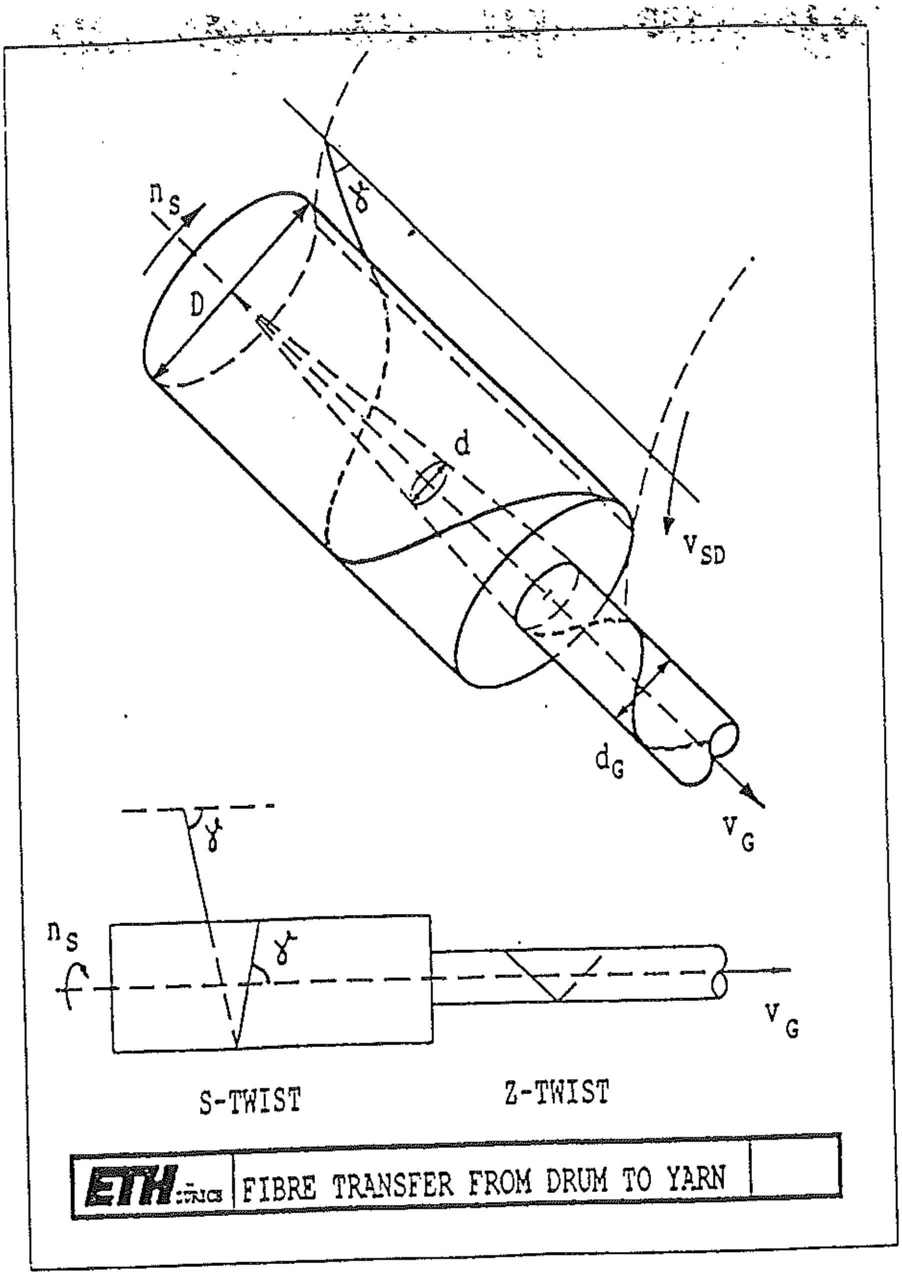

FIG 7 FIBRE TRANSFER FROM DRUM TO YARN

According to fig.7, it is assumed, that a fiber laying on the suction drum which rotates at a speed v_{SD}, will more or less maintain the angle γ upon transfer onto the fiber sleeve of diameter "D". Under the given conditions, the fiber will form an S-twist spiral on the sleeve. The yarn (diameter "d_G") is withdrawn opposite to the direction of the fiber feed ("backwards spinning") with a velocity of v_G. No slippage between suction drum and sleeve is assumed, therefore, the angular velocity ω_S of the sleeve depends only upon v_{SD} and D. As fig.7 shows, the twist direction will change from S to Z-twist during transfer from the sleeve onto the open yarn end.

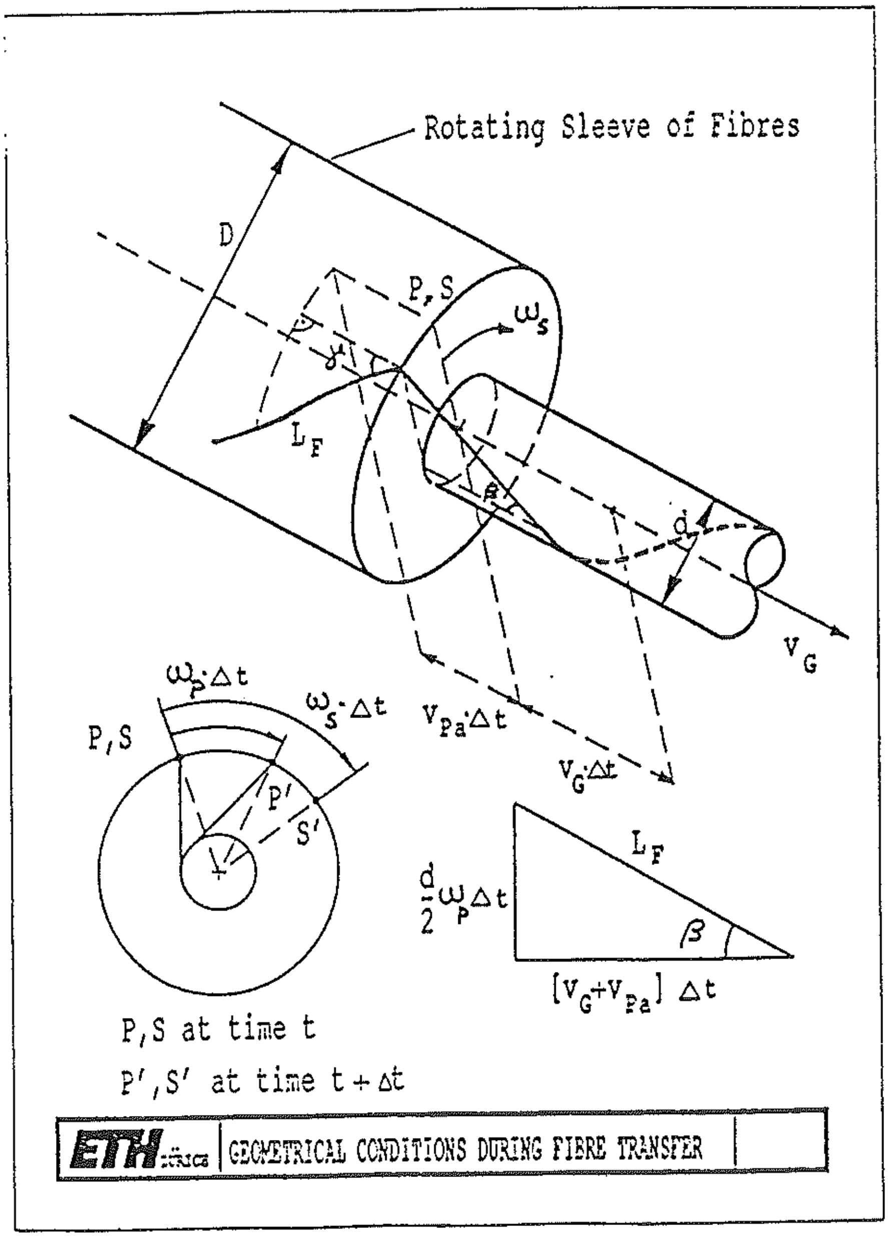

FIG 8 GEOMETRICAL CONDITIONS DURING FIBRE TRANSFER

A momentary situation of this transfer action is presented in fig.8. While the sleeve is rotating, the fiber is peeled-off from the inside of the sleeve (due to the thin fiber layer, the same diameter as the outside sleeve-diameter is assumed) and wraps around the local yarn diameter (d) at an angle ß in Z-twist direction. Since the peeled-off fiber length is equal to the length wound onto the yarn one can write

$$d * \omega_P / \sin \beta = D * (\omega_S - \omega_P) / \sin \gamma \qquad (2)$$

whereby ω_P represents the absolute angular velocity of the peeling point P which is slower than ω_S. The axial velocity at which the fiber wraps around the yarn is the sum of the yarn speed (v_G) plus the axial velocity of the peeling point (v_{PA}). This yields the equation

$$\tan \beta = (d/2) * \omega_P / (v_G + v_{PA}), \qquad (3)$$

whereby $v_{PA} = (D/2) * (\omega_S - \omega_P) / \tan \qquad (4)$

From equations (2),(3) and (4) one obtains:

$$\tan = \frac{1}{(2*v_G)/(d*\omega_P) + (\cos \gamma / \sin \beta)} \qquad (5)$$

Introducing the speed ratio factor $DY = v_{SD}/v_G$, the yarn speed, (assuming no slippage between the suction drum and the fiber sleeve) is given by

$$v_G = \frac{D * \omega_S}{2 * DY}$$

Substituting the value v_G in equation (5) and combining it with equation (2) leads to

$$\cos\beta = (D*\sin\beta / d + \sin\gamma)/DY + \cos\gamma \quad (6)$$

Considering the relation between the helix angle β and the twist T:

$$\tan\beta = \pi * d * T$$

one derives at a formulation showing the mathematical interdependence between the twist T , the local yarn diameter d, the sleeve diameter D, the speed ratio DY and the fiber depositing angle :

$$\frac{1 + \pi * D * T / DY}{sqr(1 + (\pi * d * T)^2)} = \cos\gamma + \sin\gamma / DY \quad (7)$$

Fig.9 represents the computed results (T in function of d) of this equation for a sleeve diameter of D = 0.4 mm and a fiber deposition angle $\gamma = 70^\circ$. It becomes evident, that the twist increases as the diameter d gets smaller, i.e. in a friction-yarn, the twist is highest in the center and lowest on the yarn surface. This fact can easily be experimentally veryfied by observing the untwisting characteristics on a Rockbank twist counter.

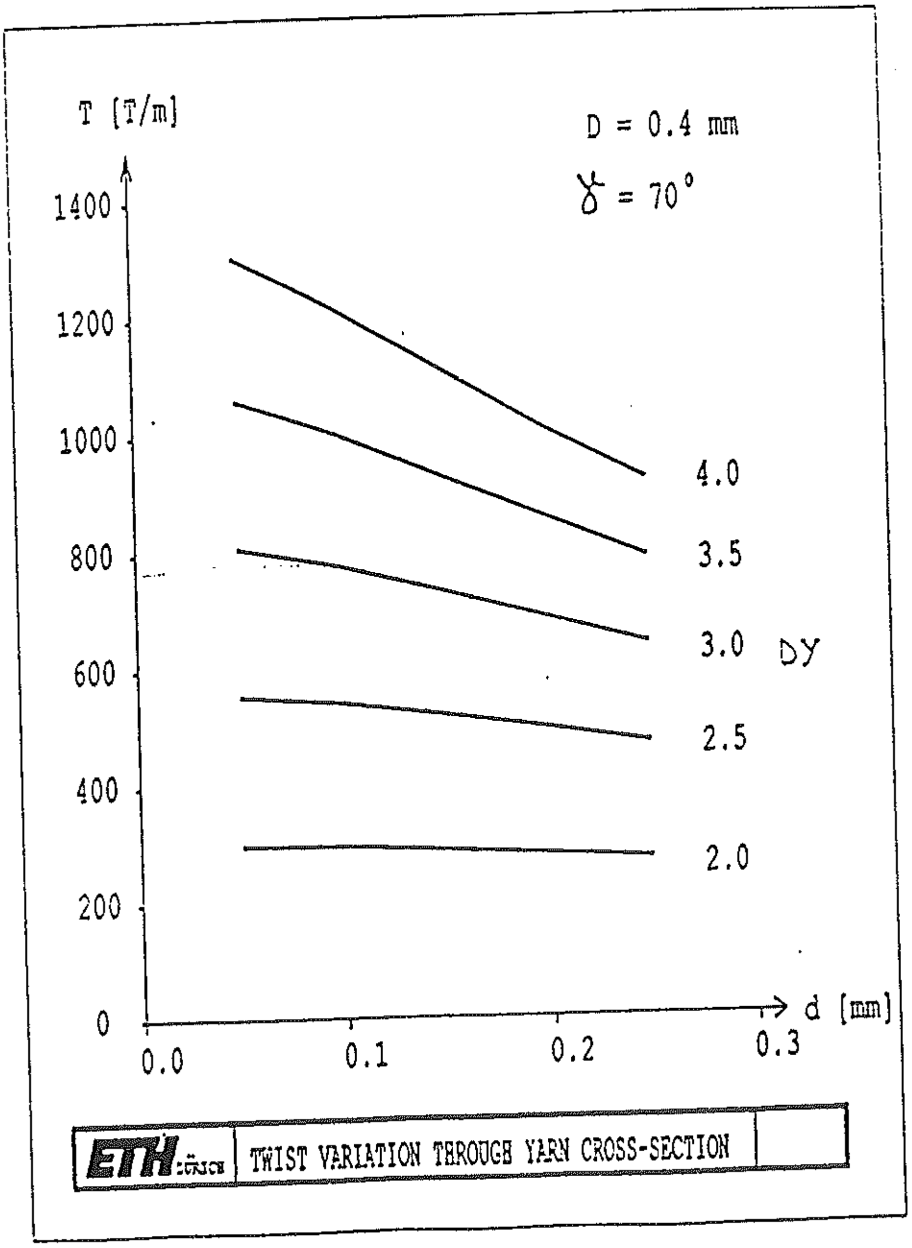

FIG 9 TWIST VARIATION
THROUGH YARN CROSS-SECTION

One must realize that the twist T, calculated in the above manner, represents only a local twist level at a given diameter within yarn cross-section. In order to arrive at a figure which would be more representative for the overall yarn twist, it becomes necessary to calculate an average twist "T_{AV}". This is done by integrating T from inside to full yarn diameter as follows:

$$T_{AV} = (1/(\pi * R^2))* \int_0^R 2*\pi*r*T*dr, \text{ where}$$

T = local Twist (at radius r=d/2), and

R = yarn radius = $d_G/2$

Furthermore, the dependencies T = T(d) shown in fig.9, can be approximated by linear relationships as

$$T = T_0 *(1 - m*d)$$

T_0 and m are yarn constants for given d_G, D, DY and γ.
With this substitution the integral for T_{AV} can be solved, leading to

$$T_{AV} = T_0 * (1 - 2*m*d_G/3),$$

This equation indicates that average twist level T_{AV} corresponds to the local twist level at a diameter which is 2/3 of the full yarn diameter. The equation (7) can now be rewritten in terms of the average twist as follows:

$$\frac{1 + \pi * D * T_{AV} / DY}{sqr(1 + (2 * \pi * d_G * T_{AV} / 3)^2)} = \cos\gamma + \sin\gamma / DY \quad (8)$$

The numerical solution of the above equation allows to predict the measured twist in a yarn providing, that besides the speed ratio DY and the final yarn diameter d_G, the fiber landing angle γ and the sleeve diameter D are known as well.

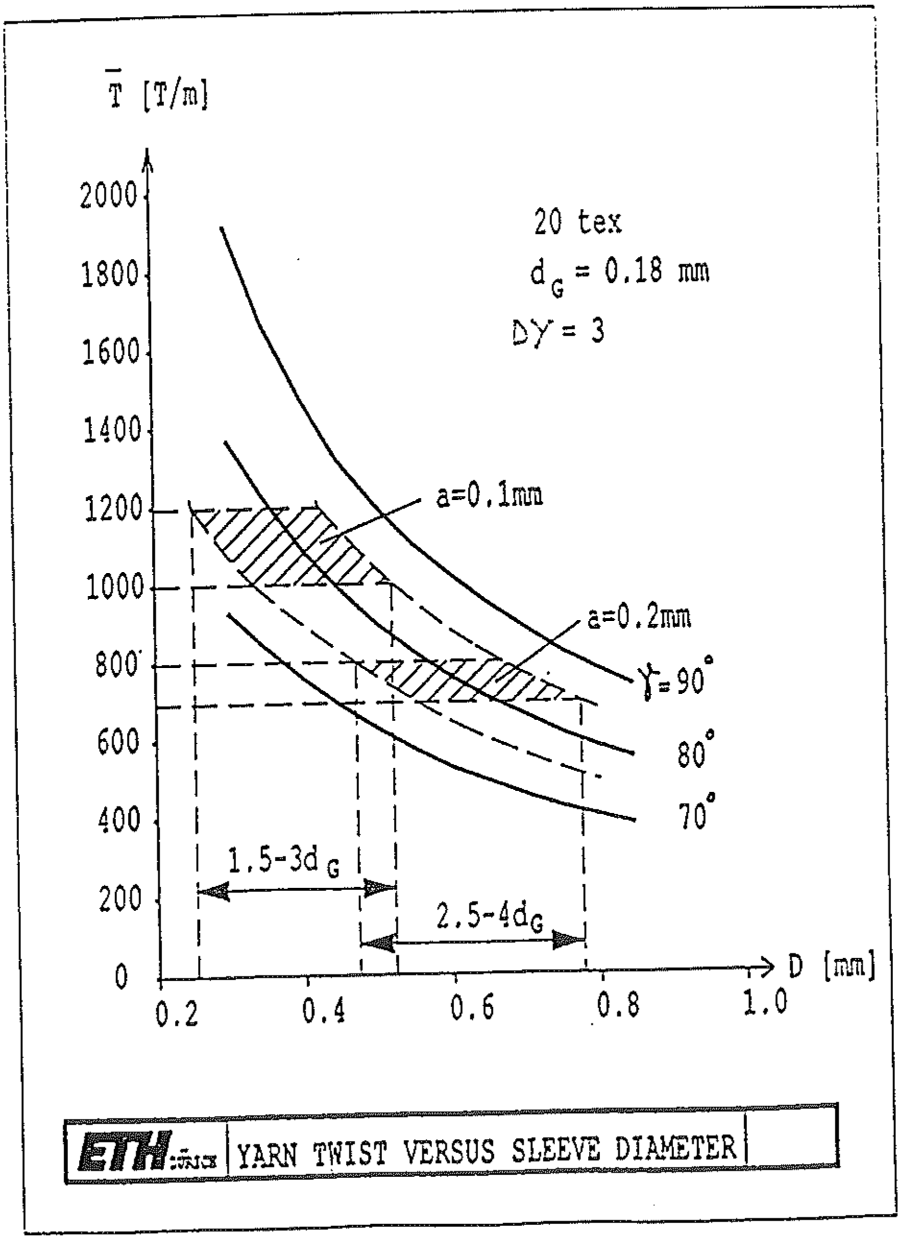

FIG. 10 YARN TWIST VERSUS SLEEVE DIAMETER

For a 20 tex yarn (d_G = 0.18mm), spun at a speed ratio DY=3, fig.10 displays the (average) yarn twist T_{AV} in function of the sleeve diameter for varying fiber landing angles. On the experimental spinning unit, when spinning a 20 tex yarn, the angle γ was photographically determined to be between 75° and 85° for a certain airflow and drum speed condition. By varying the gap between the two friction drums, yarns were obtained which differed considerably in twist level. At a gap distance of 0.1 mm, the yarn twist was 1000-1200 T/min, at a wider gap of 0.2 mm, the twist dropped to 750-800 T/m. For geometrical reasons, a wider gap will lead to larger sleeve diameters, hence slower rotational speed, and vice versa. According to fig.10 the corresponding sleeve diameters are 1.5 to 4 times larger than the yarn diameter. This corresponds very well with the geometrical configuration in the yarn forming zone and therefore proves the validity of the theory presented here.

The simplified twist calculation, considering only yarn diameter and speed ratio Y, would have led to a fictitious twist of

$$T_{Fict} = Y / pi*d_G = 5300 \text{ T/m}.$$

This indeed could lead to the (erroneous) conclusion, that high twist slippage exists, which according to the new theory certainly is not the case.

4. CONCLUSIONS

With respect to friction spinning, this new theory enables the calculation of the yarn twist and the twist distribution within the yarn cross-section and explains why the theory of "twist-slippage" is incorrect. In the yarn forming process, there exists an intermediate step, whereby the fibers assemble in the form of a rotating sleeve. The resulting twist in a friction spun yarn depends upon the following determining parameters: The landing angle of the fibers on the suction drum, the sleeve diameter, the drum-to-yarn speed ratio and the yarn diameter.