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Material and Machine Interactions During Weaving

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In the previous progress report we indicated that the distribution of fibers within the yarn structure strongly influences the mechanical behavior of the resulting yarns. In this report period we are reporting the analysis of the twist distribution in the spinning zone of an air-jet spinning system, and the effect of the use of an MIY device in Jet Spinning.

TWIST DISTRIBUTION IN SPINNING ZONE OF AIR-JET SPINNING

Introduction

Air-jet spinning method is akin to false-twisting of a yarn. The main bundle of fibers is under the false-twisting action of an air vortex. It is, therefore, important to know the twist distribution in the main bundle along the traveling direction of the yarn in the spinning zone. It was earlier thought that the twist in the core bundle along the yarn threadline prior to the twister remains constant as assumed by Krause et al [1]. However, Grosberg et al [2] have published their experimental evidence claiming that this is not the case. Lunenschloss and Bergmann [3] have reported the photographic evidence that the false-twist of the core decays gradually after the second twisting jet, as cited by Schwabe et al [4]. The experimental evidence reported in the literature indicates that core twist must vary along the threadline in air-jet spinning.

However, the published results are not in general agreement with each other, and there appears to be a need to re-analyze the previous work.

Analysis of Prior Work

The notation of symbols in the following analysis are as follows:

I: Moment of inertial per unit length of yarn;

K: Yarn torsional rigidity;

k: A positive constant;

l: Distance between the front-roller nip and delivery-roller nip;

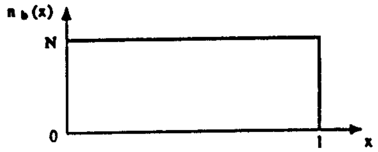

Figure 1. Balloon speed in single-jet spinning

M: Yarn torsional moment;
m: Twisting torque per unit length of yarn;
N: Twisting speed;
n: Rotating speed of the yarn bundle at a specific position;
T: Twist per unit length of yarn;
t: Time;
V: Delivery speed of spinning;
x: Distance of a particular position from the front-roller nip.

Kinematic Approach

A generalized kinematic Equation describing the yarn-twisting process has been derived in different ways [2, 5] for the variation of twist along the length of a yarn:

$$\frac{\partial T}{\partial t}+\frac{\partial (VT)}{\partial x}=\frac{\partial n}{\partial x} \ . \tag{1}$$

Under a steady state, all variables are independent of time. V(x) is assumed to be a constant. Hence Equation 1 reduces to:

$$V\frac{dT}{dx}=\frac{dn}{dx} \ . \tag{2}$$

Grosberg et al [2] divided the total rotation of the yarn, n, into two separate parts -- the rotation of the yarn about its own axis, n_t, and the balloon rotation about the axis of rotation of the yarn, n_b $(n=n_t+n_b)$. Then they further made an assumption that the rate of twist transmission is directly proportional to the twist gradient, $n_t=k(dT/dx)$, so that Equation 2 becomes

$$k\frac{d^2T}{dx^2}-V\frac{dT}{dx}=-\frac{dn_b}{dx} \ . \tag{3}$$

They proposed the boundary conditions coming from the twist relationship at the exit as follows:

$$T|_{x=1}=0, \ \left.\frac{dT}{dx}\right|_{x=1}=0 \ . \tag{4}$$

Thus, they ended up with an analytical solution expressing the twist distribution in a single-jet false-twisting zone (n_b=N as shown in Figure 1) that has the following form:

$$T(x)=\frac{N}{V}\{1-\exp[-\frac{V}{k}(1-x)]\} \ . \tag{5}$$

Unfortunately, there are a number of contradictions that show up in those results, which are discussed as follows.

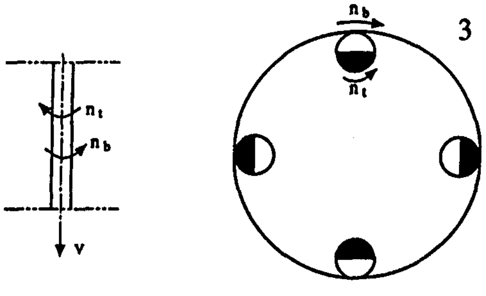

Figure 2. Rotation directions of the balloon and strand

Boundary condition

Differentiating Equation 5 gives

$$\frac{dT}{dx} = -\frac{N}{k}\exp[-\frac{V}{k}(l-x)] \ .$$

$$\therefore \quad \left.\frac{dT}{dx}\right|_{x=l} = -\frac{N}{k} \neq 0 \ .$$

Obviously, the final Equation 5 fails to satisfy the boundary condition (Equation 4) set by the authors. Equations 4 and 5 are not compatible.

Let us consider the second-order differential Equation 3.

As $n_b = N$, when $0<x<l$,

then $\frac{dn_b}{dx} = 0$, when $0<x<l$,

therefore $KT''-VT'=0$.

Let $T'=z$,

then $kz'-Vz=0$,

∴ $z=C_0\exp(vx/k)$,

i.e. $\frac{dT}{dx}=C_0\exp(vx/k)$. (6)

Equation 6 demonstrates that the value of dT/dx should always be positive. As a result, the proposed boundary condition in Equation 4, $\left.\frac{dT}{dx}\right|_{x=l} = 0$, is incorrectly associated with the differential Equation 3.

Yarn rotation

From Equation 5 we have:

$$n_t = k\frac{dT}{dx} = -N\exp[-\frac{V}{K}(l-x)] \ .$$

Clearly, n_t is always negative when N is positive. That is to say, the self-rotation of yarn bundle is supposed to be in the counter direction to the balloon rotation in the entire spinning zone, as illustrated in Figure 2. This is not plausible as such a situation cannot take place in practical spinning.

Moreover, the absolute value of n_t becomes larger as x increases. Hence n_t creates Z-twist in the strand. It is practically not possible. Even though Equation 5 is a mathematical solution to Equation 3, it yields incorrect physical consequence.

By reasoning in another way and looking into account for the underlying concept to end up with Equation 5, it may be explained as follows: n_b causes the even distribution of S-twist along the threadline, Tn_b, whereas the opposite rotation n_t leads to an exponential increase of Z-twist along the line, Tn_t, so that the final twist distribution, T(x), incorporated effect of n_b and n_t, becomes a kind of decayed S-twist all the way along the spinline, as shown in Figure 3. However, it is clear that n_b cannot contribute to any twist change since it causes no angular displacement of the strand.

Two factors may be attributed to cause the occurrence of the contradiction. Firstly, the division of n is wrong. In fact, n is just the self-rotation of the strand, namely, n_t, according to the derivation of Equation 1. Secondly, the assumption of $n_t=k(dT/dx)$ may be arbitrary, which does not reflect the implicit relation of the variables involved.

It is really confusing to find that Equation 5, the incorrect twist distribution derived, was in general agreement with the experimental observation made by the authors .

Kinetic Approach

A kinetic Equation of twisting has been derived [5]:

$$2\pi I\left(\frac{\partial n}{\partial t}+V\frac{\partial n}{\partial x}\right)=\frac{\partial M}{\partial x}+m\ .$$

In a steady state, the term related to time is eliminated:

$$2\pi IV\frac{dn}{dx}=\frac{dM}{dx}+m\ . \tag{7}$$

Miao and Chen [5] assumed a simple linear relation between M and T, i.e., M=KT. Combined with Equation 2, Equation 7 becomes:

$$\left(2\pi IV-\frac{k}{V}\right)\frac{dn}{dx}=m\ . \tag{8}$$

The twist distribution in the case of single-jet false-twisting when the yarn traveling speed along the yarn direction is less than a certain amount ($v_0=\sqrt{k\rho/q}$) is shown in Figure 4. Obviously, it is not in agreement with the published experimental findings.

Consider a simple extreme situation where the yarn traveling speed is zero in a single-jet twisting. The twist distribution in this false-twisting case is obvious and well known as illustrated in Figure 5. Clearly, this counterexample is in contradiction with Miao and Chen's results. Their conclusions are open to debate.

The above two approaches yield totally different results of the twist distribution. Neither of these approaches seems to reflect the actual twist distribution in a practical situation. It makes it necessary to conduct experimental observations on the dynamic twist distribution in a real spinning operation.

Experimental

Introduction

All experiments were carried out on MJS 802 air-jet spinning machine. A model experiment was designed where two textured filament yarns of different colors were used, instead of the staple slivers. The use of colored yarns made it easier to photograph the yarns for displaying the twist distribution. An overfeed is used in the production of staple yarns, the feed ratio usually being 0.97 or 0.98. However, overfeed caused the extra length of the filament yarns to accumulate at a position just before the delivery rollers, which resulted in the breakage of the yarn. Therefore, in these model experiments, the feed ratio exactly equal to 1 was chosen.

We used the original Murata twin-jet nozzle. By setting the air pressure of N1 to zero and only using N2, we can observe the single-jet case on the machine. The entrance of the nozzle is a few millimeters away from the nip of the front rollers in the original Murata arrangement. It is difficult to make any observation on the upstream zone. The nozzle was lowered for a few inches to a position at which both upstream and downstream zones could be observed. The other settings were kept the same as those used in the industrial production. A yarn delivery speed of 180m/min. was used. The yarn rotation speed reached a few millions of revolutions per second, depending on the air pressure supplied.

Photographing Methods

Due to the tremendously high speed of the motion of the yarn bundle, it is really hard to instantly freeze the motion and capture the picture to show the twist distribution along the threadline. Several photographing techniques have been tried, including strobe light, videotaping with the image analyzer, high-speed flash, and high-speed film.

None of these techniques except the use of high-speed film proved successful which will be described as follows.

High-speed films offer sufficient exposure in a extremely short span of time. We used TZ3200 film made by Kodak and 1/4000 second shutter speed. The pictures do show the distribution in the upstream zone pretty well (See Figure

6-12), which may be attributed to the higher tension in this region because of the forward inclined angles of the nozzle orifices. The downstream zone photos still come out blurred, particularly at higher air pressures due to higher balloon speed. Even lighting is vitally important in this process.

Results and Discussion

Figures 6-12 show the twist distributions in the upstream zone at different air pressures ranging from 0.1 to 0.4 Pa. The photographs clearly show the uneven distribution of the twist in this region. The twist appears to increase steadily from the nip of the front rollers to the jet nozzle, and reaches maximum at the position of the nozzle orifices.

In the downstream zone, there is also a twist distribution as depicted in Figure 13. Even though the balloon is blurred in Figure 14, which is the case at higher air pressure, it still shows the gradually changing twist along the yarn direction. It seems that the twist tends to decay gradually from the jet nozzle towards the delivery roller, which is in agreement with Lunenschloss and Bergmann's findings [3]. The twist distribution in the entire spinning zone is qualitatively illustrated in Figure 15.

It is easy to understand that the rotation of the strand is in the same direction as that of the balloon rotation.

Qualitatively, it seems reasonable that the strand twist decays gradually after the twister. Referring to Equation 2, $dT/dx<0$ in the downstream zone, so that $dn/dx<0$; the decreasing n actually adds Z-twist to the strand, hence the S-twist in the bundle gradually dies down to zero.

On the other hand, if $dT/dx<0$ in the upstream zone, then $dn/dx<0$ according to Equation 2. In other words, n also causes Z-twist in the bundle. This is hardly plausible, because if it were true, the case would be such that at the entrance n approaches the maximum value to insert sufficient S-twist into the initial short portion of the yarn, and then the decreasing n lets the S-twist taper off all the way down to zero. Consequently, $dT/dx>0$ must be true in the upstream zone. Also $dn/dx>0$ is established in the upstream zone.

Apparently, the qualitative analysis is in good agreement with our experimental observation of the twist distribution in both upstream and downstream zones. The test results are reliable.

YARN QUALITY WITH MIY DEVICE

A recent development in Jet Spinning bas been the introduction, by Murata, of the MIY device, which is primarily intended to improve the yarn quality. The MIY unit is placed between the take up from the nozzle section and the winding unit and because of its situation it must be judged as a false twisting device. Discussions with Murata indicated that there was still development work being carried on and various designs of MIY had been tried (including crossed belts and a bush system). Samples of yarn spun with and without the MIY device were obtained for a preliminary investigation, and the results obtained indicate that while the yarns produced with the MIY device are less hairy they are also slightly weaker. Microscopic analysis of the yarn surface also appeared to indicate that the use of an MIY device had increased the regions of the yarn which were not covered by wrapper fibers and this could account for the reduced yarn strength. Earlier work with this type of approach has shown that the tension on the yarn can critically affect the balance between tensile and aesthetic properties of the resultant yarn [6, 7].

The role of draft on yarn structure is being investigated jointly by the collaborating institutions. Polyester/cotton sliver has been prepared containing different colored tracer fibers and this will be spun into yarns and the yarn formation and internal structure will be analyzed at Clemson whereas the role of processing parameters (in particular draft) on the yam surface characteristics will be studied at State. The collation of the result from both studies should provide a greater insight into the effect of processing conditions on yarn structure and hence properties, and may throw some insight into possible approaches for successfully producing cotton rich jet spun yams.

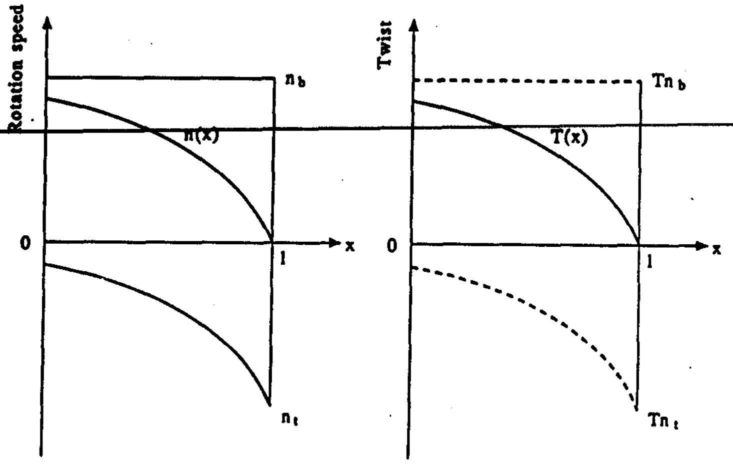

Figure 3. Twist distribution by kinematic analysis

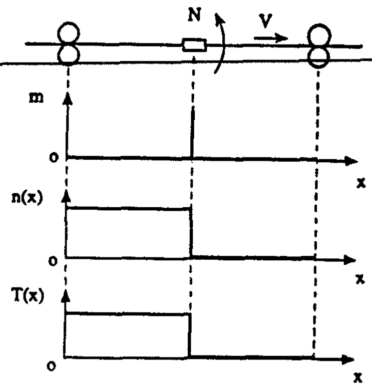

Figure 4. Twist distribution by kinetic analysis

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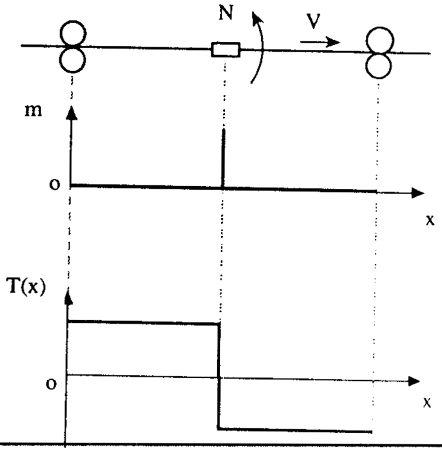


Figure 5. Twist distribution when the yarn traveling speed is zero

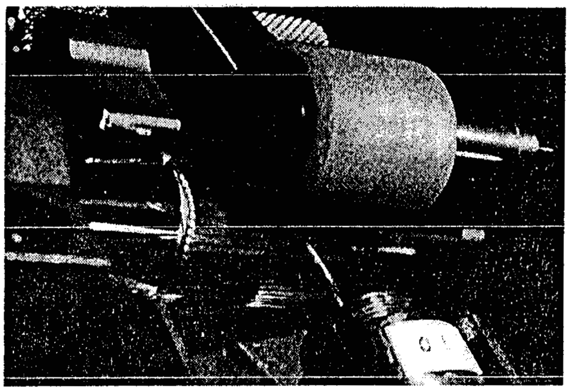


Figure 6. Twist distribution in upstream zone (N2=0.10Pa)

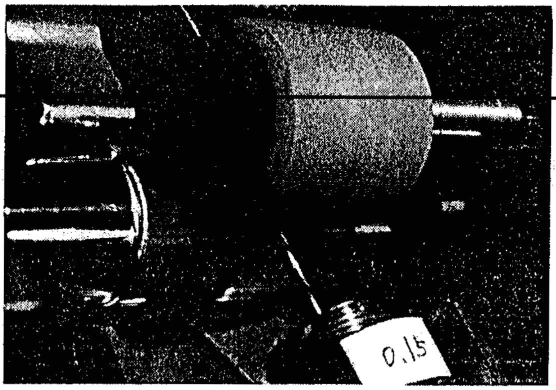


Figure 7. Twist distribution in upstream zone (N2=0.15Pa)

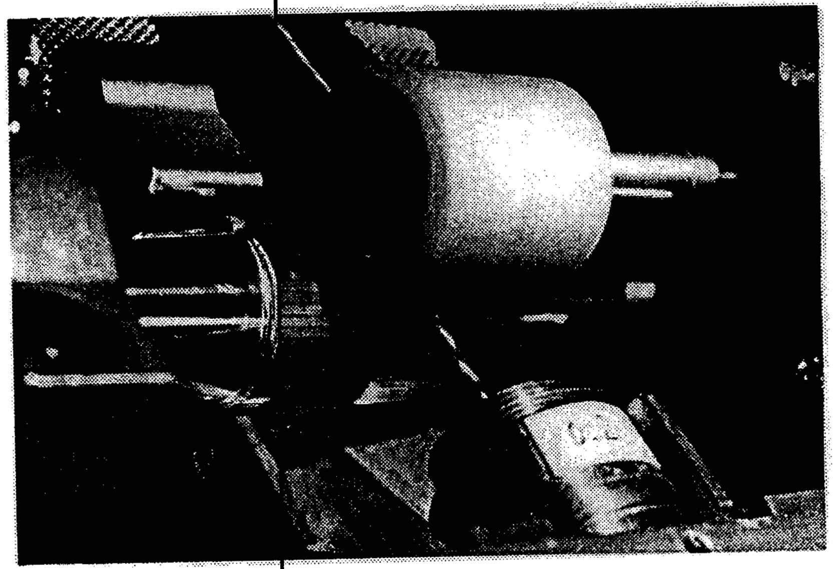


Figure 8. Twist distribution in upstream zone (N2=0.20Pa)

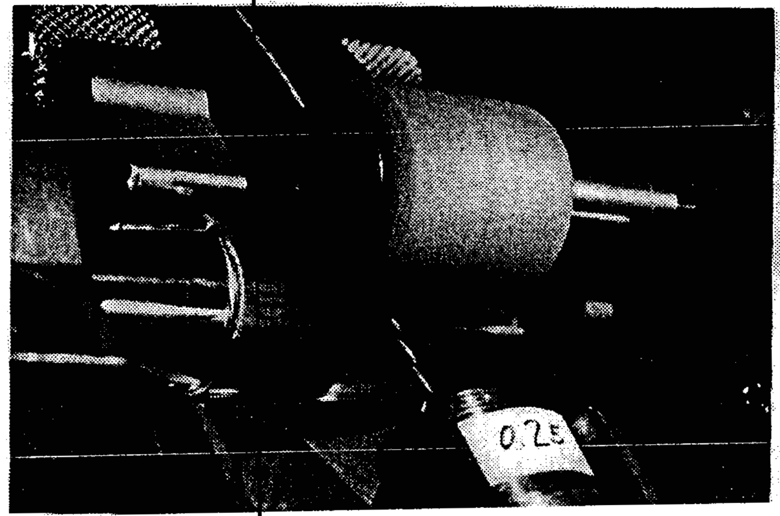


Figure 9. Twist distribution in upstream zone (N2=0.25Pa)

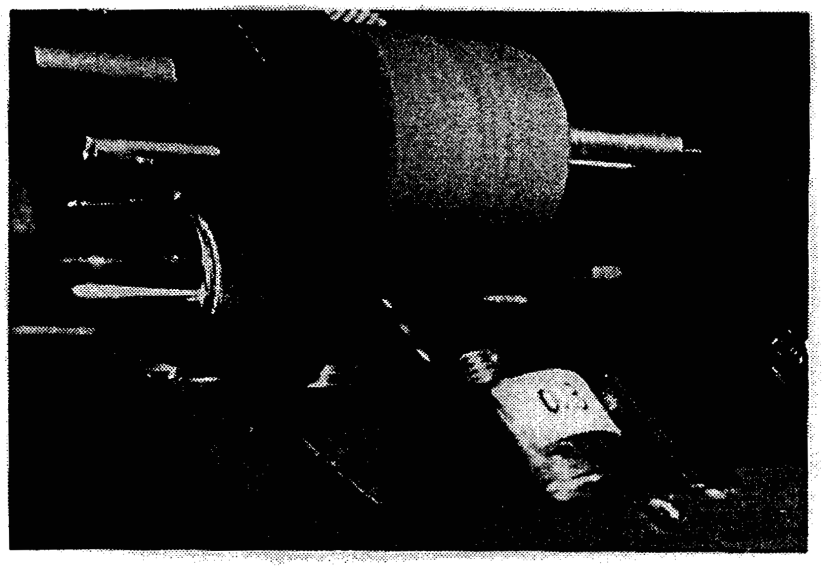


Figure 10. Twist distribution in upstream zone (N2=0.3Pa)

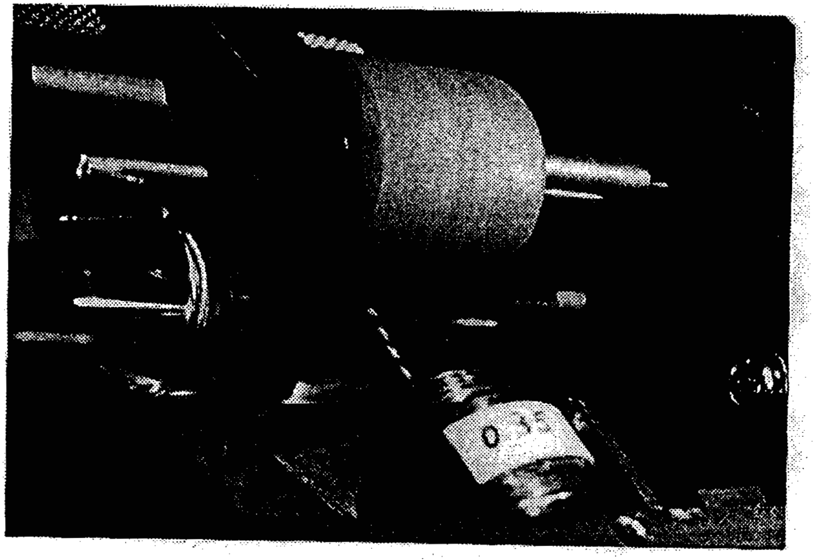


Figure 11. Twist distribution in upstream zone (N2=0.35Pa)

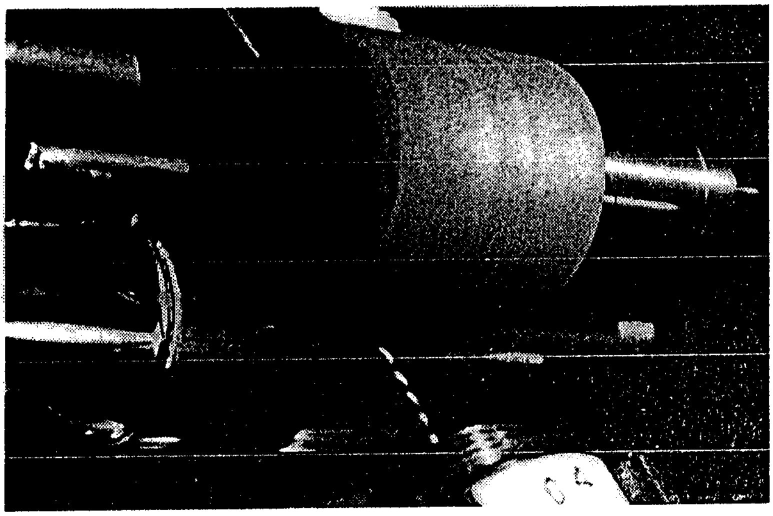
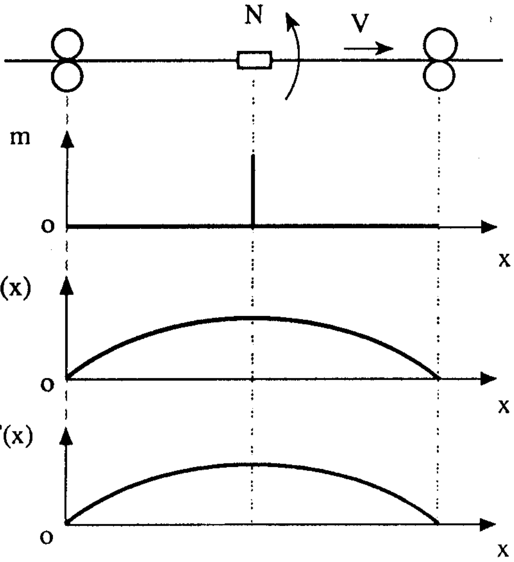


Figure 12. Twist distribution in upstream zone (N2=0.40Pa)



Twist distribution of yarn bundle in spinning zone
Figure 15.

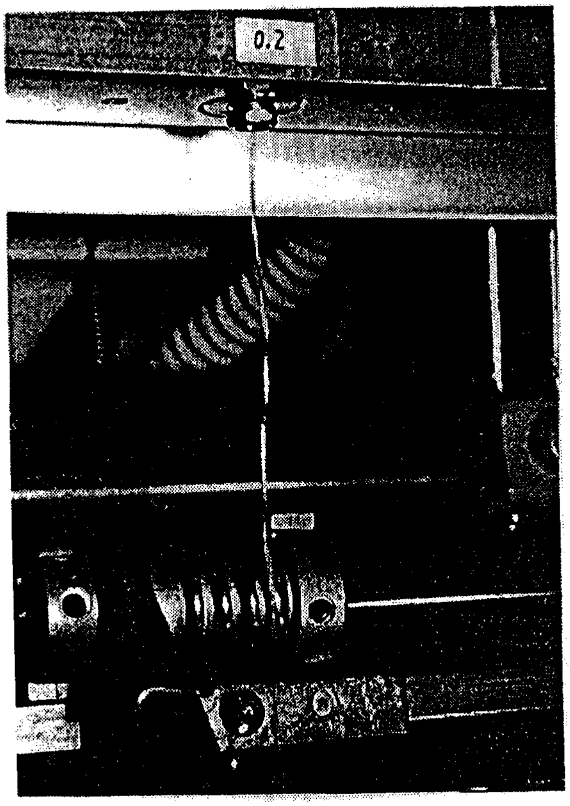


Figure 13. Twist distribution in downstream zone (N2=0.20Pa)

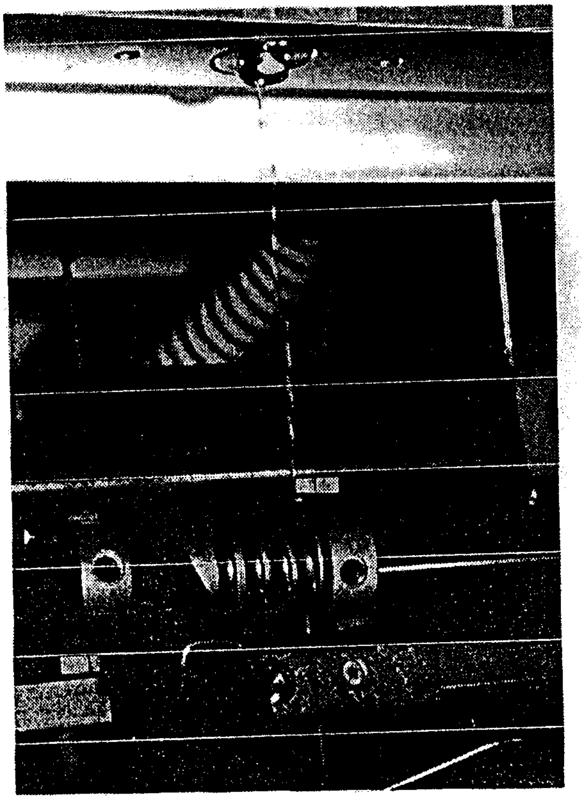


Figure 14. Twist distribution in downstream zone (N2=0.35Pa)