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# AN ANALYSIS OF THE AIR-JET YARN-TEXTURING PROCESS PART VI: THE MECHANISM OF LOOP FORMATION

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## ABSTRACT

*After a brief summary of the findings and conclusions of the previously reported investigations on the air-jet texturing process, a mechanism of loop formation is postulated. The factors affecting loop formation are analysed in the light of the mechanism described. This mechanism of loop formation is claimed to be valid for all types of texturing nozzle because the underlying requirement to create a supersonic, turbulent, and non-uniform flow is common to all satisfactory air-jet texturing nozzles.*

## INTRODUCTION

In the previous parts of this series of papers<sup>1-5</sup>, a brief history of developments in the air-jet texturing process<sup>1</sup> Was given together with an account of an experimental investigation of the air-flow<sup>2</sup> and of the investigation of filament behaviour during texturing<sup>3</sup> Fluid forces acting on the filaments were analysed and possible effects of filament cross-sections on the texturing process considered<sup>4</sup> The effects on the texturing process of wetting the yarn were also investigated<sup>5</sup>.

The findings and conclusions of all these theoretical and experimental investigations are summarized in the following section.

## SUMMARY OF THE RESULTS AND CONCLUSIONS

The flow from the texturing nozzles at the usual air-pressures used in texturing is supersonic, turbulent, slightly asymmetric, and of a non-uniform profile. The mean velocity of the flow and the degree of its non-uniformity increase with increasing air-pressure. A nozzle with a curved diverging (trumpet-shaped) exit appears to exaggerate non-uniformity in the velocity profile, while nozzles with longitudinally staggered air-inlet bores impart swirl into the flow. Asymmetry of the flow is most pronounced in planes close to the air inlets but diminishes with distance towards the nozzle exit.

Pressure waves, their strengths varying according to the particular nozzle type, occur in the flow emerging from all texturing nozzles. These waves are at least partly destroyed by the presence of filaments in the nozzle during the texturing process; nevertheless, nozzles providing varying degrees of shock

strength are apparently equally effective in producing commercially viable textured yarns. It may be concluded that the effect of pressure waves on the filament motion is negligible and that any loop-formation mechanism based on the presence of such waves is probably invalid.

During texturing, the filaments are assisted towards the lower part of the nozzle (for downward delivery) by the tension created in the yarn as a result of loop formation.

Filament segments within the nozzle may travel instantaneously at much faster speeds than the yarn-throughput speeds. Intensive turbulence has the effect of separating and scattering the filaments across the nozzle cross-section. Since the flow-velocity distribution is non-uniform and the fluid forces acting on the filaments are a function of the local air velocity, filaments that are separated and scattered across the nozzle are under the action of different driving forces and therefore move at different speeds. This in turn causes longitudinal displacements of the filaments relative to each other. Friction between the yarn and the solid surfaces plays a significant role in affecting the resultant force acting on the filaments and reduces the effects of the fluid forces.

Wetting of the yarns, which is an industrial practice known to improve the yarn quality, has a lubricating effect; this in turn reduces the friction between the yarns and the solid surfaces and thereby results in increased net forces acting on the filaments. Moreover, wetting also reduces the friction between the filaments themselves and hence enhances their longitudinal displacements and assists their entanglement as they emerge from the nozzle. Consequently, all these factors improve the texturing process.

The amount of water required to create the desired effects of wetting is only a small fraction of the total amount used in the process, because most of it is blown away by the secondary flow, only a small fraction being allowed to be carried into the nozzle. The possible effects of water mist on the primary-flow velocity are shown to be insignificant, although these effects act in such a way as to cause a slightly reduced velocity. This observation casts doubt upon any suggestions that water alters the air-flow properties sufficiently to improve the texturing conditions and the resultant yarn quality.

Filaments with different cross-sectional areas and with different cross-sectional shapes may behave differently in the air stream. For a circular cross-section, whereas the drag forces that act on the filament increase in proportion to the filament diameter, the mass and the inertial resistance of the filament to these fluid forces will increase as a function of the square of the diameter. This should cause coarser filaments to accelerate and travel more slowly under given flow conditions and therefore may result in inferior texturing conditions. In addition, finer filaments have a reduced stiffness, which makes bending and other forms of deformation of the individual filaments much easier during the loop-formation process. Increased numbers of finer filaments will also increase the likelihood of mutual entanglement and thus may be expected to improve the effectiveness of the texturing process. In conclusion, it can be stated that on all counts finer filaments contribute to better-quality air-textured yarns.

The cross-sectional shapes of the filaments could also have considerable effects upon the loop-formation process. Filaments with equal fineness but with smaller

second and polar-second moments of area and with increased surface areas may prove to be more suitable for air-jet texturing than circular filaments because such filaments will have a preferred bending axis, which leads to reduced stiffness, while the extended surface and projected areas will tend to increase the fluid forces.

#### THE POSTULATED MECHANISM OF LOOP FORMATION

On the basis of the previous observations, it is possible to postulate the mechanism of loop and entanglement formation. There are many filaments in any supply yarn suitable for air-jet texturing, but, for convenience in explaining the possible loop formation mechanism, only five filaments emerging from the nozzle are shown in Fig. 1. At any instant, some of these filaments will be moving at faster speeds than others owing to the relatively greater fluid forces acting on them. The free excess lengths provided by overfeeding the filaments enable the faster-moving filaments to slip and be displaced longitudinally with respect to the slower-moving filaments. The degree of these longitudinal displacements is affected by local drag and frictional forces instantaneously acting on the filaments and also by the overfeed.

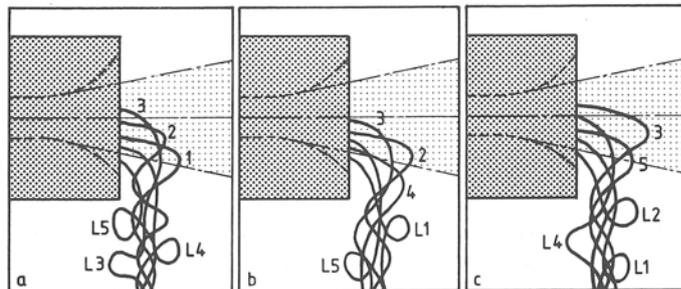


Fig. 1. Schematic illustration of the formation of loops as the filaments emerge from the nozzle

The textured yarn is withdrawn from the nozzle at right angles to the nozzle axis at the texturing speed. Since the filaments are entangled and formed into loops, the resultant textured yarn is shortened, and a tension is created of a magnitude determined by the effectiveness of the texturing. Thus, on the one hand, the emerging filaments are blown out of the nozzle along the direction of the air stream at much greater speeds than the yarn-texturing speed; on the other hand, the tension created in the yarn pulls the 'leading ends' of the emerging filaments in the direction of the yarn delivery. Whereas the 'trailing ends' of the filaments in the nozzle are blown out at very high speeds (see Part II<sup>3</sup>), the 'leading ends' of the filaments are held within the core of the much more slowly moving textured yarn and are pulled downward while being kept fairly close to the nozzle exit plane. The emerging filaments are therefore forcibly bent into bows and arcs by the fluid forces acting on them. These are then entangled with other emerging filaments, which are formed into fixed stable loops within the textured yarn.

The increased tension resulting from loop formation and subsequent entanglement causes loop-forming filaments to migrate towards the lower part of the nozzle (for the downward delivery) since they will assume the shortest possible path between the 'trailing' and the 'leading ends'. Hence the filaments in the nozzle change their positions. An instant later, the tension in the segments following these entangled filaments may be relieved on account of the overfeed, and these filaments may be blown out by the air stream to form new loops. Every filament goes through this process at a different instant, and the cycle repeats itself randomly.

This possible sequence of events is illustrated in Fig. 1, which is a simplified schematic diagram with only five filaments representing the behaviour of a more complex multifilament yarn. At stage (a), filament 1 is the fastest-moving filament, having the greatest longitudinal displacement relative to the others, and it is blown furthest out of the nozzle to form a loose bow or arc. An instant later, at stage (b), it is formed into a fixed loop L1 within the textured yarn as a result of mutual entanglement of the filaments under the action of the air stream. This newly formed fixed loop L1 increases the tension in filament 1, which thereby causes a change in its position and also contributes to the total yarn tension that is pulling the yarn down closely to the nozzle. Meanwhile filament 2 comes under the action of a greater drag force as a result of changes in the positions of the filaments across the nozzle that are due to the turbulence and varying tension in the individual filaments, and this now becomes a faster-moving filament, so that it is caused to be blown out and displaced longitudinally relative to the others to form a loose bow or arc. Immediately afterwards at stage (c), while filament 2 is being similarly entangled into a fixed loop L2, a further filament 3 commences a similar loop-formation process.

Since there are many filaments in the actual supply yarn rather than the five illustrated in Fig. 1, several loops are formed at any particular instant, and these help each other to be fixed and locked within the yarn structure by mutual entanglement. Other filaments, although they do not form visible loops on the surface of the yarn, have their originally closely packed parallel structure changed into a tangled, voluminous structure with increased bulk and linear density.

This possible mechanism of loop and entanglement formation could be valid for all types of texturing nozzle, despite detailed differences in their design, because the underlying requirement to create a supersonic, turbulent, asymmetric, and non-uniform flow and a substantial change of direction of the yarn path at the nozzle exit is common to all satisfactory air-jet texturing processes.

## **FACTORS AFFECTING LOOP FORMATION**

### **Consideration of Single Emerging Filament**

In order to analyse the effects of various process parameters on the loop-formation mechanism, a single filament emerging from the texturing nozzle is considered in Fig. 2.

The instantaneous point A is the 'trailing end' of the filament, which makes a bow on emerging from the nozzle and moves at a speed dictated by the air-flow,

i.e., filament speed,  $V_f$ . Point B is the 'leading end' of the filament and moves downwards at the texturing speed, i.e., at the speed of the textured yarn,  $V_y$ . It was estimated in Part III that the ratio of these two speeds could be of the order of 10 or higher, i.e.,

$$V_f > V_y > 10.$$

In a short interval of time, points A and B will move to positions A' and B' respectively, as illustrated in Fig. 2(b). The length of filament AA' (denoted by  $L$ ) that is blown out in this time is determined by the filament speed,  $V_f$ , and by the excess free length of filament as provided by the overfeed, whereas the distance BB' is determined by the texturing speed,  $V_y$ . The filament length between points A and B, originally  $L_0$ , becomes  $(L_0 + L)$ .

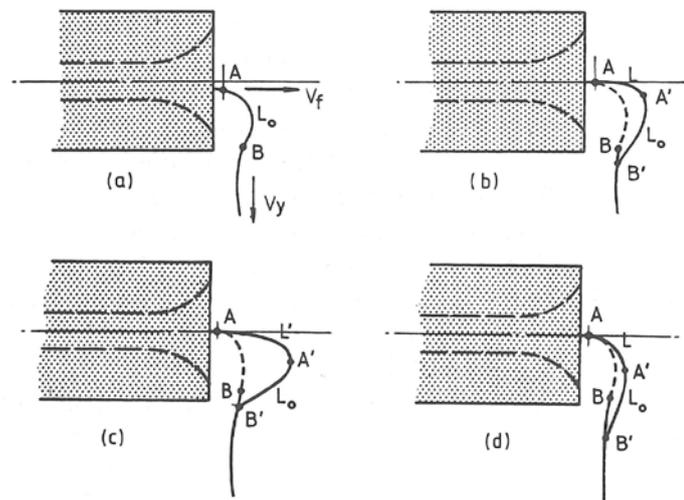


Fig. 2. Schematic diagram to illustrate the effects of process parameters on a single filament emerging from the nozzle

### Effects of Air-pressure

When the air-pressure is increased, the speed of a filament will also increase as a result of the increased air velocity, point A will therefore move more rapidly, and the time taken to blow out the free length  $L$  of the filament will become shorter. High air-pressure will also enhance the differences between the forces acting on the filaments and cause greater relative longitudinal displacements. Since the loop formation is an intermittent process, the increased filament speed could increase the frequency of the loop formation, and the entanglement process could then become more effective in flows with high velocities and intensified turbulence. Thus more effective texturing is likely to be achieved by increasing the air-pressure.

### Effects of Overfeed

When the overfeed is increased, it becomes possible for a longer length of filament to be blown out in a given time interval (i.e.,  $L' > L$ ), as illustrated in Fig. 2(c). If the yarn-texturing speed is not changed, point B will not move very far, and the longer filament between A and B' will form either a larger loop or several smaller loops in this time. Increasing the overfeed will therefore result in an increase in loop size and loop frequency, which in turn causes an increase in the

linear density. The yarn instability will also increase because the greater the number of entangled loops, the greater becomes the chance of these loops being pulled out when the yarn is tensioned.

When the overfeed is excessively high, the bow formed by the filament becomes very large; this will consequently reduce the tension in the yarn and allow the filaments and the textured yarn to be blown away from the nozzle, as is schematically shown in Fig. 3. This will result in a failure in the loop-formation process.

### Effects of Texturing Speed

Increasing the texturing speed will cause both points A and B to move faster and in turn result in longer distances AA' and BB' in a given time interval (Fig. 2(d)), but a given length of filament will be exposed to the air-flow for a shorter time. Because of this, any loops that are formed will be less stable and may be removed easily under subsequent tensioning of the textured yarn. Consequently, the number of stable loops formed will be reduced, the tension in the yarn in the delivery zone will drop, and the filaments will be blown away from the nozzle, so that failures will be caused in the continuity of the texturing process.

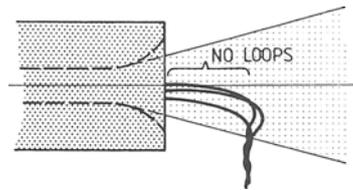


Fig. 3. Schematic illustration of unstable filaments, showing their failure to form loops

In order to counteract the adverse effects of increased texturing speeds, at least partly, the air-flow velocity could be increased. This could cause the process to become more effective, but the very high operating pressures required could make it uneconomical. The scope for increasing productivity by further increases of production speed therefore appears to be very limited with existing jet technology

### Effects of Impact Elements

Impact elements (see Part I<sup>1</sup>) are unlikely to have significant effects on the flow inside texturing nozzles, since any such element is usually situated at a distance of about one nozzle diameter from the exit. It is thus remote from the immediate nozzle-exit region, where loop formation actually takes place. One possible minor role of an impact element is to act as a physical barrier to those filaments that are blown well away from the nozzle.

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