Nov. 21, 1961 A. L. BREEN ET AL 3,009,309

FLUID JET TWIST CRIMPING PROCESS

Filed July 16, 1956 4 Sheets-Sheet 1

Fig. 1

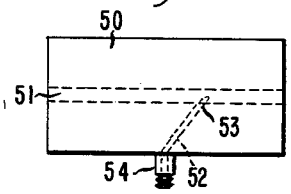


Fig. 2

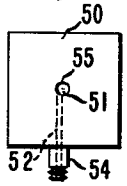


Fig. 3

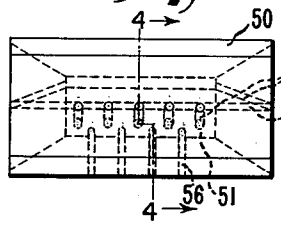


Fig. 4

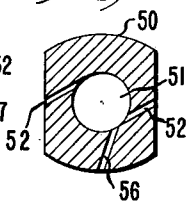


Fig. 5

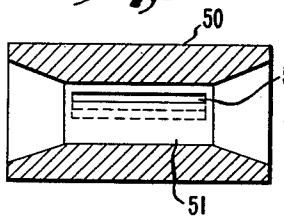


Fig. 6

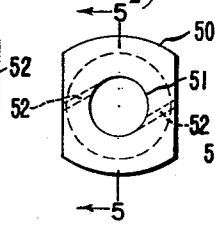


Fig. 7

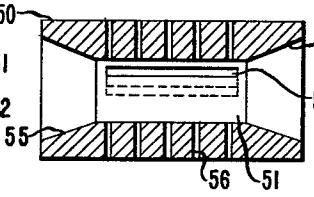


Fig. 8

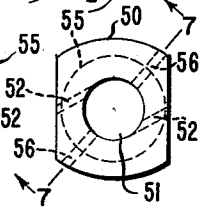


Fig. 9

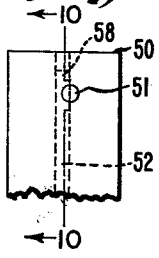


Fig. 10

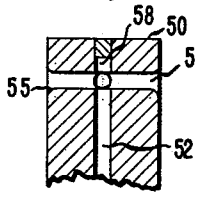


Fig. 11

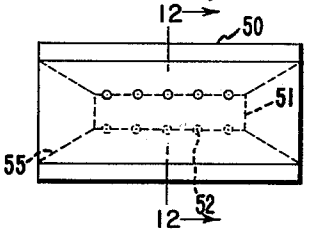


Fig. 12

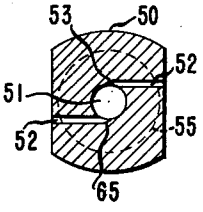


Fig. 13

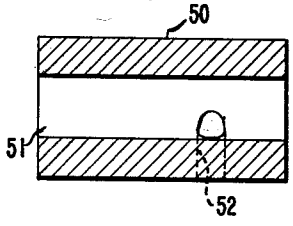


Fig. 14

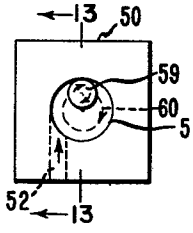


Fig. 15

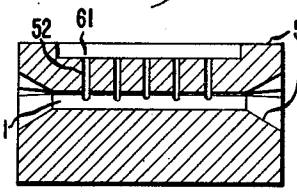
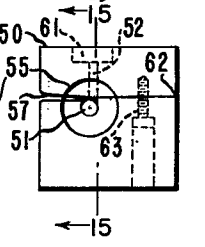


Fig. 16



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Nov. 21, 1961 A. L. BREEN ET AL 3,009,309

FLUID JET TWIST CRIMPING PROCESS

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Fig. 17

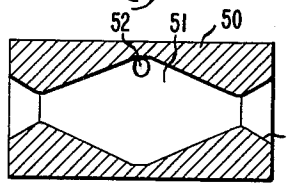


Fig. 18

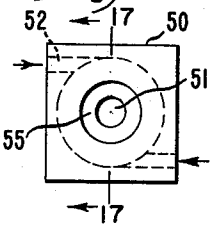


Fig. 19

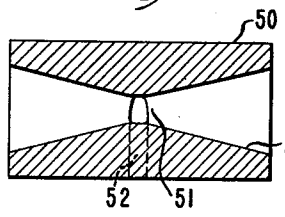


Fig. 20

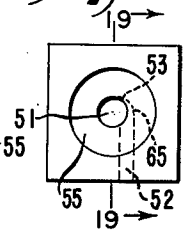


Fig. 21

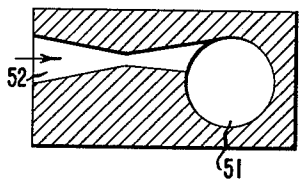


Fig. 22

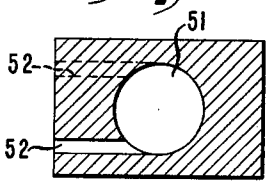


Fig. 23

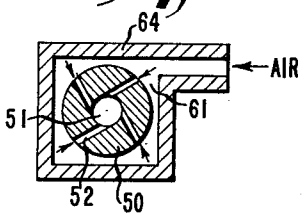


Fig. 24

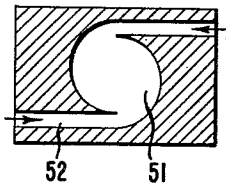


Fig. 25

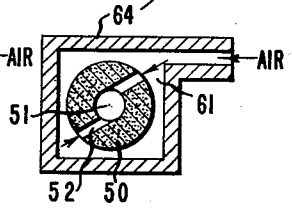


Fig. 26

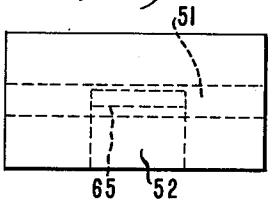


Fig. 27

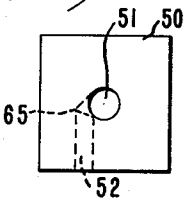


Fig. 31

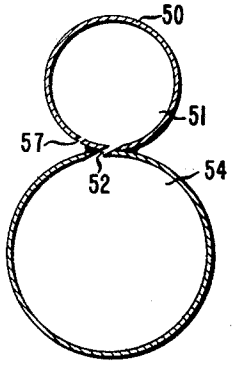


Fig. 28

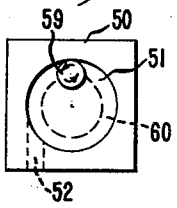


Fig. 29

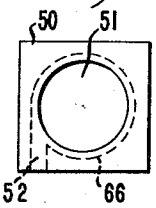
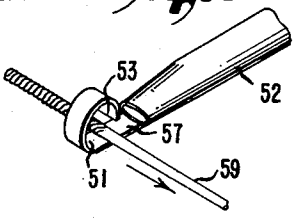


Fig. 30



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FLUID JET TWIST CRIMPING PROCESS

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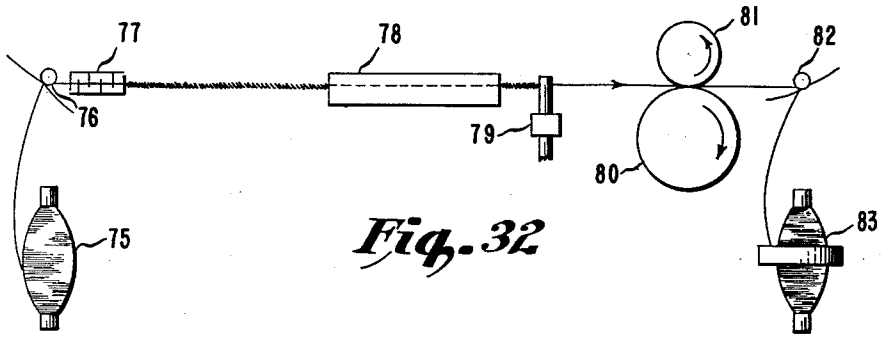


Fig. 32

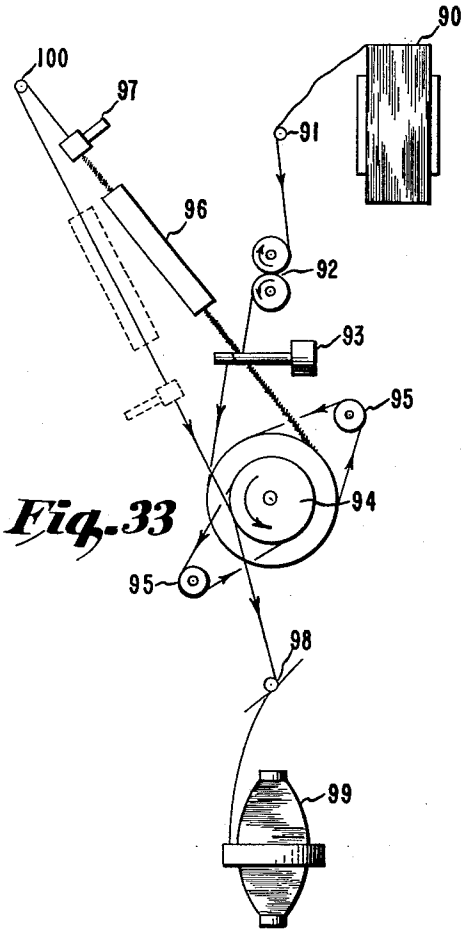


Fig. 33

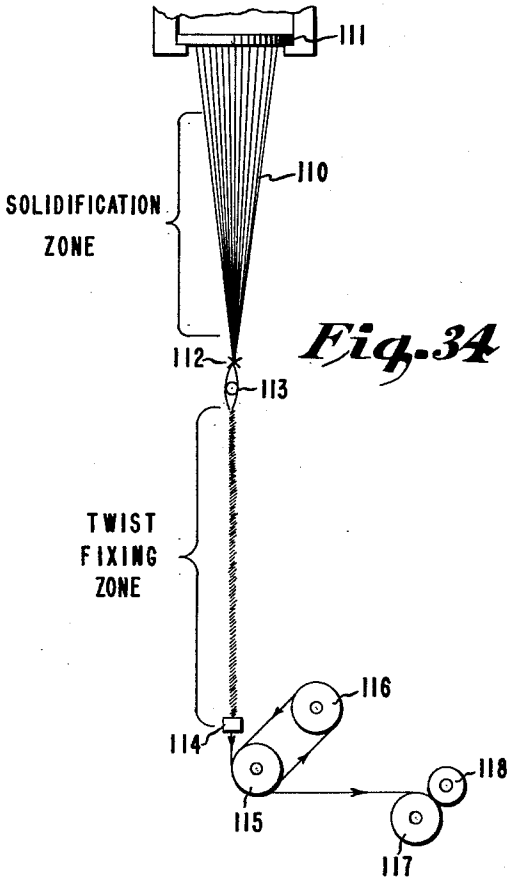


Fig. 34

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FLUID JET TWIST CRIMPING PROCESS

Filed July 16, 1956 4 Sheets-Sheet 4

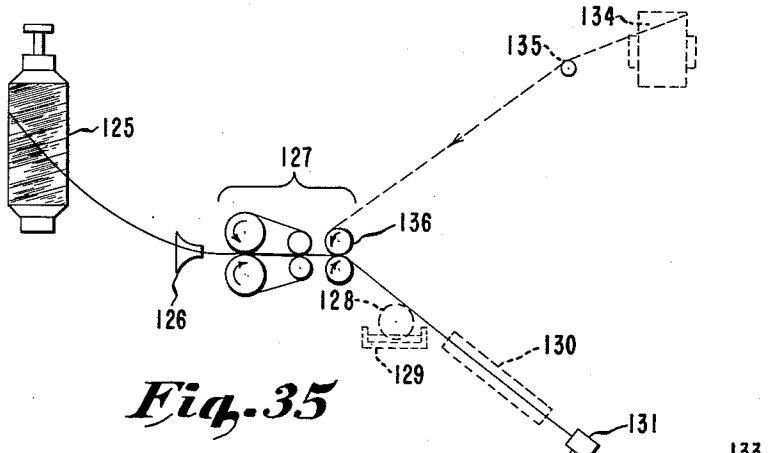


Fig. 35

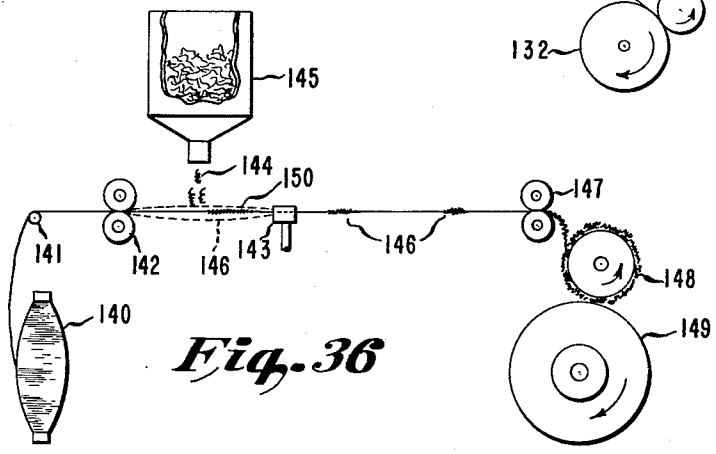


Fig. 36



Fig. 37



Fig. 38

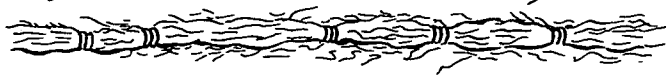


Fig. 39



Fig. 40



Fig. 41

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ATTORNEY

United States Patent Office

3,009,309

Patented Nov. 21, 1961

3,009,309

FLUID JET TWIST CRIMPING PROCESS

Alvin L. Breen, West Chester, Pa., and Martin V. Sussman, Wilmington, Del., assignors to E. I. du Pont de Nemours and Company, Wilmington, Del., a corporation of Delaware

Filed July 16, 1956, Ser. No. 598,135

1 Claim. (Cl. 57—139)

This invention relates to a process and apparatus for twisting, bulking, or crimping yarns continuously, and to products produced thereby. This application is a continuation-in-part of application Serial No. 443,313 filed July 14, 1954, by Alvin L. Breen and now abandoned.

It has long been known that a yarn can be crimped by twisting, heat-setting the twist, and then back-twisting the yarn. In a batch process a true twist is inserted into the yarn, the yarn is packaged, heat-set, and then back-twisted to give the yarn its crimp and bulk. When such a process is carried out continuously, a temporary twist is imparted to the threadline by use of a false-twister and simultaneously the yarn is exposed to a yarn-setting means, e.g., heat, steam, solvent, etc. The temporary twist is removed immediately after leaving the twister, and the yarn is taken up on a suitable package. Examples of batchwise processes for imparting twist are contained in U.S. 2,019,185—Kagi; U.S. 2,019,183—Heberlein; U.S. 2,197,896—Miles; and U.S. 2,564,245—Billion. Continuous processes and apparatus for false-twisting are disclosed in U.S. 2,089,198—Finlayson et al.; U.S. 2,089,199—Finlayson et al.; U.S. 2,189,239—Whiteheat; U.S. 2,111,211—Finlayson et al.; U.S. 2,463,620—Heberlein; and U.S. 2,741,893—Vandamme et al.

One reason why these older processes and false-twisting apparatus have not enjoyed extensive commercial success is their relatively slow speeds, low output and efficiencies and high maintenance costs which rendered the product very expensive.

Nylon filaments were the first thermoplastic textile materials capable of being heat-set and having adequate recovery from deformation so that bulky and stretch-type yarns could be prepared. The initial process developed to make such yarns was a batch-type operation, i.e., the continuous yarns were highly twisted, the packages of twisted yarn were then heated or steam-set under suitable conditions, and then these packages were back-twisted to give a yarn that, on relaxation, coiled, curled, or crimped sufficiently to bulk the yarn. In addition to the increased bulk the yarn bundle had the elastic properties of a conventional spring without the helical regularity thereof.

The most time-consuming step in producing so-called "Helanca" or stretch-yarns, is twisting. Mechanical twisters with rotating mechanical parts have severely limited rotative speed because of friction and the effect of centrifugal force on the rotating parts. The highest commercial speed known is of the order of 150,000 r.p.m. and this is for a specially designed false-twister which is more than twise as fast as a standard commercial down-twister. Relative efficiency of the specially designed false-twisting apparatus and continuous twisting process versus the conventional twister batch process is described in the magazine Fibres (Natural and Synthetic), volume 16, August 1955, p. 276, published by Leonard Hill, Ltd., Stratford House, 9 Eden Street, London, S.W. 1, England. As described therein, a 60-denier nylon yarn which is twisted 65 turns per inch, heat-set and then

back-twisted via the conventional twister route (12,000 r.p.m.) can be handled at the rate of 0.4 pound/spindle/week of 168 hours. A special false-twister (32,000 r.p.m.) can produce this same stretch-yarn at the rate of 1.8 pounds/spindle/week (168 hours) or about 4.5 times faster than the batch operation.

One object of this invention is to provide an efficient high speed yarn twisting device containing no mechanical moving parts. Another object of this invention is to provide a twisting device capable of twisting yarn at sufficiently high speed to twist staple yarn through the zero twist point without the yarn bundle pulling apart. Another object of this invention is to provide a yarn-twisting device capable of twisting yarn at a rate of over one million turns per minute. Another object of this invention is to provide an apparatus for twisting yarns at higher speeds and at lower tension than has heretofore been utilized.

A further object of this invention is to provide a process for continuously crimping yarn at substantially higher speeds and lower yarn tension than heretofore possible. Another object of this invention is to provide a process for continuously and simultaneously twisting, plasticizing, deplasticizing, and backtwisting yarn at substantially greater yarn speeds, lower yarn tension, and higher twisting rates than has heretofore been possible.

A further object of this invention is to provide a yarn-twisting apparatus and process whereby freshly drawn yarn may be directly (prior to packaging) crimped by continuously and simultaneously twisting, plasticizing, deplasticizing, and backtwisting the yarn. Another object of this invention is to provide a yarn-twisting apparatus and process whereby a freshly extruded yarn (directly from the spinneret) is continuously and simultaneously twisted, plasticized, deplasticized, and backtwisted to produce a stretch-yarn.

Still another object of this invention is to provide a yarn-twisting apparatus and process whereby staple fiber roving may be twisted to produce a spun yarn having a novel structure and characteristics. Another object of this invention is to provide a yarn-twisting apparatus and process whereby a yarn or a multiplicity of yarns may be continuously twisted together to produce a novel alternate twist yarn or multi-plyed yarn product. Another object of this invention is to provide a yarn-twisting apparatus and process for producing novel slub yarns from continuous filament yarns or from staple fiber yarns or from a combination of continuous filament and staple fiber yarns. It is a further object of this invention to provide a yarn-twisting apparatus and yarn-twisting process whereby any of the above objectives may be obtained, using either continuous filament yarn or staple fiber yarn or, where two or more yarns are utilized, a combination of continuous filament and staple fiber yarns.

It is a further object of this invention to provide a yarn-twisting apparatus and process whereby yarn may be cold-drawn and twisted simultaneously. Still another object of this invention is to provide a yarn-twisting process for producing stretch-yarns in which the yarn is twisted at tensions below about 15 grams and then immediately wound on a back-windable package. Another object of this invention is to provide new spun yarn products, new slub yarn products, and novel alternate twist yarn products prepared from either continuous filament yarns or staple fiber yarns or both. Further objects of this invention and means for obtaining them will be gained from the following description.

An essential part of this process is the use of a stream of fluid to exert a torque upon and impart a high speed crank-twisting motion to the yarn bundle. In its simplest embodiment, the apparatus of this invention comprises, in combination, a fluid twister and means for passing yarn through the twister at low tension. The fluid twister comprises a yarn passageway which is a smooth curved concave surface in combination with one or more fluid conduits positioned to direct a stream of fluid circumferentially about the inner periphery of the concave surface. The yarn passageway may be integral with the fluid conduits, or the latter may be spaced apart from the yarn passageway but in position to direct fluid substantially tangentially to the inner periphery of the curved concave surface at some point. The axis of fluid flow must not intersect the axis of the yarn passageway, but it may lie in a plane substantially perpendicular to the longitudinal axis of the concave surface, or in a plane inclined up to about 75 degrees or more from this perpendicular in order to exert forward movement or braking action upon the yarn in addition to twisting motion. There may be a plurality of conduits directing fluid flow about the periphery of the concave surface, and these conduits may be spaced longitudinally or circumferentially or both about the yarn passageway. Naturally, in order to obtain the highest degree of torque on the yarn, all of the fluid conduits, where there is a plurality, should be directed in substantially the same tangential direction. It is not necessary, however, that the longitudinal axes of all the fluid conduits lie in the same or parallel planes with respect to the axis of the yarn passageway. One or more of a plurality of fluid conduits may have axes perpendicular to the axis of the yarn passageway while one or more others may have axes inclined to impart forward or twisting motion to the yarn while a lesser number of fluid conduits may have axes inclined backward toward the axis to partially inhibit the passage of the yarn therethrough. In the case where there are a plurality of fluid conduits supplying fluid to the yarn passageway, it may be desirable to provide one or more exit ports along the yarn passageway, and these may be positioned at any convenient points.

In the drawings, which illustrate specific embodiments of the invention,

FIGURE 1 is an elevation of a simple embodiment of fluid twister, as viewed from a direction at right-angles to both the yarn passageway and the single fluid conduit,

FIGURE 2 is an end view in the axial direction of the yarn passageway of the fluid twister of FIGURE 1,

FIGURE 3 is an elevation of a more complex fluid twister having a plurality of fluid conduits and intermediate exhaust ports along the yarn passageway,

FIGURE 4 is a cross-sectional end view on line **4—4** of FIGURE 3,

FIGURE 5 is a longitudinal cross-section taken along the axis of the yarn passageway (see line **5—5** in FIGURE 6) of a modified fluid twister having a slot-shaped fluid conduit,

FIGURE 6 is an end view of the fluid twister of FIGURE 5,

FIGURE 7 is a longitudinal cross-section, similar to that of FIGURE 5, of a fluid twister having a slot-shaped fluid conduit and a plurality of exhaust ports,

FIGURE 8 is an end view of the fluid twister of FIGURE 7,

FIGURE 9 is an end view of a fluid twister similar to that shown in FIGURES 1 and 2 but modified by having the fluid conduit extended a short distance beyond the intersection with the yarn passageway,

FIGURE 10 is a cross-secton along line **10—10** of FIGURE 9,

FIGURE 11 is an elevation of a fluid twister having a plurality of fluid conduits arranged in pairs entering the yarn passageway from opposite sides, the view being taken in a direction parallel to the axes of the fluid conduits,

FIGURE 12 is a cross-sectional end view on line **12—12** of FIGURE 11,

FIGURE 13 is a longitudinal cross-section of a fluid twister similar to that of FIGURE 1 but having a single cylindrically-shaped fluid conduit at right-angles to the yarn passageway,

FIGURE 14 is an end view of the fluid twister of FIGURE 13 which also illustrates the motion of yarn in the yarn passageway during operation,

FIGURE 15 is a longitudinal cross-section of a fluid twister having a plurality of fluid conduits extending into the yarn passageway from a manifold,

FIGURE 16 is an end view of the fluid twister of FIGURE 15,

FIGURE 17 is a longitudinal cross-section of a fluid twister similar to that of FIGURE 13 but having a yarn passageway which decreases in diameter in each direction, from the maximum diameter at the fluid conduit, to a minimum diameter near the entrance and exit ends of the yarn passageway.

FIGURE 18 is a cross-sectional end view of the fluid twister of FIGURE 17.

FIGURE 19 is a longitudinal cross-section of a fluid twister similar to that of FIGURE 13 but having a yarn passageway which decreases in diameter towards the point of entry of the fluid conduit,

FIGURE 20 is an end view of the fluid twister of FIGURE 19,

FIGURE 21 is a cross-sectional end view of a fluid twister similar to that of FIGURE 2 but having a venturi-shaped fluid conduit,

FIGURE 22 is a cross-sectional end view of a fluid twister similar to that of FIGURES 13 and 14 but having an additional fluid conduit located so as to introduce fluid into the yarn passageway at a different point and in an opposing direction for the purpose of varying the rate of twisting of yarn as it passes through,

FIGURE 23 is a cross-sectional end view of a fluid twister having fluid conduits entering the yarn passageway at four locations around the circumference,

FIGURE 24 is a cross-sectional end view of a fluid twister having a pair of fluid conduits entering a non-cylindrical yarn passageway from opposite sides,

FIGURE 25 is a cross-sectional end view of a fluid twister having fluid conduits of different diameters entering a cylindrical yarn passageway from opposite sides,

FIGURE 26 is an elevation of a fluid twister similar to that of FIGURE 5 but the slot-shaped fluid conduit is arranged to impinge on a shoulder at the point of entry into the yarn passageway,

FIGURE 27 is an end view of the fluid twister of FIGURE 26,

FIGURE 28 is an end view similar to FIGURE 14 to further illustrate the motion of yarn in the yarn passageway,

FIGURE 29 is an end view of a fluid twister similar to that of FIGURE 14 but having a yarn passageway which is somewhat larger in diameter at the point of fluid entry than at either yarn passageway port,

FIGURE 30 is a perspective view of an extremely simple construction of fluid twister,

FIGURE 31 is a cross-sectional end view of a modified form of the fluid twister of FIGURE 30,

FIGURE 32 is a plan view of an apparatus for treating yarn showing the fluid twister in combination with yarn feeding means,

FIGURE 33 is a plan view of another embodiment of the apparatus,

FIGURE 34 is a plan view of a further embodiment of the apparatus,

FIGURE 35 is a plan view of still another embodiment of the apparatus,

FIGURE 36 is a plan view of an additional embodiment of the apparatus, and

FIGURES 37 to 41 illustrate various novel yarn products which can be produced in accordance with this invention.

FIGURES 1 through 31 illustrate the manner of interception of a yarn passageway **51** by one or more fluid conduits **52** and exhaust ports **56** and also show various forms which yarn passageway and fluid conduit may assume. It will be readily apparent that one or more of the cross-sectional or right-end views may be the cross-sectional or right-end views of one or more of the twister heads shown in longitudinal section or front elevation. Like numbers appearing in the various figures represent similar structures although the shape or form of the structure may vary from one figure to the next. For example, in each of the FIGURES 1 through 31 the yarn passageway is numbered **51** irrespective of whether the yarn passageway is cylindrical in form or a slot or a venturi or the like. Similarly, the fluid conduit is numbered **52** in each of the figures and so on.

FIGURE 1, which illustrates a representative fluid twister useful in this invention, contains axial yarn passageway **51** which, in this embodiment, is subtantially cylindrical in form throughout its length. A conduit for fluid **52** intercepts the yarn passageway at **53** at an angle of about 60 degrees to the axis thereof and is positioned so that the longitudinal axis of the fluid conduit **52** does not intersect the longitudinal axis of yarn passageway **51**, as shown in FIGURE 2. When gas under pressure is passed through fluid conduit **52** so that it reaches at least ½ sonic velocity upon emerging into the yarn passageway 51, sufficient torque upon any yarn in the yarn passageway is created to produce a high rate of crank twisting if the yarn is maintained at a tension of less than about 15 grams. At relatively high fluid velocities less dense fluids may be employed to obtain substantially the same torque produced by a higher density fluid traveling at lower velocity. Fluid may be supplied to the fluid conduit **52** by any convenient means. As shown by FIGURES 1 and 2, fluid may be supplied by fitting 54, which is fastened over the fluid conduit exterior port and threaded for attachment to a fluid supply pipe. Preferably, the yarn passageway will have rounded edges at both ends to minimize tearing of the yarn bundle, and, in accordance with one embodiment shown in FIGURES 7 and 8, the yarn passageway is widened by bevels **55** at the yarn entrance and exit ports. Naturally, it is not necessary that these widened portions of the yarn passageway be symmetrical or even similar in shape.

In some instances as, for example, when the yarn passage is of substantial length, it is desirable that the yarn passageway contain one or more fluid exhaust ports **56**, as illustrated in FIGURES 4 and 8, in order to facilitate removal of fluid from the yarn passageway. According to a particularly preferred embodiment, the fluid twister may be designed to provide for ease in stringing-up a threadline by providing a string-up slot running the entire length of the yarn passageway. The string-up slot may simultaneously serve as an air conduit or exhaust port, as desired. FIGURE 3 illustrates one possible form of string-up slot **57**. FIGURES 9 and 10 illustrate one manner of providing a fluid entry into the yarn passageway whereby the fluid will be cushioned against itself at the point of entry into the yarn passageway and thereby make a very smooth entry possible. This result is obtained, as shown in FIGURES 9 and 10, by designing the fluid twister so that the fluid conduit extends beyond the yarn passageway to form a fluid conduit extension **58**. In the case of twisters containing a multiplicity of fluid conduits, it is convenient to design the twister in a manner to provide a manifold region **61** (FIGURE 15) to facilitate maintenance of air at constant pressure to all fluid conduits where that is desired. FIGURE 16 illustrates a particular embodiment of fluid twister containing a string-up slot **57**. The twister of FIGURE 16 is divided in two sections, as shown, to further facilitate string-up, the two sections being held together by bolt **63**. If desired, the sections may be hinged at **62**. In FIGURES 23 and 25 there is provided a manifold housing **64** suitable for surrounding the entire twister head with fluid, and the twister head in these embodiments is porous to permit the transmission of fluid therethrough at a slow rate to reduce yarn-to-wall friction. FIGURE 27 illustrates a twister in which the fluid conduit **52** has a shoulder **65**, and FIGURE 29 illustrates a twister in which the yarn passageway is somewhat wider at the point of fluid entry than at either yarn passageway port.

FIGURE 22 illustrates a fluid twister in which two or more air conduits in opposed relationship with respect to flow of fluid about the yarn passageway are spaced longitudinally along the axial length of the yarn passageway whereby flow of fluid alternately from each fluid conduit produces an alternate S and Z twist in the yarn.

The yarn passageway of the fluid twister of this invention preferably has an internal diameter (in the case where the yarn pasageway is cylindrical) of between about 0.002 inch and about 0.125 inch. Yarn passageways which are not cylindrical will preferably have cross-sectional areas at the initial point of contact between the yarn and stream of fluid corresponding to areas of circles having these diameters. For fluid twisters of this invention having yarn passageways with cross-sectional areas comparable to a circle having a diameter up to about 0.125 inch, the direction of rotation of the yarn bundle during twisting is in the direction of fluid flow about the inner periphery of the yarn passageway, and this direction of rotation will be referred to herein as "direct twisting." With yarn passageways having cross-sectional areas comparable to a circle with a diameter of more than about 0.125 inch, centrifugal thrust forces the yarn bundle to roll on the inner periphery of the yarn passageway in a motion analogous to that of a planetary gear. This twisting action is referred to herein as "reverse twisting," and it will be apparent that with "reverse twisting" the twist imparted to the yarn is opposite to the twist obtained by "direct twisting," even though in each instance the direction of fluid flow about the yarn passageway is the same.

It is an important feature of this invention that during the twisting of the yarn bundle, whether the twisting action is "direct twisting" or "reverse twisting," the yarns undergoes a cranking action, that is, the longitudinal axis of the yarn describes a surface similar to the inner surface of the yarn passageway and spaced from the inner surface of the yarn passageway by a distance equal to about the radius of the yarn bundle. This feature of the instant invention is illustrated in FIGURES 14 and 28. FIGURE 14 illustrates direct twisting of a yarn bundle 59 in yarn passageway **51** and shows, by arrows, that the yarn twists about its axis in the same direction as fluid flow about the inner periphery of the yarn passageway while the axis of the yarn bundle describes a surface spaced from the inner surface of the yarn passageway by a distance at least the radius of the yarn bundle, both surfaces having a common longitudinal axis. FIGURE 28 illustrates the motion of a yarn bundle **59** subjected to reverse twist action showing that the yarn bundle rotates about its axis in a direction opposite to the flow of fluid about the inner periphery of the yarn passageway while the axis of the yarn bundle moving in the same direction as the flow of fluid about the passageway describes a surface spaced from the inner surface of the yarn passageway by a distance equal to the radius of the yarn bundle, both of said surfaces having a common longitudinal axis.

Some prior art attempts to rotate yarn by means of fluid flow have been characterized by endeavors to rotate the yarn about its own stationary axis by the turbine action of a fluid vortex. Yarn tensions have been maintained sufficiently high so that the yarn was maintained rigid, thereby preventing displacement of the yarn

from the center of the yarn passageway despite eccentric fluid forces acting on the yarn periphery. Low torque was imparted to the yarn because of the short lever arm through which the tangential forces must act due to the small diameter of the yarn. Other efforts (U.S. 2,515,299) require that an angular reach of a strand be formed so that the yarn could be literally cranked about its axis by this angular reach.

When operating in accordance with this invention, however, the yarn undergoes a cranking action as above described at tensions less than about 15 grams. By imparting a cranking action to the yarn, a leverage advantage is gained since the lever arm is increased by the radius of the cranking circle. High twist is thus obtained, and twisting rates in the range of one million turns per minute are observed where the path of yarn rotation is confined within a yarn passageway of small diameter, that is, less than about 0.06 inch, or in larger diameter passageways where reverse twist occurs by the yarn rolling on the inside of the passageway wall. The twisting rate may be easily determined in practice by trapping a small segment of twisted yarn emerging from the fluid twister, as with a rat-trap device, which almost instantaneously closes on the twisted yarn and maintains intact any twist therein, so that the actual number of turns per inch may be counted under a microscope. Then, of course, it is a simple matter, knowing the rate of throughput of yarn, to calculate the rate of twisting in turns per minute. For direct twisting, the rate of yarn twisting is about equal to the rate of cranking. For reverse twisting, the rate of twisting may exceed the cranking rate since the yarn may roll about its own axis many times in making one turn about the axis of the yarn passageway. Fluid twisters of this invention having a yarn passageway diameter of about 0.125 inch may be operated with direct twisting or reverse twisting by adjusting yarn tension, alignment of the yarn passageway, feed rate of yarn supply, or the like.

The fluid twisting devices of this invention may be utilized to twist yarns at exceedingly high rates (turns per minute) at exceedingly high throughput speeds (yards per minute) by continuously forcing a fluid against the periphery of successive portions of yarn maintained at low tension and constrained so that the yarn axis describes a surface, preferably a cylindrical suruface. The fluid may be a liquid or gas at the temperature of operation but inert gaseous materials, such as steam, nitrogen, carbon dioxide, etc., are preferred, and air is particularly preferred. In accordance with this invention stretch-yarns having more than 50 turns per inch are readily obtained at twisting rates substantially higher than one million turns per minute and with yarn tensions less than about 5 grams. The term "yarn" as used herein includes any strand material in the form of a monofilament or multifilament, or spun staple yarn.

The area of the yarn passageway in the fluid jet device of this invention is preferably about equal to that of the inlet conduit at the point of interception. Fluid jet devices in which the ratio of the area of the yarn passageway to the area of the fluid inlet orifices at the points of interception varies from about 4:1 to about 1:10 may be used, however. Preferably, the yarn passageway and the tube passageway are cylindrical in shape but either or both may be other than circular in cross section and neither need be uniform in area or cross-sectional form throughout its length. The figures illustrate various fluid jet devices of this invention, but it will be apparent that the figures are illustrative only, and many variations of the fluid twisters shown in the figures will be readily apparent.

Fluid may enter the yarn passageway through one or more orifices which may be arranged in a row along the length of the yarn passageway or in a multiplicity of tangential planes around the periphery of the tube. The fluid inlet conduits may be angled with respect to the yarn axis so that a portion of the fluid force results in a thrust to forward the yarn being treated (so long as the tension on the yarn does not exceed about 15 grams). If this angularity is reversed, a braking action upon the yarn will result.

The length of the yarn passageway may be widely varied. A very efficient fluid jet device is one having a yarn pasasgeway length between about 0.125 and about 0.25 inch and having only one fluid inlet port. The length of the yarn passageway should not be less than its diameter (or its substantial equivalent where the passageway is not circular in cross section). Preferably, the yarn passageway length will be about 4 times its diameter and desirably will not be more than 10 times its diameter. Longer yarn passageways may be utilized and are very efficient when "reverse twisting action" is employed. In the case of fluid jet devices having relatively long yarn passageways, it is often desirable to utilize a plurality of fluid supply conduits and one or more exhaust ports connected to the atmosphere or to a reduced pressure source to facilitate escape of the driving fluid and minimize back pressures. With short yarn passageways, exhausting of fluid is no problem since the fluid passes directly through the open ends of the yarn passageway. Thus, a multiplicity of jet devices having short yarn passageways mounted along a threadline may be more effective than a single fluid twister having a long yarn passageway, since such a design provides minimum fluid back pressure. With such a multiplicity of jets it may be desirable to have some fluid supply conduits angled forward to impart forward motion to the yarn while others exert rotative thrust. Obviously, this effect can also be achieved with a fluid twister having a longer yarn passageway and a plurality of fluid inlet ports.

Air at room temperature is preferred for twisting yarn in the fluid jet device of this invention but the air may be heated or refrigerated, if desired. Low pressure steam may also be used where its plasticizing action, if any, is not harmful. Other gases substantially inert to the yarn, such as carbon dioxide, nitrogen, and the like, may be utilized, if desirable. The invention is illustrated using air as a fluid because air is preferred in carrying out the process of this invention, but any inert fluid is suitable providing its plasticizing action, if any, is less than that of any plasticizing step utilized. In order to operate the process in accordance with the invention, it is necessary that the air immediately prior to impinging upon the yarn reaches a velocity of ½ sonic velocity or more, so that twisting of the yarn at rates of between about 100,000 and about 1,200,000 twists per minute are easily obtained. By increasing the velocity of the fluid flow, twisting speeds in excess of this amount are obtained.

It is an essential part of this invention that in order to obtain the high twist levels to produce stretch-yarns, the tension of the yarn being twisted be maintained at less than about 15 grams. Preferably, yarn tension during the twisting is maintained between about 0.1 and about 10 grams and for the most efficient twisting action at the highest rates of twist and highest throughput of yarn tension of the yarn should be maintained between about 0.5 and about 5 grams.

The high speed yarn-twisting apparatus of this invention may be utilized very effectively and efficiently to produce the so-called "Helanca" or stretch-type yarn at high rates of production. An assembly of apparatus incorporating the fluid twisters of this invention and adapted to produce stretch-type yarn at high rates of yarn throughput is shown in FIGURE 32. In this assembly, a textile denier yarn of less than about 2000 denier is taken from supply package **75**, passed through pigtail **76** through tension gate **77**, and plasticized by passing over hot plate **78** before entering fluid twister **79**. The tension gate is regulated to maintain the yarn as it passes through the fluid twister at a tension of less than about 15 grams. If desired, feed rolls may be added and tension controlled

directly by regulating the relative speed of the speed and windup rolls. Upon entering the fluid twister, the yarn is continuously subjected to a high rate of false-twisting. This twist extends backward along the yarn to the tension gate 77. The yarn in this twitsed state, upon passing over the hot plate, is plasticized in the twisted condition. The heat plasticized twisted yarn, upon leaving the presence of the hot plate and coming into contact with exhaust fluid leaving the yarn entrance port of the fluid twister, is quenched (deplasticized) prior to entering the fluid twister. In order that the fluid twister provide this quenching effect on the heated twisted yarn, it is important that the temperature of the exhaust fluids from the fluid twister be maintained at a temperature 50° C. below the plasticized yarn temperature and preferably 100° C. and ideally 150° C. below the heat plasticized yarn temperature. Due to the false-twisting action of the fluid twister, the deplasticized twisted yarn, immediately upon passing the point of greatest torque in the fluid twister, is back-twisted to substantially its original state of twist, thereby producing a stretch-type yarn which is passed through nip rolls 80 and 81, over pin 82 and taken up as a black-windable package 83 preparatory to use.

In place of the hot plate of FIGURE 32 any suitable heating means, such as a hot pin, infra-red, steam tube, hot water, and the like may be employed. Plasticizing the yarn may also be achieved in the absence of heat as, for example, with solutions of chemical plasticizing agents or similar materials.

When plasticizing is affected with heat, the temperature of the heating medium must be regulated so that the yarn temperature does not reach the melting point of the yarn material. It is quite possible, of course, that the heating medium temperature or source of heat be above the melting point of the yarn if yarn speeds are such that the yarn temperature is maintained below its melting point. Temperatures lower than the second-order transition temperature of the yarn material should usually not be employable because, under these conditions, any crimping of the filaments is not permanent and utility of the product is reduced.

To produce the highest quality stretch-yarns in accordance with this invention, that is, to achieve maximum bulking or crimping, it is essential that the tension of the yarn subjected to the fluid-twisting action be maintained below about 15 grams. This low tension in the yarn may be regulated by a tension gate or other suitable means. Conveniently and preferably low tension is achieved by utilizing feed rolls and windup rolls and operating the rolls to feed yarn into the fluid twister at a higher rate than the yarn is removed from the fluid twister. The yarn speed differential between input and output will be governed by the degree of bulking desired as well as the relative operating speed of the process, that is, throughput of yarn in yards per minute. Yarn speed differential between input and output with respect to the fluid twister may vary between about 5% to about 50%, and yarn speed through the fluid twister may vary from 0 up to about 650 yards per minute or higher. For economical operation, yarn speed will ordinarily be at least about 100 yards per minute and preferably at least 200 yards per minute.

It is essential that, in operating the process of this invention to produce a useful bulked yarn or stretch-type yarn, the back-twisted yarn leaving the fluid twister be taken up on a package suitable for back-winding. Substantial yarn tension must be employed during the windup, and preferably the yarn tension and yarn windup procedure should be in accordance with standard practices in the art. Thus, windup yarn tensions will ordinarily be greater than the twisting tensions utilized and should be sufficient to produce a good back-windable package of yarn.

The process of this invention can be used to crimp or bulk any natural or synthetic filamentary material. Thermoplastic materials, such as poly(epsilon-caproamide) and poly(hexamethylene adipamide, cellulose esters, polyethylene terephthalate, polyacrylonitrile, as well as copolymers thereof, can be crimped to produce highly elastic filamentary structures. Non-thermoplastic materials, such as the natural fibers—wool, silk, cotton, the synthetic protein fibers, regenerated cellulose and the like, can also be highly crimped or bulked although they are not as elastic as the thermoplastic fibers. Both types of materials can be made into elastic fabrics having improved bulk, covering power (opacity) and hand. This process is useful for both staple and continuous filament yarns of all types having deniers less than about 2000 and preferably less than about 800, and is particularly useful for staple yarns since it permits false-twisting of staple yarns and back-twisting of single staple yarns through the zero-twist point—feats not heretofore possible.

The process of this invention is preferably carried out on a continuous filament yarn immediately after the process of cold-drawing. An economic procedure involves incorporating a fluid twister and tension-regulating means along a threadline immediately after cold-drawing and prior to standard tension yarn takeup as shown in FIGURE 33. It is obvious, however, that the process can be carried out as a separate operation, either prior to or after drawing or after some indeterminate storage period.

Since yarn retraction of stretch-yarns in the presence of steam is a measure of wet recovery properties and varies directly with the degree of stretchiness, the quality of stretch-yarns can be graded on the basis of percent retraction, using the following formulation:

$$\text{Retraction (percent)} = \frac{(\text{skein length before steaming}) - (\text{skein length after steaming})}{(\text{skein length after steaming})} \times 100$$

To determine percent retraction of a skein of yarn the skein is wound at substantially zero tension on a reel with a periphery of 112 cm. to give a total denier of 1400. It is then suspended in front of a suitable scale and loaded with a weight of 1.82 grams to give 0.0013 g.p.d. A static eliminator is passed along the yarn bundle to prevent ballooning of the filaments. Atmospheric pressure steam is directed on the yarn bundle for one minute. High quality continuous filament nylon stretch yarns ordinarily have retraction values calculated in accordance with the above equation of the order of 75% to 95%. Such a shrinkage range is achieved only with thermoplastic continuous filament yarns. Lower retraction values of such yarns are useful if increased bulk with some stretchiness is adequate for the end use at hand. Such lower values will also result if the yarns being treated are not thermoplastic and/or are made from staple fibers.

Pneumatic twisters with yarn tubes of very small diameter show surprisingly high efficiency in terms of air consumption vs. useful work produced. This is an important consideration since air consumption is directly related to cost of manufacturing. Fluid yarn twisters of this invention appear to operate at highest efficiencies when the yarn tube is slightly larger than the air inlet tube. In a preferred embodiment, the air inlet tube axis is off-center with respect to the yarn tube axis by approximately the dimension of the air tube radius, and the yarn tube length is between about two and about five times the yarn tube diameter in order that motivating air may exhaust freely. With this arrangement, exhaust air is skewed with respect to the yarn tube axis, thereby tending to promote instability of processing particularly when yarn tension is very low (less than about 2 grams). Careful adjustment of the yarn axis positions entering and leaving the fluid twister to coincide with the axis of

air exhaust flow provides substantially much more stable and uniform operation and with fluid twisters, which are so very highly efficient as compared to mechanical twisting devices, stability of operation and uniformity of product are to be preferred over optimum efficiency. Since adjustment of the threadline with the air exhaust is difficult without some mechanical aid, the following test is useful to assist in this operation. A free end of yarn is placed in the twister so that a length of perhaps 6" protrudes from the fluid twister exhaust in both directions. The air supply is then turned on and the position of the free ends is noted. It is then a relatively easy matter to place guides aligned with the free end positions so that the running threadline may be placed along this same path. This type of arrangement is particularly important in the downstream direction.

In addition to being useful to improve the crimping and elastic properties of staple and continuous filament yarns, the process and apparatus of this invention can be applied to a single continuous filament or to staple roving and to plied roving or spun yarn or, in fact, to any filamentary strand material. While the twist applied to a running thread-line is false, the twist applied to projected ends of staple fibers is a true twist and the whipping and twisting of these ends about the yarn bundle makes it very coherent. Thus, by applying this process to staple roving, a yarn can be spun at speeds much higher than those obtainable on a conventional spinning frame. By varying the processing elements, the product can be varied all the way from a conventional spun yarn to a highly bulked stretch-type yarn.

As other variations of this process, two or more different yarns, continuous filament or staple, may be processed simultaneously at the same or different rates of feed speed and at the same or different tension levels with constant or pulsating feed rates, to give yarns of varying characteristics and/or novelty. Particularly interesting combinations can be prepared wherein the two different materials have dissimilar retraction characteristics. The differential retraction characteristics can be enhanced by using two different feed rates or tension levels, thereby increasing the ultimate bulking that will be achieved when the yarns or fabrics are given their final process retraction.

FIGURE 32 shows in schematic form one possible string-up assembly in which the pneumatic twister of this invention may be utilized. FIGURE 32 shows yarn being taken from a yarn package **75** passed through pigtail **76** to tension gate **77**. The tension gate is utilized to maintain yarn tension in the twisting zone at less than 15 grams. From the tension gate the yarn is passed through a heating zone **78** and then through the yarn passageway of twister **79**, thence between advancing rolls **80** and **81** through pigtail **82** and wound up as backwindable package **83**. Tension between the nip rolls and windup package **83** is maintained at standard windup tension.

In one method of operation of FIGURE 32 apparatus, zero twist poly-(ethylene terephthalate) continuous filament yarn is passed through the feed roll at 150 yards per minute; windup speed is 128 yards per minute and yarn tension is 3 grams measured upstream of the hot plate. Process twist is Z. The fluid twister is of the type shown in FIGURES 15 and 16 and operates on 30 pounds per square inch air. The hot plate is maintained at 270°. The fluid twister is slightly misaligned with respect to the direction of travel of the threadline with the result the yarn threadline alternately sticks and slips at the yarn passageway ports so that the yarn is twisted and cranked in a pulsating manner. The pulses permit **Z** twisted sections of the yarn to pass through the twister without twist removal, with the result that **S** twisted sections appear in the yarn between the **Z** twist sections that had escaped the twister action. The resulting yarn is called an alternating twist yarn. It has the appearance of a highly twisted crepe yarn, and is very twist lively and very cohesive. The net twist in the yarn is essentially zero, that is, there are as many turns of **S** twist as there are **Z** twist. The yarn product is illustrated in FIGURE 40 and the process in Table I, Example 54.

An alternating twist yarn is made via a process similar to the above except that instead of misaligning the jet the feed rolls are eliminated and the tension gate is vibrated at a rate of about 20 times per second. This causes a corresponding variation in yarn tension and produces an alternating twist product.

Alternating twist continuous filament yarn may be made using the fluid twister FIGURE 22. In this case, the air supply is alternated between opposing air inlets. This gives a positive alternating twist action and a product in which the **S** and **Z** portions of twist are very similar to each other in length and structure.

FIGURE 33 illustrates a string-up assembly whereby a fluid twister of this invention may be utilized to impart twist to a yarn bundle immediately after drawing the yarn and prior to packaging the drawn yarn. In accordance with this embodiment undrawn yarn is taken from a package **90**, passed over pin **91**, through nip rolls **92**, and then turned about snubbing pin **93** before passing around the larger circumference of a step-down roll **94**. Conventional canted separator rolls **95** are used in conjunction with the step-down roll. The yarn is then passed through a plasticizing zone (preferably heating) **96** prior to entering fluid twister **97**. Tension on the yarn during twisting is maintained below about 15 grams by means of step-down roll **94**. Yarn coming from the fluid twister **97** is passed around the smaller circumference of the step-down roll **94**, whereas yarn feeding the fluid twister must first pass around the larger circumference of the step-down roll. Thus, the yarn feeding to the fluid twister is traveling at a greater speed than the yarn leaving the fluid twister by an amount predetermined by the diameters of the larger and smaller sections of the step-down roll **94**. After leaving the step-down roll, the yarn is passed through pigtail **98** and wound up as backwindable package **99** at standard tension. In FIGURE 33, as just described, the yarn is plasticized and twisted prior to changing direction at pin **100**. Alternatively, the plasticizer and twister may be placed beyond pin **100** as shown in dotted lines so that the yarn will have a longer path of travel between step-down roll **94** and the plasticizing zone. This latter arrangement of heater and twister permits the insertion of supplementary heaters along the yarn path between the large section of roll **94** and pin **100**. The use of supplementary heaters is desirable when operating at yarn speeds above 200 yards per minute.

FIGURE 33 is a schematic drawing of a poly(hexamethylene adipamide) draw-twisting machine modified to permit coupling of the twisting process of this invention with a standard draw process. Undrawn poly(hexamethylene adipamide) yarn is taken directly from the spin bobbin, passed over a feed roll rotating at 28.6 yards per minute, over a draw pin, and around a draw roll, which rotates at 105 yards per minute. The yarn is drawn 3.6 times due to the difference in speed between the feed roll and the draw roll. The yarn makes three turns around a separator roll and the draw roll and then passes over a hot plate, through a pneumatic twister, over a direction changing guide, and back to a small diameter roll which is mounted concentrically and on a common shaft with the draw roll. This latter small roll has a surface speed which is 34% less than the draw roll. The yarn passes twice around this smaller roll and its separator roll. This smaller roll and separator roll can be considered as a windup roll. The difference in diameter or surface speed of the small and large concentric rolls determines the overfeed to the pneumatic twisting process and hence, determines the tension in the processing zone.

From the windup roll, the yarn travels through a standard pirn windup. The product produced is a 70–34 stretch nylon.

The yarn path between the draw roll and the windup roll can be considered as the stretch processing zone. The hot plate **96** and twister **97** can be mounted as shown in FIGURE 33 in which case the processing is designated as "up" processing. Alternatively, the twister and hot plate can be mounted as shown by the dotted outline in FIGURE 33 in which case the twisting process is designated as "down" processing. For high speed operation, the "down" processing procedure is preferred since an additional hot plate can be mounted on the up traveling leg of the processing zone which will supplement the heating effect of the hot plate immediately upstream of the pneumatic twister. The product and process characteristics are described in Example 22 of Table I.

Alternatively, yarn is treated as in the above example except that it is run from feed rolls **92** directly to heater **96**, the pin **93** and large diameter of roll **94** are by-passed. Under these conditions yarn is drawn on the hot plate while in the twisted condition. The resulting product is bulky but does not show as much crimp as the product of the previous example. The product and process characteristics are shown in Example 23 of Table I.

FIGURE 34 illustrates one procedure for utilizing the fluid twister of this invention to twist a yarn bundle coming directly from a spinneret and prior to being drawn. Filaments **110** issue from spinneret **111** and converge in guide **112**. Upon leaving the guide, the filaments are divided into two groups and pass upon opposite sides of pin **113**. The filaments are twisted immediately upon leaving pin **113** by means of fluid twister **114** farther downstream, the twist imparted by fluid twister **114** backing up to pin **113**. No heating zone is necessary with the string-up of FIGURE 34 since the filaments are in a plasticized state upon passing pin **113**. Twist imparted to the yarn bundle upon leaving pin **113** is fixed in the yarn either by cooling, evaporation, or otherwise, prior to entering fluid twister **114** from whence it is passed around rollers **115** and **116** and then to backwindable package **118** which is driven by drive roll **117**.

FIGURE 35 illustrates an assembly utilizing a fluid twister of this invention, which assembly may be utilized to produce a wide variety of novel specialty yarns. In the schematic drawing of FIGURE 35, roving is unwound from package **125** in conventional manner and passed in sequence through a trumpet guide **126**, drafting rolls **127**, and over applicator roll **128** which is revolving in a bath of adhesive solution. The roving is then plasticized in heater **130** and twisted by fluid twister **131** and subsequently wound on package **133** which is driven by drive roll **132**. It is not essential that adhesive be applied to the roving during the processing, and it is also not necessary that the roving be plasticized prior to twisting. Either or both of the adhesive application and plasticizing may be omitted or may be utilized, depending upon the particular product desired. In the case where no adhesive is applied to the roving and plasticizing is also omitted, the product produced by the twisting action of the fluid twister is a sheaf-yarn, such as illustrated in FIGURE 39. The product is called a sheaf-yarn because it resembles sheaves of wheat or, more exactly here, sheaves of staple yarn attached end to end and tied at random intervals along its length by staple fibers twisted firmly about the circumference thereof. Intermediate the tightly bound portions of the yarn the staple fibers are substantially parallel to one another.

In utilizing the assembly of FIGURE 35 and processing staple roving as above described but applying an adhesive solution to the roving prior to twisting but omitting any plasticizing of the roving prior to twisting, there is obtained an alternate twist staple yarn having an appearance similar to the twisted yarn shown in FIGURE 40 with the exception that FIGURE 40 is directed to an alternate twist continuous filament yarn. An alternate twist staple fiber yarn has essentially the same configuration but with a somewhat more fuzzy appearance due to the multiplicity of fiber ends protruding from the fiber bundle. When the assembly of FIGURE 35 is operated with a plasticizer, for example, a heat plasticizer, but without application of adhesive, a yarn product with somewhat greater bulk but somewhat less stability than the yarn product is obtained with adhesive application. When adhesive application alone is utilized in the absence of any plasticizing means, it is essential that the adhesive be sufficiently volatile so that it will be set (by polymerization or solvent volatilization) during the interval between application of the adhesive solution and entrance into the fluid twister. The air discharge from the fluid twister accelerates the setting of solvent based adhesives.

Operation of the assembly of FIGURE 35 is illustrated by passing poly(hexamethylene adipamide) staple filaments, issuing from the drafting rolls of a commercial spinning frame, through an air twister and then to a windup roll with a surface speed of 23 y.p.m. The yarn path from the drafting rolls, through the twister to a guide, located just prior to the windup, is a straight line.. Yarn tension above the twister is 2 grams. Supply air pressure to the twister is 30 p.s.i.g.

A continuous staple yarn is formed by the above process, which yarn is held together by random filament ends which are wrapped tightly about the yarn axis. The yarn is illustrated in FIGURE 39. The process conditions are shown in Example 50 of Table I.

Viscose rayon staple filament yarn issuing from the drafting rolls **127** of a commercial spinning frame at 50 y.p.m. is treated in the assembly of FIGURE 35 whereby the yarn is passed over an applicator roll **128** and a heated plate **130** prior to entering the pneumatic twister. The applicator rolls apply a size (poly vinyl alcohol emulsion) to the twisted yarn. The hot plate (280° C.) dries the size and fixes the yarn in its twisted configuration. Due to the combination of size and heat, the twist is fixed so tightly that some of the twist passes through the twister unaltered, with the result that opposite hand twist appears in portions of the yarn leaving the twister and the yarn has the appearance illustrated in FIGURE 40. The process and product are described in Example 55 of Table I.

Alternate twist continuous yarns are formed, using the application (of sizing) roll or the heater separately, however, the combined arrangement is preferred. With the hot plate at 230° C., the bonding agent is dried but the twist is removed by the fluid twister, thus yielding a zero-twist yarn made cohesive by the bonding material alone.

A poly(hexamethylene adipamide) continuous filament yarn is covered with viscose staple (1.5 d.p.f., 2½") using the equipment of FIGURE 35. Operating conditions are shown in Example 53 of Table I. The yarn is passed through the forward drafting rolls along with the drafted viscose staple fiber yarn. The filament yarn and staple yarn are immediately integrated by the twist imparted by the fluid twister. The twisted filament-staple yarn then is treated with polyvinyl alcohol by the applicator roll and heated to 250° C. to set the yarn, then passed through the twister to windup. In another example, adhesive is applied to both yarns prior to passage through the drafting rolls to produce a coated yarn having substantially greater bulk than in the case of yarn treated with adhesive after twisting.

By a variation of the assembly of FIGURE 35, it is a simple procedure to add one or more additional yarn structures to the roving prior to twisting, as indicated in the drawing. For example, a yarn package **134** containing either continuous or staple filaments may be passed over pin **135** and joined with the roving as it passes through nip rolls **136**. As in the case with the processing of roving alone in accordance with FIGURE 35 assembly, the joint processing of the multiplicity of filamentary

structures may be accompanied by the application of an adhesive solution by applicator roller **128** and/or plasticizing thereof by heat or other means as plasticizer station **130**. Alternatively, an adhesive solution may be applied to the continuous or staple filament prior to its joining with the roving, or application of adhesive to the roving or to the combination of roving and staple or continuous yarn may be omitted, as desired, to produce a wide variety of novel yarn structures.

FIGURE 36 illustrates an assembly for producing other novel yarns using a fluid twister of this invention. In using the assembly of FIGURE 36, a continuous or staple filament yarn is unwound from package **140**, passed over pin **141**, through nip rollers **142**, and subjected to the crank twisting action by fluid twister **143**. The cranking action upon the yarn is shown by dotted lines **150**. In the specific illustration shown, short lengths of a second filamentary material **144** are dropped from reservoir **145** upon the carrier yarn as it is cranked and twisted with the result that the short lengths of filamentary material are wound tightly about the cranking (carrier) yarn and become firmly bound thereto to form slubs. Alternatively, the slubs may be formed on the carrier yarn downstream of the fluid twister but this procedure is less desirable because slubs are even more firmly bound to the carrying yarn as the yarn carrying the slubs passes through fluid twister **143**. The slub yarn product is then passed through nip rollers **147** and wound on packaged roll **148** which is driven by drive roll **149**. In operating in accordance with this embodiment, the carrying yarn may be either staple or continuous filament yarn, and the secondary yarn, which is added to form slubs, may likewise be either staple or continuous filament yarn.

Using the setup shown in FIGURE 36, poly(hexamethylene adipamide) yarn is taken from a package, passed through the feed rolls, through a fluid twister operating on 40 pounds per square inch air to a windup roll, and finally to a backwindable package. Windup speed is 160 y.p.m. Tension in the threadline is maintained at 10 grams.

Immediately upstream of the twister, pieces of staple yarn (1.5 denier per filament, 3 inch viscose) are fed to the cranking, twisting threadline from a hopper. On contacting the cranking, twisting threadline, the staple fibers are immediately entrained into the threadline by the rapid cranking rotation, and form randomly spaced slubs along the threadline. An enlarged illustration of the slubbed yarn is shown in FIGURE 37. The slub yarn is novel in that the slub is held to the carrier yarn with two directions of twist. One end of the slub is twisted in the S direction, the other end is twisted in the Z direction. The process conditions are shown in Example 57 of Table I, and the product is illustrated in FIGURE 37.

Another type of slub yarn (crepe tail slub yarn) is illustrated in FIGURE 41. It is made by running a yarn through the FIGURE 36 setup at a tension of only 3 grams. The high twist imparted to the cold yarn at this low tension causes the yarn to form branched slubs which pass through the twister. The stability of the branched slubs can be improved by size applied before the twister.

These branched slubs can also be produced by plucking the threadline so as to create short rapid tension changes. The product is illustrated in FIGURE 41.

A slub yarn comprising slubs of continuous filament on a continuous filament carrier yarn is prepared by substituting a continuous filament package for the reservoir **145** in FIGURE 36. Running at a speed of 50 y.p.m. and using a fluid twister of the type shown in FIGURES 13 and 14, operated on 30 pounds per square inch air pressure, continuous filament yarn which is to be used for slubbing, is allowed to contact the rotating carrier yarn threadline. The slubbing yarn is immediately wrapped about the carrier yarn and forms slubs which consist of short sections of carrier yarn about which numerous layers of the slubbing yarn are wrapped. The tension on the carrier yarn is maintained constant at between 10 and 25 grams, whereas the tension on the slubbing yarn is varied in a rapid and random fashion between 0 and 25 grams. Wrapping occurs when the tension in the slubbing yarn drops below the tension in the carrier yarn. Layered slubs occur when the tension in the slubbing yarn approaches zero grams. The wrapping and carrying functions of each yarn may be reversed by reversing the relative tension levels. Process conditions are shown in Example 56 of Table I.

The slub yarn product (illustrated in FIGURE 38) is unique in that the slub consists of yarn wrapped about the carrier yarn in the direction of twist that exists upstream of the twister, whereas the unslubbed, but plyed sections of the yarn are twisted in the twist direction that exists downstream of the twister.

The fluid twister is particularly adapted to making of slub yarns, since the twister yarn passage offers little resistance to the passage of a slub, whereas mechanical twisters snub the yarn over pins, wheels, etc., which would offer substantial resistance to the passage of slubs, with the result that the threadline would be subject to frequent breakdowns.

Using a nozzle of the type shown in FIGURES 1 and 2 whose air port diameter is one-quarter of an inch and whose yarn passageway diameter is one-half an inch, it is possible to spin a real twisted staple fiber. For example, poly(hexamethylene adipamide) staple fiber (2 inches long, ½ denier per filament) is dropped into the air supply to the nozzle of FIGURE 1. A length of yarn is inserted in the yarn passageway and withdrawn at a rate of 20 yards per minute. The direction of withdrawal is opposite to the direction of the air port entry to the yarn passageway. The air supply pressure is 60 pounds per square inch. The air stream carrying its entrained staple fibers causes a rapidly rotating vortex in the yarn passageway and rotates the length of yarn initially placed in the yarn passageway at high speed. The rotating yarn wraps the staple fibers, carried by the air stream, about itself, and as the yarn is withdrawn from the yarn passage (in the direction previously indicated), a continuous staple yarn with real twist is formed and is continuously withdrawn from the twister. This yarn is wound on a suitable package and resembles conventional spun staple of a 5/1 cc.

Poly(hexamethylene adipamide) yarn of a type suitable for tire cord consisting of 240 filaments of approximately 6 denier per filament giving a total yarn denier of 1680 was processed in the general arrangement shown in FIGURE 32. In this case, because of the relatively poor heat transfer through the heavy yarn bundle, it was necessary to use several heating zones interspersed with booster fluid twisters which applied additional torque to the threadline to overcome air drag and other forms of friction tending to reduce the twist level in the twist heating zone. In the example at hand, three conventional slot type heaters were used in sequence. Between the first and second and second and third heaters (in the direction of threadline movement), booster fluid twisters were used supplied with high pressure steam which gave additional plasticizing action. The third heater was made several times the length of the other heaters to remove moisture in order to ensure complete deplasticizing. The zone between the last heater and the final pneumatic twister was also longer than the other similar zones. A transverse flow of air was used in this region to assist threadline cooling. The product collected at the windup in this case showed filament curliness in which the radius of curvature was somewhat larger than that observed with the textile denier yarns but sufficient to be attractive in certain forms of upholstery and carpet yarn uses.

The examples shown in Table I illustrate the operation of the fluid-twisting devices of this invention and the products which may be produced thereby. Table I indicates for each example the yarn material utilized, the conditions under which it was processed, the fluid twister utilized, the type of string-up assembly employed, and the nature of the product produced along with its stretch characteristics in terms of percent steam retraction where this data is pertinent. Air velocity in all examples where air was used as a fluid was at least ½ sonic velocity, and in Examples 1 through 7 the air was at sonic velocity. The deplasticizing (quenching) medium in all examples was air except that in Example 20 the deplasticizing medium was water, and in Example 29 steam was utilized for quenching. The temperature of the quenching medium was room temperature (26° C.) in all cases except Example 29 where steam at 100° C. was utilized for quenching. The fluid-twisting medium in all examples was air except that in Example 29 the fluid medium was steam. In Examples 8 through 14 air consumption amounted to 0.7 cubic foot per minute. In all examples illustrating production of stretch-yarn, the yarn was twisted at least 50 turns per inch, and in many instances, over 60 turns per inch.

Table I

Example	1	2	3	4	5	6	7
Yarn material	Poly(hexamethylene adipamide).	Same as 1	Same as 1	Same as 1	Same as 1	Same as 1	Same as 1.
Denier	70	70	70	200	70	40	70.
Number of filaments	34	34	34	13	34	13	34.
Source	Shipping package	Same as 1	Same as 1	Same as 1	Same as 1	Same as 1	Same as 1.
Type of yarn	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous.
Initial twist	½ Z	½ Z	½ Z	½ Z	½ Z	½ Z	½ Z.
Feed speed (y.p.m.)	103	158	645	115	451	Tension gate	115.
Windup speed (y.p.m.)	85	128	597	95	400	100–500	100.
Tension (gms.)	2	4	1–2	2	2	5	0.1.
Process twist	S	S	Z	Z	Z	Z	S.
Fluid twister	FIGS. 15 and 16	FIGS. 15 and 16.	FIG. 31	FIG. 31	FIGS. 9 and 10.	FIG. 31	FIGS. 13 and 14.
Heat-setting temp. ° C	250	270	325	260	325	240	260.
Type heater	Hot slot 1/16" x 13".	Hot slot 1/16" x 13".	Hot slot 1/16" x 26".	Hot slot 1/16" x 13".	Hot slot 1/16" x 26".	Hot plate 30"	Hot slot 1/16" x 13".
Air pressure (p.s.i.g.)	60	60	65	65	90	65	40.
Twisting action	Direct	Direct	Reverse	Reverse	Direct	Reverse	Direct.
Turns per minute	215,000	340,000	1,200,000	240,000	900,000		
Percent steam retraction	128	100	100	100	93		100.
Product characterization	Stretch yarn	Stretch yarn	Stretch yarn	Stretch yarn	Stretch yarn	Stretch yarn	Stretch yarn.
Air passage diam. (inches)	5 holes at .031	5 holes at .031	12 holes at .063	12 holes at .063	1 hole at .025	12 holes at .063	1 hole at .094
Yarn passage diam. (inches)	.047	.063	.313	.313	.035	.313	.188.

Example	8	9	10	11	12	13	14
Yarn material	Poly(hexamethylene adipamide).	Same as 8	Same as 8	Same as 8	Same as 8	Same as 8	Same as 8.
Denier	70	70	70	70	70	70	70.
Number filaments	34	34	34	34	34	34	34.
Source	Shipping package	Same as 8	Same as 8	Same as 8	Same as 8	Same as 8	Same as 8.
Type of yarn	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous.
Initial twist	½	½	½	½	½	½	½.
Feed speed (y.p.m.)	Tension gate	Tension gate	Tension gate	341	330	326	322.
Windup speed (y.p.m.)	400	450	500	309	309	309	309.
Tension (gms.)	1.5	1.5	1.2	1.5	2.5	3.5	6.0–7.5.
Process twist	S	S	S	S	S	S	S.
Fluid twister	FIGS. 9 and 10	FIGS. 9 and 10.	FIGS. 9 and 10.	FIGS. 9 and 10.	FIGS. 9 and 10.	FIGS. 9 and 10.	FIGS. 9 and 10.
Heat-setting temp. ° C	325	325	325	325	325	325	325.
Type heater	Hot slot 1/16" x 13"	Hot slot 1/16" x 13".	Hot slot 1/16" x 13".	Hot slot 1/16" x 13".	Hot slot 1/16" x 13".	Hot slot 1/16" x 13".	Hot slot 1/16" x 13".
Air pressure (p.s.i.g.)	100	100	100	100	100	100	100.
Twisting action	Direct	Direct	Direct	Direct	Direct	Direct	Direct.
Turns per minute	950,000	1,080,000	1,150,000	800,000	770,000	680,000	630,000–400,000.
Percent steam retraction	124	87	53	144	144	75	50–35.
Product characterization	Stretch yarn	Stretch yarn	Stretch yarn	Stretch yarn	Stretch yarn	Stretch yarn	Stretch yarn.
Air passage diam. (inches)	.025	.025	.025	.025	.025	.025	.025.
Yarn passage diam. (inches)	.025	.025	.025	.025	.025	.025	.025.

Example	15	16	17	18	19	20	21
Yarn material	Poly(hexamethylene adipamide).	Same as 15	Same as 15	Same as 15	Same as 15	Same as 15	Same as 15.
Denier	70	40	20	14	15	70	70.
Number filaments	34	34	7	2	1	34	34.
Source	Shipping package	Same as 15	Same as 15	Same as 15	Same as 15	Same as 15	Same as 15.
Type of yarn	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous.
Initial twist	½ Z	½ Z	½ Z	Zero	Zero	½ Z	½ Z.
Feed speed (y.p.m.)	225	Tension gate	Tension gate	117	115	160	225.
Windup speed (y.p.m.)	200	76	141	100	100	143	200.
Tension (gms.)	1.5	3	1	1	1	3	6.
Process twist	Z	S	S			Z	Z.
Fluid twister	FIGS. 9 and 10	FIG. 31	FIGS. 15 and 16.			FIG. 31	FIGS. 9 and 10.
Heat-setting temp. ° C	270	258	274	238	240	262	
Type heater	Hot slot 1/16" x 13".	Hot plate 30"	Hot slot 1/16" x 13".	Hot plate 30"	Hot slot 1/16" x 13".	Hot plate 30"	
Air pressure (p.s.i.g.)	100	65	70	40	40	65	100.
Twisting action	Direct	Reverse	Direct	Direct	Direct	Reverse	Direct.
Turns per minute							
Percent steam retraction	90		274			93	
Product characterization	Stretch yarn	Stretch yarn	Stretch yarn	Stretch bifilament yarn.	Stretch monofilament yarn.	Stretch monofilament yarn.	Crimped yarn.
Air passage diam. (inches)	1 hole at .031	12 holes at .063	5 holes at .031	1 hole at .063	1 hole at .063	12 holes at .063	1 hole at .025.
Yarn passage diam. (inches)	.010	.313	.063	.063	.063	.313	.025.

See footnotes at end of table.

Table I—Continued

Example	22	23	24	25	26	27	28
Yarn material	Poly(hexamethylene adipamide) undrawn.	Same as 22	Poly(ethylene-terephthalate).	Same as 24	Same as 24	Same as 24	Same as 24.
Denier	252 (undrawn)	252 (undrawn)	70	70	70	40	40.
Number of filaments	34	34	34	34	34	27	27.
Source	Spin bobbin	Spin bobbin	Spin bobbin	Spin bobbin	Supply package.	Same as 26	Same as 26.
Type of yarn	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous.
Initial twist	Zero	Zero	Zero	Zero	Zero	Zero	Zero.
Feed speed (y.p.m.)	103 (draw roll speed).	98 (feed roll speed).	117	114	150	114	120.
Windup speed (y.p.m.)	77 (windup roll speed).	350 (windup roll speed).	100	100	128	101	101.
Tension (gms.)	1.8	6	4	4	3.5	1.3	1.5.
Process twist	S	Z	Z	S		S	Z.
Fluid twister	FIGS. 11 and 12.	FIGS. 15 and 16.			FIGS. 11 and 12.		
Heat-setting temp. ° C	240	230	240	240	265	270	265.
Type heater	Hot slot 1/16" x 13".	Radiant tube.	Hot slot 1/16" x 13".	Hot slot 1/16" x 13".	Hot slot 1/16" x 13".	Hot slot 1/16" x 13".	Hot slot 1/16" x 13".
Air pressure (p.s.i.g.)	19	48	40	40	30	80	75.
Twisting action	Direct	Direct	Direct	Direct	Direct	Direct	Direct.
Turns per minute	220,000		240,000				
Percent steam retraction	115		115	115	87	195	154.
Product characterization	70-30 stretch yarn.	Bulked yarn	Stretch monofilament yarn.	Stretch monofilament yarn.	Stretch yarn	Stretch yarn	Stretch yarn.
Air passage diam. (inches)	10 holes at .031	5 holes at .031	1 hole at .063	1 hole at .063	10 holes at .031.	1 hole at .063	1 hole at .063.
Yarn passage diam. (inches)	.063	.063	.063	.063	.063	.063	.063.
Remarks		Simultaneous twisting and drawing.					

Example	29	30	31	32	33	34	35
Yarn material	Poly(ethylene-terephthalate).	Poly(epsilon caproamide).	Fortisan (a regenerated cellulose).	Polyacrylonitrile.	Polyethylene	Vinyon N	Raw silk.
Denier	70	70	90	100	66	130	
Number of filaments	34	34	120	40	20	160	
Source	Supply package	Same as 29	Same as 29	Same as 29	Same as 29	Same as 29	Same as 29.
Type of yarn	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous.
Initial twist	Zero		3 Z	0.3 Z	7 Z	3 Z	
Feed speed (y.p.m.)	118	115	106	115	115	115	110.
Windup speed (y.p.m.)	110	100	100	100	100	100	100.
Tension (gms.)	3	1-2	1-2	1-2	1-2	1-2	1-2.
Process twist	Z	S	S	S	S	S	S.
Fluid twister	FIG. 27	FIG. 27	FIG. 27	FIG. 27	FIG. 27	FIG. 27	FIG. 27.
Heat-setting temp. ° C	265	240	200	130	175	160	160.
Type heater	Hot slot 1/16" x 13".	Hot slot 1/16" x 13".	Same as 30	Same as 30	Same as 30	Same as 30	Same as 30.
Air pressure (p.s.i.g.)	40	40	40	40	40	40	40.
Twisting action	Direct						
Turns per minute		240,000	240,000	240,000	240,000	240,000	240,000.
Percent steam retraction	95						
Product characterization	Stretch yarn	Stretch yarn	Stretch yarn	Stretch yarn	Bulked yarn	Bulked yarn	Crimped yarn.
Air passage diam. (inches)	1 hole at .063	1 hole at .063	1 hole at .063	1 hole at .063	1 hole at .063	1 hole at .063	1 hole at .063.
Yarn passage diam. (inches)	.063	.063	.063	.063	.063	.063	.063.

Example	36	37	38	39	40	41	42
Yarn material	Viscose rayon	Cellulose acetate.	Cellulose triacetate.	(1)	Fiberglass	Cellulose acetate.	Poly(ethylene terephthalate).
Denier	150	100	292	84	110	100	1.5 D.P.F.
Number filaments	40	32	80	40	15	32	2½.
Source	Supply package	Same as 36	Same as 36	Same as 36	Same as 36	Same as 36	Same as 36. staple.
Type of yarn	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	40/2 cc.
Initial twist	2.5	Zero	Zero	½ Z		Zero	Z.
Feed speed (y.p.m.)	44	24	43	51	105	24	Tension gate.
Windup speed (y.p.m.)	42	22.5	42	22.5	100	22.5	74.
Tension (gms.)	2	1-2	4	1.3	1-2	1.2	7.
Process twist	S	Z	Z	Z		S	Z.
Fluid twister	FIGS. 11 and 12	FIG. 27	FIG. 27	FIG. 27		FIGS. 5 and 6	
Heat-setting temp. ° C	180	200	205	200	500	200	230.
Type heater	Hot Tube ½" x 13".	Hot Tube ½" x 13".	Hot Tube ½" x 13".	Hot Tube ½" x 13".		Hot Tube ½" x 13".	Hot slot ⅛" x 13".
Air pressure (p.s.i.g.)	30	40	15	24	40	15	80.
Twisting action	Direct	Direct	Direct	Direct	Direct	Direct	Direct.
Turns per minute	110,000				240,000		150,000.
Product characterization	Stretch yarn	Bulked yarn	Stretch yarn	Stretch yarn	Crimped yarn.	Stretch yarn	Stretch staple yarn with reduced fuzz.
Air passage diam. (inches)	10 holes at .031	1 hole at .063	1 hole at .063	1 hole at .063	1 hole at .063	1 hole at .063	1 hole at .063.
Yarn passage diam. (inches)	.063	.063	.063	.063	.063	.063	.063.
Remarks						Yarn wet with 20% acetone in water, before entering heater.	

See footnotes at end of table.

Table I—Continued

Example	43	44	45	46	47	48	49
Yarn material	Poly(ethylene terephthalate).	Same as 43	Same as 43	Casein	Wool	Cotton	Linen.
Denier	1.5 D.P.F	1.5 D.P.F	1.5 D.P.F			40	
Number filaments	2½"	2½"	2½"			1	
Source	Supply package	Same as 43	Same as 43				
Type of yarn	40/1 cc. staple yarn.	Same as 43	Same as 43	Staple	Staple	Staple	Staple.
Initial twist	Z	Z	Z				
Feed speed (y.p.m.)	44	44	40	110	110	105	105.
Windup speed (y.p.m.)	43	43	40	100	100	100	100.
Tension (gms.)	6	6	20	1–2	1–2	1–2	1–2.
Process twist	Z	S	Z	S	S	S	S.
Fluid twister	FIGS. 11 and 12.	FIGS. 11 and 12.	FIGS. 11 and 12.				
Heat-setting temp. ° C	170	90	26	150	130	180	190.
Type heater	Hot slot ⅛" x 13".	Hot slot ⅛" x 13".					
Air pressure (p.s.i.g.)	30	20	50	40	40	40	40.
Twisting action	Direct	Direct	Direct				
Turns per minute	100,000	100,000	100,000	240,000	240,000	240,000	240,000.
Product characterization	Stretch staple yarn with reduced fuzz.	Same as 43	Reduced fuzz staple yarn.	Crimped yarn.	Crimped yarn.	Crimped yarn.	Crimped yarn.
Air passage diam. (inches)	10 holes at .031	10 holes at .031	10 holes at .031	1 hole at .063	1 hole at .063	1 hole at .063	1 hole at .063.
Yarn passage diam. (inches)	.063	.063	.063	.063	.063	.063	.063.
Remarks		Process twist opposite to initial yarn twist. Yarn is twisted through zero point.					

Example	50	51	52	53
Yarn material	Poly(hexamethylene adipamide).	Same as 50	Same as 50	Same as 50.
Denier	1.5	70	70	70–34.
Number of filaments		34	34	Filament 1.50, 2½" staple.
Source	Bobbin	Supply package	Same as 51	Same as 51.
Type of yarn	Staple roving	Continuous fil	Same as 51	Filament and staple.
Initial twist		½ Z	½ Z	
Feed speed (y.p.m.)		Tension gate	41	9.
Windup speed (y.p.m.)	23	40	40	7.7.
Tension (gms.)	2	5	5	2.
Process twist	Z	S	Z	Z.
Fluid twister	FIGS. 11 and 12	FIG. 31	FIG. 27	FIGS. 13 and 14.
Heat-setting temp. ° C			258	250.
Type heater	None		Hot plate 30"	Hot plate 30".
Air pressure (p.s.i.g.)	30	65	60	30.
Twisting action				
Product characterization	Sheaf yarn	Semi staple yarn	Bulked yarn [2]	Staple covered yarn.
Air passage diam. (inches)	10 holes at .031	12 holes at .063	1 hole at .063	1 hole at .094.
Yarn passage diam. (inches)	.063	.313	.063	.188.
Remarks	Drafted staple fibers fed to a fluid twister are converted into a continuous yarn, see FIG. 35.	Note: Cutting edge placed upstream of twister breaks filaments which are then wrapped into the threadline.		Staple and continuous filayarn combined using the set-up shown in FIG. 35.

Example	54	55	56		57	
			Carrier	Slub	Carrier	Slub
Yarn material	Poly(ethylene terephthalate).	Viscose rayon	Poly(hexamethylene adipamide).	Same	Poly(hexamethylene adipamide).	Viscose.
Denier	70	1.5, 3"	70	40	70	1.5, 3".
Number of filaments	34		34	13	34	
Source	Same as 51	Bobbin	Supply package		Pirn	Bobbin.
Type of yarn	Continuous	Staple	Continuous		Continuous	Staple.
Initial twist	Zero		½ Z		½ Z	
Feed speed (y.p.m.)	150	5			Tension gate.	
Windup speed (y.p.m.)	128	5	50		160.	
Tension (gms.)	3	10	10–25	0–25	20	
Process twist	Z	Z			S	S.
Fluid twister	FIGS. 15 and 16.	FIGS. 15 and 16.	FIGS. 13 and 14.		FIGS. 15 and 16.	
Heat-setting temp. ° C	270	280				
Type heater	Hot slot 1/16" x 13"	Hot plate 30"	None		None.	
Air pressure (p.s.i.g.)	30	30	30		40.	
Twisting action	Direct	Direct	Direct		Direct.	
Product characterization	Crepe-like cohesive yarn	Alternating twist staple yarn.	Slub yarn		Slub yarn.	
Air passage diam. (inches)	5 holes at .031	10 holes at .031	1 hole at .040			
Yarn passage diam. (inches)	.047	.063	.063			
Remarks	Jet misaligned with respect to yarn travel direction, operates in a pulsating manner.	Size applied to threadline, while in twisted condition upstream of heater.	Tension on 40–13 yarn varied randomly. Slub produced at low tension (approx. 0).		Staple fibers are brought into contact with twisting continuous filaments in FIG. 36. Product shown in FIG. 37.	

[1] Poly(ethylene piperizine N,N'-dicarboxylate).
[2] A fluid jet for expanding yarn as described in application Serial No. 443,313 by A. L. Breen was placed downstream of the fluid twister to produce a special bulked yarn.

The claimed invention:

A sheaf-yarn characterized by random intervals along its length of substantially parallel fibers separated by areas in which ends of fibers are twisted tightly about

the circumference of the yarn bundle, the yarn resembling sheaves of wheat attached end to end and tied at random intervals by yarn fibers.

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