Nov. 23, 1965 A. L. BREEN ETAL 3,219,739

PROCESS FOR PREPARING CONVOLUTED FIBERS

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Fig. 1

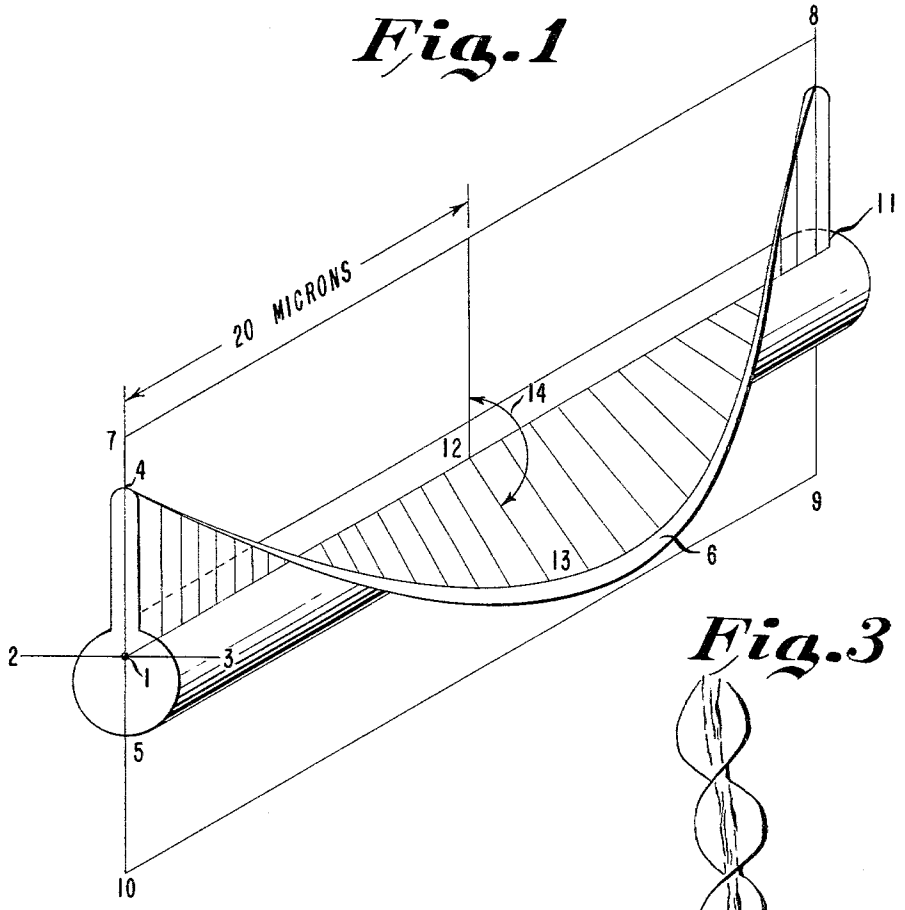


Fig. 3

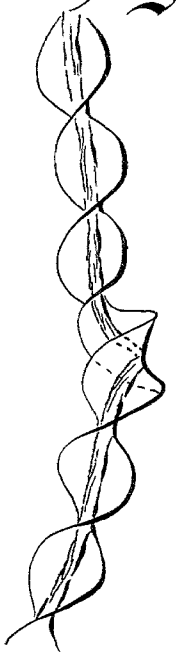
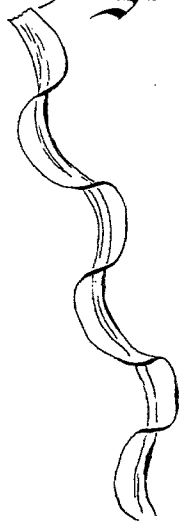


Fig. 2



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PROCESS FOR PREPARING CONVOLUTED FIBERS

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Fig. 4



Fig. 5

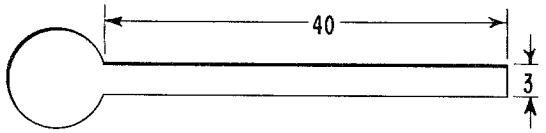


Fig. 6

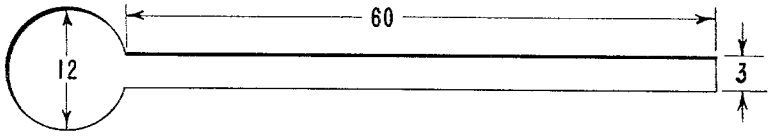


Fig. 7



Fig. 8

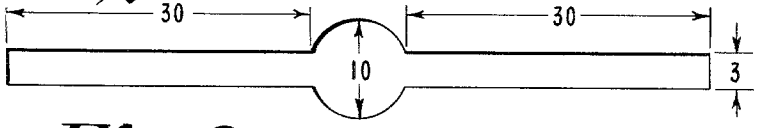


Fig. 9

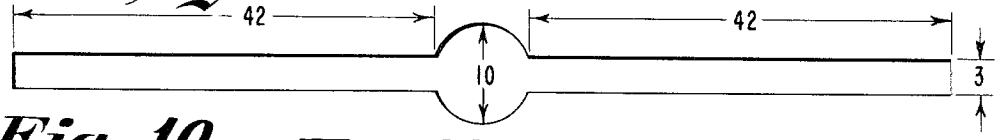


Fig. 10

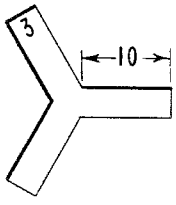


Fig. 11

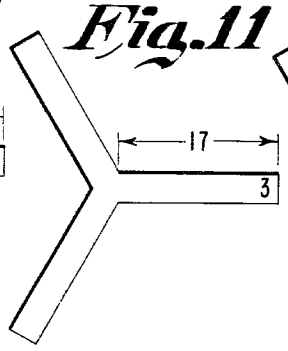
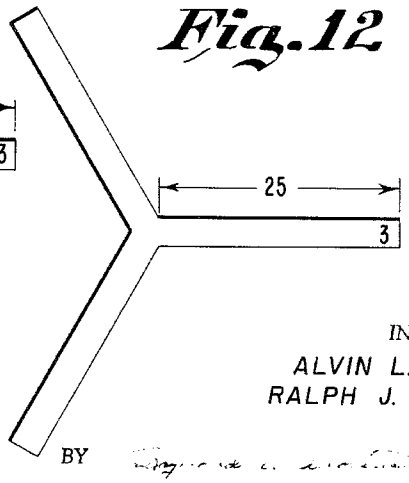


Fig. 12



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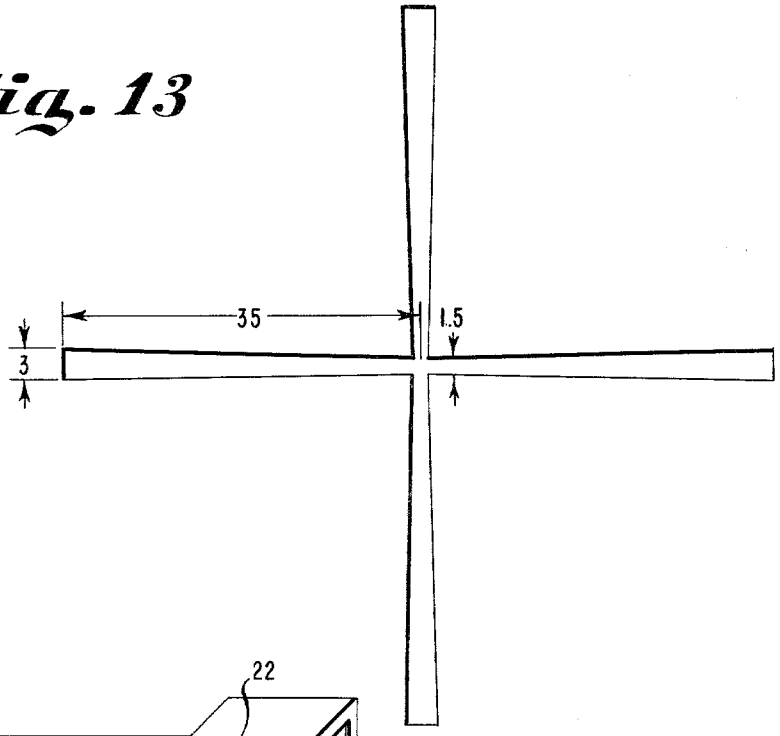
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Fig. 13



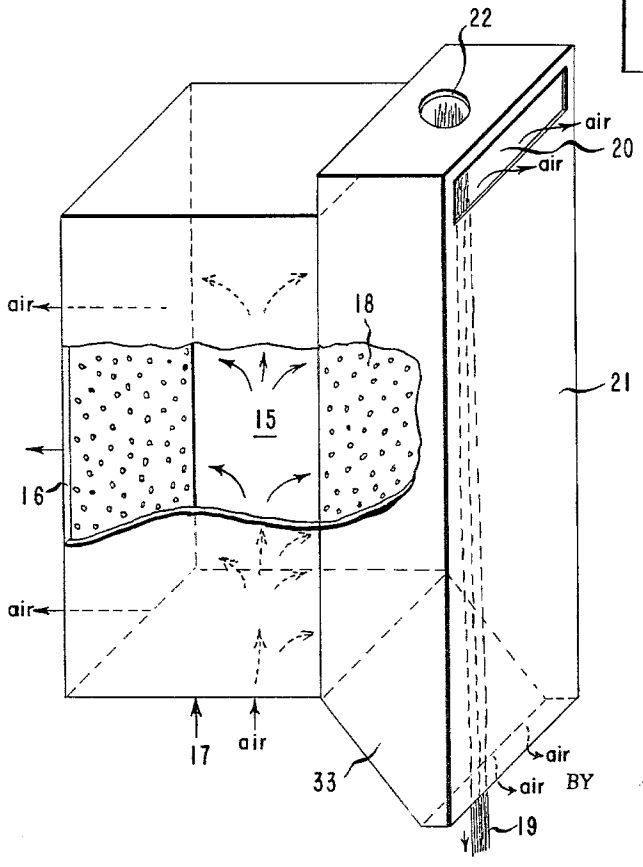


Fig. 14

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PROCESS FOR PREPARING CONVOLUTED FIBERS

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Fig. 15



Fig. 16

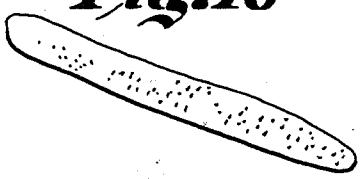


Fig. 17



Fig. 18

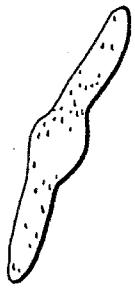


Fig. 19



Fig. 20

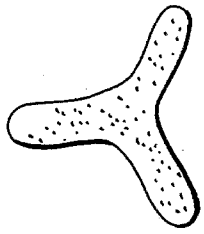


Fig. 21

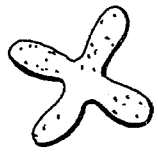


Fig. 22



Fig. 23



Fig. 24



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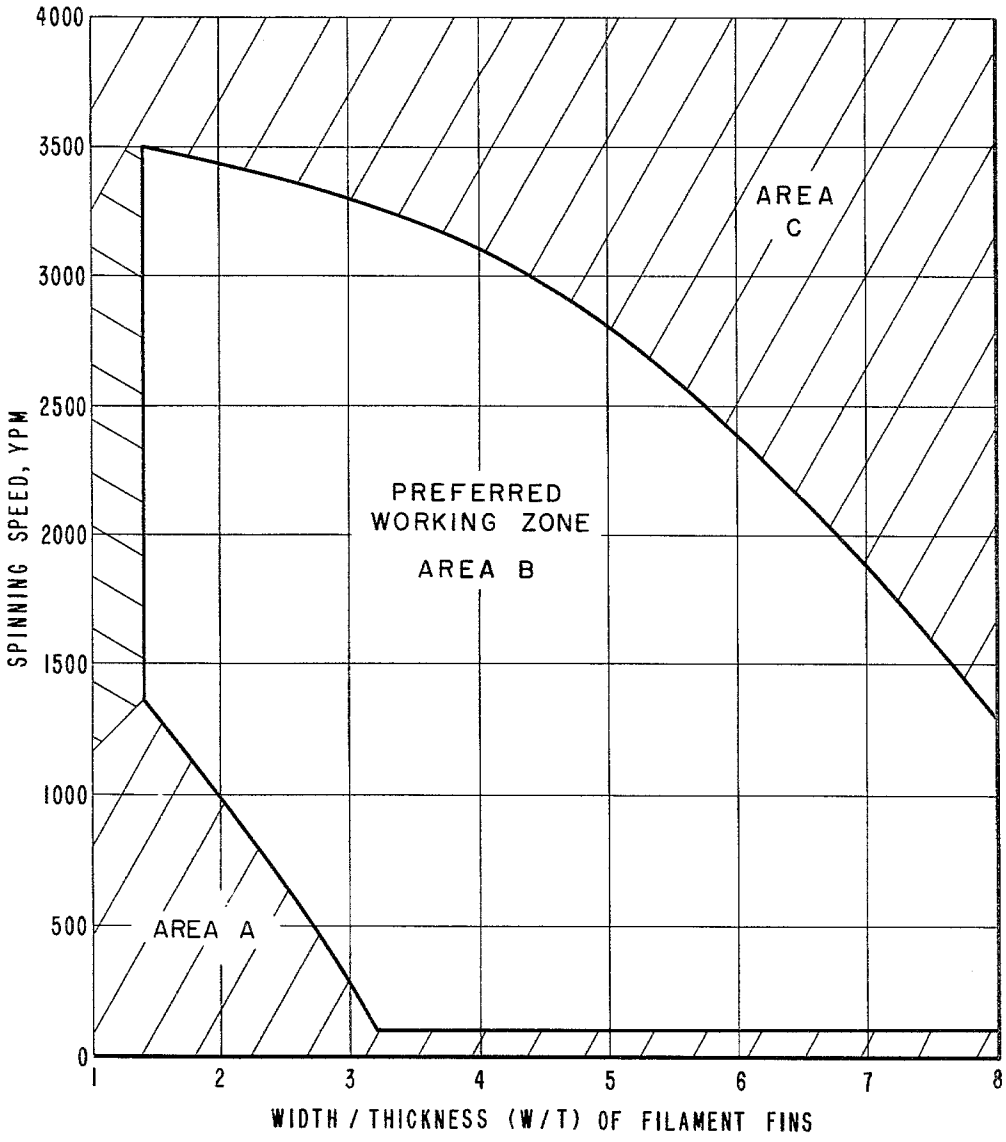
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PROCESS FOR PREPARING CONVOLUTED FIBERS

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Fig. 25



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Fig. 26

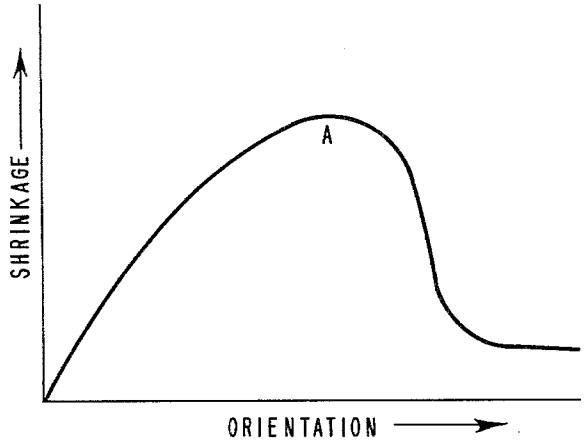
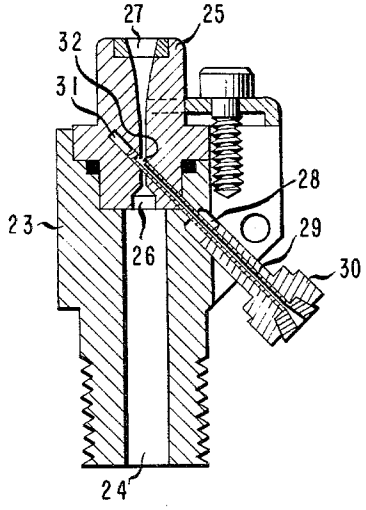


Fig. 27



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United States Patent Office 3,219,739 Patented Nov. 23, 1965

3,219,739

PROCESS FOR PREPARING CONVOLUTED FIBERS

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Filed May 27, 1963, Ser. No. 285,192
6 Claims. (Cl. 264—177)

This application is a continuation-in-part of our copending application Serial No. 675,728, filed August 1, 1957 and now abandoned.

This invention relates to a process for preparing synthetic fibers having a convoluted structure which imparts high bulk to yarns composed of such fibers.

Investigators in the textile field have long been concerned with obtaining voluminous strands of continuous filaments with properties similar to those yarns obtained from natural staple fibers. Production of staple fiber yarn (also called "spun yarn") is quite expensive and requires a complex series of operations involving aligning the fibers, combining them into an elongated band and drawing the bundle to smaller diameter while twisting to prevent excessive slippage of adjacent fibers past each other, together with still further operations required to produce a yarn or thread useful for textile purposes.

Synthetic fibers are produced directly as continuous filaments by an extrusion-spinning process. Strands or yarn can be made merely by combining the continuous filaments and without the time-consuming and expensive processing steps required for the making of spun yarn from staple fibers. The continuous filament yarn can be made very strong because of the absence of loose ends found in staple yarn that are unable to transmit imposed stresses. However, due to their lack of loose ends and their cross-sectional and longitudinal uniformity, conventional continuous filament yarns are more compact and dense than their staple counterparts since the continuous filaments lie close together in the yarn. This compactness, when the yarns are made into fabric, e.g., woven or knitted fabric, limits the amount of insulating air space present, reduces the visual covering power of a given weight of fabric and imparts to the fabric a hard slick hand typical of synthetic continuous filaments.

Bulky continuous filament yarns have been made by heat setting a highly twisted yarn of, for example, nylon, at least partially untwisting the yarn with, if necessary, further twist in the opposite direction and then plying two ends of opposite twists. Such a process is very expensive and, while affording a voluminous yarn, is too elastic for many textile applications.

It has also been proposed to make a voluminous continuous filament yarn by mechanically crimping the yarn, for example, by a hot stuffing box process. Such a product, while more voluminous than uncrimped continuous filament yarn, has the disadvantage that it must be fabricated in the bulky form and the further drawback that it loses an appreciable amount of its bulk due to the crimp being pulled out by the tensions encountered in fabric formation.

Self-crimping filaments have also been proposed. It has been suggested, for example, to spin two different fiber-forming materials in a side-by-side arrangement followed by drawing of the composite fiber to impart a difference in shrinkability between the components when relaxed under shrinking conditions. Upon shrinking, such filaments become crimped with from about 1 to 30 helical crimps per inch. Yarns made of such filaments have the disadvantage for many applications of being elastic. Also, they do not develop the desired bulk because adjacent filaments will crimp together in a "follow-the-leader"

manner such as may be observed, for example, in crimped staple chips and thus each filament will not exist as a separate and distinct crimped structure. Furthermore, the relatively coarse crimp permits the filaments to pack together readily in processing.

Other procedures for imparting crimp have been proposed, but have resulted likewise in products having a relatively coarse crimp and subject to the disadvantages recited above.

It is an object of this invention to provide a process for preparing bulky, continuous filament yarns.

A more specific object comprises a melt-spinning process for the production of bulky polyester yarns.

Other objects will appear hereinafter.

The objects of this invention are accomplished by a process comprising the steps of extruding a molten synthetic linear polyester through an orifice to form a filament having at least one fin extending from a stem portion, quenching the filament by directing a controlled flow of quenching gas across it near the orifice, and forwarding the filament through the quenching zone at a high rate of speed. The quenched filament is then drawn from 1 to 4 times its original length under amorphous retaining conditions, i.e., under conditions which induce a minimum of crystallinity.

In carrying out the process, the molten polymer is extruded through an orifice having at least one elongated slot having a width to thickness ratio of at least three, preferably 3 to 16, projecting from an aperture having a width significantly greater than the width of the slot. If the orifice has three or more slots, the aperture need not be of increased width but may be formed by the intersection of the slots at a central location. In quenching the filament, the minimum velocity of the gas is controlled in accordance with the expression

$$150 \text{ f.p.m.} \times \left(\frac{1200}{\text{forwarding speed}}\right)^2$$

with the forwarding or spinning speed being expressed in yards per minute. Preferably, the flow rate is at least 250 feet per minute with speeds up to 2500 feet per minute being operable. The quenching medium should be held at a temperature between about 15° and 40° C. The filament is forwarded through the quench zone at a speed between about 1000 and 3400 yards per minute and then drawing 1 to 4 and preferably 1.5 to 3 times its original length. The drawn filament may then be shrunk 15 to 75% to provide a convoluted filamentary structure which will be described in detail later herein. The filament may be shrunk prior to or after being incorporated into a multifilament yarn or fabric.

The filaments provided by the process of this invention comprise a stem and at least one fin having a width at least 1.4 times its thickness, the fin or fins of which have an average angular displacement (in the form of a ruffle or helix around the stem) of at least $0.3°/\mu$ (0.3° per micron); a displacement of $0.3°/\mu$ is equal, for example to about 20 complete turns per inch in the case of a helical convolution of the fin around a stem. The filaments are preferably of textile denier and may be termed "unitary" filaments since they are single-component filaments as distinct from multi-component filaments (which comprise more than one polymer). It will be understood that in a given length of filament, the distance measured along the outermost edge of a convoluted fin is at least 1% longer than the distance measured through the cross-sectional center-of-gravity.

The term "textile filament denier," as used herein, signifies a denier of from 1 to 10 per filament.

The term "ruffle," as used herein, signifies (unless otherwise indicated) a sinuous conformation of the fin, analogous to the ruffle on a window curtain.

The term "convolution," as used herein, (unless otherwise indicated) comprehends not only ruffles but also spiral or helical turns of the fins about the filament stem. By the practice of the invention either ruffles or spiral convolutions or both together are imparted to filaments.

The expression "convolutions per inch" or "ruffles per inch," as used herein, represents the number of complete (360°) cycles of a projection of a fin, whether in the form of ruffles or helices, as viewed longitudinally per inch of length of the filament.

The term "fin," as used herein, (unless otherwise indicated) signifies, with respect to cross-sectional area (although the fin will proceed lengthwise of the filament), that part of a non-round filament enscribed by (1) a line (termed "fin base line") drawn through the cross-sectional center of gravity (which may also be termed the "center of area") of the filament normal to the line that determines the width of the fin (i.e., cross-sectional length as described below) and (2) the periphery of the filament intercepting said fin base line. Thus, although the term "fin" would normally be considered as comprising only the web or extension to the filament, it also includes a portion of the filament stem or root for the purpose of description.

By the term "width" of the fin, is meant the length of the longest straight line (termed "width line") that can be drawn within the periphery of the fin cross section from the center of area to the tip of the fin, assuming the fin to be straightened out normal to its base line. Many fins are not straight and the line for determining width would not be straight if drawn within many actual fins.

By the term "thickness" of the fin, is meant the average distance across the fin periphery as measured normal to said width line.

By the term "stem" of the filament, is meant the root or body of the filament from which the fin webs protrude. The stem will, of course, include a portion of the "fin" as defined above, although, from a practical standpoint, the physically protruding fin (as distinct from the fin as defined above) is distinct from the stem.

By "angular displacement" is meant the total angle (in degrees) swept out, without regard to direction, by width lines between two spaced points along the filament axis, said angle being measured by projecting the width lines, between the two points, on the plane of a width line perpendicular to the filament axis at one of said points. The angular displacements referred to herein are determined from measurements on cross-sectional and longitudinal photomicrographs of the filaments. The longitudinal photomicrographs are used to measure the angle at which a fin crosses over the stem. It will be understood that angular displacement data and ruffles per inch will not be absolutely equivalent for all sampes due to differences in sampling.

In refering herein to the "cross section" of a filament, it will be understood that the cross sections are perpendicular to the filament axis.

Referring to the drawings, FIGURE 1 represents one-half of a convolution of a filament prepared by the process of this invention, greatly magnified, in perspective, with provision illustrated thereon for measuring angular displacement of a fin;

FIGURE 2 is a view of a longitudinal portion of a filament, greatly magnified, having one form of convolution, i.e., ruffles, characteristic of the filaments of this invention;

FIGURE 3 is a view of a longitudinal portion of a filament, greatly magnified, having a different form of convolution, i.e., spirals or helices, characteristic of the filaments of this invention;

FIGURES 4–13, inclusive, represent spinning orifices of various sizes and shapes, together with dimensions, used in the production of filaments of the present invention;

FIGURE 14 is a diagrammatic view of an air chimney, used for the quenching and solidification of filaments, in accordance with this invention, with a diagramatic showing of a spinneret and of the filaments as they pass from the spinneret through the chimney;

FIGURES 15–24, inclusive, are views of cross sections of filaments greatly magnified (1000 times) which are produced in accordance with this invention;

FIGURE 25 is a graph showing the preferred working zone area for spinning speeds in yards per minute (as ordinates) plotted against the ratio of width to thickness of filament fins;

FIGURE 26 is a graph of shrinkage percentages (as ordinates) against degrees of orientation (as abscissae) for a filament of a characteristic polymer; and

FIGURE 27 is a view of a jet used for the elongation and shrinking of filaments of this invention.

An understanding of "angular displacement" and its measurement can readily be obtained by reference to FIGURE 1 of the drawings. This figure is drawn in perspective in which the lines are approximately 30° to the horizontal so as to show the development of the fin convolution, i.e., a ruffle in this case. The filament is of keyhole cross-sectional shape such as may be obtained by use of a keyhole spinning orifice shown in FIGURES 4, 5, and 6 and has the general appearance of the filament shown in FIGURE 2 of the drawings. For convenience, in this figure, the cross-sectional end of this filament shows the fin in vertical position.

FIGURE 1 is a greatly magnified view of a short length of filament having one-half a complete convolution or ruffle of the fin (in this case one-half a complete sine wave). In this figure, the center of gravity or center of area of the filament cross section is designated as **1** and a line **2, 3** (the fin base line) is drawn, as shown, through **1**. A line **4, 5** is drawn from the center of the fin tip through **1**, this line being the longest line that can be drawn through the fin, and lines **2, 3** and **4, 5** are drawn perpendicular to each other. The fin **6** is shown as one-half a complete convolution, the other half (not shown) being in reverse in this case to that shown. (Where the convolution is a helix, the other half of the helix obviously proceeds in the same direction rather than in the opposite direction.) Vertical plane **7, 8, 9, 10** is drawn through line **4, 5** and through the filament center of gravity axis **1, 11**. Midway of the one-half fin convolution shown in FIGURE 1, a line **12, 13** (fin width line) is drawn from line **1, 11** to the tip of fin **6**, the angle **14** subtended by plane **7, 8, 9, 10** and this line being the angular displacement. In FIGURE 1, the length of filament from the left-hand side of the figure to the center point (where a value of 80° for angle **14** was measured) is 20 microns (0.02 mm.), giving an angular displacement of $4°/\mu$ (280 complete convolutions per inch). The angular displacement per micron of length that is referred to herein indicates the degree and intensity of convoluting characteristics of the filaments of this invention. It will be understood that if lines were drawn from the line of origin **1, 11** to the tip of fin **6** between the beginning of the filament section shown in FIGURE 1 and point **11**, the angular displacement would be $160°/40\mu$ or, in other words, $4°/\mu$.

Reference has been made in the above descriptions, in connection with FIGURE 1 of the drawing, to ruffles as one form of convolution characteristic of the filaments of this invention. A filament showing ruffles along a continuous length is illustrated in FIGURE 2 of the drawings.

In addition to the ruffles just referred to, the filaments of this invention may, as stated, alternatively assume a spiral or helical convolution along the axis of the filament as shown in FIGURE 3 of the drawings, which, like FIGURE 2, represents a greatly magnified view of the filament.

Both the ruffle referred to in FIGURES 1 and 2 and

the spiral convolution shown in FIGURE 3 are to be distinguished from the crimps of the prior art which merely represent either the approximate folding back of filaments upon themselves or upon adjacent filaments, as in the stuffer-box type of crimping or in mechanical gear crimping, or the helical type of crimp (which may reverse itself) in which the filaments spiral in helical or coiled spring-like fashion around a core of air.

The convolutions which characterize the filaments of this invention reverse themselves at random intervals, not only in the sense of reversal to complete a 360° path for one ruffle or convolution as described with respect to FIGURE 1, but by actual change in direction along the filament at intervals. The reversal points may be from .02 to .001 inch apart. Nevertheless, the total number of ruffles or convolutions, as designated herein in the examples, will include all regardless of direction of fin distortion. The number of ruffles per inch (i.e., the angular displacement) is a measure of the volume or space effectively swept by a filament. The reversal of the convolutions prevents intermeshing of adjacent filaments.

In the examples, the relative viscosity (η_r), i.e., the viscosity of a solution of polymer relative to that of the solvent, is used as a measure of the molecular weight. The polyester solution used for determining the relative viscosity referred to herein contained 2.15 grams of the polymer and 20 ml. of a 7/10 mixture of trichlorophenol/phenol, and the viscosity was measured at 25° C.

By the expression "draw ratio" is meant the ratio between the initial undrawn (as-spun) length of yarn or filament and the final permanently drawn length or filament. It will be understood that reference to "permanently drawn length" means the length of the filament assumed after release of the drawing force.

The volume of water retained by a standard weight of yarn is used as a measure of the bulk of the yarn. In this test a 10 gram skein of yarn is immersed in 90 mls. (milliliters) of distilled water at room temperature (75° F.) contained in a 100 ml. graduate and allowed to remain there for 15 minutes. The yarn is then removed and allowed to drain back into the graduate for 15 minutes. The water retention value is the amount of water (in mls.) retained by the skein after the 15 minutes drain. A skein of thirty-four, 2 d.p.f. (denier per filament) round cross section, uncrimped filaments of poly (ethylene terephthalate) retains 11 ml. of water by this test.

In the evaluation of fabrics the specific volume in cubic centimeters per gram ($cm.^3$/gram) is used. This volume is calculated from the weight of the given piece of fabric usually in ounces per square yard and the average thickness of the fabric as measured by a plunger-type of instrument that exerts a pressure of 5 grams/sq. cm. during the measurement.

Birefringence values are determined according to standard methods by measuring (with a microscope fitted with a quartz wedge), the retardation of light transmitted through longitudinal regions of both stem and fin and dividing the measured retardation values by the thickness of the measured regions.

With further reference to the drawings, FIGURE 14 shows a form of cross-flow air chamber and spinning cell applicable to use in the practice of this invention, in which the air chamber **15** is provided with an air inlet **17** and perforated rear wall **16** to permit some incoming air to escape so as to avoid turbulence. A perforated front wall **18** (the opening referred to in the examples with reference to flow of air against the filaments) permits the flow of air to be distributed across the filaments **19** (shown in dotted lines within spinning cell **33**) and outwardly through opening **20**, which is formed above baffle **21**, removable as described in Example VII (below). Spinneret **22** is shown disposed at the top of the spinning cell.

Referring to FIGURE 27, this figure illustrates a form of air jet similar to that used in the examples, which may forward the undrawn yarn at high speed and can be used in a shrinking of the drawn yarn. This jet and its mode of operation are discribed in the patent of John N. Hall, U.S. 2,958,112, the substance of which insofar as it is necessary to understand this jet structure and operation is incorporated herein by reference. Briefly, this jet comprises jet housing **23** having cylindrical bore **24** with fitting **25** screwed into housing **23** and being provided with a longitudinal passage comprising counterbore **26** and venturi-shaped passage **27**, together with bore **28** which angles upwardly towards and is constricted in the direction of bore **24** as shown. Bore **28** accommodates yarn tube **29** carried by casing **30**. The upper and inner end of yarn tube **29** is received in blind extension **31** of bore **28**. Yarn tube **29** is partly cut away at **32** to a half cylindrical form which is open on the upper side, in the region of the constricted portion of venturi-shaped passage **27** to permit ejection of the yarn therefrom. The threaded end of housing **23** is connected to a source of compressed air. Yarn tube **29** is supplied with yarn inserted at the outer end through the tube, the yarn tube **29** is carefully turned to position its cut away portion **32** to face upwardly so that the yarn will be ejected upwardly, the compressed air is turned on, and the upward flow of air through the main bore **26** and venturi **27** will string-up and impel the yarn at high speed through venturi-shaped passage **27**.

The following examples in which parts, proportions, and percentages are by weight, and elongations and tenacities are on a dry basis, unless otherwise indicated, illustrate the invention.

EXAMPLE I

Poly(ethylene terephthalate) of η_r 34 is extruded at 288° C. through a spinneret containing 13 regularly spaced keyhole-shaped orifices of the design and dimensions shown in FIGURE 5 into air at room temperature. The threadline is advanced by means of an air jet at a rate of about 3,000 y.p.m. (yards per minute) and cut into short lengths by a revolving cutter knife. The threadline is quenched at right angles to the direction of travel starting at a point about 1.5 inches below the spinneret with room temperature (25° C) air coming from a 2.5 x 35 inch opening in the apparatus of FIGURE 14 at a rate of about 150 c.f.m. (cubic feet per minute) and a velocity of 250 f.p.m. (feet per minute) across the filaments. The as-spun yarn resembles normal uncrimped staple fiber with no curl and has a tenacity of 1.3 g.p.d. (grams per denier), an elongation of 90%, an initial modulus of 24, and a d.p.f. (denier per filament) of 3.15. A typical filament criss section (magnified) is shown in FIGURE 15. When the staple fiber is exposed free of tension to atmospheric steam for about 5 seconds, it shrinks about 68% in length and the staple fiber becomes very bulky. About 90–100% of the filaments have ruffled fins with 100 to 150 ruffles per inch and the angular displacement of the fins is about $4.5°/\mu$ as estimated from photomicrographs of the filaments. A 10 gram bundle of the staple retains 52 ml. of water in the standard water retention test.

EXAMPLE II

Poly(ethylene terephthalate) of η_r 34 is spun at 288° C. through a spinneret containing 13 slots, each 3 x 78 mils in size, into air at room temperature and the yarn wound up at 1200 y.p.m. The extruded ribbons are quenched (i.e., rapidly chilled) with the maximum flow of air (25° C.) across the filaments that would permit spinning, estimated to be about 100 c.f.m. (a velocity of 165 f.p.m. across the filaments) from an opening 2.5 inches x 35 inches located behind the vertically moving threadline. The resulting yarn is drawn in a dry state 2.7×(170% increase in length over yarn prior to this drawing) over a pin heated to 48° C. to yield a yarn with a tenacity of 3.0

g.p.d., and dry elongation at break of 32% and a denier per filament of 3.5. A typical magnified cross section of these drawn filaments is shown in FIGURE 16. The yarn shrinks about 53% in boiling water to yield a highly bulky product in which each edge of the filaments has about 100 to 150 convolutions per inch and shows an angular displacement of about 1.8° per micron. The convolutions are reversed at frequent (1 to 100 per inch) irregular intervals. About 90–95% of the ribbons display this alternating twisting. A 10 gram skein of the yarn retains 52 ml. (milliliters) of water with the standard water retention test. The birefringence at the center of the drawn but unshrunk ribbon is +0.113 and +0.138 near the edge of the ribbon. While these ribbon-like products represent an embodiment of the invention which is less desirable than ruffle filaments of irregular cross section (illustrated in the remaining examples) they are superior to prior art two-component self-crimping filaments.

The above procedure is repeated at 700 y.p.m. with no cross-air quench. The yarn is drawn wet over a pin at room temperature to afford the best opportunity for bulking. It shrinks 60% in boiling water and does not ruffle but has only a slight crimp. The drawn but unshrunk filament has a uniform birefringence of +0.160 from the center of the ribbon to the edges.

This example illustrates a ruffle filament in which the ribbon filament is composed entirely of two fins. The filament stem in this case should be considered, from a practical standpoint, as the median portion of the ribbon cross section even though, from the standpoint of definition, the ribbon is all fin, i.e., composed entirely of two fins.

EXAMPLE III

A poly(ethylene terephthalate) of η_r 36 is extruded at 288° C. through a spinneret having 34 propellor-shaped orifices as shown in FIGURE 9. The threadline is transversely quenched by about 150 c.f.m. of air (25° C.) (a velocity of 250 f.p.m. across the filaments) from a 2½ x 35 inch opening whose longer dimension parallels the threadline and the top of which is located 1½ inches below the spinneret. The yarn is wound up at 1000 y.p.m. The resulting straight yarn is drawn 2.1× in a wet state over a pin heated to 77° C. to yield a straight, uncrimped yarn having a tenacity of 1.8 g.p.d., an elongation of 13% and a total denier of 76.5. A typical magnified cross section is shown in FIGURE 18. The yarn shrinks 70% in boiling water and became highly bulked. Microscope examination of the yarn shows that the fins of the filaments are highly convoluted so that each fin forms about 400–500 ruffles per inch. The average angular displacement is about 5°/micron. Approximately 100% of the filaments display this extent of ruffling.

Birefringence of the drawn but unshrink filaments is +0.094 and +0.174 as measured in the center of the filament and near the tip of the fins respectively and gradually increases from the center outward.

EXAMPLE IV

Item A.—Poly(ethylene terephthalate) of η_r 33 is extruded at 298° C. through a 3-inch diameter spinneret having 34 propeller-shaped orifices as shown in FIGURE 8 but having a 9 mil center hole and the yarn wound up at 1500 y.p.m. The threadline is quenched with air (24° C.) at right angles to the motion of the threadline with a chimney similar to that shown in FIGURE 14 where the opening **20** is 2 inches high and 5.25 inches wide. The total input of air at the point **17** is 400 c.f.m. which affords 54 c.f.m. across the threadline (velocity across the filaments 740 f.p.m.) and out the opening **20**. The yarn is drawn dry over a pin heated to 85° to a draw ratio of 2.04× to yield a straight uncrimped yarn with a denier per filament of 2.9, and an ultimate elongation of 17%. A typical cross section is shown in FIGURE 19.

Item B.—The same polymer as above is extruded through a spinneret containing 17 round holes of 9 mil diameter and 17 Y-shaped orifices, as shown in FIGURE 12, with other conditions as above. The yarn is drawn dry 2.31× over a pin heated to 78° C. to yield a straight uncrimped yarn with a total denier of 89 and an ultimate elongation of 13.5%. A typical cross section of a Y-shaped filament is shown in FIGURE 21.

Item C.—The above spin is repeated with a spinneret having 34 Y-shaped orifices, as shown in FIGURE 11. The yarn is drawn 2.01× over a pin heated to 85° C. to yield a straight uncrimped yarn with a total denier of 99.8 and an ultimate elongation of 18.8%. A typical Y-shaped filament is shown in FIGURE 20.

The above three items are shrunk 32, 49, and 38%, respectively, by exposure under low tension to 100° C. steam at atmospheric pressure for 1 minute. The characteristics of the shunk yarns are given in Table I. For purposes of comparison, an uncrimped, continuous 34 filament, 70 denier yarn of round cross section made from poly(ethylene terephthalate) is included as item D.

Table I

Item		Shrinkage, percent	Tenacity, g.p.d.	Elongation, percent	Initial modulus (Mi)	Yarn denier	Ruffle			Water retention
							Filaments having, percent	Frequency, lb./inch	Angular displacement, °/μ	
A	⊂⊃ shape	30, 32, 52	1.9	27.6	31	117	20–25	325–550	1.3	38/22
B	Y & O shape	38	1.6	37.9	11.1	117	60–75 (of Y)	200	1.9	39/30
C	All Y shape	49	1.2	88.5	8.0	171	15	300–500	1.3	37/18
D	All O	about 7	3.09	23.3	23.1	70/34	none	0	0	11/11

Under the heading "water retention," the values to the left and right of the virgule represent the bulked and unbulked yarns, respectively. The advantage of the convolutions afforded by as few as 15% of the fins over and above the cross section modification alone is apparent.

The above yarns are woven into fabrics with a basket weave under such conditions that all the finished fabrics have essentially the same construction after shrinking and finishing. The specific volumes ($cm.^3$/gram) are 4.2, 3.6, and 1.9 for fabrics containing 100% of item C, B, and D, respectively. The fabrics from the filaments with ruffled fins have the appearance and handle of fabric from spun staple yarns and have a low luster, whereas the fabric of item D has the typical lustrous appearance and slippery slick handle of continuous filament fibers. Items A, B, and C are also used as a filling with a warp of item D to make fabrics, and the specific volumes are 2.5, 2.7, and 3.3, respectively, as compared with the 1.9 for the all-round filament fabric. The use of these new filaments in the fill alone change the appearance and handle of the fabric so that it resembles a spun staple product.

The covering power and the specific volumes of all the fabrics of the convoluted filaments are significantly

superior to similar fabrics made of non-convoluted finned filaments having a Y or cruciform cross section so that the advantages of the convolutions are plainly evident.

EXAMPLE V

Poly(ethylene terephthalate) of η_r 33 is extruded through a spinneret having 17 cruciform-shaped orifices as shown in FIGURE 13, and 17 round holes of 9 mil diameter at 298° C. and the yarn wound up at 1500 y.p.m. The yarn is quenched by 400 c.f.m. of air (24° C.) entering at **17** and 70 c.f.m. leaving the 3 x 5.25 inch opening **20**, as shown in FIGURE 14. The velocity across the filaments was 640 f.p.m. The spun yarn is drawn 2.31× in a dry condition over a pin heated to 75° C. to give a straight, uncrimped yarn with a total denier of 59 having an ultimate elongation of 18.8% and a tenacity of 2.2 g.p.d. A typical cross section of a cruciform-shaped filament made above is shown in FIGURE 21.

The yarn shrinks 34% in boiling water to give a bulky yarn. Microscopic examination in the bulked form reveals that 80% of the fins of the cruciform filaments are highly convoluted having 400 ruffles per inch and an average angular displacement of 4.9°/μ. A ten-gram skein of the bulked yarn retains 57 ml. of water with the standard test.

In a similar manner, a highly bulked yarn is made by extruding the above polymer through a spinneret whose orifices consist of three 2 x 40 mil slots arranged crosswise to form a 6-pointed star, drawing and shrinking as above.

EXAMPLE VI

Item A.—Poly(ethylene terephthalate) of η_r 33.3 is extruded at 298° C. through a spinneret having 17 round holes 9 mils in diameter and 17 Y-shaped orifices, as shown in FIGURE 10. The spinning chimney is supplied with 400 c.f.m. of air (24° C.) at **17** (FIGURE 14) so that about 70 c.f.m. of air quenches the threadline and leaves through the 3 x 5.25 inch opening **20**. The velocity across the filaments was 640 f.p.m. The yarn is wound up at 1500 y.p.m. The dry yarn is drawn 2.43× over a pin heated to 75° C. to give a straight, uncrimped yarn having an ultimate elongation of 21% and a total denier of 100. A typical cross section of the drawn Y-shaped filaments is shown in FIGURE 20.

Item B.—The above procedure is repeated with a spinneret having 17 round holes 9 mils in diameter and 17 Y-shaped orifices, as shown in FIGURE 11. The dry yarn is drawn 2.3× over a pin heated to 75° C. to give a straight, uncrimped yarn having an elongation of 21.8% and a total denier of 102. A typical cross section of the drawn Y-shaped filaments is shown in FIGURE 20.

Item C.—The above procedure is repeated with a spinneret having 17 round holes 9 mils in diameter and 17 Y-shaped orifices, as shown in FIGURE 12. The dry yarn is drawn 2.35× over a pin heated to 75° C. to give a straight, uncrimped yarn having an elongation of 25.4% and a total denier of 102. A typical cross section of the drawn Y-shaped filaments is shown in FIGURE 20.

A skein of each of the above items is boiled in water for 5 minutes. The properties of the resulting bulked yarns are given below in Table II.

Table II

Item	FIN, W/T	Filaments having ruffle, percent	Ruffle, count/in.	Angular displacement, °/μ
A	1.6	1–5	225	2.6
B	2.4	20	300	3.6
C	3.4	50	275	2.8

It is apparent that as the width to thickness ratio (W/T) of the fins of filaments processed under similar conditions is increased, the amount of convolution and hence the bulk of the yarn is increased.

The following examples illustrate process variables in the forming of ruffled filaments from polyesters.

EXAMPLE VII

Poly(ethylene terephthalate) of η_r 33.3 is extruded at 298° C. through a spinneret with 17 Y-shaped holes, as shown in FIGURE 11, and 17 round orifices 9 mils in diameter. The baffle **21** (FIGURE 14) is removed from the 39-inch long spinning chimney and different inputs of 24° C. air (at **17** in FIGURE 14) used. A number of yarns are wound up at various speeds and drawn in a dry state over a pin heated at 75° C. at such draw ratios as would afford a drawn yarn with about 20% ultimate elongation. The yarns (except that indicated as spun at 2500 y.p.m.) are shrunk by passing them through an air jet, as shown in FIGURE 27, located between two pairs of driving rolls. The windup rolls are operated at 90 y.p.m. and the input rolls are adjusted to a speed sufficiently higher to permit the desired shrinkage. Air at 210° C. and under 3 p.s.i. (pounds per square inch gauge) pressure is delivered to the jet. The results are summarized in Table III.

Table III

Spinning speed (y.p.m.)	Conditions quench (c.f.m.)	Velocity (f.p.m.)	Draw ratio	Drawn yarn properties: Dry percent elongation	Drawn yarn properties: Shrinkage, percent	Drawn yarn properties: Dry tenacity (g.p.d.)	Filaments with ruffle* (percent)	Ruffles per inch
1,300	325	114	2.9	18	18	3.0	0	0
	525	184	2.7	23	28	2.1	50	50
1,400	125	43	2.9	21	18	3.3	0	0
	325	114	2.7	20	23	2.9	50	50
	525	184	2.5	14	21	2.2	90	50
1,600	125	43	2.9	17	16	3.7	25	50
	325	114	2.6	19	33	2.8	50	170
1,800	325	114	2.3	22	40	2.1	75	250

*Non-round cross section.

The results in Table III show the inverse relationship of the spinning speed and intensity of the quench, i.e., a higher quench must be used at lower speed to produce ruffling than is required to produce ruffling at a higher speed. In addition to the spins illustrated in Table III, the same spinning conditions are used at speeds from 2,000 to 3,750 y.p.m. with a constant quench of 400 c.f.m.

As the spinning speed increases from 2,000 up to and including 3,400 followed by similar draw ratios (which are lower than required at the lower speeds) and shrinking, yarns having approximately 90% of the filaments with ruffled fins are obtained. The frequency of the ruffles increases as the spinning speed is increased. However, at 3,600 and 3,750 ruffles are no longer produced despite lower draw ratios.

EXAMPLE VIII

Poly(ethylene terephthalate) of η_r 34 is used in the following items.

A spinneret with 15 propeller-shaped orifices as shown in FIGURE 8 but having a 9 mil center hole is used to

extrude the yarn of item A of the following table, at 1200 y.p.m. with the quenching conditions of 400 c.f.m. of 24° C. air at **17** of FIGURE 14 with a 4-inch baffle opening **20** of FIGURE 14. The velocity across the filaments was 1360 f.p.m. The yarn is then drawn at various conditions and shrinks in boiling water. The same spinneret is used to produce item B of following Table IV at 1206 y.p.m. with 500 c.f.m. of 24° C. air input to the quenching chimney and no baffle **21** of FIGURE 14. The velocity across the filaments was 173 f.p.m. The yarn is drawn over 90° and 100° pins at such a draw ratio (*a* and *b* in the table) as to obtain approximately 20% elongation. The drawn yarn is shrunk in boiling water.

To obtain the yarn in item C of following Table IV, the spinneret and polymer of Example VII is used to spin filaments at 1500 y.p.m. with 325 c.f.m. 24° C. air quench. The yarns are drawn under different conditions over a pin and then shrunk in a 190° air jet.

The effect of drawing conditions upon ruffling and physical properties are given in Table IV. It is to be noted that, if the yarn is drawn in a water-wet condition, higher temperatures can be used to obtain a product that will ruffle than if the yarn is drawn dry. Also, as the temperature of the drawing pin is increased from room temperature, the shrinkage and extent of ruffle decreases with a given filament.

Those yarns with ruffled fins have the following physical properties: tenacity, 0.4 to 1.2 g.p.d.; break elongation, 45 to 512%; initial modulus, 4 to 19.

Table IV

Item	Yarn	Drawing conditions		Drawn yarn properties		Shrunk yarn properties	
		Draw ratio	Temperature, ° C.	Elongation	Shrinkage	Non-round filaments ruffled	Ruffle frequency
1	C	2.7	105 wet	22	71	5	250
2	C	2.7	105 dry	19	10	none	0
3	B	*a*	100 wet	25	52	100	2,000
4	B	*a*	100 dry	28	18	none	0
5	B	*b*	90 wet	21	50	100	2,000
6	B	*b*	90 dry	20	15	5–10	50–100
7	A	2.1	82 dry	22	50	80	200
8	A	2.1	81 wet	15	44	70	1,000
9	A	2.1	66 wet	18	59	80	1,000
10	A	2.1	60 dry	26	48	80	350

EXAMPLE IX

The spinning conditions of Example IV–B (Y and O at 1500 y.p.m.) are repeated. The yarn is drawn at various draw ratios by wrapping it 8 times around a 3-inch diameter roll heated at 95° C. and passing around subsequent cold rolls in order to draw it. The drawn yarn is shrunk in a 190° C. air jet.

The effect of drawing conditions on shrinkage, ruffle and physical properties are given in Table V.

These data show how draw ratio controls the elongation and shrinkage of the yarn. By comparison with Example VIII (items 4 and 6), it is seen that hot roll drawing permits greater shrinkage and a higher degree of convolutions than pin drawing at the same draw ratio and temperature. The physical properties of the yarns with ruffled fins are as follows: tenacity, 0.7 to 1.7 g.p.d.; elongation at the break, 98 to 390%; initial modulus, 2.7 to 11 g.p.d.; and yarn denier, 62 to 138 denier for the 34 filaments.

At draw roll temperatures of 92° C., 89° C., and 86° C. it is found that the maximum amount of convolutions (after shrinking) are produced at draw ratios of 1.8, 1.8, and 1.9, respectively. In these yarns 80% of the filaments have ruffled fins at a frequency of 330 to 500 ruffles per inch.

Table V

Drawing conditions		Drawn yarn properties		Non-round cross section filaments ruffled, percent	Ruffle frequency
Ratio	Temperature, ° C.	Elongation, percent	Shrinkage, percent		
1.6	95	62	*71	80+	170–300
1.7	95	50	*72	80+	500
1.8	95	33	*69	80+	170
1.9	95	25	*60	70	75
2.0	95	25	*55	40	50
2.2	95	9.5	*49	15	25–50
2.3	95	8.2	*37	0	0

* By 190° air.

In the preparation of a poly(ethylene terephthalate) filament that will bulk due to the convoluting of its fins, the first process requirement is the extrusion of a filament with the proper cross section. Filaments, with one or more fins whose width/thickness ratio varies from about 1.4 to 6.0, have been illustrated.

The cross section of the extruded filament is a function of the melt viscosity of the polymer and the shape of the extrusion orifice. The melt viscosity of the polymer is a function of the extrusion temperature (inversely related) and the relative viscosity (directly related) of the polymer. The ruffled products of this invention have been made of poly(ethylene terephthalate) with η_r from 23 to 43. Extrusion temperatures of 282–298° C. have been employed with these polymers. Since an extruded filament tends to contract in volume upon solidifying, it is necessary to use an extrusion orifice that has a fin width/thickness ratio of 2 to 6 times larger than that desired in the solidified filament. With poly-ethylene terephthalate) of η_r of 23 to 43 extruded at 282–298° C., spinnerets having width/thickness fin ratios of 3 to 16 have been used to make filaments that could be convoluted.

It is postulated that the convoluted filaments of this invention are caused by a difference in shrinkage between the stem and fins of a filament. This differential shrinkage is considered to be caused by a greater orientation of the fins than the stem.

The relationships between orientation, crystallinity, and physical properties of the filament are quite complex. The orientation of filaments can occur in the spinning process due to the fact that the solidified filaments are usually accelerated to a greater linear velocity than the polymer is extruded. Filaments can be oriented in a

step subsequent to spinning by cold drawing (stretching), i.e., below about 120° C. along the fiber axis. At speeds of 100 to 2500 y.p.m. with an air quench, most of the orientation in a final yarn of round filaments is ordinarily introduced by a separate drawing step. The higher the spinning speed at a given rate of quenching, the higher the orientation as evidenced by birefringence measurements.

Filaments with no orientation have little or no tendency to shrink. As the degree of orientation is increased, the tendency for the molecules to relax from the strained condition and hence shrinkage in a hot media increases. This process would proceed indefinitely, but for the fact that increasing the extent of orientation also increases the tendency for the polymer to crystallize. Crystallization restricts shrinkage. As further orientation takes place, additional crystallization sets in and further restricts shrinkage. A schematic diagram of this relationship is shown in FIGURE 26. If filaments are drawn under conditions that aid crystallization (use of elevated temperatures in the absence of water) or exposed to crystallizing conditions (e.g., heat or latent solvents) in a taut state before relaxing (shrinking) after drawing, the shrinkage is relatively intensitive to the degree of orientation.

Other physical properties that are of importance are tenacity, initial modulus (Mi) and the ultimate elongation. In general, it can be stated that the tenacity and Mi increase with increasing orientation and that elongation decreases with increasing orientation. Elongation can be used as a rough measure of orientation if the orientating conditions are kept constant. Since a filament may be oriented by cold drawing, it is obvious that the elongation of a given filament generally decreases with an increasing draw ratio.

It is postulated that for a fin of a filament to convolute upon shrinking, it must have a greater orientation than the stem and this orientation must be greater than that shown at point A of FIGURE 26. A difference in birefringence between the stem and fins of products that can ruffle has been observed (before the filaments were shrunk). Also, no differential birefringence has been observed on unshrunk filaments that could not be ruffled although they have the proper cross section section and potential shrinkage required for ruffling. It is also believed that the tips of the fins are preferentially cooled by the cross-air quench so that the fins solidify preferentially and are thus preferentially oriented in the spinning process. It is apparent that the larger the width/thickness ratio of the fins, the more pronounced will be this effect.

FIGURE 25 defines the preferred working zone, specifically drawn for poly(ethylene terephthalate) but also applicable to fialments composed of other polyesters and other types of synthetic linear polymers, for spinning speed at various fin width/thickness ratios, that, in conjunction with sufficient quenching or cooling, will provide filaments that will ruffle when processed under conditions giving a high shrinkage. The proper quenching conditions to use with a given spinning speed and filament cross section within the working zone of FIGURE 25 can be readily determined. Quenching should be accomplished within 2 to 4 feet below the spinneret. At the highest velocities of quenching gas, the quench zone may be an inch or less below the spinneret. Increasing the intensity of the quench from a given set of conditions will increase the difference in birefringence between the stem and fin; decrease the ultimate elongation of the as-spun yarn; and increase the amount of ruffle when drawn to give the desired shrinkage. Opposite effects will be obtained by lowering the amount of quenching. In general, the most intensive quenching conditions are required in the working zone adjacent to area A of FIGURE 25. As one proceeds from area A through area B at an angle of 45° in FIGURE 26, the quenching requirements will be reduced. Area C represents a zone which, although possibly affording the required differential orientation between stem and fin, yields a filament having too low an as-spun elongation and too low a potential shrinkage, regardless of drawing conditions to afford a ruffled product.

The use of more intense quenching conditions, such as spinning into a liquid, permits the use of a lower spinning speed to give a ruffleable filament than can be obtained with the maximum air quench alone.

In order for the filaments of this invention to develop the proper bulk, from 15–75% or higher shrinkage is required with 45–65% being preferred. It is known to pin-draw a polyester filament 4× to 6× at temperatures of 80° C. to 100° C. in conjunction with a plate heated to 180° C. in order to produce a yarn that has a shrinkage of the order of 8% or less. It is believed that the higher temperatures induce crystallization which stabilizes the oriented filaments against shrinkage. It is also known that the higher the draw ratio, the more the yarn is oriented and the easier it is for it to crystallize. To prepare the filaments of this invention, particularly polyester filaments, drawing conditions are used that are termed "amorphous retaining," i.e., they tend to induce a minimum of crystallinity. These conditions are represented by a maximum draw ratio for a filament spun under certain conditions and for a maximum temperature of drawing, as discussed below. Drawing may be carried out by passing over a heated pin approximately 1.5 inches in diameter. Since a yarn has such a short contact time with the pin, much of the internal heat generated by the drawing cannot be dissipated through the pin, and the high yarn temperature helps to crystallize the yarn. In general, the lower the pin temperature, the more amorphous will be the drawn filament. A pin temperature of 90° C. is about the maximum that can be used with dry polyester yarn to obtain a yarn with an elongation as low as 20% with filaments prepared in accordance with this invention that will ruffle. Filaments having an elongation of 20–30% are commercially preferred because of their yield point and initial modulus. Somewhat higher temperatures can be used with a smaller draw ratio (to obtain an elongation greater than 20%).

By running the yarn through a water bath or over a water wick prior to pin drawing, higher temperatures (e.g., as high as 105° C.) can be used to obtain a yarn with the required high shrinkage and an elongation of 20% or more. It is believed that the water helps to dissipate the heat of drawing.

Another method of drawing is by means of 2 or more rolls, around each of which the yarn is wrapped and which revolve at different peripheral speeds. The yarn may be wrapped any desired number of times around the heated feed roll. Thus, depending on the draw ratio, the size of the roll, the number of wraps and the contact time, temperatures as high as 105° C. may be used to draw dry yarn to obtain a high shrinking yarn with an elongation of 20% or more.

The maximum draw ratio to be used will depend upon the orientation of the fins which is dependent upon spinning speed, quenching conditions and the width/thickness (W/T) ratio of the fin as previously discussed. Sufficient elongation must be present in the fiin so that a useable textile product can be made. Draw ratios of 1× to 4× can be used with 1× to 3× being preferred. The exact draw ratio and drawing conditions for any as-spun filament that will give a shrinkage in boiling water greater than 15% can readily be determined by experiment.

In general, lowering the temperature of the pin at a given draw ratio increases the amount of shrinkage, and a higher draw ratio can therefore be used to obtain the same shrinkage. Also, drawing the yarn wet gives a greater shrinkage at a given draw ratio than dry drawing, and thus a higher draw ratio can be used with wet drawing to obtain the desired high shrinkage.

Shrinkage of the yarn to cause convoluting of the fins may take place in any convenient manner. A boil-off in water, exposure to steam, or a blast of hot air or other suitable relaxing media will suffice.

It is preferred that the filaments of this invention have an average angular displacement for each convoluted fin of at least $2.0/\mu$ and at least 100 convolutions per inch; a width to thickness ratio of from 2 to 4 is also preferred. In carrying out the invention, spinning speeds of at least 1000 yards per minute are preferred.

Polymers crystallizing less readily than poly(ethylene terephthalate) are also quite useful in the practice of this invention. A copolymer, poly(ethylene terephthalate/sodium sulfoisophthalate) 98/2% by weight (described in the copending application of Griffing and Remington, Serial No. 519,269, filed June 30, 1955), now abandoned, when spun under the conditions of Example VII developed a moderate bulk when shrunk in a 210° C. air jet even though the yarn was drawn on a 93° pin to 20% elongation.

In a preferred embodiment of the invention, the polyester polymer is a synthetic linear condensation polyester of bifunctional ester-forming compounds wherein at least about 75% of the repeating structural units of the polymer chain include at least one divalent carbocyclic ring containing at least six carbon atoms present as an integral part of the polymer chain and having a minimum of four carbon atoms between the points of attachment of the ring in the polymer chain (para-relationship in the case of a single 6-membered ring). The polyesters may be derived from any suitable combination of bifunctional ester-forming compounds. Such compounds include hydroxy acids such as 4-(2-hydroxyethyl)benzoic acid and 4-(2-hydroxyethoxy)benzoic acid, or mixtures of the various suitable bifunctional acids or derivatives thereof and the various suitable dihydroxy compounds and derivatives thereof. The repeating structural units of the polymer chain comprise recurring divalent ester radicals as in-chain linking units which are separated by predominantly carbon atom chains or rings comprising hydrocarbon radicals, halogen-substituted hydrocarbon radicals, and chalcogen-containing hydrocarbon radicals wherein each chalcogen atom is bonded to carbon or a different chalcogen atom, and no carbon is bonded to more than one chalcogen atom. Thus, the repeating units may contain ether, sulfonyl, sulfide, or carbonyl radicals. Sulfonate salt substituents may also be present in minor amount, up to about 5 mol percent total sulfonate salt substituents in the polyester based on the number of ester linkages present in the polyester. See, for example, U.S. 3,018,272. Other suitable substituents may also be present.

Among the various suitable dicarboxylic acids are terephthalic acid, bromoterephthalic acid, hexahydroterephthalic acid, 4,4′-sulfonyldibenzoic acid, 4,4′-diphenic acid, 4,4′-benzophenonedicarboxylic acid, 1,2-bis (4-carboxyphenyl)ethane, 1,2 - bis(p - carboxyphenoxy)ethane bis-4-carboxyphenyl ether and various of the naphthalenedicarboxylic acids, especially the 1,4-, 1,5-, 2,6-, and 2,7-isomers. Isophthalic acid is also suitable, especially when used in combination with a 1,4-dihydroxyaromatic compound. Carbonic acid is similarly suitable.

Among the various suitable dihydroxy compounds are the glycols, such as ethylene glycol and other glycols taken from the series $HO(CH_2)_nOH$, where n is 2 to 10; cis- or trans-p-hexahydroxylylene glycol; diethylene glycol; quinitol; neopentylene glycol; 1,4-bis(hydroxyethyl)benzene; and 1,4-bis(hydroxyethoxy)benzene. Other suitable compounds include dihydroxyaromatic compounds such as 2,2-bis(4-hydroxy-3,5-dichlorophenyl)propane, hydroquinone, and 2,5- or 2,6-dihydroxynaphthalene. Other suitable glycols can be selected from the class having the general formula: $HOCH_2—Q—(R)_m—Q'—CH_2OH$ wherein Q and Q′ are saturated hydrocarbon radicals of the group consisting of 1,3-cyclohexylene, 1,4-cyclohexylene, and lower alkyl derivatives thereof; m is 0 or 1; and R is a saturated divalent hydrocarbon radical of 1 to 8 carbon atoms. Bis(4-hydroxymethylcyclohexyl) and 1,2-bis (4-hydroxymethylcyclohexyl)ethane are especially useful. This general class of glycols is made by a two-stage reduction of the corresponding bibenzoic acids or bis(carboxyphenyl) alkanes or ethers, involving reduction of the aromatic nuclei to alicyclic nuclei (e.g., hydrogenation of an ester of the acid using platinum oxide as a catalyst) followed by reduction of the carboxy groups to hydroxymethyl groups (e.g., reaction with lithium aluminum hydride).

Suitable polyesters are described, e.g., in U.S. Patents 2,465,319, 2,658,055 (DMe3E) and 2,676,945 (Poly OH acetic acid).

Although the filaments of this invention having two or more fins have been illustrated only by cross sections with fins of substantially equal length disposed in a symmetrical manner, the invention is not limited thereto. The fins on a filament can vary in length and in cross section disposition within the limits of this invention.

The advantages of the highly bulked product of this invention are obtained when only one fin is present on a filament. However, filaments having two or more fins are preferred because of the greater bulk obtained for a given weight of filament.

An especially advantageous product is a combination of Y and O cross section filaments in the same yarn bundle because of better fiber mobility in the yarn bundle and softer handle of the fabrics made therefrom.

It is preferred that both the potentially convolutable and also the convoluted filaments of this invention have a denier of 1 to 10 and that either continuous or staple yarns composed of these filaments have a denier of 30 to 8000. These denier ranges are particularly adaptable to the textile industry.

The filaments of this invention will have 20 or more complete convolutions per inch. It is preferred, however, that they have at least 100 complete convolutions per inch.

The relatively high frequency of the ruffles on the fins of these products confer bulk and resistance to packing that is not attained by the crimped filaments of the prior art. The filaments prepared by the process of this invention may be fabricated before shrinking in the form of continuous filament yarn or cut to staple fiber, formed into yarn and bulk developed in the fabric with the finishing step. Alternatively, the fibers may be shrunk to give a prebulked filament, yarn or staple before fabrication.

The products of this invention are of great utility, either as continuous filaments or staple fibers, in the production of yarns and in the formation of bulky fabrics, whether knitted, woven or felted.

The filaments and yarns made by the process of this invention prior to convoluting, may be woven into fabric and the convolutions developed in the fabric; alternatively, they may first be convoluted and then woven into fabric.

We claim:

1. The process which comprises

(1) extruding a molten synthetic linear polyester through an orifice having at least one elongated slot having a width to thickness ratio of at least three projecting from an aperture having a width greater than the width of said slot to form a filament having at least one fin extending from a stem portion,

(2) quenching said filament by directing a flow of quenching gas across said filament near said orifice at a velocity of at least

$$150 \text{ f.p.m.} \times \left(\frac{1200}{\text{forwarding speed}}\right)^2$$

where the forwarding speed is expressed in yards per minute,

(3) forwarding said filament at a speed between about 1,000 and 3,400 yards per minute and

(4) drawing said filament from 1 to 4 times its original length under amorphous retaining conditions, said quenching, forwarding and drawing steps imparting to the fin and stem portions of said filaments a differential shrinkability, and shrinking the drawn filament between about 15 to 75% thereby providing a convoluted filamentary structure.

2. The process of claim 1 wherein the velocity of said quenching gas is between 250 and 2500 feet per minute.

3. The process of claim 2 wherein said filament is forwarded at a speed between 1300 and 3400 yards per minute.

4. The process which comprises

(1) extruding a molten synthetic linear polyester through an orifice having at least three elongated slots having a width to thickness ratio of at least three projecting from a central aperture to form a filament having at least three fins extending from a stem portion,

(2) quenching said filament by directing a flow of quenching gas across said filament near said orifice at a velocity of at least

$$150 \text{ f.p.m.} \times \left(\frac{1200}{\text{forwarding speed}}\right)^2$$

where the forwarding speed is expressed in yards per minute,

(3) forwarding said filament at a speed between about 1,000 and 3,400 yards per minute and

(4) drawing said filament from 1 to 4 times its original length under amorphous retaining conditions, said quenching, forwarding and drawing steps imparting to the fin and stem portions of said filament a differential shrinkability, and shrinking the drawn filament between about 15 to 75% thereby providing a convoluted filamentary structure.

5. The process of claim 4 wherein the velocity of said quenching gas is between 250 and 2500 feet per minute.

6. The process of claim 5 wherein said filament is forwarded at a speed between 1300 and 3400 yards per minute.

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