June 1, 1965 A. L. BREEN ETAL 3,186,155
TEXTILE PRODUCT OF SYNTHETIC ORGANIC FILAMENTS HAVING
RANDOMLY VARYING TWIST ALONG EACH FILAMENT
Filed June 6, 1963 4 Sheets-Sheet 1

Fig. 1

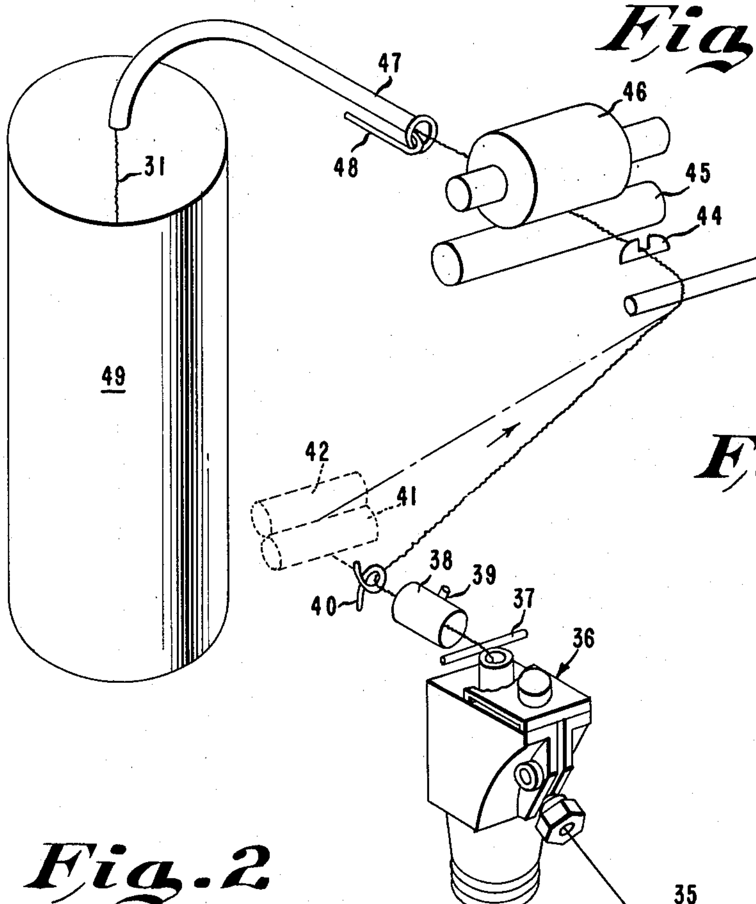

Fig. 3

Fig. 2

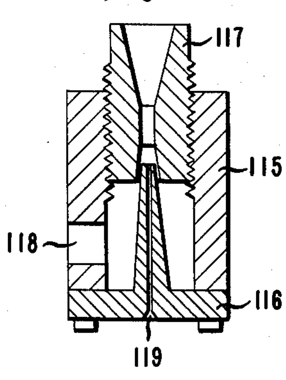

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Fig. 4

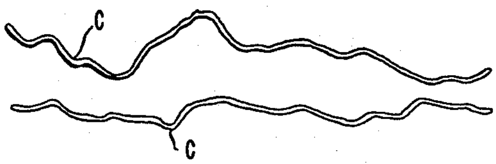

Fig. 5

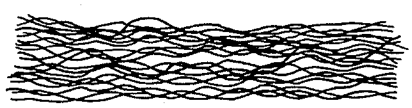

Fig. 6

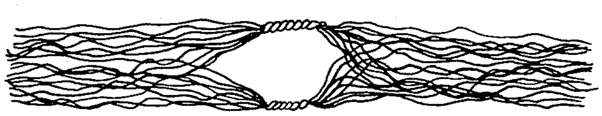

Fig. 7

Fig. 8

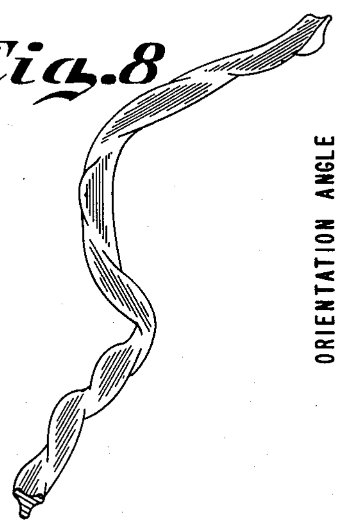

Fig. 9

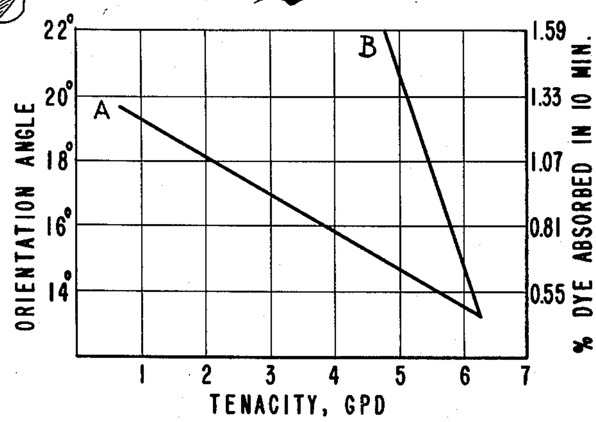

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Fig. 10

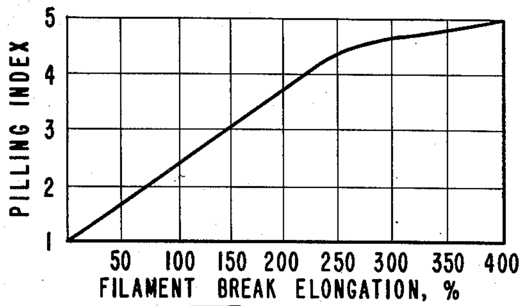


Fig. 11

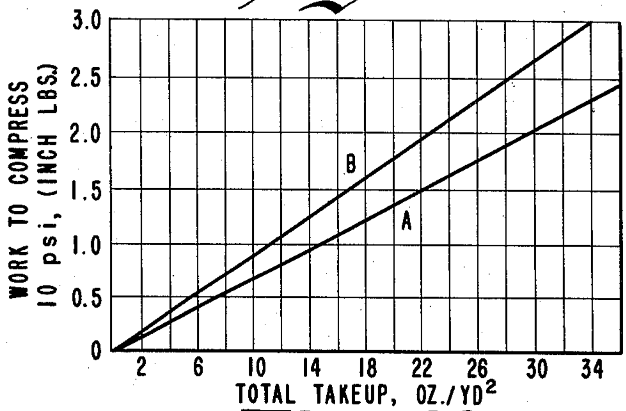
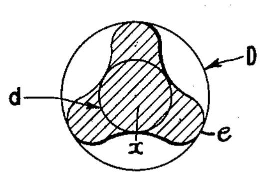


Fig. 12



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Filed June 6, 1963 4 Sheets-Sheet 4

FIG. 13

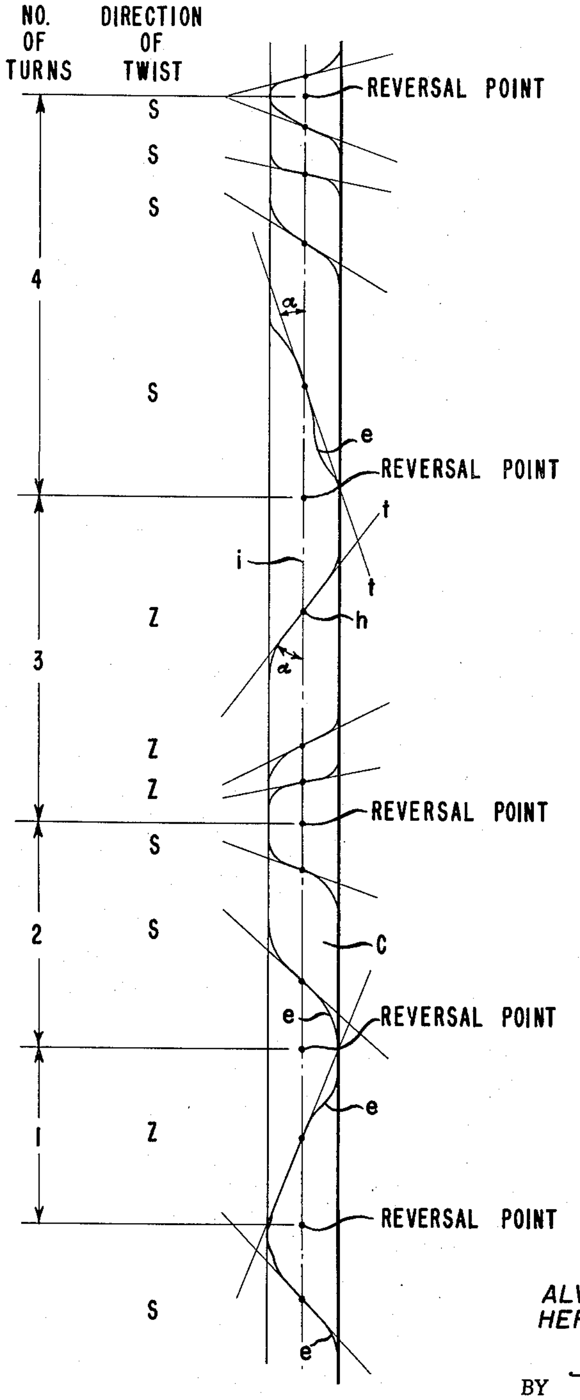
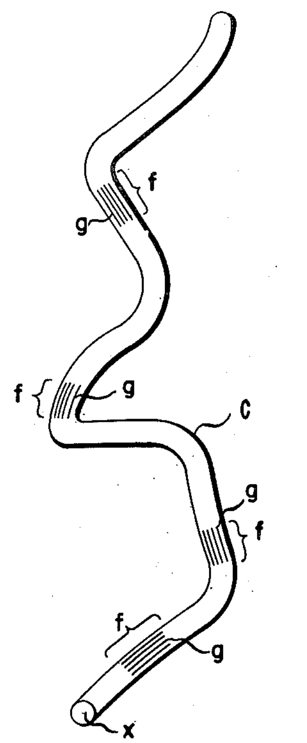


FIG. 14



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United States Patent Office

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TEXTILE PRODUCT OF SYNTHETIC ORGANIC FILAMENTS HAVING RANDOMLY VARYING TWIST ALONG EACH FILAMENT

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Filed June 6, 1963, Ser. No. 287,464
27 Claims. (Cl. 57—140)

This application is a continuation-in-part of our copending applications Serial No. 698,103, filed November 22, 1957, and Serial No. 842,524, filed September 25, 1959, now abandoned, the latter being a continuation-in-part of our application Serial No. 772,475, filed November 7, 1958 and abandoned.

This invention relates to a process for treating a bundle of filaments such as yarn or thread to produce a multifilament yarn of greatly increased tenacity and dyeability. More particularly, the invention relates to a bulky yarn composed of a plurality of individually crimped filaments having a random, three-dimensional, curvilinear configuration, high tenacity and improved level dyeing characteristics and faster dyeing rate and to the process used for preparing such yarn.

Artificial fibers are normally produced most easily as continuous filaments. These continuous filament yarns are very strong because of the absence of loose ends that are unable to transmit imposed stresses. Their extreme uniformity and lack of discontinuity, however, make conventional continuous filaments yarns much more dense than yarns made from staple fibers. The production of yarn from staple fibers, however, is time-consuming and requires a complex series of operations to crimp the fibers, align the fibers into an elongated bundle and then to draw the bundle to successively smaller diameters. The final spinning operation, which involves a high degree of twist, finally binds these discontinuous fibers together to produce a coherent yarn with considerably increased bulk. The occluded air spaces give them a lightness, covering power, and warmth-giving bulk not normally possible with continuous filament yarns. Thus to get staple fibers that can be processed on conventional wool or cotton spinning equipment, it has been the practice to cut continuous filament yarns such as rayon, acetate, nylon, as well as the polyacrylic and polyester fibers into short lengths for spinning into staple yarn.

Recent developments in the textile industry have provided useful routes for improving the bulk and covering power and recoverable elongation of continuous filament yarns without resorting to the staple spinning systems of the prior art. A well-known process for making stretch yarn involves the steps of twisting, heat-setting and then backtwisting to a low final twist level. Another yarn of improved bulk is prepared commercially by the steps of twisting, heat-setting and backtwisting on-the-run using a false-twisting apparatus. This end product can be further modified by hot relaxing to improve the bulk and handle. Still another bulk yarn is being prepared by the well-known stuffer box technique wherein the yarn is steamed to heat-set while it is in a compressed state in the stuffer box.

All of these yarns of the prior art are produced by a process which has the common elements of deforming the yarn mechanically and then heat-setting either with or without an after relaxation step. It was not until the recently disclosed product in U.S. 2,783,609 to Breen and its process of manufacture became known that an entirely new technique became available for improving the bulk of continuous filament yarns. This technique involves exposing a filamentary material to a rapidly moving turbulent fluid, thereby inducing a multitude of crunodal filament loops at random intervals along the individual filaments. These loops and snarls of entangled loops increase the bulk of the continuous-filament yarns considerably and result in fabrics of improved cover, bulk, handle, and the like. With the invention of Breen, a new tool is available for the bulking of filamentary structures, i.e., a turbulent fluid. Fluids, of course, have been used for yarn treating in many of the prior art operations such as drying, extracting, transporting, and the like. Until the invention of Breen, however, they had not been used to entangle, convolute, and bulk a filamentary material. It has now been discovered, however, that a new process utilizing the turbulent fluid technique results in new yarn products that have certain unique properties not heretofore disclosed in the art.

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It is an object of the present invention, therefore, to provide continous filaments and continuous-filament yarn having a bulkiness greater than staple yarn spun from comparable fibers. Another object is to provide multifilament yarn resembling spun staple in its desirable lightness, covering effectiveness and warmth-giving bulk but retaining the characteristic continuous filament freedom from loose ends, fuzziness, and pilling. It is also an object to prepare a bulky filamentary material especially useful for the pile component of pile fabrics. It is another object to provide both crimped and uncrimped synthetic organic filamentary strands having high tenacity and an unusually high rate of dyeability. Other objects will appear hereinbelow.

According to this invention there are provided synthetic organic filamentary strands having a combination of high tenacity and a rate of dyeability which has not been attained heretofore. These products are produced by feeding a synthetic organic filamentary strand at an overfeed of at least about 12% to a plasticizing stream of a compressible fluid, in which the individual filaments, while in a plastic state, are momentarily separated from each other and then cooled. The strand may be cooled by passing through air at normal room temperature. The product has high tenacity and also possesses a rate of dyeability at least about 75% greater than that of the feed strand. By increasing the overfeed to at least 30%, preferably at least 40%, the filamentary product produced contains, in addition to the high tenacity and high rate of dyeability set forth above, fibers possessing an independent random persistent, three-dimensional, nonhelical, curvilinear configuration along the line of the filamentary strand and is substantially free of stable crunodal loops.

The invention and the manner of carrying it out will be more clearly understood by reference to the drawings in which,

FIGURE 1 is a schematic perspective view of apparatus suitable for the production of the bulky yarn of this invention,

FIGURE 2 shows a jet device useful in the production of the yarn of this invention,

FIGURE 3 is a cross-sectional view of the bulky yarn of this invention,

FIGURE 4 is a longitudinal view of single filaments modified in accordance with the process of this invention,

FIGURE 5 is a longitudinal view of a multi-filament yarn of this invention,

FIGURES 6 and 7 show variations of the multi-filament yarn product of this invention,

FIGURE 8 shows a single filament produced in accordance with this invention from a fiber of non-round cross section,

FIGURE 9 shows a graphical relationship between the dye absorption and orientation angle of the product of this invention, and its tenacity,

FIGURE 10 shows a graphical relationship of the pilling index of the product of this invention, and its break elongation,

FIGURE 11 shows a graphical relationship of compressional characteristics versus weight for pile carpets made of the yarn of this invention compared with conventional staple yarn,

FIGURE 12 is an illustration of a fiber cross section for preparation of a preferred carpet yarn, and

FIGURES 13 and 14 are schematic representations of the structural characteristics of the filaments of this invention.

In FIGURE 1, the moving threadline **31** to be treated is passed through guide **32**, between feed rolls **33** and **34**, over guide **35**, through fluid jet **36**, over guide **37**, through quench tube **38**, provided with cooling fluid through opening **39**, through guide **40**, to guide **43**, or alternately between feed rolls **41** and **42**. Traverse guide **44** may be used to distribute the bulky yarn on package **46** driven by roll **45** or part **46** may be a roll which with roll **45** is used to feed yarn to piddle tube **47** provided with aspirating tube **48** depositing yarn in container **49**.

FIGURE 2 is a similar jet consisting of body member **115**, yarn guide **116**, and orifice **117**. Compressible fluid enters the body member through opening **118**, and the yarn enters through opening **119**.

FIGURE 3 is a thin cross section of the yarn showing short lengths of filaments in randomly disposed arrangement. Fibers at points *a* show a random wrapping effect which in some cases improves the cohesiveness of the yarn bundle without inhibiting its bulkiness and stretch properties. The freedom from protruding loops indicated here gives desirable improvement in yarn handling characteristics and freedom from snagging problems in end use form. The yarn cross section was made by supporting the sample in a transparent mounting of polymethyl methacrylate prior to sectioning so as to hold the short lengths of fibers in position.

FIGURE 4 is an illustration of the individual filaments of the invention. Points *c* show what appear to be angular crimp form. This is intended to represent a region where the filament path is in the general direction perpendicular to the plane of the illustration causing apparent distortion of the curvilinear form.

The above statements apply similarly to the filaments comprising the yarns illustrated in FIGURES 5, 6, and 7.

FIGURE 5 shows a multifilament yarn composed of filaments of FIGURE 4 and it can be seen that the filaments are substantially interentangled within the yarn bundle. FIGURE 6 shows a yarn bundle such as in FIGURE 5 after having been false twisted. FIGURE 7 also shows a yarn bundle composed of filaments of FIGURE 4 and containing a divided region characterized by opposite directions of twist in the adjacent portions thereof.

FIGURE 8 depicts a single filament of this invention having a non-round cross section.

FIGURE 9 expresses graphically the relationship between orientation angle, tenacity, and dye absorption rate to illustrate the data of Example XI.

FIGURE 10 shows graphically the relationship between pilling index and filament break elongation as explained more fully in Example I.

FIGURE 11 shows graphically the work required to compress carpets of various weights prepared from staple yarns as described more fully in Example V.

FIGURE 12 shows a cross section of a trilobal filament in which *x* is the axis of the filament, which is defined for present purposes as a line running lengthwise through the cross-sectional center of gravity of the filament, and *e* is a point on the surface of the filament. D represents the smallest circle circumscribing the filament, and *d* is the largest circle which can be inscribed within the filament. The ratio of the radii of D to *d* is called the modification ratio of the filament.

FIGURE 13 depicts a tensioned filament *c* of this invention having a non-round cross section with *e* representing a single element on the surface of the filament (a line on the surface of the filament which, in the straight filament, prior to twisting or crimping of the filament, is straight and parallel to the axis of the filament), also shown by point *e* in the cross-sectional view of FIGURE 12. It will be noted in FIGURE 13 that the direction of twist is alternately S and Z in adjacent sections of the filament. The angle of twist of the filament at any point *h* of element *e* is shown by angle α, the acute angle between a tangent *t* to element *e* at that point and plane *i* (perpendicular to the plane of the paper) which contains both the axis of the filament and point *h*. In filaments of this invention, both crimped and uncrimped, twist angle α varies continuously and randomly throughout the length of the filaments.

FIGURE 14 is a schematic view of a crimped filament *c* of this invention as viewed under a pair of Nicol's prisms crossed at 90°. Because of the crimp, only portions *f* of the filament lie at an angle of 45° to the planes of polarization of the prisms and also perpendicular to the line of view through the prisms. In the birefringence pattern exhibited by filaments of this invention the lines of constant retardation *g* lie parallel to the axis of the filament throughout the filament length, although they have maximum visibility only in those portions *f* of the filament. By proper manipulation of the filament it can be seen that the lines of retardation are parallel to the axis of the filament throughout the filament length, thereby distinguishing prior art crimped filaments wherein the lines of retardation are parallel to the filament axis only in straight portions of the filament. This method is especially useful for identifying round filaments of this invention because the twisted configuration as shown in FIGURE 13 may be very difficult to observe in a round filament even under high magnification.

For certain uses where subdued luster and tactile dryness are desired the preferred product of this invention should be made from fibers having a non-round shape of critically selected character. In carpet yarns, for example, it has been found that the approximately symmetrical cross-sectional form indicated in FIGURE 12 is preferred. This is disclosed by Holland in U.S. Patent No. 2,939,201 issued June 7, 1960.

The individual filaments of the products of this invention are characterized by possessing alternate S and Z twist sections throughout their lengths, with at least one S turn and at least one Z turn per inch of filament which have a twist angle averaging at least 5°. This twist is further characterized by random variation along the filament length, having a random number of turns between twist reversals, having a random continuously varying angle of twist along its length, and having a random number of twist reversals per inch. Nevertheless, the filaments are free from cross-sectional deformation, as contrasted to the deformed cross-sections characteristic of gear-crimped filaments and those produced by mechanical bulking processes in general.

These important properties of filaments of this invention are particularly noticeable with non-round fiber forms as illustrated in FIGURE 8. Here the fiber has not only a random, three-dimensional, non-helical, curvilinear configuration, but is also formed into a randomly twisted configuration, portions of which are in an S direction with other portions being in a Z direction. The twist is completely random along the length of the filament particularly with respect to (1) the angle of twist which varies continuously and randomly, (2) the number of twist reversals per inch of filament, and (3) the number of turns between twist reversals. Each filament contains at least 2 (absolute) turns per inch of twist (only full turns being counted).

To determine the extent of the random twist modification of the individual fiber, a specimen is mounted between microscope slides with sufficient tension to hold the fiber axis in an approximately straight condition but a tension low enough that the twist is not appreciably reduced. The angle is then measured between imaginary lines following the outermost points of the filaments and the filament axis at a number of points sufficient to provide a meaningful average. This average angle should be at least 1°. There will be points where the angle is essentially zero where the twist reverses direction. Other points are found where the angle is considerably greater than the average value. In well modified samples maximum values in the order of 30° are observed and the average may be as much as 5° or more.

Since the twist of each filament is random along its length, a yarn made up of a group of these non-round filaments is prevented from packing in a closely nested configuration. This is true even when considerable tension is applied to the yarn sufficient to straighten the random curvilinear crimp configuration. This latter property is particularly useful in increasing the bulk of tightly woven fabrics where loom tension and fabric construction tends to reduce the bulking effect due to crimp. The random twist is likewise useful in highly crimped pile yarns or bulky knit structures where it tends to reduce objectionable glitter or luster associated with light reflection from the fiber surfaces.

By a direct experiment, it has been possible to confirm the presence of random alternating twist in round filaments treated by the process of this invention. A nylon yarn was prepared having round filaments with two polymeric components spun side-by-side. One half of each filament contained .02% TiO_2 pigment and the other 2.0% pigment. The filaments, examined under the microscope, were initially free of twist as indicated by the line of demarcation between the two filament halves. After fluid treatment as described, the treated filaments were found to have a high degree of random alternating twist, the angle of twist at many points along the filament being equivalent to 20 turns per inch.

In the preferred process of this invention, filaments and yarns meeting the above objects are provided by a process in which a stream of a compressible fluid at a temperature above the second-order transition temperature of the polymer of which the filament is made and preferably at least about 300° F. is vigorously jetted to form a turbulent plasticizing region. The yarn or filaments to be treated are positively fed at a rate greater than the yarn take-up speed into the fluid plasticizing stream so that the yarn is supported by it and individual filaments are separated from each other and crimped individually by whipping about in the hot turbulent plasticizing region, and rapidly cooled while being maintained at low tension to set the convolutions. Under these conditions the yarn temperature is above the "cold point" as described more fully hereinafter and below the melting point of the yarn. During the jetting treatment, filament shrinkage occurs because of the heat transmitted to the fibers. The process elements such as temperature, pressure, fluid flow, yarn speed, tension, and wind-up speed are adjusted so as to give a final yarn denier (measured in relaxed form after hot-wet relaxation) greater than the feed yarn denier and preferably at least 30% greater than the feed yarn denier.

The crimped filaments are withdrawn from the plasticizing zone by the fluid exhaust and the take-up rolls. The filaments pass through a cooling zone before or after the take-up rolls to prevent further plastic flow and to insure retention of the crimp while maintaining the yarn in a substantially relaxed and tensionless condition. After cooling, the yarn may be tensioned to remove any fiber loops, eliminate any packing of filaments and to improve the bulking characteristics of the yarn. Tensioning is desirable also for forming a suitable package on any wind-up device. Tension applied in pulling the yarn away from the jet or in winding the yarn on a package appears to cause some temporary removal of fiber crimp, but this crimp is subsequently recovered when the yarn is relaxed and boiled-off. Stable crunodal loops are avoided or at least kept to a minimum by control of the process conditions since such entangled loops prevent maximum bulk from being obtained in the yarns. The crimped yarn, of course, may be cut into staple after passing through the turbulent hot fluid. This process, therefore, provides a highly productive way of crimping tow which is to be used in staple products. This process may also be used for *setting* dyes in the yarn. A yarn padded with dyes may be either treated with a turbulent fluid to *set* the dyes in the fiber by diffusion through the fiber or it may be treated with a turbulent fluid to simultaneously bulk the yarn and *set* the dyes.

Bulky yarn can be prepared by the process of this invention from any plasticizable fiber. The process is applicable primarily to continuous filament yarns and multifilament yarns in particular although monofilaments can also be crimped in the same manner. Staple yarns can also be processed to give products of greatly increased crimp and bulk particularly in the surface fiber.

Bulky products of this invention are different in fundamental physical structure from any of the bulked yarns described in prior art. During the jetting treatment, at least 12% lengthwise shrinkage of the filaments and substantial deorientation of the filaments occur. When jetted under optimum conditions, this shrinkage and relaxation far exceeds that which occurs when the yarn is exposed to the same fluid at the same temperature and under low tension for a long period of time without agitation. The instantaneous application of heat to fibers in the jet and extremely short exposure time permit deorientation to occur before substantial crystallization can occur. The yarn does not, therefore, become permanently set before deorienting and does not become brittle or weak. This dynamic relaxation is responsible for a considerable amount of deorientation of the molecules and an increase in crystallinity. In addition, there is a significant increase in dye receptivity with little loss in tenacity. The improved combination of dyeability rate and tenacity of filaments of this invention can be expressed by the equation

$$\frac{D_s}{D_0}\times\frac{T_s}{T_0}>0.8$$

where D_0 and D_s are the dyeability rates of the filament before and after shrinking, respectively, and T_0 and T_s are the tenacities of the filament before and after shrinking, respectively. This relationship holds true for both crimped and uncrimped filaments of this invention.

The higher filament temperatures under relaxed conditions and the repeated stressing cause the amorphous molecular structure to open-up giving more lateral space between molecules and greater distance between crystallites along the fiber axis. The great changes in the amorphous molecular structure are shown clearly by low angle X-ray patterns using the techniques described by W. O. Statton, J. Polymer Sci. 22, 385 (1956). This new opened-up condition, plus the deorientation which occurs, gives fibers with greatly improved dyeing rate without substantial reduction in tenacity. The dyeing rate is increased about 75% to 250% by the process of this invention and there is no change in the chemical composition of the fiber during treatment. Of course, moderate improvements in dye rate have been shown in prior art by relaxed heat treatment, but such increases in dye rate with such small losses in tenacity and with luster advantages due to random twist have not been known. In addition, the uniform turbulent heating in the present process permits much higher average filament temperatures to be obtained since there is no danger of surface filaments being heated above their melting point or fusing filaments.

All commercial procedures for manufacturing synthetic fibers inadvertently subject a portion of the yarn or certain segments of a portion of the yarn and filaments to plucks or other stresses as, for example, when processing with fluids or passing over guides, which causes these yarns or segments to dye at a different rate and/or to a different depth relative to the bulk of the yarn. Undesirable deformations, which cause non-uniform dyeing, result from mechanical treatment of heat-softened filaments. This is particularly true of processes in which hot filaments are mechanically twisted or pressed against surfaces or bent abruptly, as in mechanical twist-setting operations and gear or stuffer box crimping. The filament cross-sections are deformed by pressure on the twisting device or other hard surface, by pressing together of cross filaments, and by sharp creasing of the filaments. The dynamic relaxation employed in this invention avoids these non-uniformities in structure and produces filaments with exceptional dyeability and tenacity but without cross-sectional configuration distortions.

The yarns of this invention are uniform in cross section, a characteristic particularly noticeable with filaments of round or symmetrical cross sections. The unusual uniformity of a filament of this invention may be seen by its uniform birefringence pattern under crossed Nicol's prisms as illustrated in FIGURE 14. By proper manipulation of the observed filament, it will be seen that the lines of constant retardation in the pattern are parallel to the filament axis throughout the filament length as distinguished from prior art crimped filaments where such lines are parallel to the filament axis only in straight portions of the filament. The bulked yarns prepared by the process of this invention also have better dyeing uniformity than bulked yarns prepared by the twist-heat set method, by gear crimping, by stuffer-box crimping, or by other mechanical crimping methods which produce filament distortion during the crimping process.

The crimped products of this invention have a three-dimensional, non-helical, random, curvilinear configuration. This structure is different from the bulked materials prepared by the various twist-setting operations, since these have predominantly a helical and regular type of filamentary deformation. It is different also from those prepared by the well-known stuffer box technique, since the latter are characterized by the regular and reversing zig-zag planar type of crimp illustrated in Spence et al. U.S. Patent No. 2,917,784 dated December 22, 1959. The crimp in the products of the present invention is three-dimensional and random in crimp amplitude and period. The turbulent fluid treatment of filaments which are free to crimp individually results in a very high crimp level, and a curvilinear, random configuration, that is, the crimp in the filament is in the form of an irregular smooth curve throughout and entirely free from the sharp creases and folds found in mechanically crimped filamentary configurations. The filaments are substantially free from crunodal loops. The crimp is permanent to normal fiber processing conditions and will persist in filaments taken from the yarn bundle. On exposure to hot water, further increases in crimp amplitude and frequency are obtained. The useful products of this invention have a crimp level in excess of 5 per inch, preferably above 10 per inch, and there may even be as high as 70 or 80 crimps per inch.

The products of this invention can be prepared from any natural or synthetic plasticizable filamentary material. A monocomponent synthetic organic filament structure is preferred, i.e., each filament is formed from a single fiber-forming melt or solution; this includes mixtures of monocomponent filaments of different composition in multi-filament strands. Especially preferred are filaments composed of thermoplastic materials of the types illustrated herein. Exemplary thermoplastic materials include polyamides, e.g., poly(epsilon caproamide) and poly(hexamethylene adipamide); cellulose esters, e.g., cellulose acetate; polyesters, particularly polyesters of terephthalic acid or isophthalic acid and a lower glycol, e.g., poly(ethylene terephthalate), poly(hexahydro-p-

xylylene terephthalate); polyalkylenes, e.g., polyethylene, polypropylene, etc.; polyvinyls and polyacrylics, e.g., polyacrylonitrile, as well as copolymers of acrylonitrile and other copolymerizable monomers can be crimped to give the three-dimensional, random, curvilinear crimped configuration and the alternate and random S and Z twist. Copolymers of ethylene terephthalate containing less than 15% combined monomers other than ethylene terephthalate and copolymerizable with ethylene terephthalate are also very useful in practicing this invention. While the preferred form of material is continuous filaments, the process and resultant improvements occur with staple yarns as well. Both types of materials can be made into bulky yarns and fabrics having improved bulk, covering power (opacity) and hand.

Products of this invention may be prepared from both monofilament and multifilament yarns in textile deniers as well as the heavier carpet and industrial yarn sizes either singly or combined in the form of a heavy tow. Fine count and heavy count staple yarns can be processed both singles and plied. The process and product are also not restricted in the case of the synthetic materials to any one particular type of filament cross section. Cruciform, Y-shaped, delta-shaped, ribbon, and dumbbell and other such filamentary cross sections can be processed at least as well as round filaments and usually contribute still more bulk than is obtained with round filaments.

The turbulent fluid used to treat the filamentary material may be air, steam, or any other compressible fluid or vapor capable of plasticizing action on the yarn provided that it has a temperature above the second-order transition temperature of the filament. Hot air will give sufficient plasticization in the turbulent region for many fibers although it may be desirable for certain fibers to supplement the temperature effect with an auxiliary plasticizing medium. Steam is a cheap and convenient source of high pressure fluid with a compound plasticizing action.

The temperature of the fluid medium must be regulated so that the yarn temperature does not reach the melting point of the fiber. However, with fibers made from fusible polymers, the most effective bulking and the greatest productivity is obtained when the temperature of the turbulent fluid is above the melting point of the fiber. In this case the yarn speeds should be great enough so that melting does not occur. Because of the great turbulence and the high heat, yarns are heated rapidly. Temperatures lower than the second-order transition temperature (T_g) of the yarn material should usually not be employed because under these conditions the crimping or bulking of the filaments is not permanent and utility of the fibers is reduced.

One of the essential elements of the process is that the filaments or yarn must be inherently elastic but must be rendered non-elastic and plastic in the turbulent atmosphere. The plastic condition may be brought about by the temperature of the compressible fluid. In any case, the plastic condition of the filaments must be temporary and transitory. The term "plasticizing" or "plastic" is intended to mean that the conditions to which the term relates are such that the filaments are in a temporary flaccid, non-elastic, deformable condition. After the plasticizing conditions are removed such as by lowering the temperature, chilling, removing the solvent, or similar considerations, the filaments and yarns must return to their normal elastic state. The use of an inert compressible fluid such as air or steam under conditions which do not plasticize, soften, or render the filaments non-elastic, does not fall within the scope of the invention. Wet steam will fail to produce configurations in the yarn described above if the temperature of the yarn does not reach a point sufficiently high to render it plastic and non-elastic. Under such conditions, crimps and crunodal loops may be formed, but they are not stable and must be treated under plasticizing conditions to set and stabilize the crimps. On the other hand, relatively low temperatures may be used if there is sufficient residual volatile solvent in the filaments. It wlil also be apparent that large amounts of non-volatile plasticizers such as dibutyl phthalate, tricresyl phosphate, oils, plasticizing resins, etc., are relatively permanent, and when these are present, the yarns will not return to an elastic condition and should be avoided except for special purposes.

At high speeds and with certain polymers the fiber temperature should be well above the second-order transition temperature. A preferred minimum temperature defined as a "cold point" is given by J. W. Ballou and J. C. Smith in the Journal of Applied Physics, Volume 20, page 499 (1949). The cold point is the second inflection in the sonic modulus-temperature curve for the polymer or fiber in question. In general, this temperature may be 50° C. or more above the second-order transition temperature.

There are a number of means and apparatus whereby a turbulent stream of fluid can be produced. Suitable jets or devices for treating a filamentary material with a turbulent plasticizing fluid to achieve the improvements of this invention are described by Breen in U.S. Patents No. 2,783,609 and No. 2,852,906, and by Hall in U.S. Patent No. 2,958,112.

The process is well adapted for using a number of ends of yarn in the same jet. Thus, it is possible to pass two to five or more ends through a single jet at the same time. The resulting yarn may have the ends well blended or it may have bulked ends which will be distinctly separate and independently windable depending on the processing conditions. Two or more yarns may also be treated using different tensions or feed rates so as to produce a tension stable bulky yarn with extensibility confined to that of the shorter member. Likewise, two different types of yarn such as nylon and rayon may be passed through the jet. The differential shrinkage and heat-setting of the two types of yarn provide many interesting effects which are desirable for aesthetic reasons in textile materials. The crimp of the product is extremely stable and is not removed by subjecting the crimped fibers to tensions up to the draw tension; the crimp returns upon release of tension. The bulked yarns disclosed in U.S. Patent No. 2,783,609 require a high degree of intertangling or twist in order to maintain their bulk properties. The new yarns described here are stable and keep their bulk even when there is no entanglement or appreciable twist. Monofilament may be treated in a similar fashion to obtain a single crimped continuous filament. It is also to be understood that any treatment of yarns herein disclosed is to be construed as being applicable also to single filaments although for reasons of economy bundles of filaments or yarns are treated. The term "yarn" refers to any long or continuous length of a bundle of filaments.

The process of this invention can produce a gross increase in the bulk of the filamentary structures. The comparison of the starting denier to the final denier is a crude indication of the bulk increase. However, a better measure of bulk can be obtained by determining the volume of a definite weight of yarn while under pressure. This measurement of bulk under compressional loads is useful for estimating the bulk which a yarn will have when fabricated into carpet or other fabrics. It correlates very well, for example, with subjective compressions obtained by feeling a carpet with the fingers. For the purpose of this invention bulk is, therefore, measured under a pressure of 3.1 lbs./sq. in. The crimped yarn samples are measured in the untwisted state, that is, with less than one turn per inch in the gross yarn. Before testing, the untwisted yarn is given a hot wet relaxed treatment to develope maximum bulk and is then dried and conditioned at 70° F. and 65% relative humidity. Weighed samples of exactly 2.0 g. are then cut into ½ to ¾ inch pieces. The cut pieces are then dropped at random into a hollow stainless steel cylinder having an inside diameter of 1.008 inches. A round stainless steel piston of 1.000-inch diameter is then lowered slowly into the cylinder to compress the yarn and finally to exert a pressure of 3.1 lbs./sq. in. on the top of the yarn sample. After maintaining this pressure for 100 seconds, the volume of the compressed yarn is determined. The volume in cubic centimeters divided by the weight of the yarn in grams is the specific volume (cc./g.). This measurement is always made with a load of 3.1 lbs./sq. in. on the yarn. The specific volume of yarn prepared by this process is much greater than the specific volume of yarns prepared by other crimping processes such as stuffer-box crimping, false swist-heat set, or knife-edge crimping. The specific volume of carpet yarns prepared by this process ranges from 7 to 14 cc./g. Carpet yarns from other bulking processes, on the other hand, have specific volumes from 3 to 7 cc./g.

The synthetic filamentary materials to be treated by the process of this invention should preferably be in a high state of orientation to reduce pilling in the finished fabrics. Drawable filaments tend to snag and pull out of the fabrics. The resulting fuzz fibers then tend to wind-up into fuzz balls usually referred to as "pills" in the finished fabric. When the oriented filamentary structures are passed under low tension through the hot turbulent plasticizing fluid medium, a considerable degree of deorientation and crystallization occurs.

Because of the unusually large increase in crystallinity, during processing, the final yarns have a break elongation that is much smaller than would be expected considering the large decrease in orientation. Similarly, the tenacity changes less than expected. At the same time, the yarns have a surprisingly high dyeing rate. The net result is to obtain unusual yarns having a desirable combination of low elongation, low pilling tendency, and rapid dyeability. Pilling is avoided because yarns of low elongation do not easily draw or pull out of the yarn or fabric when snagged to give long fuzz fibers. These undesirable fuzz fibers cause pilling by winding and entangling around one another until balls of fuzz are formed. Of course, yarns with low elongations can be obtained in other bulk-yarn processes by drawing the feed yarn adequately, but these highly drawn yarns then have relatively low dyeing rates.

In addition to the increase in relaxed yarn denier due to the convoluted form, the high degree of deorientation that accompanies the relaxation in a preferred process results in a gross increase in the filament denier of the yarn being treated. Some increase in denier, of course, accompanies almost any relaxation or bulking process, i.e., 1–10%. The filament denier of the new products formed by the subject process, however, increases in denier from 12 to 25% or more as compared to the filament denier prior to treatment. In this instance, of course, denier is measured by the change in filament weight per unit length with the crimp removed by a light tension, eliminating the denier increase associated with crimp contraction.

The bulky yarns of the process of this invention are generally characterized by a very desirable tendency to develop increased crimp amplitude and yarn bulkiness as a result of mechanical exercising followed by the application of heat and/or plasticizer to the yarn while it is in a relaxed or low-tension condition. These steps coincide generally with the normal treatments involved in the formation of the usual fabric types and in the subsequent dyeing and finishing operations. The tufting operation in the formation of a tufted carpet, for example applies momentary high tension to the pile yarn as the tufting needle forces the yarn through the backing fabric. The loop, once in place, is in a low tension or relaxed state as the hot-wet finishing steps are used as, for example, in piece dyeing of the carpet. The bulking action accompanying these treatments is particularly beneficial in the tufted carpet since it causes the individual pile loops to increase their coverage of the backing material giving much improved appearance. Increasing surface cover with the above treatments is not essential, however, because of the great bulking power inherent to the extensible random curvilinear filament form. On tensioning, for example, in the carpet tufting operation, the substantially continuous-filament yarns of this invention are held in an essentially straight condition with a bulkiness little more than that of a conventional yarn of similar weight and filament count. Upon release of the tension as the tufting needle is withdrawn, however, the elastic recovery of the well-set crimp form causes the filaments to resume their randomly crimped configuration producing a great increase in bulk of the individual tufts so that the backing material is effectively obscured. Yarn portions held against the backing fabric between adjacent tufts, however, remain in a low-bulk tensioned condition. This gives a desirable preponderance of pile yarn on the face of the fabric and a minimum on the back. This applies similarly to other pile fabrics such as those useful in upholstery.

In normal weaving and knitting operations, the bulking character of this yarn is similarly beneficial. In sweater weight knit form, for example, the bulking action tends to obliterate undesirable threadiness. In woven fabrics, this action gives improved covering power, a drier tactile quality, and increased fabric-to-fabric friction, as compared with fabrics of unmodified yarn.

Since tensioning and hot-wet finishing are important factors in the utilization of these bulky yarn products, tests were devised to characterize the response of the yarns to these treatments.

Yarn crimp elongation, abbreviated YCE, is a measure of the extensibility of the yarn of this invention. The method for measuring this property employs a lightweight skein of yarn equivalent to about 5000 denier (measured through the double loop thickness). With heavy yarns, a single loop will suffice for the test. The length is cut to any value suitable for measurement of lengths in both the relaxed and taut condition. A load of 0.5 gm./den. is applied to the sample. The load is then reduced to 0.1 gm./den. At this latter load, the sample length is measured and recorded at $L_{0.1}$. The weight is removed and the sample is treated with atmospheric steam until contraction ceases. The sample length is remeasured and recorded as L_0. Yarn crimp elongation, expressed as a percent change in crimped yarn length, is calculated as follows:

$$YCE=\left[\frac{L_{0.1}}{L_0}-1\right]\times 100$$

YCE is also a measure of crimp amplitude which in turn is a measure of yarn bulkiness provided the crimp frequency is in a suitable range (5–50 crimps/inch) and random in character so that "in-phase" packing is eliminated. In general, for a desirable bulky yarn for the purposes of this invention a YCE of at least 10% is necessary and 25% or more is preferred.

Similar measurements may be applied to single filaments. In this specification the terms "fiber" and "filament" are used interchangeably. Filament or fiber crimp elongation, FCE, is determined by cutting a known length of bulked yarn, separating the individual filaments from the yarn segment. The excess of length of the average filament when extended sufficiently to remove the crimp divided by the length of the yarn segment and multiplied by 100, is the percent FCE. FCE may differ from YCE because of such factors as interfiber friction.

The bulked yarn denier, BYD, of the crimped yarn is measured in the relaxed state under the conditions described above for the measurement of L_0. A tensioned yarn denier, TYD, may also be calculated based on $L_{0.1}$.

Since it is likewise desirable that true fiber shrinkage accompanied by molecular deorientation be accomplished in a preferred embodiment of this invention, this shrinkage has ben determined as follows:

$$\text{Percent shrinkage}=\left[1-\frac{Den_I}{TYD}\right]\times 100$$

in which Den_I is the denier of the yarn before treatment by this process and TYD is the tensioned yarn denier as defined above. In order that the greatly improved dyeability may be achieved at acceptably low yarn elongation values, it is necessary that the true fiber shrinkage accompanying this process be at least 12% and preferably 25% or more.

The fluid process used to produce the filaments of this invention not only causes individual filaments to assume a randomly alternating twist and an irregular three-dimensional crimp configuration but also, when a plurality of filaments are processed simultaneously as a yarn or tow, the turbulent fluid action tends to cause the filaments to become interentangled. The degree of intermingling of the filaments may depend upon many factors, such as the size, shape, stiffness, tension and linear speed of the moving filaments, the geometry of the fluid jet, the temperature, pressure and velocity of the treating fluid. On occasion, it may be desirable to supplement the bulking process with a fluid interlacing treatment, such as described in Bunting et al. U.S. Patent No. 2,985,995. One method of characterizing the degree of interlacing in this patent is termed the "hook-drop test."

The hook-drop test is based on the distance a weighted hook inserted through a yarn bundle can be lowered before the weight of the hook is supported by the resistance of the yarn to further passage of the hook down the yarn. The result is calculated as 100 divided by this distance in centimeters so that greater coherency is indicated by higher values. The procedure for the hook-drop test is detailed in Bunting et al. U.S. Patent No. 2,985,995. The "coherency factors" for the bulky yarns in this disclosure have been obtained by this test.

The dyeing rates for feed and jet processed yarns are determined by analyzing the dye baths or fibers. The amount of dye in the fiber is determined after dyeing for a short interval at a given temperature. Complete dye rate curves can be obtained by dyeing a number of separate samples each for different lengths of time. For the purpose of this invention, however, the dye rate is defined as the amount of dye absorbed by the fiber in ten minutes at a given temperature. Each fiber sample is dyed in a separate dye bath. The percent dye in the fiber may be determined by ultraviolet spectral analysis of the dye bath or of a solution obtained by extracting dye from the fiber. The ratio by weight of dye bath to yarn is 400:1.

Slightly different methods are used for acid-dyeable polymers, basic dyeable polymers and those which dye with neither acidic nor basic dyes. Yarns having basic sites in the polymer such as the polyamide yarns, 6 and 66 nylon, are dyed at 140° F. for ten minutes with 8% acetic acid and 4% Dupont Anthraquinone Blue SWF based on weight of fiber. Anthraquinone Blue SWF is Acid Blue 165 of the Colour Index, Society of Dyers and Colourists and American Association of Textile Chemists and Colorists, 1956. The percent dye in fiber is calculated from the percent in the dye bath based on light transmission at wave lengths of 595 millimicrons. The initial dye bath with a known amount of dye serves as the standard sample for calculating concentration of dye in unknown solutions after dyeing. The dye baths, including the standard, are diluted two-fold before measuring transmission. The concentrations of dye in the bath are calculated from percent transmission by the use of Lambert's Law.

Yarns having acidic sites in the polymer such as modified polyethylene terephthalates containing 2% or more of a sulfoisophthalic ester are dyed using 4% Dupont "Sevron" Blue 5G (generic name, Basic Blue 4 and Color Index No. 51004) and 4% acetic acid for 10 minutes at the boil in the absence of carriers. The percent dye in the fiber is calculated from the percent dye in the bath using the transmission at 660 millimicrons. The bath is diluted tenfold for this determination.

Yarns which do not have acidic or basic sites, such as unmodified polyethylene terephthalate, are dyed with a dispersed color in the absence of carriers. It is desirable to use a color which is sensitive to physical changes in the fibers. The polymers with no acidic or basic groups are dyed, therefore, with 4% Latyl Violet BN (generic name Disperse Violet 27 in the Color Index) and 2% sodium lauryl sulfate dispersing agent based on fiber weight for 10 minutes at the boil without carrier to establish the dye rate. After drying, fiber samples weighing 0.5 g. are analyzed for percent dye by extracting several times with chlorobenzene at 100° C. for about 5 minutes. The combined extracts are then diluted to a total volume of 100 ml. Analysis is made by using an ultraviolet spectrophotometer at 580 millimicron wave lengths.

The stem treated yarns and the feed yarns are examined by standard X-ray diffraction techniques after relaxed boil off. Methods for determining orientation angle are described by W. A. Sisson in the Journal of Textile Research, 7, 425 (1937) or Ingersoll, H. G., J. Appl. Phys. 17, 924 (1946). For the purposes of this invention, fibers are mounted for X-ray examination with 0.015 g.p.d. tension applied to remove substantially all crimp during exposure. The orientation angle is defined here in terms of the aximuthal width of an intense equatorial diffraction arc. The angle is the width in degrees between the two points midway the peak intensity and the background intensity. This parameter decreases in value as orientation increases.

Higher temperature of the turbulent fluid tends to give higher orientation angles (low crystalline orientation). Orientation angles as high as 40° have been obtained by the process of this invention. It is preferred that the treated yarn have an orientation angle greater than that of the feed yarn. Orientation angles for 6 nylon are obtained in the range 13 to 35 degrees by varying the process condition. For 66 nylon the orientation angle ranges from 13 to 40 degrees and for polyethylene terephthalate homopolymer orientation angles are obtained in the range 24 to 50 degrees. The basic-dyeable polyethylene terephthalates obtained by copolymerization of terephthalate esters with sulfoisophthalic esters likewise deorient in this bulking process, and orientation angles of 22 to 50 degrees are obtained. Yarns from crystallizable polymers have greatly increased crystallinity after treating in the hot turbulent jet.

The surprising feature in the bulky yarns of this invention is the combination of high bulk, high tenacity and low orientation (high orientation angle). Other known processes (e.g., British Patents 684,046 and 735,171) give high tenacity even though the filaments are deoriented, but these other processes result in yarns with filaments stuck together, with no crimp, and without the random S and Z twist of filaments of this invention.

If the overfeed is kept low enough at any given set of processing conditions, uncrimped yarns with random S and Z filament twist may also be obtained by the process of this invention. These uncrimped yarns are superior to other heat-relaxed yarns since, in addition to the novel twist, the filaments do not stick together, and they have very high dye rates and high tenacity.

Additional information may be obtained by studying low-angle X-ray patterns by the method of W. O. Statton (J. Polymer Sci. 22, 385 (1956), "Crystallite Regularity and Void Content in Cellulosic Fibers as Shown by Small Angle X-Ray Scattering"). The low-angle pattern shows a higher amount of crystallite placement regularity in the bulked yarns of this invention compared to the feed yarns.

At the same time there is a great increase in the size of the long period. A typical steam-bulked 6–6 nylon yarn, for example, had a long period of 98 A. while the feed yarn had a long period of only 86 A. Higher temperatures and longer exposures to hot fluids in the jets give greater long periods. It is preferred that the treated yarn have a long period at least 4 A. greater than the feed yarn. By the process of this invention, filaments of various polymers having long periods in the following ranges are obtained. 66 nylon, 75–100 A.; polyethylene terephthalate, 95–140 A.; 6 nylon, 80–110 A.; copolymers of polyethylene terephthalate, 95–140 A.

According to this invention there are produced filaments having outstanding tenacity and very high dyeability, for example, poly(hexamethylene adipamide) having a long period of at least 90 A., a tenacity (T_1) of at least 3.0 and an orientation angle of at least (23.5–1.4; T_1) poly(epsilon caproamide), said filament having a long period of at least 92 A., a tenacity (T_2) of at least 2.5 and an orientation angle of at least (23.5–1.4 T_1); poly(ethylene terephthalate), said filament having a long period of at least 110 A., a tenacity (T_3) of at least 1.0 and an orientation angle of at least (47–4.0 T_3); and copolymers of ethylene terephthalate containing less than about 10% combined monomers other than ethylene terephthalate and copolymerizable with ethylene terephthalate, said filament having a long period of at least 110 A., a tenacity (T_4) of at least 1.0 and an orientation angle of at least (28–2.3 T_4).

The following examples illustrate filaments of this invention and methods for preparing them. It is to be understood that while they illustrate the use of certain synthetic polymeric yarns having certain cross sections these may be substituted by any other polymeric yarn or filament herein disclosed having any cross section such as circular, square, rectangular, flat, star-shaped, or those having three or more cusps and similar shapes. Likewise the denier, speed, temperature, take-up speed, and other considerations may vary widely within the limits given above.

All of the filaments of this invention illustrated in the following examples have completely random S and Z twist as described heretofore, and all the bulky yarns contain filaments which have both random S and Z twist and in addition have a random, persistent, three-dimensional, non-helical curvilinear crimped configuration continuously along the filament length as described above.

EXAMPLE I

Three ends of a 1000 denier-68 filament-zero twist-bright 6–6 nylon (round filament cross section) were passed simultaneously through the jet of FIGURE 2 using the process of FIGURE 1. The yarn passed over a feed roll at 110 y.p.m. just before entering the jet. It was bulked with turbulent superheated steam in the jet at 500° F., the steam pressure being 45 p.s.i.g. As it emerged from the jet, it passed over a take-up roll at 76 y.p.m. so that the overfeed rate was 40%. The yarn was cooled in the surrounding air, and collected as a piddle cake. The above feed yarn was obtained by cold drawing 6–6 nylon 400% (5×). Additional 1000 denier feed yarns were obtained by drawing specially prepared yarns at lower draw ratios (4×, 3×, 2.5×, and undrawn). Each of these 1000-denier feed yarns was steam bulked under the same conditions as described for the 5× drawn yarn above. The treated yarn properties are given in Table II. The undrawn yarns tended to draw in the turbulent steam rather than contracting; the bulked undrawn yarns, therefore, had high filament crimp elongation but the denier decreased. The unusual combination of high tenacity and high dye rate for a jet-bulked product is shown in Table I. The dye rate of the bulked yarn is many times faster than the dye rate of a 2.5× drawn feed yarn, but the tenacity is still almost equivalent to that of a 5× drawn feed yarn.

Table I

DYE RATES AND PHYSICAL PROPERTIES OF 6–6 NYLON YARNS

Draw ratio and type of yarn	Percent acid dye absorbed in 10 minutes at 140° F.	Properties of boiled off filaments		
		Tenacity, g.p.d.	Elongation at break, percent	Modulus, g.p.d.
2.5× feed yarn	0.53	3.7	135	28
3× feed yarn	0.34	4.3	103	30
4× feed yarn	0.21	5.4	67	29
5× feed yarn	0.25	7.8	63	38
5× steam bulked	1.43	7.3	73	20

Table II

EFFECT OF DRAW RATIO ON STEAM BULKING OF 6–6 NYLON YARNS [1]

Draw ratio of feed yarn	Bulked yarn denier			Yarn denier increase, percent		Filament crimp elongation, percent	
	Piddled	After tensioning	After tens. and boil-off	Piddled 40% overfeed	After tens. and boil-off	Piddled	After tens. and boil-off
1×	4,617	4,610	4,898	54	63	75.1	67.3
2.5×	4,468	4,468	5,058	49	69	32.1	42.9
3.0×	4,538	4,538	5,310	51	72	30.4	53.5
4.0×	4,720	4,720	5,517	57	80	36.0	59.1
5.0×	4,380	4,380	4,905	46	64	37.3	66.4

[1] All yarns were run with 3 ends of 1000 denier through jet. Total feed yarn denier was therefore 3000. All yarns were run with 40.5% machine overfeed, at 500° F., 45 p.s.i.g., and 110 y.p.m. feed speed.

Bulked yarns having high filament break elongations tended to pill readily in carpets as shown in FIGURE 10. The pilling index is a number which was determined by subjective rating using a test panel. An index of 5 is completely unacceptable, index of 3 is borderline acceptable, and index of 1 indicates no pilling. The carpet samples were tested together in a tumble-pilling device (a converted home laundry dryer) for 20 hours using wooden blocks and pieces of rubber sheeting to give the pilling action. The test was run at room temperature. The ratings shown in FIGURE 10 indicate that elongations greater than 200% gave unacceptable carpets. Similar pilling tendencies were noted for yarns of high elongation in knitted, woven materials, and other constructions. Yarns having low filament break elongation, on the other hand, gave fabrics with little or no pilling. The preferred non-pilling yarns had break elongation less than 200%.

EXAMPLE II

A number of bulked yarns were prepared from 4× drawn 6–6 nylon. The processing conditions were adjusted to give a wide range of useful bulked products. The effect of processing conditions on the geometry of the bulked products is shown in Table III. At low overfeeds, the increase in yarn denier (after exercise and boil-off) was greater than the machine overfeed. For example, 37% machine overfeed gave a boil-off yarn denier increase of 89%. At high overfeeds, the actual yarn denier increase tended to be less than the machine overfeed because of the unstable loops which pulled out when the yarn was exercised. At higher speeds the crimps per inch developed in the process was less than at low speeds (Nos. 5 and 6). Single ends or triple ends were passed through the jet with equal success (Nos. 7 and 8). Higher pressures tended to give higher crimps per inch because of the greater throughput of heat in the jet. Monofilament was easily processed through the system as shown in No. 10. Hot air was equally effective and produced good bulk yarns as shown in No. 11. The superior bulking quality of Y over round cross section is shown in No. 12 and No. 13. The yarn with Y cross section increased 99% in denier while the yarn with round cross section increased only 67%. The percents increase in filament denier in Nos. 4, 7, 8, 12, and 13 are 38, 70, 29, 11, and 7, respectively. Birefringence patterns for items 7, 8, 9, 10, and 12 show lines of constant retardation parallel to the axes of these filaments throughout the filament lengths. These products when viewed under reflected light in a non-polarizing microscope are seen to be free from cross-sectional distortions throughout their lengths, that is, there were no grooves, dents, or bulges.

Table III

EFFECT OF PROCESSING CONDITION ON GEOMETRY OF BULKED YARNS FROM 4× DRAWN 6–6 NYLON

[All feed yarns were BR* luster except as noted]

Feed yarn				Processing conditions					Bulked product (after tensioning and relaxed boil-off)			
Yarn [1] denier/end	No. of fils.	Twist	Cross section	Jet fig.	Machine overfeed, percent	Feed speed, y.p.m.	Temp., ° F.	Press., p.s.i.g.	Bulked yarn denier	Percent increase in yarn denier	Fiber crimp elong., percent	Crimps/in.
2,300	158	0	"Y" (2.2MR)*	2	37	200	603	108	4,340	89	59	10.7
2,300	158	0	"Y" (2.2MR)	2	100	200	610	108	5,169	125	110	11.1
2,300	158	0	"Y" (2.2MR)	2	150	200	610	108	5,188	126	115	12.9
2,300	158	0	"Y" (2.2MR) [4]	1	100	50	460	110	6,945	202	131	16.5
2,000	138	0	"Y" (2.2MR)	2	100	200	575	85	4,729	137	86	14.9
2,000	138	0	"Y" (2.2MR)	2	100	400	600	85	4,071	104	82	9.8
780	51	0.75Z	R*	1	100	50	460	100	1,760	126	53	19.6
780 [2]	51	0.75Z	R	1	100	50	450	100	5,979	158	101	18.2
1,000 [2]	68	0	R	2	40.5	110	500	45	4,660	55	37	8.9
15	†1	0	R	1	75	50	580	90	‡18.3	22	110	18.0
2,000	136	0.5Z	"Y" (2.2MR) [4]	1	76	50	353	[3] 85	5,395	170	152	21.0
1,000 [2]	68	0.4Z	R	2	41	110	500	45	5,022	67	59	7.9
1,000 [2]	68	0.4Z	"Y" (2.2MR) [4]	2	41	110	500	45	5,975	99	116	11.1

[1] A single end of yarn was used in all cases except as noted.
[2] Three ends of this yarn were used.
[3] Air was used as the turbulent fluid.
[4] These feed yarns were SD* Luster.
*MR means modification ratio. R means round. BR means bright. SD means semi-dull.
† Monofil. ‡ D.p.f.
All entries were prepared using steam as the turbulent fluid except as noted.

EXAMPLE III

A number of different polymeric synthetic yarns were processed as shown in Table IV. In each case a bulky product was obtained. Some of the yarns had unstable loops which were pulled out by exercising, but the individual filaments when removed from the yarn had crimp which was stable outside of the yarn bundle. The considerable increase in bulk which was obtained is shown by the increase in yarn denier and fiber crimp elongation in Table IV.

All of the bulked yarns had filaments with random, three-dimensional, non-helical, curvilinear crimp, which was independent in each filament in that it did not coincide with adjacent filaments.

Table IV

PROCESSING CONDITIONS AND CHARACTERISTICS OF BULKED YARNS PREPARED FROM A VARIETY OF SYNTHETIC POLYMERIC FIBERS

Feed yarn					Processing conditions					Bulked product (as produced)				
Polymer	Yarn den. 1 end	No. of of fils.	Twist	Den. per fil.	Jet of fig.	Mach. over feed, percent	Feed speed, y.p.m.	Temp., ° F.	Press., p.s.i.g.	Bulked yarn den.	Percent inc. in yarn den.	Den. per fil.	Fiber crimp elong., percent	Crimps per inch
1. Polyethylene terephthalate	1,100	250	0	4.40	1	50	110	495	90	1,620	47.3	4.44	43.5	9.2
2. Polyacrylonitrile	{3× 100}	40	0.3Z	2.50	1	26	38	408	48	378	26.0	2.58	52.5	10.1
3. Cellulose acetate	1,800	88	25	20.4	1	60	200	400	80	2,686	29.0	18.9	47.5	9.8
4. Viscose	2,700	150	0	18.0	1	97	50	415	95	3,384	24.0	17.5	36.5	7.2

1. A single end of yarn was used in each entry except entry 2 in which case three ends of this yarn were used.
2. The feed yarns in entries 1 and 2 were SD Luster and in entries 3 and 4 the feed yarns were B R Luster.
3. All entries were prepared using steam as the turbulent fluid.

EXAMPLE IV

The superior bulk of steam bulked yarns in carpets was demonstrated by preparing carpets with staple yarn and carpets with steam bulked yarn in which the polymer was 6–6 nylon. A three-ply cotton-system staple yarn prepared from 15 d.p.f. nylon was tufted to prepare carpets having several different weights of yarn in the pile (depending upon number of stitches per inch). All carpets had 0.43" pile height. Similarly, steam-bulked yarns were put into tufted carpets. The steam-bulked yarn was prepared from one end of 2000 denier-136 filament-.38Z-round-bright-6–6 nylon using 100% overfeed, 200 y.p.m., 575° F., and 90 p.s.i.g. The work required to compress carpets of the steam-bulked yarn and of staple yarns to 10 p.s.i. was determined using an Instron testing machine. The work required to compress 4-square-inch areas of staple carpets of various weights and steam bulked carpets of various weights is shown in FIGURE 11. The steam-bulked yarns were much firmer to the hand in carpets of identical weight and this observation was confirmed by the Instrom tests. Consequently, carpets with 25% to 30% less yarn were needed for steam-bulked continuous-filament yarns to get the same performance as staple carpets. In FIGURE 11, Curve A shows the work required to compress carpets of various weights prepared from staple yarns. The "Total take-up" in FIGURE 11 is the weight of tufted yarn in a square yard of fabric and does not includ the jute backing. Curve B shows the work required to compress steam-bulked continuous-filament yarns in carpet.

EXAMPLE V

Item A.—840–140–½Z bright nylon yarn was processed with a jet having a needle and venturi as in FIGURE 2. An overfeed of 44.6%, a feed speed of 150 y.p.m., a steam temperature of 440° F., and a steam pressure of 85 p.s.i.g. were used.

Item B.—840–140–½Z bright filament nylon unbulked control yarn.

These two yarns were knit on a 6-cut circular knitting machine (Jacquard) using a half-cardigan stitch. Fabric was finished by scouring at the boil for 15 minutes in a

detergent solution followed by rinsing and drying in a hot-air tumble drier.

Fabric properties are tabulated in Table V.

Table V

	Item A	Item B
Courses on machine (per inch)	3.5	5.0
Gray fabric construction (courses and wales)	6.1 x 4.0	7.5 x 5.0
Finished fabric construction (courses and wales)	8.1 x 3.8	8.3 x 5.5
Finished fabric weight (oz./yd.^{2})	10	16
Bulk (cm.^{3}/g.)	10.3	4.9
Fabric thickness (inches)	0.138	0.104
Opacity, IR (percent light reflected)	81	63
Opacity, IT (percent light transmitted)	6	25

Item A shows a marked improvement over Item B in bulk and opacity. The fabric has a pleasing, wool-like hand and is scroopy and resilient in hand as compared with the unattractive hand of the control.

EXAMPLE VI

A bulk yarn was prepared from 2700 denier-180 filament-zero twist 66-nylon by passing the yarn through the jet shown in FIGURE 2, using steam at 515° F., the yarn being fed at 200 y.p.m. and with an overfeed of 100%. This yarn was put into an upholstery construction. The backing yarns were high twist 20/2 cotton. The filling yarns were 12/2 cotton. The weaving construction was 18.7 pile ends per inch, 56 back ends per inch, 17 picks per inch, and the reed width was 55½ inches. The gauge wire was 0.10 inch. A similar upholstery material was prepared from the uncrimped yarn. This unbulked material required 21 picks per inch to get the same optical cover as was obtained using the bulk yarn.

EXAMPLE VII

A nylon tow of 80,000 denier and 20,000 filaments was fed at 2 yards per minute to a jet similar in cross section to FIGURE 2. This jet, however, was elongated in a direction perpendicular to the plane of the cross section so that the yarn opening **119** was a slot four inches wide, and orifice member **117** was provided with an orifice in the shape of a similar slot, likewise four inches in width. The orifice angle was 30°. The tow was fed to the jet in a flattened ribbon form so that all parts of the yarn opening and jet orifice were filled in a substantially uniform fashion. The turbulent fluid was 70 p.s.i.g steam, heated to 550° F. The bulked tow had a relaxed denier of about 150,000. Filaments removed from the tow showed an average FCE (filament crimp elongation) of 86% and a fine uniform crimp of 22 crimps per inch. It showed a fabric-like cohesiveness in both lengthwise and widthwise directions. Although the process rate in this example was low (2 yards per minute), the high denier (80,000) was such as to give reasonable productivity expressed in denyards/minute which is the product of denier times yards/minute. In this instance the productivity was 160,000 denyards/minute.

EXAMPLE VIII

A 15-denier 66-nylon monofilament yarn prepared at a feed speed of 50, an overfeed of 76%, using steam at a pressure of 90 p.s.i. at a temperature of 580° F., was knit into a full-fashioned sheer hose using a 60-gauge knitting machine set at 50 courses per inch. A similar hose was constructed of the unmodified monofilament. The garment made from the modified monofil showed a subtle crepe-like txeture and a subdued luster. It also showed a moderate amount of stretchiness, improved form fitting characteristics, and freedom from bagging at the knee as compared with the unmodified control.

EXAMPLE IX

Two ends of polyhexamethylene adipamide yarn were bulked simultaneously in the jet shown in FIGURE 1 using steam at three different temperatures. The yarn was 780 denier-51 filament-0.75Z twist bright nylon with round filament cross section. Each sample was fed into the jet at 108 yards per minute, and the steam pressure was maintained at 85 p.s.i. Each of the jet-processed yarns had definite curvilinear crimp in the filaments. A description of these yarns and the processing conditions are given in Table VI. The tenacity decreased slightly to 5 grams per denier in the most rigorous treatment. At the same time, the dye rate with an acid dye (Du Pont Anthraquinone Blue SWF) increased from 0.42% in 10 minutes for the feed yarn to 1.43% for the 450° F. bulked yarn. The orientation angles increased from 13.0 degrees to 20.8 degrees as the temperature increased to 450° F. Other samples of the same feed yarn were treated by immersing in water for 15 minutes at 275° F. or 325° F. in a sealed autoclave. There was a drastic reduction in tenacity to 1.4 grams per denier in the autoclaved sample prepared at 325° F. The dye rate for the autoclaved yarn increased to 1.20% for the sample treated at 325° F. The autoclaved yarns had no crimp even though the orientation angle increased greatly. The data show that the yarns of this invention have the rare combination of high tenacity and high dye rate. At the same time, these yarns may be produced with curvilinear crimp. The amount of crimp and the dye rate each increased as the jet temperature increased. The data from this experiment are shown graphically in FIGURE 9 where line A represents autoclaved yarn and line B refers to bulked yarn prepared in a steam jet.

Table VI

Yarn treatment	Dye rate acid dye (percent absorbed in 10 min. at 140° F.)	Filament tensile properties (boiled off)				Orientation [1] angle, deg.
		Ten., g.p.d.	Elong., percent	Mi, g.p.d.	Denier per filament (d.p.f.)	
Feed yarn	0.42	6.0	36	29	15.8	13.0
Jet, 275° F., 40% overfeed	0.55	6.5	38	25	15.7	13.3
Jet, 325° F., 40% overfeed	0.71	7.1	45	24	15.3	14.4
Jet, 450° F., 100% overfeed	1.43	5.0	98	8.5	19.7	20.8
Autoclave, 275° F., 15 minutes, H_2O	0.83	5.7	108	26	14.8	14.4
Autoclave, 325° F., 15 minutes, H_2O	1.20	1.4	23	21	18.7	18.6

[1] Measured using 100 diffraction spot.

EXAMPLE X

A single end of a continuous-filament poly(epsilon-caproamide) yarn was bulked under several different conditions using steam in the jet of FIGURE 2. The feed yarn was 4200 denier-224 filament-zero twist bright yarn. Each of the yarns was processed with 200-yards-per-minute feed speed and 80 p.s.i. steam pressure. Additional processing data and description of the product are shown in Table VII. Each of the jet processed yarns was crimped, but the most desirable crimp was obtained at the highest temperature. The data show again that tenacity was maintained at a relatively high level as the dye rate increased. When the same feed yarn was autoclaved at 275° F., a much lower tenacity was obtained at a comparable dye rate. At still higher autoclave temperatures, such as 325° F., the yarn melted. It was not possible to obtain strong yarns in the autoclave with dyeability similar to that of the 460° F. or 530° F. jet-bulked yarns.

Table VII

Yarn treatment	Dye rate acid dye (percent absorbed in 10 min. at 140° F.)	Filament tensile properties (boiled off)				Orientation [1] angle, deg.
		Ten., g.p.d.	Elong., percent	Mi, g.p.d.	Denier per filament (d.p.f.)	
Feed yarn	0.74	8.1	40	27	18.8	12.0
Jet, 415° F., 75% overfeed	1.98	6.8	58	14	20.5	13.3
Jet, 460° F., 75% overfeed	2.14	6.4	80	10	22.5	----------
Jet, 530° F., 125% overfeed	2.21	3.8	128	7.9	27.2	18.9
Autoclaved 275° F., 15 minutes, H_2O	1.79	5.9	56	15	20.9	11.3

[1] Measured using 100 diffraction spot.

EXAMPLE XI

A single end of continuous-filament yarn spun from polyethylene terephthalate was bulked using the jet of FIGURE 1. The feed yarn was a 70-denier-34 filament-zero twist semi-dull yarn with round filament cross section. Each of the yarns was processed as indicated in Table VIII, using 500 yards per minute feed speed and 55 p.s.i. steam. Only moderate crimp was obtained at 500° F., but at the higher temperatures shown, 610° F. and 660° F., excellent crimp was obtained, and the dye rates were very greatly increased. The bulked yarns were dyed with Latyl Violet BN, a dispersed dye, in the absence of carrier. Autoclaved samples, on the other hand, had greatly reduced dye rate after treatment at 275° F., 325° F., or 350° F. as indicated in Table VIII. The orientation angles increased for the autoclaved yarns and for jet-treated yarns, but only the jet-treated yarns had the combination of good crimp, high dye rate, and high tenacity. The jet of FIGURE 1 is described in detail by John N. Hall in U.S. Patent No. 2,958,112.

Table VIII

Yarn treatment	Dye rate dispersed dye (percent absorbed in 10 min. at boil)	Filament tensile properties (boiled off)				Orientation [2] angle, deg.
		Ten., g.p.d.	Elong., percent	Mi, g.p.d.[1]	Denier per filament (d.p.f.)	
Feed yarn	1.02	4.7	48	59	2.2	25
Jet, 500° F., 42% overfeed	1.06	4.2	75	33	2.5	24.1
Jet, 610° F., 80% overfeed	1.41	3.1	127	16	3.2	----------
Jet, 660° F., 125% overfeed	2.32	2.8	126	21	3.2	43.6
Autoclave, 275° F., 15 minutes, H_2O	0.25	4.8	60	55	2.2	----------
Autoclaye, 325° F., 15 minutes, H_2O	0.26	4.5	53	54	2.3	----------
Autoclave, 350° F., 15 minutes, H_2O	0.08	4.1	45	57	2.4	18.4

[1] Mi is initial modulus which is the slope of the straight line portion of stress-strain curves beyond the point of crimp removal (load in grams/denier vs. fractional elongation).
[2] Measured using 100 diffraction spot.

EXAMPLE XII

A modified poly(ethylene terephthalate) yarn having 2.0% sulfoisophthalic ester in the polymer was treated as shown in Table IX. The feed yarn was a single end of 70 denier-50 filament-zero twist semidull yarn having filaments with triangular cross section. All of the yarns were processed in the jet at 500 y.p.m. and 55 p.s.i. steam pressure. Moderately crimped filaments were obtained at the lower temperatures. Very highly crimped filaments were obtained from the jet treatment at 500° F. The bulked yarns were dyed with basic dyes and the dye rate increased very greatly for the 500° F. samples. This increase in dye rate was obtained without appreciable loss in tenacity. On the other hand, yarns which were treated in the autoclave, as shown in the table, had much lower dye rates and were not crimped.

Table IX

Yarn treatment	Dye rate basic dye (percent absorbed in 10 min. at boil)	Filament tensile properties (boiled off)				Orientation [2] angle, deg.	Long period, deg. A.
		Ten., g.p.d.	Elong., percent	Mi,[1] g.p.d.	Denier per filament (d.p.f.)		
Feed yarn	1.26	3.2	61	44	1.5	18.5	99
Jet, 300° F., 19% overfeed	0.90	3.3	52	48	1.6	22.7	98
Jet, 400° F., 35% overfeed	1.24	2.8	59	43	1.6	----------	----------
Jet, 500° F., 145% overfeed	2.50	2.6	91	25	2.0	24.7	122
Autoclave, 275° F., 15 minutes, H_2O	0.16	2.6	25	50	1.4	----------	----------
Autoclave, 325° F., 15 minutes, H_2O	0.66	2.0	16	59	1.4	15.1	102

[1] Mi is initial modulus which is the slope of the straight line portion of stress-strain curves beyond the point of crimp removal (load in grams/denier vs. fractional elongation).
[2] Measured using 100 diffraction spot.

EXAMPLE XIII

Filament yarn (70 denier-50 filament-zero twist, Y cross section) of poly(ethylene terephthalate) modified with 2.0% of a sulfonated derivative of isophthalic acid to provide dyeability with basic (cationic) dyes, was fed to a steam jet at 393 y.p.m. with an overfeed of 40% through a jet similar to FIGURE 1 of Hallden, Jr., et al., U.S. Patent No. 3,005,251. The steam supply to the jet was superheated to a temperature of 460° F. at a pressure of 71 p.s.i. The yarn was wound up at a speed of 280 y.p.m. The treated yarn picked up more than twice as much basic dye as the untreated yarn when dyed with Du Pont "Sevron" Blue 5G. The treated yarn, in fact, had 105% improvement in dye rate over the untreated yarn. There was no crimp in the jet processed yarn, but the individual filaments possessed random S and Z twist throughout their length. This improvement in dye rate achieved with the treated yarn is not specific to the conditions used in this given dyeing procedure. Numerous other basic dyes had equivalent improvement including Du Pont Brilliant Green Crystals, Du Pont Fuchsine, and "Sevron" Blue BGL. Similar improvements in dyeability have been achieved with fabrics prepared from the yarns using bath-to-fabric ratios as low as 15:1 and as high as 500:1.

EXAMPLE XIV

Two ends of a 1020 denier-68 filament-½Z twist-semi-dull 6–6 nylon (tri-lobal cross section) were passed simultaneously through the jet of FIGURE 2 using the basic process of FIGURE 1. The two ends of yarn were passed over individual feed rolls at 150 and 186 y.p.m. just before entering the jet. The combined ends were bulked with turbulent superheated steam in the jet at 550° F. The steam pressure was 70 p.s.i.g. As the composite yarn emerged from the jet, it passed over a take-up roll at 95 y.p.m. so that the overfeed rates for the two individual ends were 56% and 95%, respectively. The yarn was cooled in the surrounding air and collected as a piddle cake. The resultant product was a bulked yarn that when twisted to high twist-levels, for example, 7 turns per inch, exhibited much greater bulk than a comparable double-end structure processed at equal overfeeds.

EXAMPLE XV

A single end of 1800 denier-88 filament-zero twist bright cellulose diacetate yarn (Y cross-section filaments) was passed through the jet of FIGURE 1 using steam at 288° F. and 16 p.s.i.g. The feed speed was 150 y.p.m. and the overfeed was 40%. A highly bulked product was obtained. It was wound up on cones at 4 grams tension. The resulting product had a bulked yarn denier in the relaxed state of 2100, a yarn crimp elongation of 20%, and a tensioned yarn denier of 1750 (when loaded to 0.1 g.p.d.). The average number of crimps per inch in the filaments was 12, and the tenacity of the filaments was 0.8 g.p.d. The filaments had a very pronounced random twist, being alternately S and Z and having a random number of turns between twist reversals and random angles of twist. The total S and Z twist was about 20 turns per inch, which corresponds to an average twist angle of about 10°. There was at least one S turn and at least one Z turn per inch of filament which has a twist angle averaging at least 10°.

Filament twist may be easily determined using the American Optical Baker Interference Microscope using techniques specified by the manufacturer in the operating manual for this microscope. Several individual filaments are removed from a sample of yarn, mounted on clean microscope slides under only sufficient tension to hold the filaments substantially straight, and visually evaluated for twist at 30 to 150-power magnification (depending upon the size of filament) while traversing a measured distance along a filament. The number of full turns of S twist and of Z twist are counted, and the effective twist angle of each full turn is determined.

EXAMPLE XVI

Yarns of linear polypropylene were bulked using saturated steam in the jet of FIGURE 2. The processing conditions for three different yarns are shown in Table X. The properties of the feed yarns and of the bulked yarns are also shown. There was considerable filament shrinkage during processing. This is indicated by the tensioned yarn denier after bulking and the denier of the feed yarns. The long period increased in a manner similar to that of poly(hexamethylene adipamide) and poly(ethylene terephthalate). The filaments had random twist as described hertofore, and undistorted cross-section. The round filaments had uniform cross-sectional configuration throughout in that there were no dents or grooves in the filaments. On the other hand, conventional twist heat-set bulked yarns or stuffer-box yarns prepared from round filaments had a considerable amount of deformation in the surface of the fibers after bulking.

The filaments crimped in accordance with this invention had a random, three-dimensional, crimped configuration and a random alternating twist with effective twist angles in the full turns, measured as above, ranging from 4° to 18°. There was at least one S turn per inch and at least one Z turn per inch of filament having an effective or average twist angle of at least 5°.

Table X

BULKED LINEAR POLYPROPYLENE YARNS

	No. 1	No. 2	No. 3
Feed Yarns:[1]			
Number of yarn ends fed to jet	3	3	2
Denier per end	300	275	640
No. of filaments per end	20	23	23
Luster	Bright	Semi-dull	Semidull
Cross section	Round	Trilobal	Trilobal
Tenacity (g.p.d.)	4.5	5.7	5.4
Break elongation (percent)	120	35	40
Initial modulus (g.p.d.)	201	51	50
Long period (A.)	116	122	122
Processing conditions:[2]			
Steam temperature (° F.)	315	295	315
Steam pressure (p.s.i.g.)	65	40	65
Percent Overfeed	60	80	80
Bulked yarn:[3]			
Bulked yarn denier (BYD)	1,340	1,042	1,628
Tensioned yarn denier (TYD)	1,055	928	1,445
Yarn crimp elongation (YCE)	27	13	13
Crimps per inch	10	10	8
Tenacity (g.p.d.)	3.2	4.9	4.0
Break elongation (percent)	153	41	40
Initial modulus (g.p.d.)	12	29	19
Long period (A.)	130	130	130

[1] All feed yarns had zero twist; tensile properties are for boiled-off single filaments.
[2] All yarns fed to jet at 150 y.p.m.
[3] Tensile properties are for boiled-off single filaments.

EXAMPLE XVII

Heavy denier poly(hexamethylene adipamide) yarns were processed using the conditions described in Table XI. The process depicted in FIGURE 1 was modified by using two canted rolls in place of feed rolls **33** and **34**. These rolls were used to heat the yarn before it passed into the jet. The rolls had an average diameter of 3½ inches and were separated slightly. The feed yarn followed a figure-eight pattern around the two rolls. There were 4 to 7 wraps around each roll as indicated in the table, the rolls being heated in an air chest which was provided with electrical resistance heaters. The yarns were passed through an impingement type jet similar to the one described and shown in FIGURE 1 of Hallden et al., United States Patent No. 3,005,251.

Superheated steam was fed into the jet from a manifold which completely surrounded the jet except for the feed and exit ends. In one process a single end of 1020 denier-68 filament-0.5Z twist-semi-dull nylon with trilobal cross section in the filaments was used to prepare a bulked yarn having a tensioned yarn denier of about 1300. In operating continuously over a period of several days, the tensioned yarn deniers fell within the range 1298 to 1336. Other property ranges are shown in Table XI. By a similar process, three ends of the 1020 yarn were passed through a jet of similar construction. The tensioned yarn denier of this product was about 3700. Over a period of time the range was 3644 to 3753. The above yarns were wound on cones rather than being piddled to the cans described in FIGURE 1. The coning tensions were 50 to 150 grams for the 1300-denier product and 75 to 225 grams for the 3700-denier product. Specific volumes as determined by the cylinder bulk test described heretofore ranged from 8.1 to 8.5. On the other hand, poly(hexamethylene adipamide) staple yarns had specific volumes of 5.6, and continuous filament stuffer box yarns had specific volumes of 6.5 to 7.3. Furthermore, these filaments did not have the random twist of the jet processed yarns described here. The jet-bulked yarns were found to be very excellent carpet yarns, and much less yarn was required with the jet-bulked yarns than with staple yarns to prepare a carpet with good resistance to compression. Carpets of poly(hexamethylene adipamide) staple required at least 25% more yarn to produce carpets of similar compressional quality. The above process may be modified by using bright yarns instead of semi-dull yarns. These bright yarns provide bulked products which are excellent upholstery yarns.

The yarns of this example had pronounced random varying alternating S and Z filament twist. A total of 7 to 10 turns S and Z twist per inch of filament were measured by visual examination as in Example XVI. The angles of separate turns of twist were in the range of 4° to 40°, with an over-all average twist angle of about 9°. Hence, the angle of filament twist was highly erratic random, completely independent of yarn bundle twist. The angle varied randomly and continuously along the filament length with a random number of twist reversals per inch and a random number of turns between twist reversals. There was at least one S turn and at least one Z turn per inch having an average twist angle in excess of 5°.

Table XI

BULKED HEAVY DENIER 6-6 NYLON

	No. 1	No. 2
Feed yarn: [1]		
Number of yarn ends fed to jet	1	3
Denier per end	1,020	1,020
No. of filaments per end	68	68
Twist per end	0.5Z	0.5Z
Luster	Semi-dull	Semi-dull
Cross section	Trilobal	Trilobal
Tenacity (g.p.d.)	4.8	4.8
Break elongation (percent)	72	72
Initial modulus (g.p.d.)	21	21
Dyeing rate (percent/10 min.)	0.65	0.65
Long period (A.)	73	73
Processing conditions: [1]		
Preheater, number of wraps on each end	7	4
Preheater temperature (° F.)	410	350
Feed speed (y.p.m.)	380	250
Manifold temperature (° F.)	509	473
Manifold pressure (p.s.i.g.)	95	65
Percent overfeed to takeup roll	81	85
Takeup roll speed (y.p.m.)	210	135
Coning speed (y.p.m.)	241	155
Coning tension (grams)	50–150	75–225
Bulked yarn: [1]		
Bulked yarn denier (BYD)	1,940–2,020	5,038–5,903
Tensioned yarn denier (TYD)	1,298–1,336	3,644–3,753
Yarn crimp elongation (YCE), percent	50–51	38–57
Crimps per inch	19–21	15–18
Tenacity (g.p.d.)	3.0–3.1	3.3
Break elongation (percent)	78–93	65–67
Initial modulus (g.p.d.)	6.2–5.6	8.3–9.0
Dyeing rate (percent/10 min.)	1.78–1.97	1.46–1.51
Specific volume (cc./g. at 3.1 p.s.i.)	8.1–8.5	8.3–8.4
Long period (A.)	92–93	83–87

[1] Tensile properties are for single filaments, boiled-off.

EXAMPLE XVIII

Another modification of the process of FIGURE 1 consisted of impinging the yarn, as it emerged from the jet, on a moving screen. The moving screen was traveling at a much slower speed than the yarn as it emerged from the jet. As the yarn moved away from the jet on the moving screen, it cooled and the crimp became very stable. After the yarn had traveled far enough on the moving screen to have cooled adequately, it was passed over a takeup roll as in FIGURE 1 and then to a windup. Yarns which were bulked by this process included poly(hexamethylene adipamide), basic dyeable poly(ethylene terephthalate) copolymers having 2 to 3½ mol percent of the sodium salt of poly(ethylene sulfoisophthalate), and a polyester of trans-1,4-bis(hydroxymethyl)cyclohexane and terephthalic acid. The bulking of these yarns is described in Table XII. The denier of the starting yarn and the tensioned yarn denier of the products indicated that filament shrinkages were at least 12% in all of the products.

Table XII

BULKED YARNS FROM JET AND SCREEN PROCESS

	No. 1	No. 2	No. 3	No. 4	No. 5
Feed Yarn:					
Polymer	[1] 6-6	[1] 6-6	[2] 2GT/SI (.98/.02)	[2] 2GT/SI (.965/.035)	[3] HPXGT
Denier	40	70	70	78	150
Number of filaments	13	34	50	50	34
Twist	0.5Z	0.5Z	0	0	0.5Z
Luster	Semidull	Semidull	Semidull	Semidull	Semidull
Cross section	Trilobal	Trilobal	Trilobal	Trilobal	Round
Tenacity (g.p.d.) [4]	4.9	6.2	3.2	2.3	3.2
Break elongation (percent) [4]	44	54	61	26	12
Initial modulus (g.p.d.) [4]	14.5	14.7	44	------	51
Dyeing rate (percent/10 min.)	1.05	[5] 1.45	[6] 1.26	[6] 3.35	------
Long period (A.)	75	80	99	------	------
Processing conditions:					
Feed speed (y.p.n.)	1,000	566	1,000	1,039	633
Steam temperature (° V.)	550	556	500	427	580
Steam pressure (p.s.i.g.)	40	38	50	50	50
Yarn speed on screen (y.p.m.)	40	33	45	33	40
Takeup roll speed (y.p.m.)	750	388	570	771	503
Percent overfeed, feed roll to takeup roll	33	47	75	34	26
Windup speed (y.p.m.)	790	407	594	810	557
Bulked yarn (boiled-off):					
Bulked denier (BYD)	72	112	170–190	113	228
Tensioned denier (TYD)	48	80	110–120	95	188
Crimp elongation (YCE), percent	50	40	25–30	18	15
Crimps per inch	31	25	18–22	13	12
Tenacity (g.p.d.)	4.5	4.3	3.0	1.7	1.8
Break elongation (percent)	65	70	50	46	38
Initial modulus (g.p.d.)	8.8	11.8	29	------	8.3
Dyeing rate (percent/10 min.)	[5] 3.15	[5] 2.57	[6] 3.55	[6] 4.00	------
Specific volume (cc./g. at 3.1 p.s.i.)	6.5	6.5	8.5	7.4	------
Long period (A)	89	96	146	------	------

[1] 6-6 is poly(hexamethylene adipamide).
[2] 2GT/SI is a copolymer of poly(ethylene terephthalate) and the sodium salt of poly(ethylene sulfoisophthalate). the mole fraction of the respective constituents being indicated in parentheses.
[3] HPXGT is the polyester derived from trans-1,4-bis-(hydroxymethyl)cyclohexane and terephthalic acid.
[4] Single filaments, boiled-off.
[5] Acid dyeing rate.
[6] Basic dyeing rate.

EXAMPLE XIX

A fiber of a polymer of acrylonitrile having 93.65% by weight acrylonitrile, 5.98% methylacrylate and 0.37% styrene sulfonic acid was bulked using the jet of FIGURE 1. The feed yarn was 900 denier-80 filament-0.3Z twist-semi-dull fiber with dogbone-shaped cross section in the filaments. The boiled-off tensile properties of single filaments before bulking were as follows: 3.1 g.p.d. tenacity, 34% elongation, and 33 g.p.d. initial modulus. This yarn was processed using the screen described in Example XVIII. The steam temperature in the jet was 510° F. and the pressure was 75 p.s.i.g. The yarn passed into the jet at 495 y.p.m. and impinged on the screen as it emerged from the jet. The yarn was carried along the screen at 30 y.p.m. for about 24 inches. Then the yarn was continuously removed from the screen and passed over a takeup roll at 305 y.p.m. Finally, the yarn was collected by piddling. The overfeed from the feed roll to the takeup roll was 62%. The product was a very bulky yarn having bulked denier of 1848, a yarn crimp elongation of 48%, a tensioned yarn denier (at 0.1 g.p.d.) of 1249, and having 11 crimps per inch in the filaments. The boiled-off filaments had a tenacity of 2.7 g.p.d., 33% elongation at break, and an initial modulus of 35 g.p.d. The excellent bulk of this product was demonstrated in the cylinder bulk test. Before boil-off, the yarn bulk was 13.2 cc. per gram, and after boil-off, the yarn bulk was still 10.8 cc. per gram.

EXAMPLE XX

A yarn of a polyester copolymer of 98 mol percent poly(ethylene terephthalate) and 2 mol percent of poly(ethylene sulfoisophthalate), previously designated as 2GT/SI, with filaments of trilobal cross-section about 1.9 modification ratio was melt-spun and drawn on heated rolls, at about 330° F. in an air chest. The drawn yarn was delivered from the draw rolls at speeds in excess of 1000 y.p.m. to a jet device in which two streams of air at about 65 p.s.i.g. and 570° F. and impinged upon the traveling threadline in its pasasgeway. The fluid stream served to pull the yarn from the draw rolls, heat the yarn, whip the filaments randomly about, and deposit the yarn on a slowly moving screen surface. The treated yarn was allowed to cool in a tensionless state on the moving surface and was then withdrawn to a windup.

The continuous-filament yarn passing from the draw rolls to the treating jet was 83-denier 50-filament yarn with about 3.0 g.p.d. tenacity and 38% break elongation. The net rate of overfeed to the jet was 50%. The treated yarn was 125 denier with about 1.7 g.p.d. tenacity and approximately 70% break elongation. The treated yarn was bulky, with random, three-dimensional crimped configuration of the filaments. The yarn, however, was highly interlaced and coherent, having a coherency factor about 56.

The individual filaments had alternate S and Z twist throughout the treated length, with a random number of twist reversals per inch and a random number of turns of twist between reversals and at least one S and one Z turn per inch of over 5° average angle. By microscopic examination of filaments, for example, an average of 7 full S twists and 5 Z twists per inch were observed along the lengths of filaments.

The dye rate increased from 1.4 (percent per 10 min.) to 3.68% as a result of the fluid treatment. Therefore, the dye rate-tenacity relationship D_sT_s/D_0T_0 equalled 1.45.

Fabrics woven from the bulked yarn had a dry pleasing hand, less tendency toward pickiness and pilling, and lower fabric shrinkage than fabrics of untreated yarn.

EXAMPLE XXI

A continuous multi-filament 66 nylon yarn was melt-spun and continuously drawn on rolls in an air chest heated to about 435° F. The yarn was composed of 34 filaments of trilobal cross-section with 1.9 modification ratio. The drawn heated yarn was fed at high speed to a jet in which the filaments were impinged with an air stream at 95 p.s.i.g. and 580° F. The treated yarn was discharged onto a slowly rotating screen wheel, allowing the filaments to separate from the air stream, where it was conveyed in a tensionless state before being withdrawn to a package take-up at a speed in excess of 1000 y.p.m. The yarn overfeed to the jet was of the order of 14%.

The treated yarn had a crimpy bulk. The denier was 85 and the acid dyeing rate was 2.79 (percent/10 min.), almost 100% greater than the 1.40 dyeing rate of the drawn yarn fed to the jet. The filaments were interentangled, as evidenced by a coherency factor of approximately 8. The individual filaments were highly twisted, with approximately 4 S and 3 Z turns, of at least 5° twist angle, per inch of length.

The extent of filament twist does not appear to be significantly affected by filament size, a 105–10 nylon yarn bulked under conditions described above having approximately 4 S and 8 Z twists, of at least 5° twist angle, per inch of length. The larger filaments, however, were interentangled to a lesser degree, the yarn having a coherency factor of 2.

When further treated by the interlacing process disclosed in Bunting and Nelson U.S. Patent No. 2,985,995, the bulky yarn bundle was rendered more coherent by more intimate intermingling of the filaments without affecting their crimp and twist. The coherency factor of the 85-denier yarn was increased to 15 by this treatment and the 105 yarn was increased to factors in the range 10 to 40. The interlacing treatment of the yarn imparted improved performance in textile operations and increased abrasion resistance in woven fabric.

EXAMPLE XXII

Continuous filament yarns of 66 nylon with filaments of trilobal cross-section were melt-spun and drawn on heated rolls in an air chest at about 420° F. The filaments passed continuously from the drawing zone at speeds in excess of 1000 y.p.m. to a fluid jet in which the filaments were subjected to the action of air at 420° F. and then discharged upon a slowly moving screen surface. After separation from the air stream and cooling in a tensionless state on the moving surface, the filaments were conveyed to a windup. The yarn was overfed to the jet at a rate about 22% greater than the takeup speed.

The properties of yarns A, B, and C which were processed under the above conditions are shown in Table XIII. The trilobal cross-sectional configuration of the filaments was unaffected by the fluid treatment although the filaments were individually twisted with random alternate S and Z twist portions.

In this example, the hot yarn from the drawing zone entered the crimping jet at substantially the treating temperature. This facilitated treatment at high speed and was also found to increase the resistance of the dyed product to fading in the presence of fumes. It is frequently desirable, especially when producing the products of this invention at high speed, for the feed yarn to be heated prior to introduction into the heated fluid stream, although this is not a requirement to produce the described filamentary structures.

Table XIII

	Yarn A	Yarn B	Yarn C
Feed Yarn:			
Number of filaments	204	68	68
Amine ends (equiv./10^6 g.)	40	13	75
Carboxyl ends (equiv./10^6 g.)	65	98	36
Yarn twist	0	0	0
Acid dyeing rate (percent/10 min.)	1.08	0.83	1.52
Bulked Yarn (as produced):			
Denier	3,700	1,300	1,300
Tenacity, g.p.d	3.2	3.2	3.0
Break elongation, percent	47	45	40
Initial modulus, g.p.d	5.8	7.0	6.9
Filament twist (number turns/in):			
"S"	7	7	9
"Z"	6	5	5
Coherency factor	45–75	----------	----------
Bulked Yarn (after boil-off):			
Crimp elongation (YCE), percent	68	100	110
Crimps per inch	14	15	18
Acid dyeing rate (percent/10 min.)	1.92	1.97	3.80
Increase in dyeing rate, percent	78	140	150

Yarn A comprised a bulky yarn with a coherent structure of intimately interentangled filaments with random irregular curvilinear three-dimensional crimp. The bulked yarn was particularly suited for the manufacture of carpets. The bulked yarn is unique in that the dyeing rate of the treated yarn is significantly greater than the untreated yarn and yet the resistance of the dyed yarn (particularly when disperse dyes are used) to fading in the presence of sunlight or chemical fumes (NO_2 or O_2) is substantially equivalent to the resistance of carpet yarns of staple fibers which have been produced by more costly mechanically crimping heat-setting and yarn spinning processes.

Yarns B and C demonstrate the ability to produce yarns with the desired degree of dyeability by appropriate choice of polymer composition. By a higher proportion of amine ends in the fiber-forming polyamide, the receptivity for acid dyes for the unbulked feed yarn and, in turn, the treated product is greatly enhanced, with all other tensile, bulk and other physical properties being retained. The differences in dye receptivity of yarns B and C, when woven into tufted carpeting in a predetermined pattern and dyed competitively in the piece, produce a distinctive and desirable tone-on-tone effect.

In addition to the polyamide yarns illustrated in the examples, other suitable yarn materials include the polyamides derived from meta xylene αα'diamine and adipic acid; para xylene αα'diamine and azelaic acid; 4,4'-methylene biscyclohexlamine and azelaic, sebacic or dodecanedioic acid; or hexamethylene diamine and sebacic acid. Poly(hexamethylene isophthalamide) may be employed as a homopolymer or as a copolymer with other polyamides. Vinyl polymers may be grafted to polyamides by means of irradiation to improve dyeability, soil resistance, antistatic properties or flame resistance.

Suitable polyester yarns, in addition to those already disclosed, include those of poly(hydroxypivalate), poly(ethylene-2,6-nathphalate), poly(tetrachloro diphenylol propane isophthalate), poly(diphenylol propane isophthalate), poly(ethylene terephthalate/bibenzoate), and poly(bicyclohexyldimethane bibenzoate). Polycarbonates may also be used.

The filaments may be modified with the conventional pigments, delustrants, fillers, antistatic agents, antioxidants, or other additives, and the polymers may be modified to adjust the affinity for various dyestuffs. Polyamides, for example, may be modified by the incorporation during polymerization of a diamine salt of an alkyl or aryl phosphinic acid such as the hexamethylene diamine salt of phenyl phosphinic acid or by regulating the proportions of amine end groups. The acceptance of all dyestuffs by polyamides is enhanced by the inclusion of other polymeric materials such as polyethylene oxide or polyvinylpyrrolidone. The affinity of polyesters for basic dyes is increased by modification with organic radicals, a preferred modifier being sodium sulfoisophthalic acid salt.

The bulky multifilament yarn of this invention has the desirable properties of spun staple yarn and avoids the necessity of cutting continuous filaments into staple and then reforming the staple into yarn. The continuous filament bulky yarn is simply and economically prepared, by a process which requires little equipment, directly from the continuous filament bundle produced initially in synthetic fiber manufacture. The bulky yarn is superior to spun staple for many purposes because of its freedom from loose ends. The hand of fabrics made from the bulky yarn usually is stiffer than that of corresponding staple materials, making them more suitable for use in draperies, suits, overcoats, etc. As discussed previously, staple yarns can be processed by this invention to improve bulk and achieve special effects.

The yarn is sufficiently uniform to be handled easily by textile machinery and to form highly uniform fabrics without the sacrifice of bulk or fiber interlocking characteristics that occur with some mechanically crimped yarns having too regular a structural pattern. The yarn has been used without difficulty on both automatic weaving, knitting, and tufting machines. The increased covering effectiveness of fabric made with the bulky yarn permits the production of more fabric from the same weight of yarn and, in addition, by greatly extending the utility of artificial fibers, enables them to replace expensive or scarce fibers in many uses. An additional saving in yarn weight is realized in tufted materials since the crimp is largely removed by tension provided in tufting so that much less yarn is used on the reverse of the base material. The relaxed yarn on the front side of the fabric, of course, will still have its high crimp and bulk.

The low denier yarns and monofils can be used in any normal textile operations and end uses. They are particularly useful in the preparation of very light fabrics because of the greatly increased bulk and covering power per unit of weight. The heavy denier yarns have many uses normal to such yarns and are particularly suited as the pile element of pile structures. They can be used as cut or loop pile in garments and rugs or carpets. The high bulk permits the production of woven or tufted carpets with much improved cover and resilience. The absence of loose fibers also makes such structures very pill-resistant.

Another advantage is the suitability of this process for combining filaments of extremely fine denier into light bulky yarns, having a highly uniform appearance, for which there is no spun staple counterpart. More than one kind of filament may be processed simultaneously to create yarns with a desirable blend of fiber characteristics. Intermittent impulsing of the multi-filament being processed can be used to produce a novelty yarn having alternating smooth lengths and bulked regions produced according to the described process. This can be accomplished by varying feed tension, feed rate, or fluid flow. A simple apparatus for achieving this effect is disclosed by Frederick C. Field, in U.S. Patent No. 2,931,090.

Since many different embodiments of the invention may be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited by the specific illustrations except to the extent defined in the following claims.

We claim:

1. A monocomponent synthetic organic filament possessing alternate S and Z twist sections throughout its length; having a random number of turns between twist reversals; having a random continuously varying angle of twist along its length; having a random number of twist reversals per inch; and having at least one S turn and at least one Z turn per inch which have a twist angle averaging at least 5°.

2. A filament of claim 1 prepared by shrinking a synthetic organic filament at least 12% in length, said shrunk filament having a macromolecular structure such that its dyeability rate and tenacity are governed by the equation

$$\frac{D_s}{D_0}\times\frac{T_s}{T_0}>0.8$$

where D_0 and D_s are the dyeing rates of the filament before and after shrinking, respectively, and T_0 and T_s are the tenacities (grams per denier) of the filament before and after shrinking, respectively.

3. A filament of claim 1 in which the twist angle averages at least about 10°.

4. A stable multi-filament strand comprising the filaments of claim 3.

5. A monocomponent synthetic organic filament possessing alternate S and Z twist sections throughout its length; having a random number of turns between twist reversals; having a random continuously varying angle of twist along its length; having a random number of twist reversals per inch; and having at least one S turn and at least one Z turn per inch which have a twist intensity (angle) equivalent to at least 20 turns per inch.

6. A monocomponent synthetic organic filament possessing alternate S and Z twist sections throughout its length; having a random number of turns between twist reversals; having a random continuously varying angle of twist along its length; having a random number of twist reversals per inch; having at least one S turn and at least one Z turn per inch which have a twist angle averag-

ing at least 10°; and having a random, persistent, three-dimensional, non-helical, curvilinear, crimped configuration continuously along its length and being substantially free from crunodal loops.

7. A synthetic organic filament having a uniform cross-sectional configuration (free from distortion) throughout its length; having a random, persistent, three-dimensional, non-helical, curvilinear, crimped configuration continuously along its length; possessing alternate S and Z twist sections throughout its length; having a random number of turns between twist reversals; having a random continuously varying angle of twist along its length; having a random number of twist reversals per inch; and having at least one S turn and at least one Z turn per inch which have a twist angle averaging at least 5°.

8. A filament of claim 7 composed of a crystallizable thermoplastic material.

9. A filament of claim 7 comprising a polyamide.

10. A filament of claim 9 comprising poly(hexamethylene adipamide) having a long period of about 83 to 100 A., a tenacity of at least 3 grams per denier and an orientation angle of about 17 to 40° and having at least 10 crimps per inch.

11. A filament of claim 9 comprising poly(epsilon caproamide) having a long period of about 80 to 110 A., a tenacity of at least 2.5 grams per denier and an orientation angle of about 17 to 35° and having at least 10 crimps per inch.

12. A filament of claim 7 comprising a polyester.

13. A filament of claim 12 comprising a polyester of terephthalic acid and a glycol.

14. A filament of claim 12 comprising poly(hexahydro-p-xylylene terephthalate).

15. A filament of claim 12 comprising poly(ethylene terephthalate) having a long period of at least 110 A., a tenacity (T_3) of at least 1.0 and an orientation angle of at least (47–4.0 T_3) and having at least 5 crimps per inch.

16. A filament of claim 12 comprising a copolymer of ethylene terephthalate containing less than 15% combined monomers other than ethylene terephthalate and copolymerizable with ethylene terephthalate and having a long period of at least 110 A., a tenacity (T_4) of at least 1.0 and an orientation angle of at least (28–2.3 T_4) and having at least 5 crimps per inch.

17. A filament of claim 7 comprising linear polypropylene.

18. A filament of claim 7 comprising acrylonitrile polymer containing at least 85% combined acrylonitrile.

19. A filament of claim 7 composed of cellulose acetate.

20. The filament of claim 7 in which the average filament crimp elongation after loading to 0.5 gram per denier and hot wet relaxation is at least 15%.

21. The filament of claim 7 in which the filaments have at least 10 crimps per inch.

22. A filament of claim 7 in which the cross section of the filaments is non-circular.

23. A stable bulky multi-filament strand comprising filaments of claim 7, the crimp configuration of each filament being independent of the crimp configuration of adjacent filaments.

24. A stable bulky multi-filament strand of claim 7 having a specific volume at 3.1 lbs./sq. in. of between about 7 and about 14 cubic centimeters per gram.

25. A multi-filament strand of claim 7 in which at least one filament differs in composition from the remaining filaments.

26. A multi-filament strand of filaments having a circular cross-section; possessing alternate S and Z twist sections throughout their lengths; having a random number of turns between twist reversals; having a random continuously varying angle of twist along their lengths; having a random number of twist reversals per inch; and having at least one S turn and at least one Z turn per inch which have a twist angle averaging at least 5°; said filaments having lines of constant retardation which are parallel to the fiber axis throughout the length of the filament, said lines of retardation being visible in the birefringence pattern produced by the filament under Nicol's prisms crossed at 90° wherever the axis of the filament lies at an angle of 45° to each of the planes of polarization of the prisms and is perpendicular to the axis of view.

27. A monocomponent synthetic organic filament possessing alternate S and Z twist sections throughout its length; having a random number of turns between twist reversals; having a random continuously varying angle of twist along its length; having a random number of twist reversals per inch; and having at least one S turn and at least one Z turn per inch which have a twist angle averaging at least 5°, having a random, persistent, three-dimensional, non-helical, curvilinear, crimped configuration continuously throughout its length and being substantially free from crunodal loops, said filament being prepared by shrinking a synthetic organic filament at least 12% in length, said shrunk filament having a macromolecular structure such that its dyeability rate and tenacity are governed by the equation

$$\frac{D_s}{D_0} \times \frac{T_s}{T_0} > 0.8$$

where D_0 and D_s are the dyeing rates of the filament before and after shrinking, respectively, and T_0 and T_s are the tenacities (grams per denier) of the filament before and after shrinking, respectively.

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