Dec. 1, 1970 A. L. BREEN ET AL 3,543,358

PROCESS FOR INCREASING THE BULK OF MULTIFILAMENT YARN

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FIG. 1

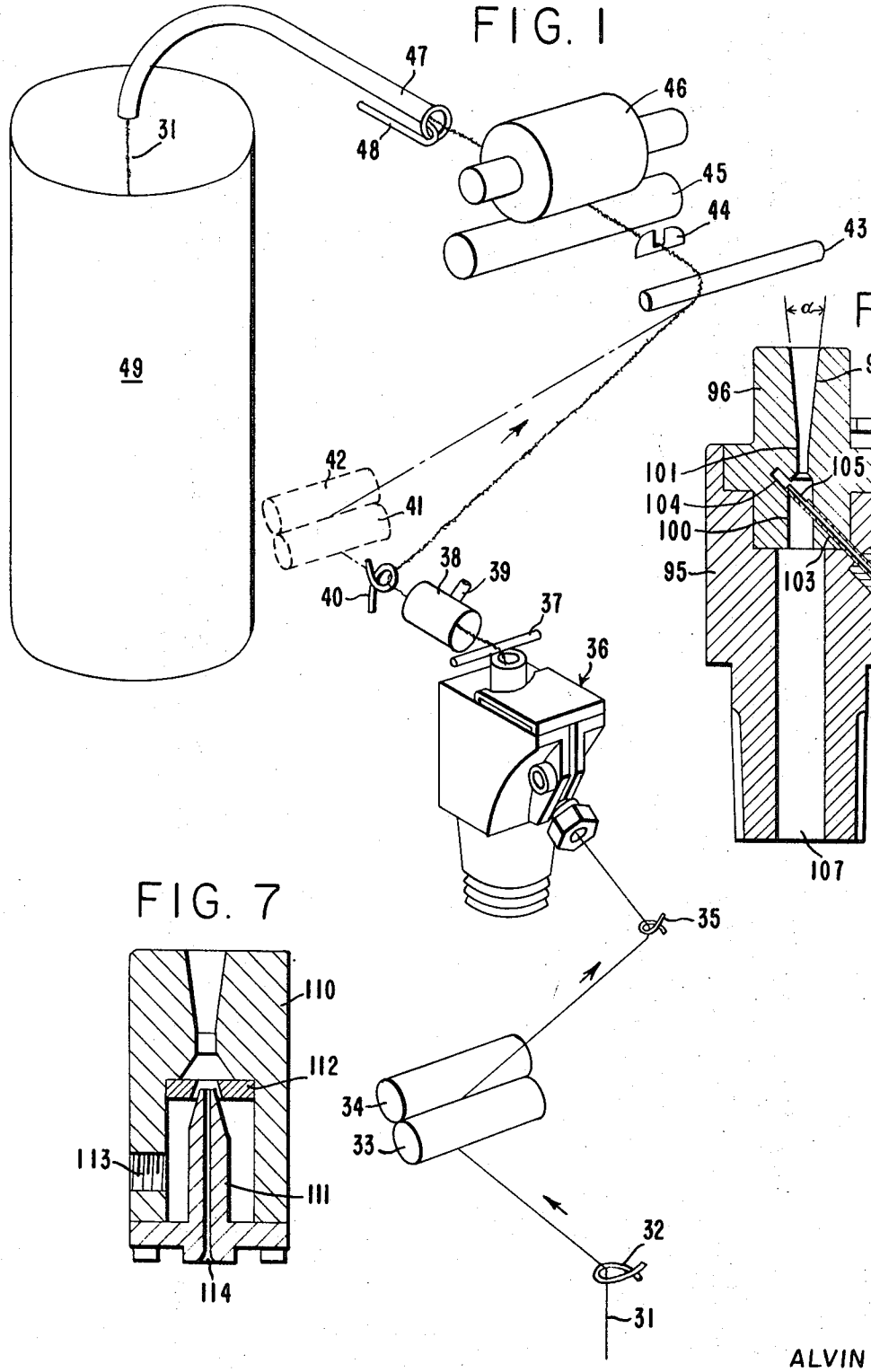


FIG. 6

FIG. 7

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FIG. 2

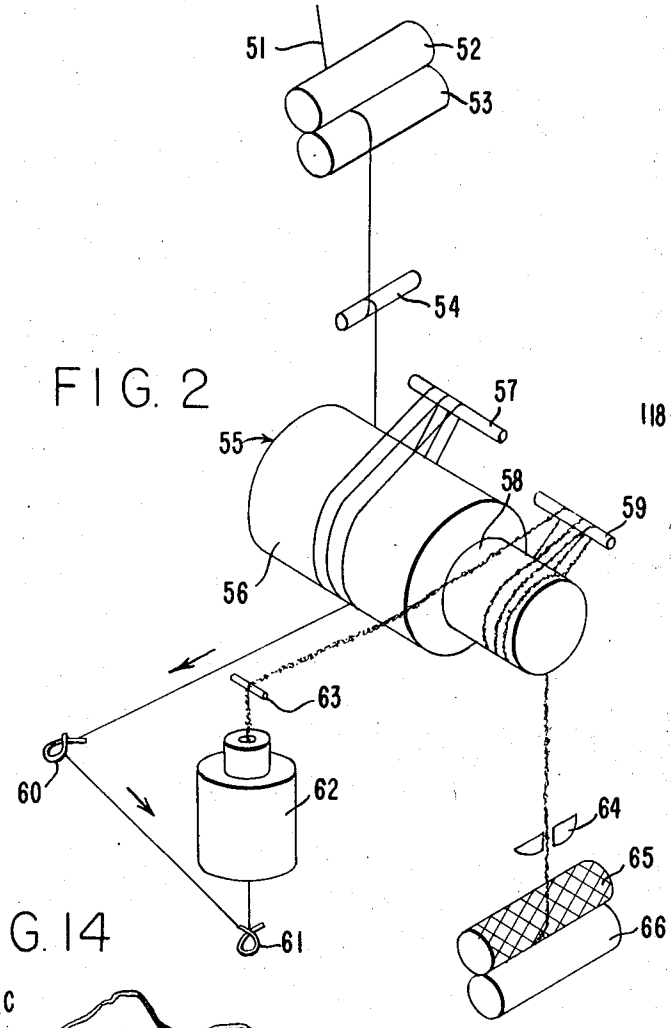


FIG. 8

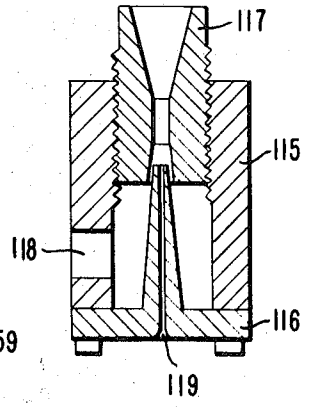


FIG. 13

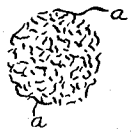


FIG. 14

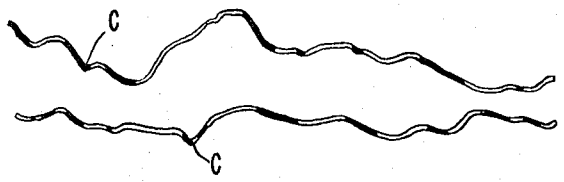


FIG. 15



FIG. 16

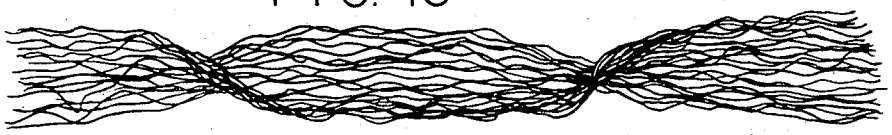
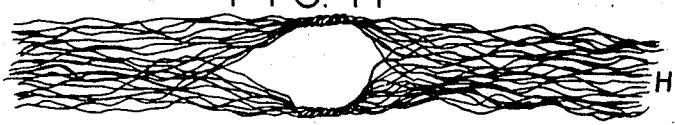


FIG. 17



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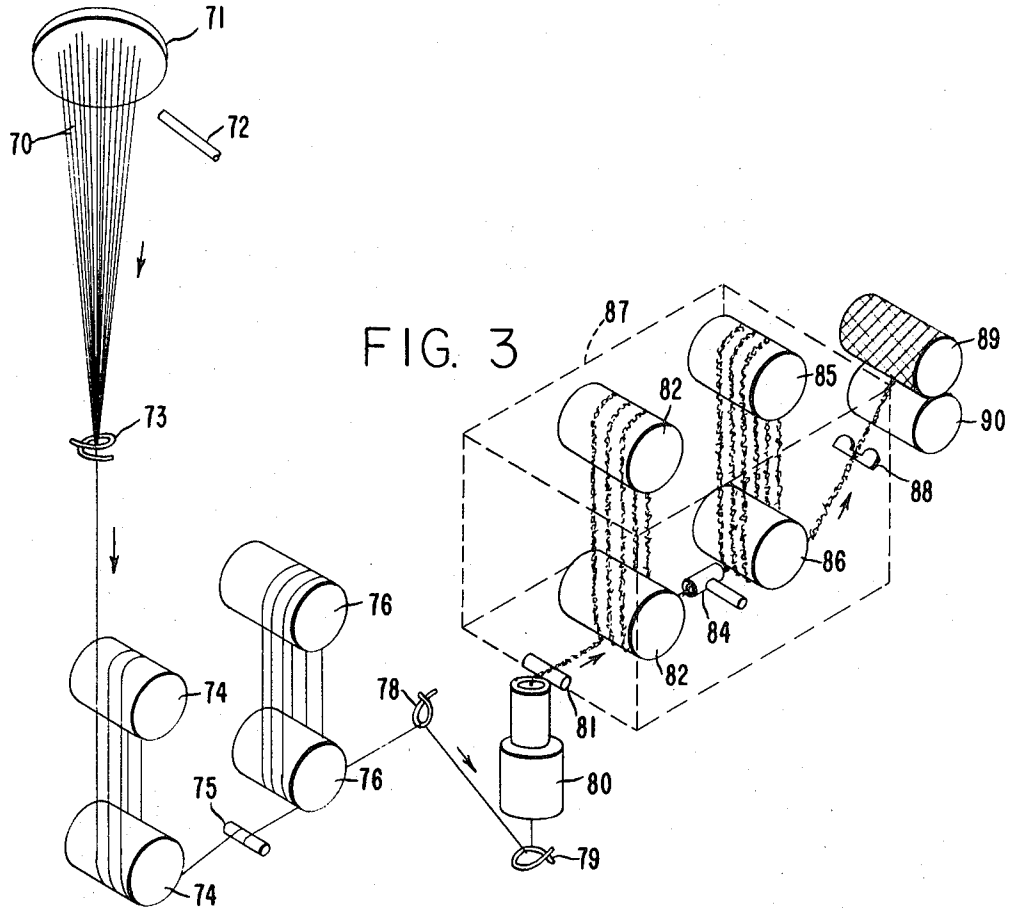


FIG. 3

FIG. 4

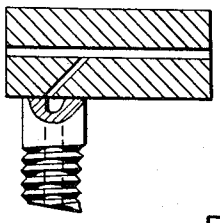


FIG. 5

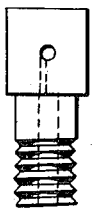
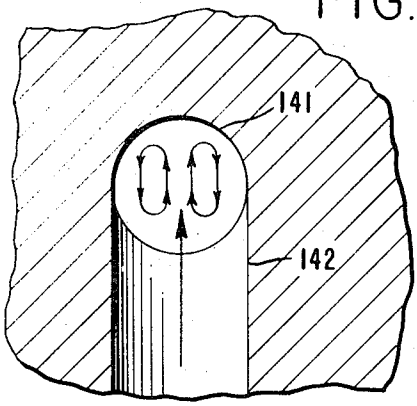


FIG. 11



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FIG. 9

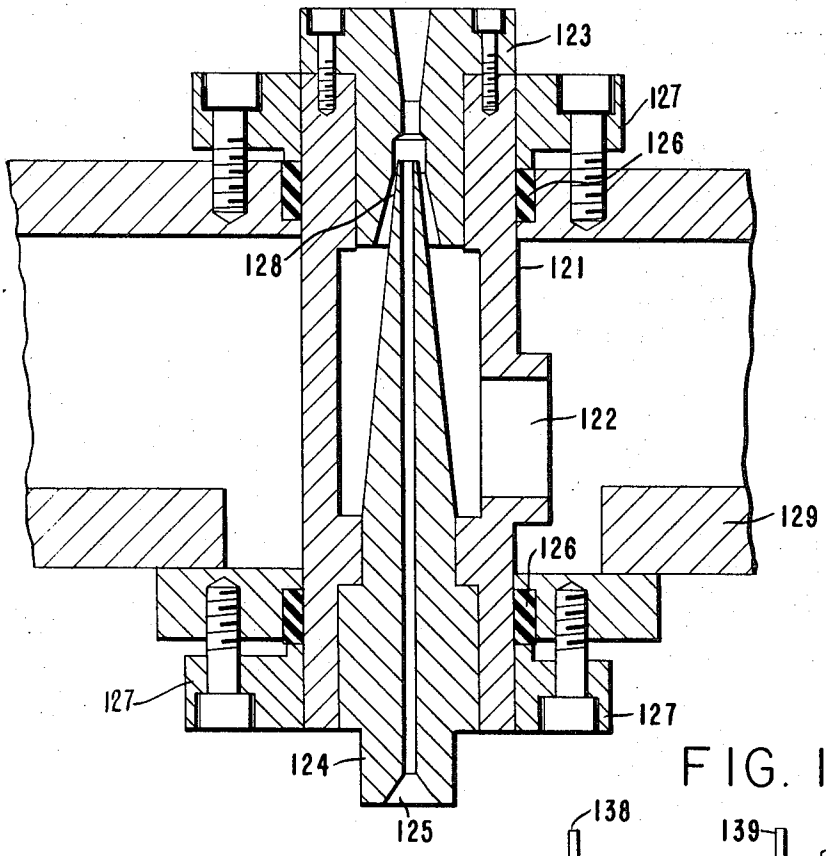


FIG. 10

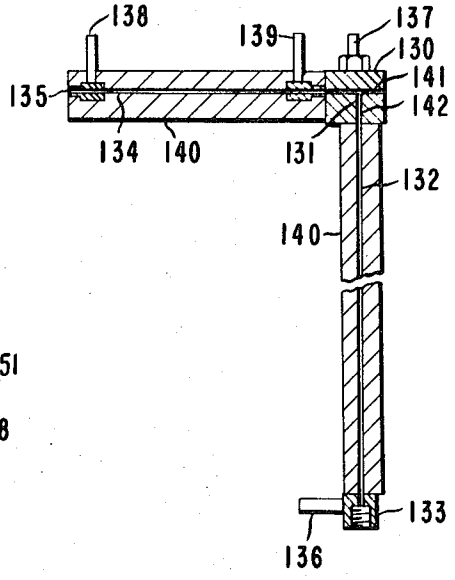
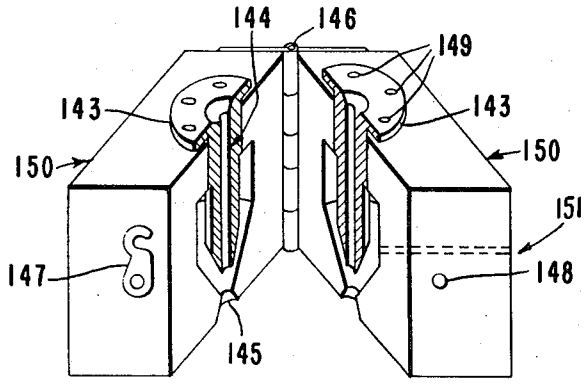


FIG. 12



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FIG. 20

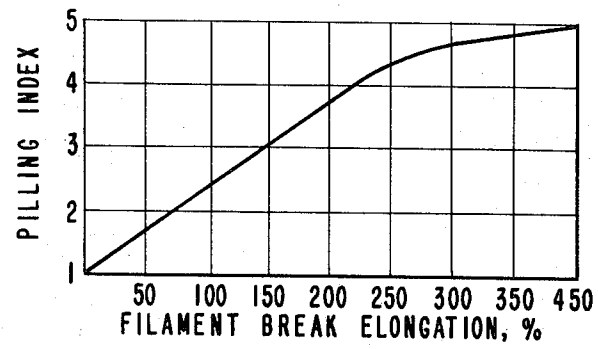


FIG. 22

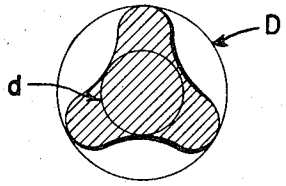


FIG. 21

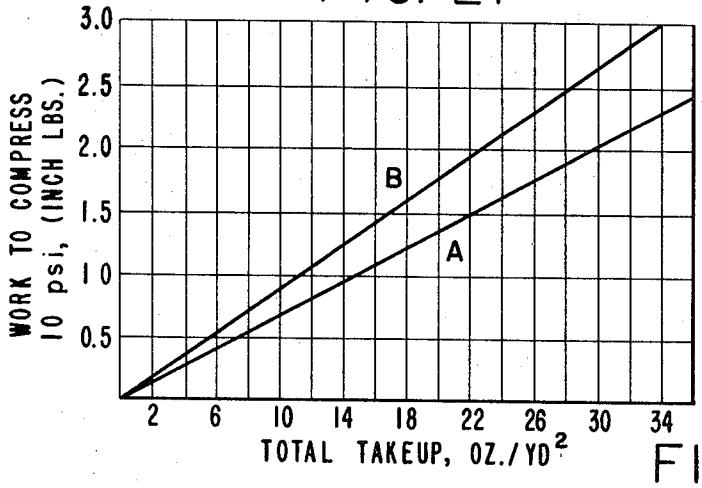


FIG. 19

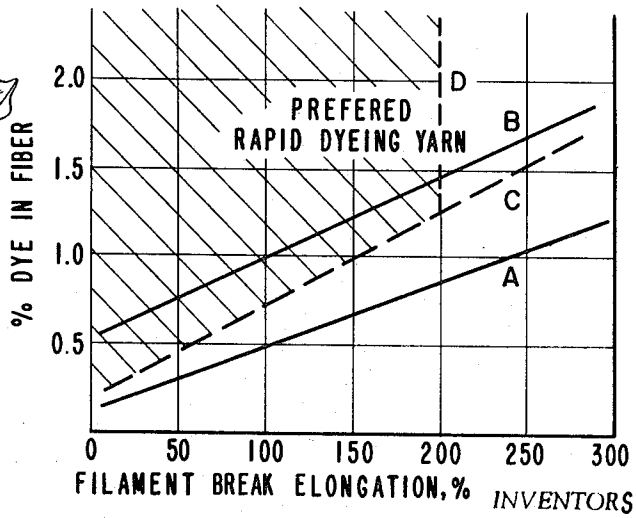
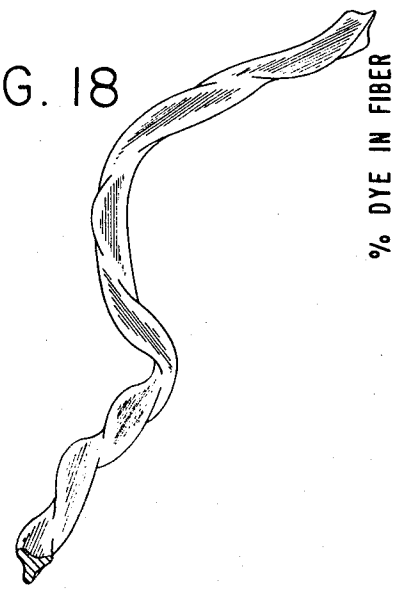


FIG. 18



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3,543,358

PROCESS FOR INCREASING THE BULK OF MULTIFILAMENT YARN

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Continuation-in-part of application Ser. No. 698,103, Nov. 22, 1957. This application Oct. 24, 1967, Ser. No. 699,753

Int. Cl. D02g 1/16

U.S. Cl. 28—72.12 17 Claims

ABSTRACT OF THE DISCLOSURE

Processes and apparatus are disclosed for treating a bundle of continuous filaments to produce a multifilament yarn of greatly increased bulk, wherein the filaments have a unique nonhelical crimp. The treatment also improves the dyeing characteristics. A hot compressible fluid, such as air or steam, is jetted to form a turbulent region. Yarn or zero or very low twist is fed through the turbulent regions, is plasticized by the hot fluid and is led away from the fluid and cooled. The yarn feed and take-up speeds, temperature and other conditions are adjusted to provide the desired amount of crimp. The examples illustrate a wide variety of treatments for different purposes.

REFERENCES TO RELATED APPLICATIONS

This is a continuation-in-part of copending application Ser. No. 698,103, filed Nov. 22, 1957 now abandoned, and Ser. No. 43,897 filed July 19, 1960, and now abandoned. Products referred to herein are claimed in U.S. Pat. No. 3,186,155 dated June 1, 1965, which was filed as a continuation-in-part of said first mentioned application.

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 bulk. More particularly, the invention relates to the production of a bulky yarn composed of a plurality of substantially continuous individually crimped filaments having a random three-dimensional curvilinear configuration and improved level dyeing characteristic and faster dyeing rate.

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, makes conventional continuous synthetic filament yarns much more dense than yarns made from synthetic 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 product 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, issued Mar. 5, 1957, 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.

It is an object of the present invention therefore to provide continuous 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. A further object is to provide a process for preparing continuous filament yarn having a bulk greater than that of comparable staple yarn without abrading or cutting the constituent filaments. A still further object is to provide a process which is suitable for rapidly and economically treating ordinary multifilament continous yarn to greatly increase the bulk without the use of moving mechanical parts other than in the windup. It is also an object to prepare a bulky filamentary material especially useful for the pile component of pile fabrics. Other objects include the provision of continuous filament yarn having greater bulk than staple yarn together with increased uniformity of dyeing rate with low elongation and very low pilling tendency. Other objects will appear as the description of the invention proceeds.

The objects are accomplished by feeding a yarn bundle which has no more than 1 turn per inch (t.p.i.) of bundle twist to a turbulent plasticizing region formed by a stream of a compressible fluid jetted at a temperature of at least 300° F., then cooling the filaments under low tension and taking them up at a rate which provides at least 30% overfeed to the stream. Under these conditions the filaments are crimped individually in a nonhelical, three-dimensional, random, curvilinier configuration which persists after tensioning and hot-wet relaxation.

The amount of twist in the feed yarn has a surprising effect on the filament crimp and yarn bulk of the products, whereas twists of 1 t.p.i. or less provide a nonhelical,

random filament crimp and high yarn bulk. However, when twists of 2 t.p.i. or more are used with otherwise comparable conditions, a fairly regular helical-type filament crimp is obtained and the yarn product is relatively compact with protruding surface loops which impart a degree of voluminosity without much bulk. Feed yarns having 1.5 t.p.i. or less twist provide more random crimp and greater bulk. This indicates that the presence of normal yarn twists will prevent adequate filament separation and movement in the turbulent fluid. The filaments must have substantial freedom to whip about during the bulking operation in order to achieve the antique crimp and high bulk.

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

FIG. 1 is a schematic perspective view of apparatus suitable for the production of the bulky yarn of this invention; FIG. 2 is a schematic perspective view of a variation of this equipment suitable for stretching the yarn and bulking it in successive steps without intermediate packaging; FIG. 3 is a schematic perspective view of similar equipment adapted to spinning, drawing, and bulking in successive steps without intermediate handling or packaging; FIGS. 4, 5, 6, 7, 8, 9, 10, 11 and 12 show various jet devices useful in the production of the yarn of this invention; FIG. 13 is a cross-sectional view of the bulky yarn of this invention; FIG. 14 is a longitudinal view of single filaments modified in accordance with the process of this invention; FIG. 15 is a longitudinal view of a multifilament yarn of this invention; FIGS. 16 and 17 show variations of the multifilament yarn product of this invention; FIG. 18 shows a single filament produced in accordance with this invention from a fiber of non-round cross section; FIG. 19 shows a graphical relationship between the dyeing rate of the product in this invention and its break elongation; FIG. 20 shows a graphical relationship of the pilling index of the product of this invention and its break elongation; FIG. 21 shows a graphical relationship of compressional characteristics versus weight for pile carpets made of the yarn of this invention compared with conventional staple yarn; and FIG. 22 is an illustration of a fiber cross section for preparation of a preferred carpet yarn.

In FIG. 1 the moving threadline to be treated **31** 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 package **46** may be a roll which with **45** is used to feed yarn to piddle tube **47** provided with aspirating tube **48** depositing yarn in container **49**.

FIG. 2 shows undrawn yarn **51** passing continuously between feed rolls **52** and **53** around pin **54** to draw roll **55** having two cylindrical surfaces **56** and **58**. Several wraps of yarn are placed about surface **56** and idler roll **57**. The yarn is then passed continuously through guides **60** and **61**, jet **62** and over guide **63**. Several wraps of the bulky yarn from the jet are placed about roll surface **58** and idler roll **59**. Idler rolls **57** and **59** are positioned with their axes at a slight angle to the axis of roll **55** to spread the yarn wraps. From roll surface **58** and idler roll **59**, the yarn is passed continuously through traverse guide **64** to package **65** driven by roll **66**.

In FIG. 3 filaments **70** from spinneret **71** quenched asymmetrically by cold fluid directed to the face of the spinneret by fluid nozzle **72** are converged at guide **73** and passed around rolls **74**. The yarn is continuously drawn on draw pin **75** by wraps around rolls **76** moving at higher speed and is then fed through guides **78** and **79** and jet **80**. The bulked yarn leaving the jet is passed around guide **81** and rolls **82**. Quenching device **84** cools the yarn or alternatively it is cooled by the flow of cold air through box **87** around cooling rolls **82**, **85**, and **86**. From the cooling rolls, the yarn is fed continuously through traverse guide **88** to package **89** driven by roll **90**.

FIG. 6 is a jet suitable for the practice of this invention, consisting of body member **95**, orifice member **96**, held in place by clamp **97**, and screw **98**. This jet is illustrated more fully in co-pending application Ser. No. 604,564 filed by Hall on Aug. 16, 1956, now Pat. No. 2,958,112. The passage through orifice member **96** consists of cylindrical opening **100**, connecting with concentric cylindrical opening **101**, and outwardly tapered opening **99**, characterized by the angle α. Yarn tube member **102**, supporting hollow needle **103**, in hole **104**, with cutaway section giving a lip **105**, is supported in body member **95**, in an adjustable fashion by screw tightened in tapped hole **106**. The compressible fluid is applied to the nozzle at **107**, and the yarn is fed to needle member through hole **108**.

FIG. 7 is another jet consisting of body member **110**, and yarn guide member **111**, with perforated disc **112**, and fluid entrance **113**. Yarn is fed to this nozzle through opening **114**.

FIG. 8 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**.

FIG. 9 is a similar jet particularly adaptable to multiple end operation where precise temperature control is desired from position to position. It consists of jet body **121**, with opening **122** for the turbulent fluid, and replaceable orifice **123**. Yarn guide member **124**, provided with yarn opening **125**, is machined so that tip **128** is eccentric to the jet axis. Jet body **121** is sealed in manifold **129** by gaskets **126**, and flanges **127**.

FIG. 10 is a simplified jet suitable for the practice of this invention consisting of body member **130** with drilled holes as shown to provide a T-shaped intersection at **131**. Thin-walled tubing **132** connecting to compressible fluid supply through adapter **133** serves as a combination conduit and heater for the compressible fluid. Similar thin-walled tubing **134** attached to body member **130** serving as a yarn "preheater" is provided with yarn entrance **135**. A high amperage electrical current applied between lugs **136** and **137** heats the compressible fluid passing through tube **132** by virtue of the electrical resistance of the tubing. Similarly, high-amperage current applied between lugs **138** and **139** provides additional heating to the turbulent fluid exhausting a counter-current direction to the thread line moving from **135** toward **131**. This arrangement preheats the yarn so that it is in a desirably plasticized state as it traverses the zone of greatest turbulence between **131** and **141**. Turbulent fluid exhausting preferentially from orifice **141** produces the desired bulking action. Insulation **140** prevents excessive heat loss from tubes **132** and **134** and also tends to support these fragile elements. This unit is particularly useful for treating yarns at very high speeds in the range of 500–1000 y.p.m. or more. FIG. 11 shows the intersection **131** of the jet in cross section of FIG. 10. It is to be understood that other devices employing heated plates or rolls may be substituted for the preheater of FIG. 10. Similarly, the preheating fluid could be a hot gas applied by an auxiliary nozzle or a hot liquid applied in an open bath or semi-confining tube. Such devices likewise may be made as an integral part of any of the fluid nozzles of FIGS. 6, 7, 8, 9, or 12 or those described in the reference patents and pending applications, for example, application Ser. No. 604,564 filed by Hall on Aug. 16, 1956, now Pat. No. 2,958,112, and U.S. 2,783,609 to Breen, issued Mar. 5, 1957.

FIG. 12 shows one form of jet particularly useful for the practice of the process of this invention as indicated in FIG. 3 where the thread line being treated is taken directly from a spinning operation. In this case, body member **150** is split into two similar portions. Likewise, yarn guide member **143** is split into similar parts, laying open

the yarn passage **144** and orifice **145**. For stringup, these parts are held in the open position by hinge **146**. During the bulking operation, the parts are held in a closed position by hook **147** and pin **148**. Screws **149** are used to adjust the depth of yarn guide member **143** within body piece **150**. An adjustment of the opposing yarn guide members **143** to slightly differing depths produces a desirable eccentricity of the turbulent fluid flow pattern. Other forms of jets similar in principle to FIG. 12 but having rotating or sliding parts or other mechanisms to provide access to the turbulent fluid chamber are likewise useful in the process of this invention.

FIG. 13 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 stretching 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.

FIG. 14 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 applying similarly to the filaments comprising the yarns illustrated in FIGS. 15, 16, and 17.

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 FIG. 22 is preferred. This is defined in terms of a modification ratio which is the ratio of the diameter of the enscribing circle D to the inscribed circle *d*.

A desirable property of the product of this invention based on these non-round fiber forms is illustrated in FIG. 18. Here the fiber has not only the 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.

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 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 of bulky knit structures where it tends to reduce objectionable glitter or luster associated with light reflection from the fiber surfaces.

Other methods of producing this random twisted or convoluted structure are described in copending application Ser. No. 675,728, filed Aug. 1, 1957, by Breen and Covell, and now abandoned.

In the preferred process of this invention, filaments and yarns meeting the above objects are provided by a process in which a stream of 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. Under these conditions the yarn temperature is above the "cold point" as described more fully hereinafter and below the melting point of the yarn. Yarn having substantially no twist is 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 is then cooled while being maintained at low tension to set the convolutions. 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) 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.

The products of this invention are different in fundamental physical structure from any of the bulked yarns described in prior art. During the jetting treatment, a most surprising shrinkage of the filaments and relaxation of the molecules making up 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 zero tension for a long period of time without agitation. This dynamic relaxation is responsible for a considerable amount of deorientation of the molecules and an increase in crystallinity. In addition, there is a large increase in dye receptivity. In retrospect, it is now believed that the turbulent conditions in the jet subject

each section of the filament to innumerable and successive stressings and complete relaxations. These repeated stressings are believed to supply a part of the energy of activation needed to break bonds between the molecules making up the filaments and thus to permit more complete relaxation of the molecules during the subsequent short intervals when the sections of the filament are under no tension, or perhaps even under compression, than would occur if the filaments were not subjected to multiple stressings. Thus a practical way has been found to accomplish a very valuable reorganization of the molecular structure of the filament which would otherwise be utterly impossible to accomplish.

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 conditions, plus the deorientation which occurs, gives fibers with greatly improved dyeing rate not heretofore encountered in textile yarns. The dyeing rate is increased about 50% to 150% 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 increases in dye rate greater than 50% have not heretofore been encountered. 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.

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, at 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. The dynamic relaxation employed in this invention eliminates most of the non-uniformities in structure caused by these plucks and stress and thus the treated yarns have much more uniform dyeability along and across the bundle than can be obtained by non-turbulent radiant heating or by contact with heated mechanical surfaces. The yarns prepared by the process of this invention therefore have better dyeing uniformity than bulk yarns prepared by the twist-heat set method, by stuffer-box crimping, or by other processes known in the art.

The products of this invention assume 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 a regular and reversing or saw-tooth planar type of crimp. Because of the turbulent and random fluid currents in the treating chamber of the subject process, the crimp in the subject products is three-dimensional and random in crimp amplitude and period. The high degree of turbulence in a confined space results in a very high crimp level, and a curvilinear rather than rectilinear, saw-tooth, helical or crunodal loop type of filamentary configuration. The crimp is permanent to normal fiber processing conditions and will persist in filaments taken from the yarn bundle. On exposure to hot water, marked increases in crimp amplitude and frequency are obtained. The useful products of this invention have a crimp level in excess of 5 per inch, and preferably above 10 per inch. They may even be as high as 70 or 80 crimps per inch.

The process of this invention can be used to crimp and bulk any natural or synthetic plasticizable filamentary material. Thermoplastic materials such as polyamides; e.g., poly(epsilon caproamide) and poly(hexamethylene adipamide), cellulose esters, polyesters; e.g., polyethylene terephthalate, polyvinyls and polyacrylics; e.g., polyethylene and polyacrylonitrile, as well as copolymers thereof can be crimped to give the three-dimension, random, curvilinear configuration described herein. 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.

This process is useful for 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. Actually, steam is preferentially used in the subject process since it is a cheap and convenient source of a 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 temperatures (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 or in the filaments. In any case, the plastic condition of the filaments must be temporary and transistory. 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 will 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, vol. 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.

The temperature of the filamentary structure is difficult to measure under the usual working conditions. At high speed it is indicated that the surface temperature of the fiber being treated may be well above the temperature of the fiber interior. At low speeds, however, the filamentary structure tends to come to equilibrium with the turbulent fluid temperature. The minimum temperature useful for treating the filamentary structure at low speeds in the range of 1 to 5 y.p.m. may be considered the minimum useful yarn temperature for the process of this invention.

To achieve maximum bulking or crimping it is essential that the tension of the yarn subject to the turbulent fluid medium be maintained below about 0.1 gm./denier. Preferably yarn tension during the bulking is maintained between about 0.0001 and about 0.01 gm./denier. For the most efficient bulking action at the highest degrees of bulk and highest throughput of yarn, tension of the yarn should be maintained between about 0.0005 and about 0.005 gm./denier. This low tension in the yarn is preferably regulated by controlling the yarn feed rate vs. the yarn take-up rate so that the bulky yarn forms a shallow catenary between the jet and the downstream guide. The tension can also be governed by the degree of forwarding or braking action of the fluid plasticizing medium.

Yarn feed speed can be varied over a considerable range depending on the material, temperature, denier, degree of bulking, tension and other variables. For economic reasons (productivity/position) the feed rate should be at least 30 y.p.m. although slower speeds may be used for specific items or special effect. Feed rates can run as high as 1000 y.p.m. or even higher. Preferred feed rates are in the range of 100 to 800 y.p.m.

The temperature of the heating fluid must be high enough so that either alone or in combination with some auxiliary plasticizing component, e.g., water, acetone or other solvent, it will soften or plasticize the filamentary material passing through the heating area. The optimum temperature, of course, varies depending upon the material being treated, the form of the material being treated; i.e., staple or continuous filament, the denier or yarn size, the rate of throughput, the degree of turbulence and/or pressure of the treating fluid, the design of the treating chamber, and the degree of crimping desired. The temperature can range as shigh as 700° F. or more and a preferred range is 400°–600° F. The controlling factors are the characteristics of the material being treated and the temperature to insure permanence of crimp. The true upduring treatment. The yarn temperature during the crimping operation should exceed the second order transition temperature to insure permanence of crimp. The true upper limit, of course, is the temperature at which objectionable melting and/or chemical degradation of a given yarn takes place.

There are a number of means and apparatus whereby a turbulent plasticizing fluid to achieve the improvements jets or devices for treating a filamentary material with a turbulent plasticizing fluid to achieve the improvements of this invention are described in U.S. 2,783,609 and copending applications Ser. Nos. 375,372, now U.S. 2,852,-906 to Breen, issued Sept. 23, 1958; 604,564, filed Aug. 16, 1956, by Hall, now Pat. No. 2,958,112; and 598,135 filed July 16, 1956, by Breen and Sussman, now Pat. No. 3,009,309, as well as those in FIGS. 6 through 12.

It is necessary to cool the crimped yarns after treatment in the turbulent plasticizing fluid and prior to any further operation that imposes tension on the yarn bundle. This quenching, cooling, or freezing operation is necessary to lock in the three-dimensional, random, curvilinear configuration imposed on the various filamentary elements by the hot turbulent fluid. This quenching operation should preferably cool the yarn below the second order transition temperature, T_g. After cooling, the yarn can be subjected to normal processing tensions and wound into any of the conventional yarn packages. This quenching operation can be carried out by piddling into a sliver can or onto a moving belt or screen but from an economic viewpoint, it is preferred to cool the yarn on-the-run as an integral element of the over-all crimping or buckling process. It is preferred to use a positive cooling operation either immediately before or after the take-up roll—the important factor is that cooling is effected prior to imposing any substantial tension on the hot plastic crimped filamentary material.

Adequate cooling of the yarn can be achieved by passage across a chilled plate or roll. Passage of the yarn through a suitable liquid bath will also cool the yarn adequately. The preferred embodiment, however, is the use of a flow of a cooling fluid—preferably a gas. This can be in the form of a jet that impinges the gas on the yarn bundle or it can take the form of the jets described previously for treating the yarn with a hot turbulent plasticizing medium. Cooling jets can be designed to forward the yarn, apply a braking action, or so designed and balanced that they exert neither a forwarding action nor a braking action. Good results may be obtained if the quenching jet applies a braking action to the filamentary material since this enhances and increases the amplitude of the crimp by its action on the still plastic filaments on the upstream side of the cooling jet. The cooling jet may be at room temperature or even refrigerated.

The yarn overfeed should be adjusted so that the tension in the processing zone is in the range indicated above. The overfeed rate can be as high as 250% or higher but for most yarns this value is from 15% to 100%, preferably above 30%.

The feed pressure of the hot plasticizing fluid will depend on the degree of turbulence desired, feed speed, yarn denier, material being processed, design of jet and the like. Pressures in the range of 20 p.s.i.g. to 200 p.s.i.g. or more are useful while the preferred range is from 40–100 p.s.i.g. Normally economics will dictate that the optimum pressure is the lowest that still gives the desired degree of crimping

In U.S. 2,783,609 it is disclosed that the filamentary material should be removed abruptly from the fluid stream. It has been found advantageous in the subject process to remove the filaments gradually from the hot fluid stream thus keeping the yarn hot for a longer period of time prior to quenching. The rapidly expanding fluid medium will also give a cooling action outside of the yarn heating zone.

It is preferred that the feed yarn contain little or no twist. The twist level should be below 2.0 t.p.i. and preferably below 1.0 t.p.i. in order to avoid formation of a regular helical-type crimp. Yarns of higher twist levels can obviously be processed; however, the tendency is for the formation of stable loops and filament intertangling at the expense of bulk and extensibility of the yarn bundle —thus the yarn bundles become increasingly compact as the twist level rises.

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 provides many interesting effects which are desirable for esthetic reasons in textile materials. The crimp of the product is extremely stable and is not removed by tensions up to the draw tension. The bulked yarns disclosed in U.S. Pat. 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 more 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 process of this invention results in 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, since yarn of a given denier may have an open bulky structure or may have a very compact structure, a better measure of bulk can be obtained by determining the weight of a definite volume of yarn. The yarn diameter may be measured and the weight per unit length may be determined in g./cm. Assuming that the yarn bundle is round, one may determine the yarn cross section in cm.^{2}. Then by also determining the length per unit weight, one may calculate the bulk in cubic centimeters per gram (specific volume), The bulk of yarns prepared by this process is much greater than the bulk of yarns prepared by the process of U.S. 2,783,-609. For example: the bulk of a yarn prepared by the process of this patent from 2,000 denier feed yarn is about 7 cm.^{3}/g. Yarns from the present process, on the other hand, have specific volumes in the range 10 to 50. The comparison of the starting denier to the final denier is an indication of this bulk increase.

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 decreace 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 bulky 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 yarns produced by 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. The property of increasing bulk 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 yarn products, tests were devised to characterize the response of the yarns to these treatments.

In general, these tests employ 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 as $L_{0.1}$. 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. The denier of the crimped yarn is then measured in the relaxed state and recorded as Den_0. A taut denier value may also be calculated based on $L_{0.1}$. Yarn crimp elongation is then calculated as follows expressed as a percent increased in crimped yarn length

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

Crimp elongation is a measure of the extensibility of the yarn of this invention and its is to be understood that the terms are qualitatively interchangable. It 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 crimp/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.

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 been determined as follows:

$$\text{Percent shrinkage} = \left[1 - \frac{\text{Den}_I}{\text{Den}_{0.1}}\right] \times 100$$

Similar measurements may be applied to single filaments. FCE will be understood to mean fiber crimp elongation. This may differ from YCE because of such factors as interfiber friction, where Den_I is the denier of the yarn before treatment. 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.

Another parameter derived from the above measurements is useful in comparing yarns made at uncontrolled overfeed (FIG. 1 without rolls **41**, **42**, **45**, and **46**), with those made with the double roll or triple roll systems (FIG. 1 as shown). This has been termed the effective overfeed (EOF) and is calculated as follows:

$$\text{EOF percent} = \left[\frac{\text{Den}_0}{\text{Den}_I} - 1\right] \times 100$$

All of the jets useful in the process of this invention are characterized by an arrangement for the common exit of the turbulent fluid and the yarn bundle being treated. The turbulent fluid in all cases exhausts at high velocity relative to the yarn velocity. One surprising quality common to all jets which are adjustable is the need for careful adjustment of the jet for optimum bulking action. The jet shown in FIG. 6 is easily adjusted by moving part **102** in or out with respect to part **95**. A second adjustment is accomplished with the rotation of part **102** within the opening **104**. In general, with heavy weight yarns, lip **105**, on needle **103**, should be withdrawn from the center position. For light denier yarns the optimum adjustment is with the lip beyond the center line of opening **100**. The needle obstruction in the air flow also adds turbulence to the system which in some cases gives a superior product.

Jets shown in FIGS. 7, 8, 9 and 12 are also sensitive to adjustment. In general, the part (**111**, **116**, **124**, or **143**) introducing the yarn to the air stream should be slightly off-center with respect to the orifice axis for best bulking action. A 60° angle α (FIG. 6) favored ease of adjustment for best bulking action. In the jet of FIG. 10 the eccentricity factor is provided by the abrupt change of direction of the high velocity fluid as it enters the yarn passage from one side. A variation of this apparatus having several fluid entry ports spread about the periphery of the yarn passageway is likewise made eccentric in its action on the yarn by using ports of different sizes and/or by disposing them in a preferred unsymmetrical grouping. Sationary baffles within the jet may be used similarly to provide the eccentric flow pattern.

The following examples are given by way of illustration and not limitation. 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.

EXAMPLE I

8000–136 undrawn 66 nylon yarn with Y cross-section filaments having a modification ratio of 2.2 as in FIG. 22 was processed using the apparatus of FIG. 2. The yarn **51** was fed through a guide to feed rolls moving at 133 y.p.m. to draw pin **54**. From this pin the yarn was taken to draw roll **56** turning at a surface rate of 400 y.p.m. with a sufficient number of wraps to draw the yarn and cause it to stretch 200%. From this point, the yarn was passed through jet **62**, fed by 100 p.s.i. steam, superheated to 575° F. The bulked yarn was carried to step roll **58** having a surface speed of 300 y.p.m. so that the bulking operation was controlled at 33% overfeed. The yarn was then carried to a wind-up system moving at 370 y.p.m. to give a dense package structure in which the fibers were held in a nearly straight condition. This yarn, when tested according to the above procedure, developed a crimpted denier of 3200 and showed a yarn crimp elongation of 37%. The actual fiber shrinkage was such that the average fiber cross-sectional area was increased 14%.

EXAMPLE II

8000–136 yarn with Y cross-section filaments having a modification ratio of 1.8 was spun from spinneret **71** FIG. 3 to rolls **74** moving at 175 y.p.m. over pin **75** heated to 110° C. and then to draw rolls **76** moving at 700 y.p.m. From these rolls the yarn was fed to jet **80** operated with 105 p.s.i. steam superheated to 610° F. The bulked yarn exhausting from the jet was fed to rolls **82** moving at 500 y.p.m. and from there to wind-up roll **89** moving at 590 y.p.m. to give a hard package in which the filaments were essentially straight. After testing according to the above procedure, the bulked yarn denier was found to be 2700 and the yarn crimp elongation was 14%. The shrinkage was 15%.

EXAMPLE III

The process was operated in the same fashion as Example II but with the added element of the cold air quenching device **84** added as shown in FIG. 3. This gave a yarn with a bulked denier of 3400 and a YCE of 45% as measured by the above procedure. The yarn of this example was much bulkier than that of Example II made without the quenching device.

EXAMPLE IV

Yarn was bulked as in Example II but with a modified take-up system as shown in FIG. 1. This consisted of a tube **47** leading from rolls **45**, **46**, to piddle barrel **49**. Air flow entering through tube **48** served to advance the yarn to the barrel allowing it to fall in a tension free condition into the container. The tube was mounted on a suitable traversing mechanism so that the yarn built up in rewindable layers. This yarn showed the same desirable properties as that from Example III. Jet **36** was of the design as indicated in FIG. 6. The orifice section **101** had a diameter of .076" and an intermediate diameter **100** of .099". This jet operated in a superior fashion to the jet in which the entire orifice was of the larger 0.99" diameter.

The following examples are given in table form. The general procedure in each of these examples is shown in FIG. 1. In Table II under the description of the yarn, the first number indicates the overall yarn denier, the second number is the number of filaments in the yarn, the third number where present represents the twist in number of turns per inch. The letters Z and S represent the direction of the twist. The letters R or Y following the S or Z twist indicate the cross section of the filaments, R representing round, and Y indicating the cross section similar to that shown in FIG. 22. The final letter or letters indicate the luster in which D stands for Dull; SD for Semi Dull; and BR for Bright. Unless otherwise noted

the jet employed is shown in FIG. 6. The first number refers to the value of α in FIG. 6. Unless otherwise noted this value is 7°. Of the remaining two letters, the first refers to the venturi size and the latter to the needle size, the values of which appear below in Table I. The number under feed speed is yards per minute. The overfeed is the difference between feed rate and the take-up rate divided by the take-up rate and multiplied by 100 to obtain percentage. Unless otherwise noted, the tension in all of the examples was just enough to draw the yarn away from the jet and in general was less than 5 grams. The steam pressure is expressed in p.s.i.g.

TABLE I

	Diameter of 100, Fig. 6, inch	Diameter of 101, Fig. 6, inch	Needle	OD, inch	ID, inch
Venturi:					
A	.055	.055	R	0.28	.016
B	.076	.076	S	.042	.028
C	.099	.076	U	.058	.042
D	.099	.099			
E*	.125	.112			

* The E venturi had a final constriction of .093" between the .112" section and the tapered opening (99) in Figure 6.

TABLE II

Number:	Yarn	Jet	Feed speed	Percent overfeed	Steam Press	Steam Temp. ° F,
	66 NYLON					
1	15 monofil	B/S	50	76	90	580
2	1 end, 70-50-1/2Z-D	60°, A/R	42	44	70	560
3	2 ends, 70-50-1/2Z-D	60°, A/R	42	44	85	595
4	1 end 70-17-1/2Z-D	60°, A/S	42	44	70	575
5	2 ends, 70-50-1/2Z-D	60°, A/S	42	44	85	590
6	2 ends, 70-34-1/2Z-Y-SD	60°, D/U	60	44	85	560
7	4 ends, 70-34-1/2Z-SD	A/R	50	37	90	450
8	100-34-1/2Z-SD	B/S	125	37	80	400
9	200-34-3/4Z-SD	B/S	50	37	90	450
10	780-51-3/4Z-SD	B/S	49	100	90	450
11	3 ends, 780-51-3/4Z-SD	8	50	37	61	282
12	3 ends, 780-51-3/4Z-SD	8	50	37	60	510
13	3 ends, 780-51-3/4Z-SD	8	200	37	90	510
14	3 ends, 780-51-1.7Z-SD	D/U	200	74	100	550
15	840-140-1/2Z-SD	D/U	50	37	90	525
16	840-140-1/2Z-B R	60°, B/S	90	44	90	530
17	840-140-1/2Z-B R	60°, B/S	90	44	90	530
18	840-140-1/2Z-B R	60°, B/S	90	44	90	530
19	840-140-1/2Z-B R	60°, D/U	85	44	85	585
20	1,050-79-1/2Z-Y-SD	8	100	75	90	550
21	1,560-104-0-R-B R	7	200	75	85	550
22	2,000-136-0.38Z-B R-R	7	200	62	85	530
23	2,000-136-0.38Z-B R-R	7	200	100	100	350
24	2,000-136-0.38Z-B R-R	7	200	100	100	450
25	2,000-136-0.38Z-B R-R	7	200	100	100	510
26	2,000-136-0.38Z-B R-R	7	400	100	85	600
27	2,000-136-1/2Z-Y-SD	8	200	74	90	550
28	2,000-136-1/2Z-Y-SD	8	200	100	90	550
29	2,000-136-1/2Z-Y-SD	7	200	80	90	550
30	2,000-136-1/2Z-Y-SD	7	350	74	90	550
31	2,000-136-1/2Z-Y-SD	C/U	200	108	90	554
32	2,300-158-0-Y-B R	D/U	50	37	50	270
33	2,300-158-0-Y-B R	D/U	50	37	64	282
34	2,300-158-0-Y-B R	D/U	50	37	75	295
35	2,300-158-0-Y-B R	D/U	50	37	75	298
36	2,300-158-0-Y-B R	D/U	50	37	60	344
37	2,300-158-0-Y-B R	D/U	50	37	60	378
38	2,300-158-0-Y-B R	D/U	50	37	105	395
39	2,300-158-0-Y-B R	D/U	50	37	105	418
40	2,300-158-0-Y-B R	D/U	50	37	105	473
41	2,300-158-0-Y-B R	D/U	50	37	105	560
42	2,300-158-0-Y-B R	D/U	50	97	12	250
43	2,300-1/2Z-Y-SD	D/U	50	252	90	450
44	2,300-12Z-Y-B R	D/U	50	(1)	64	300
45	2,300-1/2Z-Y-B R	D/U	50	(1)	90	322
46	2,300-1/2Z-Y-B R	D/U	50	(1)	64	340
47	2,300-1/2Z-Y-B R	D/U	50	(1)	60	460
48	2,300-1/2Z-Y-B R	D/U	50	(1)	60	495
49	2,300-1/2Z-Y-B R	D/U	200	(1)	64	460
50	2,300-1/2Z-Y-B R	D/U	200	(1)	80	460
51	2,300-158-0-Y-B R	D/U	50	(1)	80	460
52	2,300-158-0-Y-SD	7	200	50	90	550
53	2,300-158-1/2Z-Y-B R	D/U	200	74	100	550
54	2,300-158-1.0Z-Y-B R	D/U	200	74	100	550
55	2,300-158-0-Y-SD	7	200	100	90	550
56	2,300-158-0-Y-SD	7	200	97	85	550
57	2,300-158-0-Y-B R	D/U	50	37	63	473
58	2,300-158-2Z-Y-B R	D/U	50	37	63	487
59	2,300-158-1Z-Y-B R	D/U	50	37	63	454
60	2,300-158-0.38Z-Y-B R	D/U	40	37	100	460
61	2 ends, 2,300-158-1.8Z-Y	D/U	40	37	100	460
62	Undrawn, 4,000-158-0	D/U	40	37	100	385
63	2,520-420-1/2Z-R	D/U	50	37	100	460
64	3,000-200-1/2Z-Y-SD	7	200	97	90	550
65	3,000-200-1/2Z-Y-SD	7	200	(1)	90	550
66	4,000-272-1/2Z-Y-SD	7	200	97	90	550
67	1,148-86-0	D/U	37	60	100	356
68	2,000-136-1/2Z-Y-SD	C/U	210	108	90	554
68a	2,000-136-1/2Z-Y-SD	C/U	700	41	100	602
	YARNS OTHER THAN 66 NYLON					
	DACRON					
69	220-50-0-5,600	60°, A/S	42	44	85	580
70	1,100-250-0-51	60°, C/S	98	47	85	572
71	1,100-250-0-51	60°, C/S	98	47	85	570
	ACETATE					
72	1,800-88-0-B R	D/U	50	75	90	450
73	1,800-88-.25-B R	D/U	200	60	80	400
	RAYON					
74	5,400	D/U	60	97	90	340
75	5,400	D/U	60	37	90	524
76	2,700	D/U	60	70	90	458
77	2,700	D/U	60	94	90	410

TABLE II.—Continued

Number:	Yarn	Jet	Feed speed	Percent Over-feed	Air Press.	Air Temp., °F.
	ORLON					
78	2 ends, 100-40-0.3Z-50	60°, A/R	50	42	60	300
	BLENDS					
79	1,800-88-0 BR Acetate, 1,050-79-0 SD Nylon	D/U	50	75	90	450
80	2,000-136-1/2Z-Y-SD Nylon / Plus 900-50 Rayon	D/U	50	82	90	424
81	2,000-136-1/2Z-Y-SD Nylon / Plus 900-50 Rayon	D/U	50	82 / 38	90	424
82	2,000-136-1/2Z-Y-SD Nylon / Plus 900-50 Rayon	D/U	50	38 / 82	90	422
83	55+45 Dacron-Wool-15cc. 12Z T.P.I	D/U	110	20	60	510
84	2/28 Turbo [2] 8Z-4S spun Orlon	DU	42	0	35	550
85	2/28 Turbo 8Z-4S spun Orlon	8	40	2	35	550
86	2/28 Turbo 8Z-4S spun Orlon	8	40	27	35	550
	AIR-BULKED YARN					
	NYLON					
87	1,050-79-1/2Z-Y-SD	D/U	50	76	85	180
88	2,000-136-1/2Z-Y-SD	D/U	51	76	85	220
89	2,000-136-1/2Z-Y-SD	10	50	76	85	320
90	2,000-136-1/2Z-Y-SD	10	240	76	85	440
91	2,000-136-1/2Z-Y-SD	10	900	[1]	85	800
92	2,000-136-1/2Z-Y-SD	10	900	[1]	85	640
93	2,000-136-1/2Z-Y-SD	10	900	[1]	85	640
94	2,000-136-1/2Z-Y-SD	D/U	51	76	85	327
95	2,000-136-1/2Z-Y-SD	D/U	51	76	85	353
96	2,000-136-1/2Z-Y-SD	D/U	51	76	85	458
97	2,000-136-1/2Z-Y-SD	D/U	100	76	85	350
98	2,000-136-1/2Z-Y-SD	D/U	150	76	85	530
99	2,000-136-1/2Z-Y-SD	D/U	200	76	85	516
100	2,100-112-0-BR	D/U	50	76	85	307
101	2,100-112-0-BR	D/U	50	76	85	325
102	2,100-112-0-BR	D/U	50	76	85	445
	DACRON					
103	1,100-250-0-51	D/U	50	96	85	255
104	1,100-250-0-51	60°, D/U	150	76	85	377
105	1,100-250-0-51	D/U	250	55	85	445
106	1,100-250-0-51	D/U	50	76	85	290
107	1,100-250-0-51	B/U	50	76	85	290
	ORLON					
108	100-40-3Z	60°, A/R	50	76	85	520
	RAYON					
109	1,350-150-BR	D/U	50	76	85	325
	ACETATE					
110	1,800-88-0-BR	D/U	50	76	85	190
111	1,800-88-0-BR	D/U	50	76	85	211
112	1,800-88-0-BR	D/U	50	76	85	355
113	1,800-88-0-BR	D/U	50	76	85	461
114	1,800-88-2S-BR	D/U	50	76	85	470
115	1,800-88-2S-BR	D/U	50	76	85	477
116	1,800-88-2S-BR	D/U	200	76	85	375
117	1,800-88-2S-BR	C/U	50	76	85	315

[1] Maximum.
[2] Turbo is the trademark for a stretch-break process of the J. L. Lohrke Co.

In the above table the term "Dacron" is the trade name of E. I. du Pont de Nemours and Company's polyester fiber. The fibers used in the table under this designation were homopolymers of ethylene glycol terephthalate. The term "Orlon" is E. I. du Pont de Nemours and Company's trade name for their acrylic fibers. The ones used in the table were copolymers containing more than 85% acrylonitrile and intermediate amount of a modifying comonomer such as methyl acrylate and a small percentage, usually less than three of a vinylarenesulfonate such as sodium or potassium styrene sulfonate. The 6-6 type nylon is a term used in the art to designate the number of carbon atoms in the components of the linear polyamide, and this type was used unless otherwise indicated.

In entries 11 and 12 of the above table the lower temperature produced a yarn of low bulk; whereas, the higher temperature produced a yarn of very high bulk. In entries 16, 17, and 18 the jet shown in FIG. 6 was used in each case but the lip **105** was adjusted in three different positions. In 16, the lip was as shown in FIG. 6; in 17, the lip was in an intermediate position; and in the third case, the lip was near the opposite wall. The first adjustment resulted in a relatively high crimp of about 16 per inch. The intermediate position produced about 10 crimps per inch and the third position produced only about 5 crimps per inch. In entry 45 the turbulent fluid was saturated steam. Normally condensation or the presence of liquid in the turbulent zone should be avoided.

In entries **23**, **24**, and **25**, crimps of 3, 8 and 15 per inch were obtained by using temperatures of 350°, 450°, and 510° F., respectively. In entry **27**, high bulk uniform crimp was produced; whereas, in entry **34** a lower bulk was obtained due primarily to tension applied to the yarn in the bulking zone of about 40 grams instead of less than 5 grams as in the preceding entries. In entries **32** to **41**, temperatures below 350° F. required post tensioning to obtain maximum bulk. The optimum bulk in this group is obtained with 10 to 15 crimps per inch at about 450° F. Above this temperature the bulk becomes less as the crimps become smaller and more frequent until fusion takes place above about 560° F., under the conditions given in entries **32–41**. Entries **44** to **50** illustrate conditions under which the jet was allowed to bulk the yarn under maximum overfeed with no take-up roll. In these entries the higher pressures produced higher bulk. At 50 y.p.m. at approximately 450° F. the highest bulk was obtained. An increase in speed generally reduces bulk unless fluid temperature and/or fluid flow rates are increased. Entry **52** produced a good bulk; whereas, entry **53** and **54** produced poorer bulk using a different jet, but the same yarn speed. Entries **55** and **56** both produced good bulk but the latter was slightly inferior to the former.

In entry **73** the yarn was fed directly from the spinning cell in the acetone plasticized condition to the turbulent fluid treatment. The bulky yarn packaged in a low tension state was deplasticized at room conditions for one week before use. It showed good crimped permanence.

Entries **57**, **58**, and **59** show that the yarn normally has less bulk as the yarn twist is increased. With respect to temperatures, bulking starts at about 150° F. Up to about 300° F. the yarn is characterized by numerous unstable loops which are removed by tensioning. Above about 300° F. the preferred yarn with greater bulk and few loops is obtained. At 50 p.p.m., temperatures above 480° F. produce less bulk due to more frequent and smaller crimps. Entry **61** produced less bulk than entry **60**. Entry **62** using undrawn nylon produced a yarn with poor bulk for pile carpet use but a suitable form of bulk for other applications such as upholstery stuffing materials. In entry **63** the bulk was fair but there were 5 to 8 crimps per inch while in entry **64** the bulk was poor and there were 3 to 4 crimps per inch. In entry **65**, the yarn was excellent with respect to bulking and number of crimps and it will be noted the feed speed was 200 y.p.m. In entries **110** to **112** as the temperature was increased the bulk became greater with a maximum bulking at 355° F. Entry **113**, where a temperature of 461° F. was used, showed slightly decreased bulk. In entry **115**, the bulk was low and in entry **116** the bulk was poor. In entry **117** the bulk was high. In some entries such as No. **87** where the turbulent fluid temperature is less than about 300° F. the crimp is formed to give a bulky yarn, but the crimp is less permanent than is required for many purposes. If greater crimp permance is desired, this may be imparted by a subsequent relaxed setting treatment.

In entries **89–93** the jet of FIG. 10 was employed producing yarns which in some instances showed the alternating false twist form indicated in FIG. 16. This is attributed to the twisting action of the T-shaped junction of the yarn and air holes in this jet and minor misalignment of the axes of these holes. The yarn form indicated in FIG. 16 may be preferred for frieze yarns imparting an attractive texture to carpets or other fabric forms. Control of the length of the false-twisted zones may be achieved by employing a jet of the type shown in FIGS. 4 and 5 in which the air flow is pulse at suitable intervals. Other jets suitable for imparting false twist to the bulky yarn of this invention are disclosed in copending application Ser. No. 598,135, now U.S. Pat. No. 3,009,309. The twisting jets may be combined with the bulking jets or used in sequence with them.

The yarn of entry **90** shows a variation of the above form. In this case the yarn bundle shows divided regions characterized by opposite directions of twist in the adjacent portions as indicated in FIG. 17. This is caused by the double eddy at the T junction of the jet of FIG. 10 indicated in FIG. 11. For those uses where maximum bulk is desired the false-twist structures of FIGS. 16 and 17 should be avoided.

In entry **70** the feed yarn of polyethylene terephthalate was prepared by a warm, wet, drawing process such that the filaments were maintained at a temperature during drawing below the second order transition temperature. This produced a well oriented but essentially amorphous yarn product. The crimp permance of the product of entry **70** was superior to that of the product of entry **71**. Entry **71** feed yarn differed from entry **70** feed yarn only in respect to the drawing method used. In entry **71** a draw pin heated to 230° F. was used to stretch the yarn producing a well oriented and highly crystalline yarn form.

Entry **91** was made at 900 y.p.m. using 800° F. air to produce a bulky extensible yarn with 38% crimp elongation. Entry **92** was similar but the air temperature was reduced to 640° F. and the yarn product showed reduced bulk and a crimp elongation of only 10%. In entry **93**, 20 amperes at 5 volts were applied to the preheater of the jet of FIG. 10, other factors remaining the same as entry **92**. The product of entry **93** showed greater bulk than entry **92** and a crimp elongation of 35%.

EXAMPLE V

Three ends of a 1000 denier—68 filament—zero twist—bright 6-6 nylon (round filament cross section) were passed simultaneously through jet of FIG. 8 using the process of FIG. 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 III. 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.

TABLE III.—EFFECT OF DRAW RATIO ON STEAM BULKING OF 6-6 NYLON YARNS*

	Bulked yarn denier			Percent yarn denier increase		Filament crimp elongation, percent		Denier per filament		
	Piddled	After tensioning	After tens. and boil-off	Piddled 40% overfeed	After tens. and boil-off	Piddled	After tens. and boil-off	Before bulking	After bulking	Filament shrinkage percent
Draw ratio of feed yarn:										
1X	4,617	4,610	4,898	54	63	75.1	67.3	15.0	13.2	−14.0
4.5X	4,468	4,468	5,058	49	69	32.1	42.9	14.2	15.7	+9.5
3.0X	4,538	4,538	5,310	51	72	30.4	53.5	14.3	16.0	+10.6
4.0X	4,720	4,720	5,517	57	80	36.0	59.1	14.5	16.3	+11.0
5.0X	4,380	4,380	4,905	46	64	37.3	66.4	12.8	14.6	+12.3

*All yarns were run with 3 ends of 1,000 denier through jet. Total feed yarn denier was therefore 3,000. All yarns were run with 40.5% machine overfeed, at 500° F., 45 p.s.i.g., and 110 y.p.m. feed speed.

The dyeing rates of the steam bulked yarns and of the feed yarns were determined by dyeing at the boil for 60 minutes with 2% of an acid dye Colour Index number acid blue 165,[1] 2% of a polypropylene oxide leveling agent and 2% "Duponol" [2] RA surface active agent (percent based on fiber). The percent dye on the fibers was determined by ultraviolet spectrophotometry using solutions of the fiber in 90% formic acid and measuring percent light transmission at 550 millimicron wave length. The steam bulked yarns dyed at a faster rate than the feed yarns. Part of this increased dyeability was due to deorientation of the molecular structure in the drawn yarns as evidenced by increased elongation and lower tenacity (see Table IV). But this deorientation did not account for all of the increase in dyeability; the steam bulked yarns had much higher dyeability than feed yarns with the same percent elongation. FIG. 19 shows the dyeing rates of feed yarns and steam bulked yarns as a function of break elongation. Curve A shows the relation of dyeing rate to filament break elongation in untreated 6-6 nylon yarns prepared at various draw ratios. Curve B shows the relation of dyeing rate to break elongation in a series of bulky yarns of this invention. Filament crimp elongation was not included in the break elongation. The dyeing rates were increased still more than shown in Curve B by using higher fluid temperatures, higher pressures or longer exposures

[1] The Colour Index, 1956.

[2] Trademark of E. I. du Pont de Nemours and Company for a sodium alkyl sulfate surface active agent.

in the jet (higher overfeeds, lower feed speeds). Conversely, milder conditions gave somewhat slower dyeing rates. Curve C represents theoretical yarns having 50% greater dyeing rate than the untreated yarns of Curve A. The preferred yarns are represented by the cross-hatched area above Curve C in FIG. 19. At the same time, the preferred yarns should have less than 200% elongation to reduce the pilling tendency in fabrics. The preferred non-pilling yarns lie to the left of Line D in FIG. 19.

Bulked yarns having high filament break elongations tended to pill readily in carpets as shown in FIG. 20. 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 FIG. 20 indicates 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%.

ercised. 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 through-put 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.

TABLE V.—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.	Yarn denier	Percent increase in yarn denier	Fiber crimp elong., percent	Crimps/in.
Number:													
1	2,300	158	0	Y (2.2MR)	7	37	200	603	108	4,340	89	59	10.7
2	2,300	158	0	Y (2.2MR)	7	100	200	610	108	5,169	125	110	11.1
3	2,300	158	0	Y (2.2MR)	7	150	200	610	108	5,188	126	115	12.9
4	2,300	158	0	Y (2.2MR) [5]	6	100	50	460	110	6,945	202	131	16.5
5	2,000	138	0	Y (2.2MR)	7	100	200	575	85	4,729	137	86	14.9
6	2,000	138	0	Y (2.2MR)	7	100	400	600	85	4,071	104	82	9.8
7	780	51	0.75Z	R	6	100	50	460	100	1,760	126	53	19.6
8	[2] 780	51	0.75Z	R	6	100	50	450	100	5,979	158	101	18.2
9	[2] 1,000	68	0	R	7	40.5	110	500	45	4,660	55	37	8.9
10	15	([3])	0	R	6	75	50	580	90	([4])	22	110	18.0
11	2,000	136	0.5Z	Y (2.2MR) [5]	6	76	50	353	[6] 85	5,395	170	152	21.0
12	[2] 1,000	68	0.4Z	R	7	41	110	500	45	5,022	67	59	7.9
13	[2] 1,000	68	0.4Z	Y (2.2MR) [5]	7	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] 1 Monofilament.
[4] 18.3 denier per filament.
[5] These feed yarns were SD Luster.
[6] Air was used as the turbulent fluid.

All entries were prepared using steam as the turbulent fluid except as noted.

TABLE IV.—DYEABILITY VS. PHYSICAL PROPERTIES OF FILAMENTS BEFORE AND AFTER STEAM BULKING

[All yarns dyed at boil before physical testing—C.I. Acid Blue 165 dyeing at boil 60 min.]

	Percent dye absorbed		Tenacity (GPD)		Break elongation percent		Initial modulus, GPD	
	Before	After	Before	After	Before	After	Before	After
Draw ratio:								
1×	1.64	1.65	1.56	1.30	413	326	11.4	8.9
2.5×	0.64	1.11	3.65	2.90	135	137	27.9	14.3
3×	0.43	1.16	4.29	4.18	103	118	30.3	17.3
4×	0.37	0.90	5.35	5.54	67	80	28.6	20.6
5×	0.30	0.86	7.80	7.30	63	73	38.0	20.0

EXAMPLE VI

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 V. 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.

EXAMPLE VII

Three ends of 780 denier—51 filament—0.75Z twist—round—bright 6-6 nylon were passed through the jet of FIG. 8 with 75% machine overfeed 50 y.p.m. feed speed at 508° F., 85 p.s.i.g. steam. The steam bulked yarn and the feed yarn were examined by X-ray techniques, using just enough tension to straighten the yarn crimp. The steam bulked yarn had a higher orientation angle than the feed yarn. The orientation angle was determined by measuring the degrees of angle of the inner equatorial arc at half maximum intensity. The arc increases as orientation decreases. The inner equatorial arcs were 17° and 13°, respectively, for steam bulked and feed yarn. The crystallinity of the feed yarn was high but the crystallinity of the steam bulked yarn was much higher. The increased crystallinity was also shown by an increase in the fiber density. The density of the steam bulked yarn was 1.148 and of the feed yarn was 1.145. Additional information on orientation was obtained by measuring the birefringence of filaments from a steam bulked yarn and from a feed yarn. The birefringence decreased in the steam bulking operation from 0.0628 to .0598, showing that deorientation had occurred and that this deorienta-

tion outweighed any increased birefringence resulting from increased crystallinity.

The angle of the inner arcs can be obtained in the range of 15° to 30° by adjusting the process conditions. Higher temperatures of the turbulent fluid tend to give lower crystalline orientation. It is preferred that the treated yarn have an orientation angle at least 2° greater than that of the feed yarn.

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 VII.

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

TABLE VII.—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 fils.	Twist	Den. per fila.	Jet of Fig. 6	Mach. over feed, percent	Feed speed y.p.m.	Temp., ° F.	Press., p.s.i.g.	Yarn den.	Percent inc. in yarn den.	Den. per filament	Fiber crimp elong., percent	Crimps/ in.
Polyethylene terephthalate (Dacron).	1,100	250	0	4.40	D/U	50	110	495	90	1,620	47.3	4.44	43.5	9.2
Polyacrylonitrile (Orlon).	100	40	0.3Z	2.50	D/U	26	38	408	48	378	26.0	2.58	52.5	10.1
Cellulose acetate	1,800	88	.25	20.4	D/U	60	200	400	80	2,686	29.0	18.9	47.5	9.8
Viscose	2,700	150	0	18.0	D/U	97	50	415	95	3,384	24.0	17.5	36.5	7.2

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

Considerably more information was obtained by studying the low angle X-ray patterns by the methods of W. O. Statton as described in 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 showed a higher amount of crystallite placement regularity in the steam bulked yarn when compared to the feed yarn. At the same time there was a great increase in the long space distance between crystallites along the fiber axis. The steam bulked yarn had a long space distance of 98 angstrom units and the feed yarn had a spacing of 86 angstrom units. The lateral order of the long lattice structure was very high in the steam bulked yarn and only moderate in the feed yarn, indicating greater distance between crystallites across the fiber axis. Long space distance along the axis can be adjusted to any value in the range 86 to 120 angstroms by adjusting the processing conditions. Higher temperatures and longer exposures give greater long space distance. It is preferred that the treated yarn have a long space distance at least four angstroms greater than the feed yarn.

EXAMPLE VIII

A 2100 denier 6 nylon yarn having 112 filaments and zero twist was passed through the jet shown in FIG. 6 The machine overfeed was 100% and the feed speed was 200 y.p.m. Three different processing temperatures were studied: 375° F., 435° F., and 515° F. The yarn processed at 375° F. had only moderate bulk. The yarn processed at 435° F. had high bulk and the yarn processed at 515° F. had very high bulk. Using this jet and this feed speed, it was not possible to process the yarn at temperatures as high as 550° F. without melting the yarn. The properties of the bulked yarn are show in Table VI.

TABLE VI.—STEAM BULKED YARNS FROM 6 NYLON AFTER TENSIONING AND RELAXED BOIL-OFF

	Bulked yarn	Filament crimp elong., percent	Crimps per inch	Denier per filament	Filament shrinkage, percent (based on original filament denier
Steam, temperature, ° F.:					
375	3,265	38.6	4.8	21.1	12.2
435	4,713	87.8	11.5	22.3	18.6
515	4,299	59.2	8.5	24.1	28.2

EXAMPLE IX

A number of different polymeric synthetic yarns were processed as shown in Table VII. 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

EXAMPLE X

A 6-6 nylon yarn having 2000 denier—68 filaments—zero twist—round cross section was passed through a pad bath containing dye liquor before going to the steam jet. The pad bath contained the following material:

	G.
Water	1000
Benzyl alcohol	35.0
Duponol surface active agent	0.25
Ammonium acetate	4.0
Anthraquinone Green GNN C.I. No. 1078	10.0

After passing through the pad bath, the yarn was squeezed through nip rolls to remove excess dye. The yarn went directly then to a jet as shown in FIG. 8. The steam temperature was 350° F., the feed speed was 50 y.p.m., and the pressure was 40 p.s.i.g. When the overfeed rate was maintained at zero percent, an unbulked uniformly dyed yarn was obtained. When the overfeed was set at 40%, a very bulky uniformly dyed yarn was obtained. The dyes diffused well into the filaments during steam bulking as shown by fiber cross sections.

EXAMPLE XI

The dyeing rate of a steam bulked yarn was compared to the dyeing rate of a feed yarn and of unbulked yarn which had been autoclaved at 30 p.s.i.g. for one hour at 265° F. without bulking. The feed yarn was 780 denier—51 filament—0.75Z—round—bright 6-6 nylon. It was bulked in the steam jet using 75% overfeed and 50 y.p.m. feed speed. The steam temperature was 500° F. and the pressure was 90 p.s.i.g. The yarns were dyed separately for ten minutes at the boil with 2% Anthraquinone Blue SWF [3], 2% polypropylene oxide leveling agent and 2% Duponol RA (all based on fiber). The bath was at a neutral pH and the bath to fiber ratio was 250:1.

The percent dye on fiber was determined using the tech-

[3] C.I. prototype 12.

niques of Example V. The analytical data are shown in Table VIII.

TABLE VIII

Yarn		Percent dye in fiber/ 10 min.	Percent increase in dye rate
Number:			
A	Autoclave 30 p.s.i., 265° F., 1 hr.	.035	+40
B	Feed yarn	.025	
C	Steam-bulked at 500° F	.057	+128

The data in the table show that the yarn which was bulked at 500° F. had 128% faster dyeing rate than the untreated feed yarn. The yarn treated in autoclave had a much lower improvement in dye rate than steam bulked yarn. The autoclave treatment was similar to the practice used in heat-setting frieze yarns for carpets.

EXAMPLE XII

The improved uniformity in dyeing which is obtained in the product of this invention was demonstrated in the following manner. The feed yarn was 1000 denier—68 filament—.38Z twist—Y (2.2MR) cross section—semidull 6-6 nylon. Samples of yarn taken from several pirns were air textured at room temperature by the method of U.S. No. 2,783,609 to Breen, issued Mar. 5, 1957, and were then tufted side-by-side in carpets. The carpets were dyed with 1% Anthraquinone Blue SWF as in Example XI. Various yarns in the carpet from different pirns showed several shades difference after dyeing. Yarns from the above pirns were bulked in steam by the process of this invention using three ends through a jet at 75% overfeed, 200 y.p.m., 565° F., and 85 p.s.i.g. The resulting steam bulked yarns were tufted side-by-side in carpets and dyed with Anthraquinone Blue SWF. There was no discernible yarn dye streaks in the tufted carpets after steam bulking.

EXAMPLE XIII

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 (4 sq. in. in area) 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 staple carpets of various weights and steam bulked carpets of various weights is shown in FIG. 21. The steam bulked yarns were much firmer to the hand in carpets of identical weight and this observation was confirmed by the Instron 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 FIG. 21, Curve A shows the work required to compress carpets of various weights prepared from staple yarns. The "total take-up" in FIG. 21 is the weight of tufted yarn in a square yarn of fabric and does not include the jute backing. Curve B shows the work required to compress steam bulked continuous filament yarns in carpet.

EXAMPLE XIV

Item A.—70–34–0–200 semidull nylon was processed with the jet of FIG. 6 having an R needle and a venturi with a diameter at point **101**, FIG. 6 of .029" and a diameter at point **100** of .042". An overfeed of 35.1%, a feed speed of 150 y.p.m., a steam temperature of 450° F. and steam pressure of 50 p.s.i.g. were used.

Item B.—70–34–1/2Z semidull yarn (Y cross-section yarn with 1.9 modification ratio) processed exactly as above.

Item C.—70–34–1/2Z semidull filament nylon unbulked control. The three yarns (A, B, and C) were woven as filling yarns with a pick gear of 72 in a stock nylon warp of 70–34–7Z semidull nylon reeded 104 ends per inch. Fabric was crab-scoured at the boil, frame dried and heat-set at 390° F., 20 second exposure, 5% under wet width and no overfeed. Yarn crimp properties are given in Table IX and fabric properties in Table X.

TABLE IX

	Yarn A	Yarn B	Yarn C
Fiber crimps per inch	8.3	17.9	0 [1]
Fiber crimp elong. (percent)	5.4	12.5	0 [1]

[1] As produced.

TABLE X

	Fabric		
	Item A	Item B	Item C
Finished construction (warp-fill.)	114 x 76	115 x 76	118 x 78
Finished weight (Oz./Yd.^{2})	1.92	1.96	1.99
Fabric thickness (inch)	0.0050	0.0055	0.0050
Opacity:			
I_R (Percent light reflected)	52	58	57
I_T (Percent light transmitted)	13	11	10
Fabric friction (vs. wool blanket)	0.53	0.63	0.47

Of these fabrics, Item B is preferred to Items A and C and Item A is preferred to Item C. Item B has greater bulk, opacity and friction. Friction of the fabric against a blanket is high enough to give improved performance as a sheet fabric, whereas, Item C does not approach the friction requirements for satisfactory sheet fabrics. The greater bulk and friction of Item B gives a pleasing, dry handle resembling that of silks, and these properties are desirable in apparel fabrics such as blouses and slip fabrics.

EXAMPLE XV

Item A.—840–140–1/2Z–700 bright nylon yarn was processed with the jet of FIG. 6 having a U needle and a C venturi. An overfeed of 44.6%, a feed speed of 150 y.p.m., a steam temp. of 440° F. and a steam pressure of 85 p.s.i.g., were used.

Item B.—840–140–1/2Z–700 bright filament nylon unbulked control yarn. These two yarns were knit on a 6-cut circular knitting machine (Jacquard) using a half-cardigan stitch. Fabrics 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 XI.

TABLE IX

	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 factor (cc./g.)	1.90	0.90
Fabric thickness (inch)	0.138	0.104
Opacity:		
I_R (percent light reflected)	81	63
I_T (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 XVI

A bulk yarn prepared from 2700 denier-180 filament-zero twist 66-nylon was prepared by the conditions of

Example VIII (515° F.). 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 inches. 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 XVII

A nylon tow of 80,000 denier and 20,000 filaments was fed at 2 yards/min. to a jet similar in cross section to FIG. 8. 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 α 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 of 86% and a fine uniform crimp of 22 crimps per inch. In relaxed form, this product had a bulkiness of 70 cm.^{3} per gram. It showed a fabric-like cohesiveness in both lengthwise and widthwise directions. Although the process rate in this example was low (2 yards/min.) the high denier (80,000) was such as to give reasonable productivity expressed in denyards/min. which is the product of denier times yards/min. In this instance the productivity was 160,000 denyards/min.

EXAMPLE XVIII

40 ends of 2000–156 nylon yarns were fed to the jet of Example XVII through a comb-like multiple guide within the opening **119** so as to maintain the yarns separated from each other prior to contact with the turbulent fluid. Other factors were the same as Example XVII. The 40 ends were wound as individual bulky yarns on a spool in the form of a warp sheet. The ends retained their individuality and could be fed to individual needles of a fabric-tufting machine.

EXAMPLE XIX

A 15-denier 66 nylon monofilament yarn modified as in entry **1** Table II 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 texture 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.

There is a well-defined relationship between the diameter of the yarn being treated and the diameter of the jet orifice which produces the optimum bulking. Table IX shows several examples of a preferred jet for a given type of yarn. From this material, it may be inferred that the optimum orifice is between about 1.5 and 10 times the diameter of the unbulked yarn, with a preferred range of between 2 and 6. For heaviest denier yarns bulked at highest speed, the optimum diameter sometimes is too small to allow the turbulent fluid to exhaust as freely as is desired. Accordingly, it is sometimes preferred to provide separate exhaust ports for the texturing fluid around the periphery of the orifice. These exhaust ports should be kept small and should be positioned at an angle to the yarn path so that the yarn does not tend to exhaust through them. For good operability it is important that the yarn path through the jet should be relatively unobstructed and smooth to prevent snagging and choking.

TABLE XII

	Nylon yarn count	Yarn diameter, mils,	Jet orifice diameter, mils	Remarks—bulk yarn
Example No.:				
201	280–136	10	55	High.
202	280–136	10	76	Medium.
203	200–68	8	76	Do.
204	200–68	8	93	Low.
205	840–140	17	76	High.
206	840–140	17	99	Medium.
207	2,000–136	27	76	High.
208	2,000–136	27	99	Medium.

Conversely a uniformly controlled degree of choking seems to be desirable. This is associated with the filaments splashing against the interior wall of the venturi and can be controlled by careful adjustment of the yarn tube position with respect to the orifice. The splashing can initiate convolutions which tend to be restricted in their passage particularly through the smaller diameter region of the jet orifice. Factors affecting friction between the filaments and the jet wall such as yarn finish and surface roughness of the jet wall tend to influence this effect. Eccentric fluid forces within the jet tending to throw the filaments against the jet wall are similarly influencing. The initiated convolution may then be increased in amplitude during the passage of the yarn through the venturi particularly when the exit angle α illustrated in FIG. 6 is relatively large.

It will be noted that in the several jets shown in FIGS. 6 through 12 that the yarn enters at an angle to the air stream in some cases and co-axially in others. These jets operate in similar fashion irrespective of this feature indicating that the angle of entry is unimportant. These jets also have the common feature that the air and yarn exhaust together but the process is operable with even such extreme variations in jet design as indicated in FIG. 10 wherein the entry port for the turbulent fluid **142** is continued beyond the yarn passageway in such a manner that the turbulent fluid exhausts preferentially through an orifice coaxial with hole **142**. In this case the yarn entry angle to the air stream is 90° and the yarn exhausts from a port other than the exhaust port for the turbulent fluid. Similarly several entrance and exhaust ports for the turbulent fluid may be located at intervals along the yarn passage with entrances and exhausts either aligned or staggered. The entrance of the fluid in this case may also be in the same or opposed directions in a single plane or in a number of planes passing through the axis of the yarn passageway. Fluid ports in jets of this design may be disposed at any desired angle to the yarn.

Throughout the series of examples there is considerable variation in yarn composition, yarn denier, yarn speed, steam temperature, and steam flow rate. These variables can be correlated through considerations of heat transfer. For complete setting, a certain minimum temperature must be experienced by the yarn. Within 66 nylon this temperature is in the order of 300° F. At high speed, with heavy denier yarns the mass flow rate of the yarn can be so great relative to the mass flow rate of steam through the jet that in sufficient heat is available to bring the yarn to the desired temperature. This can be expressed in the form of an equation as follows:

$$MFR_s \times HC_s \times (T_4 - T_2) \geqq MFR_y \times HC_y \times (T_2 - T_1)$$

where:

T_4=Superheated steam temperature
T_2=Desired yarn temperature
T_1=Starting yarn temperature
HC_s=Heat capacity of steam
HC_y=Heat capacity of yarn
MFR_s=Mass flow rate of steam
MFR_y=Mass flow rate of yarn

T_2 should be at least about the second order transition temperature (T_g) and preferably above the (cold point) of the polymer in question as hereinbefore defined.

The above equation indicates the importance of preheating since a yarn preheater in effect increases T_1 and reduces the value of T_2-T_1. In the high speed examples given in Table II entry No. 93, it was necessary to use the preheater built into the jet design (FIG. 10) to get effective bulking. This helped to compensate for the limited steam flow rate inherent to the jet design and dimensioning. It may, also, be noted that the steam temperature (800° F.) used at very high yarn throughputs was far above the yarn melting point. Accordingly temperatures well above the melting point of the yarn are operative.

Care must be taken, however, to avoid excessive heating of the yarn since this tends to produce a fused product with filaments stuck together reducing bulk and imparting undesirable hardness or in severe cases a yarn no longer useful in normal textile applications.

The mathematical relationship indicating the upper limits of heating are not as readily defined since the efficiency of heat transfer between the hot fluid and the yarn can vary over wide limits. Calculation indicates that the efficiency level in the preferred process is at least 50%. This is indicated in the following equation.

$$MFR_s \times HC_s \times (T_4-T_3) \leqq 2[MFR_y \times HC_y \times (T_3-T_1)]$$

In this case, T_3 represents the crystalline melting point of the fiber being tested or the interfiber fusion temperature if this is lower.

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 filamet bulky yarn is simply and economically prepared, by 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 artifical fibers, enables them to replace expensive or scarce fibers in many uses. An additional saving in yarn weight is realized intufted material 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 yarn with a desirable blend of fiber characteristics. Intermittent impulsing of the multifilament 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 in Ser. No. 610,546, filed Sept. 18, 1956, by Field, now Pat. No. 2,931,090.

The simplicity of the new process permits its use at any point in yarn manufacturing or winding with no interruption of processig routine ad little outlay for new equipment. Distinct advantages of the process are that it requires little supervision, demands very little maintenance because of its freedom from moving parts, and does not require humidity control.

It will be apparent that many widely different embodiments of this invention may be made without departing from the spirit and scope thereof, and therefore it is not intended to be limited except as indicated in the appended claims.

We claim:

1. In the process of imparting a persistent crimp to synthetic linear polymeric filaments of a yarn by feeding the yarn to a stream of a compressible fluid, jetted into a jet device at 20 to 200 pounds per square inch gage pressure and at a temperature of at least about 400° F. to form a turbulent plasticizing region, and then taking up the yarn, the improvement for the preparation of continuous filament yarn having a bulkiness greater than staple yarn spun from comparable fibers, wherein the improvement comprises feeding 0 to 1 turn per inch twist yarn of said continuous filaments eccentrically to the stream so that the yarn entering the stream is subjected to eccentric fluid forces, the yarn being fed at a rate at least 30% greater than the yarn take-up speed so that the filaments are separated and whipped about by the stream in the turbulent region, removing the filaments from the hot stream before the treated yarn has travelled appreciably beyond the jet device and then cooling the filaments under low tension, to crimp the filaments individually, and thereafter cross-winding said yarn into a package.

2. The process of claim **1** in which the filaments, after cooling under low tension, are tensioned to remove any loops and the yarn is wound-up under tension to form a package.

3. The process of claim **1** in which the fluid is air.

4. The process of claim **1** in which the fluid is steam.

5. The process of claim **1** in which the filaments are made of a crystallizable thermoplastic synthetic linear polymer.

6. The process of claim **5** in which the treated filaments have a lower degree of orientation and a higher degree of crystallinity than they had before the fluid treatment.

7. The process of claim **5** in which the filaments before treatment are substantially amorphous and oriented, and after treatment with the turbulent fluid are crystalline and oriented.

8. The process of claim **1** in which the yarn travels at a rate greater than about 200,000 den-yards per minute.

9. The process of claim **8** in which the yarn is of more than 50,000 denier.

10. The process of claim **1** in which the filaments are passed directly from the spinning operation to the fluid stream.

11. The process of claim **1** in which the crimp configuration of the filaments is equivalent to a filament crimp elongation of at least 15%.

12. The process of claim **1** in which the feed yarn is

taken from a yarn drawing process to the turbulent fluid stream without intermediate packaging.

13. In the process for increasing the bulk of synthetic linear polymer multifilament yarn, wherein the yarn is fed into a chamber of a jet device, a compressible fluid at a temperature of at least 300° F. is jetted into the chamber from an orifice under sufficient pressure to separate and crimp the filaments while in a plastic state, and the treated yarn is withdrawn from the hot fluid at a rate providing an overfeed of yarn into the chamber; the improvement therein which comprises feeding yarn composed of filaments having non-round cross sections into the chamber to enter the fluid off-center with respect to the axis of said fluid orifice, jetting compressible fluid at a temperature of about 350° to 610° F. through the orifice to impart crimp and randomly twisted configurations along individual filaments, with portions twisted at an average angle of at least 1° in an S direction and other portions in a Z direction, and withdrawing the yarn from the hot fluid at a rate providing an overfeed within the range of about 40% to 150%.

14. The process defined in claim 13 wherein the yarn is fed at a speed of about 100 to 400 yards per minute into an eccentric flow of fluid jetted at a temperature of at least about 500° F. and a pressure of at least 40 pounds per square inch gauge to provide a yarn which is increased in denier about 100% to 200% without filaments being stuck together, and which is characterized by filaments having alternate S and Z twist sections throughout the length; having a random number of turns between twist reversals; having a random continuously varying angle of twist along the 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°.

15. The process of claim 1 in which the filaments, after treatment in the turbulent plasticizing fluid and prior to any further operation that imposes tension on the yarn, are piddled onto a moving belt and cooled thereon.

16. The process of claim 1 in which the filaments, after treatment in the turbulent plasticizing fluid and prior to any further operation that imposes tension on the yarn, are piddled onto a moving screen and cooled thereon.

17. The process of claim 1 in which the filaments pass from the hot turbulent region to a cooling jet and are cooled with flowing fluid prior to imposing any substantial tension on the crimped filaments.

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