MANUFACTURE OF TAPERED FILAMENTS

Filed April 29, 1943 3 Sheets-Sheet 1

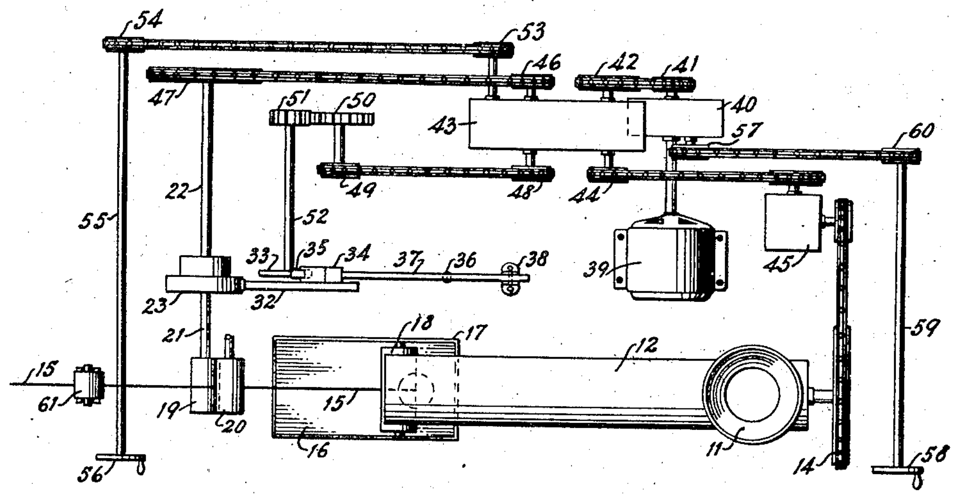

Fig. 1p

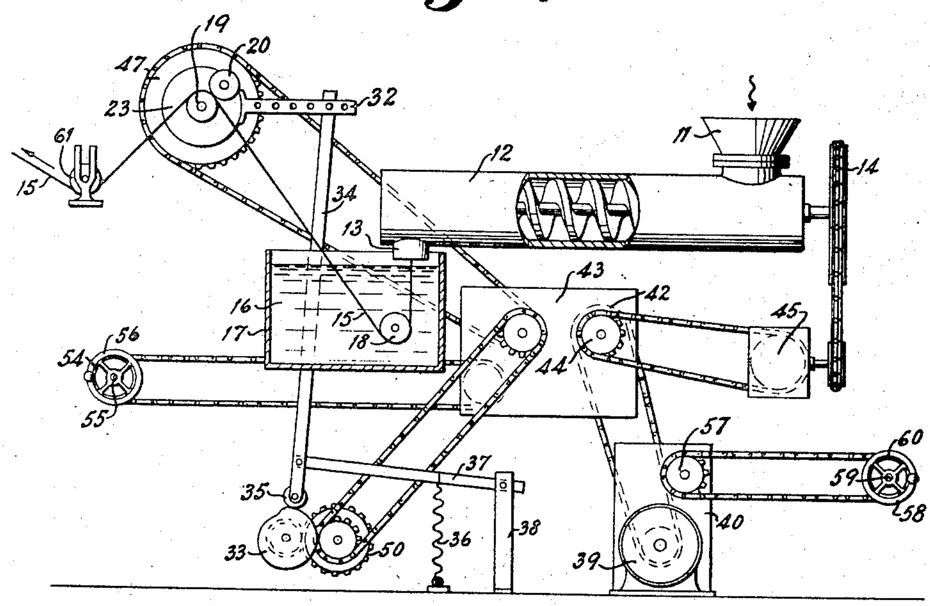

Fig. 1e

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April 8, 1947. J. ALFTHAN ET AL 2,418,492
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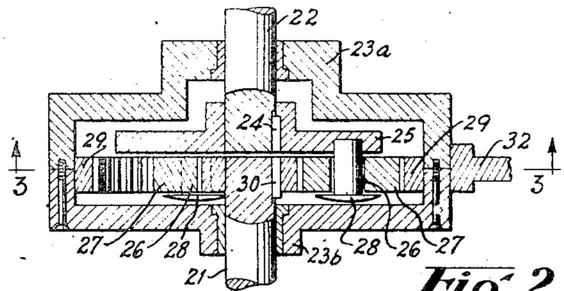


Fig. 2

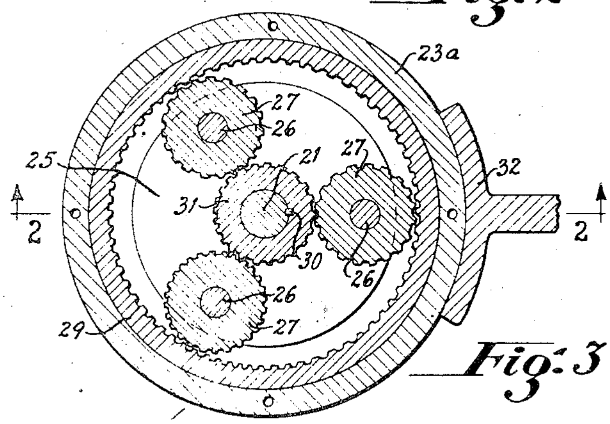
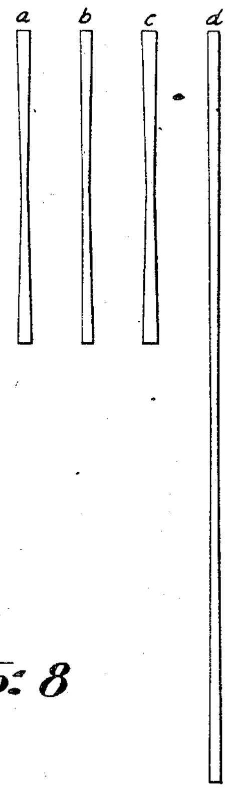


Fig. 3

Fig. 4



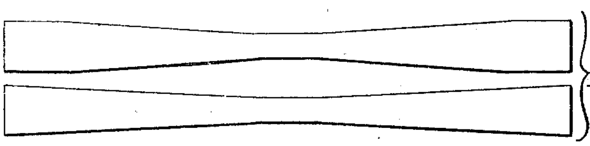


Fig. 8

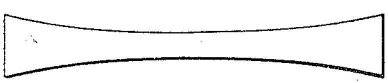


Fig. 7

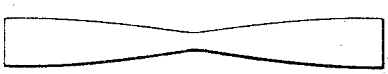


Fig. 6

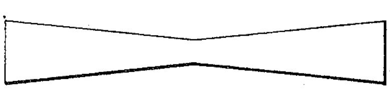


Fig. 5

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MANUFACTURE OF TAPERED FILAMENTS

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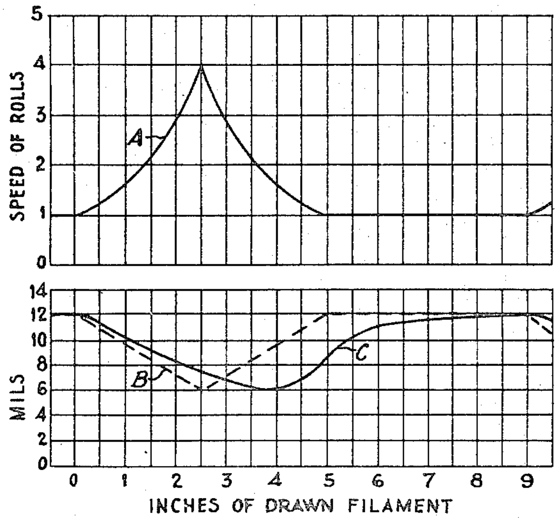

Fig. 9

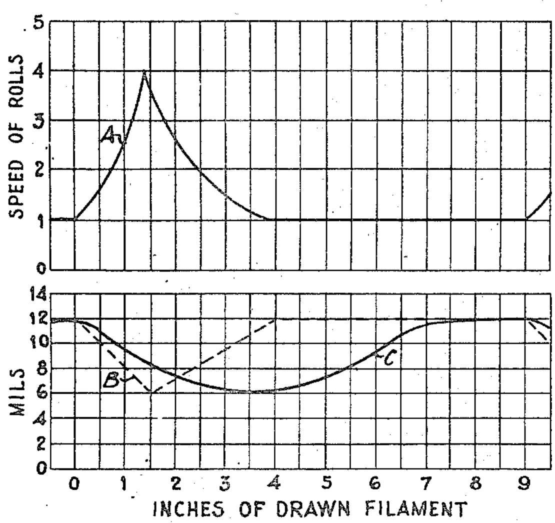

Fig. 10

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UNITED STATES PATENT OFFICE

2,418,492

MANUFACTURE OF TAPERED FILAMENTS

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Application April 29, 1943, Serial No. 485,024

6 Claims. (Cl. 18—8)

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This invention relates to synthetic filaments having uniformly recurring tapered units. More particularly, it relates to filaments composed of synthetic linear polyamides capable of being cold-drawn, which have uniformly recurring tapered units disposed lengthwise therein. Still more particularly, it relates to a method of producing filaments with uniformly recurring symmetrical tapered units in lengths suitable for the manufacture of tapered bristles.

Tapered filaments have considerable utility in the art and there is a constant demand for them in the trade, especially those of bristle lengths. Until recently the only source of tapered bristles has been from hogs. The supply of such bristles is uncertain, at best. Since the coarseness, length, and taper of hog bristles are variable, it is necessary that this natural product be laboriously sorted into grades and length. Because of the more uniform size, shape, and form of tapered synthetic polymer bristles, they have replaced the natural bristles for many brush purposes.

The prior methods of preparing tapered filaments, especially those having a short unit length which are suitable for bristle purposes, have some disadvantages. The solvent methods and coating methods do not produce a satisfactory taper, require constant attention, and require considerable time. The extrusion from a spinneret uniformly varying at repeated regular intervals has a disadvantage that a grading and trimming of the bristles formed becomes necessary.

It is an object of this invention to improve the art of making tapered filaments. Another object is to provide a method of making filaments having recurring tapered units which have an approximately symmetrical taper. A further object is to provide a filament having recurring tapered units which can be cut without waste into brush bristles. A still further object is to provide a method of preparing filaments having uniformly recurring tapered portions of a contour which can be varied over a wide range by simple adjustment. Yet another object is to provide simple apparatus for the attainment of the foregoing objects with which one can effect a wide range in the character and unit length of taper in a recurring tapered filament. Still other objects will be apparent from the following description of the invention.

It has been found that improved filaments of uniform shape, size, and properties having uniformly recurring symmetrically tapered portions may be produced by extruding organic filament-forming material in molten condition and at a

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constant volume rate through a spinneret across a gap into a cooling bath whereby it becomes solidified to constitute a filament, and directly withdrawing said filament from its zone of origin according to a schedule of repetitive linear rates which includes in sequence a period of acceleration from a minimum to a maximum rate, a period of deceleration to the minimum, which latter period is substantially longer than the period of acceleration, and a period of uniform withdrawal at the minimum rate.

It has been found that when the period of deceleration is substantially equal to that of acceleration, then the taper of the recurring units in the filament is distinctly unsymmetrical. However, if the period of deceleration is made substantially greater, a symmetrical unit tapered shape can be obtained. Moreover, if the schedule of rates does not include the period of uniform withdrawal at the minimum rate, the diameter of the filament fails to reach maximum value desired.

The invention may be conveniently carried out by equipment which comprises a vertical spinneret facing downward, means (e. g., a screw pump) for extruding filament-forming material in molten condition at a constant volume rate through said spinneret, a cooling bath of inert liquid (conveniently water) located below the face of said spinneret in close proximity to, but not in contact with, said face, separated therefrom by an air gap, means (such as a pair of pinch rolls) for withdrawing filament from said bath under a tension transmitted to the zone of origin of said filament, and means of effecting the withdrawal of filament in accordance with a schedule of rates, as specified above.

The distance between the face of the spinneret and the free surface of the cooling bath, i. e., the width of the air gap, is preferably between one-eighth and three-eighths inch, and generally not in excess of one inch. The temperature of the cooling bath should be materially below the solidification temperature of the filament-forming material. It may conveniently be between 15 and 25° C., but substantially higher temperatures than 25° C. are useful.

In a practical apparatus, the filament is withdrawn from its point of origin by passage between a pair of pinch rolls, and the means provided for increasing and decreasing the rate of rotation of these pinch rolls to provide the periods of acceleration and deceleration, which comprises a planetary gear train, of which the intermediate members, as a group, are rotated at constant rate, the central member determines the rotation of the pinch rolls, and the annular member bears a radial arm which is raised and lowered by action of a cam.

The resulting alternating rotations of the annular member of the planetary gear train result in geometrically calculable acceleration and deceleration of the rotational speed of the pinch rolls and hence of the linear rate of withdrawal of filament from its point of origin. The figure of the cam is calculated to effect the withdrawal of the filament in accordance with a schedule of rates rather than on the geometry of the system.

The invention will now be described in more detail with reference to the accompanying drawing wherein similar reference numerals refer to similar parts throughout the several views, but it is to be understood that this description is given by way of example and is in no respect limitative.

Figure 1*p* is a plane view of apparatus suitable for carrying out the process;

Figure 1*e* is an elevation view of such apparatus with parts shown in section;

Figure 2 is a cross sectional view of a system of planetary gears for controlling the drawing of the spun filaments, taken along the line 2—2, of Figure 3;

Figure 3 is a cross sectional view of the system taken along the lines 3—3 of Figure 2;

Figure 4 is a longitudinal profile view of a unit length of four different tapered filaments which can be made with the apparatus;

Figure 5 is a similar view of a modified tapered filament unit;

Figure 6 is a similar view of a further modified tapered filament unit;

Figure 7 is a similar view of a further modified tapered filament unit;

Figure 8 is a similar view of a further modified tapered filament unit;

Fig. 9 is a graph indicating the relationship between the rate of withdrawal of a filament from its point of origin and the diameter of the filament when a symmetrical schedule of acceleration and deceleration of withdrawal is employed; and

Fig. 10 is a graph similar to that of Fig. 9 except that it shows the relationship when a schedule of acceleration and deceleration of withdrawal according to the present invention is employed.

The polymer is extruded in molten form through a spinneret at a constant volume rate from a suitable equipment comprising a melting grid **11** into which the filament forming material is fed and from which the molten polymer is delivered into the casing of a screw pump **12**, which delivers it to a spinneret **13**. The screw pump **12** is driven through a sprocket **14** by means presently to be described. In these figures the spinneret **13** is shown as delivering a single filament **15**, but in practice it is advantageous to spin a plurality of filaments instead of only one.

The molten material emerging from the spinneret **13** passes vertically downward across an air gap into a bath **16** of water, or other inert liquid, and becomes solidified to constitute the filament **15**. The vessel **17** which contains the bath **16** can be provided with an overflow pipe or other means for maintaining the level of the surface of the bath at a fixed distance below the spinneret **13**. This distance is preferably small, e. g., from one-eighth to one inch.

The filament **15** passes around an idler roll **18** mounted within the bath **16** and thence upward out of the bath **16** between pinch rolls **19** and **20**, of which **19** is driven, by means presently to be described. The roll **20** is held against **19** by e. g., weight or the tension of a spring or by other equivalent means, and may be geared to **19** if desired. The rotation of these pinch rolls, **19** counterclockwise and **20** clockwise in the drawing, provides the pull upon the filament **15** which carries it away from the spinneret **13** and through the bath **16**. Roll **19** is mounted on shaft **21** to which it is keyed.

The temperature and viscosity of the molten material in the screw pump **12** is made uniform and the screw pump **12** is driven at a steady rate so that the volume rate at which the molten material is extruded through the spinneret **13** is uniform. If the angular velocity of the pinch rolls **19** and **20** is also made uniform, the filament produced will be of uniform diameter. The periodic tapering of the filament formed, however, is accomplished by regularly and uniformly varying the angular velocity of the pinch rolls **19, 20**. To this end there is provided a shaft **22**, coaxial with the shaft **21** and rotating at a constant speed, a planetary gear train, of which only the housing **23** is shown in Figures 1*p* and 1*e*, but which is shown in detail in Figures 2 and 3, and means of imparting predesigned non-uniform angular motion to the annular member of the gear train.

The gear train and parts immediately associated therewith are shown in Figure 2 and Figure 3. Attached to the driving shaft **22** by a key **24**, so as to rotate with the shaft **22**, is a disc **25** fitted with three pins **26** located 120° apart on the circumference of a circle concentric with the shaft **22**. Mounted upon these three pins **26** are three intermediate gears **27**. Each of these gears **27** is free to rotate upon its pin **26**, and the pins are provided with heads **28** to hold the gears in position upon them. The gears **27** mesh with the interior of an annular gear **29**, which is attached to a housing member **23*a***, through which passes, with minimum friction, the shaft **22**.

To the end of the driven shaft **21** is attached, by means of a key **30**, a central gear **31**, of such size as to mesh with the three gears **27**. The housing of the train of gears is completed by the member **23*b***, which is fastened to the housing member **23*a***. The shaft **21** passes through the housing member **23*b*** with minimum friction.

If the housing **23** is held stationary, then rotation of the driving shaft **22** at a steady rate is transmitted through the train of gears and brings about uniform rotation of the drive shaft **21**, hence of the pinch rolls **19** and **20**. Counterclockwise rotation of the shaft **22** causes counterclockwise rotation of the disc **25** and the system of pins **26**. With the housing **23*a*** stationary, and with it the annular gear **29**, the counterclockwise rotation of the system of pins **26**, around each of which the respective gear **27** is free to rotate, will cause clockwise rotation of each of the gears **27**, and this in turn will cause counterclockwise rotation of the gear **31**, and hence of the shaft **21** to which the latter is attached.

When the housing **23** and annular gear **29** are moved, however, the motion of the annular gear **29** introduces another component into the rotational motion delivered to the shaft **21**. If, with the shaft **22** rotating counterclockwise at a steady rate, the annular gear **29** be rotated clockwise, then, during such motion of the annular gear, and in accordance with its rate, the angular velocity of the rotation of the intermediate gears

27 about their pins 26 will be increased, and thereby the rate of rotation counterclockwise of the central gear 31, and of the shaft 21, will be increased. If, on the other hand, the annular gear 29 be moved counterclockwise, then, during such movement and proportion to its rate, the rotational speed of the gears 27 about their pins 26, and hence that of the gear 31 and of the shaft 21 will be decreased.

The rotational speed of the pinch roll 19, which is mounted upon the shaft 21, thus can be alternately accelerated and decelerated in controlled manner by suitably rotating the annular gear 29 alternately clockwise and counterclockwise. A small angular rotation of the latter can be made to produce a relatively large angular acceleration or deceleration of the former.

Since the diameter of the filament 15 should vary (theoretically) inversely as the square root of the speed at which it is carried away from the spinneret, alternation of clockwise and counterclockwise motion of the annular gear 29 should cause the filament 15 to exhibit alternate decreases and increases in diameter, thus producing uniformly disposed tapered units in the spun filament. Controlled motion of the annular gear 29, alternately clockwise and counterclockwise, is accomplished by alternately lowering and raising a lever arm 32 which is rigidly attached to the housing 23.

For the purposes of the invention, sufficient variations in the speed of rotation of the pinch roll 19 are secured by rotating the annular gear 29 back and forth within a rather small angle; if, for example, the pitch diameters are, for 29, 27, and 31, 3 inches, 1 inch, and 1 inch, an amplitude of ten degrees or less will be enough in most cases. This movement could be produced by holding the lever arm 32, or a bearing surface attached directly thereto, in contact with a cam of predesigned figure. In the preferred embodiment of the invention, however, as illustrated in Figures 1*p* and 1*e*, there is provided a cam, 33, which transmits motion to the lever arm 32 through an interposed member or push rod 34. It may be attached to the lever arm 32 by the use of any one of a plurality of holes along the length of the latter. The lower end of the member 34 carries a roller 35 which bears upon the surface of the cam 33, and its contact therewith at all times is ensured by the tension of a spring 36 attached to an auxiliary lever 37, of which one end is pinned to the member 34 and the other to a stationary fulcrum 38. A selection from among the available holes in the lever arm 32 results in a corresponding selection in the amplitude of the motion imparted to the lever arm 32 by rotation of the cam 33.

The various parts of the equipment are preferably driven from a single source of power, in order that their synchronization may be preserved. In Figures 1*p* and 1*e* the source of power is a constant-speed motor 39, directly connected to a variable-speed reducing gear 40, beyond which all drives are by sprocket and chain or by meshing gears, in order to ensure unvarying maintenance of desired ratios. The reducing gear 40, through its sprocket 41, drives, through sprocket 42, a variable-speed transmission 43, which in turn supplies power to extrude the molten material, to rotate the pinch roll 19, and to rotate the cam 33 which controls the variation in rotational speed of the pinch roll 19.

The sprocket 44 of the variable-speed transmission 43 transmits power through a right angle drive 45 to the sprocket 14 on the shaft of the screw pump 12. The sprocket 46 of the variable-speed transmission 43 drives the shaft 22 through the sprocket 47. The sprocket 48 of the variable-speed transmission 43 drives a countershaft 49 which, through meshing gears 50 and 51, drives the shaft 52 upon which is mounted the cam 33.

An adjusting wheel 53 on the variable-speed transmission 43 provides for making changes in the ratio of speed between the two shafts which carry, respectively, the sprockets 42 and 44 and the sprockets 46 and 48. For convenience, this adjusting wheel 53 is connected through a sprocket 54 on shaft 55 with a hand wheel 56, by which the necessary adjustments can readily be made. An adjusting wheel 57 on the reducing gear 40 provides for making changes in the speed of the system as a whole. For convenience, a hand wheel 58 is provided for the operation of this adjusting wheel through a countershaft 59 and sprocket 60. At the start of a run, the system is operated at a low rate of speed until the filament is threaded and any adjustments are made, and then, by operation of the hand wheel 58, the system is speeded up without altering the relations between the speeds of individual parts.

A weighted roller 61, free to move upward and downward, serves to maintain a light tension upon the filament beyond the pinch rolls 19, 20 and to convert the fluctuating linear speed of the filament leaving these rolls into a steady linear speed in its delivery to a windup reel (not shown) or to the next operation.

The melting grid 11 and screw pump 12 may be jacketed, if desired, and similar in construction to that in U. S. P. 2,295,942.

When any given cam 33 is used with the equipment of the invention, the character of the tapered filament produced can be varied in three respects.

1. As has already been mentioned, the amplitude of the oscillation of the lever arm 32 may be varied by attaching the member 34 to the arm 32 at different points along the length of the latter. This affords a means of control of the gradient of the taper, and thus of the difference between the largest and smallest diameters of the filament, without changing the distance between successive points of maximum (or of minimum) diameter (the unit length) and without changing the volume or weight of material contained in such a unit, and without changing the general character of the taper. A difference produced by this means is illustrated by the profile sections of unit lengths of filaments *a* and *b* in Figure 4. The change from section *a* to section *b* is accomplished by reducing the amplitude of the oscillation of the arm 32.

2. A change in the volume of material contained in a unit length of filament may be made by altering the ratio between the speed of sprockets 46, 48 and the speed of the sprocket 14. Such a change is illustrated by the difference between the longitudinal sections *a* and *c* in Figure 4, accomplished by decreasing the rate of takeoff without changing the rate at which the screw pump 12 forces molten material through the spinneret 13.

3. A change in the unit length, without change in volume per unit length, is effected by altering the speed of rotation of the cam 33. This is accomplished very simply by substituting for the gears 50 and 51 another pair having a different

ratio (if, instead of by meshing gears, the shaft 49 drives the shaft 52 through sprockets and chain, then by changing one or both of the sprockets). A change in the longitudinal section of a filament resulting from reducing the rotational speed of the cam is illustrated by a comparison of the longitudinal sections *c* and *d* in Figure 4.

By the use of a cam of appropriate figure, tapers of various kinds may be produced, including approximations of straight or wedge-shaped (Figure 5), convex (Figure 6), concave (Figure 7), or desired combinations of these, or a filament (Figure 8) in which tapered sections alternate with untapered.

In the case of tapered filaments which have untapered portions, the term "point of maximum diameter" is to be understood to be the point midway in the length of an untapered portion of maximum diameter. In Figures 4–8, all of the unit lengths are shown as having been cut at the respective points of maximum diameter.

An important feature of the invention, with respect to the control of the profile of the filament produced, is based upon the discovery that, although the magnitudes of the maximum and minimum diameters of the filament are, as expected, approximately inversely proportional to the square roots of the respective minimum and maximum linear rates of withdrawal of the filament from its point of origin, yet the slopes and lengths of the tapers between points or zones of maximum and minimum diameters do not match those which, on the basis of geometrical calculations, should theoretically be produced by a given schedule of acceleration and deceleration of the rate of withdrawal of the filament from its point of origin. The deviation is a systematic one, in that the decrease in diameter of the filament proceeds at a rate less rapid than that calculated on a geometrical basis from the rate of the acceleration of withdrawal by which it is caused, and also continues for a longer time, while the subsequent increase in diameter of the filament proceeds for the most part at approximately the rate calculated on a geometrical basis from the rate of the deceleration of withdrawal by which it is caused, and thus is largely, although not altogether, completed within a period of time equal to, but not coinciding with, that occupied by the deceleration of withdrawal.

These relationships are indicated diagrammatically in Figures 9 and 10, in each of which the abscissae are inches of length of filament (after the subsequent step of drawing), and the solid line A represents a schedule of rates of withdrawal of the filament (linear speed as ordinates), the dotted line B represents the profile of the filament which should theoretically be produced by that schedule (mils of diameter as ordinates), and the solid line C represents the profile of the filament which is actually produced (mils of diameter as ordinates). The line C is placed in the diagram so that the beginning of its downward taper coincides with the point at which this taper should theoretically begin. It is not practicable to verify this assumption that the diameter of the filament begins to decrease at the moment when the rate of withdrawal begins to increase, but this reasonable assumption is convenient for the comparison of lines B and C and its validity is immaterial.

Figure 9 illustrates the fact that a symmetrical schedule of acceleration and deceleration of withdrawal results in a filament of distinctly unsymmetrical profile. The schedule 9A of acceleration and deceleration should theoretically produce a taper of profile represented by 9B, with a straight line decrease of diameter between 0 and 2.5 inches along the filament, followed by a straight line increase between 2.5 and 5 inches, and this in turn followed by a span of no taper between 5 and 9 inches, at which point the cycle begins again. A filament of the profile 9B would be symmetrical with respect to the point of minimum diameter (at 2.5 inches) and with respect to the midpoint of the untapered section (at 7 inches).

The filament actually produced, however, has the profile indicated by 9C, made up of a section of decreasing diameter from 0 to about 4.0 inches, a section of relatively abrupt increase in diameter from about 4.0 to about 6.0 inches, and a section of approximately uniform diameter from about 6.0 to 9 inches. This filament is obviously not of symmetrical taper, and a unit length of it cannot be cut into two filaments of equal lengths and substantially matching tapers. From the point of minimum diameter (at 4.0 inches) to the midpoint of the untapered section (at 7.5 inches) is 3.5 inches in one direction and 5.5 inches in the other.

Also, the total distance occupied by the downward and upward tapers of the actual filament 9C is about 6 inches as against the 5 inches which would have resulted from theoretical performance, 9B, and correspondingly the untapered section is actually 3 inches long instead of 4 inches.

In accordance with the invention an approximately symmetrically tapered filament is produced by the use of a schedule of acceleration and deceleration which is unsymmetrical in that the acceleration is made more rapid than the deceleration, and which compresses the period of acceleration and deceleration into a shorter part of the cycle than that corresponding to the actual downward and upward tapering desired in the filament. This is illustrated by Figure 10.

The schedule of acceleration and deceleration, 10A, is made up in this case of (1) a relatively short period of relatively rapid acceleration, which raises the speed of withdrawal from the same minimum to the same maximum as in Figure 9, but within a time corresponding to about 1.4 inches of length of the filament theoretically formed, instead of 2.5 inches as in Figure 9, (2) a period of deceleration of approximately the same length and rate as that of Figure 9, and (3) a period of constant speed which is longer than that of Figure 9. The time of deceleration is about 40% greater than the period of acceleration. The decrease in diameter of the actual filament, 10C, lags behind the theoretical, 10B, but the more rapid acceleration of withdrawal in Figure 10 brings the filament to its minimum diameter within about 3.5 inches, or more quickly than in Figure 9. From this point the filament responds to the deceleration of rate of withdrawal, which has started at about 1.4 inches, and its diameter increases during the next 3.5 inches of its length, reaching substantially the maximum at about 7.0 inches and maintaining this maximum to the end of the cycle at 9.0 inches. This filament 10C is substantially symmetrical in taper. From its point of minimum diameter (at 3.5 inches) to the midpoint of the untapered section (at 8 inches) is 4.5 inches in either direction, and the downward and upward tapers match each other, approximately, in slope. If cut at 3.5 and

8.0 inches of successive unit lengths this filament will yield "bristles" (half unit lengths) in which those of downward taper and those of upward taper are, practically speaking, indistinguishable.

In general, the period of deceleration should be at least 20% greater, and preferably about 40% greater, than the period of acceleration. The period varies with the taper ratio, length of unit, material, etc. It is to be noted, further, that, since the interval between the beginning of the downward taper and the ending of the upward taper in the filament is greater than that between the beginning of the acceleration and the ending of the deceleration of withdrawal, it follows that the schedule of rates of withdrawal must include not only a period of acceleration and a period of deceleration but also a period of constant rate of withdrawal, in which latter, the upward tapering of the filament is completed. In the case illustrated in Figure 10, this period corresponds to the distance between 4 inches and 7 inches along the filament.

It has further been found that a period of constant rate of withdrawal must be included in the schedule of withdrawal even in the case of a filament which is to consist merely of an alternation of downward and upward tapers, with no untapered section. Such a filament would be made, for example, by following the schedule **10A** up to the point (7 inches) at which the upward taper of the resulting filament is completed, and then at this point accelerating the withdrawal as at 0 inch. The result would be a filament of unit length 7 inches with no untapered section, but produced by a rate schedule which includes a period of constant rate of withdrawal.

An understanding of the reason for the deviation of the profile of the filament from that which would be expected, on the basis of the geometry of the system, to result from the schedule of rate of withdrawal is not essential to the validity of the invention, nor to its successful operation. It is believed that the deviation results primarily from the rheological characteristics of the material during the brief period in which it is being converted from a liquid to a filamentary solid, and also from the poor thermal conductivity of the material.

The molten material is being extruded through the spinneret **13** at a constant volume rate and, if it were being extruded in the form of a solid capable of being inelastically stretched in accordance with purely geometrical laws, the profile of the resulting filament should follow geometrically the schedule of rates of withdrawal. Instead, however, the material issuing from the spinneret is liquid, and it remains liquid for an appreciable time, for two reasons, namely, (1) the inadequacy of the cooling capacity of the air gap which must be maintained between the spinneret **13** and the surface of the bath **16**, in order to avoid the risk that minor fluctuations or oscillations in the surface of the liquid would bring it into actual contact with the spinneret and cause premature hardening of the filament material within the orifice of the spinneret, and (2) the low thermal conductivity of the material. As long as the material remains liquid, the attempt to regulate its diameter in accordance with geometrical considerations is defeated by its mobility and its surface tension. Then, when it begins to solidify, its interior remains liquid longer than its exterior. Both the delay in the beginning of solidification and the delay in completion of solidification are governed not only by the passage across an air gap which delays the application of the effective cooling influence of the liquid bath, but also by the diameter of the filamentary mass, whether liquid or solidifying. This diameter, moreover, is deliberately being varied in order to produce taper. As a result of these factors, which in effect cause a fluctuation in the rheological behavior of the material which is in process of being converted from liquid to solid, the change in diameter of the filament fails to follow the geometrical expectation that it vary inversely as the square root of the linear rate of travel.

It has been found that the width of the air gap between the face of the spinneret and the free surface of the cooling bath has an important effect on the spinning of tapered filaments. It should be quite small in extent. The provision of too great a gap results in the creation of an excessive "reservoir" of liquid material in the newly spun filament with an excessive tendency to damp out the desired effects of predesigned variations in rate of withdrawal and thus to impair the desired control of the profile of the filament produced. A gap of not more than one inch has been found to be practical. In general, a gap from ⅛ to ⅜ inch gives the best results and is thus preferred.

In the preferred embodiment of the invention illustrated in Figures 1*p*, 1*e*, 2 and 3, the schedule of rate of withdrawal of the filament from its point or zone of origin is controlled by the figure of the cam **33**. One revolution of the cam will normally be made to determine the schedule for a single unit length of filament, rather than for a multiple of the unit length. A suitable schedule of rates of withdrawal is set up on the basis of the relationships set up herein, as part of the present invention, between the schedule and the profile actually produced. Then, from this schedule is calculated the figure of a cam by which it will be produced; this calculation is, of course, a matter of simple geometry, involving the various fixed diameters and ratios of rotation of the pertinent moving parts of the equipment, and the numbers of teeth in the gears **27**, **29**, and **31** of the planetary train.

Because the discrepancies between the rate schedule actually required and the rate schedule theoretically required cannot be expressed in fully quantitative terms, and may, indeed, be influenced to minor extents by such operating details as the distance across the air gap, the temperature of the cooling liquid, the average diameter of the filament and its average linear rate of production, the rate schedule first set up as the basis for the production of a filament of a given profile may be found to be inaccurate under the conditions of operation, and correspondingly it may be found necessary to make minor changes in the figure of the controlling cam. Hence, it may be desirable to make a trial cam out of an inexpensive and easily machined material and then, on the basis of measurements of the profile of the filament produced in a trial run, to make any necessary minor modifications in the figure before constructing a cam for regular use. But the cost of such cams is small compared with that of gears of special configuration.

The invention may be applied to any tapered filament which can be cold-drawn. The preferred polymeric filaments are polyamides of the types described in U. S. Patents 2,071,250, 2,071,253, and 2,130,948. These polyamides are prepared from bifunctional polyamide-forming reactants and contain amide groups as an integral part of the main chain of atoms in the polymer. It is not essential that the linking group in the polymer chain consist solely of amide groups; they may also contain other groups, e. g., ester groups.

The polyamides are of two general types, those derived from diamines and suitable dicarboxylic acids or amide-forming derivatives of dibasic carboxylic acid, and those derived from polymerizable amino acids or amide-forming derivatives thereof, e. g. esters and lactams. On hydrolysis with hydrochloric acid the polyamides yield polyamide-forming reactants; polyamides of the diamine-dibasic acid type yield a diamine hydrochloride and a dibasic carboxylic acid, whereas those of the amino acid type yield an amino acid hydrochloride. As specific examples of such polyamides may be mentioned polydecamethylene adipamide, polyhexamethylene sebacamide, polypentamethylene sebacamide, polyoctamethylene adipamide, 6-aminocaproic acid polymer, and 11 aminoundecanoic acid polymer. Mixtures of polyamides and interpolyamides may also be used. Examples of such interpolyamides are those derived from hexamethylenediamine, decamethylenediamine, adipic acid and sebacic acid, and from hexamethylenediamide, adipic acid, and 6-aminocaproic acid. As examples of polyamides containing groupings other than amide-groupings, may be mentioned esteramide interpolymers, such as may be derived from a diamine, a dibasic acid, and a glycol or from an amino acid and an hydroxy acid. For paint brushes preferred materials will include the superpolyamide hexamethylene sebacamide or hexamethylene adipamide alone or in admixture with 2% to 30%, and especially about 10%, of phenol-formaldehyde resin. Such materials are described in assignee's application Serial No. 397,887.

The term "polyamide" as used in this application includes polymers containing a plurality of groups of structure

$$-\underset{}{\overset{\displaystyle H}{\overset{|}{N}}}-\overset{\displaystyle O}{\overset{\|}{C}}-$$

regardless of the nature of the atom to which the indicated free linkages are attached. The term includes polymers derived from a glycol and a diisocyanate or a diisothiocyanate.

The tapered filaments of this invention need not necessarily consist wholly of polyamide or modified polyamide. It is frequently desired to deluster and/or color the filaments by adding a pigment to the polymer or to the reactants from which the polymer is prepared. It is also useful in many cases to dye the filament, for example with nigrosine black, Sudan brown, etc. Thus, fishing lines or leaders may be made to resemble closely water of almost any color or turbidity by the proper choice of dyes or pigments. Bristles may also be made of any desired color and length. For paint brushes a unit length of 4 to 18 inches is practical.

This invention has the advantage that the drawing of tapered filaments can be accomplished in a manner which requires no close supervision. A further advantage is that symmetrical tapered filaments of variable contour can be made on a commercial scale. Another advantage resides in the fact that waste of filament material in cutting the tapered units is substantially eliminated. The method and equipment give uniform results without a need of excessive or close attention. The character of the equipment or apparatus makes it easily and cheaply adaptable to desired changes in the diameter, unit length, and profile.

As many apparently widely different embodiments of this invention may be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the appended claims.

We claim:

1. A method of producing a filament having uniformly recurring symmetrically tapered portions which comprises extruding an organic filament-forming material in molten condition at a constant volume rate through a spinneret across an air gap into a liquid cooling bath maintained at a temperature below the temperature of solidification of said material, and directly withdrawing the filament formed in accordance with a repetitive schedule of linear rates comprising a period of acceleration, a period of deceleration of greater duration than that of acceleration, and a period of uniform withdrawal.

2. A method of producing a filament having uniformly recurring symmetrically tapered portions which comprises extruding an organic filament-forming material in molten condition at a constant volume rate through a spinneret across an air gap into an inert liquid cooling bath spaced not more than one inch therefrom maintained at a temperature substantially below the temperature of solidification of said material and directly withdrawing the filament formed in accordance with a repetitive schedule of linear rates comprising a period of acceleration from minimum to maximum rate and a period of deceleration from said maximum and a period of uniform withdrawal at the minimum rate, the second period being at least 20% greater than the first.

3. A method of producing a filament having uniformly recurring symmetrically tapered portions which comprises extruding a molten filament-forming synthetic polyamide through a spinneret across an air gap into an aqueous liquid cooling bath spaced not more than one inch therefrom maintained at a temperature between 15° and 45° C., and directly withdrawing the filament formed in accordance with a repetitive schedule of linear rates comprising a period of acceleration from minimum to maximum rate and a period of deceleration from said maximum, and a period of uniform withdrawal at the minimum rate the second period being at least 20% greater than the first.

4. A method of producing a filament having uniformly recurring symmetrically tapered portions which comprises extruding a molten filament-forming synthetic polyamide through a spinneret across an air gap into an aqueous liquid cooling bath spaced from ⅛ to ⅜ inch therefrom maintained at a temperature between 15° and 25° C., and directly withdrawing the filament formed in accordance with a repetitive schedule of linear rates comprising a period of acceleration from minimum to maximum rate and a period of deceleration from said maximum and a period of uniform withdrawal at the minimum rate, the second period being at least 20% greater than the first.

5. In an apparatus for the production of filaments having uniformly recurring tapered units, said apparatus including a spinneret, means for extruding molten filament-forming material through said spinneret, a cooling bath located below said spinneret, and a pair of pinch rolls

for withdrawing a formed filament from the bath under tension, one of said pair of pinch rolls being a driving member: means for periodically varying the speed of the driving member of said pair of pinch rolls, comprising a drive shaft, a yoke fixedly mounted on said drive shaft, a set of intermediate gears mounted on said yoke upon the circumference of a circle concentric with said drive shaft and individually free to rotate each upon its own axis with respect to said yoke, a shaft carrying the driving member of said pair of pinch rolls and axially aligned with said drive shaft, a central gear mounted on said shaft carrying said driving member, said central gear meshing with said intermediate gears, a peripheral annular gear with which said intermediate gears mesh, a lever attached to said annular gear and controlling movement of said annular gear about its axis, a cam, and means for rotating said cam, said lever being operatively associated with said cam whereby rotation of said cam causes movement of said lever to effect periodic variation in the speed of said driving member.

6. In an apparatus for the production of filaments having uniformly recurring tapered units, said apparatus including a spinneret, means for extruding molten filament-forming material through said spinneret, a cooling bath located below said spinneret, and a pair of pinch rolls for withdrawing a formed filament from the bath under tension, one of said pair of pinch rolls being a driving member: means for periodically varying the speed of the driving member of said pair of pinch rolls, comprising a drive shaft, a yoke fixedly mounted on said drive shaft, a set of intermediate gears mounted on said yoke upon the circumference of a circle concentric with said drive shaft and individually free to rotate each upon its own axis with respect to said yoke, a shaft carrying the driving member of said pair of pinch rolls and axially aligned with said drive shaft, a central gear mounted on said shaft carrying said driving member, said central gear meshing with said intermediate gears, a peripheral annular gear with which said intermediate gears mesh, a lever attached to said annular gear and controlling movement of said annular gear about its axis, a cam, means for rotating said cam in synchronization with the rotation of said drive shaft, and a push rod pivotally connected at one end to said lever and having its other end operatively associated with the face of said cam whereby rotation of said cam causes movement of said lever to effect a periodic variation in the speed of said driving member.

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The following references are of record in the file of this patent:

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