May 7, 1963 N. S. KAPANY ET AL 3,088,297

APPARATUS FOR DRAWING FIBERS

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FIG. 1

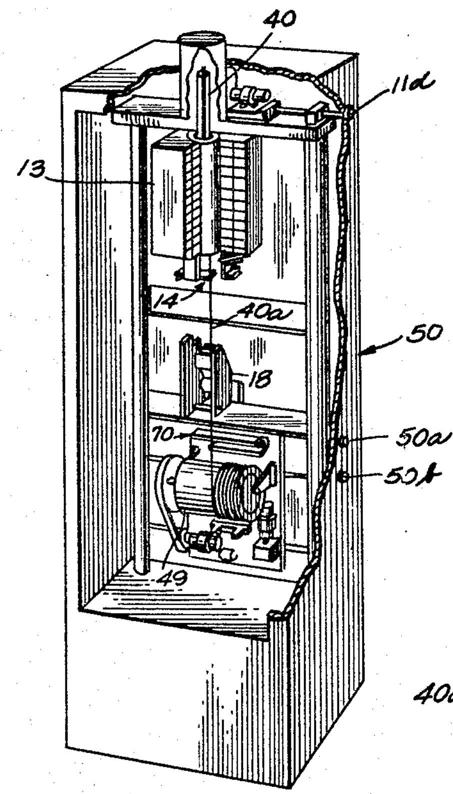

FIG. 3

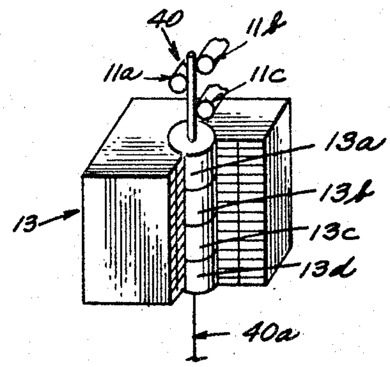

FIG. 4

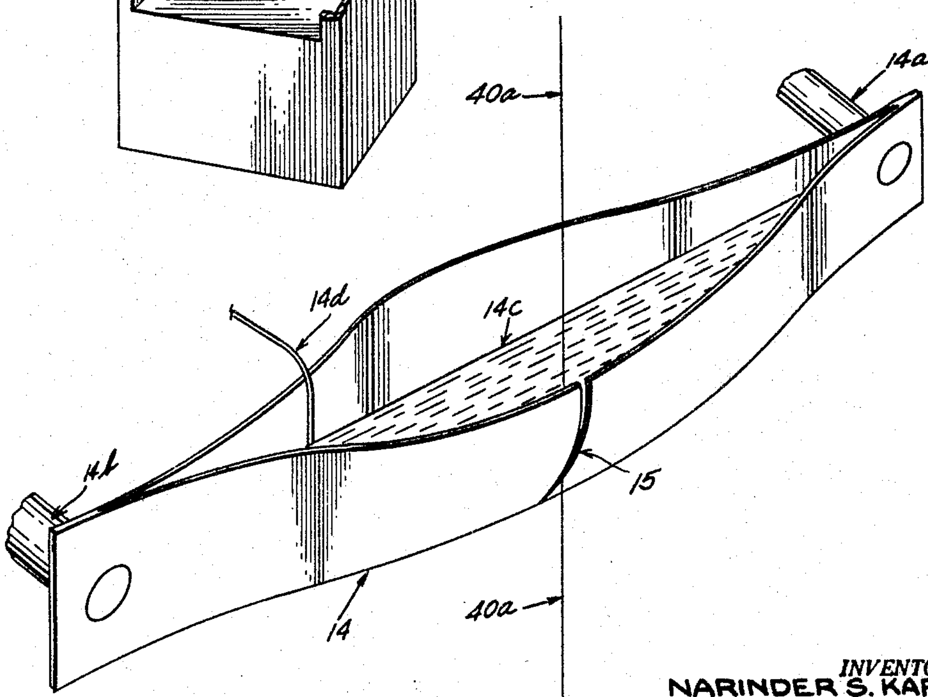

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FIG. 2

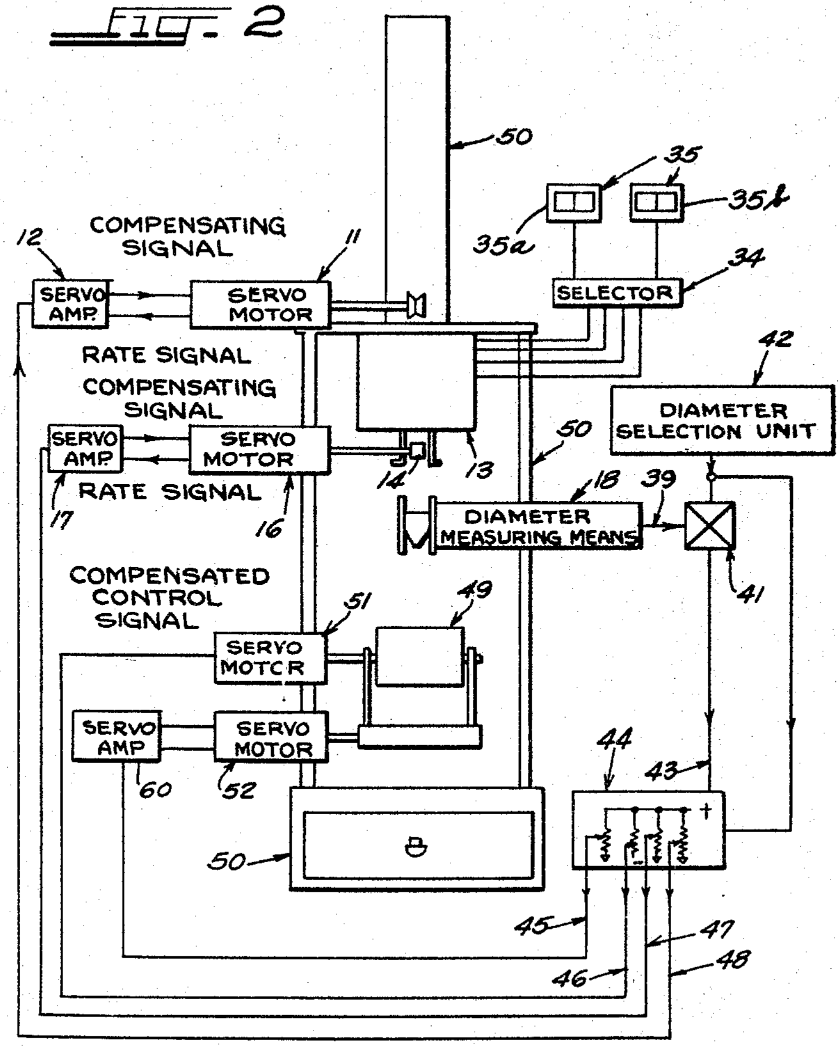

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FIG. 5

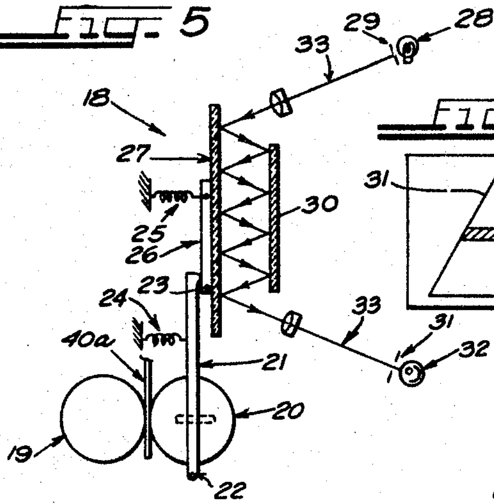


FIG. 5A

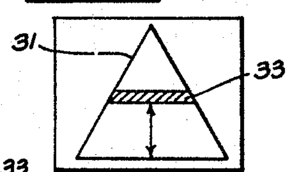


FIG. 6

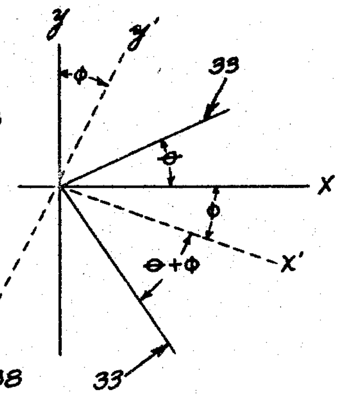
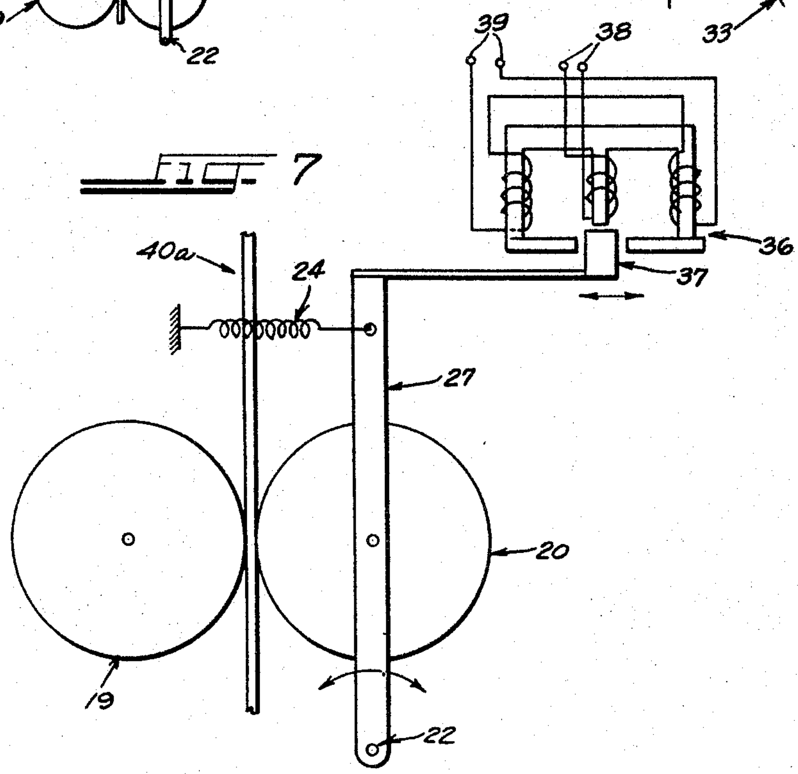


FIG. 7



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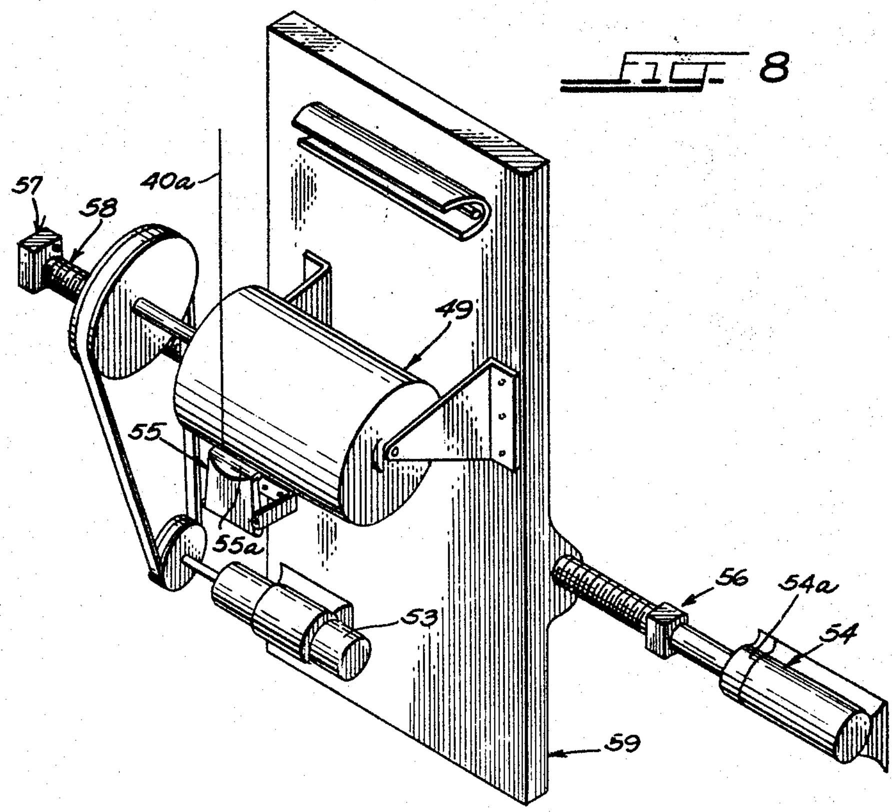

FIG. 8

FIG. 9

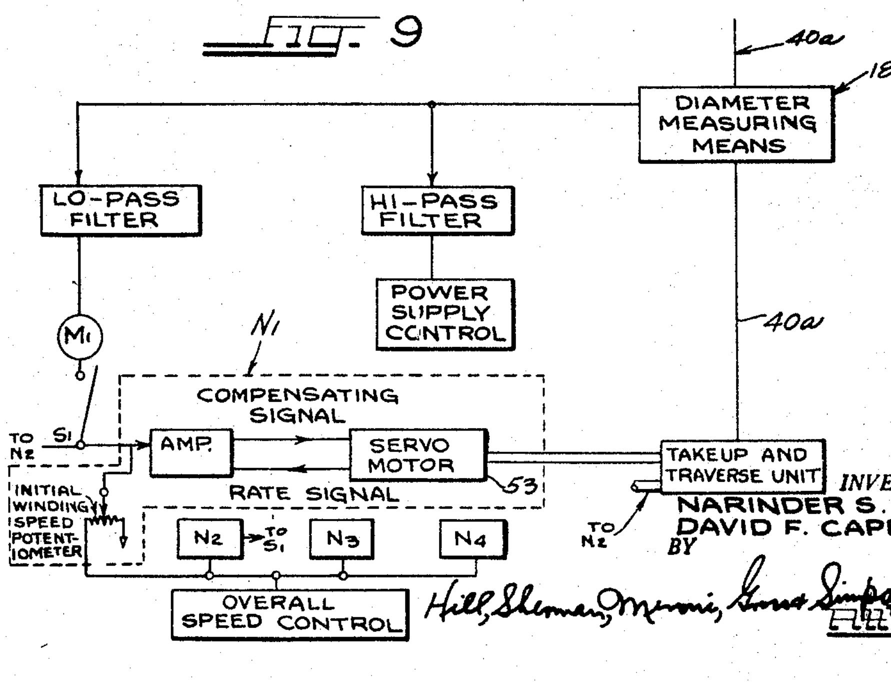

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FIG. 10

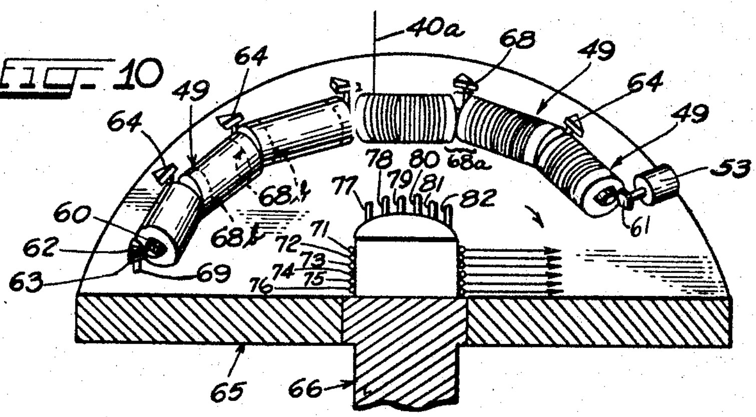


FIG. 11

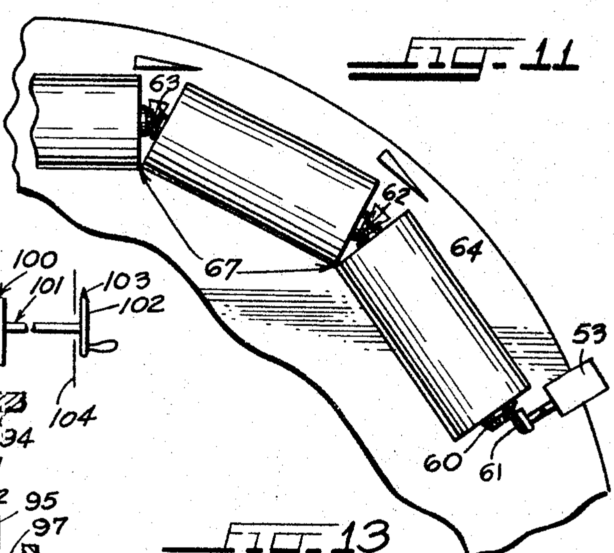


FIG. 12

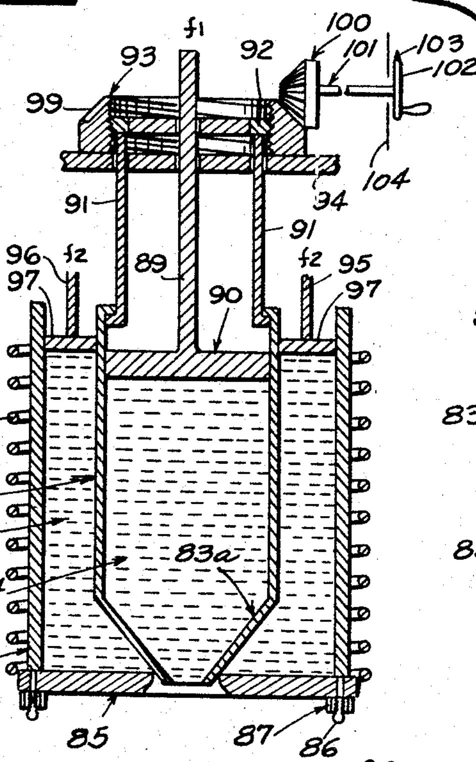
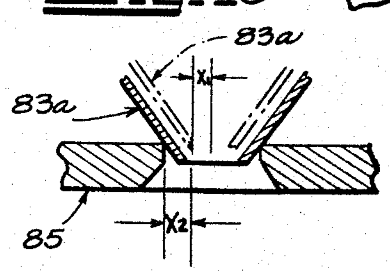


FIG. 13



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United States Patent Office

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3,088,297

APPARATUS FOR DRAWING FIBERS

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Filed June 1, 1960, Ser. No. 33,240
4 Claims. (Cl. 65—13)

The present invention is directed to fiber drawing apparatus and more particularly, such apparatus whereby fiber size is maintained constant within small tolerance by varying one of several parameters which affect such size.

A number of factors influence the diameter of drawn fibers. Principal among these are the chemical composition of the material in the furnace, the temperature of the furnace affecting the viscosity of the material and the rate at which the fiber is drawn from the furnace.

Up to the present time many machines have been designed whereby drawn fibers would have uniform diameters. Such machines generally embody two principles. First; the drawn fibers may be made to contain uniform diameters by regulating the fiber drawing rate. For example, if the fibers were reeled on a drum, the angular velocity of such drum must decrease in predetermined steps to account for the increasing radius caused by the wound fibers. That is to say, the take-up drum would decrease its revolutions per minute by discrete percentages at definite time intervals. This method exhibits an inherent difficulty in that temperature variations in the furnace or imperfections in the fiber material may cause variation in fiber diameter notwithstanding constant fiber drawing rates. Second; the temperature of the furnace melting the fiber material (hereinafter referred to as glass rod) may be varied, thereby varying the viscosity of such material and consequently, changing the fiber diameter for a given winding rate. Exemplary difficulties with this technique are: (1) the time delay required in changing the furnace temperature, necessarily adding to the cost of the process; and (2) the fiber drawing rate can cause nonuniformity in fiber diameters independent of furnace temperature changes.

At ths point, one might say a combination of the two above described techniques should obviate the difficulties mentioned. Perhaps it would; however, this combination would be cumbersome and would require almost constant supervision by a machine operator. Further, it is believed that the time delay caused by furnace temperature change would not be completely eliminated. Still further, a method of detecting changes in fiber diameter must be employed before corrective action may be taken.

It is accordingly, a general object of the instant invention to provide a novel fiber drawing means which obviate the disadvantages incident to those available in the past.

Another object is to devise means which will draw uniform flexible fibers within the accuracy necessary to enable such fibers to be used as optical components.

A different object is to devise drawing means for producing optical fibers whereby once such means is set into operation the machine will produce such fibers autonomously.

A more specific object is to devise a fiber drawing machine whereby substantially uniform optical fibers are produced by continuously monitoring the fiber diameter.

Another different object is to produce coated optical fibers of substantially uniform diameter by continuously monitoring the fiber diameter and comparing any changes thereof to a preset standard and controlling the apparatus therewith.

Still another object is to devise a fiber drawing machine whereby fused, aligned, substantially uniform optical fiber assemblies are produced by continuously monitoring the fiber diameter.

Yet another different object is to devise a fiber drawing machine whereby coated fibers of substantially uniform diameter which are aligned and fused are produced by continuously monitoring the fiber diameter.

These and other objects of the invention will become more apparent from the specification and the drawings wherein:

FIGURE 1 is a perspective view, partly in section, of most of the essential elements of the instant invention.

FIGURE 2 is a block diagram of a fiber drawing machine embodying the principles of the instant invention.

FIGURE 3 is a schematic perspective view partly in section of a furnace which may be used in the instant invention.

FIGURE 4 is an enlarged perspective view of a means for coating the drawn fibers in accordance with the principles of the instant invention.

FIGURE 5 is a schematic representation of one type of fiber measuring means.

FIGURE 5A is an enlarged view of the triangular aperture **31**.

FIGURE 6 is a diagram useful for explaining the operation of measuring means of FIGURE 4.

FIGURE 7 is a schematic diagram of an electromechanical fiber diameter measuring unit.

FIGURE 8 is a schematic perspective view of the take-up drum and the traverse unit.

FIGURE 9 is a block diagram of the preferred embodiment of the disclosed invention.

FIGURE 10 is a perspective illustration partly in section of the take-up and traverse means employed in the preferred embodiment.

FIGURE 11 is a top view of part of the means shown in FIGURE 10 illustrating an arrangement of the take-up motor and the supports for take-up drums **49**.

FIGURE 12 depicts a furnace which may be employed in conjunction with, or in place of, furnace **13**.

FIGURE 13 is a view of a section of the furnace shown in FIGURE 12.

Before describing our apparatus in detail, it will be helpful to outline the utility of superfine dielectric fibers as optical components. It is well known that one or a bundle of flexible dielectric fibers will transmit radiant energy from one end to the other. Hence, optical images (a form of radiant energy) impinging one end of an aligned bundle of fibers are reproducible at its opposite end. Of course, an individual fiber or a multitude thereof may act as a light transmitter. This light transmission depends on the principal of total internal reflection from the side walls of the conducting element of the light which has entered at one end of the element, thereby allowing this light to be transmitted therethrough to the opposite end thereof. It has been found that improvements occur when the individual fibers are individually coated with a thin layer of a material having a lower refractive index than that of the fiber itself. Also, an additional coating of an opaque material is desirable in certain cases. Furthermore, the resolving power of such a transmission means is primarily dependent upon fiber diameter and has been found to improve with lesser fiber diameters. It follows, therefore, that if the fiber bundle consisted of a multitude of uniformly small diameter fibers it would have high resolving power.

For a more detailed analysis of the utility of dielectric fibers the reader's attention is directed to co-pending application Serial Number 750,811 filed July 24, 1958, now abandoned and assigned to the assignee of the present invention.

It is known that a length of thermoplastic dielectric rod **40** comprising a length of solid round dielectric encased within a hollow dielectric cylinder having a lower index of refraction and concentric therewith, may be co-drawn such that the end product, fiber 40*a*, will bear substantially the same dimensional ratio in cross-section of rod and cylinder, as the glass material had in its original form. Use is made of this procedure to eliminate a multi-step drawing process. Hence, by this method the additional coating, if desired, is all that is necessary in the drawing process. Along these lines, it is noted that in the detailed description to follow, the glass rod **40** represents a solid rod of radiation transmittent material and a hollow cylinder encasing said rod, but having a lower refractive index and substantially the same melting point as that of the solid rod.

The fibers, rod or cylinders of the instant invention may be made of any dielectric material—viz., capable of transmitting electromagnetic radiation in the region of interest which may be ultra-violet, visible, infra-red or the microwave region. When used as a visible light transmitter, glass has been found to be an excellent material to meet the above-mentioned requirements and can be drawn into extremely small, flexible fibers. However, various plastic materials such as Lucite may also be used and many other similar transmissive materials will occur to those skilled in this particular art.

Turning to the drawings in detail, FIGURES 1 and 2 depict a fiber drawing machine for producing coated optical fibers, having an accurate speed glass rod feed means **11**, which includes a velocity controlled servo-motor that is regulated by amplifier **12**. Amplifier **12** is responsive to control signals from master comparator **44** which establishes a predetermined rate of glass rod feed **40** to the four sectioned furnace **13**. The mass of glass rod **40** fed into furnace **13** is immediately controlled by the feed means **11**. A signal proportional to the rate of rod feed is continuously compared to a master control signal generated by master comparator **44** and transmitted to amplifier **12**. Any error measured by amplifier **12** between the master signal and the rate signal from rod feed means **11** causes a compensating signal to be fed into rod feed means **11** causing the rod feed rate to change in a manner that reduces the measured error to zero.

FIGURE 3 is an enlarged perspective view of the four section tubular furnace **13**. Furnace **13** is secured to, and supported by, frame **50** and is suspended such that the longitudinal axis thereof is concentric with the axis of the rod **40** fed thereto. The four tubular sections are controllable by means of pyrometers **35** through selection unit **34**. In this way, known thermal gradients are established along the axis of the glass rod **40**, to create optimum conditions for the fusion and production of fibers **40*a***. Before the machine is set into operation the temperature of the individual sections of the furnace **13** are predetermined and set by means of pyrometers **35**. Each section **13*a–d*** has its own thermocouple at the heated surface and its own power supply leads. The power supplied to the furnace section **13*a–d*** is controlled by selection unit **34**, which is controlled by pyrometers **35**. As only two pyrometers are used to control the four furnace elements **13*a–d***, switches are provided in selection unit **34** in order that any combination of pyrometers **35** and sections **13*a–d*** may be used in that a pyrometer may only be controlled from a thermocouple in a furnace element connected to it. A feature of these combinations is that in addition to the break protection afforded to the thermocouples, an indication if an incorrect thermocouple has been selected to control one of the pyrometers **35** is also available.

Assuming that the proper temperatures have been selected and the pyrometers **35** are connected in proper order; the temperature gradient established along the vertical axis of the furnace **13** is continuously checked by pyrometers **35*a*** and **35*b***. Control signals from the pyrometers are supplied to selection unit **34** in order that said gradient be maintained constant throughout the drawing operation.

The selection of furnace temperature is dependent upon the rod material, and the fiber size required. The peak temperature within the furnace **13** usually varies from 800 to 1700° F. and generally this maximum temperature is maintained approximately between elements **13*c*** and **13*d***. It is understood, however, that any thermal gradient may be maintained. Furthermore, a greater or lesser number of furnace sections may be employed, the number of sections being controlled by the particular application called for.

There is a limitation on furnace temperature, however. Said temperature must be maintained below the point at which the solid dielectric rod and its surrounding cylinder would diffuse. On the other hand, the material is sufficiently heated to enable its being drawn into a fine fiber. At the present time no tables exist tabulating the diffusion temperature between various dielectrics. However, such temperatures are experimentally determinable without much difficulty.

The cold rod **40** enters furnace **13** and by the time it reaches the region of section **13*c*** and **13*d*** a drop of glass is formed and eventually falls from the end of the rod drawing a fiber **40*a*** with it. This drop is removed allowing a fiber to be wound onto the take-up drum **49**.

If fiber **40*a*** is required to be metallized, it is passed through a unit **14** which comprises a boat containing a molten globule **14*c*** of the metal required for the coating. The coating material **14*c*** need not be a metal; however, for optimum results, it should be opaque. To this end, we have coated with opaque glass, combinations of opaque and clear glass, lead, aluminum and indium. Of course, in all cases the coating material must be one that is fusible to the film 40*a*.

Referring to FIGURE 4, the boat **14** is insulatingly supported from the frame **50** by elements **14*a*** and **14*b***. Elements **14*a*** and **14*b*** in addition to acting as supports, supply electric power to the boat **14** as a heating element and thereby maintain the coating material **14*c*** in its molten state. Fiber **40*a*** passes into one side of boat **14** through molten material **14*c*** and out through a narrow V-shaped slit **15**. Slit **15** is large enough to pass the fiber **40*a***, but small enough to prevent escape of the molten material **14*c*** due to its surface tension. The molten coating material **14*c*** is shown passing into the boat **14**. The coating material supply reel and its operative association to servo-motor **16** have been omitted for illustration purposes only. Coating rod **14*d*** may be wound on a supply reel which is belt driven by servo-motor **16**. And in a manner described below a constant supply of molten coating material is maintained while the machine is in operation.

Most metals which will serve as coating media suffer severe oxidation, which eventually produces a weak and ineffective coating. Accordingly, where the coating material **14*c*** is liable to oxidation in its molten state, the present machine should be enclosed in a cabinet containing an inert atmosphere. To this end, everything but the electric controls are mounted within the airtight framework **50** and said controls are mounted on a separate cabinet. The cabinet **50** is made airtight in a conventional manner and an inert atmosphere may be circulated therethrough. The gas and pump means have been omitted from the drawings for purposes of clearness of illustration inasmuch as such means form no part of the instant invention and their application thereto would amount to the ordinary skill of an artisan.

A continuous coating feed means **16** including a velocity controlled servo-motor is provided to replenish molten material **14*c*** as it is consumed. The rate of said feed means **16** is accurately regulated by amplifier **17** which is responsive to a master control signal from comparator **44**. The coating feed rate is regulated in the same manner as rod **40** feed rate. That is to say, any error between the master control signal and the rate signal causes a compensating signal to be generated which changes the coating feed rate in a direction to reduce said error to zero.

The heart of the system is fiber diameter measurement means **18** in that the rates of the: glass rod feed **11**; coating rod feed **16**; take-up drum **51**; and traverse unit **52** are all governed by said measurement means **18**.

Fiber diameter measurement means **18** generates a signal proportional to fiber diameter and such signal is fed into differential amplifier **41** and compared with a signal from control **42** corresponding to the desired fiber diameter size. Control **42** may take many forms and this case comprises a calibrated potentiometer whereby signal magnitude is correlated to fiber diameter. In this manner, a preset amplitude which will correspond to a selected fiber diameter will control the various rates of the different mechanisms which comprise the fiber drawing machine. Any error measured, is fed into master comparator **44**. In order to determine the degree of error, the desired diameter signal is compared to the error signal. This is effected by coupling the signal from desired fiber diameter signal means to comparator **44**. Master comparator **44** is a composite of four signal generators responsive to an input error signal derived from the fiber diameter measuring means. However, such generators each transmit a master control signal, by means of connections **45–48** inclusive, to their respective circuits in such magnitudes that the control signals, if any, all bear a ratio in magnitude with respect to each other. In other words, the rate change of glass rod feed means **11** will be a submultiple of the rate change of take-up of drum means **51** because the mass of glass rod **40** fed into furnace **13** should always equal the mass of fiber **40*a*** drawn for any given fiber diameter. For example, if a rod diameter attenuation of one thousand were sought, the linear drawing rate must be one million times the rod feed rate in order that the rate of volume in equals the rate of volume out, and thereby, precluding a build-up of molten glass rod **40** in the furnace **13**.

FIGURE 5 represents one type of device used to measure fiber diameter. The fiber **40*a*** is journaled between rollers **19** and **20**. Roller **19** has a stationary axis, however, roller **20** does not. Roller **20** is attached to arm **21** and is arranged to pivot about point **22**. The arm **21** is spring biased in such a manner that the arm **21** conjointly with roller **20** will always bear light pressure against the fiber **40*a***. The arm **21** is mechanically coupled to member **26** and member **26** is biased in the same direction as arm **21** by means of spring **25**. Member **26** has a mirror **27** attached thereto and serves to reflect any light rays **33** incident thereupon to stationary mirror **30**. The rays **33** are generated by source **28**, which may take the form of a lamp, and passes through horizontal slit **29** and impinges the mirror **27**. After a number of reflections the light passes through a triangular (or any other geometric shape) aperture **31** and is incident upon transducer **32**. In this particular embodiment, transducer **32** is a photoelectric cell. The signal generated by transducer **32** is dependent upon the amount of light incident thereupon. This amount of light **33** (see FIG. 5A) varies as to the relative positions of the image of the slit and the triangular aperture, the triangular aperture **31** having its base parallel to horizontal slit **29** and is arranged such that a greater amount of light is passed by aperture **31** if the light ray **31** is incident at the base of triangular aperture **31**.

In operation, any variation in fiber diameter is transmitted about pivot point **22** by the conjoint action of roller **20** and arm **21**. Any action thereby, displaces mirror **27** about its vertical axis around its pivot point **23**. Consequently, the angle of incidence of the light **33** upon mirror **27** is changed by an amount linearly proportional to the angular deviation of mirror **27** from its vertical axis. Such deviation vertically displaces the point at which beam **33** passes through triangular aperture **31**. In this way, any variation in the diameter of fiber **40** changes the amount of light passing through aperture **31**. Hence, a change in fiber diameter is converted into a mechanical variation and ultimately as an electric signal from transducer **32**.

The optical amplification of fiber diameter variation is best understood by referring to FIGURE 6. The coordinate y represents the vertical axis of mirror **27**. And the ordinate x represents the horizontal. When a change in fiber diameter occurs mirror **27** is angularly displaced about its vertical axis y by an angle represented by the dotted line y'. Prior to such deflection light beam **33** was incident upon mirror **27** at an angle θ. After deflection, the angle of incidence remains unchanged when measured from the ordinate x. However, since the angle of reflection equals the angle of incidence; when measured from x' it is $\theta+\phi$. Then, if the angle of reflection is measured from the ordinate x it is $\theta+2\phi$. Where 2ϕ represents twice the angular deviation of mirror **27**. Since mirror **27** was deflected in proportion to the variation in fiber diameter, it thus can be seen that for every reflection from mirror **27** the magnitude of angular deviation is doubled.

With the optical measuring system depicted in FIGURE 5 we have obtained accuracy of measurement, which was measured to be plus or minus one micron in fifty microns. In use, the unit appears to have very little affect on the drawing of the fiber **40*a*** and seems to provide a stabilizing influence. However, due to the extremely high sensitivity of the device, the signal derived from the passage of fiber **40*a*** through it contains periodic fluctuations caused by the lack of concentricity in rotating parts and similar mechanical reasons.

In general these fluctuations are of a high frequency compared to those it is required to measure and in this embodiment a simple resistor-capacitor filter circuit serves to separate the required components.

FIGURE 7 depicts another type of fiber diameter measuring means **18** that is more stable than the optical system and furthermore, provides an A.C. signal output which is more useful to control the velocity of the various servo-motors. This system comprises the same rollers **19** and **20** operating on the same principle as that described in connection with FIGURE 4. However, the angular displacement of arm **21** is converted into a horizontal deviation and operates as follows. The arm **21** is secured to a slug **37** which forms a part of transducer core **36**. A sixty cycle magnetomotive force is applied to the transducer, on leads **38**, forming part of a magnetic circuit on the center leg of core **36**. The outer legs of core **36** complete the magnetic circuit and have coil **39** wound therearound. Coil **39** represents the output circuit and detects any changes in flux in the outer legs of core **36**. By varying the position of slug **37** the flux distribution in the outer legs of **36** is changed. Since coil **39** is responsive to flux change, it detects the variation in flux distribution and represents it by a change in amplitude of the A.C. signal. This output signal is coupled to a differential amplifier and used in the manner previously described.

Applicant's description has shown the fiber **40*a*** to be coated prior to fiber measurement, however, it is noted that the order of fiber measurement and coating is interchangeable and for best results fiber measurement should occur prior to fiber coating. This arrangement is best in that the possibility of coating material **14*c*** building up on rollers **19** and **20** is eliminated thereby.

After the fiber **40*a*** passes through fiber measurement means **18** it is reeled on take-up drum **49**. Take-up drum **49** is driven by variable take-up motor means **51** responsive to control signal **47** from master comparator **44**.

As shown in the drawings and particularly in FIGURES 2 and 8 the take-up mechanism is arranged to wind the fiber **40*a*** in a helical fashion. Take-up drum **49** is driven by velocity controlled servo-motor **53** responsive to master comparator **44** in the form of a compensated control signal fed thereto. Drum **49** starting mechanism **55** and motor **53** are all secured to carriage **59**. Carriage **59** has a passage extending therethrough and is threadably engaged to shaft **58**. Shaft **58** is operably connected to traverse servo-motor **54**. Motor **54** rotates shaft **58** via gear box **54*a***. Gear box **54*a*** includes a magnetic clutch reversing assembly responsive to adjustable stop switches **56** and **57**. Each clutch in the reversing assembly is constantly in mesh with the drive from the motor by means of a bevel gear. When carriage **59** reaches its limit of travel in either direction a switch is tripped at stop **56** or **57** and switches the operation of motor **54** from one clutch to the other in gear box **54*a***. In this mode, reversal of traverse is accomplished. Furthermore, this method isolates the backlash within the motor **54** and gear box **54*a*** from the motion reversal of the carriage **59**.

After the speed of the take-up drum has reached the proper rate for the required fiber diameter the fiber is passed between drum **49** and starter **55** including pulley **55*a***. The fiber **40*a*** is stuck to the drum by means of an adhesive tape affixed to the edge of drum **49**. Starter **55**, by means of pulley **55*a***, urges fiber **40*a*** against the adhesive layer on drum **49** thus creating adhesion therebetween. The moment after fiber **40*a*** passes between starter **55** and drum **49**, starter **55** is withdrawn by means of a solenoid allowing the drum **49*a*** to reel the attenuated fibers. The electrical connections necessary for the operation of the apparatus shown have been omitted from the drawings only in the interests of simplicity of illustration and not as a result of oversight or lack of technical comprehension.

In operation, the proper furnace temperatures are selected and preset by means of pyrometers **35**. The glass rod is suspended above the furnace **13** and guided by capstans **11*a–c***. Capstans **11*a–c*** are laterally adjustable by means of knob **11*d*** (see FIG. 1) to compensate for various glass rod **40** diameters.

The required fiber diameter is set on the calibrated control **42**. Control **42** thereby generates a signal proportional to the desired fiber diameter into master comparator **44**. The signals from comparator **44** are taken off voltage divider networks included therein and coupled to their respective subservo-systems. The control signals coupled to rod feed means **11**, coating feed means **16**, and traverse unit **52** come from taps off voltage dividers referenced to ground. These voltage dividers are included in master comparator **44** and serve to couple any error signal generated to the proper circuits and in the proper magnitude. However, the control signal fed into fiber winding means **51** is taken off a resistor, included in comparator **44**, with a floating potential reference. If this were not done a changing signal would result in equal percentage change of all the controls and hence, effectively no change at all. The couplers from the comparator **44** need not be potentiometers but may be transformer couplers for example, variacs.

After the proper rates have been established a drawn fiber **40*a*** is passed through coating boat **14** fiber diameter measurement means **18** and onto pick-up drum **49** as hereinbefore described. From this point on the machine will operate by itself in the following manner: the fiber diameter is continuously monitored and a signal proportional thereto is continuously compared to the desired signal corresponding to the desired fiber diameter in differential amplifier **41**. If there is any difference in magnitude therebetween an error signal is generated which is fed to master comparator **44**. Such error signal is compared to the desired fiber diameter signal and causes a compensated control signal to be generated and fed to the various servo-motor systems previously described. The light **70** (see FIG. 1) serves as a heat source and is selected to generate enough heat to render the coating **14*c*** adhesive. Hence, as the fiber **40*a*** is reeled on drum **49** the adhesive state of the coating **14*c*** fuses the wound fiber together. However, if the fibers **40*a*** are not to be fused one need only turn off the light **70**. In this way, fused optical fibers with uniformity independent of furnace temperature via the measurement of one variable are automatically manufactured.

In one application of the embodiment described, elements **13*a*** and ***b*** of furnace **13** were controlled by one pyrometer **35*a*** to maintain a constant temperature of 1640° F. Elements *c* and *d* in furnace **13** were connected through selector **34** to the other pyrometer **35*b*** and adjusted to maintain a constant temperature of 1400 F. The rate of rod **40** fed into furnace **13** was preset to $\frac{1}{10}$ inch per minute. Take-up drum winding rate was 400 r.p.m. The drum **49** was five inches in diameter which corresponds to a linear velocity 6280 inches per minute. The traverse rate was calculated and set to be ½ inch per minute in a direction lateral to the direction of winding of fiber **40*a***. Under these conditions uniformly fine fibers having a diameter in crossection of 75 microns were produced.

Turning now to the preferred embodiment of our invention, the reader's attention is directed to FIGURE 9. This embodiment is preferred in that once the machine is set into operation only two rates are varied and furthermore, the machine is equipped to turn off automatically if there is a break in fiber **40*a***. The components and elements involved in this embodiment are essentially the same as those previously described except as distinguished above.

Included in the fiber diameter measurement means is a high pass filter in parallel with the low pass filter and a meter M_1 in series or parallel with the output of the low pass filter. As was discussed, the low pass filter only passes the low frequency signal corresponding to the fiber diameter. Such signal is fed into meter M_1 which may take the form of an ammeter or voltmeter whose scale is calibrated to read directly in microns. The high pass filter only passes that signal due to vibration and noise of the machine. The high frequency signal is fed into a detector in the power supply control which operates a solenoid acting as a power supply switch. Hence, if the fiber **40*a*** breaks, the measuring device will no longer vibrate, in that there is no longer a fiber **40*a*** passing therethrough, therefore, the high frequency signal ceases to be generated and the detector sensing the absence thereof is arranged to open the solenoid and thereby cut off the power supplied to the machine.

The glass rod feed, and coating feed are preset according to predetermined values for a calculated fiber diameter in their respective units N_3 and N_4. Once these controls are set they do not depend upon fiber diameter measuring means **18** for further correction as in the previous embodiment. The take-up drum winding rate is preset, in unit N_1 by means of the potentiometer coupled to the input of the servoamplifier. Traverse rate is also adjusted prior to operation of the machine by a potentiometer in unit N_2.

Included in diameter measuring means **18** is a selection control with a dial calibrated to read directly in microns. This control is mechanically connected to roller **20** and is to vary its displacement from roller **19**. The functions of the selector is to adjust a spacing between pulleys **19** and **20** corresponding to a desired fiber diameter and to cause zero error signal to be generated (substantially low frequency signal) at this spacing. In other words, if a fiber **40*a*** varies the spacing between rollers **19** and **20**, from its adjusted value, an error signal is generated.

FIGURES 10 and 11 depict the traverse and take-up means (included in the preferred embodiment of the instant invention) capable of mass producing aligned fiber bundles. In this embodiment the traverse means comprises drive shaft **66** and turntable **65** arranged to rotate in the direction indicated by the arrow FIGURE 10. Mounted upon the upper surface of turntable **65** are take-up drums **49** adjacent to the outer edge of turntable **65**. Drums **49** are supported from the upper surface of turntable **65** by means of posts **69**. Posts **69** are secured to turntable **65** and have a suitably shaped termination **62** journaled between the gears **60**. A pyramidally shaped termination **62** will provide adequate support, however, other geometries may be equally suitable. The terminations **62** of posts **69** have bearings **63** embedded therein and are arranged to cooperate with the flat planar portion of gears **60**, whereby the drums are free to rotate conjointly about their horizontally fixed axes. Cooperating with the bevel gears **60** is pinion gear **61** driven by servo-motor **53**. Motor **53** provides the winding motion to drums **49**. Servo-motor **53** is velocity controlled and is regulated in a manner previously described. In order to provide electrical connection to motor **53** from the amplifier in unit N_1 (see FIG. 9) shaft **66** extends above the upper surface of turntable **65** and has slip rings **71—76** affixed thereto. Electrical contact is established by contact members **77—82** which are connected to the amplifier in unit N_1.

Turntable drive shaft **66** is cam operated and the cam is designed to provide a constant linear velocity between the edges of the drum (dotted lines **68*b***). On the other hand, when the wound fiber **40*a*** is approaching the edge of a drum **49** (the dotted line) the turntable very rapidly moves a distance equal to that bracketed by numeral **68**. At this point the cam operating drive shaft **66** has completed its cycle. As turntable **65** very rapidly moves to the next drum **49** fiber **40*a*** engages a wedge **64**, which is wider than the gap **68** between the drums **49** but less than the width of gap **68*a*** and transports fiber **40*a*** over gap **68** and drops it onto the next succeeding drum **49** at the point indicated by the dotted lines on the drums. Wedges **64** are stationary relative to the drums **49** and are mounted on turntable **65**.

The fiber **40*a*** is prevented from entering the area between the drums **49** by the wedge **64** and the arrangement of the drums **49** in that they are contacting each other at points **67**, and as such drums **49** form a continuous circle of winding means on turntable **65**. Hence, by winding in the direction shown (from the underside of the drum) the fiber is continuously wound on succeeding drums as they are rotated by turntable **65**. By the arrangement described, multiple layers of aligned fibers (in side by side parallel relationship) are mass produced without the use of drum direction reversal means and/or quick return traverse mechanisms. The outer edges of drums **49** may have rubber flanges in order to maintain light pressure contact at points **67** therebetween and thereby minimize wear. Furthermore, wedges **64** may be hollow and contain a sponge like area along the face of the wedge engaging the fiber **40*a***. By filling wedges **64** with glue, such glue will be applied to fiber **40*a*** as it passes thereover thus insuring adhesion of fiber **40*a*** to the next succeeding drum **49**.

In operation, the first step is to set the rates for the drum take-up N_1, traverse means N_2, rod feed means N_3, and coating feed means N_4. The overall speed control is, with switch S_1 in the open position, varied from a speed near zero r.p.m. up to the desired drum take-up speed. The signal from the overall speed control is fed, in parallel, to means N_1, N_2, N_3, and N_4 and controls their respective units in accordance with their preset values. As the overall speed is increased, and fiber **40*a*** is drawing down to its desired diameter, meter M_1 will approach a zero error signal reading because means **18** is approaching the point at which the error signal is zero. Now switch S_1 is closed and the machine produces aligned coated fibers **40*a*** by controlling only the winding and traverse rates. To this end, any error signal generated by means **18** is algebraically added to the overall speed control signal in units N_1 and N_2. More particularly, the signal from the low pass filter will add or subtract to the magnitude of the overall speed signal regulating units N_1 and N_2 and accordingly, change the control signal fed into variable speed servo-motors **53** and **54**. Furthermore, variable speed servo-motors **53** and **54** include tachometers that continuously generate rate signals which are compared to the adjusted overall speed signal in their respective amplifiers and any errors therebetween, resulting in compensating control signals coupled respectively to their motors **53** and **54** thereby adjusting their speeds to reduce the errors to zero. It is noted that the circuitry of traverse unit N_2 is not illustrated in FIGURE 9 in that it has the same stages as that depicted for unit N_1.

In essence, what is accomplished is to make all but one of the parameters affecting the diameter of fiber **40*a*** (winding speed, feed rate and temperature) constant, at the desired fiber size, and accurately controlling such size by regulating one parameter; the winding speed of the machine.

It is noted that the dimensional ratio in cross-section of rod and cylinder of the dielectric material supplied to the furnace **13** is fixed for any single operation of the machine in any of the embodiments heretofore described. In other words, the ratio is fixed and dependent upon the particular sizes of dielectric rod and cylinder assembled to form rod **40**. In many applications this ratio may want to be changed before the supply of rod **40** is completely consumed. To this end, the furnace illustrated in FIGURE 13 was designed, and is used in conjunction with, or in place of, furnace **13**. The furnace depicted in FIGURE 12 enhances the versatility of the machine enabling instantaneous variation of the dimensional ratio in cross-section of rod and cylinder comprising dielectric material **40**.

Cylinder **84** and base plate **85**, secured together by means of bolt **86**, integral with and extending from cylinder **86**, and nuts **87** form the outer vessel of the furnace. This outer vessel is adapted to contain dielectric material **103** which has a specific index of refraction N_d. An inner vessel concentric with said outer one is defined by cylinder **83** having a tapered open ended portion **83*a***. The inner vessel is adapted to contain dielectric material **104** having an index of refraction N'_d which is numerically higher than that of dielectric material **103**. The materials are kept in a plastic state by electric heat means **88**.

Use is made of the well known principle that a material in its viscous plastic state will not flow freely from the reduced opening of a container if the upper end of said container is airtight. To this end, plungers **90** and **97** are provided in sliding, substantially airtight relation with said inner and outer vessels. That is to say, annular disc **97** with shafts **95** and **96** extending upwardly therefrom is interposed between the inner wall of cylinder **84** and the outer wall of cylinder **83**. Likewise, circular plate **90** is interposed between the inner walls of cylinder **83** with shaft **89** extending upwardly therefrom. In order to extrude dielectric **104** from the outer vessel, a vertical force f_1 sufficient to extrude the dielectric **104** is applied thereto. Similarly, force f_2 is applied to shafts **95** and **96** and coupled to the medium by disc **97**. In this manner dielectrics **103** and **104** are extruded from their respective openings at the bottom of the vessels at a uniform rate.

In any application of the machine a particular disc **85** with a certain diameter opening is selected and secured to cylinder **84**. By such selection, the extreme limit of coating thickness is established and may be thought of as a "coarse" adjustment. In addition, a "fine" adjustment is provided by enabling vertical displacement of the inner vessel by utilizing its sloping termination **83*a***.

FIGURE 13 illustrates the principle of the "fine" adjustment mechanism of this furnace. The dotted line configuration of inner vessel 83a depicts its uppermost vertical extent. In its uppermost position it will readily be noted that the amount of dielectric 103 extruded from its container will be greatest; hence, maximum coating thickness. However, the inner cylinder 83 can be lowered to a point whereby its lower termination 83a touches the opening in disc 85 and thereby prevents any flow of dielectric 103. By this expedient, one can establish a maximum coating thickness (coarse adjustment) and by vertically displacing said inner cylinder 83 a fine adjustment within the range selected is obtained.

The fine adjustment is operated by the mechanism secured to base plate 94. Base plate 94 is bolted or welded to the frame 50. Secured to the inner wall of cylinder 83, and extending upwardly therefrom, are rods 91. Rods 91 pass through circular openings in base plate 94 and are secured to threaded annular disc 92. Disc 92 is adapted to cooperate with the inner threaded portion of coupling 93. Coupling 93 is arranged to rotate about its central axis. The outer circumferential portion of coupling 93 has bevel gear 99 machined thereon. Bevel gear 99 cooperates with pinion gear 100 which couples rotational motion thereto. Pinion gear 100 is driven by shaft 101 which in turn is motivated by hand wheel 102.

By rotating hand wheel 102 coupling 93 rotates and dependent upon the direction and the pitch of the threads on coupling 93, the cylinder 83 will be displaced a discrete distance in a vertical direction. Hand wheel 102 has an indicator 103 affixed thereto. The projection of pointer 103 on a calibrated index mounted on wall 104 enables a determination of the size X_2 of the opening in the outer vessel. For example, if the slope of the conical portion 83a of the inner vessel were 45 degrees, the vertical displacement of the vessel will change the size X_2 of the opening by an equal amount. On the other hand, if the slope of cylinder 83a were not 45°; a simple trigonometric calculation would readily enable one to determine the size X_2 of the coating opening.

From the foregoing it will be seen that we have provided a novel automatic drawing machine capable of producing uniformly small coated optical fibers or aligned fused fiber bundles independent of furnace temperature with a high degree of accuracy.

Obviously many modifications and variations of the present invention are possible in light of the above teachings. For example, the transducer employed in measurement means 18 could take the form of a capacitance probe forming part of an electronic oscillator. As such, the error signal would be in the form of a frequency modulated signal and would require a discriminator or ratio detector to transform such signal into a more usable form. This type of transducer is highly accurate and is presently employed in many other fields; viz., the phonograph transducer in a high fidelity audio system. Another possibility would be a collimator type measuring system. That is to say, the shadow of the fiber 40a would be compared to a reference size and would generate an electric signal proportional to any difference therebetween. Also, a different traversing mechanism may be employed, i.e., a guide that would cause the fiber to travel the length of drum 49 and the drum itself would have no translatory motion.

Many other combinations are possible for enabling proper fiber alignment. One example, would be a fiber guide with substantially instantaneous travel return whereby very little of the fiber 40a would be non-parallel to the previously wound fiber. Furthermore, the apparatus may be used for drawing conical fiber bundles. To this end, the proper gradient is selected for furnace 13 whereby a conical fiber melting configuration is established. However, inasmuch as fibers are the starting material, it is noted that in this application the fiber diameter measuring means would not be included in the

operation of the machine. Another obvious modification would be an additional coating of cement to fuse the fibers and thereby eliminate the necessity of heat source 70. The additional coating device should contain an adhesive type material to secure the successive fibers, side by side. For this purpose waterglass, glass solder, or other suitable epoxy resins will give good results.

Accordingly, it is to be understood that within the scope of the appended claims the invention may be practiced otherwise than has been specifically set out in this specification.

We claim:

1. In combination a system for drawing a thermoplastic material into fine flexible aligned fiber bundles comprising: a multisection furnace for heating said material; means for selecting various temperatures for the individual sections of the furnace; means for maintaining said temperatures constant; means for feeding the thermoplastic material into the furnace at a predetermined constant rate; means for drawing said material from said furnace into a fine flexible fiber at a constant rate; means for detecting any variation in the diameter of the fiber after it has been drawn from the furnace; means for displacing said drawing means in a direction lateral to the drawing direction so that the fiber is wound in aligned, multiple, parallel, layers upon said drawing means; and means responsive to said detecting means for regulating the rates of the drawing means and the displacing means in accordance with any detected variation in the diameter of the fiber.

2. In combination a system for drawing a thermoplastic material consisting of a dielectric encased by another dielectric having a lower refractive index but substantially the same melting point into fine, flexible, aligned fiber bundles comprising: a multisection furnace for heating said material; means for selecting various temperatures for the individual sections of the furnace; means for maintaining said temperatures constant; means for feeding the thermoplastic material into the furnace at a predetermined constant rate; means for drawing said material from said furnace into a fine flexible fiber at a constant rate; means for detecting any variation in the diameter of the fiber after it has been drawn from the furnace; means for applying an adherent opaque coating to the fiber after it has been measured; means for displacing said drawing means in a direction lateral to the drawing direction so that the fiber is wound in multiple, parallel, layers upon said drawing means; and means responsive to said detecting means for regulating the rates of the drawing means and the displacing means in accordance with any detected variation in the diameter of the fiber.

3. In combination a system for drawing a thermoplastic material consisting of a dielectric encased by another dielectric having a lower refractive index but substantially the same melting point into fine, flexible, aligned fiber bundles comprising: an inner vessel for heating the dielectric material having the lower refractive index; an outer vessel surrounding said inner vessel for heating the other dielectric material; means for extruding both dielectric materials from reduced annular openings at the bottom of their respective vessels such that the extruded dielectrics are concentric with each other and form an integral nondiffused solid; a multisection furnace for receiving and heating said solid; means for selecting various temperatures for the individual sections of the furnace; means for maintaining said temperatures constant; means for feeding said solid into the multisection furnace at a predetermined constant rate; means for drawing said solid from said furnace into a fine flexible fiber at a constant rate; means for detecting any variation in the diameter of the fiber after it has been drawn from the furnace; means for detecting a discontinuance of drawn fiber from the furnace; means for applying an adherent opaque coating to the fiber after it has been measured;

means for displacing said drawing means in a direction lateral to the drawing direction so that the fiber is wound in multiple, parallel, layers upon said drawing means; means responsive to said detecting means for regulating the rates of the drawing means and the displacing means in accordance with any detected variation in the diameter of the fiber; means responsive to the discontinuance detecting means for turning off the system if such a discontinuance is detected; and means for adjusting the reduced annular opening of said outer vessel.

4. In combination a system for drawing a thermoplastic material consisting of a dielectric encased by another dielectric having a lower refractive index but substantially the same melting point into fine, flexible, aligned fiber bundles comprising: an inner vessel for heating the dielectric material having the lower refractive index, an outer vessel surrounding said inner vessel for heating the other dielectric material; means for extruding both dielectric materials from reduced annular openings at the bottom of their respective vessels such that the extruded dielectrics are concentric with each other and form an integral nondiffused solid; means for drawing said solid from said annular openings into a fine flexible fiber at a constant rate; means for detecting any variation in the diameter of the fiber after it has been drawn from the openings; means for detecting a discontinuance of drawn fiber from the openings; means for applying an adherent opaque coating to the fiber after it has been measured; turntable means supporting said drawing means for displacing said drawing means in a direction lateral to the drawing direction so that the fiber is wound in multiple, parallel, layers upon said drawing means; means responsive to said detecting means for regulating the rate of the drawing means and the displacing means in accordance with any detected variation in the diameter of the fiber; and means for adjusting the reduced annular opening of said outer vessel.

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