

[54] **APPARATUS AND METHOD FOR
CONTINUOUS MATERIAL FEEDING
AND DEFORMATION**

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1969.

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[58] Field of Search **72/60, 710, 253, 270, 284-286,**
72/287-291; 226/7, 97; 164/81

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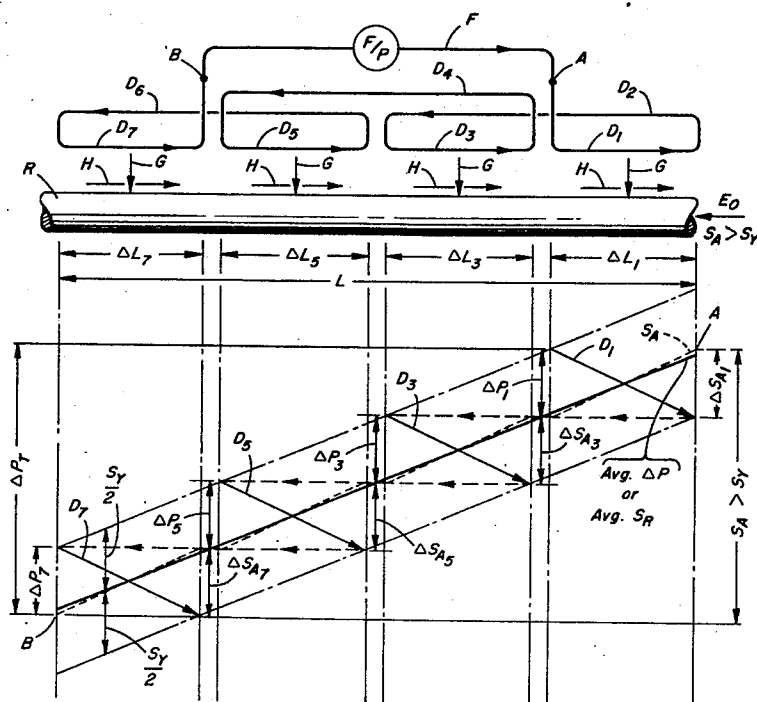
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[57] **ABSTRACT**

Disclosed herein is a process in which flowing fluids are utilized to apply viscous drag forces to a rod of indefinite length and advance it continuously through an extrusion die, to produce a continuous product, for example, a wire. The flowing fluids also control the axial and radial stresses in the rod, sealing it into and out of a treating environment so that undesirable rod pinch-off, bulging, or tension failure is avoided. The temperature, and hence viscosity, of the flowing fluids may be adjusted to control viscous drag forces.

75 Claims, 11 Drawing Figures



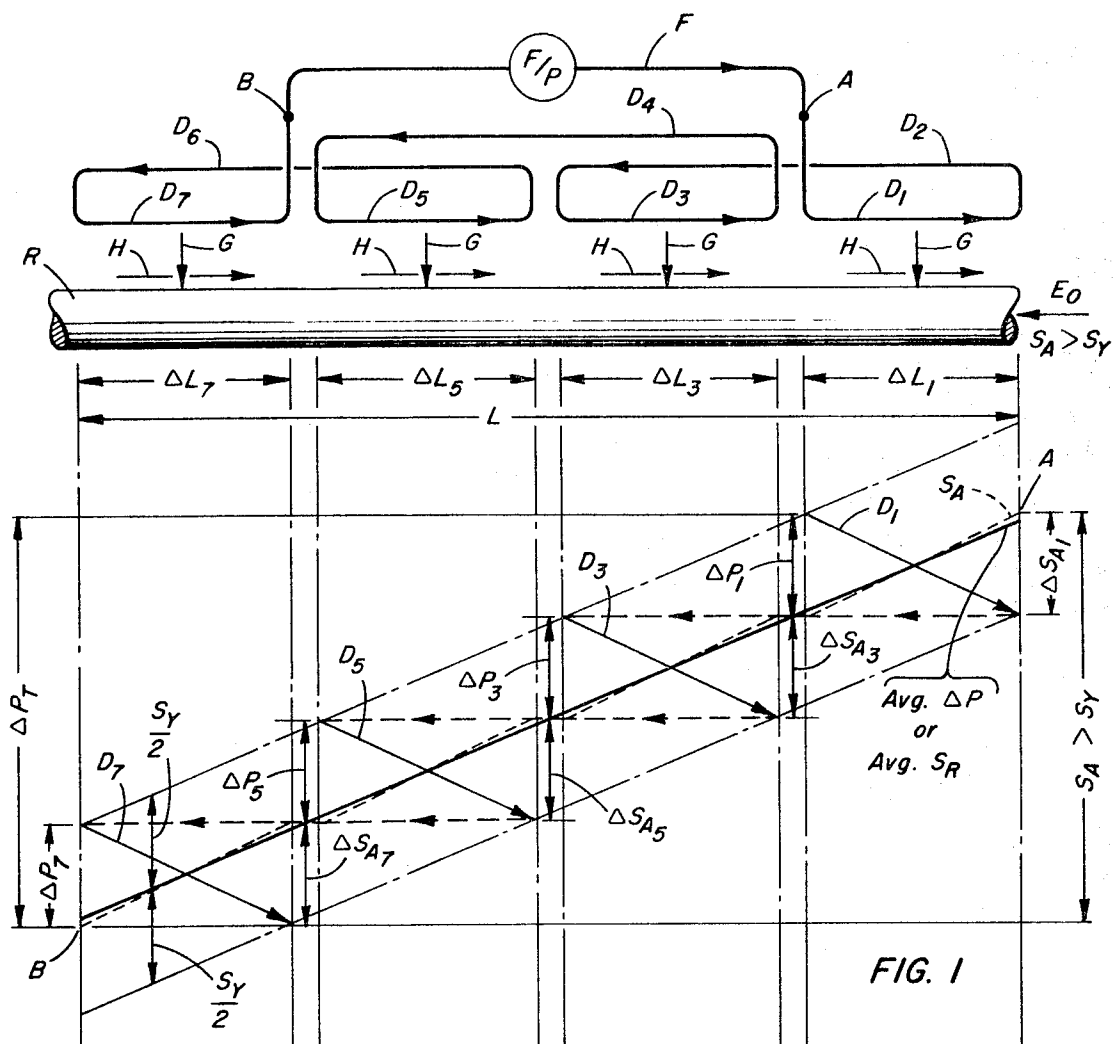
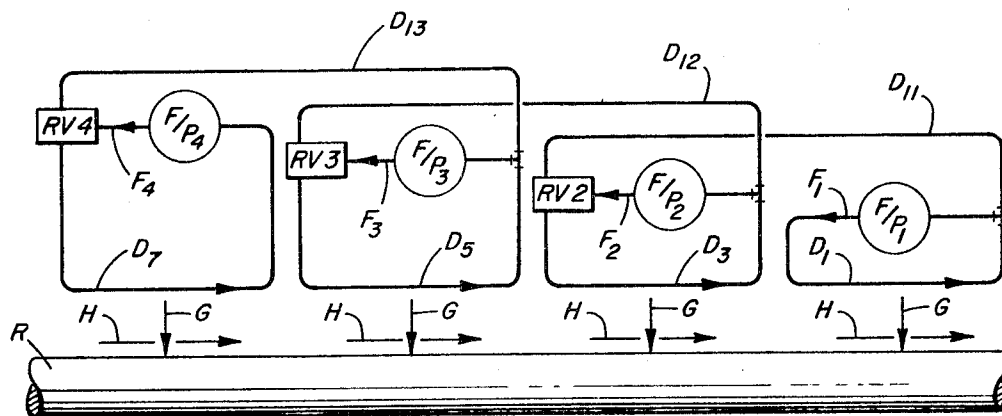
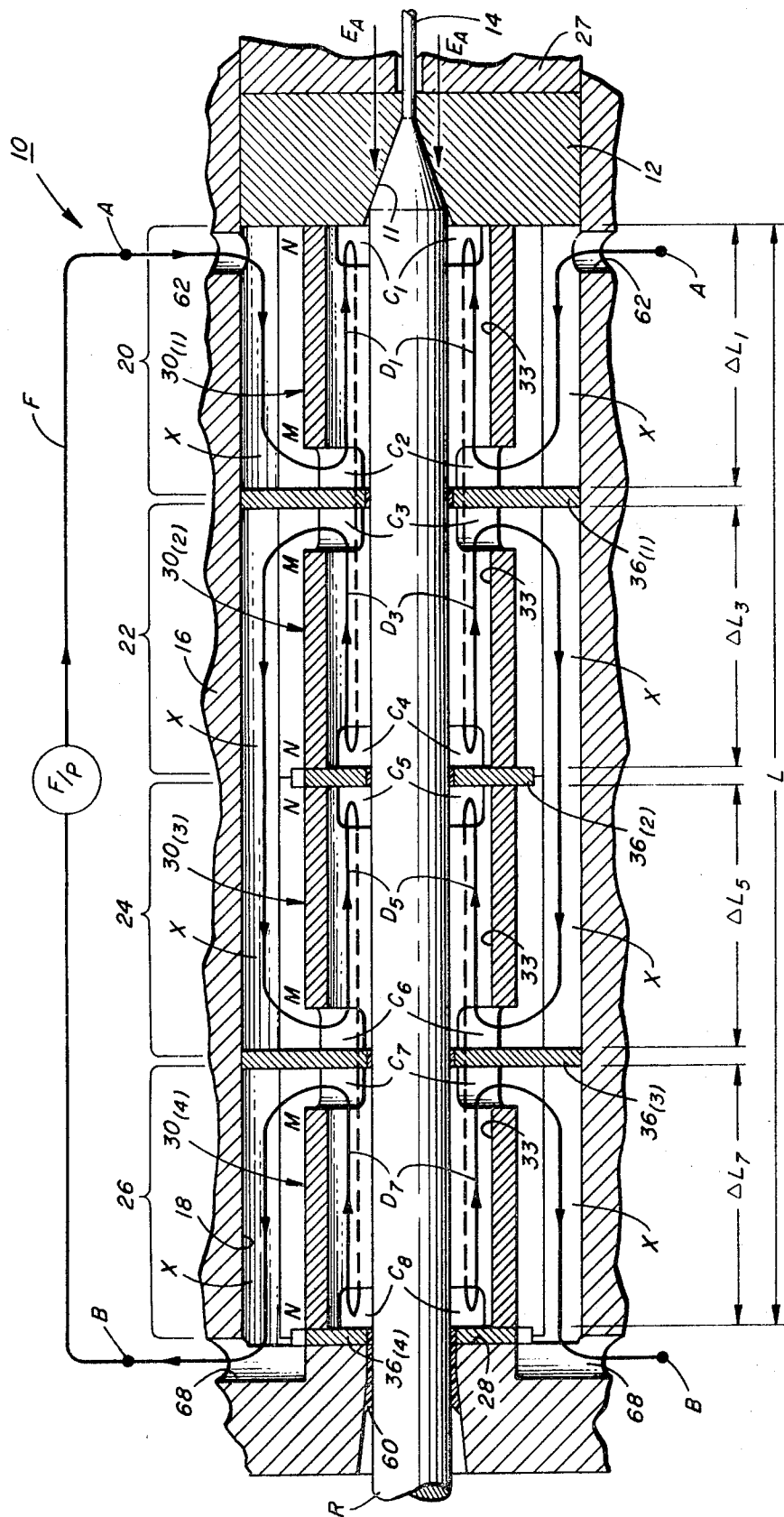
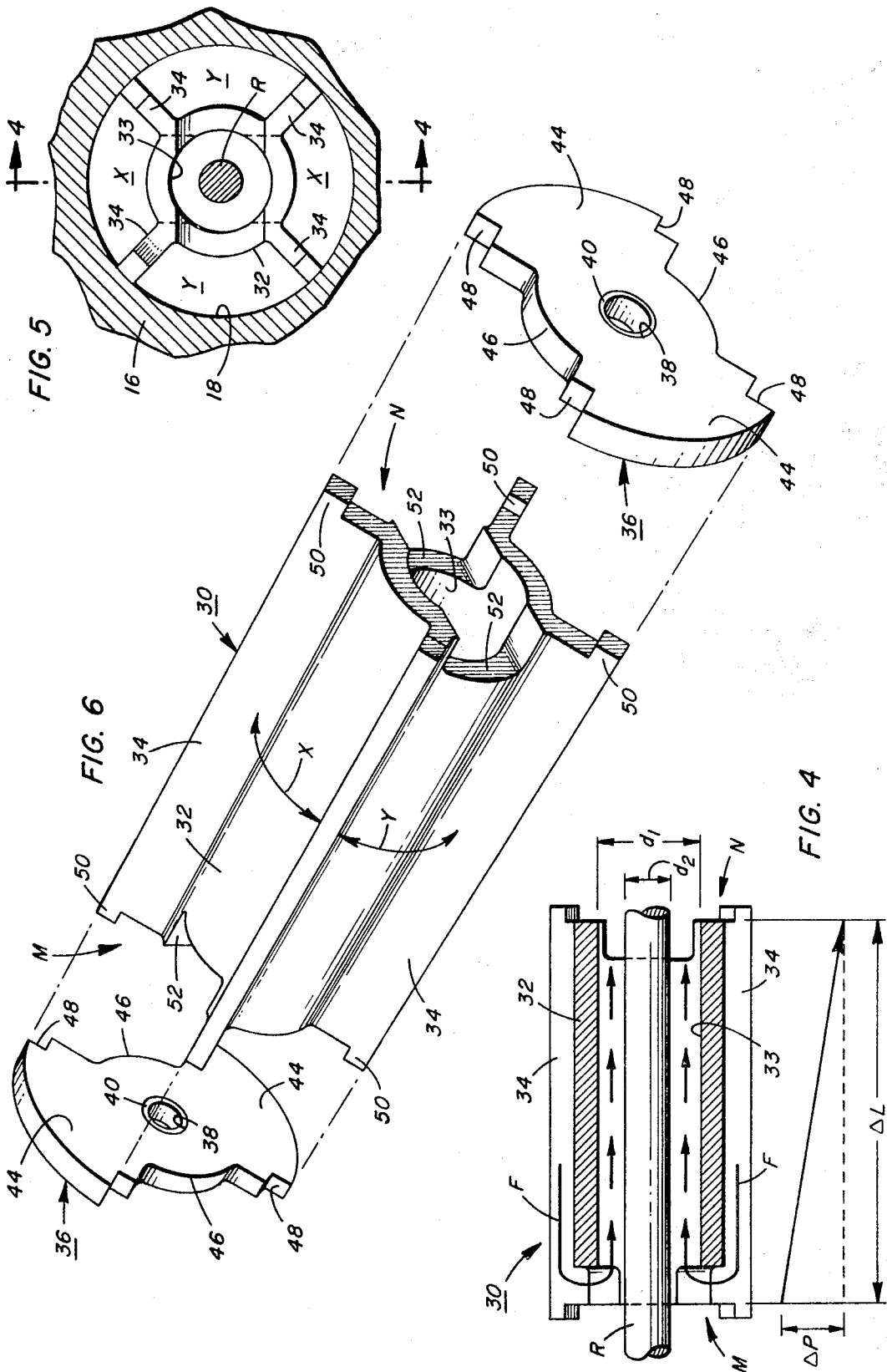


FIG. 2

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FIG. 3





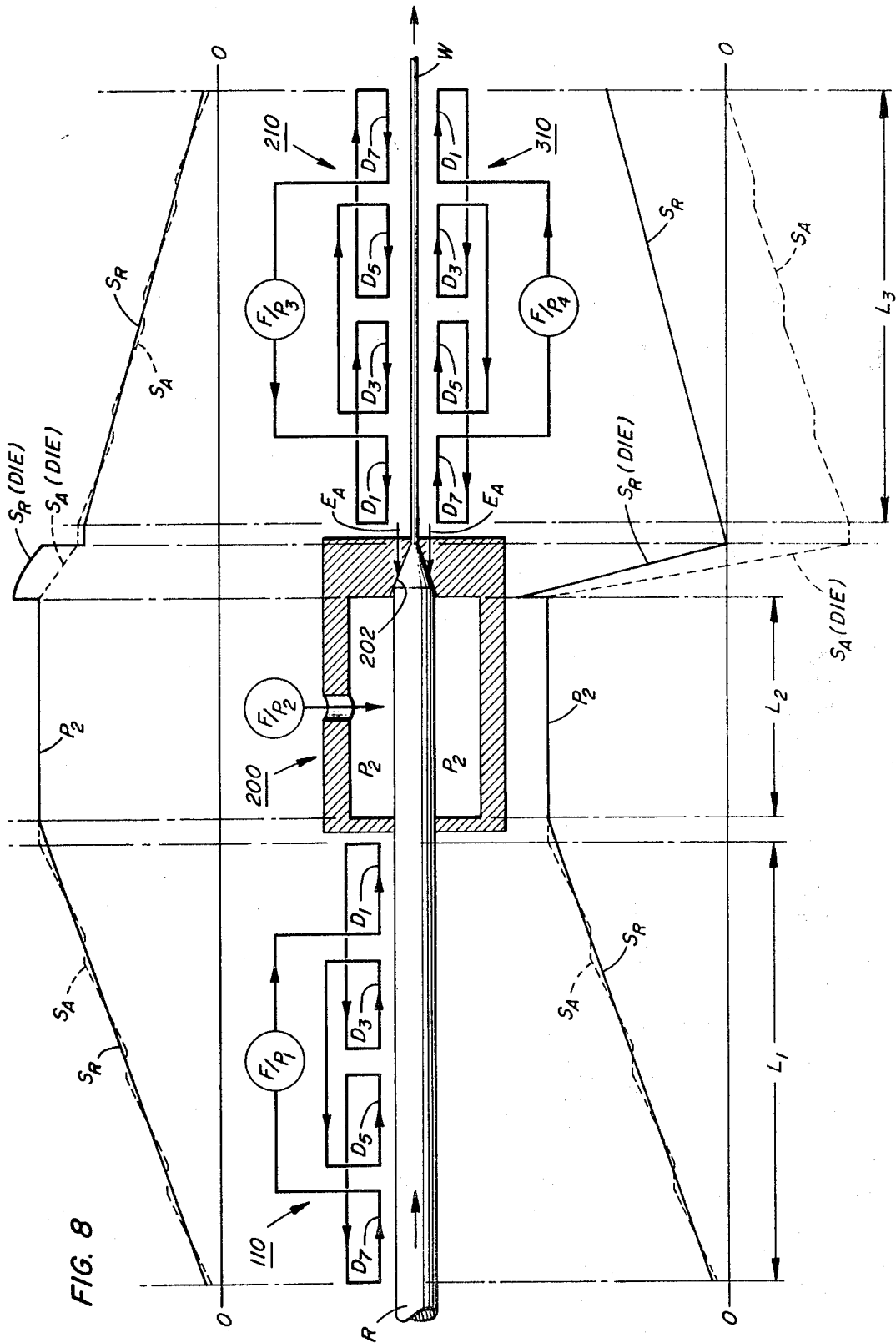


FIG. 9

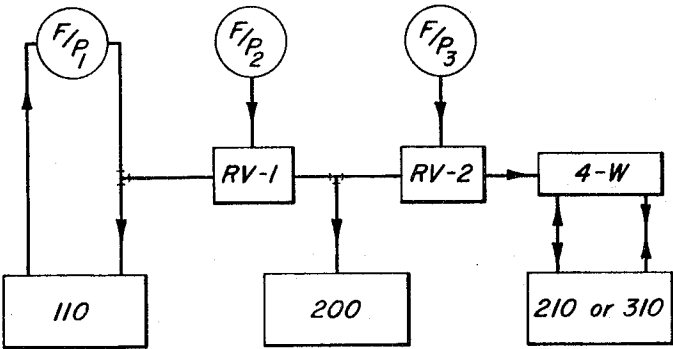
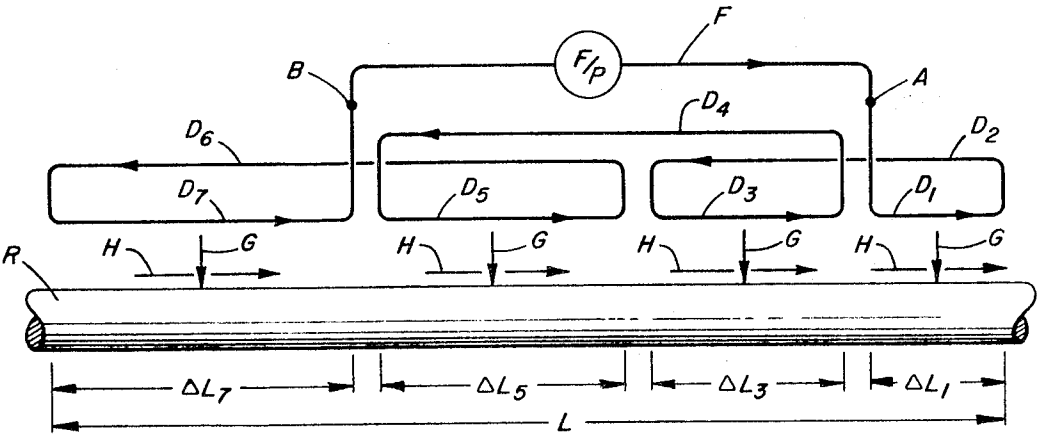
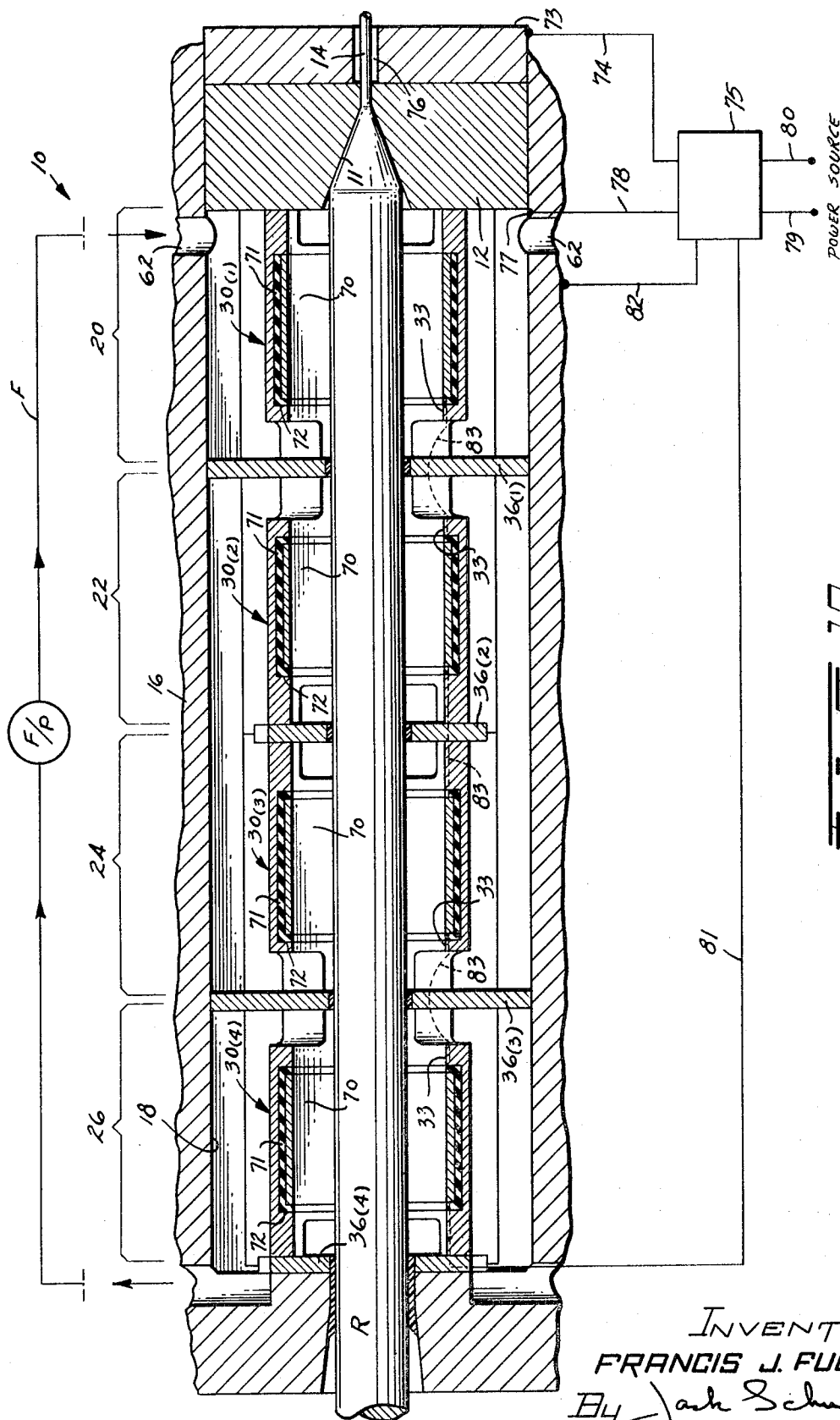


FIG. 7

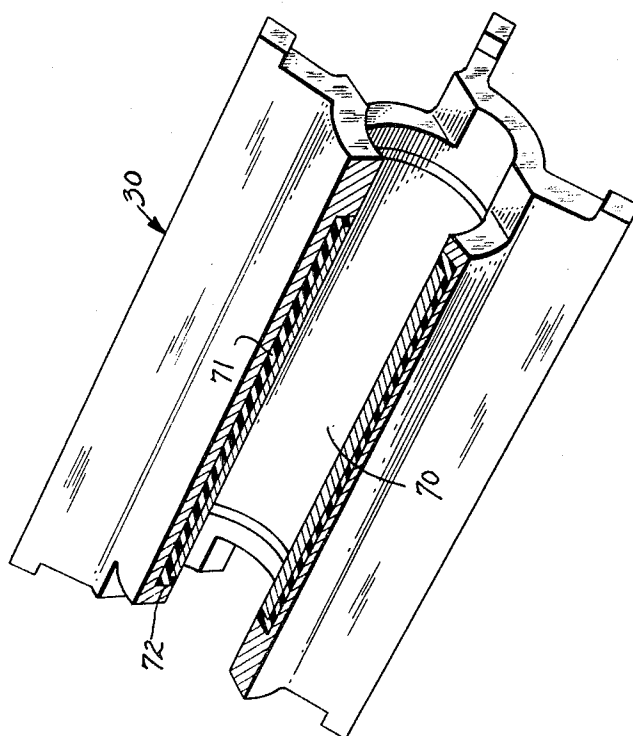




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FIG- 11



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APPARATUS AND METHOD FOR CONTINUOUS MATERIAL FEEDING AND DEFORMATION

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of my pending application, Ser. No. 794,488 filed Jan. 28, 1969, and titled "Continuous Material Feeding and Deformation Process."

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to material feeding and treatment processes. In various embodiments, flowing fluid is utilized to control the axial stress and pressure conditions within the material, continuously advance it into and/or withdraw it from a treatment environment, especially one involving high pressure, and also to seal the material into and/or out of that environment. This invention is particularly useful in continuously advancing a rod of indefinite length through an extrusion die to produce a wire, also of indefinite length.

2. Description of the Prior Art

It is known to utilize flowing fluids to transport material. For example, yarns and threads have been conveyed in streams of flowing fluid. However, none of these prior art techniques has utilized the fluid to advance material and also to control the axial and radial stresses therein so that the shape of material is controlled as it is advanced.

Continuous materials deformation processes are known. For example, conventional wire drawing involves pulling a rod of indefinite length through a series of drawing dies, each of which reduces its size to produce a wire. Conventional wire drawing is limited because the drawing forces applied to the wire, as it is being formed, may not produce tension stresses therein which exceed the yield strength of the wire. This, and other reasons, have lead to a consideration of extrusion as a method for making wire-like products.

Various extrusion processes are also known. In some of these, a discrete billet is pressurized and forced through an extrusion die. Such processes have the disadvantage that when the billet is consumed, product formation ends, and the extrusion apparatus must be recharged with a new billet. Recharging is time-consuming and, of course, the product is not continuous but rather is produced in discrete lengths. Also, the properties of such a product may vary undesirably, especially at the ends thereof.

Other extrusion processes have been proposed in which an extrusion vessel is charged with rod, pressurized to extrude a product therefrom, depressurized, and recharged with rod, and repressurized to extrude product, in repeating cycles. In such processes the rod is not advanced continuously, nor does the product issue therefrom continuously. Therefore, they are essentially discontinuous processes, suffering both in operating speed and product uniformity.

SUMMARY OF THE INVENTION

One aspect of this invention involves the use of flowing fluids to advance material by application of viscous drag forces thereto while at the same time controlling the axial and radial stresses therein.

Another aspect of this invention involves continuously exerting upon the surface of material advancing forces, for example, viscous drag forces, which push and continuously advance the workpiece against a deforming agency, which may be an extrusion die, to produce a continuous product such as a wire.

Another aspect of this invention involves the use of viscous drag forces to advance material into and withdraw material from a pressurized environment. These fluids may be utilized to control the axial and radial stresses in the material, for example, to avoid pinch-off, bulging, or tension failure.

Yet another aspect of this invention involves the use of flowing fluids to seal and control stress gradients in the material as it is introduced into a treating environment and, where desired, to seal and control stress gradients in the material as it is withdrawn.

In still another aspect of this invention, viscous drag forces continuously advance a rod toward an extrusion die and the temperature and hence viscosity of the motive fluids are adjusted to control such viscous drag forces.

It is especially significant that in various embodiments of this invention, flowing fluids are utilized to advance and produce stresses in the material which exceed the yield strength thereof. Indeed, these stresses may greatly exceed the material yield strength, and increase the ductility of the material, enhancing the deformation thereof without fracture.

In one specific embodiment of this invention, flowing fluid is applied to the surface of a rod of indefinite length to continuously advance the rod, while controlling the axial and radial stresses therein, into an extrusion die, from which a wire, also of indefinite length, issues continuously. The axial and radial stresses in the wire may also be controlled, as desired, by flowing fluids. It is noteworthy that this, and other extrusion processes according to this invention are continuous as distinguished from the discontinuous extrusion processes mentioned above.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other various aspects of this invention will be appreciated by referring to the drawings, wherein:

FIG. 1 is a schematic representation of a viscous drag rod feeding process involving an alternate-reverse flow pattern, together with a graph which shows the stress conditions in the rod within the process;

FIG. 2 is a schematic representation of an alternate viscous drag rod feeding process in which the flow of fluid is in discrete fluid currents rather than in an alternate-reverse flow pattern, the graph of FIG. 1 also being applicable to FIG. 2;

FIG. 3 shows a viscous drag rod feeder, including a series of flow reversal cells, and the fluid flow therethrough, utilized for feeding and extruding a rod to produce a wire;

FIGS. 4-6 illustrate details of a flow reversal cell within the feeder of FIG. 3;

FIG. 7 is a schematic representation of a viscous drag rod feeding process, involving alternate-reverse flow, but in which the individual flow portions vary in length in relation to pressure-induced viscosity changes in the fluid thereof;

FIG. 8 is a schematic representation of continuous extrusion processes in which viscous drag rod feeders both advance rod and withdraw product wire from the process, together with graphs showing stress conditions in the rod and wire;

FIG. 9 is a diagram of a hydraulic control circuit for the processes illustrated in FIG. 8.

FIG. 10 is a view similar to FIG. 3, showing a modification employing a heating element in each of the flow reversal cells and means for controlling the flow of electrical current through the heating elements; and

FIG. 11 is a view similar to FIG. 6, showing in perspective a typical cell insert, partially broken away to show the heating element employed with the modification illustrated in FIG. 10.

DETAILED DESCRIPTION

FIG. 1 illustrates diagrammatically the viscous drag feeding method of the present invention, employed in continuously advancing an indefinite length of rod R against an opposition force E_0 of sufficient magnitude to build up axial stress S_A in the rod in excess of the rod yield strength S_Y , such axial stress S_A being shown along the ordinate of the graph of FIG. 1. A viscous fluid F is pressurized by a fluid pump F/P and caused to flow in the flow pattern shown by the arrowed solid line between the points A and B. This flow pattern is referred to as an alternate-reverse flow or flow pattern. More specifically, the viscous fluid F is pumped from point A in the direction of the arrows rightwardly along the portion of the flow pattern identified as D_1 , thence leftwardly along the portion of the flow pattern identified as D_2 , and again rightwardly along the portion of the flow pattern indicated as D_3 . This alternate-reverse flow is repeated, as shown, with the fluid flowing alternately rightwardly and leftwardly until it reaches the point

B, whereupon it is recycled through to fluid pump F/P, repressurized, and again pumped along the described alternate-reverse flow pattern. This cycle is repeated continuously to sustain the fluid flow in this pattern.

As will be discussed in detail below, the cyclically interrupted portions of the flow pattern, D_1 , D_3 , D_5 , and D_7 , are applied respectively to rod portions ΔL_1 , ΔL_3 , ΔL_5 , ΔL_7 , which are spaced at regular intervals along the length L of rod R. However, certain features of the alternate-reverse flow pattern should be specially noted at this point.

The flow of fluid is from point A to point B, not leftward flow as seen in FIG. 1. However, the direction of flow is in the opposite direction, rightward, in flow portions D_1 , D_3 , D_5 , and D_7 . Thus, flow of fluid along the rod surface is from B to A.

As seen in the graph of FIG. 1, the total pressure drop between points A and B, ΔP_T , is distributed over the flow pattern, pressure drops ΔP_1 , ΔP_3 , ΔP_5 , and ΔP_7 being associated respectively with flow portions D_1 , D_3 , D_5 , and D_7 . These pressure drops ΔP are indicated graphically by the downward, rightwardly directed arrows D_1 ... D_7 . Assuming that the pressure drop in portions D_2 , D_4 , and D_6 may be adjusted to be very small, the sum of ΔP_1 ... ΔP_7 is substantially equal to ΔP_T .

While the flow in portions D_1 , D_3 , D_5 , and D_7 is rightward, the pressure gradient represented by the average fluid pressures in each of these successive flow portions also increases to the rightward. This pressure gradient is shown as an inclined solid line in the graph of FIG. 1.

The fluid of flow portion D_1 , D_3 , D_5 , and D_7 is applied to the surface of rod R at spaced intervals therealong, portions ΔL_1 , ΔL_3 , ΔL_5 , ΔL_7 , respectively. The pressure of the fluid within each of the flow portions D_1 ... D_7 , indicated by arrows G on the graph, produces radial pressure stresses S_R in the rod. The radial stress S_R at any point is equal to the static fluid pressure producing that stress. The viscous drag forces, indicated by arrows H, exerted by the flowing fluid produce axial stresses S_A in the rod, which stresses are cumulative and therefore increase from left to right as shown by the inclined dashed line on the graph of FIG. 1.

Since the radial stress S_R is equal to the static pressure head in the fluid producing that stress, the radial stress increment ΔS_R over any portion of rod ΔL is also equal to the pressure drop ΔP over that portion of the rod. It follows that the inclined solid line of the FIG. 1 graph represents a plot of the average of the radial stress increments ΔS_R and also a similar plot for the average of the pressure drop ΔP .

Rod pinch-off or bulging would occur if, at any point, the axial stress S_A therein should differ from the radial stress therein by an amount exceeding the yield strength of the rod, S_Y . In accordance with this invention, the individual pressure drops ΔP are controlled so that the axial stress increments ΔS_A , which are induced by the viscous drag forces H do not produce in the rod these conditions producing rod pinch-off or bulging.

The axial stress increments ΔS_A are shown by the inclined, stepped line on the graph of FIG. 1. Ideally, this line would overlie the solid line representing the average radial pressure S_R in the rod, thus assuring that neither pinch-off nor bulging would occur. These conditions are illustrated in the graph. In practice, these ideal conditions may be difficult to realize. The uppermost and lowermost inclined dashed lines on the graph define the boundaries between which the axial stress S_A and radial stress S_R may differ at any point along the rod length L and avoid the condition producing pinch-off or bulging. These dashed lines are displaced from the plots of the average radial stress and the axial stress by an amount equal to half of the rod yield strength, or $S_Y/2$.

As noted above, the viscous drag forces H are applied to the surface of the rod. When the sum of these forces exceeds the opposition force E_0 , the rod will be advanced against that opposition force, producing a corresponding axial stress in the rod.

Opposition force E_0 represents any reaction force against which the rod may be applied. It may, for example, be the

reaction force exerted by an extrusion die or other agency for deforming the rod.

Referring now to FIG. 2, the method of the present invention may also be practiced by employing a plurality of separate or discrete fluid currents, F_1 , F_2 , F_3 , and F_4 , each fluid current providing a separate one of the flow portions D_1 , D_3 , D_5 , and D_7 . As shown in FIG. 2, such flow portions are pressurized by individual fluid pumps F/P_1 , F/P_2 , F/P_3 , and F/P_4 , respectively. To provide the relationship between the axial and radial stresses indicated by the graph of FIG. 1, pressure levels in the fluids F_1 ... F_4 are controlled by their respectively associated individual pressure ratio valves $RV-2$, $RV-3$, and $RV-4$, so as to bear the proper pressure relationships. For example, the pressure level or pressure drop ΔP over the flow portion D_3 is provided with the proper pressure relationship with respect to the pressure drop in the preceding pressurized fluid F_1 by pressure control valve $RV-2$, which controls the pressure level in the pressurized fluid F_2 (and thus the pressure drop ΔP in the flow portion D_3) by receiving a pressure control signal from the pressurized fluid F_1 over control line D_{11} . Similarly, the pressure levels in the fluids F_3 and F_4 are so controlled by their respectively associated pressure control valves $RV-3$ and $RV-4$.

The valves mentioned above may be pressure reducing valves, or pressure ratio valves, for example, such as disclosed in copending patent application, Ser. No. 769,935 filed Oct. 23, 1968.

An advantage of utilizing discrete fluid currents F_1 , F_2 , F_3 , and F_4 is that it permits each fluid to be of a different viscosity, thus adding flexibility to the control of the above-described axial and radial stress relations. Further, if desired, this arrangement permits the use of the fluids to perform separate treatment functions upon the portions of the rod exposed thereto; for example, the fluid F_4 could be chosen to provide rod cleansing or descaling; the fluid F_3 chosen so as to provide a rinsing action; the fluid F_2 chosen so as to provide a chemical treating or pre-conditioning process; and fluid F_1 chosen so as to apply a lubricant to the surface of the rod exposed thereto.

FIG. 3 shows a viscous drag rod feeder 10, suitable for practicing the viscous drag feeding method of the present invention to continuously advance and extrude rod R through the orifice 11 of an extrusion die 12, to continuously form wire 14.

The feeder includes a housing 16 having a bore 18 therein for accommodating a plurality of flow reversal cells 20, 22, 24, and 26; and for accommodating the extrusion die 12. A retaining plug 27, threaded into housing 16, as shown, securely positions the extrusion die 12 and the flow reversal cells within the housing against a shoulder 28 formed within the bore 18.

Feeder 10 provides pressurized viscous fluid F with an alternate-reverse flow pattern, as indicated by the dual solid and dashed lines and the arrows thereon; the fluid F being driven continuously through the reversal cells 20, 22, 24, and 26 of the feeder by the fluid pump F/P. D_1 , D_3 , D_5 , and D_7 represent the annular, linearly interrupted flow portions of the alternate-reverse flow applied, respectively, to rod portions ΔL_1 , ΔL_3 ... ΔL_7 within flow reversal cells 20, 22, 24, and 26. This flow pattern will be more readily understood by the detailed explanation set forth below of the structure of a representative flow reversal cell, and the manner in which the flow reversal cells are arranged within the feeder housing 16.

The pressure drops ΔP of flow portions D_1 , D_3 ... D_7 , as taught above, are controlled so that at any point along rod length L , the axial stress S_A and radial stress S_R in the rod do not differ by any amount greater than the yield strength of the rod, S_Y . Additionally, as before, the pressure drops ΔP are controlled so that the applied viscous drag forces H are of sufficient magnitude to continuously advance and extrude the rod R through the extrusion die 12, that is, against the force E_A . In this example, E_A is sufficiently great that the axial stress S_A built up in the rod by feeder 10 will exceed the yield strength of the rod material S_Y .

Referring to FIGS. 4-6, each flow reversal cell includes a universal cell insert, indicated generally at 30, which includes

a generally cylindrical, longitudinally extending central body portion 32 having a central bore 33, and a plurality of integrally formed, radially disposed, longitudinally extending ribs 34. As shown in FIGS. 4 and 5, the inner diameter d_1 of bore 33 is larger than the diameter d_2 of the rod R. The opposite ends of each cell insert 30, as shown in FIG. 6, are designated respectively M and N faces. When assembled and positioned in the bore 18 of the feeder housing 16, as best seen in FIG. 5, the central body portion 32 and ribs 34 of the cell insert provide, in combination with the surface of the bore 18, a plurality of radially disposed and circumferentially spaced channels, alternate channels being designated X and Y channels.

Each cell 30 also includes a pair of barrier plates 36, FIGS. 3 and 6; and as will be noted in FIG. 3 the barrier plates between adjacent flow reversal cells are common to both cells. As best seen in FIG. 6, each barrier plate 36 is a partial disk having an outer diameter equal to the inner bore 18 of the feeder housing 16. Each barrier plate is provided with a central bore 38 into which is suitably press-fitted a seal 40 whose inner diameter is dimensioned to slidably accommodate the passage therethrough of the rod R. This seal may be made, for example, of Teflon. The barrier plates are also provided with imperforate blocking areas indicated generally at 44 which, as will be discussed in detail infra, reverse and redirect the flow of the pressurized viscous fluid F. Diametrically opposite portions of the barrier plates have been removed at 46 so as to permit free flow of the pressurized fluid thereacross. For contiguous assembly with the cell insert 30, the barrier plates 36 are provided with portions 48 dimensioned to closely receive the extending portions 50 of insert ribs 34. As seen in FIG. 6, identical barrier plates 36 are assembled to opposite ends of the cell insert 30, and when so assembled, are rotated 90° with respect to each other.

Referring again to FIG. 3, cell inserts 30(1), 30(2), 30(3), and 30(4), comprising the respective flow reversal cells 20, 22, 24, and 26, are assembled such that the M and N faces are reversed for adjacent flow reversal cells, that is, the M faces of flow reversal cells 20-22 and 24-26 are opposite to each other across an intervening barrier plates 36(1) and 36(4), and the N faces of the flow reversal cells 22-24 are opposite to each other across an intervening barrier plate 36(2). When so assembled, the X-channels and the Y-channels of all the flow reversal cells are aligned with one another.

Further, when the barrier plates 36 are assembled to the cell inserts as shown in FIG. 3, with each plate being angularly displaced 90° with respect to the adjacent plate, the imperforate portions 44 of the barrier plates and the portions of the barrier plates removed at 46, alternately from right to left, block and connect the aligned X-channels as shown, and alternately from right to left (not shown in FIG. 3) connect and block the aligned Y-channels.

As seen in FIG. 6, portions of the ends of the central body portion 32 of the flow cell insert 30 have been removed at 52, such removed portions being diametrically opposite each other at each end, with the portions 52 at opposite ends being angularly displaced from each other by 90°. The removed body portions 52, upon the barrier plates 36 being assembled as suggested above and indicated in FIG. 6, provide, in cooperation with the imperforate portions 44 of the barrier plates, fluid communication channels $C_1, C_2, \dots, C_8$. As best seen in FIG. 3, when the flow reversal inserts 30 and barrier plates 36 are assembled and aligned as shown, the communication channels C_1, C_4, C_5 , and C_8 place the central bores 33 of the flow reversal cells in communication with the Y-channels; and the communication channels C_2, C_3, C_7 , and C_6 place the central bores 33 in communication with the X-channels.

Referring again to FIG. 3, in operation, rod R is passed through an input seal 60 (similar to barrier plate seals 40) provided in the rear of the feeder housing 16, through the aligned central bores 33 of the flow reversal cells 26, 24, 22, and 20, and the bores 38 of the seals 40 of the barrier plates 36, and into orifice 11 of extrusion die 12. The fluid pump F/P is actu-

ated to pressurize and pump fluid F to point A, and from point A through the input ports 62 provided in the housing 16, which input ports are in fluid communication with the X-channels of the first flow reversal cell 20. The pressurized fluid is divided and flows leftwardly through the two X-channels of the first flow reversal cell 20 and through the communication channels C_2 where the fluid is reunited and flows into the annular space between the rod R and the bore 33 of the first flow reversal cell insert 30(1). The fluid flows rightwardly along the surface of the rod R as indicated by the linearly interrupted flow portions designated D_1-D_1 . (As mentioned above, the dual arrows D_1-D_1 are representative of an annular flow and not two separate flow paths as when the fluid P is flowing through the diametrically separated X-channels.) The fluid flows rightwardly along the surface of the rod length ΔL_1 residing in the first flow reversal cell 20, and as discussed with regard to FIG. 1, applies to the rod radially acting pressure indicated by the arrows G and longitudinally acting viscous drag forces indicated by the arrows H.

Upon reaching the face of the extrusion die 12, fluid F is diverted or redirected through the fluid communication channels C_1 into the Y-channels of the flow reversal cell 20, and as indicated by the dashed lines, the fluid flows leftwardly through the aligned and connected Y-channels of the flow reversal cells 20 and 22. Upon reaching the imperforate or blocking portions 44 of the barrier plate 36(2), the fluid is diverted and redirected through the fluid communication channels C_4 into the annular space between rod R and the central bore 33 of the second flow reversal cell insert 30(2). As indicated by the arrows D_3-D_3 , the fluid flows rightwardly along the length ΔL_3 of the rod R residing in the second flow reversal cell 22, where it applies the aforementioned axial and radial stress increments to the rod R along length ΔL_3 .

Upon reaching the imperforate or blocking portions 44 of the barrier plate 36(1), the pressurized fluid P is again diverted and flows leftwardly through the fluid communication channels C_3 into and through the aligned and connected X-channels of the flow reversal cells 22 and 24. Upon reaching the blocking or imperforate portion of the barrier plate 36(3), the fluid flows through communication channels C_6 into the annular space between the surface of the rod and the bore 33 of the flow reversal cell insert 30(3). As indicated by arrows D_5-D_5 , the fluid flows rightwardly along the surface of rod length ΔL_5 in the third flow reversal cell 24, building up axial and radial stress increments in that portion of the rod. Upon reaching the imperforate or blocking areas 44 of the barrier plate 36(2), the fluid is diverted or redirected through the communication channels C_5 and into the Y-channels of the flow reversal cells 24 and 26. The fluid, in the foregoing described manner, is directed rightwardly through the fourth flow reversal cell 26 by barrier plates 36(4) and 36(3), then leftwardly through the Y-channels of the flow reversal cell, and through exit ports 68, to point B. At this point, suitable fluid cooling may be provided. The fluid returns to the fluid pump F/P where it is repressurized and recycled through the alternate-reverse flow pattern described above.

The sum of the viscous drag forces imparted to the rod, as described above, advances the rod against the opposition force E_A exerted on the rod by extrusion die 12, and the rod is continuously extruded as wire 14. Thus, in the example described above, rod R of indefinite length is continuously received within the viscous drag rod feeder 10, there pressurized, and, by application of viscous drag forces, fed against a deforming agency, extrusion die 12, and continuously extruded therefrom as a wire 14 of indefinite length.

To advance and extrude a rod R of a given diameter d_2 with the viscous drag feeding method of the present invention, the flow reversal cell design criteria set forth below have been found to provide satisfactory results. These design criteria are based on a stationary rod R, a stationary flow reversal insert 30, and a flowing viscous fluid. Referring to FIG. 3, and recalling from the foregoing that the radial stress increment ΔS_r

across a flow cell ΔL is equal to the pressure drop ΔP thereacross:

1. The pressure drop ΔP in the viscous fluid, across the length ΔL of flow reversal cell 30, will not exceed the yield strength of the rod S_y , and the drop ΔP is made equal to the axial stress increment ΔS_A built up in the portion of the rod ΔL residing in the cell insert 30, i.e., $\Delta P = \Delta S_A$.
2. The total force required to pump the fluid through the annular space between the rod and the bore 33 of the cell insert 30 is equal to $(d_1^2 - d_2^2) \pi/4 \Delta P$, which d_1 is diameter of the cell bore and d_2 is the diameter of the rod.
3. It is assumed that the total force required to pump the fluid through the annular space will be dissipated proportionately between the surface of the rod and the surface of the cell bore (as indicated by the arrows therealong) in accordance with the relative surface areas. Thus, the portion of such total force dissipated on the rod surface will be equal to $(d_1^2 - d_2^2) \pi/4 \Delta P (d_2)/(d_1 + d_2)$.
4. The axial force increment generated in the rod by the viscous drag of the flowing fluid along the surface thereof, is equal to $\Delta S_A D_2^2 \pi/4$.
5. Also, the axial force increment generated in the rod is equal to the proportional force dissipated on the surface of the rod by the flowing fluid. Thus, the expressions of Paragraphs 3 and 4 must be equal to each other; therefore:

$$(d_1^2 - d_2^2) \pi/4 \Delta P (d_2)/(d_1 + d_2) = S_A d_2^2 \pi/4.$$

Since from Paragraph 1 $\Delta P = \Delta S_A$, these terms cancel out and the equation can be solved to show that the cell bore diameter d_1 is equal to twice the rod diameter d_2 , i.e., $d_1 = 2d_2$.

As noted above, the above design criteria are based on a stationary rod, of course such condition changes for rod advancement, and it has been found that in actual practice the cell bore diameter d_1 must be greater than twice the rod diameter d_2 . For example, to advance and extrude aluminum rod at a rate of 34 feet per minute with a 17 percent reduction in rod area, a flow reversal cell bore d_1 equal to 2.2 times the rod diameter d_2 has been found to provide satisfactory results.

It will also be noted from the above design criteria, in particular paragraph 5, that the diameter d_1 of the bore of flow reversal cell insert 30 is dependent only on the diameter d_2 of the rod. The following equation provides the necessary interrelationship between other factors, each one of which can be varied with respect to the others:

$$\Delta P = \frac{\nu L Q}{9,833,102 \left[\frac{d_1^2 - d_2^2}{2} \right] 3d_2} \quad (6)$$

where:

- ΔP = pressure drop across the flow reversal cell.
- ν = viscosity of the fluid P in centistokes at room pressure.
- L = length of the flow reversal cell in feet.
- Q = rate of fluid flow P through the annular space between the rod R and the bore 33 of the cell insert 30, in cubic inches per minute.
- d_1 and d_2 = the cell bore diameter and rod diameter, respectively (in the relationship taught in Paragraph 5 above), in inches.

It will be understood by those skilled in the art that practical considerations will make their usual import felt in using the equation of the foregoing Paragraph 6. For example, having chosen a ΔP in accordance with the design criteria of Paragraph 1, i.e., some value less than the yield strength of the material or rod to be advanced, and having determined the relationship between d_1 and d_2 in accordance with Paragraph 5, the viscosity ν and hence the fluid to be chosen, the length of the flow reversal cell L , and the flow rate Q , may each be varied with respect to the other. The viscosity ν and flow rate Q may be chosen, for example, with practical regard to the commercial availability of correspondingly appropriate fluids and fluid pumps.

In an embodiment of the present invention, using the foregoing design criteria, aluminum rod having a yield strength of approximately 5,000 psi was advanced at the rate of 34 feet per minute and extruded at an extrusion pressure of approximately 10,000 psi through a conical die (included angle of 40°), with the rod experiencing a 17 percent reduction in rod area. The viscous drag rod feeder employed included forty flow reversal cells and each was 2.5 inches in length. The rod diameter d_2 was 0.296 inch and the cell bore diameter d_1 of the flow reversal cell inserts was 0.651 inch. The rate of flow Q was 126 cubic inches per minute, and ΔP across each flow reversal cell was, on the average, approximately 250 psi. The viscous fluid employed had a room pressure viscosity of 2,000,000 centistokes and was comprised of 50 percent by volume of polyethylene micropowder and 50 percent by volume of 5,000,000 centistokes (room pressure) silicone fluid.

In general, the viscous fluids which may be utilized in practicing this present invention should provide good wetting action upon the material or rod to be advanced, and, for convenience, fluids should have minimal viscosity variation with respect to pressure, temperature, and shearing rate.

With general reference to the fluid pumps which may be utilized to pressurize and pump the viscous fluid F, double-acting or dual-piston pumps which provide a continuous output at the appropriate pressure level discharge capacity Q , are preferable. However, for a given continuous run, a single piston pump having a suitably large reservoir would be satisfactory.

With regard to the dimension of the X-channels and the Y-channels, such channels are made sufficiently large that any pressure drop experienced by the fluid in passing through these channels is small with respect to the pressure drops ΔP .

Thus, the overall pressure drop ΔP_T experienced by the fluid between points A and B, is substantially distributed over only the linearly interrupted flow portions $D_1, D_3, \dots, D_7$. With regard to the foregoing example and specific viscous drag rod feeder, the distance between the outer surface of the central portion 32 of the fluid cell insert 30 and the surface of the bore 18 of the housing 16, was 0.375 inch. The width of each barrier plate was 0.125 inch.

FIG. 7 illustrates diagrammatically a further embodiment of the present invention similar to that of FIG. 1, but wherein the flow portions D_1, D_3, D_5 , and D_7 of an alternate-reverse flow are of varying length, in particular, wherein such lengths vary in proportion to the overall pressure drop (from A to B) of the pressurized fluid F. As is known, the viscosity of a given fluid varies with pressure, usually decreasing with decreasing pressure. Thus, it will be understood that the viscosity of the fluid will decrease as the fluid generally drops in pressure from point A to point B.

Accordingly, the efficiency of a viscous drag feeder, such as that shown in FIG. 3, may be enhanced by increasing the length of the flow reversal cells, from right to left. Thus, utilizing the formula of paragraph 6 and the foregoing design criteria, one can further assure the maintenance of a desired pressure drop ΔP across each flow reversal cell by calculating a separate flow cell length L in accordance with the particular viscosity the pressurized fluid will have when flowing therethrough. By so varying the length of the flow reversal cell, it is possible to provide a given increasing axial stress gradient over a shorter length of material, and hence by means of fewer flow reversal cells, than would otherwise be possible with flow cells of equal length and with a fluid decreasing in viscosity in the direction of flow therethrough.

FIG. 8 shows a high pressure material treating process to which continuous access, both with respect to input and output, is gained in accordance with the principles of this invention. Very generally, a rod R of indefinite length proceeds continuously from atmospheric or room pressure through a stream of flowing fluid, into a high pressure material treating process, illustrating an extrusion process, and through a second stream of flowing fluid to return to room pressure. The streams of flowing fluid seal the rod (and product) into and

out of the treating process, controlling the pressures, pressure gradients, and axial stresses in the rod, and exerting viscous drag advancing or motion opposing forces thereon.

More specifically, FIG. 8 shows an input viscous drag feeder 110, a high pressure chamber 200, and an output viscous drag feeder 210, 310 which may function, as desired, in various modes of operation, for example that shown for a feeder 210 or that shown for a feeder 310. The feeders may be, for example, as illustrated and described with reference to FIGS. 1-7, that of FIG. 3 being shown.

In the illustrated process, a rod of indefinite length R is advanced by feeder 110, into high pressure chamber 200 which is filled with a suitable pressure transmitting fluid pressurized to a level P_2 by pump F/ P_2 , and passed through an extrusion die 202, to continuously form a wire W.

As indicated by the arrows, flow portions $D_1, D_3 \dots D_7$ of the output viscous drag feeder 210 apply viscous drag forces to the rod R which act in opposition to the viscous drag friction forces applied to the rod R by feeder 110. On the other hand, flow portions $D_1, D_3 \dots D_7$ of the output feeder 310 apply viscous drag friction forces to the rod R which aid or act in concert with the viscous drag forces applied to the rod R by the feeder 110.

While the feeder 210, 310 is shown for comparison in FIG. 8 as two different feeders, in actual practice, one output feeder would be operated as desired, to apply viscous drag friction forces to the rod acting in either direction. Returning briefly to FIG. 3, viscous drag rod feeder 10 is a bilateral fluid device which may be pumped or exhausted from either end. If the port 62 is made the input port, flow portions $D_1, D_3 \dots D_7$ will apply rightwardly acting viscous drag forces, as shown in FIG. 3. However, if fluid F is pumped into port 68, the fluid will be provided with an alternate-reverse flow opposite of that shown in FIG. 3, and the flow portions will apply leftwardly directed viscous drag forces. When the output feeder is operated in the manner of feeder 210, it will be referred to as operating in the "backward mode;" conversely, when operating in the manner of feeder 310, it will be referred to as operating in the "forward mode."

Generally, input feeder 110 provides continuous input access to the high pressure chamber 200; and the output feeder 210, 310 provides continuous output access to the chamber. Additionally, the input and output feeders build up axial and radial stress gradients in the material of rod R entering and exiting the chamber, such gradients being controllable to match the axial and radial stress conditions experienced by the material when entering and exiting the high pressure chamber. Further, as discussed with reference to FIGS. 1-3, such gradients may be controlled so that at no point within the feeders does the axial stress S_A in the rod depart from the radial stress S_R , by an amount greater than the rod yield strength, S_Y . Thus, rod pinch-off, bulging, and tension failure may be prevented.

Depending upon the specific characteristics of the continuous process to be performed, for example an extrusion process, and considering such factors as the material and yield strength of the rod, the percentage reduction to be achieved, the desired rate of extrusion, the need for back pressure or pulling force at the exit end of the die, and the like, the output viscous drag feeder 210, 310 may be operated either in the forward or backward mode of operation. Further, for a given process and considering "start-up," "continuous operation" for a period, and "shut-down," the output feeder may be operated in different modes at different times.

Assume, for example, that for a given extrusion process it is desirable or necessary to pressurize the material of rod R to a level greatly in excess of its yield strength, say four times that level, so as to increase the ductility of that material and facilitate its extrusion, without fracture through die 202. Feeder 110 would be provided with sufficient flow reversal cells and driven to build up in the rod, against the reaction forces E_A exerted by the die, an axial stress S_A in length L, four times as great as the yield strength, S_Y . The feeder 110 would

also apply radial stress S_R to the rod at no point differing from the axial stress S_A in the rod by an amount exceeding the rod material yield strength, S_Y . Simultaneously, the fluid in chamber 200 would be pressurized to a level P_2 substantially equal to the pressure level of P_2 . These radial pressure and axial stress relationships are illustrated in the upper graph of FIG. 8.

Under these conditions, material being deformed in passing through the die is also highly pressurized and increased in ductility as desired.

Referring to FIG. 8 and the upper graph thereof, output feeder 210, operating in the backward mode may be used to facilitate smooth extrusion start-up, to start up extrusion where the rod is highly pressurized to increase its ductility, and to maintain extrusion where back pressure on the extrusion product, for example wire W, is necessary or desirable.

It is well known that smooth start-up of extrusion may be facilitated by applying back pressure to the extrusion product. Feeder 210, running in the backward mode may apply this back pressure upon wire W as it emerges from die 202.

The start-up of extrusion where the rod must be in a highly pressurized state, in order to take advantage of the aforementioned ductility increase, may be especially difficult, or even impossible, in the absence of such back pressure. For example, in a particular extrusion situation, the reaction forces, E_A , exerted by the die may not be sufficient to build up the necessary pressures in the material being extruded. Operation of feeder 210 in the backward mode, against the action of input feeder 110, and the confining pressure P_2 within chamber 200 may assure the necessary rod pressurization and ductility increase as extrusion is initiated.

Once this condition is reached, feeders 110 and 210 are preferably controlled so that the rightwardly acting viscous drag friction forces applied to the rod by the input feeder gradually overdrive the leftwardly acting forces applied by the output feeder. Thus, smooth extrusion start-up is accomplished with the rod extrusion from the immediate inception, being performed with the portion of the rod undergoing deformation in a desired state of increased ductility. Further, once such extrusion is so begun, the output feeder can continue to be operated in the backward mode, at the appropriate relationship with respect to the input feeder 110, to provide back pressure to the extrusion process and also prevent, or assist in preventing, post extrusion fracture.

It is known in the art that many materials, especially brittle materials, for example, bismuth and beryllium, can best be extruded when in net compressional stress greatly in excess (4 to 5 times) of their yield strength. For example, a typical beryllium material may have a yield strength in the order of 50,000 psi.; however, due to its brittleness, large percentage reductions in area by extrusion can be more readily accomplished (if at all) when the beryllium is subjected to net compressional stress four to 5 times its yield strength. If not sufficiently pressurized, it may be expected that post-extrusion fracture will occur. Further, to avoid post-extrusion fracture when the extrusion product is returned to atmospheric or room pressure, the compressional stress present in the material must be reduced while maintaining properly related, decreasing axial and radial stress gradients which range between the immediate post-extrusion stress as in the rod and atmospheric or room pressure stress conditions. Viscous drag feeder 210 operating in the backward mode, uniquely meets the foregoing requirements.

Reference will now be made to the continuous forming method of the present invention illustrated by the bottom graph of FIG. 8, wherein the output viscous drag feeder 310 is operated in the forward mode. As suggested above, when the output feeder 310 applies viscous drag forces acting rightwardly as indicated by the arrows in the flow portions $D_1, D_3 \dots D_7$, such forces build up an axial stress gradient in the length of rod L_3 , which gradient increases in the direction of the rod advancement. Such forces assist input feeder 110 by pulling the rod through the die 202.

As an illustration, it will be assumed that the yield strength of the rod R and the percentage of area reduction to be imparted to the rod by extrusion through the die 202, are such that the extrusion pressure required is 10,000 psi. Such extrusion may be accomplished with the axial and radial stresses built up in the rod length L_2 at the die 9,000 psi, if the output feeder 310 also applies a pulling force on the wire W sufficient in magnitude to provide the additional 1,000 psi.

In some operations, finer control and smoother extrusion may be realized by both pushing with feeder 110 and pulling with output feeder 310, the pushing and pulling forces together cooperating to pass the rod through die 202.

The lower graph of FIG. 8 shows the axial stress S_A and radial S_R in rod R when pushed and pulled in accordance with this mode of operation. It is noteworthy that the portion of the rod within die 202 experiences an axial stress transition, from compression to tension. Thereafter, the tensile stress in the wire W is gradually relaxed to zero as the wire progresses through output feeder 310. In order to avoid pulling the wire in two, the output feeder is controlled so that the sum of the tensile and radial stresses in the wire do not exceed the yield strength of the wire material, causing it to fail in tension.

In some operations, it may be desirable to deform material such as rod by pulling it against or through a deforming agency, perhaps a drawing die. Output feeder 310 may be operated to accomplish this with or without the assistance of input feeder.

FIG. 9 is a diagram of a fluid control circuit suitable for controlling the fluid pumps F/P_1 , F/P_2 , and F/P_3 of FIG. 8 to assure that the pressure levels P_1 , P_2 and P_3 bear the proper pressure relationships to each other. More specifically, the adjustable pressure control valve RV-1 receives a pressure signal at pressure P_1 over the interconnecting control line as shown, and, in accordance with its adjustment, controls the pressure level P_2 provided by pump F/P_2 . Similarly, adjustable pressure control valve RV-2 assures that pressure level P_3 bears the proper pressure relationship to pressure level P_2 . Further, the output from valve RV-2 may be fed into a four-way valve 4W as shown, so that simple reversal of the four-way valve reverses direction of flow through the output viscous drag feeder, thereby providing a convenient manner of selectively operating the output feeder in either the backward mode or in the forward mode.

The above-mentioned valves may be pressure relief valves or pressure ratio valves, for example, valves as disclosed in the aforementioned copending patent application.

From the discussion of FIG. 8, it will be appreciated that viscous drag feeder 110 operates as an input seal, more specifically a continuous access, pressure gradient, input seal, which permits material, for example, rod R, to be introduced into and advanced continuously through a high pressure chamber wherein the material is subjected to pressure P_2 which may exceed the material yield strength. This pressure gradient seal can be most readily appreciated from the plot of the average pressure P_1 or S_R along the length L_1 in feeder 110 and the plot of the pressure P_2 or S_{R2} in length L_2 in the pressure vessel 200, such plots meeting at common points. The pressure range of this seal may be extended from zero, or room pressure, upwardly to any elevated pressure (limited only by practical considerations) by the mere provision of additional flow reversal cells, FIGS. 3-6, over which to drop or distribute the total pressure drop of the desired pressure range.

It will also be appreciated that drag feeders 210 and 310 operating as described with reference to FIG. 8 operate as continuous access, pressure gradient, output seals with the same desirable features and characteristics ascribed above to the input feeder 110. Thus, the input and output viscous drag feeders operating as described, and in conjunction with the extrusion process described above, constitute a high pressure material treating operation with continuous entrance and exiting access, through continuous input and output, pressure gradient, seals.

FIG. 8 shows rod R passing into extrusion die 202 and wire W extending therefrom, the illustrated extrusion processes being in the dynamic condition. Startup of those processes may be facilitated by suitable rod preparation. For example, the rod end first presented to the die may be prepared by the process of copending patent application, Ser. No. 758,732, filed Sept. 10, 1968. It may also be machined or otherwise provided with a leader of wire having the dimensions of wire W, suitable for introduction into the output feeder.

On occasion, it may be required to adjust the viscous drag frictional forces applied to rod R, for instance, to maintain the proper relationship between S_R and S_A as hereinbefore described, when proceeding from starting to full speed operation wherein the rod R will be accelerated from zero velocity to an operating velocity of perhaps 40 feet per minute thus necessitating the application of viscous drag frictional forces on the rod R of appropriately varying magnitude.

Adjustment of viscous drag frictional forces on rod R can, of course, be made by suitably controlling the pump rate. However, this may require the expenditure of large amounts of power to accelerate the viscous fluid, and the total amount of viscous drag applied to the rod R and to the wall of the cell bore 33 will accordingly be increased. I have discovered that the magnitude of the viscous drag frictional forces on rod R can be varied as required without adjusting the pump rate and without varying the total viscous drag frictional forces generated by the viscous fluid on both the rod R and the wall of the cell bore 33. Specifically, I have discovered that the proportion of total viscous drag frictional forces dissipated between the rod R and the wall of the cell bore 33 can be varied.

In the modification shown in FIGS. 10 and 11, means are provided to automatically maintain the proper relationship between S_A and S_R (viz., the difference between S_A and S_R must not exceed the yield strength, S_Y , of the rod R) by varying the proportion of the total viscous drag frictional forces dissipated between the surface of rod R and the wall of the cell bore 33.

As hereinbefore described, the total viscous drag frictional forces available from the fluid F in any specific flow reversal cell 20, 22, 24, 26 (i.e., the total force required to pump fluid F through the said reversal cell 20, 22, 24, 26) are ordinarily developed or dissipated between the surface of rod R and the wall of the cell bore 33 generally proportionately to their respective areas. The means shown in FIGS. 10 and 11 permit this generally proportional distribution of viscous drag frictional forces to be varied as required, so as to apply a greater proportion, and hence amount, of such viscous drag frictional forces to the rod R when S_A falls below S_R by such an amount that $S_R - S_A$ approaches the S_Y for rod R (as a practical matter, the proportion of the total viscous drag frictional forces applied to rod R will be increased when $S_R - S_A$ exceeds one-half S_Y), and so as to apply a lesser proportion, and hence amount, of such viscous drag frictional forces to the rod R when S_A rises above S_R by such an amount that $S_A - S_R$ approaches the S_Y for rod R (as a practical matter, the proportion of the total viscous drag frictional forces applied to rod R will be decreased when $S_A - S_R$ exceeds one-half S_Y).

More specifically, the amount of viscous drag frictional forces applied to a surface by a pressurized viscous fluid flowing along the surface is a function of the viscosity of the fluid. Viscosity is a function of temperature, and therefore the viscosity of the layer of viscous fluid flowing along a surface, and the viscous drag frictional forces applied to the surface by the flowing viscous fluid can be varied by varying the temperature of the surface. By suitable choice of flow conditions, such adjustment of fluid viscosity can be confined substantially to the layer of fluid immediately adjacent the said surfaces. It will, therefore, be seen that for a given total amount of viscous drag frictional forces available from a viscous fluid flowing between two surfaces, various and selected proportions thereof can be transferred from one surface to the other surface by adjusting the temperature of one surface to change the

viscosity of the layer of flowing viscous fluid adjacent the said one surface.

Referring now to the particular disclosure of FIGS. 10 and 11, it will be seen that each cell insert 30 of viscous drag rod feeder 10 of FIG. 3 has mounted in its respective central bore 33 a cylindrical liner 70 extending substantially the entire length thereof and adapted to function as an electrically powered heating element. Liner 70 is constructed of a material whose temperature can be controllably elevated by varying the amount of electrical current flowing therethrough. Specifically, liner 70 may be metallic in nature. The alloy known as Nichrome has current temperature characteristics which are eminently suited for this purpose, and consequently liner 70 is preferably made of this material. A cylindrical sleeve 71 of electrically insulating material is interposed between cell insert 30 and liner 70, and may have an intumed flange 72 at either end thereof whereby liner 70 is electrically isolated from cell insert 30 except as hereinafter provided.

Transducer 73, operatively associated with extrusion die 12, senses the force required to extrude rod R through the said extrusion die 12, which force is a function of S_A in rod R, and transmits through line 74 a signal responsive to said force to one input of amplifier 75 hereinafter to be described. Transducer 73 is shown only diagrammatically, and may have a central aperture 76 aligned with the orifice 11 of extrusion die 12 and thus be adapted to surround extruded wire 14. Transducer 73 is shown abutting extrusion die 12 and may be mechanically connected thereto in a manner known to those familiar with the art. Such details have been omitted as not being necessary to a full and complete understanding of the present invention and would, if illustrated, merely obfuscate the drawing.

Means are provided to sense the pressure of fluid F in cell 20 adjacent the face of extrusion die 12 and to transmit a signal in response to said fluid pressure to another input of amplifier 75. Such means, as shown diagrammatically in FIG. 10, may comprise a transducer 77 mounted in the wall of housing 16 and connected through line 78 to the said other input of amplifier 75.

Amplifier 75 produces an output responsive to the difference between the signals fed to the two inputs through lines 74 and 78, and the output of amplifier 75 is thus responsive to $S_A - S_R$ or $S_R - S_A$. Amplifier 75 is powered through lines 79 and 80, and the output of amplifier 75 appears across lines 81 and 82.

Liners 70 are electrically connected in series to the output of amplifier 75 in any suitable manner. As shown diagrammatically in FIG. 10, such series connection may be made by means of line 81 extending between amplifier 75 and one end of that liner 70 in the fourth or last flow reversal cell 26, line 83 extending between adjacent ends of liner 70 in flow reversal cells 24, 22 and 20, and line 82 extending between amplifier 75 and a suitable ground, it being seen that that end of liner 70 in the first flow reversal cell 20 adjacent port 62 is suitably grounded, for instance, by direct contact between the end of this last-mentioned liner 70 and cell insert 30, the intumed flange 72 on the adjacent end of sleeve 71 being removed for this purpose. It will be understood that, where any lines (such as line 81 and 83) pass through housing 16, barrier plates 36 and cell insert 30, suitable electrically insulating pressure resistant sleeves (not shown) may be provided to protect these lines and to prevent the escape of fluid F.

In the preferred manner of operation, sufficient current is passed through liners 70 to maintain a median temperature therein corresponding to a desired relationship between S_A and S_R in cell 20. For instance, it may be desired, as a practical matter, to maintain the difference between S_A and S_R at no more than one-half S_y . Excursions in the difference between S_A and S_R above the said desired difference are sensed by amplifier 75 through transducers 73 and 77, and appropriate transitory and compensatory excursions of the temperature of liner 70 from their median temperature are produced by controlled variation of the temperature current flowing therethrough.

Specifically, when amplifier 75 senses, through transducers 73 and 77, that $S_R - S_A$ is increasing above the desired limit, the output of amplifier 75 will increase so as to increase the current flow through liners 70, thereby to elevate the temperatures of liners 70 above the median temperature. This will increase the temperature of fluid F adjacent the walls of cell bores 33, and cause a greater proportion of the total viscous drag frictional forces to be applied to rod R, whereupon S_A will increase and $S_R - S_A$ will be appropriately decreased below the desired limit.

Conversely, when amplifier 75 senses, through transducers 73 and 77, that $S_A - S_R$ is increasing above the desired limit, the output of amplifier 75 will decrease so as to decrease the current flow through liners 70, thereby to lower the temperature of liner 70 below the median temperature. This will decrease the temperature of fluid F adjacent the walls of cell bores 33 and cause a lesser proportion of the total viscous drag frictional force to be applied to rod R, whereupon S_A will decrease and $S_A - S_R$ will be appropriately decreased below the desired limit.

It should be clearly understood that the disclosure of FIGS. 10 and 11, described as applicable to viscous drag rod feeder 10 of FIG. 3 applies also to input viscous drag feeder 110 of FIG. 8, in which instance transducer 73 would be physically associated with extrusion die 202. Moreover, under some conditions, it may be desired to control the difference between S_R and S_A in wire W past the extrusion die 202 by control of the viscosity of the viscous fluid in output viscous drag feeders 210 or 310 of FIG. 8, in the manner heretofore described. Thus, feeders 210 or 310 would be constructed according to the disclosure of FIGS. 10 and 11, transducer 73 being physically associated with extrusion die 202 and transducer 79 being mounted in that cell adjacent extrusion die 202.

What is claimed is:

1. A method for the continuous extrusion of wire from a rod of indefinite length, said method comprising:
 - a. producing a stream of fluid having an alternate-reverse flow pattern;
 - b. applying the stream of fluid to spaced lengths along the rod
 - i. to produce viscous drag force which advances and develops axial stresses in the rod, and
 - ii. to produce normal pressures in the rod which increase in the direction of advancement of the rod, the difference at any point along the rod between the axial stress and normal pressure not exceeding the yield strength of said rod, and
 - c. passing the rod through an extrusion die to produce a wire.
2. Method as in claim 1, further comprising:
 - d. adjusting viscosity in the fluid to adjust the magnitude of said viscous drag force.
3. Method as in claim 1, further comprising:
 - d. adjusting temperature in the fluid to adjust viscosity in the fluid whereby to adjust the magnitude of said viscous drag force.
4. Method according to claim 1 wherein the extrusion die is associated with a hydrostatic extrusion chamber and the fluid stream advances the rod into the extrusion chamber from which it is extruded through the extrusion die.
5. Method according to claim 1 wherein axial stress in the wire is controlled by application of force to the wire as it exits the extrusion die.
6. Method according to claim 5 wherein axial stress in the wire is controlled by application to the wire of viscous drag forces.
7. Method of advancing rod into an extrusion die, said method comprising:
 - a. pumping an annular flow of pressurized viscous fluid along the surface of the rod to apply viscous drag force to the rod;
 - b. controlling the flow of said viscous fluid such that the viscous drag force applied to the rod is of sufficient magnitude to generate a compressive axial stress in said rod

upstream of said extrusion die exceeding the yield strength of the rod material and to advance said rod through said extrusion die and such that the pressure in said flow of viscous fluid increases from a station upstream of said extrusion die toward said extrusion die;

5 c. further controlling the flow of said viscous fluid such that the fluid pressure drop (ΔP) per increment of rod length exposed to the flow of viscous fluid does not differ from the axial stress increment (ΔS_A) produced in the rod for the same increment of rod length (ΔL) by an amount greater than the yield strength of the rod material.

8. Method as in claim 7, further comprising:

d. adjusting viscosity in said viscous fluid to adjust the magnitude of said viscous drag force.

9. Method as in claim 7, further comprising:

d. adjusting temperature in said viscous fluid to adjust viscosity in said viscous fluid whereby to adjust the magnitude of said viscous drag force.

10. Method of continuously advancing an indefinite length of rod into an extrusion die wherein the extrusion of said rod produces axial stress in said rod in excess of the yield strength of said rod, said method comprising:

a. providing an annular alternate-reverse flow of a viscous fluid, said flow having linearly interrupted portions;

b. applying said linearly interrupted portions to the surface of said rod, said portions building up radial stress in said rod and applying viscous drag forces to said rod, said viscous drag forces building up axial stress in said rod; and

c. controlling the pressure drops in said linearly interrupted portions such that at any point along the rod the difference between said radial stress and said axial stress does not exceed the yield strength of said rod, and wherein said viscous drag forces applied to said rod are of magnitude sufficient to continuously advance said rod into said die.

11. Method as in claim 10, further comprising:

d. adjusting viscosity in said viscous fluid to adjust the magnitude of said viscous drag forces.

12. Method as in claim 10, further comprising:

d. adjusting temperature in said viscous fluid to adjust viscosity in said viscous fluid whereby to adjust the magnitude of said viscous drag forces.

13. Method of continuously advancing an indefinite length of material into an extrusion die, wherein the extrusion thereof produces opposition force of sufficient magnitude to produce stress in said material along the direction of material advancement in excess of the yield strength of said material, said method comprising:

a. providing an alternate-reverse flow of a pressurized viscous fluid, said flow having cyclically interrupted portions with each portion having a pressure drop (ΔP);

b. applying said cyclically interrupted portions of said flow to the surface of said material, said portions:

i. applying pressure to the surface of said material which builds up normal stress in said material perpendicular to the direction of said material advancement, and

ii. applying viscous drag frictional forces to the surface of said material which build up longitudinal stress in said material acting in the direction of said material advancement;

c. controlling the pressure drops (ΔP) in said cyclically interrupted portions such that at any point along said material to which said interrupted portions are applied, the difference between the normal stress and the longitudinal stress does not exceed the yield strength of said material, and said viscous drag frictional forces are of magnitude sufficient to continuously advance said material into said die.

14. Method of continuously advancing an indefinite length of rod into an extrusion die wherein the extrusion of said rod produces axial stress in said rod in excess of the yield strength (S_Y) of said rod, said method comprising:

a. providing an annular alternate-reverse flow of a pressurized viscous fluid, said flow having linearly interrupted portions with each portion having a pressure drop (ΔP);

b. applying said linearly interrupted portions of said flow to the surface of said rod, said portions:

i. applying radially acting pressure to the surface of said rod which builds up radial stress (S_R) in said rod, and

ii. applying viscous drag forces to the surface of said rod which build up axial stress (S_A) in said rod; and

c. controlling the pressure drops (ΔP) so that at any point along said rod to which said interrupted portions are applied, (S_R) does not differ from (S_A) by an amount greater than (S_Y), and wherein said viscous drag forces applied to said rod by said portions are of magnitude sufficient to continuously advance said rod into said die.

15. A method of advancing a rod through an extrusion die, said method comprising:

a. directing a flow of pressurized viscous fluid along the perimeter of said rod toward an extrusion die to produce viscous drag force on said rod in the direction of said extrusion die, which viscous drag force advances said rod through said extrusion die and produces axial stress in said rod, the said viscous fluid producing radial stress in the rod;

b. detecting the magnitude of the difference between said radial stress and said axial stress;

c. adjusting viscosity in said viscous fluid when the difference between said axial stress and said radial stress exceeds a predetermined value thereby adjusting the magnitude of said viscous drag force on said rod;

d. whereby the difference between said axial stress and said radial stress is reduced to a value not exceeding said predetermined value.

16. Method as in claim 15, said predetermined value being the yield strength of said rod.

17. Method as in claim 15, said predetermined value being one-half the yield strength of said rod.

18. A method of advancing a rod through an extrusion die, said method comprising:

a. directing a flow of pressurized viscous fluid along the perimeter of said rod toward an extrusion die to produce viscous drag force on said rod in the direction of said extrusion die, which viscous drag force advances said rod through said extrusion die and produces axial stress in said rod, the said viscous fluid producing radial stress in the said rod;

b. detecting the magnitude of the difference between said radial stress and said axial stress;

c. adjusting temperature in said viscous fluid when the difference between said axial stress and said radial stress exceeds a predetermined value thereby adjusting viscosity in said viscous fluid whereby to adjust the magnitude of said viscous drag force on said rod;

d. whereby the difference between said axial stress and said radial stress is reduced to a value not exceeding said predetermined value.

19. Method as in claim 18, said predetermined value being the yield strength of said rod.

20. Method as in claim 18, said predetermined value being one-half the yield strength of said rod.

21. Method of producing elongated product of indefinite length from elongated billet material of indefinite length, said method comprising:

a. advancing said elongated billet material through pressurized fluid, the pressure in said pressurized fluid increasing in the direction of advancement of said elongated billet material, and thence into a high pressure environment;

b. continuously hydrostatically extruding said elongated billet material from said high pressure environment in the form of elongated product.

22. Method for deforming an elongated workpiece of indefinite length to produce an elongated product of indefinite length, said method comprising:

- a. exerting along the elongated surface of the workpiece force which drags and advances the workpiece against a deforming agency; 5
- b. generating a compressive axial stress in said workpiece at least in part by said force, said axial stress having a magnitude upstream of said deforming agency in excess of the yield strength of the workpiece material; 10
- c. generating a normal stress in said workpiece, said normal stress increasing from a station upstream of said deforming agency toward said deforming agency; 15
- d. controlling the difference between said axial stress and normal stress in the workpiece upstream of said deforming agency so that the difference does not exceed the yield strength of the workpiece material; 20
- e. deforming the workpiece against the deforming agency to produce the elongated product of indefinite length and of cross-section different from that of the workpiece.

23. Method as in claim 22, comprising:

- e. performing steps (a), (b), (c) and (d) on metal rod to produce metal wire as the elongated product.

24. Method as in claim 22, comprising:

- e. performing step (d) by means of an extrusion die. 25

25. Method as in claim 22, wherein:

- e. said axial and normal stresses in the workpiece upstream of said deforming agency have sufficient magnitude to increase the ductility of the workpiece material and permit deformation thereof without fracture. 30

26. Method for deforming an elongated workpiece of indefinite length to produce an elongated product of indefinite length, said method comprising:

- a. exerting along the elongated surface of the workpiece force which drags and continuously and non-intermittently advances the workpiece and produces a compressive axial stress in said workpiece in excess of the yield strength of said workpiece: 35
 - i. into and through a pressurized chamber wherein the pressure level is sufficient to increase the ductility of the workpiece and permit the desired deformation thereof without fracture, normal stress in said workpiece in said pressurized chamber being in excess of the yield strength of said workpiece; and 40
 - ii. thence against a deforming agency; 45
- b. simultaneously with step (a), applying normal pressure to said workpiece prior to entry of said workpiece into said pressure chamber, said normal pressure increasing from a station upstream of said pressure chamber to said pressure chamber; and 50
- c. continuously and non-intermittently deforming the workpiece against the deforming agency to produce the product of indefinite length and of cross-section different from that of the workpiece. 55

27. Method as in claim 22, comprising:

- e. performing step (a) by applying a flow of fluid along the surface of the workpiece to exert viscous drag force along the surface of the workpiece. 60

28. Method for deforming an elongated workpiece of indefinite length to produce an elongated product of indefinite length, said method comprising:

- a. providing viscous fluid with an alternate-reverse flow pattern, 65
- b. applying portions of said alternate-reverse flow pattern of viscous fluid along the elongated surface of said workpiece towards a deforming agency thereby to apply viscous drag force along said elongated surface of said workpiece toward said deforming agency whereby to advance said workpiece against said deforming agency, 70
- c. deforming the workpiece against the deforming agency to produce the product of indefinite length and of cross-section different from that of the workpiece.

29. Method as in claim 28, further comprising: 75

- d. adjusting viscosity in said viscous fluid to adjust the magnitude of said viscous drag force on said workpiece.

30. Method as in claim 28, further comprising:

- d. adjusting temperature in said viscous fluid thereby to adjust viscosity in said viscous fluid whereby to control the magnitude of said viscous drag force on said workpiece.

31. Method for deforming an elongated workpiece of indefinite length to produce an elongated product of indefinite length, said method comprising:

- a. providing a plurality of discrete streams of viscous fluid arranged as a series having a first discrete stream of viscous fluid at one end of said series and a second discrete stream of viscous fluid at the other end of said series; 10
- b. controlling the pressure in each discrete stream of viscous fluid in a manner related to the pressures in the other discrete streams of viscous fluid to provide said series with a pressure gradient increasing from said first discrete stream of viscous fluid to said second discrete stream of viscous fluid; 15
- c. applying a portion of each of said discrete streams of viscous fluid of said series along the elongated surface of said workpiece towards a deforming agency thereby to apply viscous drag force along said elongated surface of said workpiece toward said deforming agency whereby to advance said workpiece against said deforming agency, said series being arranged relative to said workpiece and said deforming agency so that said first discrete stream of viscous fluid is at the end of said series furthest from said deforming agency and said second discrete stream of viscous fluid is at the end of said series closest to said deforming agency whereby to pressurize said workpiece with a gradient increasing towards said deforming agency; 20
- d. deforming the workpiece against the deforming agency to produce the product of indefinite length and of cross-section different from that of the workpiece. 25

32. Method as in claim 31, further comprising:

- e. adjusting viscosity in said discrete streams of viscous fluid to adjust the magnitude of said viscous drag force on said workpiece. 40

33. Method as in claim 31, further comprising:

- e. adjusting temperature in said discrete streams of viscous fluid thereby to adjust viscosity in said discrete streams of viscous fluid whereby to adjust the magnitude of said viscous drag force on said workpiece. 45

34. Method for deforming an elongated workpiece of indefinite length, said method comprising:

- a. providing viscous fluid with an alternate-reverse flow pattern, 50
- b. applying said alternate-reverse flow pattern of viscous fluid at spaced lengths along the elongated surface of the elongated workpiece thereby to produce viscous drag force on the elongated workpiece, 55
- c. advancing the elongated workpiece by means of said viscous drag force against a deforming agency to produce an elongated product of indefinite length having a cross-section different from that of the elongated workpiece. 60

35. Method as in claim 34, further comprising:

- d. adjusting viscosity in the viscous fluid thereby to adjust the magnitude of said viscous drag force on said elongated workpiece.

36. Method as in claim 34, further comprising:

- d. adjusting temperature in the viscous fluid thereby to adjust viscosity in said viscous fluid whereby to adjust the magnitude of said viscous drag force on said elongated workpiece.

37. Method for continuously deforming an elongated workpiece of indefinite length, said method comprising:

- a. providing a plurality of discrete currents of fluid arranged as a series, the discrete currents of fluid of said series each having a different pressure and being so arranged as to provide said series with a pressure gradient increasing from one end of said series to the other end of said series; 75

- b. applying said plurality of discrete currents of fluid at spaced lengths along the elongated surface of said workpiece to produce viscous drag force on the elongated workpiece;
- c. advancing the elongated workpiece by means of said viscous drag force against a deforming agency to produce an elongated product of indefinite length having a cross-section different from that of the elongated workpiece; 5
- d. said series of discrete currents of fluid being arranged relative to said elongated workpiece and said deforming agency so that that end of said series at lowest pressure is furthest from said deforming agency and that end of said series at highest pressure is closest to said deforming agency whereby to pressurize said elongated workpiece with a gradient increasing toward said deforming agency. 10
- 38. Method as in claim 37, further comprising:
 - d. adjusting viscosity in the fluid to adjust the magnitude of said viscous drag force on said elongated workpiece.
- 39. Method as in claim 37, further comprising:
 - d. adjusting temperature in the fluid thereby to adjust viscosity in the fluid whereby to adjust the magnitude of said viscous drag force on said elongated workpiece. 15
- 40. Method for deforming an elongated workpiece of indefinite length, said method comprising:
 - a. applying a flow of fluid along the elongated surface of the elongated workpiece to produce viscous drag force thereon and continuously advance the elongated workpiece against a deforming agency, 20
 - b. said viscous drag force producing in the elongated workpiece a compressive axial stress which exceeds the yield strength of the elongated workpiece upstream of said deforming agency, 25
 - c. the pressure gradient within the fluid along the elongated workpiece increasing from a station upstream of said deforming agency toward said deforming agency and being such that at no point upstream of the deforming agency does the fluid pressure differ from the axial stress in the elongated workpiece by an amount exceeding the yield strength of the elongated workpiece material, 30
 - d. deforming the elongated workpiece against the deforming agency to produce an elongated product of indefinite length having a cross-section different from that of the elongated workpiece. 35
- 41. Method as in claim 40, comprising:
 - e. adjusting viscosity in the fluid to adjust the magnitude of said viscous drag force. 40
- 42. Method as in claim 41, comprising:
 - f. performing step (e) by adjusting temperature in the fluid. 45
- 43. Method for changing the cross-section of an elongated workpiece of indefinite length, said method comprising:
 - a. establishing a pressure zone having an inlet and an outlet, the pressure in said pressure zone increasing at least part of the way between said inlet and said outlet from said inlet toward said outlet; 50
 - b. advancing said elongated workpiece into the inlet of said pressure zone and through said pressure zone to the outlet of said pressure zone without deforming said elongated workpiece, thereby to apply a pressure gradient to the elongated surface of said undeformed elongated workpiece and thereby to create a predetermined stress condition in said undeformed elongated workpiece; 55
 - c. deforming said elongated workpiece at the outlet of said pressure zone. 60
- 44. Method as in claim 43, comprising:
 - d. performing step (a) by flowing pressurized viscous fluid along the elongated surface of said workpiece. 65
- 45. Method as in claim 43, comprising:
 - d. performing step (c) by advancing said elongated workpiece against a tool, 70
 - e. performing step (b) by applying longitudinally directed force along the entire elongated surface of said elongated workpiece toward said tool from the inlet of said pressure zone to said tool.
- 46. Method as in claim 43, comprising: 75

- d. performing step (c) by advancing said elongated workpiece against a tool;
- e. applying longitudinally directed force along the entire elongated surface of said elongated workpiece toward said tool from the inlet of said pressure zone to said tool, said longitudinally directed force being of magnitude such that the axial stress in said elongated workpiece adjacent said tool exceeds the yield strength of said elongated workpiece;
- f. maintaining the difference between said axial stress and the normal stress induced in said elongated workpiece perpendicular to said axial stress by the pressure in said pressure zone at a value not exceeding the yield strength of said elongated workpiece.
- 47. Method as in claim 43, comprising:
 - d. performing step (b) by flowing viscous fluid along the elongated surface of said elongated workpiece from the inlet of said pressure zone toward the outlet of said pressure zone, said viscous fluid exerting viscous drag force along the elongated surface of said elongated workpiece.
- 48. Method as in claim 43, comprising:
 - d. performing step (c) by advancing said elongated workpiece against a tool,
 - e. performing steps (a) and (b) by flowing pressurized viscous fluid along the elongated surface of said workpiece from the inlet of said pressure zone toward said tool.
- 49. Method as in claim 43, comprising:
 - d. performing step (c) by advancing said elongated workpiece against a tool,
 - e. performing steps (a) and (b) by flowing pressurized viscous fluid at successive lengths along the elongated surface of said elongated workpiece from the inlet of said pressure zone toward said tool.
- 50. Method as in claim 43, comprising:
 - d. performing step (c) by advancing said elongated workpiece against a tool,
 - e. performing steps (a) and (b) by flowing pressurized viscous fluid in an alternate-reverse flow pattern along the elongated surface of said elongated workpiece from the inlet of said pressure zone toward said tool.
- 51. Method as in claim 43, comprising:
 - d. performing step (c) by advancing said elongated workpiece against a tool,
 - e. performing steps (a) and (b) by flowing pressurized viscous fluid as a plurality of separate fluid currents along the elongated surface of said elongated workpiece from the inlet of said pressure zone toward said tool.
- 52. Method as in claim 43, comprising:
 - d. performing step (c) by advancing said elongated workpiece against a tool,
 - e. performing steps (a) and (b) by flowing pressurized viscous fluid at successive lengths along the elongated surface of said elongated workpiece from the inlet of said pressure zone toward said tool in such manner that the average fluid pressure in successive lengths increases in the direction of said tool.
- 53. Method as in claim 43, comprising:
 - d. performing step (a) by advancing said elongated workpiece against a tool,
 - e. performing steps (a) and (b) by flowing pressurized viscous fluid as a plurality of separate fluid currents having different viscosities along the elongated surface of said elongated workpiece from the inlet of said pressure zone toward said tool.
- 54. Method as in claim 49, comprising:
 - f. proportioning the lengths of said successive lengths of viscous fluid in said manner that the pressure drop in said viscous fluid across each of said successive lengths is substantially the same.
- 55. Method as in claim 46, comprising:
 - g. performing steps (a) and (e) to produce normal and axial stresses in said elongated workpiece of magnitude sufficient to cause the elongated workpiece to increase in ductility, whereby to permit the desired deformation thereof.

56. Method as in claim 47, comprising:
- e. adjusting viscosity in said viscous fluid to control the magnitude of viscous drag force exerted along the elongated surface of said elongated workpiece.
57. Method as in claim 47, comprising:
- e. adjusting temperature in said viscous fluid thereby to adjust viscosity in said viscous fluid whereby to adjust the magnitude of viscous drag force exerted along the elongated surface of said elongated workpiece.
58. Method as in claim 43, comprising:
- d. performing step (b) by flowing viscous fluid along the elongated surface of said elongated workpiece between said elongated surface and a second surface spaced from said elongated surface, said viscous fluid being flowed from the inlet of said pressure zone toward the outlet of said pressure zone,
 - e. adjusting the viscosity of said viscous fluid adjacent said second surface thereby to control the magnitude of viscous drag force exerted along the elongated surface of said elongated workpiece.
59. Method as in claim 43, comprising:
- d. performing step (b) by flowing viscous fluid along the elongated surface of said elongated workpiece between said elongated surface and a second surface spaced from said elongated surface, said viscous fluid being flowed from the inlet of said pressure zone toward the outlet of said pressure zone;
 - e. adjusting the temperature of said viscous fluid adjacent said second surface thereby to adjust the viscosity of said viscous fluid adjacent said second surface whereby to control the magnitude of viscous drag force exerted along the elongated surface of said elongated workpiece.
60. Method as in claim 43, wherein said elongated workpiece is deformed to produce an elongated product, said method comprising:
- d. flowing viscous fluid along the elongated surface of said elongated product to control the advancement of said elongated product.
61. Method as in claim 43, wherein said elongated workpiece is deformed to produce an elongated product, said method comprising:
- d. flowing viscous fluid at successive lengths along the elongated surface of said elongated product to control the advancement of said elongated product.
62. Method as in claim 43, wherein said elongated workpiece is deformed to produce an elongated product, said method comprising:
- (d) flowing viscous fluid in an alternate-reverse flow pattern along the elongated surface of said elongated product to control the advancement of said elongated product.
63. Method as in claim 43, wherein said elongated workpiece is deformed to produce an elongated product, said method comprising:
- d. flowing viscous fluid as a plurality of separate fluid currents along the elongated surface of said elongated product to control the advancement of said elongated product.
64. Method as in claim 43, wherein said elongated workpiece is deformed to produce an elongated product, said method comprising:
- d. flowing viscous fluid at successive lengths along the elongated surface of said elongated product to control the advancement of said elongated product,
 - e. controlling the average fluid pressure in each of said successive lengths so as to establish a predetermined pressure gradient along said elongated product.
65. Method as in claim 43, wherein said elongated workpiece is deformed to produce an elongated product, said method comprising:
- d. flowing viscous fluid at successive lengths along the elongated surface of said elongated product to control the advancement of said elongated product,
 - e. proportioning the lengths of said successive lengths of viscous fluid in such manner that the pressure drop in said

- viscous fluid across each of said successive lengths is substantially the same.
66. Method as in claim 43, wherein said elongated workpiece is deformed to produce an elongated product, said method comprising:
- d. flowing viscous fluid along the elongated surface of said elongated product, said viscous fluid exerting viscous drag force along the elongated surface of said elongated product to control the advancement of said elongated product;
 - e. adjusting viscosity in said viscous fluid to control the magnitude of viscous drag force exerted along the elongated surface of said elongated product.
67. Method as in claim 43, wherein said elongated workpiece is deformed to produce an elongated product, said method comprising:
- d. flowing viscous fluid along the elongated surface of said elongated product, said viscous fluid exerting viscous drag force along the elongated surface of said elongated product to control the advancement of said elongated product;
 - e. adjusting temperature in said viscous fluid thereby to adjust viscosity in said viscous fluid whereby to control the magnitude of said viscous drag force exerted along the elongated surface of said elongated product.
68. Method as in claim 43, wherein said elongated workpiece is deformed to produce an elongated product, said method comprising:
- d. flowing viscous fluid along the elongated surface of said elongated product between said elongated surface and a second surface spaced from said elongated surface, said viscous fluid exerting viscous drag force along the elongated surface of said elongated product to control the advancement of said elongated product;
 - e. adjusting the viscosity of said viscous fluid adjacent said second surface to control the magnitude of viscous drag force exerted along the elongated surface of said elongated product.
69. Method as in claim 43, wherein said elongated workpiece is deformed to produce an elongated product, said method comprising:
- d. flowing viscous fluid along the elongated surface of said elongated product between said elongated surface and a second surface spaced from said elongated surface, said viscous fluid exerting viscous drag force along the elongated surface of said elongated product to control the advancement of said elongated product;
 - e. adjusting the temperature of said viscous fluid adjacent said second surface thereby to adjust the viscosity of said viscous fluid adjacent said second surface whereby to control the magnitude of viscous drag force exerted along the elongated surface of said elongated product.
70. Method for advancing an elongated member of indefinite length against a deforming agency to deform said elongated member, said method comprising:
- a. operatively engaging the entire perimetric surface of said elongated member from a station before said deforming agency to immediately adjacent said deforming agency and exerting force along the entire said perimetric surface from said station toward said deforming agency to advance said elongated member against said deforming agency whereby a compressive axial stress is induced in said elongated member, the magnitude of said force being such that the axial stress in said elongated member increases from said station toward said deforming agency and at said deforming agency said axial stress exceeds the yield strength of said elongated member;
 - b. simultaneously with step (a) exerting pressure normal to the entire said perimetric surface between said station and said deforming agency whereby a normal stress is induced in said elongated member, said pressure having a gradient of magnitude such that said normal stress increases from said station toward said deforming agency

and the difference between said axial stress and said normal stress at any point between said station and said deforming agency does not exceed the yield strength of said elongated member.

71. Apparatus for deforming an elongated member of indefinite length, said apparatus comprising:

- a. elongated conduit means having a first end and a second end, said elongated conduit means being adapted to receive said elongated member through said first end with an annular space between said elongated conduit means and said elongated member;
- b. deforming means positioned adjacent the second end of said elongated conduit means;
- c. fluid outlet means positioned adjacent the second end of said elongated conduit means;
- d. pump means adapted to pump viscous fluid through said annular space from the first end of said elongated conduit means to said fluid outlet means adjacent the second end of said elongated conduit means thereby to exert viscous drag force along the elongated surface of said elongated member directed toward said deforming means to advance said elongated member through said elongated conduit means and against said deforming means;
- e. said elongated conduit means comprising a plurality of conduits connected and arranged to provide said viscous fluid with an alternate-reverse flow pattern.

72. Apparatus for deforming an elongated member of indefinite length, said apparatus comprising:

- a. elongated conduit means having a first end and a second end, said elongated conduit means being adapted to receive said elongated member through said first end with an annular space between said elongated conduit means and said elongated member;
- b. deforming means positioned adjacent the second end of said elongated conduit means;
- c. fluid outlet means positioned adjacent the second end of said elongated conduit means;
- d. pump means adapted to pump viscous fluid through said annular space from the first end of said elongated conduit means to said fluid outlet means adjacent the second end of said elongated conduit means thereby to exert viscous drag force along the elongated surface of said elongated member directed toward said deforming means to advance said elongated member through said elongated conduit means and against said deforming means;
- e. said elongated conduit means comprising a plurality of conduits with a first conduit at the first end of said elongated conduit means and a second conduit at the second end of said elongated conduit means;
- f. said pump means comprising a plurality of pumps, each pump being operatively associated with one of said conduits, thereby to provide a plurality of separate currents of viscous fluid to said conduits;
- g. said pump means being adapted to provide the viscous fluid in said elongated conduit means with a pressure gradient increasing from said first conduit to said second conduit.

73. Apparatus for deforming an elongated member of indefinite length, said apparatus comprising:

- a. elongated conduit means having a first end and a second end, said elongated conduit means being adapted to receive said elongated member through said first end with an annular space between said elongated conduit means and said elongated member;
- b. deforming means positioned adjacent the second end of said elongated conduit means;
- c. fluid outlet means positioned adjacent the second end of said elongated conduit means;
- d. pump means adapted to pump viscous fluid through said annular space from the first end of said elongated conduit means to said fluid outlet means adjacent the second end of said elongated conduit means thereby to exert viscous drag force along the elongated surface of said elongated

member directed toward said deforming means to advance said elongated member through said elongated conduit means and against said deforming means;

e. said elongated conduit means comprising a plurality of longitudinally spaced aligned conduits comprising a first conduit at the second end of said elongated conduit means and a second conduit at the first end of said elongated conduit means, each of said conduits having a first end and a second end, the second end of said first conduit facing the first end of said second conduit, the first end of said first conduit being remote from the second end of said second conduit;

f. first connecting means communicating between the discharge of said pump means and the second end of said first conduit, said first connecting means being adapted to direct viscous fluid under pressure through the space between said first conduit and said elongated workpiece whereby to establish a flow of viscous fluid exerting viscous drag force on said elongated workpiece from said second end toward said first end of said first conduit, said viscous fluid exerting first average pressure in said first conduit normal to said elongated workpiece;

g. second connecting means communicating between the first end of said first conduit and the second end of said second conduit, said second connecting means being adapted to direct viscous fluid exiting from the first end of said first conduit to the second end of said second conduit whereby to establish a flow of viscous fluid exerting viscous drag force on said elongated member from said second end toward said first end of said second conduit, said viscous fluid exerting second average pressure in said second conduit normal to said elongated workpiece;

h. third connecting means communicating between the first end of said second conduit and the intake of said pump means;

i. said pump means being adapted to provide said viscous fluid in said elongated conduit means with a pressure gradient increasing from said second average pressure in said second conduit to said first average pressure in said first conduit.

74. Apparatus for deforming an elongated member of indefinite length, said apparatus comprising:

- a. elongated conduit means having a first end and a second end, said elongated conduit means being adapted to receive said elongated member through said first end with an annular space between said elongated conduit means and said elongated member;
- b. deforming means positioned adjacent the second end of said elongated conduit means;
- c. fluid outlet means positioned adjacent the second end of said elongated conduit means;
- d. pump means adapted to pump viscous fluid through said annular space from the first end of said elongated conduit means to said fluid outlet means adjacent the second end of said elongated conduit means thereby to exert viscous drag force along the elongated surface of said elongated member directed toward said deforming means to advance said elongated member through said elongated conduit means and against said deforming means;
- e. said elongated conduit means comprising a plurality of longitudinally spaced aligned conduits comprising a first conduit at the second end of said elongated conduit means and a second conduit at the first end of said elongated conduit means, each of said conduits having a first end and a second end, the second end of said first conduit facing the first end of said second conduit, the first end of said first conduit being remote from the second end of said second conduit;
- f. said pump means comprising a first pump associated with said first conduit and adapted to direct pressurized first viscous fluid through the space between said first conduit and said elongated member from the second end to the first end of said first conduit whereby to establish a flow

of first viscous fluid exerting first viscous drag force on said elongated member from said second end toward said first end of said first conduit, said first viscous fluid exerting first average pressure in said first conduit normal to said elongated member;

g. said pump means further comprising a second pump associated with said second conduit and adapted to direct pressurized second viscous fluid through the space between said second conduit and said elongated member from the second end to the first end of said second conduit whereby to establish a flow of second viscous fluid exerting second viscous drag force on said elongated member from said second end to said first end of said second conduit, said second viscous fluid exerting second average pressure in said second conduit normal to said elongated member;

h. said first and second pumps being operated simultaneously and being adapted to provide said viscous fluid in said elongated conduit means with a pressure gradient increasing from said second average pressure in said second conduit to said first average pressure in said first conduit.

75. Apparatus for advancing an elongated member of indefinite length against a deforming agency to deform said elongated member, said apparatus comprising:

a. means operatively engaging the entire perimetric surface of said elongated member from a station before said deforming agency to immediately adjacent said deforming agency, said means being adapted to exert force along the entire said perimetric surface from said station toward said deforming agency to advance said elongated member against said deforming agency whereby a compressive axial stress is induced in said elongated member, said means being proportioned to exert force of magnitude such that the axial stress in said elongated member increases from said station to said deforming agency and upstream of said deforming agency said axial stress exceeds the yield strength of said elongated member;

b. said means simultaneously exerting pressure normal to the entire said perimetric surface between said station and said deforming agency whereby a normal stress is induced in said elongated member, said means being proportioned to exert pressure of magnitude such that said normal stress increases from said station toward said deforming agency and the difference between said axial stress and said normal stress at any point between said station and said deforming agency does not exceed the yield strength of said elongated member.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,667,267 Dated June 6, 1972

Inventor(s) FRANCIS JOSEPH FUCHS, JR.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the specification:

Column 4, line 66 (page 10, line 20 in application file) "any" should read --an--.

Column 7, line 49 (page 17, line 27 in application file) delete "(6)" after equation and insert --6--.

Column 13, line 74 (page 33, lines 27 and 28 in application file) after "the" delete "temperature".

Column 14, line 24 (page 34, line 21 in application file) "by" should read --be--.

Column 16, line 4 (page 57, line 9 in application file) delete "P;".

Signed and sealed this 21st day of November 1972.

(SEAL)

Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents