United States Patent [19]

Fuchs, Jr.

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[54] **CONTINUOUS MATERIAL FEEDING AND DEFORMATION PROCESS**

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[21] Appl. No.: **186,375**

Related U.S. Application Data

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[52] **U.S. Cl.** **72/60,** 72/257

[51] **Int. Cl.** **B21c 31/00**

[58] **Field of Search** 72/60, 257, 271

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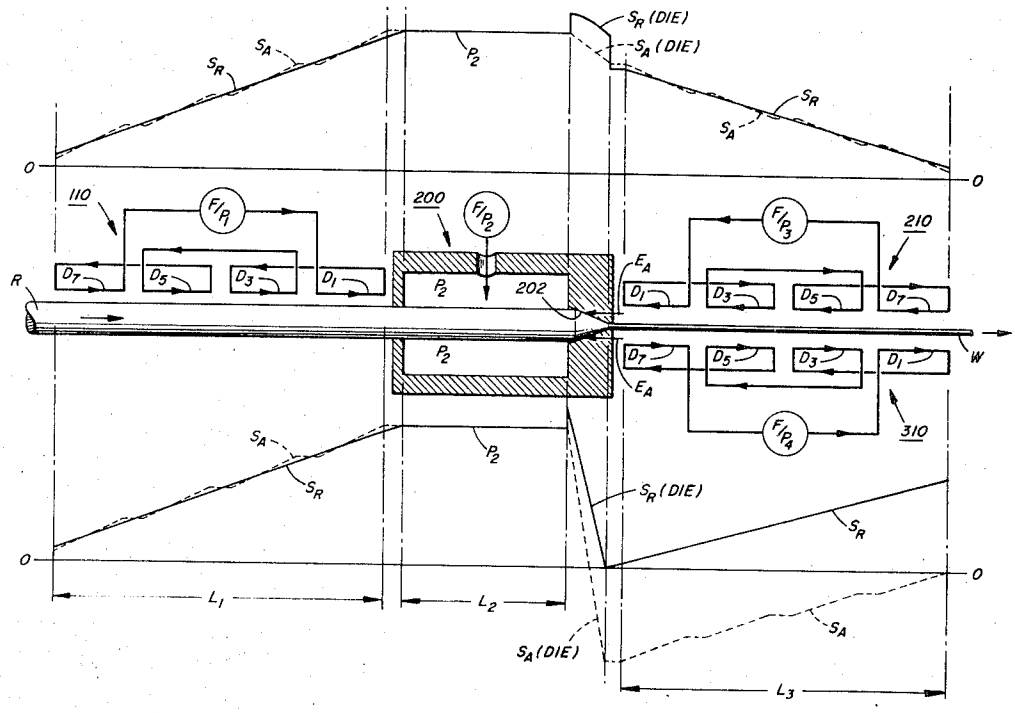
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Attorney—Jack Schuman

[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 continously 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 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.

11 Claims, 11 Drawing Figures



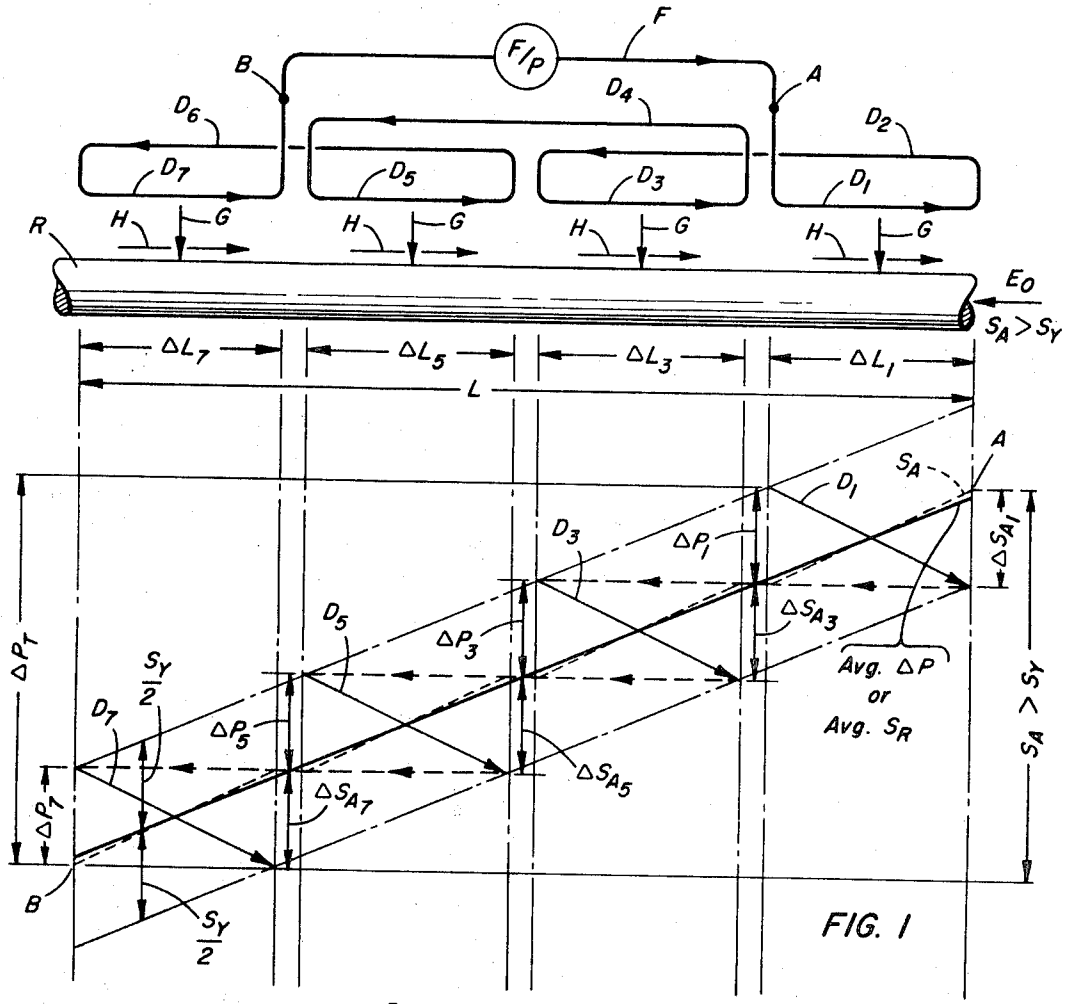

F/P
F
B
A
D6
D4
D2
D7
D5
D3
D1
H
G
R
E0
SA > SY
ΔL7
ΔL5
ΔL3
ΔL1
L
SA
ΔP1
ΔSA1
ΔP3
ΔSA3
ΔP5
ΔSA5
ΔP7
ΔSA7
ΔPT
SY/2
Avg. ΔP
or
Avg. SR

FIG. 1

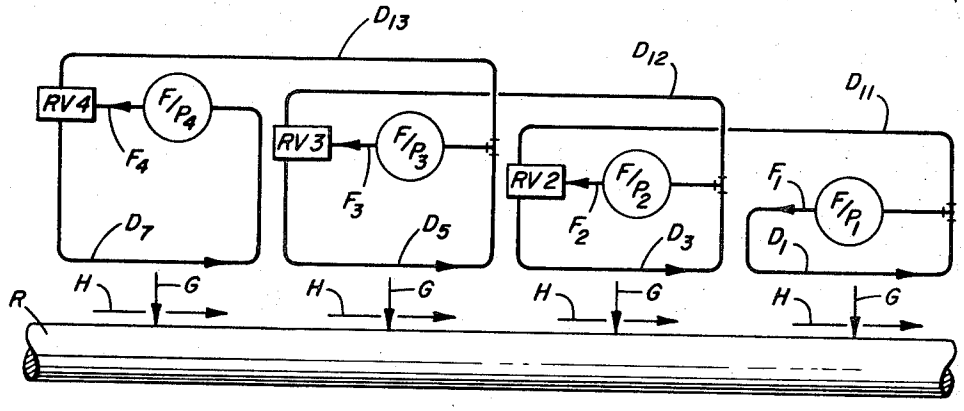

D13
D12
D11
RV4
RV3
RV2
F/P4
F/P3
F/P2
F/P1
F4
F3
F2
F1
D7
D5
D3
D1
H
G
R

FIG. 2

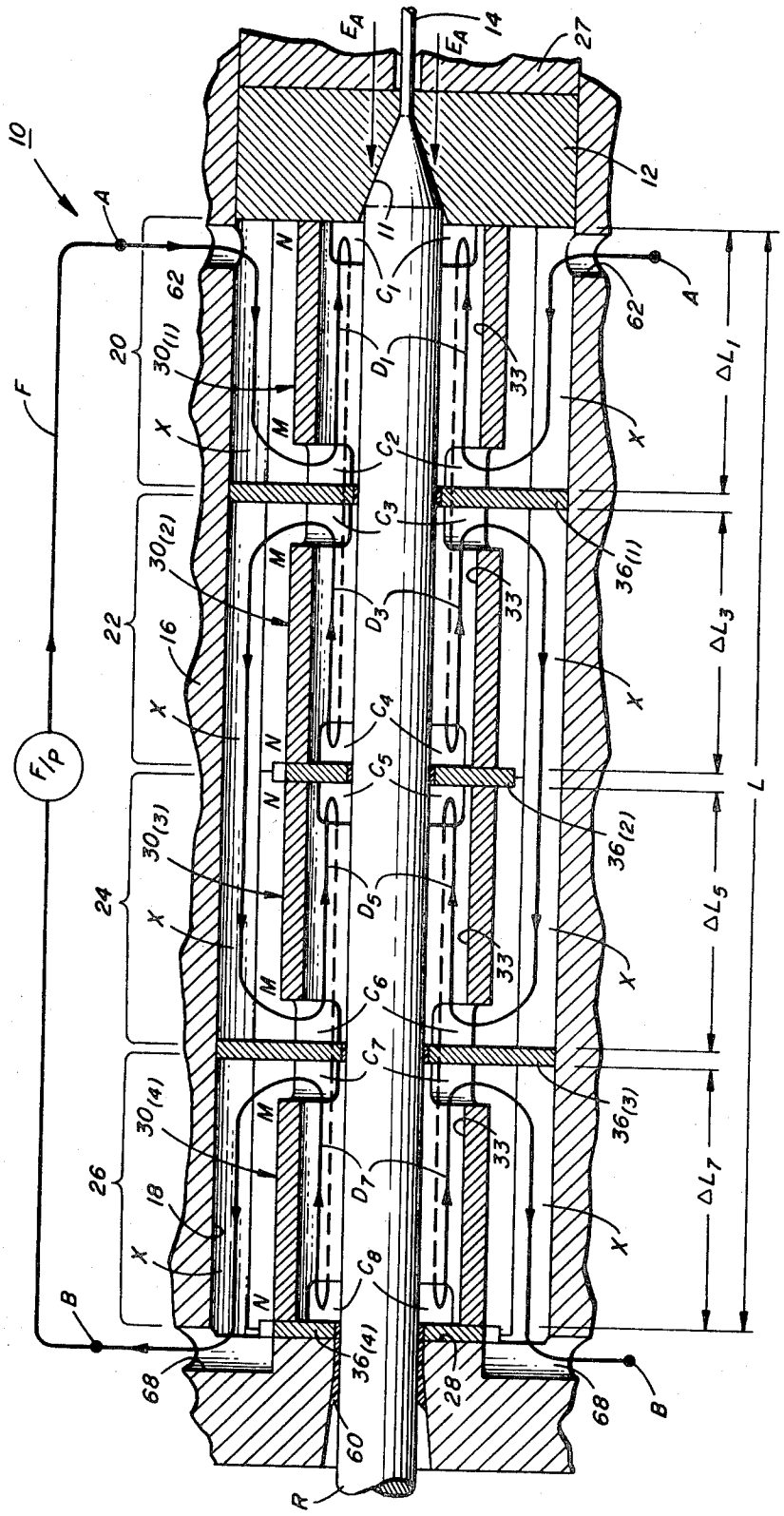

10
A
F
F/P
B
R
E_A
E_A
14
27
12
11
C1
D1
C2
C3
C4
C5
C6
C7
C8
D3
D5
D7
M
N
X
33
33'
62
62
A
20
22
24
26
30(1)
30(2)
30(3)
30(4)
16
18
36(1)
36(2)
36(3)
36(4)
68
68
28
60
ΔL1
ΔL3
ΔL5
ΔL7
L

FIG. 3

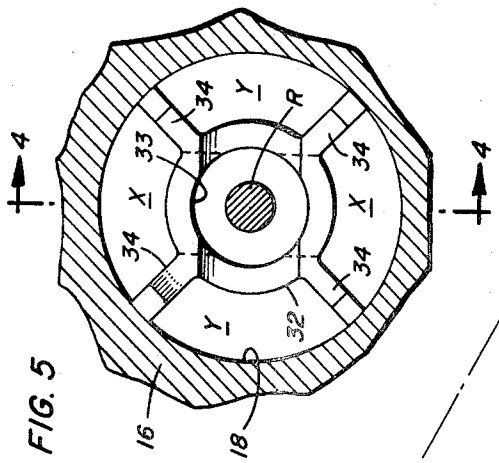


FIG. 5

FIG. 6

FIG. 4

FIG. 9

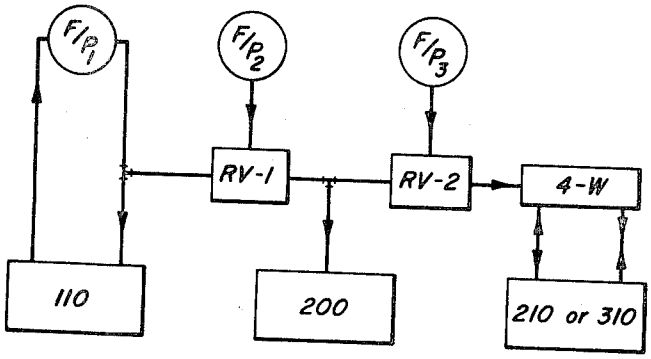
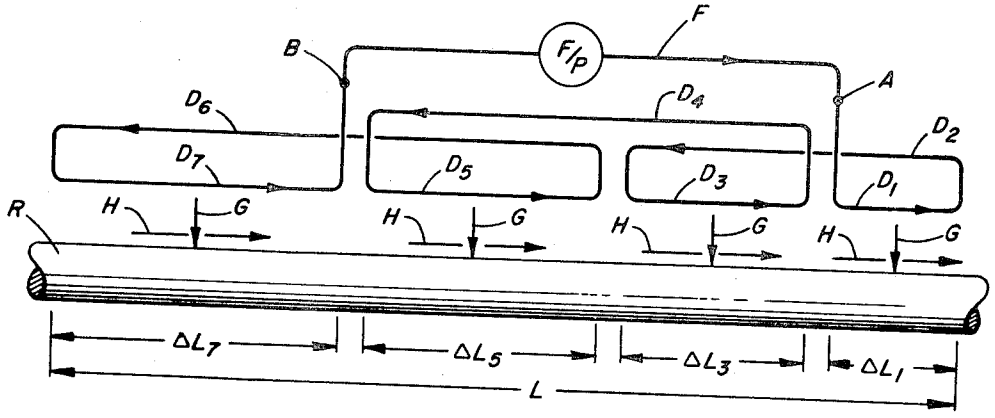

F/P1
F/P2
F/P3
RV-1
RV-2
4-W
110
200
210 or 310

FIG. 7


F/P
F
B
A
D6
D4
D2
D7
D5
D3
D1
R
H
G
ΔL7
ΔL5
ΔL3
ΔL1
L

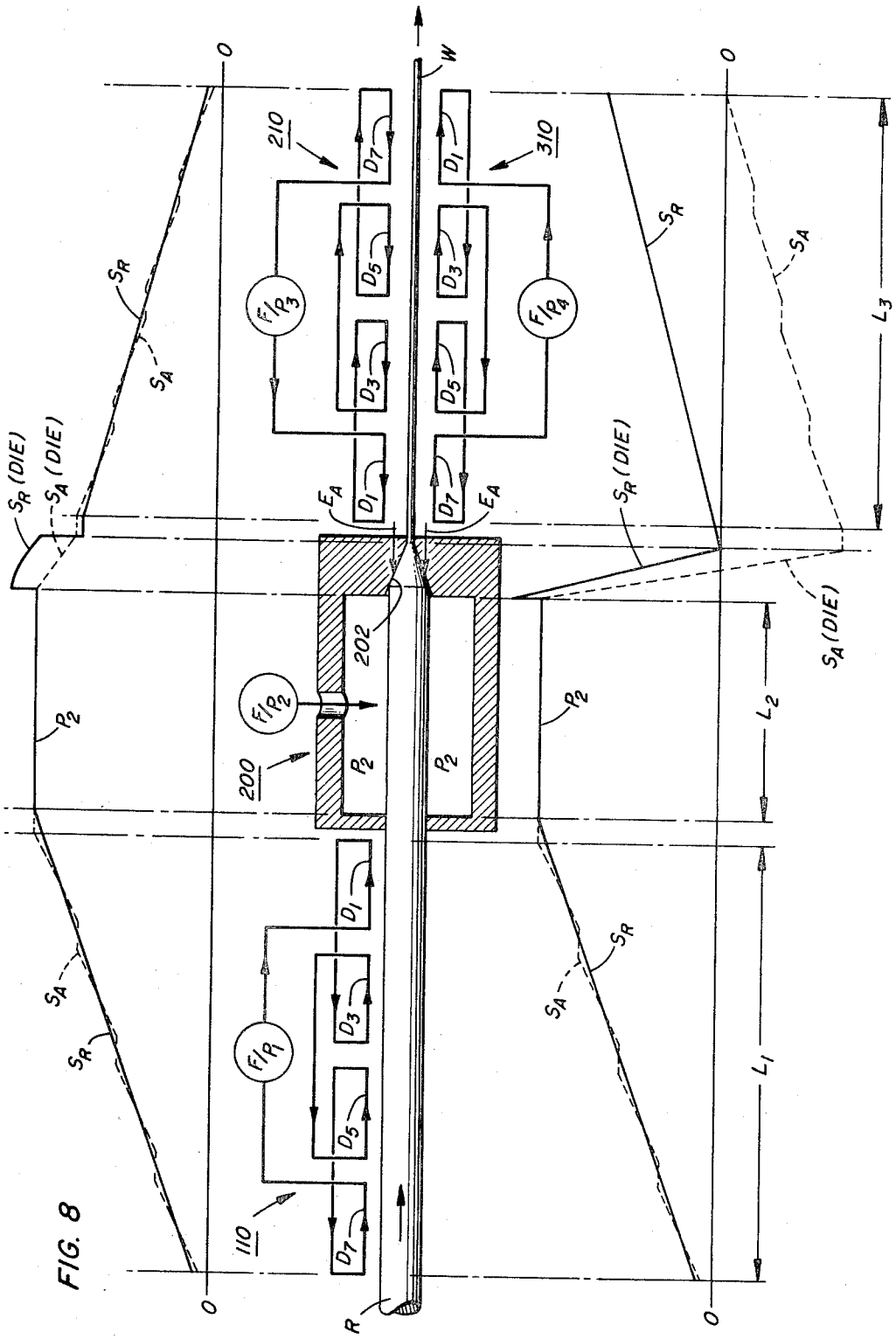

W
O
O
O
O
R
210
310
200
110
202
D_1
D_3
D_5
D_7
F/P_1
F/P_2
F/P_3
F/P_4
P_2
E_A
S_R
S_A
S_R (DIE)
S_A (DIE)
L_1
L_2
L_3

FIG. 8

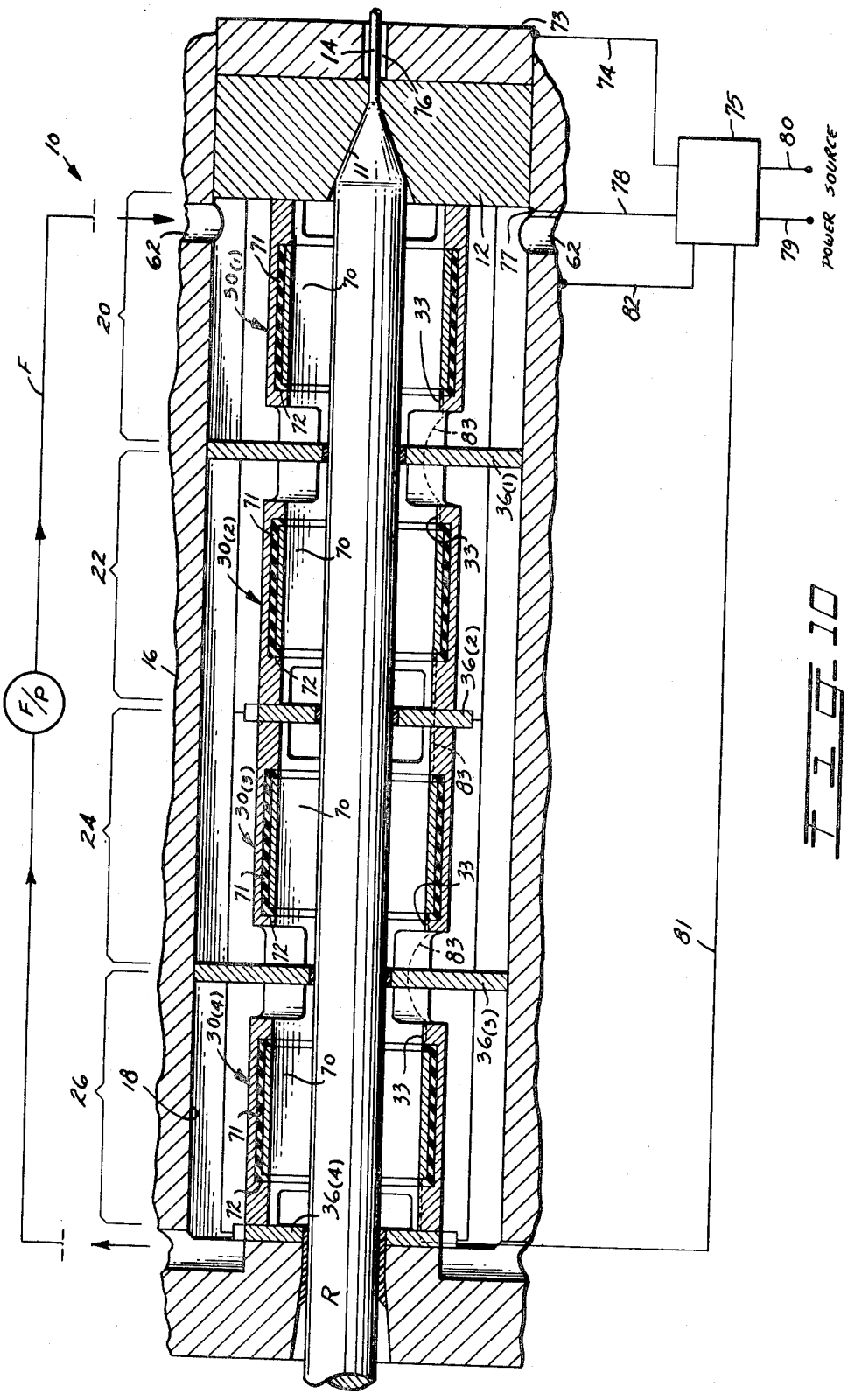
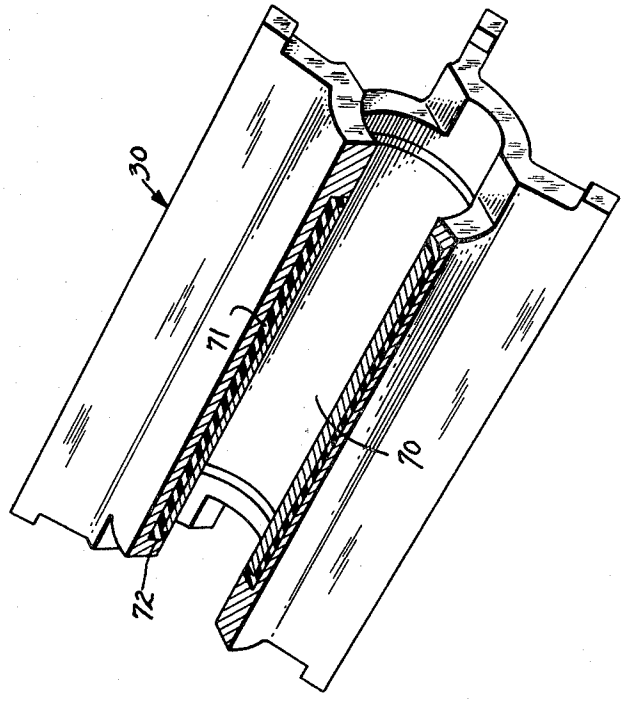

10
F
F/P
20
22
16
24
26
18
62
30(1)
30(2)
30(3)
30(4)
71
72
70
33
83
36(1)
36(2)
36(3)
36(4)
11
14
76
12
77
73
74
75
78
79
80
82
81
R
POWER SOURCE

FIG. 10

FIG. 11



CONTINUOUS MATERIAL FEEDING AND DEFORMATION PROCESS

CROSS-REFERENCE TO RELATED APPLICATION

This application is a division of copending application Ser. No. 876,940, filed Nov. 14, 1969 and titled "Apparatus and Method for Continuous Material Feeding and Deformation Process," now U. S. Pat. No. 3,667,267, the said application Ser. No. 876,940 being 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_2, D_3, 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 $D_1 \ldots D_7$. Assuming that the pressure drop in portions D_2, D_4, and D_6 may be adjusted to be very small, the sum of $\Delta P_1 \ldots \Delta P_7$ 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 portions D_1, D_2, D_3, 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 $D_1 \ldots D_7$, 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 yeild 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_O, the rod will be advanced against that opposition force, producing a corresponding axial stress in the rod.

Opposition force E_O 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 $F_1 \ldots F_4$ are controlled by their respec-

tively 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 Δ P 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 Δ P 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 Δ L_1, Δ L_3 . . . Δ L_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 Δ P 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 an amount greater than the yield strength of the rod, S_Y. Additionally, as before, the pressure drops Δ P 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 slidingly 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 within 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 . . . 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_2C_3, C_7, and C_8 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 actuated 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 righwardly 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:

$$o,\ \Delta P = \frac{\sim LQ}{9,833,102\left[\frac{d_1 - d_2}{2}\right]^3 d_2}$$

where:

Δ P = 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.

and d_1, 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 Δ P 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 40 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_2 of the flow reversal cell inserts was 0.651 inch. The rate of flow Q was 126 cubic inches per minute, and Δ P 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 Δ P. 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 . . . 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 Δ P 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 . . . 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 . . . 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 . . . 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 4 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, 4 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 4 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 . . . 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_R 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, by 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 inturned 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 inturned 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 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**.

In summary and as clearly described in the specification, the term "alternate-reverse flow" as used throughout the disclosure and claims is defined as follows: A fluid is flowed along a surface (e.g., an elongated member) in a series of segments connected and arranged so that the fluid from the pump enters the series at the upstream end of the downstream-most segment and at the highest pressure of any point in the series; flows along the surface in this downstream-most segment; leaves the surface at the downstream end of the downstream-most segment at a lower pressure due to pressure drop in such segment; and through a bypass (the "reverse" of "alternate-reverse"), reenters the series at the upstream end of the next upstream segment. In this latter segment, the fluid flows along the surface and leaves the surface at the downstream end of this next upstream segment at a yet lower pressure due to pressure drop therein; and through another bypass, reenters the series at the upstream end of the next-again-upstream segment, the flow pattern being repeated as often as required. It will be seen that the average fluid pressure in each segment increases as one proceeds downstream along the series of segments, and the effect is an overall increase in pressure in the direction of fluid flow.

What is claimed is:

1. A method for the continuous extrusion through an extrusion die of wire from a rod of indefinite length, said method comprising:

a. applying first viscous drag force upstream of the extrusion die to the rod to advance it,

b. advancing the rod through the extrusion die to produce a wire, and

c. applying second viscous drag force downstream of the extrusion die to the wire to control axial stress therein as it exits the extrusion die.

2. Method according to claim **1** wherein axial stress in the wire is controlled by application of the said second viscous drag force to said wire in a direction which opposes the advancement of said wire.

3. Method according to claim **1** wherein axial stress in the wire is controlled by application of the said second viscous drag force to said wire in the same direction as the direction of advancement of said wire.

4. 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,

b. 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,

c. applying viscous drag force along the elongated surface of the product to pull upon the product or selectively to oppose the advance of said product thereby to control axial stress in said product.

5. Method as in claim **4**, comprising:

d. performing step c by:

i. providing viscous fluid with an alternate-reverse flow pattern,

ii. applying portions of said alternate-reverse flow pattern of viscous fluid along the surface of said product.

6. Method as in claim **5**, further comprising:

e. adjusting viscosity in said viscous fluid thereby to adjust the magnitude of said viscous drag force on said product.

7. Method as in claim **5**, further comprising:

e. adjusting temperature in said viscous fluid thereby to adjust viscosity in said viscous fluid whereby to adjust the magnitude of said viscous drag force on said product.

8. Method as in claim **4**, comprising:

d. performing step c by:

i. providing a plurality of discrete currents of viscous fluid,

ii. controlling the pressure in each discrete current of viscous fluid in a manner related to the pressures of the other discrete currents of viscous fluid,

iii. applying portions of said discrete currents of viscous fluid along the surface of said product.

9. Method as in claim **8**, further comprising:

e. adjusting viscosity in said fluid currents thereby to adjust the magnitude of said viscous drag force on said product.

10. Method as in claim **8**, further comprising:

e. adjusting temperature in said fluid currents thereby to adjust viscosity in said fluid currents whereby to adjust the magnitude of said viscous drag force on said product.

11. 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, said deforming means having an inlet side receiving said elongated member and an exit side from which passes an elongated product of deformation;

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. second elongated conduit means having a first end adjacent the exit side of said deforming means and a second end, said second elongated conduit means being adapted to receive said elongated product through said first end from the exit side of said deforming means with an annular space between said second elongated conduit means and said elongated product;

f. second pump means adapted to pump second viscous fluid through said annular space in said second elongated conduit means from said first end to said second end of said second elongated conduit means in the same direction as the direction of advancement of said elongated product or selectively from said second end to said first end of said second elongated conduit means in a direction opposite to the direction of advancement of said elongated product thereby to exert viscous drag force along the elongated surface of said elongated product to control the advancement of said elongated product.

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