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Vatne

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(54) **HIGH FREQUENCY FLUID DRIVEN DRILL HAMMER PERCUSSION DRILLING IN HARD FORMATIONS**

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E21B 1/00 (2006.01)
E21B 1/12 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***E21B 4/14*** (2013.01)

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(Continued)

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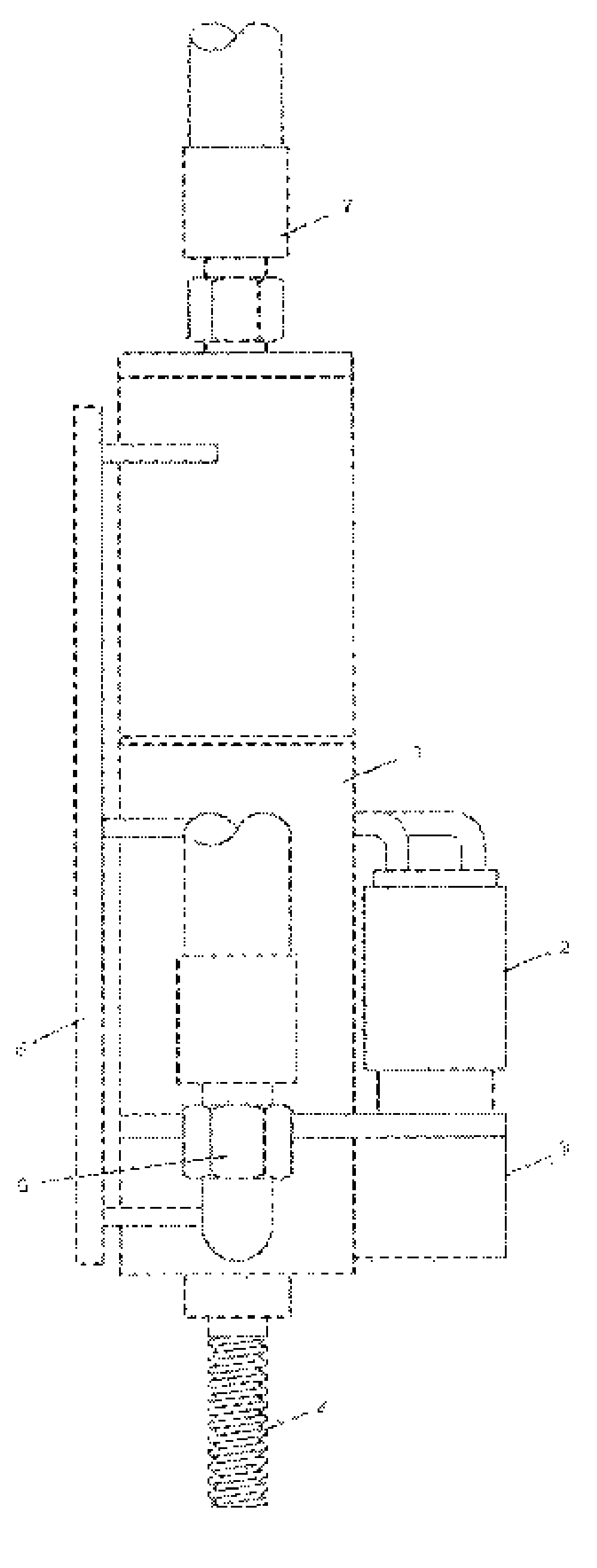
(57) **ABSTRACT**

A fluid pressure driven, high frequency percussion hammer for drilling in hard formations is presented. The hammer piston (**20**) of the percussion hammer has a relatively large and longitudinally extending bore (**41**) that provides minimal flow resistance for a drilling fluid flowing through the bore (**41**) during the return stroke of the hammer piston (**20**). The bore (**41**) is closeable in the upstream direction by a valve plug (**23**) that follows the hammer piston (**20**) during the stroke. The valve plug (**23**) is controlled by a relatively long and slender valve stem (**49**) that is mechanically able to stop the valve plug (**23**) by approximately 75% of the full stroke length of the hammer piston (**20**) and separates the plug (**23**) from a seat ring (**40**). Thus the bore (**41**) opens up such that the bore fluid can flow there trough, and the inherent tension spring properties of the valve stem (**49**) returns the valve plug (**23**) so rapid that it will be good through flow during return of the hammer piston (**20**).

10 Claims, 9 Drawing Sheets



(51) **Int. Cl.**

E21B 1/38	(2006.01)
E21B 4/14	(2006.01)

(58) **Field of Classification Search**

USPC 173/90, 200

See application file for complete search history.

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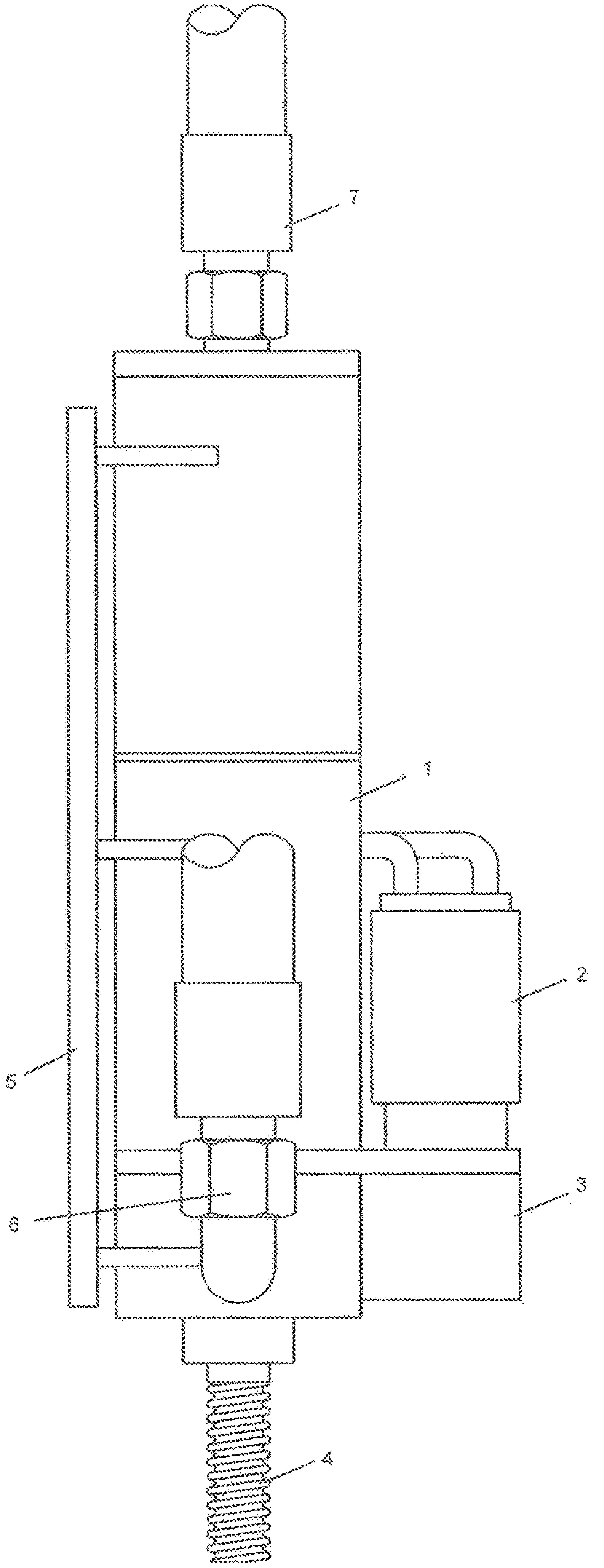


Fig 1

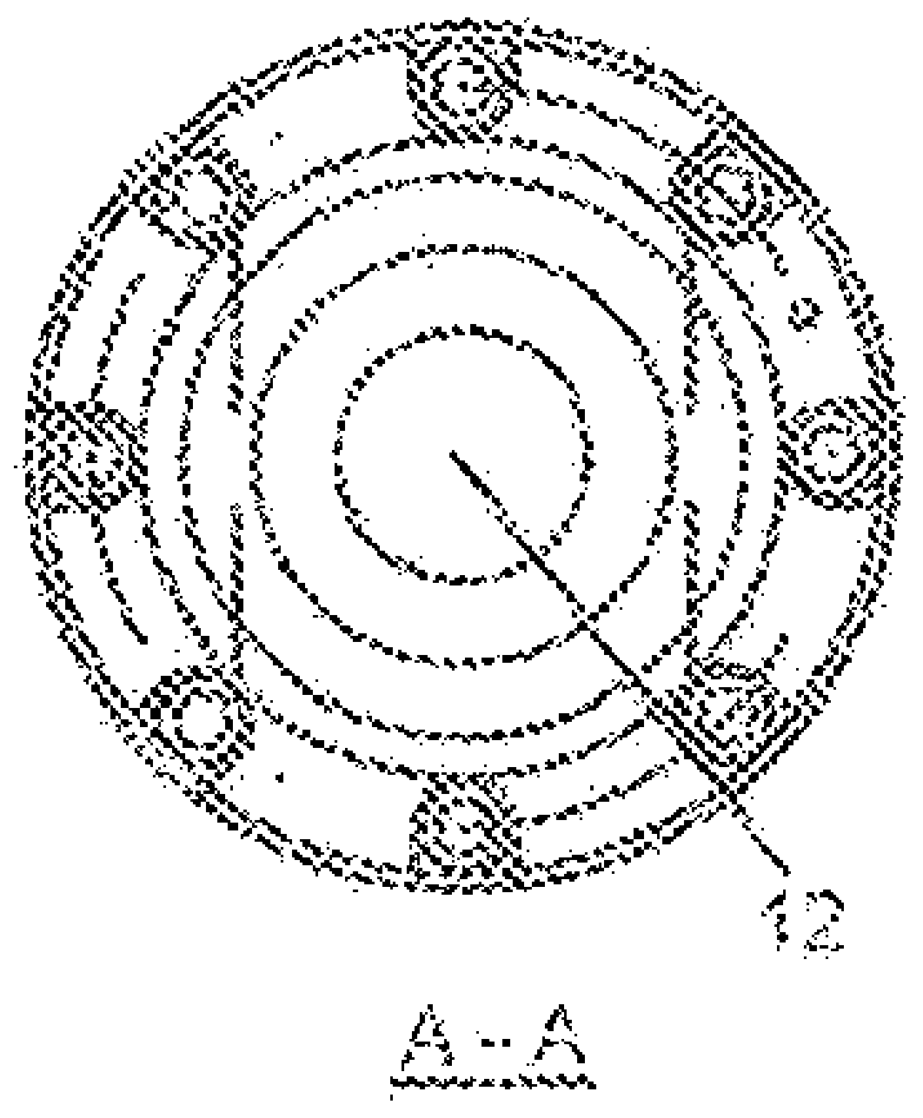


Fig 2 C

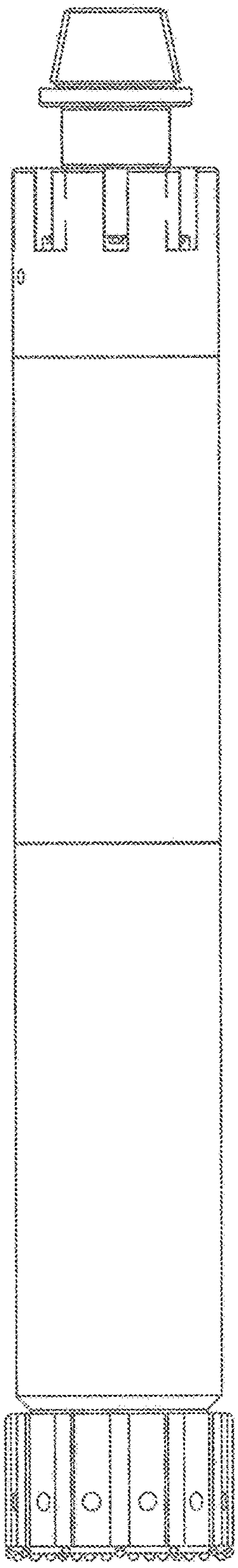


Fig 2 B

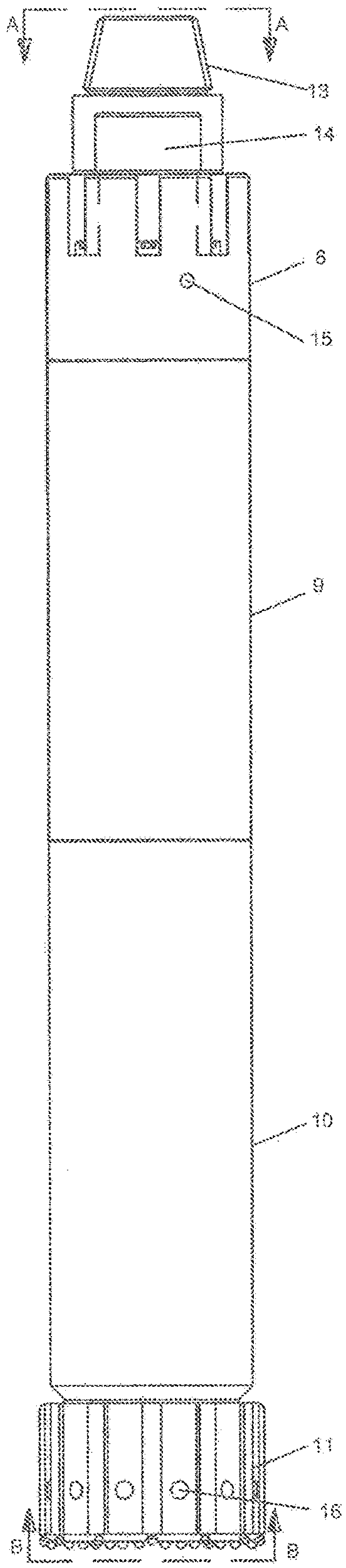


Fig 2 A

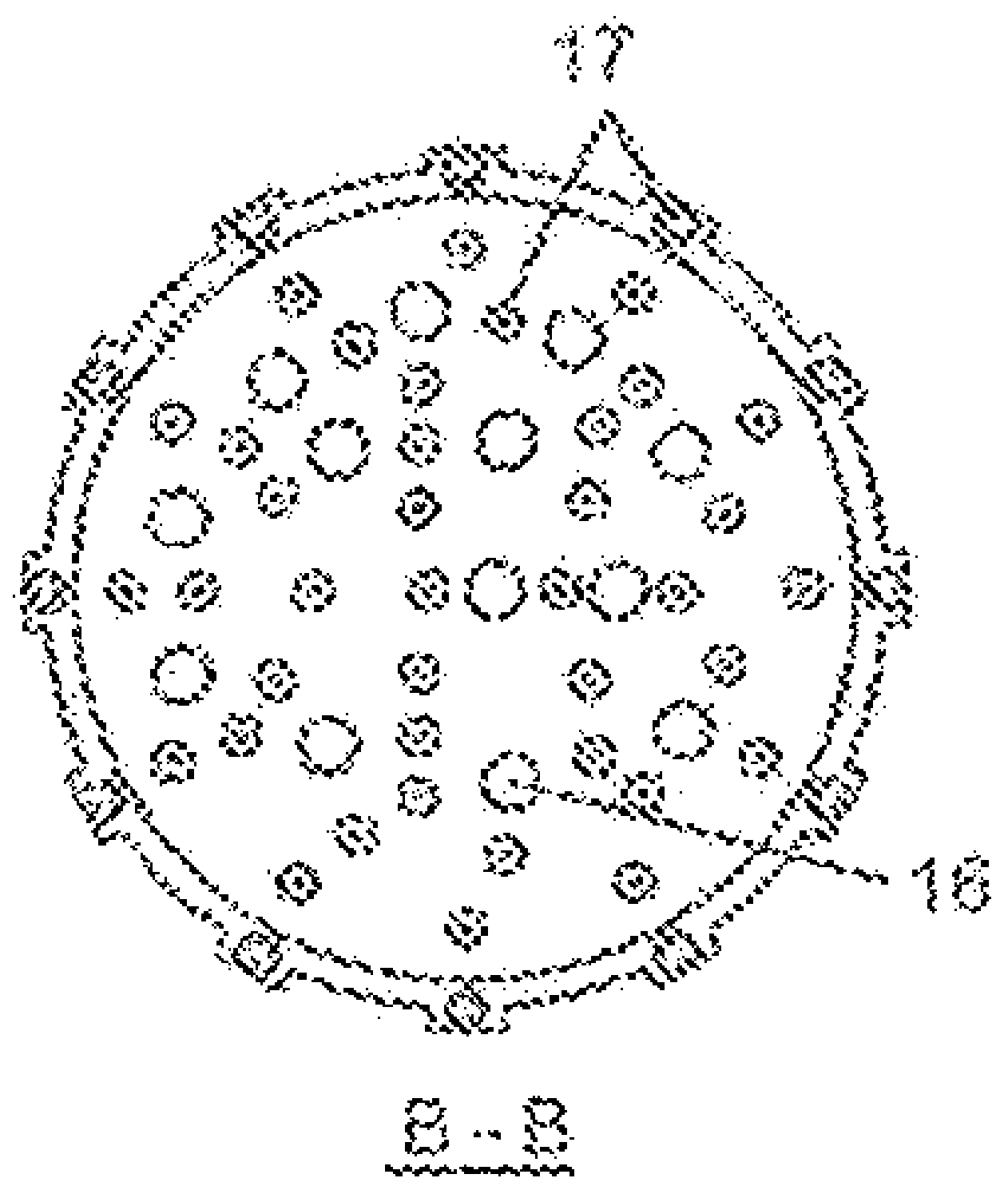


Fig 2 D

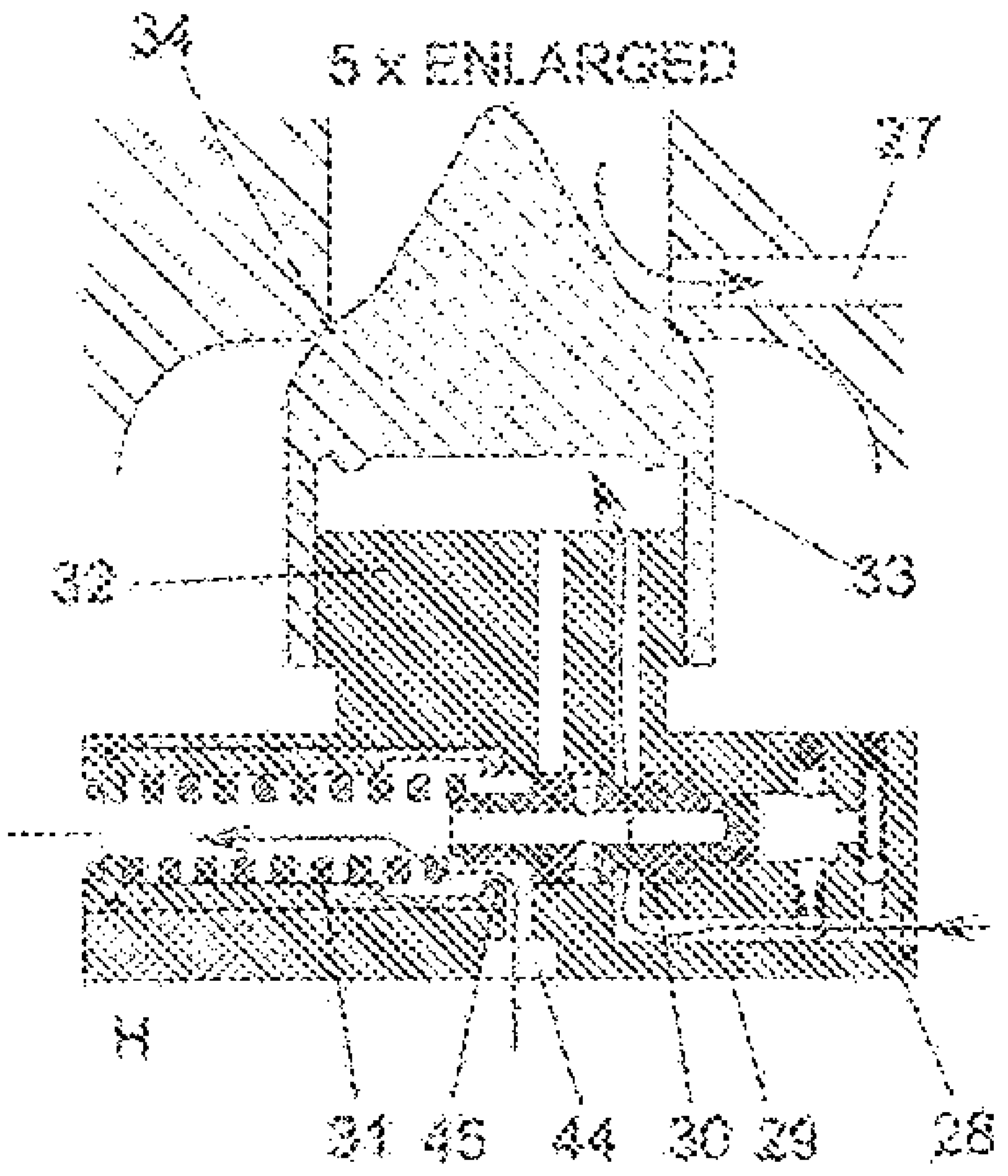


Fig 3 F

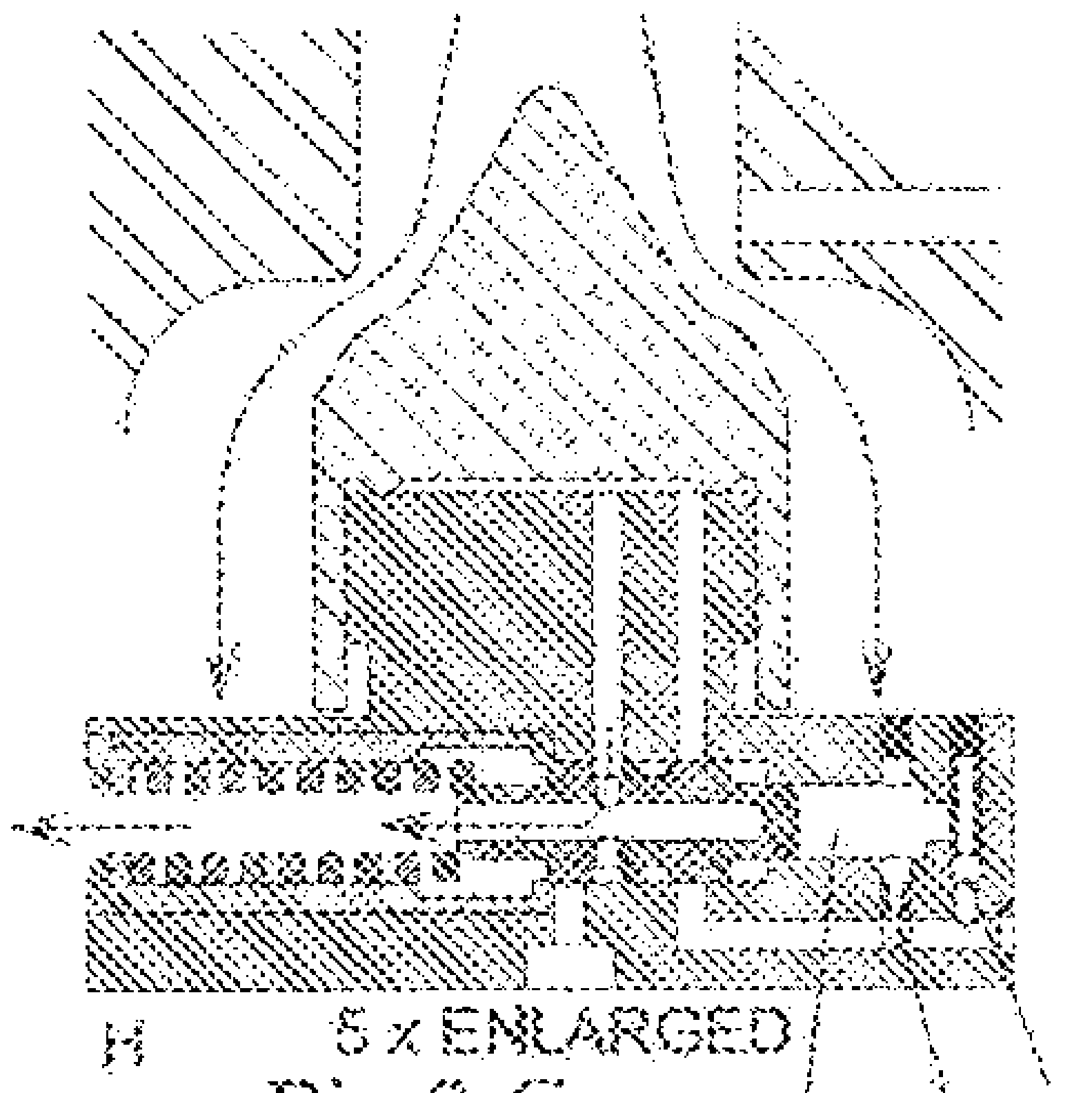


Fig 3 G

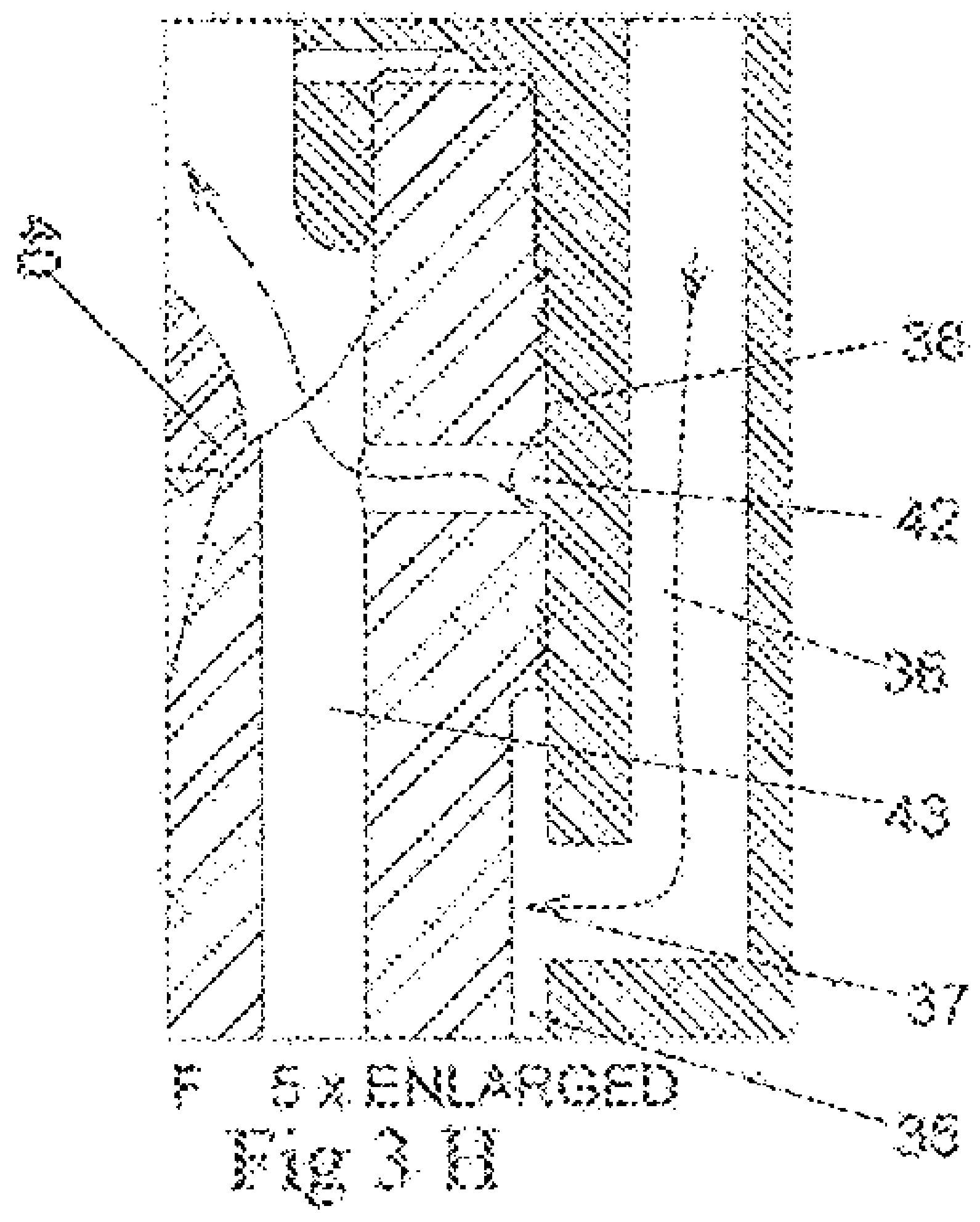


Fig 3 H

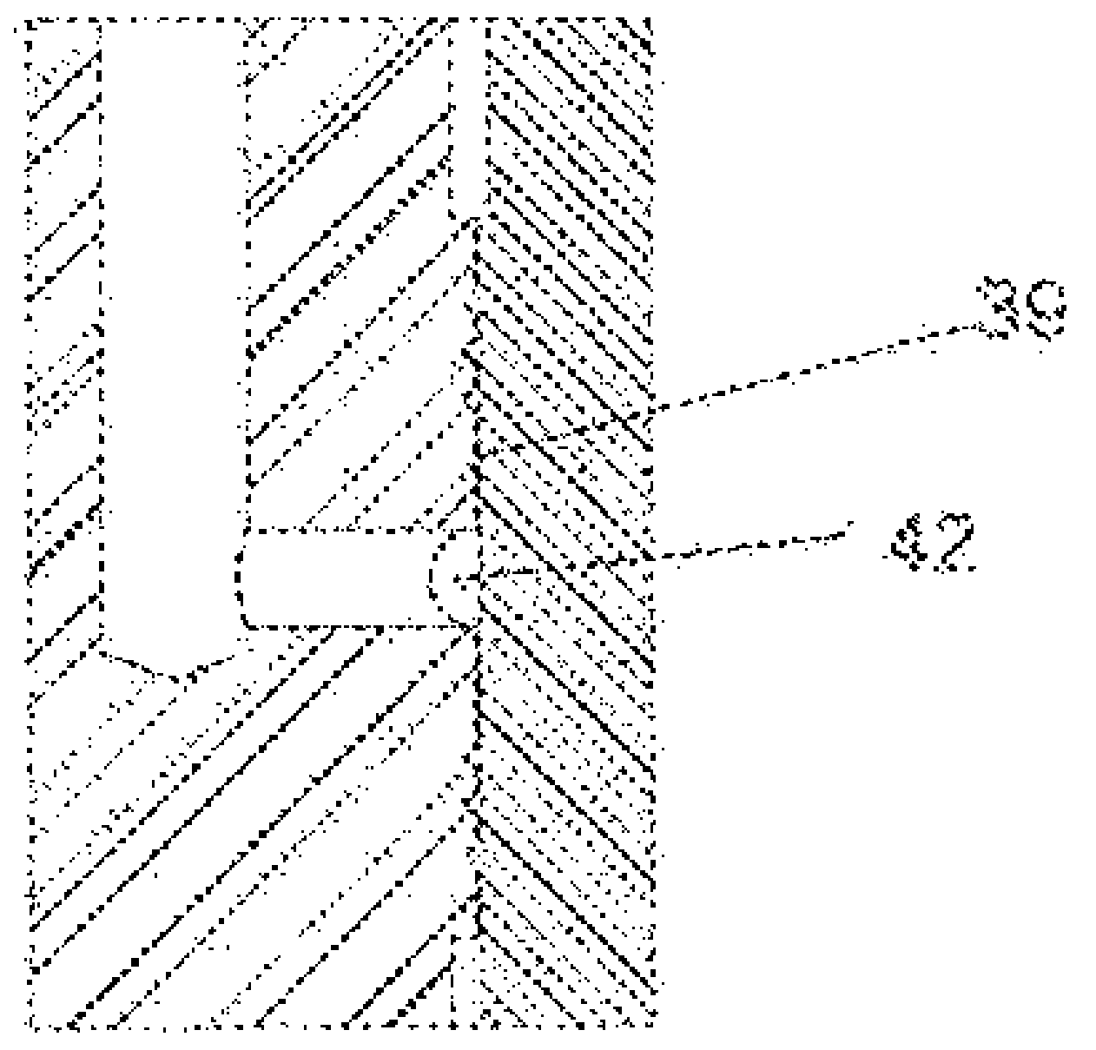


Fig 3 I

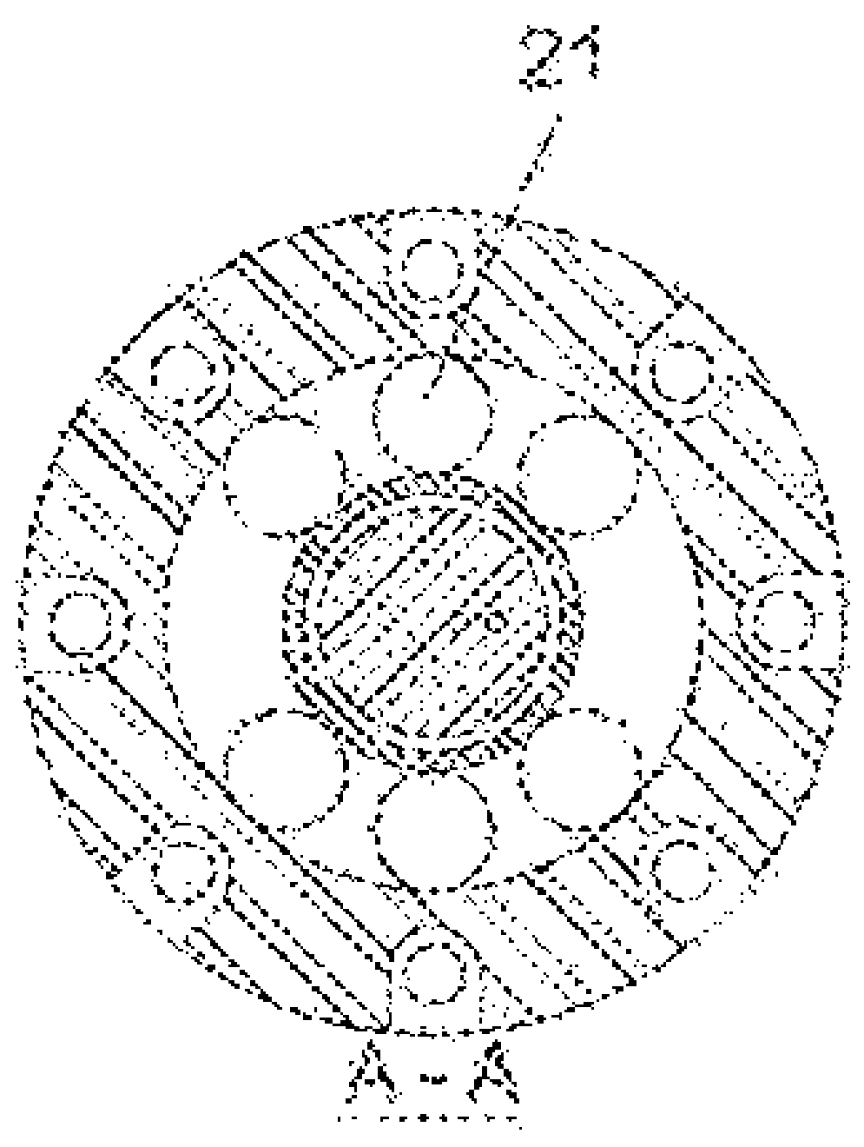


Fig 3 B

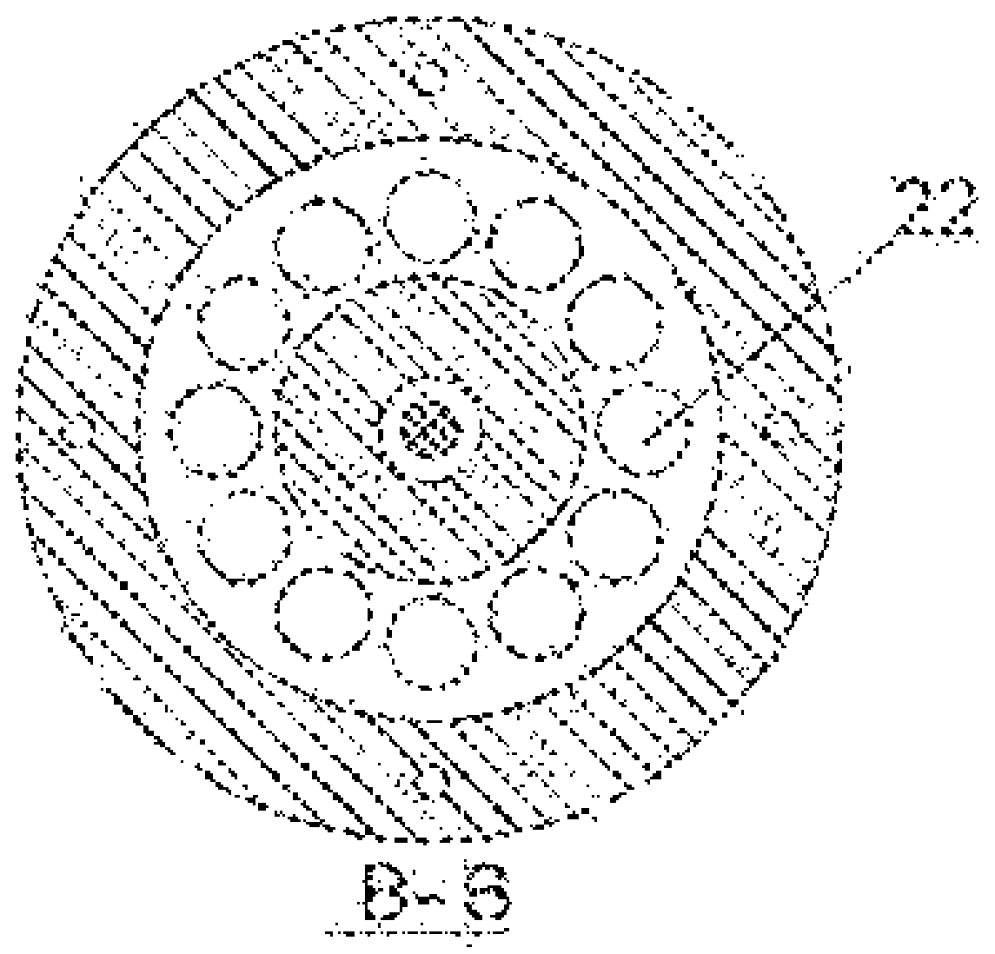
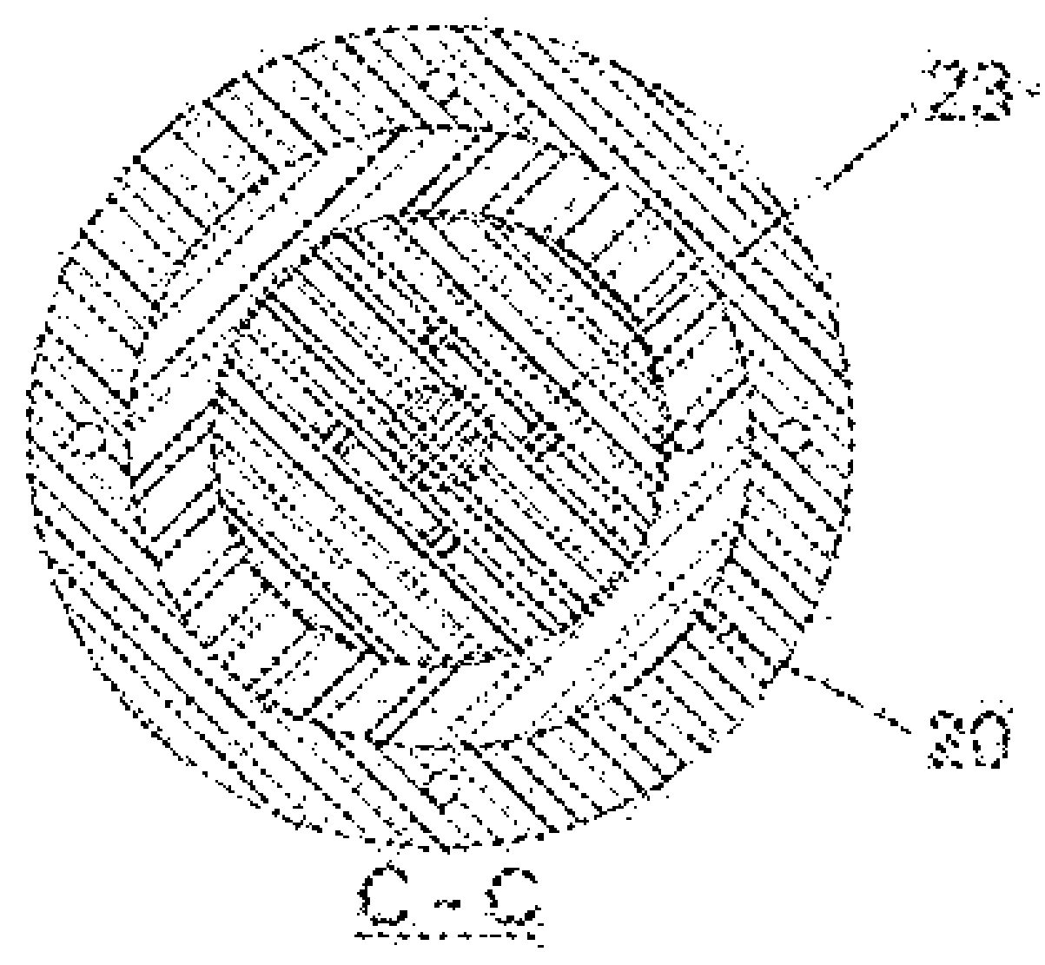


Fig 3 C



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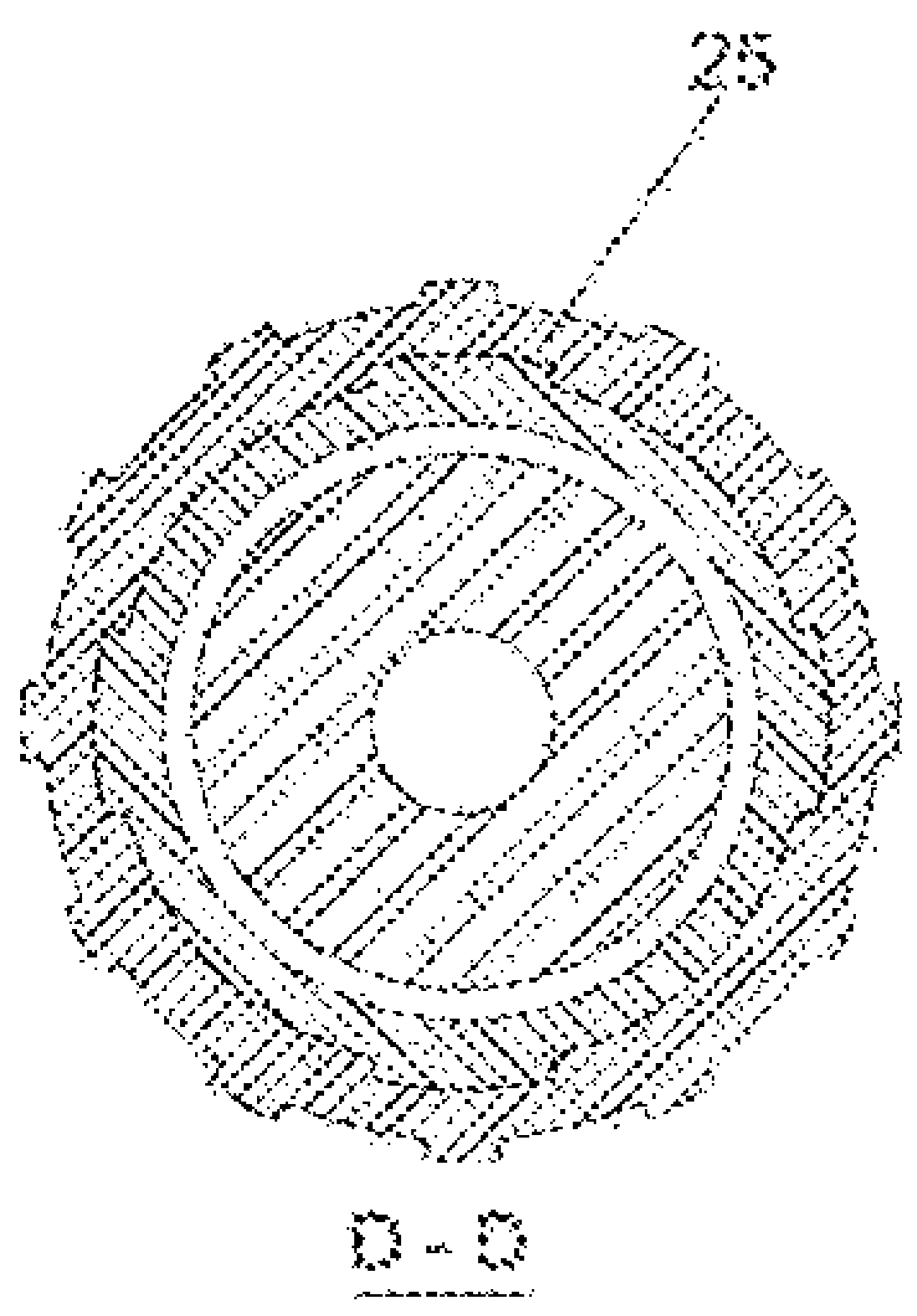


Fig 3 E

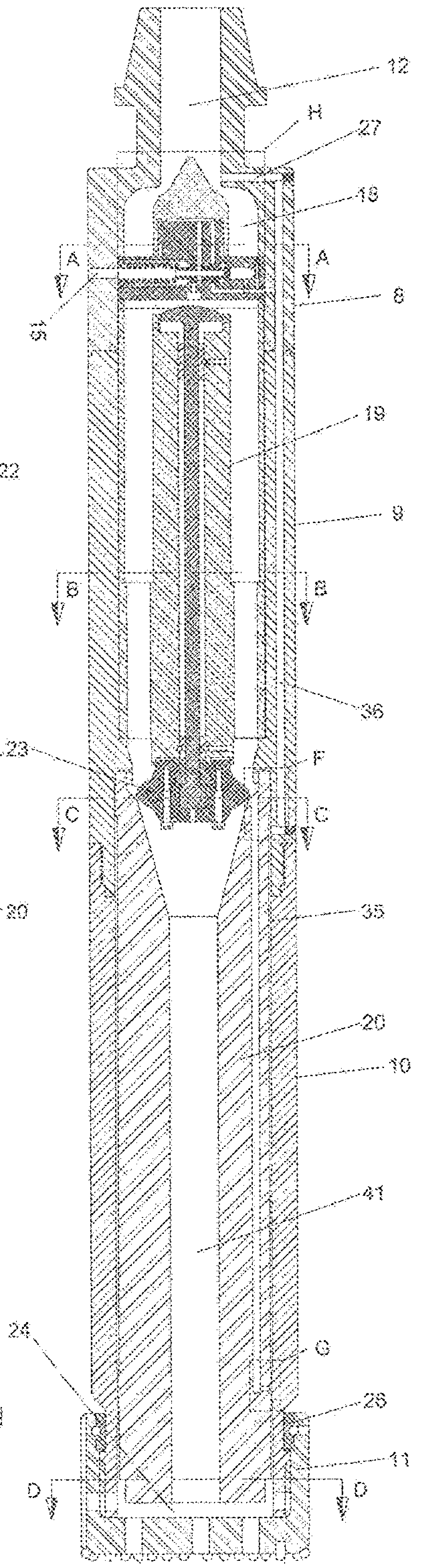


Fig 3 A

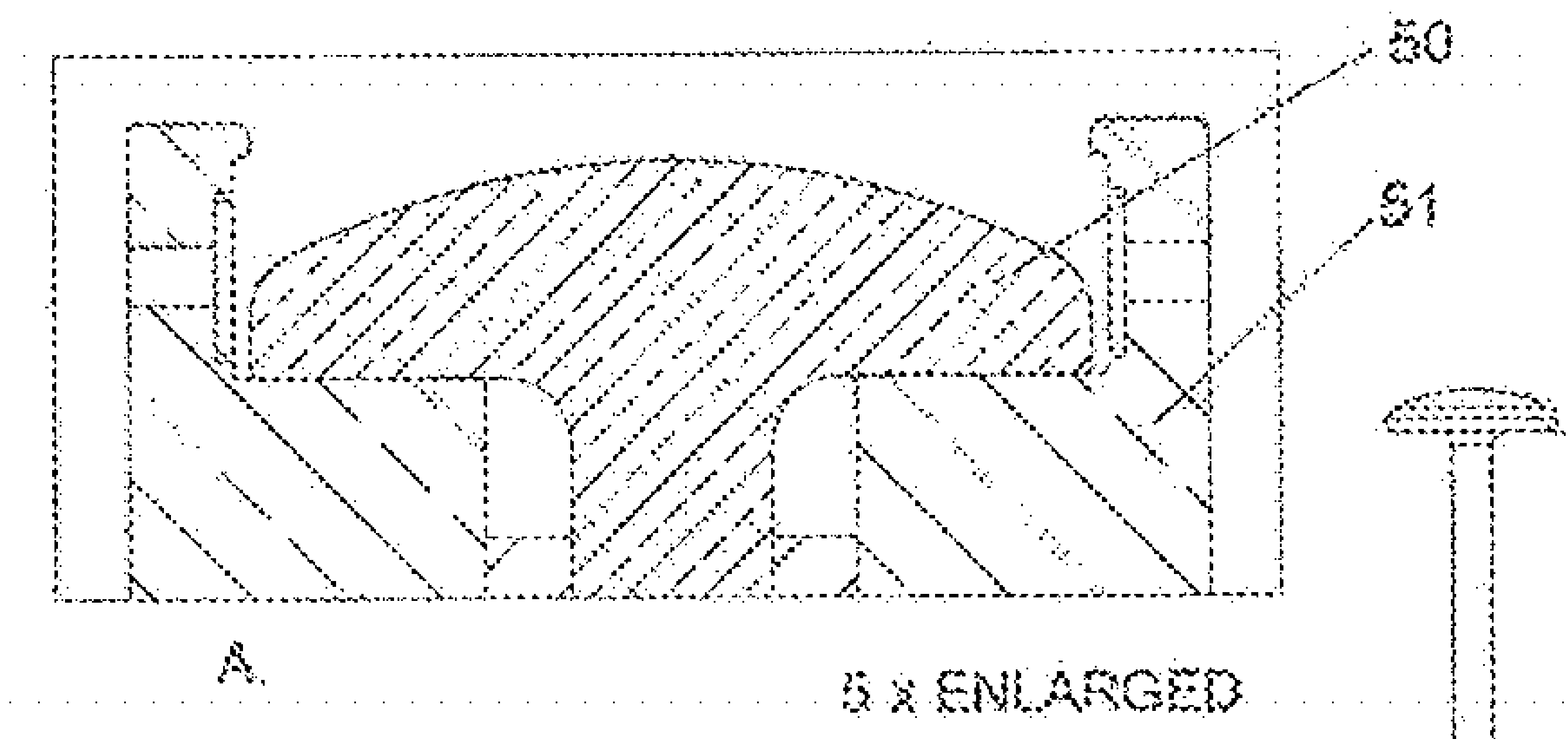


Fig 4 D

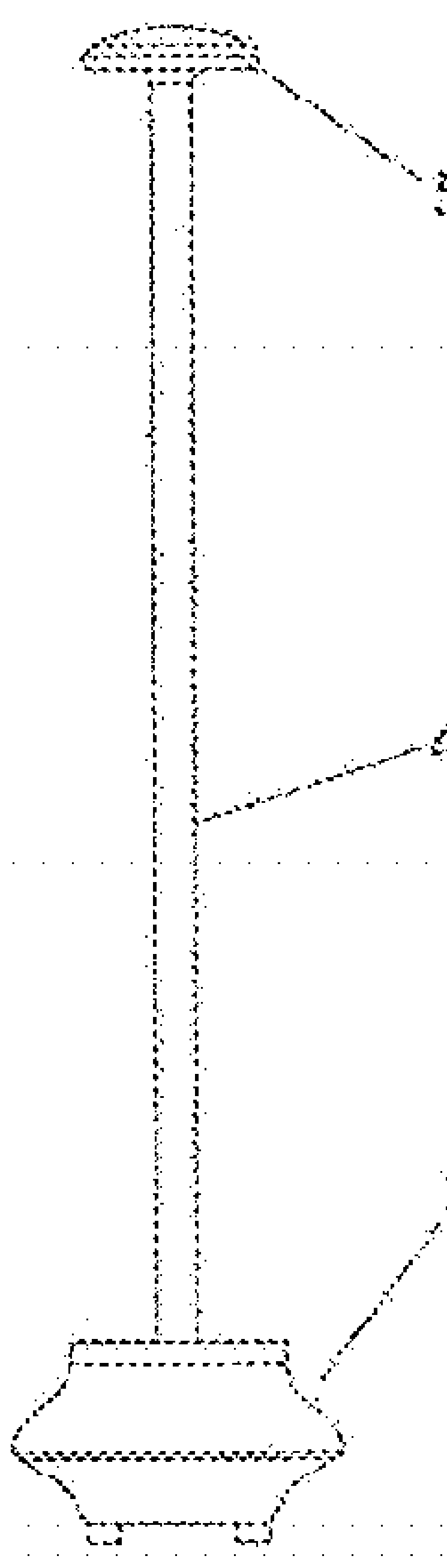


Fig 4 B

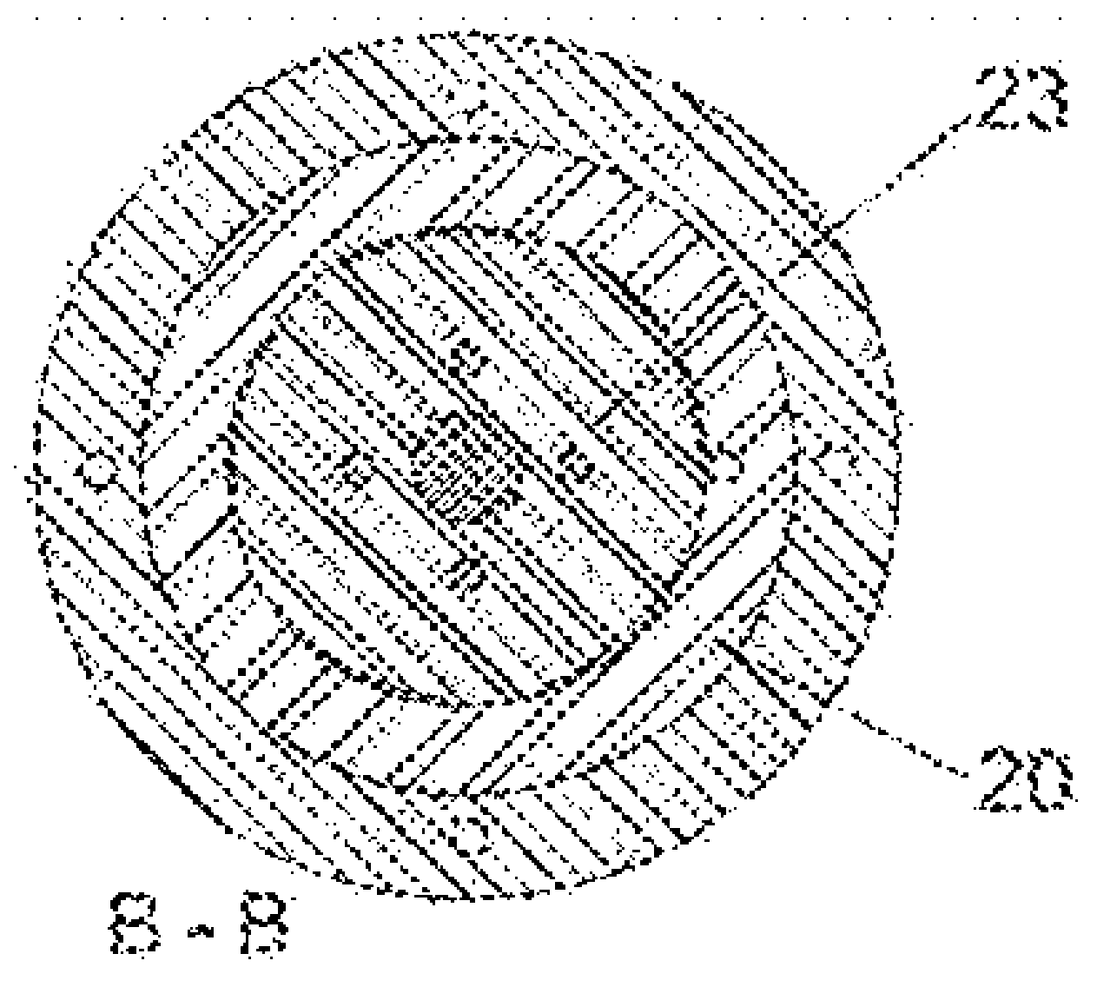


Fig 4 C

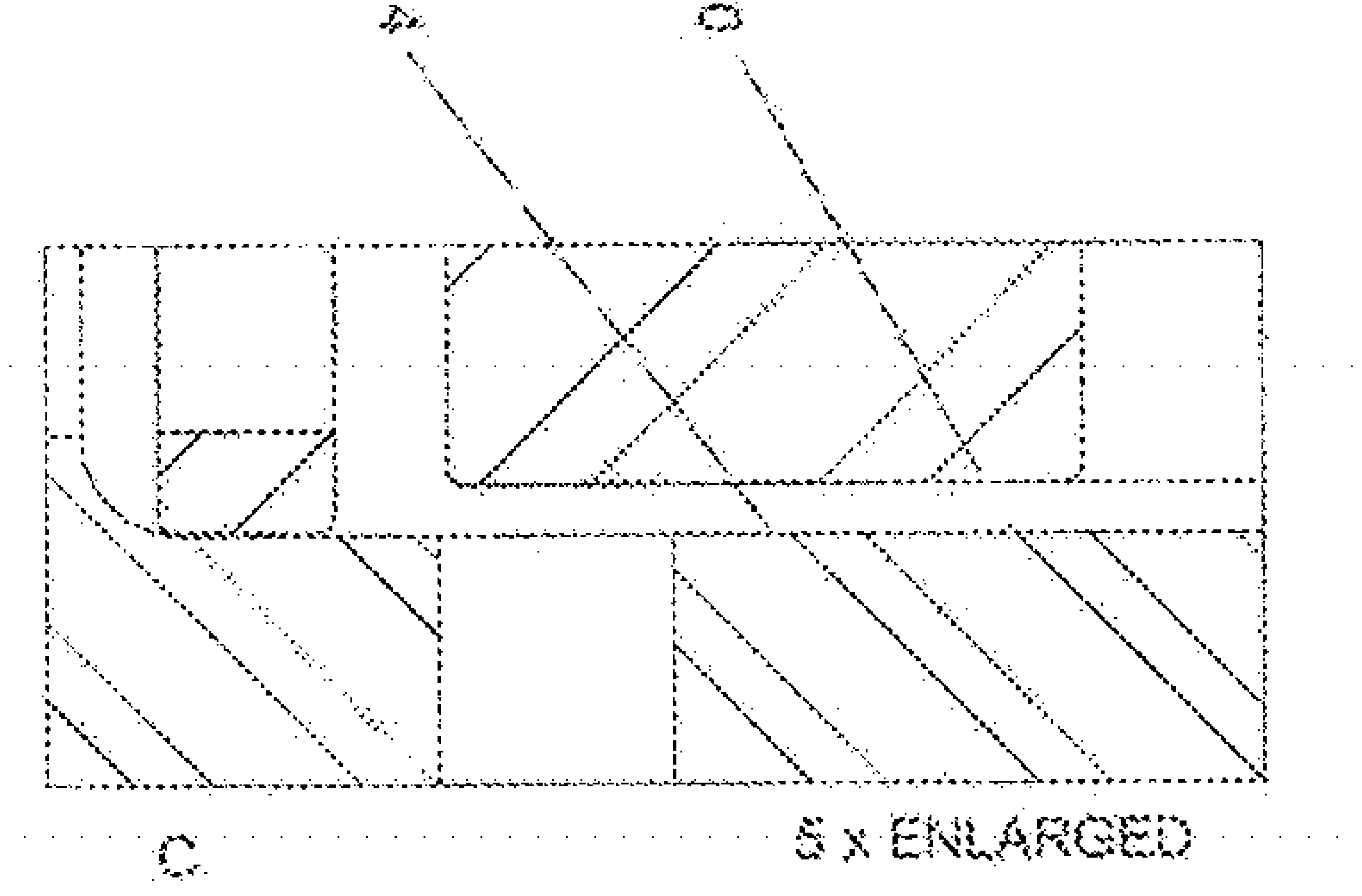


Fig 4 E

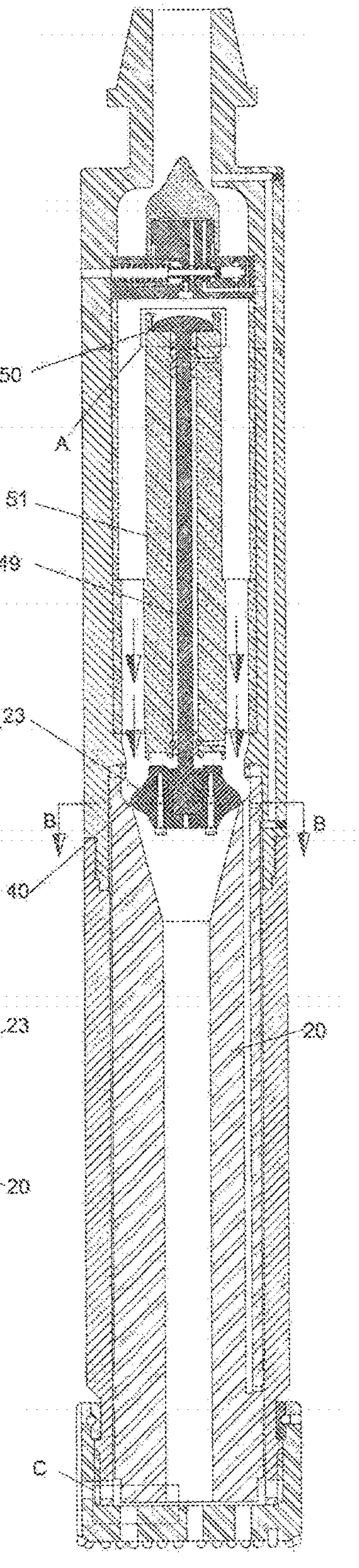


Fig 4 A

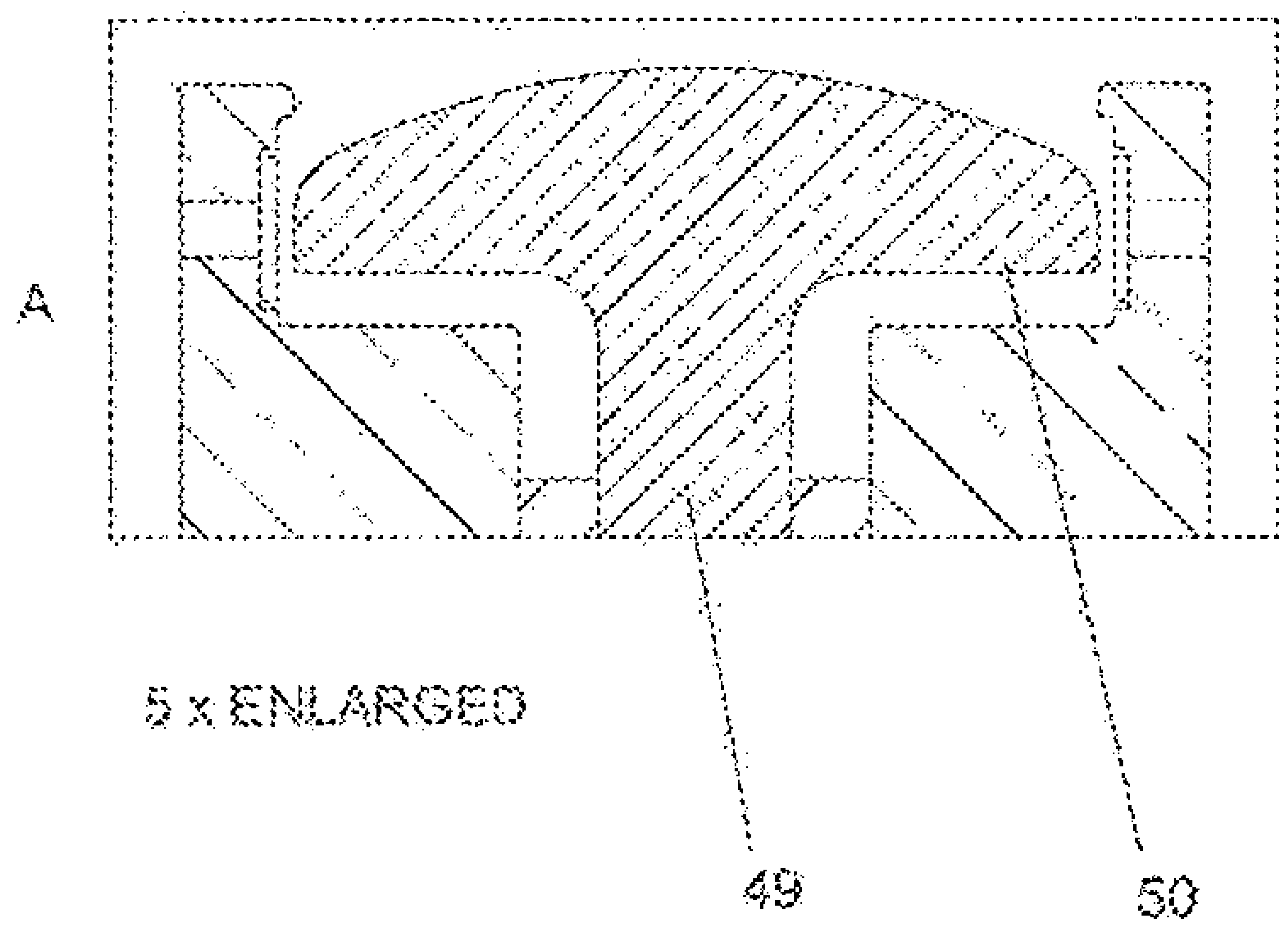


Fig 5B

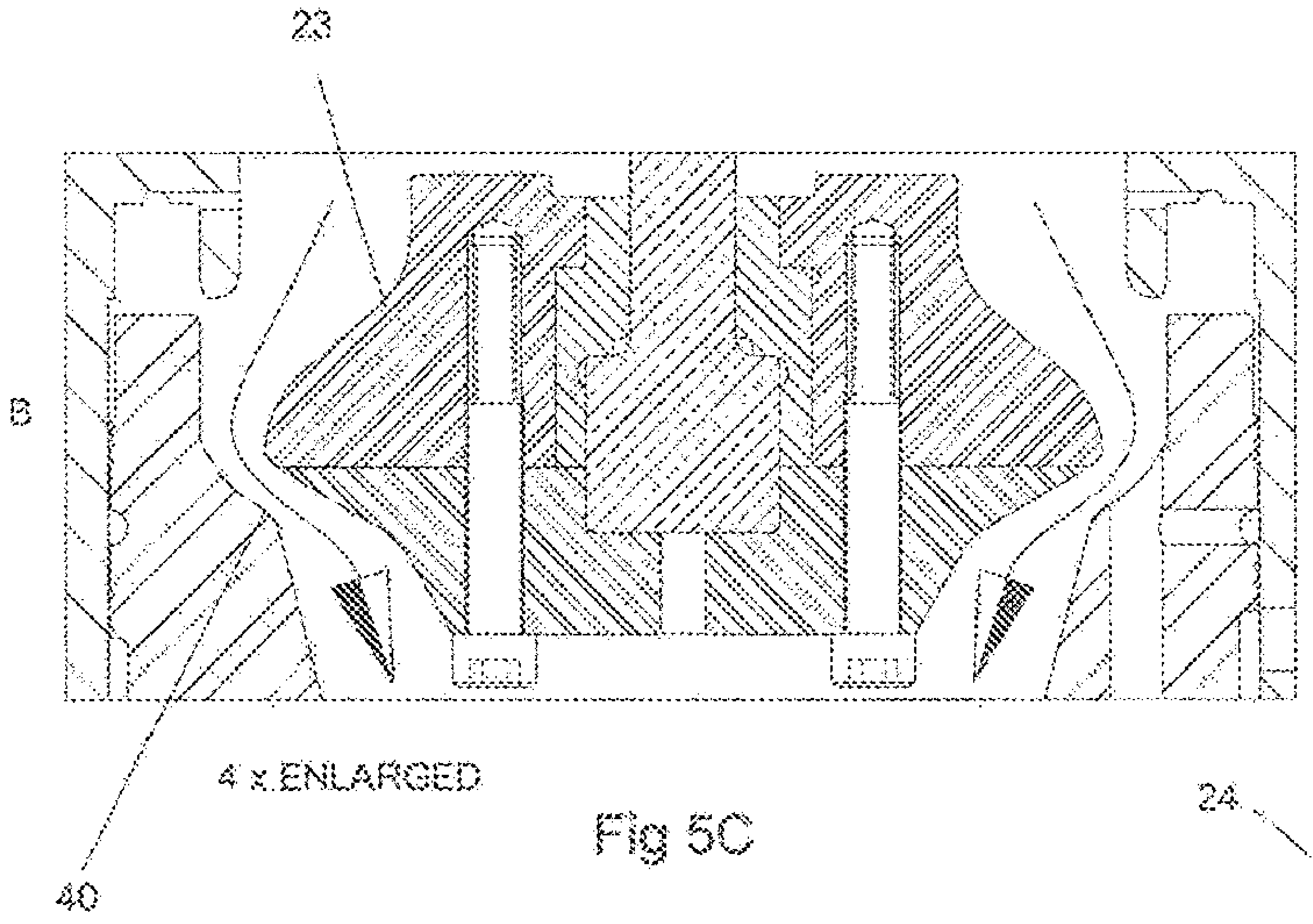


Fig 5C

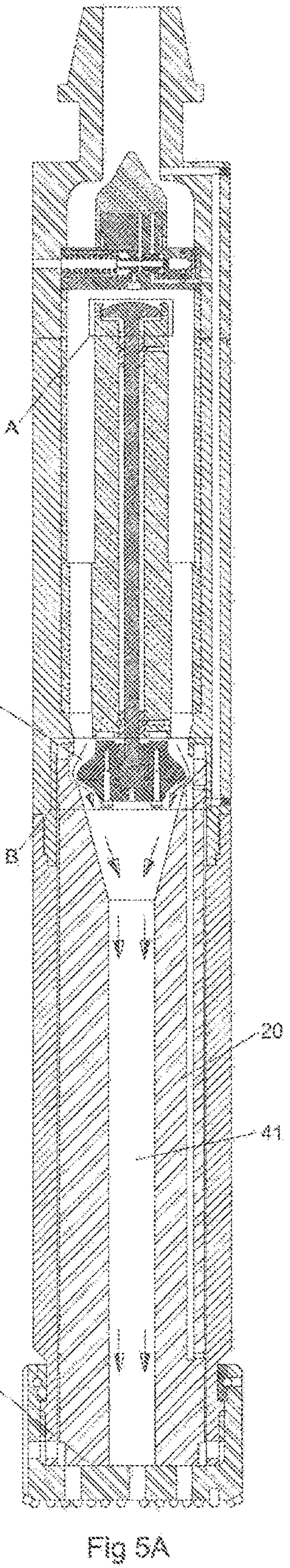
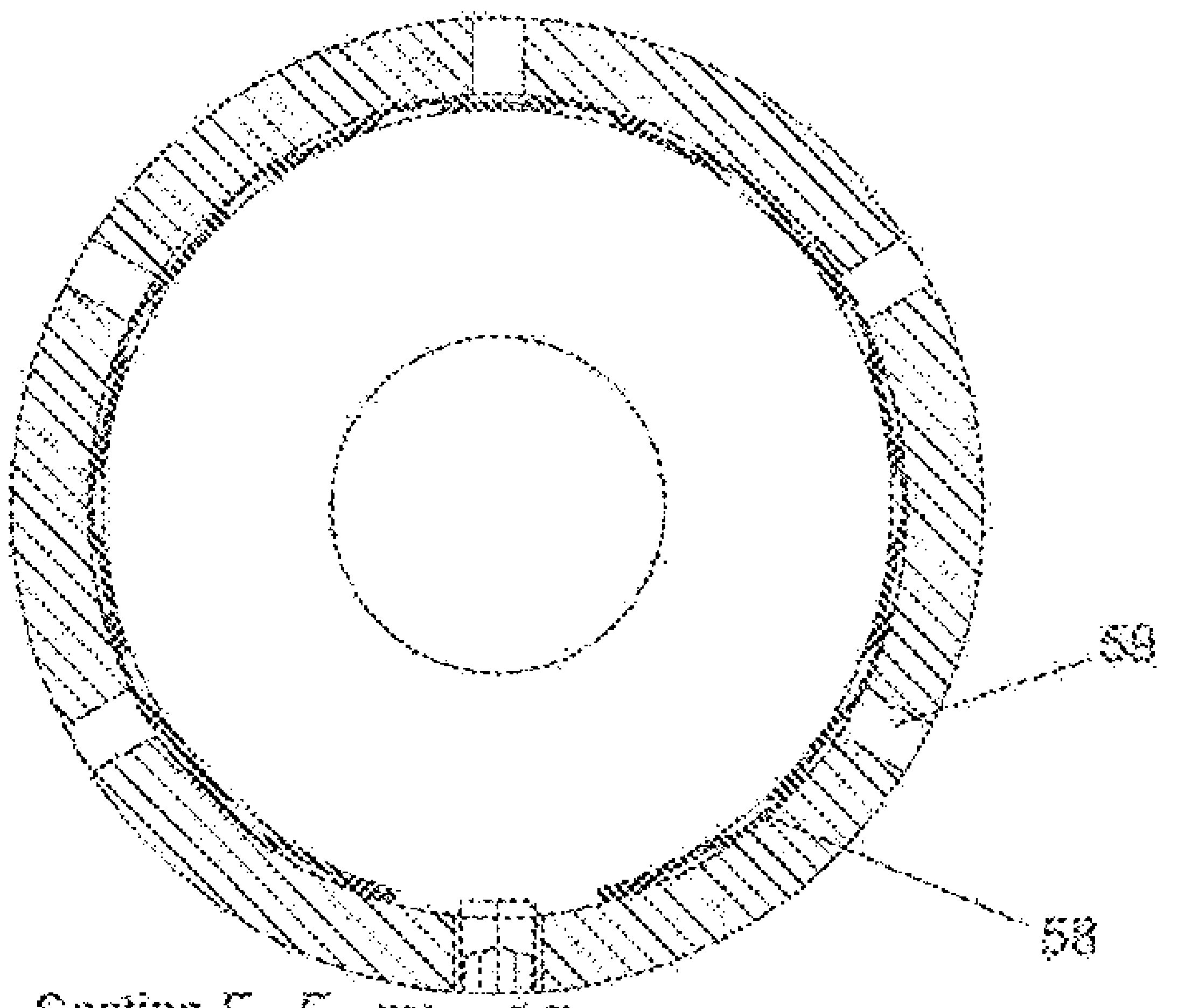
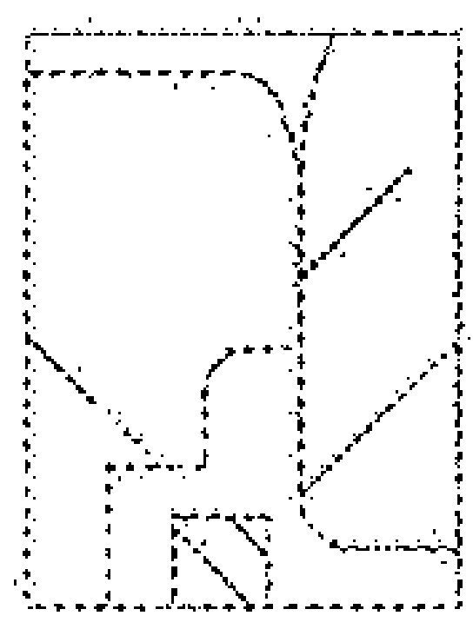


Fig 5A

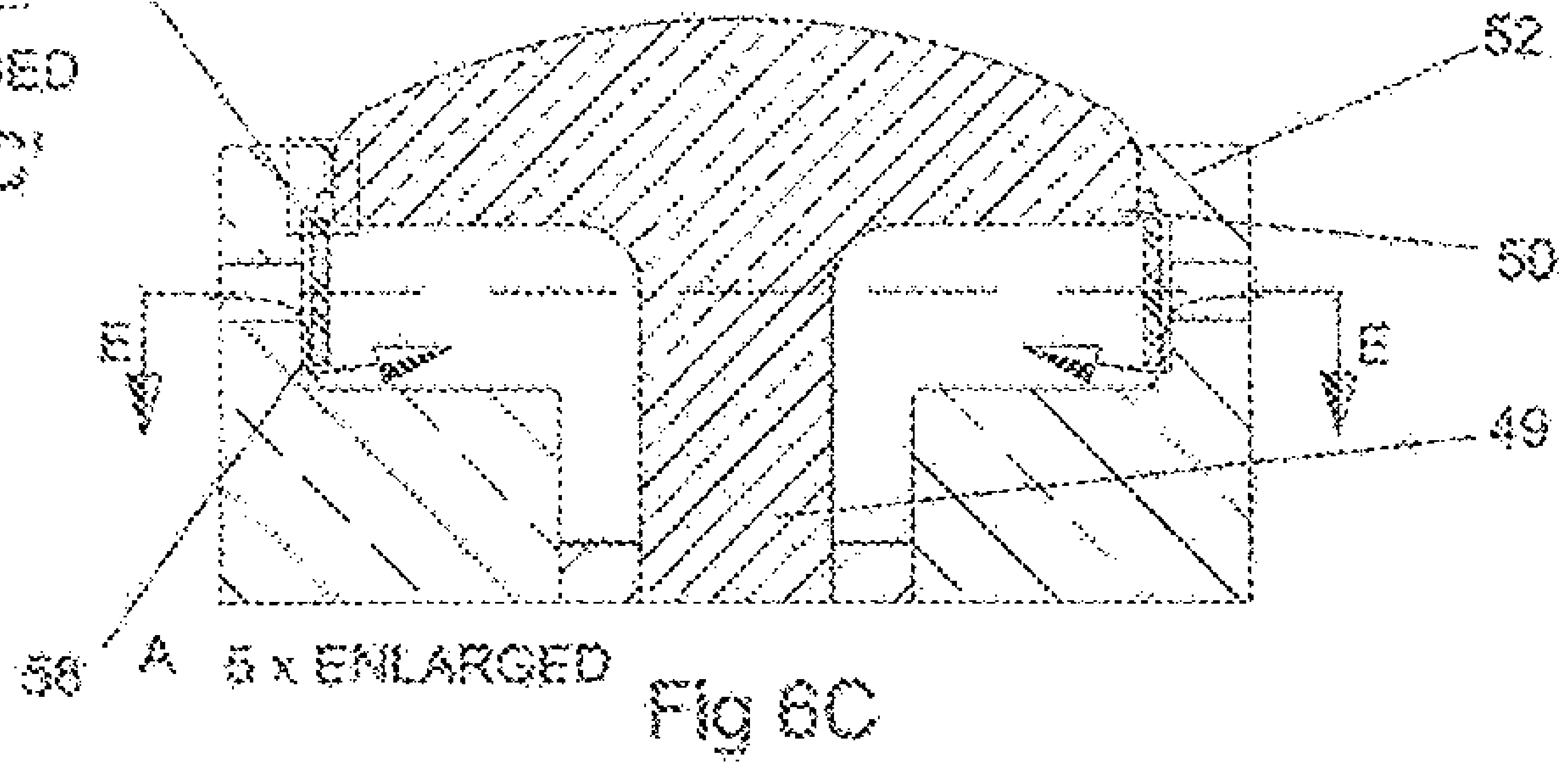


Section E - E Fig 6B

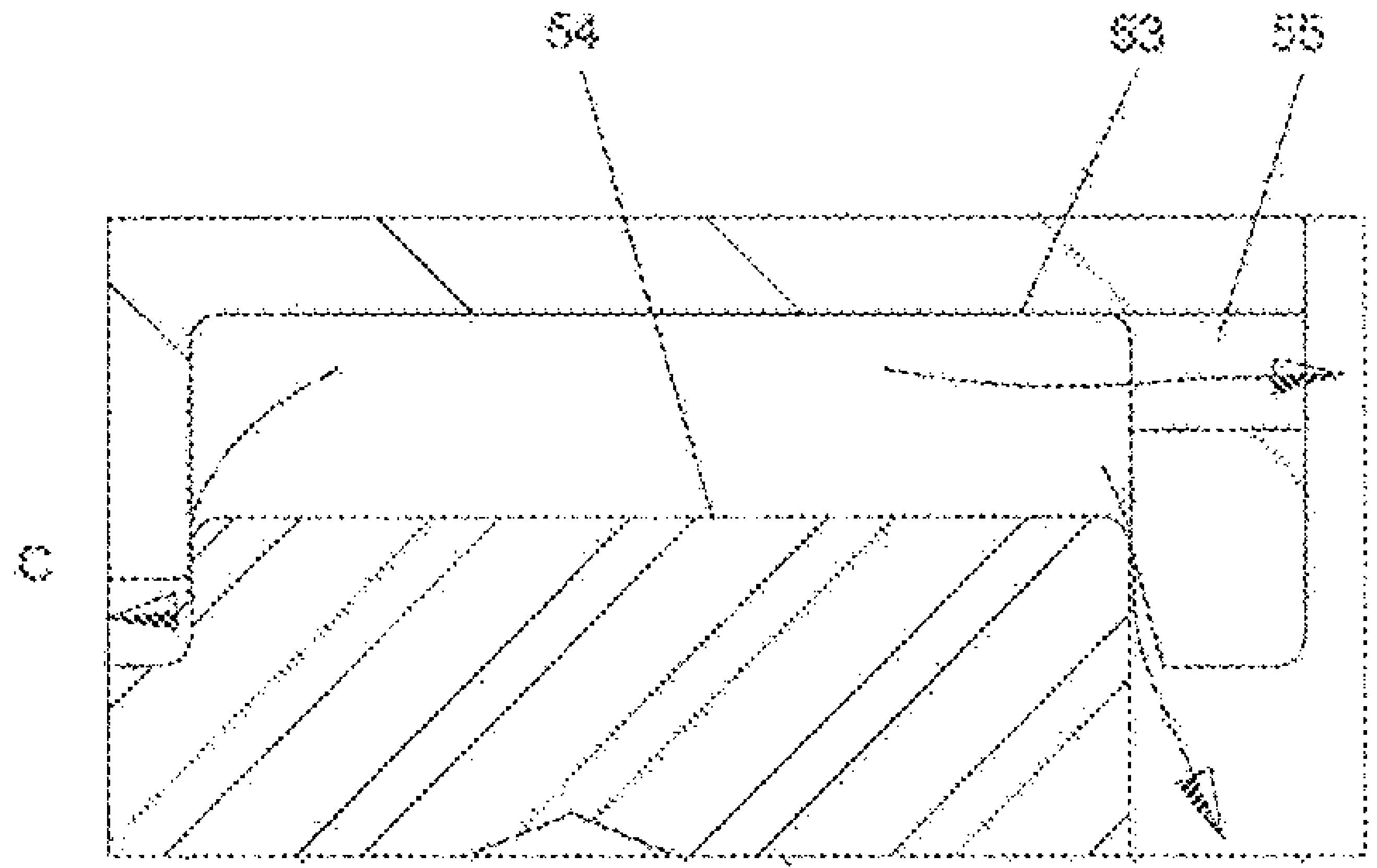


20 x ENLARGED

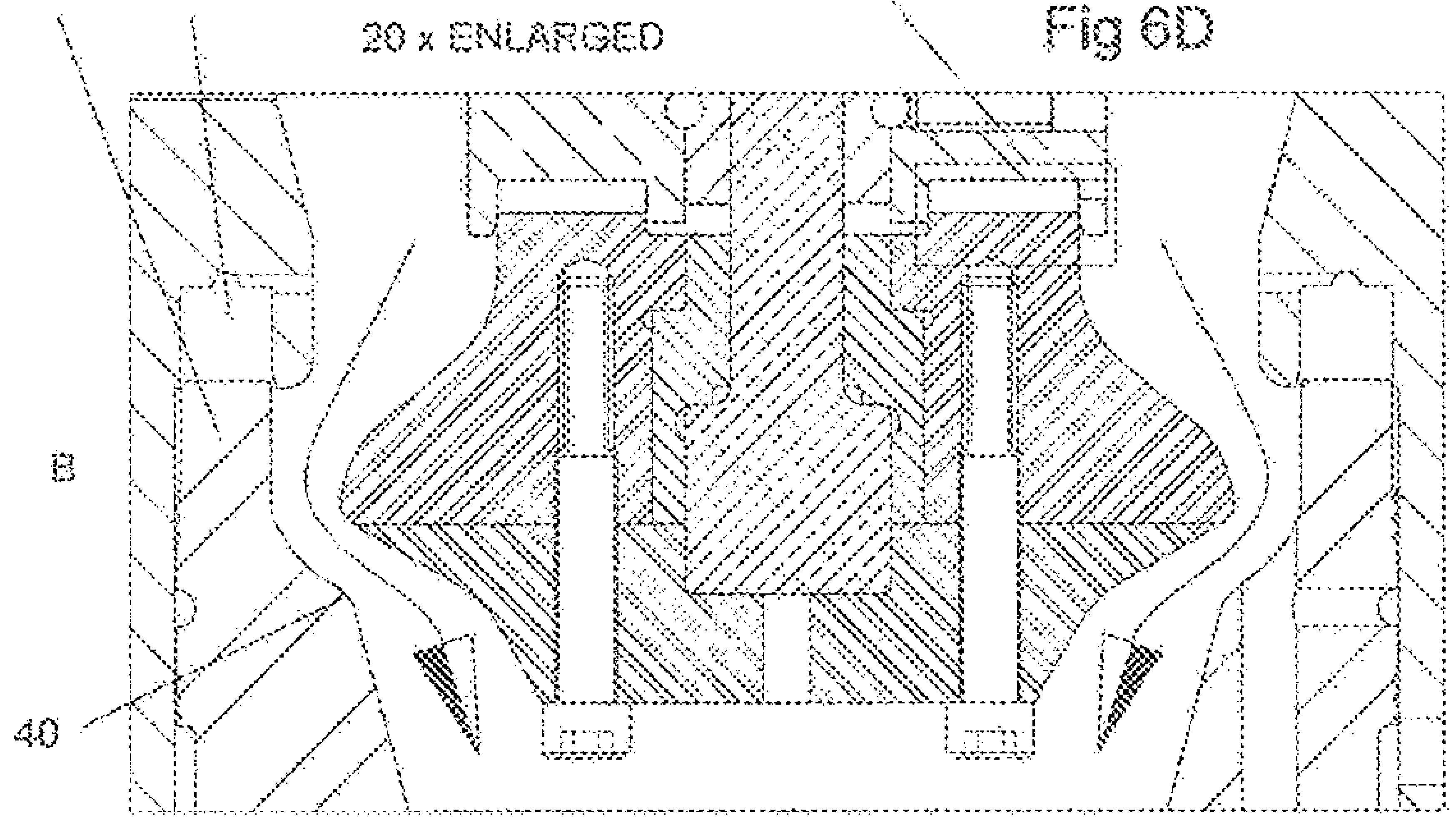
Fig 6C'



5 x ENLARGED Fig 6C



20 x ENLARGED Fig 6D



4 x ENLARGED Fig 6E

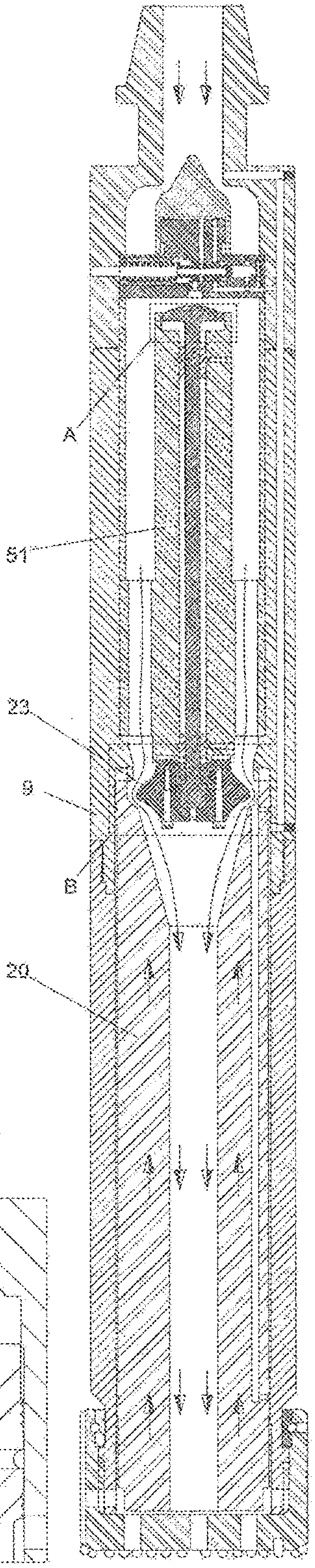


Fig 6A

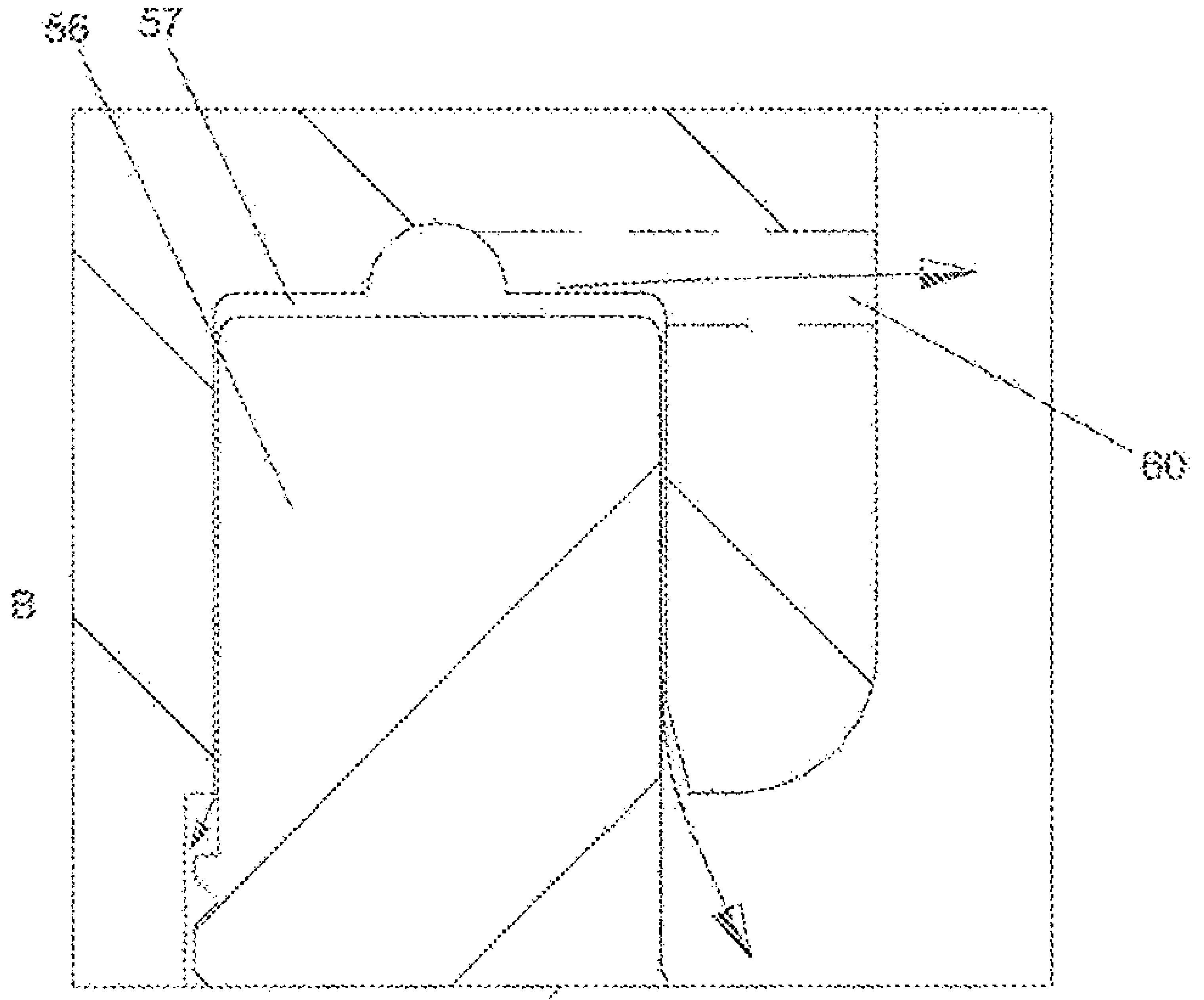


Fig 7B

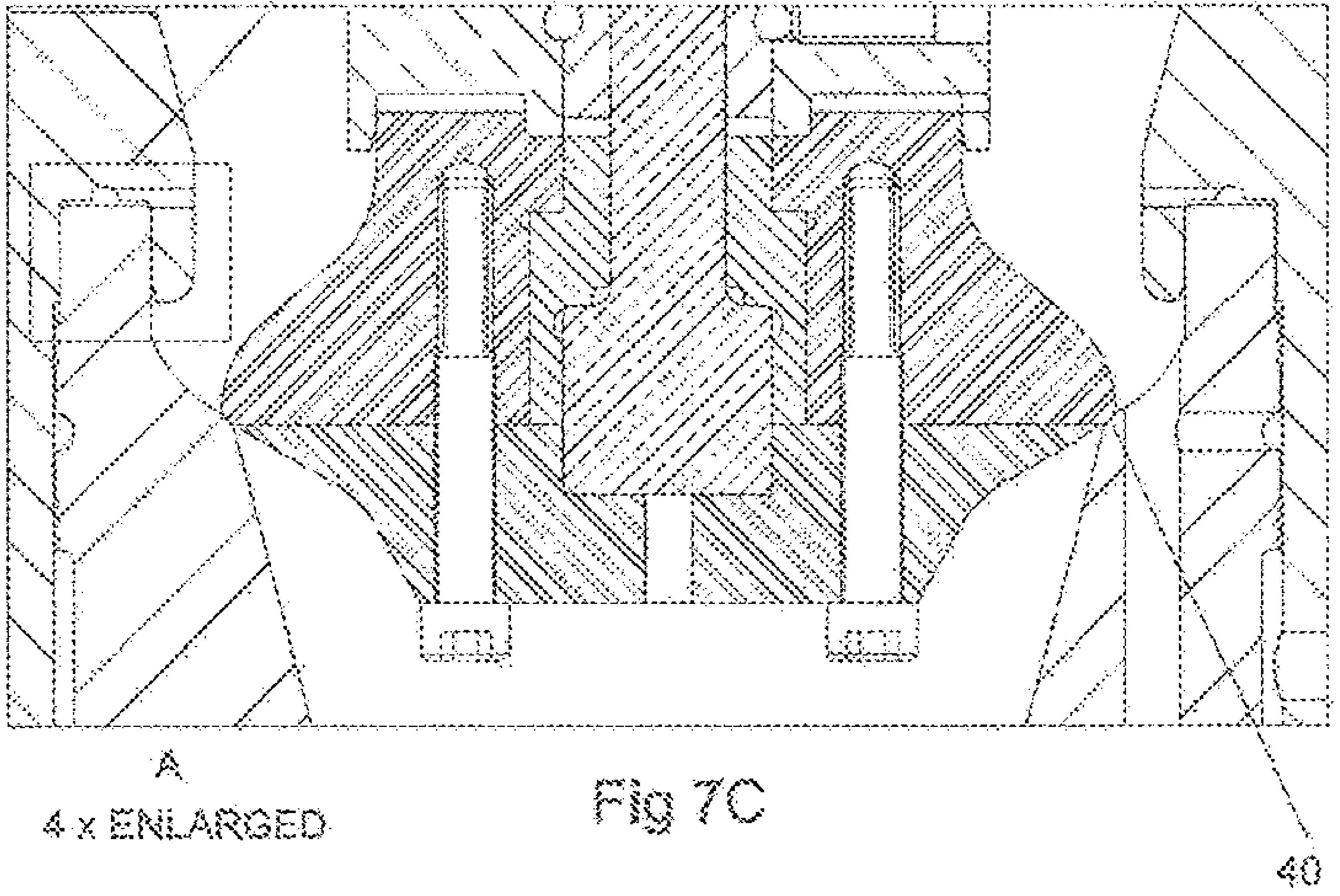


Fig 7C

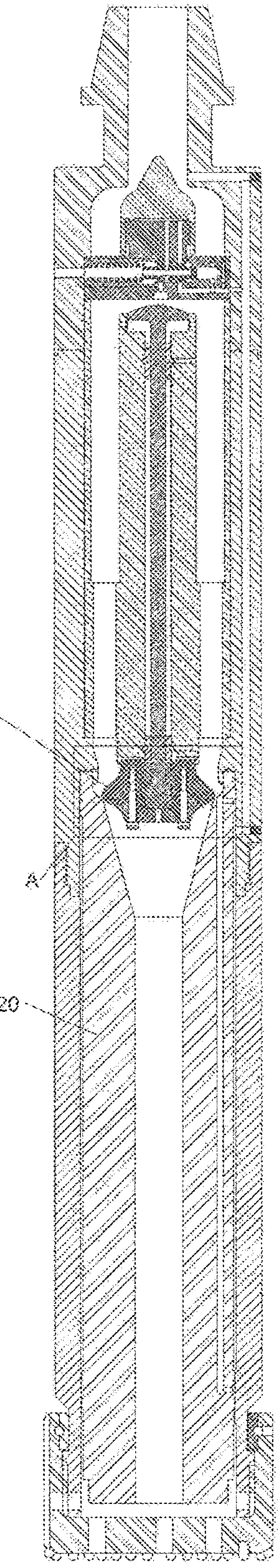
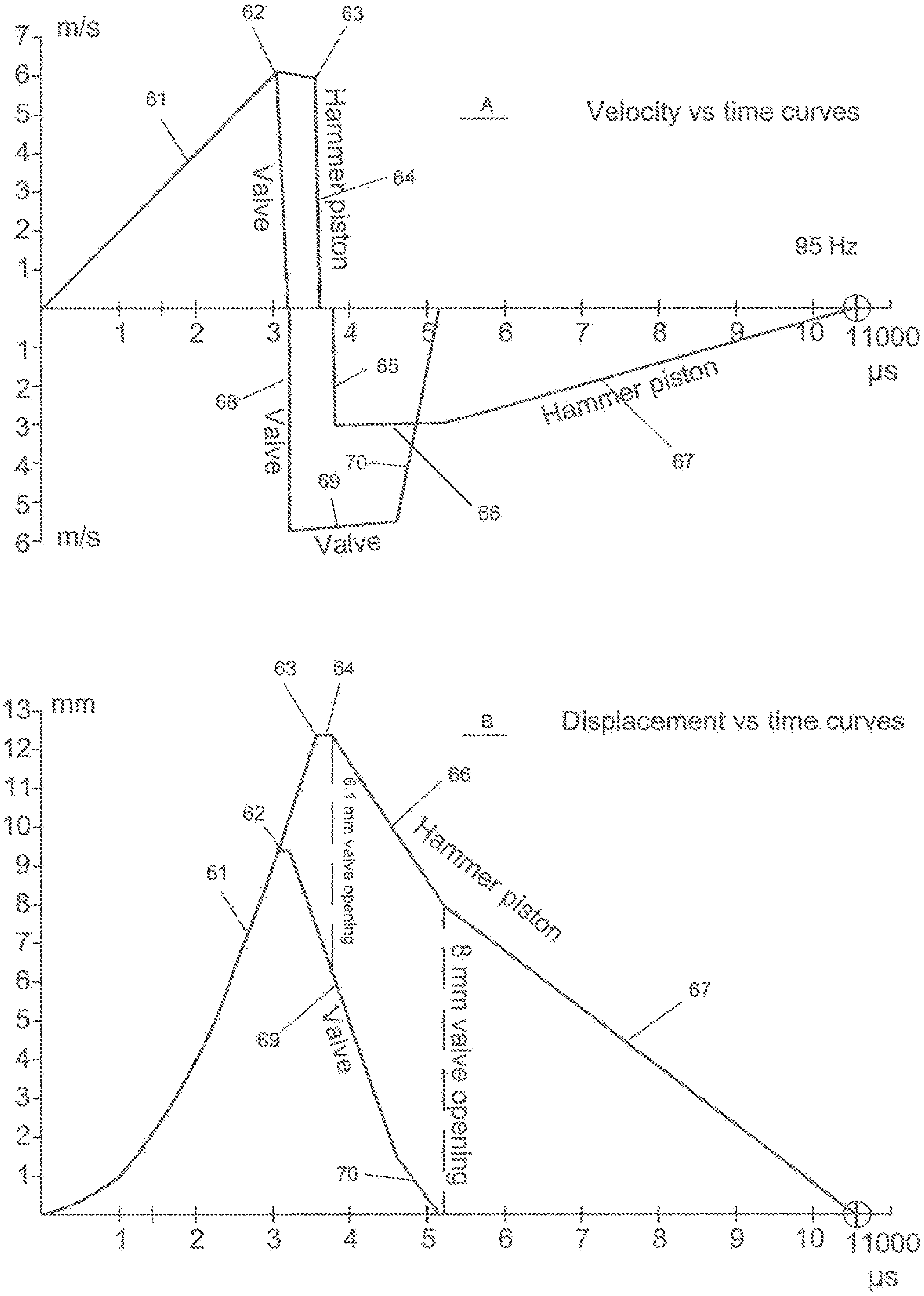


Fig 7A



A
Velocity vs time curves
m/s
7
6
5
4
3
2
1
1
2
3
4
5
6
m/s
62
63
61
Valve
Hammer piston
64
95 Hz
1
2
3
4
5
6
7
8
9
10
11000
µs
65
68
Valve
Hammer piston
67
70
69
66
Valve
B
Displacement vs time curves
mm
13
12
11
10
9
8
7
6
5
4
3
2
1
63
64
66
6,1 mm valve opening
62
61
Hammer piston
8 mm valve opening
67
69
Valve
70
1
2
3
4
5
6
7
8
9
10
11000
µs

Fig 8

Pressure drop over the gradually closing valve

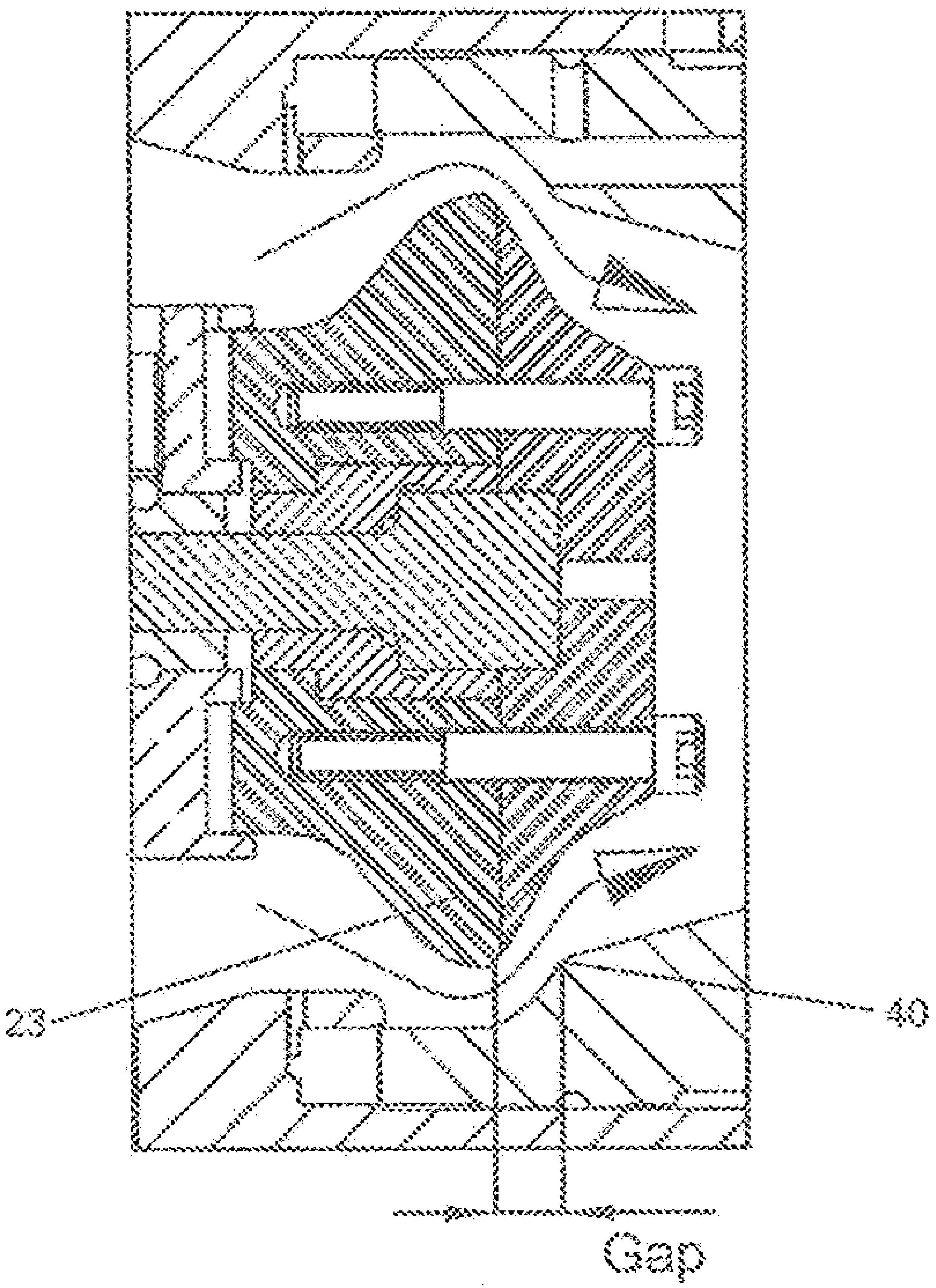


Fig 9B

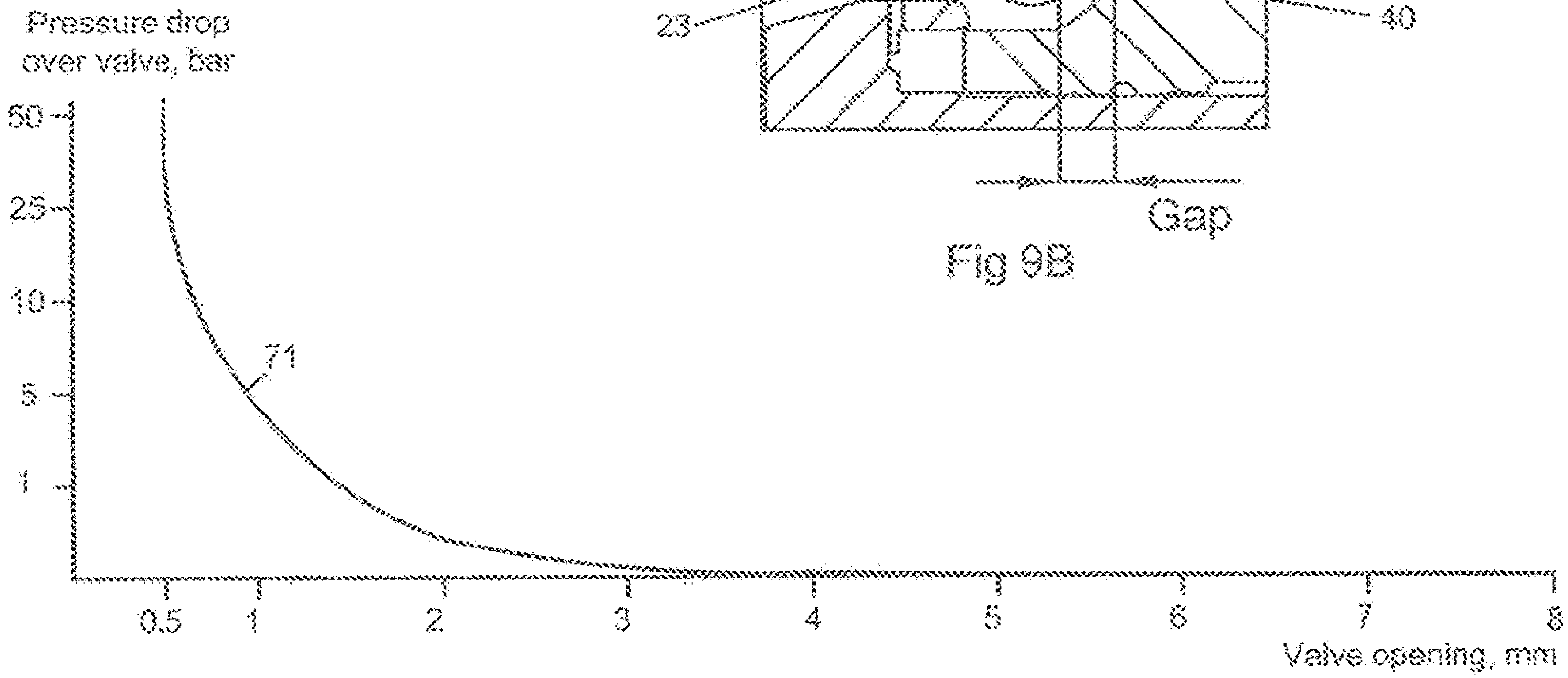


Fig 9A

HIGH FREQUENCY FLUID DRIVEN DRILL HAMMER PERCUSSION DRILLING IN HARD FORMATIONS

The present invention relates to a fluid pressure driven, high frequency percussion hammer for drilling in hard formations, which percussion hammer comprises a housing, which in one end thereof is provided with a drill bit designed to act directly on the hard formation, which percussion hammer further comprises a hammer piston moveably received in said housing and acts on the drill bit, which hammer piston has a longitudinally extending bore having predetermined flow capacity, and the bore being closeable in the upstream direction by a valve plug that partly follows the hammer piston during its stroke.

Hydraulically driven percussion hammers for drilling in rock have been in commercial use for more that 30 years. These are used with jointable drill rods where the drilling depth is restricted by the fact that the percussion energy fades through the joints, in addition to the fact that the weight of the drill rod becomes too heavy such that little energy finally reaches the drill bit.

Downhole hammer drills, i.e. hammer drills installed right above the drill bit, is much more effective and are used in large extent for drilling of wells down to 2-300 meter depth. These are driven by compressed air and have pressures up to approximately 22 bars, which then restricting the drilling depth to approximately 20 meters if water ingress into the well exists. High pressure water driven hammer drills have been commercial available more than 10 years now, but these are limited in dimension, which means up to about 130 mm hole diameter. In addition, they are known to have limited life time and are sensitive for impurities in the water. They are used in large extent in the mining industries since they are drilling very efficiently and drill very straight bores. They are used in a limited extent for vertical well drilling down to 1000-1500 meters depth, and then without any directional control.

It is desired to manufacture downhole drill fluid driven hammer drills which can be used together with directional control equipment, which have high efficiency, can be used with water as drill fluid and can also be used with water based drill fluid having additives, and having economical lifetime. It is expected great usage both for deepwater drilling for geothermic energy and for hard accessible oil and gas resources.

In percussion drilling, drill bits are used having inserted hard metal lugs, so called "indenters". These are made of tungsten carbide and are typically from 8 to 14 mm in diameter and have spherical or conical end. Ideally viewed, each indenter should strike with optimal percussion energy related to the hardness and the compressive strength of the rock, such that a small crater or pit is made in the rock. The drill bit is rotated such that next blow, ideally viewed, forms a new crater having connection to the previous one. The drilling diameter and the geometry determine the number of indenters.

Optimal percussion energy is determined by the compressive strength of the rock, it can be drilled in rock having compressive strength over 300 MPa. The supply of percussion energy beyond the optimal amount, is lost energy since it is not used to destroy the rock, only propagates as waves of energy. Too little percussion energy does not make craters at all. When percussion energy per indenter is known and the number of indenters is determined, then the optimal percussion energy for the drill bit is given. The pull, or drilling rate, (ROP—rate of penetration) can then be increased by just increasing the percussion frequency.

The amount of drilling fluid pumped is determined by minimum necessary return rate (annular velocity) within the annulus between the drill string and the well bore wall. This should at least be over 1 m/s, preferably 2 m/s, such that the drilled out material, the cuttings, will be transported to the surface. The harder and brittle the rock is, and the higher percussion frequency one is able to provide, the finer the cuttings become, and the slower return rate or speed can be accepted. Hard rock and high frequency will produce cuttings that appear as dust or fine sand.

The hydraulic effect applied to the hammer drill is determined by the pressure drop multiplied with pumped quantity per time unit.

The percussion energy per blow multiplied with the frequency provides the effect. If we look into an imaginary example where drilling into granite having 260 MPa compressive strength and drilling diameter of 190 mm is performed, water is pumped by 750 l/min (12.5 liters/second) from the surface. It is calculated that approximately 900 J is optimal percussion energy.

With reference to known data for corresponding drilling, but with smaller diameters, a drilling rate (ROP) of 22 m/h (meters per hour) with a percussion frequency of 60 Hz, can be expected. It is here assumed to increase the percussion frequency to 95 Hz, consequently ROP then become 35 m/h. Required net effect on the drill bit then becomes: 0.9 kJ×95=86 kW. We assume the present hammer construction to have a mechanical-hydraulic efficiency of 0.89, which then provides 7.7 MPa required pressure drop over the hammer.

This hammer drill will then drill 60% quicker and by 60% less energy consumption than known available water propelled hammer drills.

This is achieved by a percussion hammer of the introductory said kind, which hammer is distinguished in that the valve plug is controlled by an associated valve stem slideably received in a valve stem sleeve, said valve stem comprises stopping means able to stop the valve plug by a predetermined percentage of the full stroke length of the hammer piston and separates the valve plug from a seat seal on the hammer piston, said bore thus being opened and allows the bore fluid to flow through the bore.

Preferably the stopping means comprises a stop plate at the upstream end of the valve stem, and a cooperating internal stop surface in the valve stem sleeve.

In one embodiment the predetermined percentage of the full stroke length of the hammer piston can be in the order of magnitude 75%.

Conveniently, it is the inherent tension spring properties of the valve stem that returns the valve plug, which valve stem being long and slender.

Preferably, the percussion hammer can further be provided with an inlet valve assembly, which is not opening for operation of the hammer piston until the pressure is build up to approximately 95% of full working pressure, which inlet valve assembly being adapted to close off a main barrel, and a side barrel within the hammer housing can pressurize an annulus between the hammer piston and the housing elevating the hammer piston to seal against the valve plug.

Conveniently, the hammer piston and the valve assembly can be returned by recoil, where both the hammer piston and the valve assembly are provided with hydraulic dampening controlling the retardation of the return stroke until stop.

Conveniently, the hydraulic dampening takes place with an annular piston which is forced into a corresponding annular cylinder with controllable clearances, and thus restricts or chokes the evacuation of the trapped fluid.

Further, an opening can be arranged in the top of the valve stem sleeve, into which opening the stop plate of the valve stem is able to enter, and the radial portions of the stop plate can seal against the internal side of the opening with relatively narrow radial clearance.

Further, an annular backup valve can be arranged in a ring groove underneath the opening, which backup valve being able to open and replenish fluid through bores in the valve stem sleeve.

The percussion hammer housing can be divided into an inlet valve housing, a valve housing and a hammer housing.

The hammer drill construction according to the present invention is of the type labeled "Direct Acting Hammer", i.e. that the hammer piston has a closing valve thereon, which valve in closed position enables the pressure to propel the piston forward, and in open position enables the hammer piston to be subjected to recoil. The previous variant of a hydraulic hammer has a valve system that by means of pressure propels the hammer piston both ways. This provides poor efficiency, but more precise control of the piston.

The key to good efficiency and high percussion frequency, is in the valve construction. The valve needs to operate with high frequency and have well through flow characteristics in open position.

With great advantage, the hammer drill construction can also be used as surface mounted hydraulically driven hammer for drilling with drill rods, but it is the use as a downhole hammer drill that will be described in detail here.

Other and further objects, features and advantages will appear from the following description of preferred embodiments of the invention, which is given for the purpose of description, and given in context with the appended drawings where:

FIG. **1** shows in schematic view a typical hydraulic hammer drill according to the invention,

FIG. **2**A shows an elevational view of a downhole hammer drill with drill bit,

FIG. **2**B shows the hammer drill of FIG. **2**A turned about 90°,

FIG. **2**C shows a view in the direction of the arrows A-A in FIG. **2**A,

FIG. **2**D shows a view in the direction of the arrows B-B in FIG. **2**A,

FIG. **3**A shows a longitudinal sectional view of the hammer drill shown in FIG. **2**A where the internal main parts are shown,

FIG. **3**B shows a transversal cross sectional view along the line A-A in FIG. **3**A,

FIG. **3**C shows a transversal cross sectional view along the line B-B in FIG. **3**A,

FIG. **3**D shows a transversal cross sectional view along the line C-C in FIG. **3**A,

FIG. **3**E shows a transversal cross sectional view along the line D-D in FIG. **3**A,

FIG. **3**F shows a two times enlarged, encircled detail view H in FIG. **3**A,

FIG. **3**G shows a two times enlarged, encircled detail view H in FIG. **3**A,

FIG. **3**H shows a five times enlarged, encircled detail view F in FIG. **3**A,

FIG. **3**I shows a five times enlarged, encircled detail view G in FIG. **3**A,

FIG. **4**A shows correspondingly to that shown in FIG. **3**A, but at the end of an acceleration phase,

FIG. **4**B shows an elevational view of the valve assembly shown in section in FIG. **4**A,

FIG. **4**C shows a transversal cross sectional view along the line B-B in FIG. **4**A,

FIG. **4**D shows a five times enlarged, encircled detail view A in FIG. **4**A,

FIG. **4**E shows a five times enlarged, encircled detail view C in FIG. **4**A,

FIG. **5**A shows correspondingly to that shown in FIGS. **3**A and **4**A, but in that moment when the hammer piston strikes against the impact surface in the drill bit,

FIG. **5**B shows a five times enlarged, encircled detail view A in FIG. **5**A,

FIG. **5**C shows a four times enlarged, encircled detail view B in FIG. **5**A,

FIG. **6**A shows correspondingly to that shown in FIGS. **3**A, **4**A and **5**A, but when the hammer piston is in full return,

FIG. **6**B shows a section along the line E-E in FIG. **6**C,

FIG. **6**C shows a five times enlarged, encircled detail view A in FIG. **6**A,

FIG. **6**C' shows a 20 times enlarged, encircled detail view D in FIG. **6**C,

FIG. **6**D shows a 20 times enlarged, encircled detail view C in FIG. **6**E,

FIG. **6**E shows a four times enlarged, encircled detail view B in FIG. **6**A,

FIG. **7**A shows correspondingly to that shown in FIGS. **3**A, **4**A, **5**A and **6**A, but when the hammer piston is in the final part of the return,

FIG. **7**B shows a 20 times enlarged, encircled detail view B in FIG. **7**C,

FIG. **7**C shows a four times enlarged, encircled detail view A in FIG. **7**A,

FIG. **8** shows curves that illustrates the working cycle of the hammer piston and the valve,

FIG. **9**A shows the curve that illustrates the abrupt closing characteristic of the valve relative to pressure drop, and

FIG. **9**B illustrates flow and pressure drop over the gradually closing valve.

FIG. **1** shows a typical hydraulic hammer drill for attachment on top of jointable drill rods where the hammer mechanism is located internal of a housing **1** constructed by several house sections, where a rotary motor **2** rotates a drill rod via a transmission **3** rotating an axle having a threaded portion **4** to be screwed to the drill rod and a drill bit (not shown). The hammer machine is normally equipped with a fixation plate **5** for attachment to a feeding apparatus on a drill rig (not shown). Supply of hydraulic drive fluid takes place via pipes and a coupling **6** and hydraulic return via pipes with a coupling **7**.

FIGS. **2**A and **2**B show a downhole hammer drill with drill bit. These will be used in the following description. The illustrated housing **1** has a first house section **8** that receives what later on will be described as the inlet valve, while a second house section **9** contains a valve, a third house section **10** contains a hammer piston and the reference number **11** denotes the drill bit. Drill fluid is pumped in through an opening or main run **12**, and a threaded portion **13** connects the hammer to the drill string (not shown). A flat portion **14** is provided for use of a torque wrench to screw the hammer to/from the drill string. A drain hole **15** is required for the function of the later on explained inlet valve, outlet hole **16** is present for return of the drill fluid in the annulus between the drill hole wall and the hammer drill housing (not shown) back to the surface. Hard metal lugs **17** are those elements that crush the rock being drilled. FIG. **2**C shows a view in the direction of the arrows A-A in FIG. **2**A, and FIG. **2**D shows a view seen towards the drill bit **11** in the direction of the arrows B-B in FIG. **2**A.

FIG. **3**A shows a longitudinal section of the hammer drill where the internal main parts are: an inlet valve assembly **18**, a valve assembly **19** and a hammer piston **20**. The drilling fluid is pumped in through the inlet **12**, passes the inlet valve **18** in open position through bores **21** shown on section A-A in FIG. **3**B, further through bores **22** in section B-B in FIG. **3**C to a valve plug **23** that is shown in closed position in section C-C in FIG. **3**D against the hammer piston **20** and drives the piston to abutment against the bottom portion **24** of the drill bit. Section D-D in FIG. **3**E shows a longitudinally extending spline portion **25** in the drill bit **11** and the lowermost part of the hammer housing **10** that transfer the torque at the same time as the drill bit **11** can move axially within accepted clearances determined by a locking ring mechanism **26**. This because by blows of the hammer piston **20** against the drill bit **11**, it is only the mass or weight of this that is displaced in concert with penetration of the hard metal lugs **17** into the rock. This is to obtain that as much as possible of the percussion energy shall be transferred to the crushing of the rock and as little as possible to be lost to mass displacement of the relatively light drill bit **11**.

The detailed section in FIG. **3**F showing the inlet valve **18** in closed position is taken from H in FIG. **3**A. When the hammer function is to be initiated, the pumping operation of the drill fluid in the inlet **12** is commenced. A side, or branch off, bore **27** through the wall of the valve house **8** has hydraulic communication with a pilot bore **28** in the mounting plate **29** of the inlet valve **18**. The mounting plate **29** is stationary in the valve house **8** and contains a pilot valve **30** that is retained in open position by a spring **31**. The drill fluid flows freely to a first pilot chamber above a first pilot piston **32**, the diameter and area of which are larger than the area of the inlet **12**. During pressure buildup, a limited moveable valve plug **33** will be forced to closure against a valve seat **34** in the housing **8**. Under pressure buildup against closed inlet valve **18**, an annulus **35** between the housing **10** and the hammer piston **20** is pressurized through the side bore **27**, which via longitudinally extending bores **36** in the valve housing **9** feed an inlet **37**, see detailed view F.

The detailed sections in FIG. **3**H and FIG. **3**I are taken from F and G in FIG. **3**A and show the abutment of the hammer piston **20** against the inner wall of the hammer housings **9**, **10**. The diameter of a piston **38** is somewhat larger than the diameter of a second piston **39**. By the use of the hammer drill to drill vertically downwards, the hammer piston **20** will in unpressurized condition, due to the gravity, obviously creep towards the strike or impact surface **24** in the drill bit **11**. In this condition there will be clearance between the valve plug **23** and its seat **40** (see detailed view F) in the hammer piston **20**. Accordingly the drill fluid will flow freely through the valve at the plug **23**, through a bore **41** in the hammer piston **20** and the bores **16** (see FIG. **2**A), and therefore too little pressure buildup takes place to start the hammer.

The arrangement shown in detailed section in FIG. **3**F, having closed inlet valve **18** and pressure buildup in the annulus **35**, elevates the hammer piston **20** to seal against the valve plug **23**. Due to the required clearance between the surface of the piston **38** and the inner wall of the housing **9**, drilling fluid leaks out in the space above the valve plug **23** through lubrication channels **42** and a bore **43** such as an arrow shows in detailed view F. In order to prevent that this leakage volume shall provide pressure buildup in the space above the valve plug **23**, this is drained through a bore **44** in the valve mounting plate **29** and an opening **45** that the pilot valve **30** in this position allows, and further out through the drain hole **15**. When the pressure has increased to over 90% of the working pressure the hammer is designed for, the piston force in a second pilot chamber **46** exceeds the closing force of the spring **31** and the pilot valve **30** shifts position such as illustrated in FIG. **3**G.

The first pilot chamber above the pilot piston **32** is drained and the inlet valve **18** opens up. At the same time the opening **45** is closed such that drainage through the bore **44** is shut off so that pressure is not lost through this bore in operating mode. The pressure in the chamber above the hammer piston **20** and the closed valve plug **23** results in start of the working cycle with instant full effect. The arrangement with a backup valve **47** and a nozzle **48** is provided to obtain a reduced drainage time of the second pilot chamber **46** for thereby achieve relatively slow closure of the inlet valve **18**. This to obtain that the inlet valve **18** remains fully open and is not to make disturbances during a working mode since the pressure then fluctuates with the percussion frequency.

FIG. **4**A shows the hammer drill at the end of an accelerating phase. The hammer piston **20** has at this moment arrived at max velocity, typically about 6 m/s. This is a result of available pressure, as an example here just below 8 MPa, the hydraulic area of the hammer piston, here for example with a diameter of 130 mm, and the weight of the hammer piston, here for example 49 kg. The valve plug **23** is kept closed against the seat opening of the hammer piston since the hydraulic area of the valve plug **23**, here for example with a diameter of 95 mm, is a bit larger, about 4%, than the annular area of the hammer piston shown in section B-B in FIG. **4**C as **23** and **24** respectively. At this moment the hammer piston has covered about 75% of its full stroke, about 9 mm. The clearance between the hammer piston **20** and the strike surface **24** of the drill bit is about 3 mm, shown in enlarged detailed view C in FIG. **4**E.

A moveable valve stem **49** having a stop plate **50** now lands on the abutment surface of a stationary valve stem sleeve **51** in the housing **9** and stops the valve stem **49** from further motion, as shown in enlarged detailed view A in FIG. **4**D, after which the valve plug **23** is separated from the seat **40** in the hammer piston **20** and thereby being opened. The moveable valve assembly **23**, **49**, **50** is shown in elevational view in FIG. **4**B.

The kinetic energy of the valve plugs **23** momentum will by the abrupt stop thereof marginally elongate the relatively long and slender valve stem **49**, and thereby transform to a relatively large spring force that very quick accelerates the valve in return. The marginal elongation of the valve stem **49**, here as an example calculated to be about 0.8 mm, needs to be lower than the utilization rate of the material, which material in this case is high tensile spring steel. The mass of the valve plug **23** should be as small as possible, here as an example made of aluminum, combined with the length, the diameter and the properties of the material of the valve stem **49**, determines the natural frequency of the valve assembly.

For practical usages, this should be minimum 8-10 times the frequency it is to be used for. The natural frequency is determined by the formulas:

$$fn = \frac{1}{2\pi}\sqrt{\frac{k}{M}} \text{ where } k = \frac{F}{\sigma}$$

The mass and the spring constant have most significance. The natural frequency for the shown construction is about 1100-1200 Hz and therefore usable for a working frequency over 100 Hz.

The shown construction has in this example a recoil velocity that is 93% of the impact or strike velocity.

FIG. **5**A shows the position and the moment for when the hammer piston **20** strikes against the strike or abutment surface **24** within the drill bit **11**. The valve plug **23** including the stem **49** and the stop plate **50** are in full return speed, see detailed view A in FIG. **5**B, such that relatively fast a large opening between the valve plug **23** and the valve seat **40** on the hammer piston **20** is created, such that drilling fluid now flows by relatively small resistance through the longitudinal bore **41** in the hammer piston **20**, see detailed view B in FIG. **5**C.

The kinetic energy of the hammer pistons **20** momentum is partly transformed into a spring force in the hammer piston **20**, since the piston is somewhat compressed during the impact. When the energy wave from the impact has migrated through the hammer piston **20** to the opposite end and back, the hammer piston **20** accelerates in return. The return velocity here at the start is calculated to be about 3.2 m/s, about 53% of the strike or impact velocity, this because a portion of the energy has been used for mass displacement of the drill bit **11**, while the rest has been used to depress the indenters into the rock.

FIG. **6**A shows that moment when the hammer piston **20** is in its full return speed. The valve plug **23** has at this point of time almost returned to the end stop where the detailed view A in FIG. **6**C shows the stem **49** including the stop plate **50** entering an opening **52** in the top of the valve stem sleeve **51**.

The detailed view D in FIG. **6**C' shows how the radial portion of the stop plate **50** seals, with relatively narrow radial clearance, against the internal side of the opening **52**. A small negative pressure is created in the chamber underneath the stop plate **50** when the stop plate **50** moves the last 2 mm until stop. An annular backup valve **58** opens and replenishes liquid through the bore **59**. The confined or trapped volume under the stop plate **50** prevents that the valve plug **23** performs a recoil motion and remains in position until next cycle starts.

The backup valve **58** of the type “annular backup valve”, which in this embodiment is an annular leaf spring, is chosen since this has little mass and relatively large spring force and accordingly is able to work with high frequency.

The detailed view B in FIG. **6**E shows the relatively large opening between the valve plug **23** and the valve seat **40** in the hammer piston **20**, in order that the flow of drilling fluid there through takes place with a minimum of resistance. The underside of the valve stem sleeve **51** is formed as an annular cylinder pit **53** shown in detailed view C in FIG. **6**D. The top of the valve plug **23** is formed as an annular piston **54**, which by relatively narrow clearances fits into the annular cylinder pit **53**. The confined fluid volume is, as the valve returns all the way to the end stop, evacuated in a controlled way through the radial clearances between the annular piston **54** and the annular cylinder **53** plus an evacuation hole **55**. This controlled evacuation acts as a dampening force and stops the return of the valve in such a way that the valve does not perform recoil motions. The same type of dampening arrangement is present on the hammer piston **20**. On the detailed view B is an annular piston **56** shown on top of the hammer piston **20**, in addition to an annular cylinder groove **57** in the lower part of the valve housing **9**.

FIG. **7**A shows the last part of the return of the hammer piston **20**. The termination of the return stroke is dampened in a controlled way until full stop at the same time as the valve seat **40** meets the valve plug **23**, shown in detailed view A in FIG. **7**C. The detailed view B in FIG. **7**B illustrates how the confined or trapped fluid volume within the annular cylinder pit **57** is displaced through the radial clearances between the annular piston **56** and a drain hole **60**.

The gap between the valve seat **40** and the valve plug **23** needs not to be closed completely in order that the pressure to build up and a new cycle starts.

Calculations show that with an opening of 0.5 mm the pressure drop is approximately the same as the working pressure. This results in that the surface pressure on the contact surface between the valve plug **23** and the seat **40** becomes small and the components can experience long life time.

FIG. **8** shows curves that illustrate the working cycle of the hammer piston **20** and the valve. Curve A shows the velocity course and curve B the position course through a working cycle. For both curves the horizontal axis is the time axis, divided into micro seconds.

The vertical axis for curve A shows the velocity in m/s, stroke direction against the drill bit **11** as + upwards and − downwards, here the return velocity.

The vertical axis for the curve B shows distance in mm from the start position. The curve section **61** shows the acceleration phase, where the point **62** is the moment when the valve is stopped and the return thereof is initiated. The point **63** is the impact of the hammer piston **20** against the drill bit **11**.

The curve section **64** is the displacement of the drill bit **11** by progress into the rock, **65** is the acceleration of the recoil, **66** is the return velocity without dampening and **67** is the return velocity with dampening. The curve section **68** is the recoil acceleration for the valve, **69** is the return velocity for the valve without dampening and **70** is the slow down dampening phase for the return of the valve.

FIG. **9**A shows a curve **71** that illustrates the abrupt closing characteristics for the valve with regard to the pressure drop and opening between the valve plug **23** and the seat **40** in the hammer piston. This situation is shown in FIG. **9**B. The horizontal axis is the opening gap in mm and the vertical axis the designed pressure drop in bar at nominal rate of pumped drilling fluid, which, as an example here, is 12.5 l/sec. As shown, the closing gap needs to get under 1.5 mm before a substantial pressure resistance is received.

The invention claimed is:

1. A fluid pressure driven high frequency percussion hammer for drilling in hard formations, the percussion hammer comprising:

- a housing which in one end thereof is provided with a drill bit designed to act directly on the hard formation;
- a hammer piston moveably received in said housing and that acts on the drill bit, the hammer piston having formed therein a longitudinally extending bore having a predetermined flow capacity, the longitudinally extending bore being closeable in an upstream direction by a valve plug that partly follows the hammer piston during its stroke;
- a valve stem operatively coupled to the valve plug and slideably received in a valve stem sleeve, said valve stem comprising:
  - a stop plate disposed at an upstream end of the valve stem, the stop plate engaging the valve stem sleeve to: 1) stop the valve plug at a predetermined per-

centage of a full stroke length of the hammer piston thereby opening the bore; and 2) elastically strain the valve stem such that said elastically strained valve stem is recoiled back to an uppermost position of the valve stem in the valve stem sleeve by non-helical tension spring properties of the valve stem; and

wherein said hammer piston is mechanically compressed when striking the drill bit so that said mechanically compressed hammer piston is recoiled back towards the uppermost position of the hammer piston in the housing due to pressure tension properties of the hammer piston.

2. The percussion hammer according to claim **1**, wherein the stop plate is adapted to cooperate with an internal stop surface in the valve stem sleeve.

3. The percussion hammer according to claim **1**, wherein the predetermined percentage of the full stroke length of the hammer piston is in an order of magnitude 75%.

4. The percussion hammer according to claim **1**, wherein said valve stem being long and slender.

5. The percussion hammer according to claim **1**, comprising an inlet valve assembly, which inlet valve assembly does not open for operation of the hammer piston until the pressure is built up to approximately 95% of full working pressure, said inlet valve assembly being adapted to close off a main barrel, and that a side barrel within the hammer housing pressurizes an annulus between the hammer piston and the housing elevating the hammer piston to seal against the valve plug.

6. The percussion hammer according to claim **5**, wherein the hammer piston and the inlet valve assembly return by recoil, where both the hammer piston and the inlet valve assembly are provided with hydraulic dampening controlling retardation of a return stroke until stop.

7. The percussion hammer according to claim **6**, wherein the hydraulic dampening takes place by an annular piston, which annular piston is forced into a corresponding annular cylinder having controllable clearances, and thus restricts or chokes evacuation of trapped fluid.

8. The percussion hammer according to claim **1**, wherein an opening is arranged in a top of the valve stem sleeve, into which opening a stop plate of the valve stem is able to enter, radial portions of the stop plate seals against an internal side of the opening with relatively narrow radial clearance.

9. The percussion hammer according to claim **8**, wherein an annular backup valve is arranged in a ring groove underneath the opening, wherein the backup valve is able to open and replenish fluid through bores in the valve stem sleeve.

10. The percussion hammer according to claim **1**, wherein the percussion hammer housing is divided into an inlet valve housing, a valve housing and a hammer housing.

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