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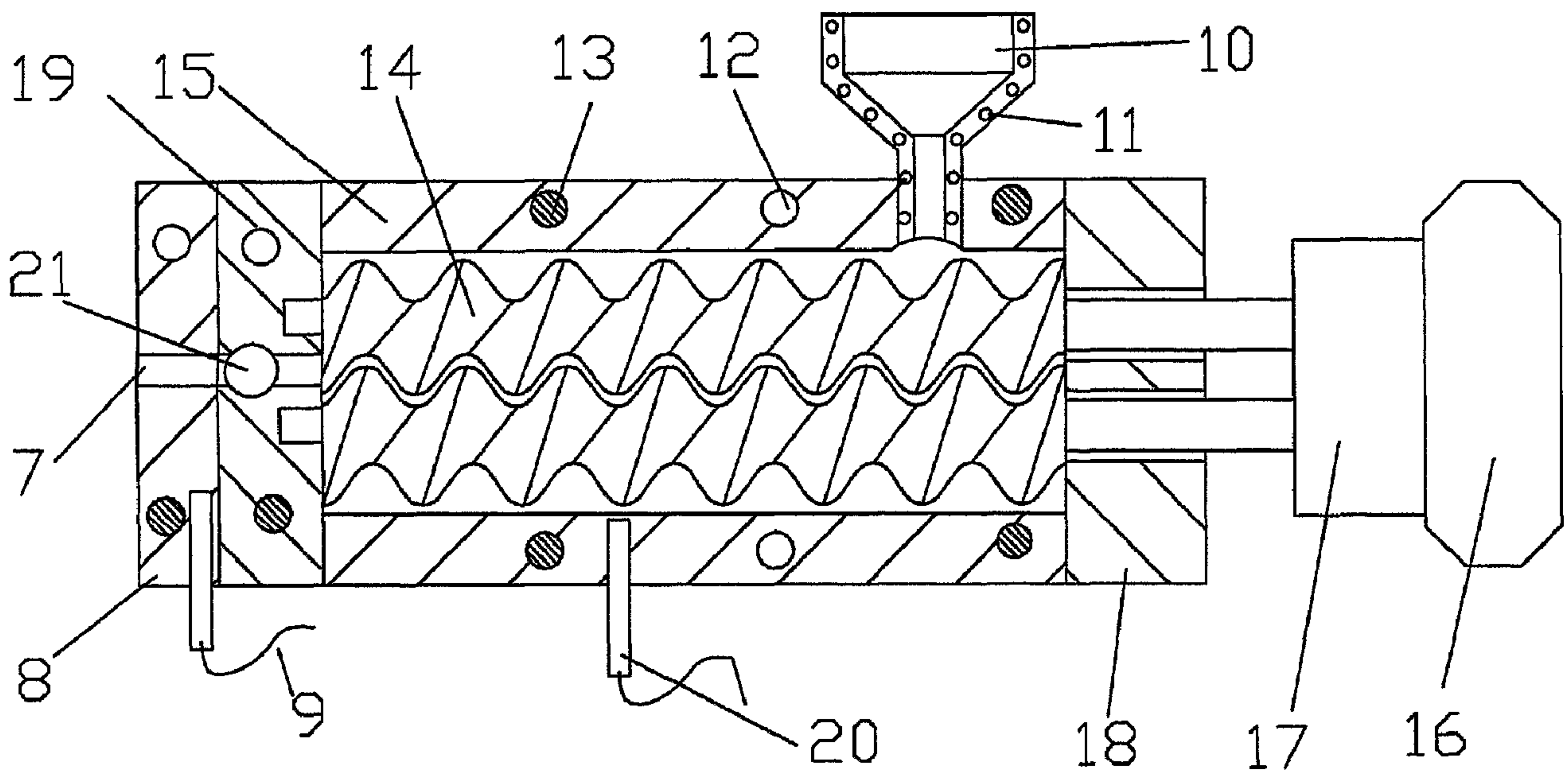
(54) Titre : PROCEDE ET APPAREIL DE PRODUCTION DE PIECES COULEES D'ALLIAGE
(54) Title: METHOD AND APPARATUS FOR MAKING METAL ALLOY CASTINGS



(57) **Abrégé/Abstract:**
A method and apparatus are provided for fabricating of continuous castings with fine and uniform microstructure, which can be used as feedstock for secondary processing routes, such as thixoforming, forging and machining or direct application in industry. An overheated liquid alloy is fed into a high shear device (for example, a twin-screw extruder) and sheared intensively to produce a sheared liquid alloy or a semisolid slurry, wherein the sheared liquid alloy is at a temperature close to its liquidus and the semisolid slurry is then transferred to a shaping device for production of continuous castings with fine and uniform microstructures through a solidification process. The shaping device is any device capable of forming continuous (i.e. infinite length) products, such as a direct chill (DC) caster (2) (DC rheocasting) for production of continuous billets, an extrusion die (8) (rheo-extrusion) for production of continuous bars or wires, or a twin-roll caster (twin-roll rheocasting) for producing of continuous strips. In all those cases, the cross-section of the continuous castings exhibits a microstructure in which a controlled volume fraction of fine and spherical primary particles are uniformly distributed in a fine structured matrix.

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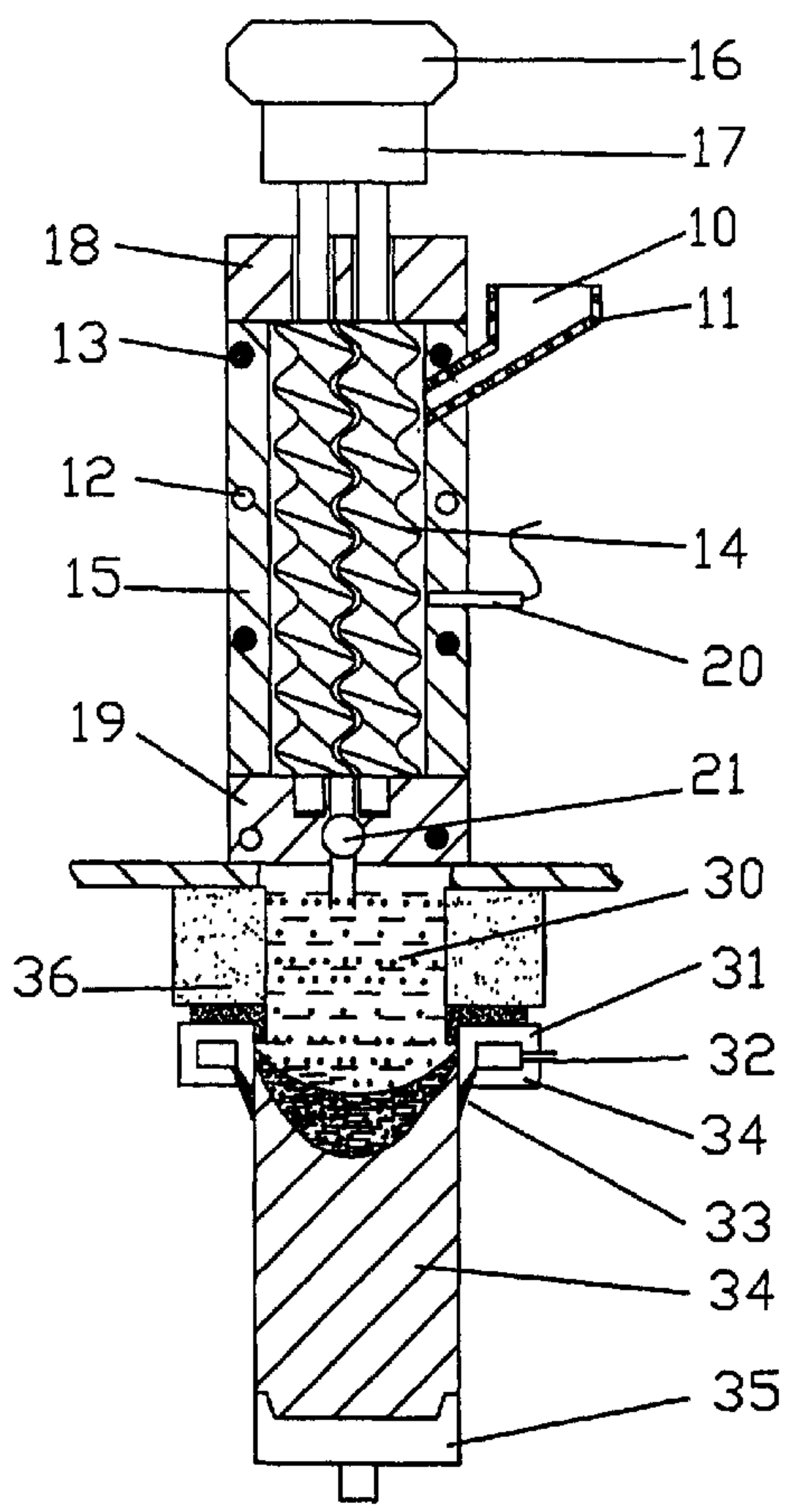
(54) Title: METHOD AND APPARATUS FOR MAKING METAL ALLOY CASTINGS



(57) Abstract: A method and apparatus are provided for fabricating of continuous castings with fine and uniform microstructure, which can be used as feedstock for secondary processing routes, such as thixoforming, forging and machining or direct application in industry. An overheated liquid alloy is fed into a high shear device (for example, a twin-screw extruder) and sheared intensively to produce a sheared liquid alloy or a semisolid slurry, wherein the sheared liquid alloy is at a temperature close to its liquidus and the semisolid slurry is then transferred to a shaping device for production of continuous castings with fine and uniform microstructures through a solidification process. The shaping device is any device capable of forming continuous (i.e. infinite length) products, such as a direct chill (DC) caster (2) (DC rheocasting) for production of continuous billets, an extrusion die (8) (rheo-extrusion) for production of continuous bars or wires, or a twin-roll caster (twin-roll rheocasting) for producing of continuous strips. In all those cases, the cross-section of the continuous castings exhibits a microstructure in which a controlled volume fraction of fine and spherical primary particles are uniformly distributed in a fine structured matrix.

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Method and apparatus for making metal alloy castings

The present application relates to a method and apparatus for forming a continuous product from a liquid metal alloy, and in particular for making continuous castings with fine and uniform microstructures, which may be used as feedstock for secondary processing methods, such as thixoforming, forging and machining. The application also relates to articles formed from these methods, such as billets, bars, wires, tubes or strips.

In the metal forming industry, a continuous billet is usually produced by direct chill (DC) casting process. In this process, an over-heated liquid alloy is fed continuously into a water-cooled cylindrical mould and the solidified alloy is withdrawn continuously to produce a continuous billet. The resulting cross-section of the billet exhibits three characteristic zones: the chilled zone at the surface, the columnar zone and the coarse equiaxed zone at the centre. Such microstructural non-uniformity has limited the direct application of the DC cast billets.

Extensive secondary processing methods, such as rolling, extrusion and recrystallisation, are usually used to achieve microstructural refinement and uniformity. Such secondary processing routes are energy-intensive, time-consuming and costly. Therefore, it is desirable to develop a continuous casting process, which can produce directly continuous billet with a fine and uniform microstructure without involving those secondary processing routes.

One known process uses DC cast billets as feedstock materials is an extrusion process to produce bars with either simple or complex cross-sections. Extrusion of metals can be classified into two categories: cold extrusion and hot extrusion. In cold extrusion, the cold metal is forced into an open die near room temperature. During the cold extrusion of metals, considerable pressure is necessary to force the metal through the die block, resulting a high cost of capital equipment, a reduced die life and a low energy-efficiency. In hot extrusion, an alloy billet is heated below its solidus and extruded thereby like a cold extrusion process. In hot extrusion, the die life is improved but the efficiency of the energy is still limited.

Meanwhile the accurate extrusion such as fine wire is difficult with such a hot extrusion process. It would be advantageous therefore to develop an extrusion process which can directly produce bars and wires from liquid alloys.

Another process which uses DC cast billets as feedstock materials is the rolling process to produce strip product by successive rolling of a continuously cast billet to the required thickness. Compared with the extrusion process, the rolling process is even more cost intensive because of the high-energy consumption, high capital equipment cost and low material yield.

An alternative technology for strip production is twin-roll casting process, which is effective to a limited extent on a variety of metals. In a twin-roll casting process, a pair of rolls having horizontal axes and rotating in opposite directions are disposed parallel to each other with an appropriate gap therebetween, a pool of liquid alloy is formed on the upper circumferential surfaces of the rolls above the gap and the liquid alloy is continuously cast into an alloy strip.

The problems associated with the conventional twin-roll casting process include the leakage of liquid alloy in the vicinity of the side dams, the damages of the side dams, crack formation at the sides of the cast strip, the short life of rolls, the difficulties in process control and chemical segregation in the solidified products.

Yet another process which uses DC cast billets as feedstock materials is the recently developed thixoforming process. This is basically a two-step process. In the first step, a thixotropic feedstock is produced by a modified DC casting process for creation of a cast billet with a non-dendritc microstructure. In the second step, a thixotropic billet/feedstock is reheated to its semisolid state (at a temperature between its liquidus and solidus) and then shaped into a cavity by either casting (thixocasting) or forging (thixoforging).

Ideally, a feedstock material for thixoforming should contain a controlled volume fraction of fine and spherical solid particles in a matrix. Thixoforming is currently limited by the low quality and high cost of the feedstock materials. Processes for thixotropic feedstock production include simple mechanical stirring, electromagnetic stirring, coarsening an initial dendritic microstructure, addition of excessive grain refiner during continuous casting and application of ultrasonic vibration. However, these processes have considerable disadvantages. One important disadvantage of the known methods is that the microstructure on the cross-section is not uniform, giving rise to difficulties during reheating process and relatively poor mechanical properties of the final components. The other disadvantage is caused by the non-spherical particle morphology, which requires long reheating time to spheroidise the solid particles, compromising the potential benefits offered by semi-solid processing. A further disadvantage is the high cost for the feedstock materials, which currently accounts for up to 50% of the final component cost.

A number of references disclose thixomoulding processes, in which a solid or semisolid feed is first processed (for example by heating the feed to liquefy it whilst subjecting it to shear) and then injected into a mould to form a component. Examples of such references include: EP 0867246 A1 (Mazda Motor Corporation); WO 90/09251 (The Dow Chemical Company); US 5,711,366 (Thixomat, Inc.); US 5,735,333 (The Japan Steel Works, Limited); US 5,685,357 (The Japan Steel Works, Limited); US 4,694,882 (The Dow Chemical Company); and CA 2,164,759 (Inventronics Limited).

The disadvantage however with heating solid granules in order to convert them into the thixotropic state (thixomoulding) rather than cooling liquid metal into the thixotropic state (rheomoulding) is that it is very difficult to control particle size and particle size distribution in the sub-structure of the thixotropic slurry. Specifically, particle sizes of thixomoulded slurries tend to be an order of magnitude larger than those of rheomoulded slurries, and to have a wider sized distribution. This has negative implications for the structural properties of the casted components.

Furthermore, the above-mentioned references employ a standard single screw extruder for subjecting the thixotropic slurry to shear. The result is a component of low quality.

A number of references do disclose rheomoulding processes. For example, WO 97/21509 (Thixomat, Inc.) relates to a process for forming metal compositions in which an alloy is heated to a temperature above its liquidus, and then employing a single screw extruder to shear the liquid metal as it is cooled into the region of two phase equilibrium.

US 4,694,881 (The Dow Chemical Company) relates to a process in which a material having a non-thixotropic-type structure is fed in solid form into a single screw extruder. The material is heated to a temperature above its liquidus, and then cooled to a temperature lower than its liquidus and greater than its solidus whilst being subjected to a shearing action.

WO 95/34393 (Cornell Research Foundation, Inc.) also discloses a rheomoulding process in which super-heated liquid metal is cooled into a semisolid state in the barrel of a single screw extruder, where it is subjected to shear whilst being cooled, prior to being injection moulded into a cast.

WO 01/21343 (Brunel University) is a co-pending application published after the priority date of the present invention. It discloses a method of forming a shaped component from a liquid metal alloy by cooling the alloy below its liquidus whilst applying shear in order to convert the alloy into its thixotropic state. The alloy is then transferred into a discrete mould to form a shaped component. There is no disclosure of the formation of a continuous product.

WO 01/23124 (Brunel University) is another co-pending application published after the priority date of the present invention. It relates specifically to a method of producing a casting from a metal alloy having at least two immiscible components, wherein the components are subjected to shear and converted into a semi-solid slurry. The slurry can then be transferred to a mould or a pre-heated metal band.

None of the thixomoulding or rheomoulding references describe a process which enables continuous products of a sufficiently high structural integrity to be formed.

According to a first aspect of the present invention, there is provided a method for forming a continuous product from a liquid metal alloy, comprising the steps of cooling the alloy to about the liquidus or from the solidus to the liquidus of the alloy, applying shear to the alloy at a sufficiently high shear rate and intensity of turbulence to convert the alloy into its thixotropic state, and transferring the sheared liquid alloy or sheared semisolid slurry into a shaping device in order to form a solid product, wherein the shaping device is capable of forming a continuous product.

By "continuous product" is meant a product which is formed continuously, so that a product of any length can be formed, provided that sufficient feedstock is provided. This is in contrast to a discrete product, such as is formed in a mould.

The shaping device can be a DC caster (DC rheocasting), or an extrusion die (rheo-extrusion), or a twin-roll caster (twin-roll rheocasting). The materials can be processed according to the present invention can be either miscible or immiscible alloys. In the case of immiscible alloy, the process is referred as rheomixing process.

It has been discovered that most of the disadvantages of the prior art the thixoforming, conventional DC casting, twin-roll casting and extrusion processes can be overcome if the feeding liquid alloy has lower temperature and higher viscosity, which can be achieved by shearing liquid alloy at a temperature close to its liquidus or between its liquidus and soliduss. The higher viscosity of the intensively sheared liquid alloy or semisolid slurry can shorten the solidification time, prevent the leakage in twin roll casting, reduce the chemical segregation during solidification in continuous casting and extrusion and increase the production rate. The lower pouring/feeding temperature can also improve die life, energy efficiency and product quality.

In a second aspect of the present invention, there is provided a method for forming a continuous product from a liquid metal alloy, comprising the steps of cooling the alloy to about the liquidus or from the solidus to the liquidus of the alloy, applying shear to the alloy at a sufficiently high shear rate and intensity of turbulence to convert the alloy into its thixotropic state, and transferring the sheared liquid alloy or sheared semisolid slurry into a shaping device in order to form a solid product, wherein the shaping device is capable of forming a continuous product, and wherein the alloy is formed from miscible components.

According to a third aspect of the present invention, there is provided a method for forming a continuous product from a liquid metal alloy, comprising the steps of cooling the alloy to about its liquidus, applying shear to the alloy at a sufficiently high shear rate and intensity of turbulence to convert the alloy into its thixotropic state, and transferring the sheared liquid alloy into a shaping device in order to form a solid product. Preferably, the shaping device is capable of forming a continuous product. The alloy may be formed from either miscible or immiscible components.

In a further aspect of the present invention, there is provided a method for forming a continuous product from a liquid metal alloy having immiscible components, comprising the steps of cooling the alloy to a temperature below its immiscibility gap, applying shear to the alloy at a sufficiently high shear rate and intensity of turbulence to convert the alloy into its thixotropic state, and transferring the sheared liquid alloy or sheared semisolid slurry into a shaping device in order to form a solid product, wherein the shaping device is capable of forming a continuous product but wherein the shaping device is not a pre-heated metal band.

Generally, the shearing device is a high shear extruder, comprising the steps of receiving the liquid alloy into a temperature-controlled barrel, operating the screw, positioned in barrel, at a sufficiently high shear rate to convert the liquid alloy into its intensively sheared state and/or thixotropic state. The profile of the screw should be specially designed to provide high shear rate and high intensity of turbulence and to achieve positive pumping action during the transfer of the liquid alloy from one end to another end of the barrel. The extruder can be any kinds of extruder which at least has one screw positioned in the barrel.

Preferably, the extruder is a twin-screw extruder having at least two screws which are at least partially intermeshed, and more preferably are substantially fully intermeshed.

The shaping device can be different kinds of dies or moulds with accompanying accessories depending on the requirement of the final product to be produced. (a) In the DC rheocasting process, the die/mould can be a simple cylinder with an optional start-up base, in which the cylinder can have a cooling system. The solidified alloy is continuously extracted out of the die/mould via the start-up base, whereby a casting is formed continuously. (b) In the twin-roll rheocasting process, the die/mould comprises a pair of rotating rolls and a pair of side dams disposed on both axial ends of the rolls so that a pool of sheared liquid alloy or semisolid slurry is defined by both the rolls and the side dams, the rolls rotate in counter-directions so that the sheared liquid alloy or semisolid slurry is subsequently solidified to form solidification shells which are then pressure-bonded to each other as they pass through the gap defined between the rolls, thus forming a continuous strip. (c) In the rheo-extrusion process, the die/mould can be a simple open hole attached on the end of the extruder. The positive pumping action provided by the extruder will force the sheared liquid alloy or semisolid slurry through the pre-heated open die to form rods or thin wires or any other suitable sectional shapes.

The mould may be heated to or maintained at a predetermined temperature when the sheared liquid alloy or semisolid slurry is transferred into it. There may be a predetermined relationship between the mould temperature and the metal shearing temperature, which is established by the requirements of the individual art.

The continuous casting method and apparatus of the present invention preferably employs an the extruder having an inlet toward one end and having an outlet at another end, a temperature-controllable barrel communicating said inlet with said outlet and at least one screw located within the said barrel.

The said screw in the said extruder preferably includes a body having at least one vane thereon, the said vane at least partially defining a helix around said body to propel the metal through said barrel, wherein said screw can be rotated to shear said liquid alloy at a rate sufficient to inhibit complete formation of dendritic structures therein while said metal is in a semisolid state, rotation of the said screw further causing said metal to be transported from the said inlet to the said outlet through the said barrel.

In one embodiment, temperature controllable means are employed for adjusting the temperature of the extruder barrel, the screw and the alloy, such that the alloy is maintained either at a temperature near its liquidus or at a temperature between its liquidus and solidus. The extruder outlet may have a controllable valve for transferring the allow from the extruder to the shaping device. The amount of liquid alloy or semisolid slurry transferred from the extruder to the shaping device can be controlled by said valve in order to maintain the consistency of the semisolid slurry in the shaping device.

In a preferred embodiment, an extrusion die is directly attached to the extruder for production of continuous rods with various cross-sections. This process is called rheo-extrusion.

Alternatively, a single screw extruder may be employed in addition to the high shear device, wherein the sheared liquid alloy or semisolid slurry discharged from the said high shear device can be extruded via the continuous rotation of the screw in said single screw extruder for production of continuous castings like rods or fine wires or billets.

The continuous products formed by the method of the present invention may be further deformed by a conventional extrusion process.

Generally, the materials which can be processed according to this invention can be any metallic alloys, such as alloys based on Al, Mg, Zn, Cu, Fe and so on. An important group of materials, which can be processed according to this invention, are those with a liquid immiscibility gap, for instance, those alloys based on Al-Pb, Al-Bi, Al-In and Cu-Pb.

An important advantage of the method according to this invention is the resulting fine and uniform microstructure throughout the cross-section of the billet, wherein a controlled volume fraction of fine and spherical particles are uniformly distributed in a matrix. Consequently, the billet produced has a high degree of thixotropy and particularly suitable as feedstock for thixoforming.

A further advantage of the process of the present invention resides in the fact that no secondary processing procedures, such as extrusion and recrystallisation, are required for microstructural control, since the billets produced already have a fine and uniform microstructure. Therefore, they can be used directly for solid state processing, such as machining, forging and so on.

The cylinder type mould/die for the DC rheocasting may be made from any kind of material, but preferably the mould is made of graphite or cooper-based alloy. A cooling system may be attached to the cylinder type die/mould, by which the sheared liquid alloy or semisolid slurry can be solidified at a proper cooling rate. A start-up base may be used at the initial stage of casting.

The rotating rolls in the twin-roll caster can have any kinds of profiles which are capable of providing a narrowest gap during turning. Preferably, the profile of the rolls is flat.

The extrusion die in the rheo-extrusion process can be any kinds of sectional shapes, including either simple shapes like round, triangle, square, rectangle or complex shapes like polygon or any other suitable shapes. The sectional size can be varied in a large scale, which means that the products can be a fine wire or a large rod.

The said method may employ sheared liquid alloy at a temperature close to its liquidus or semisolid slurry with fine and uniform microstructures with different solid volume fractions (0% to 750%) via shearing liquid alloy at temperatures between its liquidus and solidus. When shearing is carried out at a temperature near its liquidus, a fine and uniform microstructure is produced in the finally solidified product due to the enhanced effective nucleation rate in the intensively sheared liquid alloy with a uniform temperature and chemical composition. When shearing is carried out at a temperature between liquidus and solidus, semisolid slurry with fine and spherical particles can be produced under intensive shearing. Such a slurry can be directly used for forming a component or for shaping into billet as a feedstock for thixoforming process. The said apparatus and method can also offer metallic component with the improved mechanical properties due to the effective modification of microstructures, especially for alloys close to eutectic composition.

The said apparatus and method preferably comprises the steps of:

- providing liquid alloy in the liquid state and feeding said liquid alloy to a temperature-controlled extruder through an inlet, located toward one end of the said extruder;
- shearing the said liquid alloy by a sufficiently high shear rate offered by the extruder with at least one screw to form a sheared liquid alloy or semisolid slurry;
- transferring said sheared liquid alloy or semisolid slurry from the said extruder into a shaping device, which can be either a cylinder type mould for DC rheocasting, or a twin-

roll nip for twin-roll rheocasting or a open die for rheo-extrusion by opening a control valve located at one end of the said extruder; and

- solidifying the sheared liquid alloy or semisolid slurry in the shaping device to produce continuous castings with various cross-sections. The said shaping device can be a DC caster, or an extrusion die or a twin-roll caster.

Generally, the extruder, consisting of a barrel, one or more screws and a driving system, is adopted to receive liquid alloy through an inlet located generally toward one end of the extruder. Once in the passageway of the extruder, liquid alloy is either cooled down or maintained at a predetermined temperature. In either situation, the processing temperature is either at a temperature near liquidus or at a temperature between its solidus and liquidus.

The processing temperature, which depends upon the liquidus and solidus of the alloy, will vary from alloy to alloy. The appropriate temperature is apparent to one skilled in the art.

Also in the extruder, the liquid alloy is subjected to shearing. The shear rate is such that it is sufficient to achieve spherical particles and a fine and uniform microstructure in the final product. The shearing action is induced by the screw(s) located within the barrel and is further invigorated by helical screw flights formed on the body of the screws. Enhanced shearing is generated in the annular space between the barrel and the screw flights and between the flights of the screws. The positive displacement in extruder can result in the sheared liquid alloy or semisolid slurry to travel from the inlet of the extruder toward the outlet of the extruder, where it is discharged.

In the twin-roll rheocasting process, a nip, consisting of a pair of rolls, a pair of side dams and a driving system, is preferably adopted to receive sheared liquid alloy or semisolid slurry through a pool located above and formed by inner surface of the two side dams and the upward surface of two rolls. Once in the pool of twin-roll caster, the sheared liquid alloy or semisolid slurry is cooled to form a shell on the surface of the rolls. The temperature of the rolls varies from alloy to alloy. The appropriate temperature will be apparent to one skilled in the art, but usually it should be lower than the solidus of the alloy. Also in the twin-roll casting process, the sheared liquid alloy or semisolid slurry is subjected to actions of solidification, deformation, bonding of the solidified shell and continuous extraction of the solid strip. The extraction speed is such that it is sufficient to keep the continuity of the process. The deformation and bonding are such that it is sufficient to keep the effective bonding in the sheet section.

In the case of the rheo-extrusion process, the pressure needed for extrusion of the sheared liquid alloy or semisolid slurry may be controlled by the temperature and shear rate for a given composition. The variation of the temperature between extruder barrel and the open die can drastically reduce the outer friction between the sheared liquid alloy or semisolid slurry and the open die during extrusion. The balance of the outer friction, the viscosity of the sheared liquid alloy or semisolid slurry and the positive pumping pressure of the extruder determine the extrusion speed through the open die. Extrusion dies with different sectional shapes can be used to continuous castings with different cross-sectional shapes.

When undertaking rheomixing, either a homogeneous liquid alloy at a temperature above its miscibility gap or a preliminarily mixed liquid mixture at a temperature within the miscibility gap can be fed into the extruder for intensive mixing to create a fine and uniform liquid mixture. Inside the extruder, the liquid alloy experiences both cooling and intensive shearing. The extruder can be operated at temperatures either above or below the monotectic temperature. The shaping device can be either an extrusion die, or a twin-roll caster.

A number of preferred embodiments of the invention are described in detail below with reference to the drawings, in which:

Fig. 1 is a schematic illustration of an embodiment of an apparatus for converting liquid alloy into an intensively sheared liquid alloy or semisolid slurry according to the principles of the present invention;

Fig. 2 is a schematic illustration of an embodiment of an apparatus for converting liquid alloy into an intensively sheared liquid alloy or semisolid slurry and subsequently producing metal billet with a DC-rheocasting process according to the principles of the present invention;

Fig. 3 is a schematic illustration of an alternative embodiment of an apparatus for converting liquid alloy into an intensively sheared liquid alloy or semisolid slurry and subsequently producing metal rod/wire with a rheo-extrusion process using an extrusion die according to the principles of the present invention;

Fig. 4 is a schematic illustration of an alternative embodiment of an apparatus of extrusion die for a rheo-extrusion process.

Fig. 5 is a schematic illustration of an alternative embodiment of an apparatus for converting liquid alloy into an intensively sheared liquid alloy or semisolid slurry and subsequently producing metal rod/wire with a rheo-extrusion process using a single screw extruder according to the principles of the present invention;

Fig. 6 is a schematic illustration of an embodiment of an apparatus for converting liquid alloy into an intensively sheared liquid alloy or semisolid slurry and subsequently producing metal strip with a twin-roll rheocasting process according to the principles of the present invention.

In the description of the preferred embodiment, which follows, the casting is produced by an extruder and a shaping device from an AZ91D liquid alloy. The invention is not limited to

AZ91D magnesium alloy and is equally applicable to any other types of metals including aluminium alloys, magnesium alloys, zinc alloys, copper alloys, ferrous alloys and any other alloys possibly suitable for shearing-induced metal processing and/or semisolid metal processing. Furthermore, specific temperature and temperature ranges cited in the description of the preferred embodiment are only applicable to AZ91D magnesium alloy, but could be modified readily in accordance with the principles of the invention by those skilled in the art in order to accommodate other alloys, such as those based on Al, Mg, Zn and Cu.

Fig. 1 illustrates an extruder system according to an embodiment of this invention. A liquid alloy is supplied to the feeder 10. The feeder 10 is provided with a series of heating elements 11 disposed around the outer periphery. The heating elements may be of any conventional type and operate to maintain the feeder 10 at a temperature high enough to keep the metal supplied through the feeder 10 in the liquid state. For AZ91D alloy, this temperature would be over 600°C, the liquidus of the alloy. The extruder has a plurality of cooling channels 12 and heating elements 13 dispersed along the length of the extruder. The matched cooling channels 12 and heating elements 13 may form a series of heating and cooling zones respectively. The heating and cooling zones make it possible to maintain a complex temperature profile along the extruder axis, which may satisfy the special requirement during semisolid processing. The temperature control of each individual zone is achieved by balancing the heating and cooling power input by a central control system through the thermal couple 20. The methods of heating can be resistance heating, induction heating or any other means of heating. The cooling media may be water or gas or any other media depending on the process requirement. While only one heating/cooling zone is shown in figure 1, the extruder can be equipped with between 1 to 10 separately controllable heating/cooling zones.

The extruder also has a physical slope or an inclination. The inclination is usually between 0-90° relative to the metal sheet-moving plane. The inclination is designed to assist the transfer of the sheared liquid alloy or semisolid slurry from the extruder to the next steps in different processes.

The extruder is also provided with two screws 14 that are driven by an electric motor or hydraulic motor 16 through a gearbox 17. The two screws 14 are positioned within barrel 15 and kept in line with end cap 18, 19. The two screws 14 are designed to provide high shear rate, which are necessary to achieve fine and uniform solid particles. Different types of screw profiles may of course be used. In addition, any device that offers high shear may also be used to replace the twin-screw extruder.

The sheared liquid alloy or semisolid slurry existing in the extruder is transferred to shaping device through a valve 21, connected with the end cap 19. The valve 21 operates in response to a signal from the central control system. The valve 21 is provided for supplying a constantly regulated flow of the semisolid slurry so as to form a proper pool for next step of the process. The optional opening of valve 21 should match the process requirement. The valve 21 can be opened continuously with a limited flow rate or discretely without flow rate limitation.

Fig. 2 illustrates a DC rheocasting system. The system has two functional units: a twin-screw extruder 1 and a DC caster 2. The extruder 1 has been described in Fig. 1. The DC caster 2 mainly includes a cylindrical mould 31 and a cooling media 33. The mould is attached on a supporter 36 with a predetermined gap to extruder 1. A start-up base is enclosed so as to be continuously movable. The discharged sheared liquid alloy or semisolid slurry is enclosed in the DC caster. The direct chilling unit 31 is filled by cooling media 33 via inlet 32 and flow out via outlet 34. The sheared liquid alloy or semisolid slurry in pool 30 can be therefor solidified to form a continuously billet 34, which is supported by the base 35 for starting of the process and continuous drawing the billet.

Fig. 3 illustrates a rheo-extrusion system. The system is modified from an extruder, as shown in Fig. 1. A temperature-controlled extrusion die 8 is directly attached to the outlet valve 21. The extrusion die 8 has a separate thermal couple 9 to maintain the required die temperature and has an outlet 7 to extrude the alloy. The higher temperature variation around open die may significantly reduce the resistant to the flow of the sheared liquid alloy or semisolid slurry. The sheared liquid alloy or semisolid slurry is forced out from the extrusion die to form a rod or a wire.

Fig. 4 illustrates an alternative extrusion die, in which an alternative cross sectional shape 7 is incorporated in the extrusion die 8 to produce different cross-sectional shapes. Generally, the cross-section of the extrusion die can be any simple or complex shapes, or any other shapes suitable for extrusion.

Fig. 5 illustrates an alternative rheo-extrusion system. The system has two functional units: a twin-screw extruder and a single screw extruder. The twin-screw extruder has been described in Fig. 1. The single screw extruder is used as a shaping device for production rods/wires from the sheared liquid alloy or semisolid slurry. The single screw extruder consists of a barrel 42, screw 43, nozzle 41 and heating elements 45 along the barrel 42 with a thermal couple 46 for the required temperature. The sheared liquid alloy or semisolid slurry is discharged into the single screw extruder via the valve 21. The continuous rotation of the screw 43 forced the sheared liquid alloy or semisolid slurry forward to the nozzle 41 to form a continuous product. The temperature control of barrel 42 via heating elements 45 may significantly reduce the flow-out resistant of the sheared liquid alloy or semisolid slurry or semisolid slurry. The sectional shapes of the nozzle 41 determine the shape of the extruded part. The nozzle can be simply a small circle, which forms a metal wire, or any other possible shapes. Such a prior art extruder can be modified by application of the alternative embodiment in the present invention wherein at least the open die can be modified to different shapes.

Fig. 6 illustrates a twin-roll rheocasting system. The system has two functional units: a twin-screw extruder 1 and a DC caster 2. The extruder 1 has been described in Fig. 1. The DC caster 2 mainly includes a pair of rolls 22 and a pair of side dams 23. The twin-rolls are disposed horizontally and parallel with each other with a predetermined gap, one or both of the rolls are supported so as to be selectively movable in the radial direction of the roll. The rolls 22 rotate in the directions indicated by the arrows. The interior of each roll 22 may constitute a cooling jacket or heating jacket. Side dams 23 are disposed in contact with the rolls 22 in the axial direction of the roll. A pool 24 for reserving the semisolid slurry is formed between upper surfaces of the opposite ends of the rolls 22 and the inner surface of the two side dams 23. The transferred semisolid slurry in pool 24 can be further solidified to form a shell 25 on the surfaces of rolls 22. Under this condition, the rolls 22 is rotated in the direction of the arrows shown in the figure so that the solidified shells 25 formed on the surfaces of the rolls 22 are pulled down and bonded together by pressure to form a continuously cast strip 26.

As noted in Fig. 6, the roll peripheral surfaces are generally flat, i.e., the rolls are of plain cylindrical form. Such a prior art caster can be modified by application of the alternative embodiment in the present invention wherein at least a portion of the roll surface is a convex or concave surface or any other appropriate surfaces.

Generally, the system has a control device to realise all the functions. Preferably, the control device is programmable so that the desired characteristics of the metal can be achieved. Control device (not shown in the Figures) may, for example, comprise a microprocessor, which may be easily and quickly reprogrammed to change the relative parameters depending on the type of the finished product.

The embodiment may also have a presence device attached to the extruder to increase the pressure in the barrel. The embodiment may also have a presence device attached to the extruder and relative parts to supply protective gas in order to avoid oxidation. Such a gas may be argon, nitrogen or any other suitable gas.

While particular embodiments according to the invention have been illustrated and described above, it will be clear that the invention can take a variety of forms and embodiments within the scope of the appended claims. For example, the barrel and screw can be of a modular design.

CLAIMS

1. A method of forming a continuous product from a liquid metal alloy, comprising the steps of:

cooling the alloy to about the liquidus or from the solidus to the liquidus of the alloy,

applying shear to the alloy at a sufficiently high shear rate and intensity of turbulence to form a sheared liquid alloy or semisolid slurry, and

transferring the sheared liquid alloy or semisolid slurry into a shaping device in order to form a solid product,

wherein the shaping device is capable of forming a continuous product, and

wherein shear is applied to the alloy by means of a twin screw extruder having at least two screws which are at least partially intermeshed.

2. A method as claimed in claim 1, wherein the at least two screws each have at least one vane thereon, the vane at least partially defining a helix around the screw to propel the alloy through the extruder, wherein the screws can be rotated to shear said liquid alloy at a rate sufficient to inhibit complete formation of dendritic structures therein while the alloy is in a semisolid state.

3. A method as claimed in claim 1, wherein the screws are substantially fully intermeshed.

4. A method as claimed in any one of claims 1 to 3, wherein the shaping device is a direct chill caster, and extrusion die, or a twin roll caster.

5. A method as claimed in any one of claims 1 to 4, wherein the alloy comprises at least two immiscible components, and wherein said components are provided separately in liquid form, and pre-mixed before being subjected to shear.

6. A method as claimed in claim 5, wherein the alloy is subjected to sufficient shear to be converted into a liquid suspension in which the minor immiscible component is dispersed in the major immiscible component in the liquid phase.

7. A method as claimed in claim 6, wherein the liquid suspension is cooled to its monotectic temperature or below whilst being sheared in order to form a semisolid slurry.

8. A method as claimed in claim 7, wherein the viscosity of the slurry is sufficiently high to prevent coarse segregation of the immiscible system.

9. A method as claimed in any one of claims 5 to 8, wherein the shaping device is not a pre-heated metal band.

10. A method as claimed in any one of claims 1 to 5, wherein the alloy does not include any immiscible components.

11. Apparatus for forming a continuous product from a liquid metal alloy, comprising:

a temperature-controlled shearing device capable of imparting sufficient shear and intensity of turbulence to a liquid metal alloy to form a sheared liquid alloy or semisolid slurry, and

a shaping device in fluid communication with the shearing device,

wherein the shaping device is capable of forming a continuous product, and

wherein the shearing device is a twin screw extruder having at least two screws which are at least partially intermeshed.

12. Apparatus as claimed in claim 11, wherein the at least two screws each have at least one vane thereon, the vane at least partially defining a helix around the screw to propel the alloy through the extruder, wherein the screws can be rotated to shear said liquid alloy at a rate sufficient to inhibit complete formation of dendritic structures therein while the alloy is in a semisolid state.

13. Apparatus as claimed in claim 11 or 12, wherein the screws are substantially fully intermeshed.

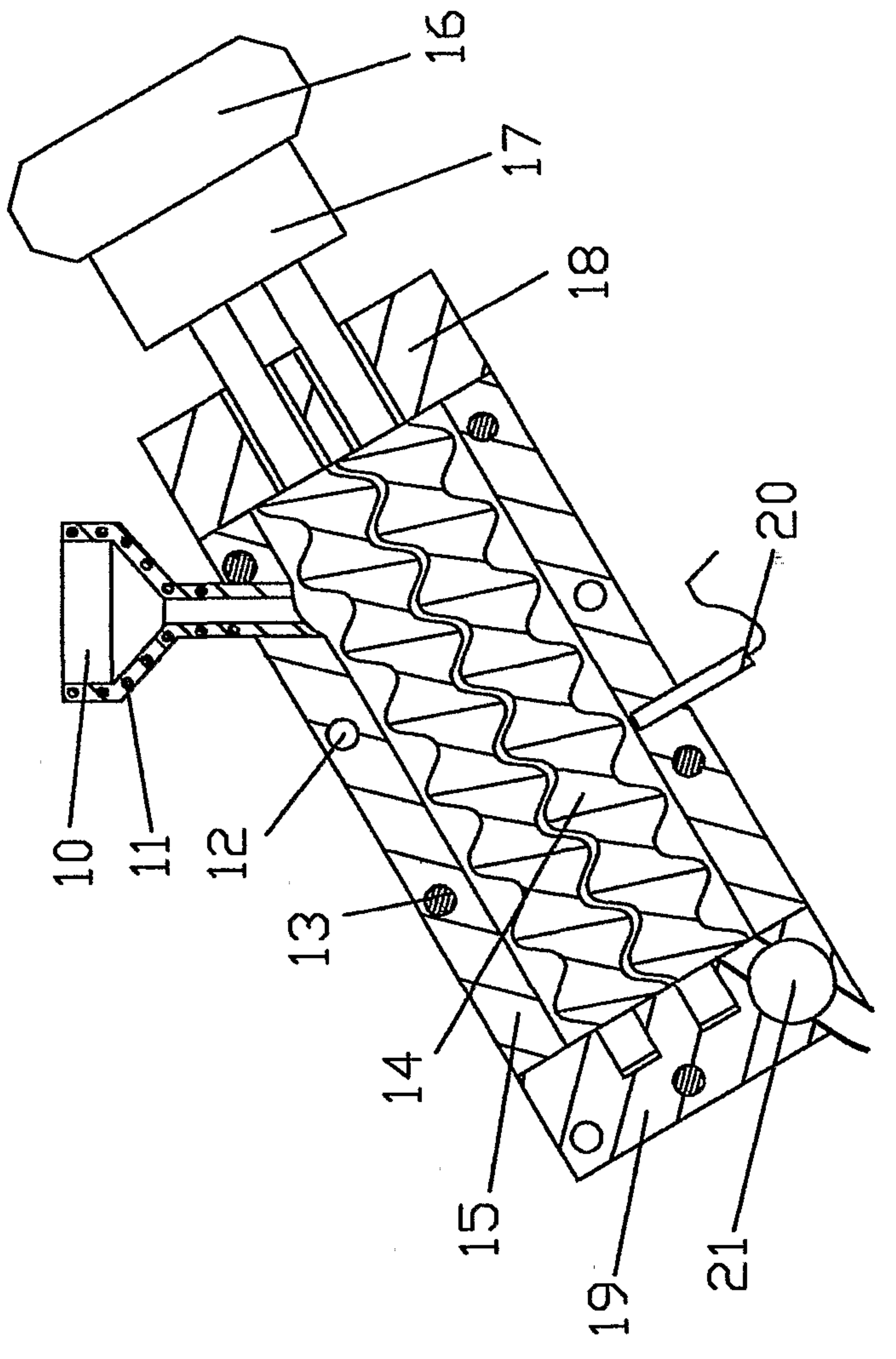


Fig. 1

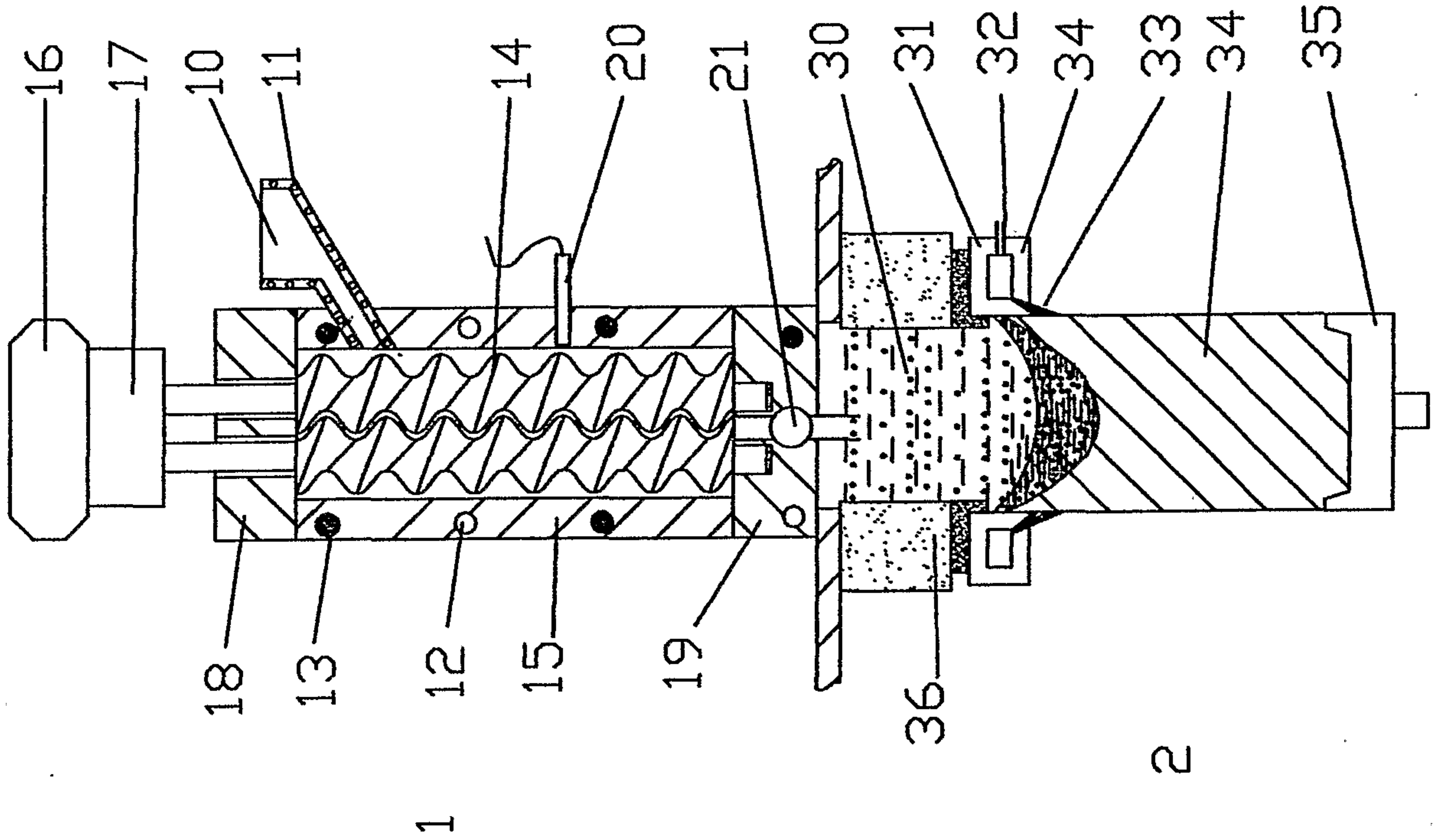


Fig. 2

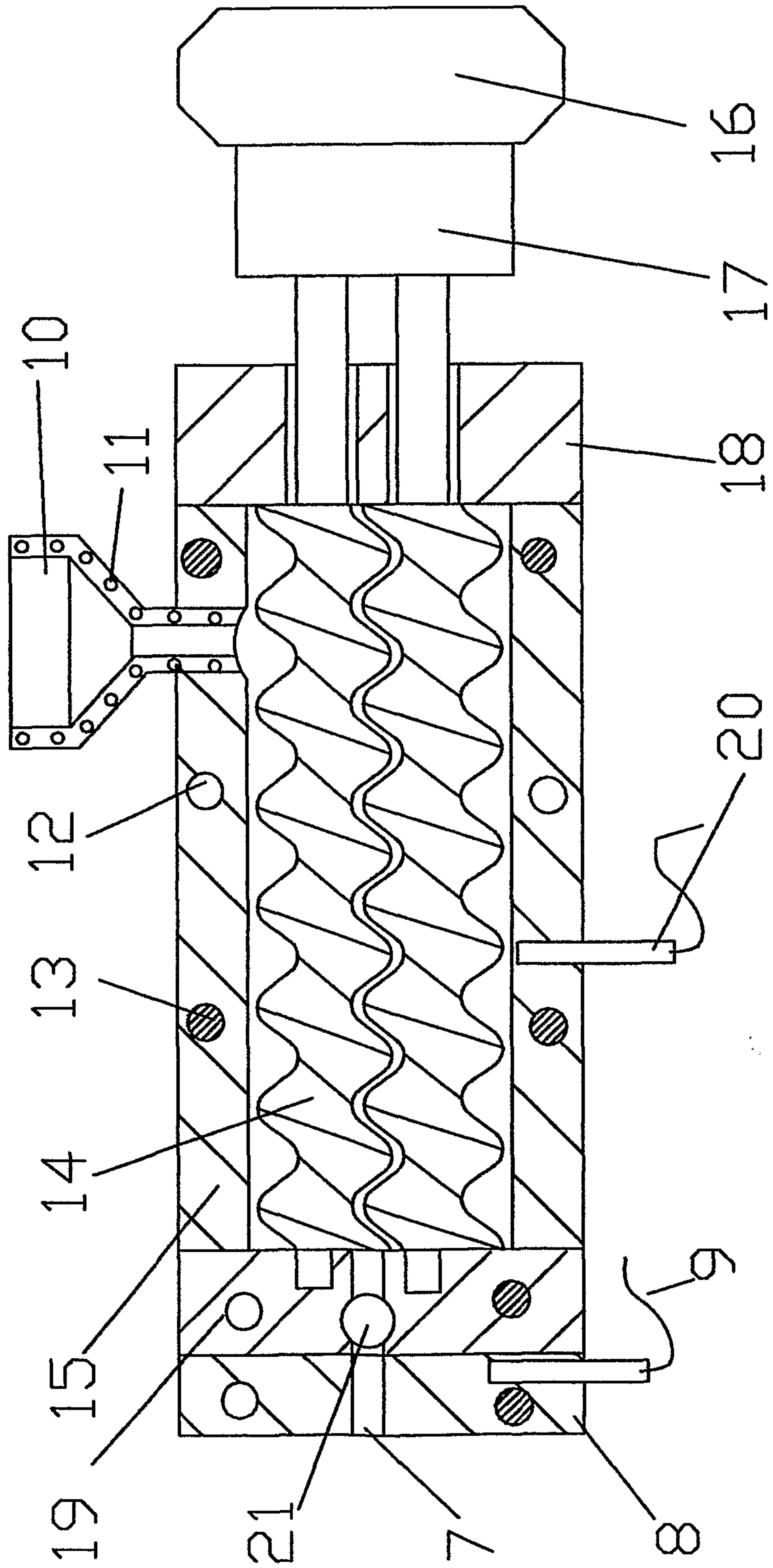


Fig. 3

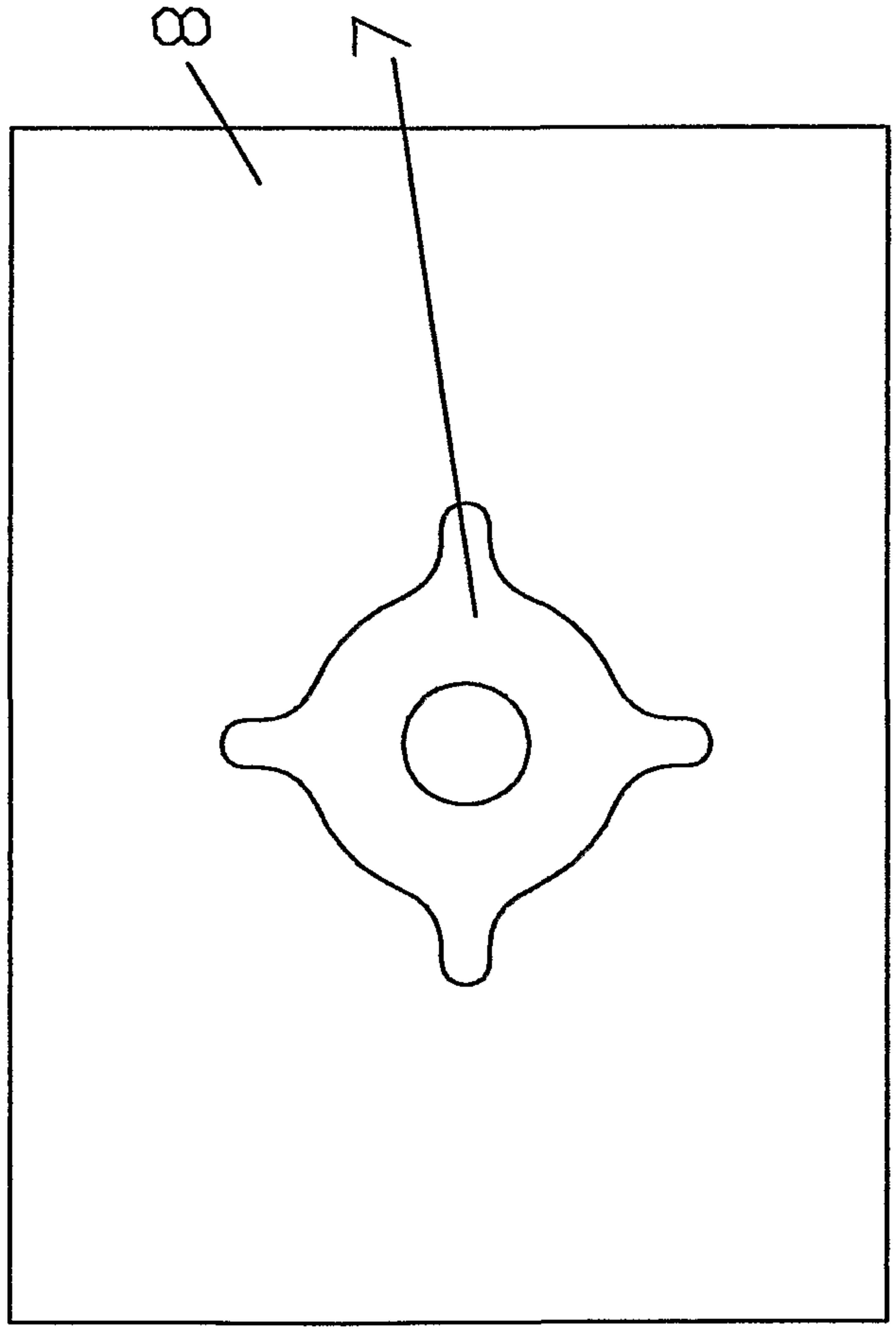


Fig. 4

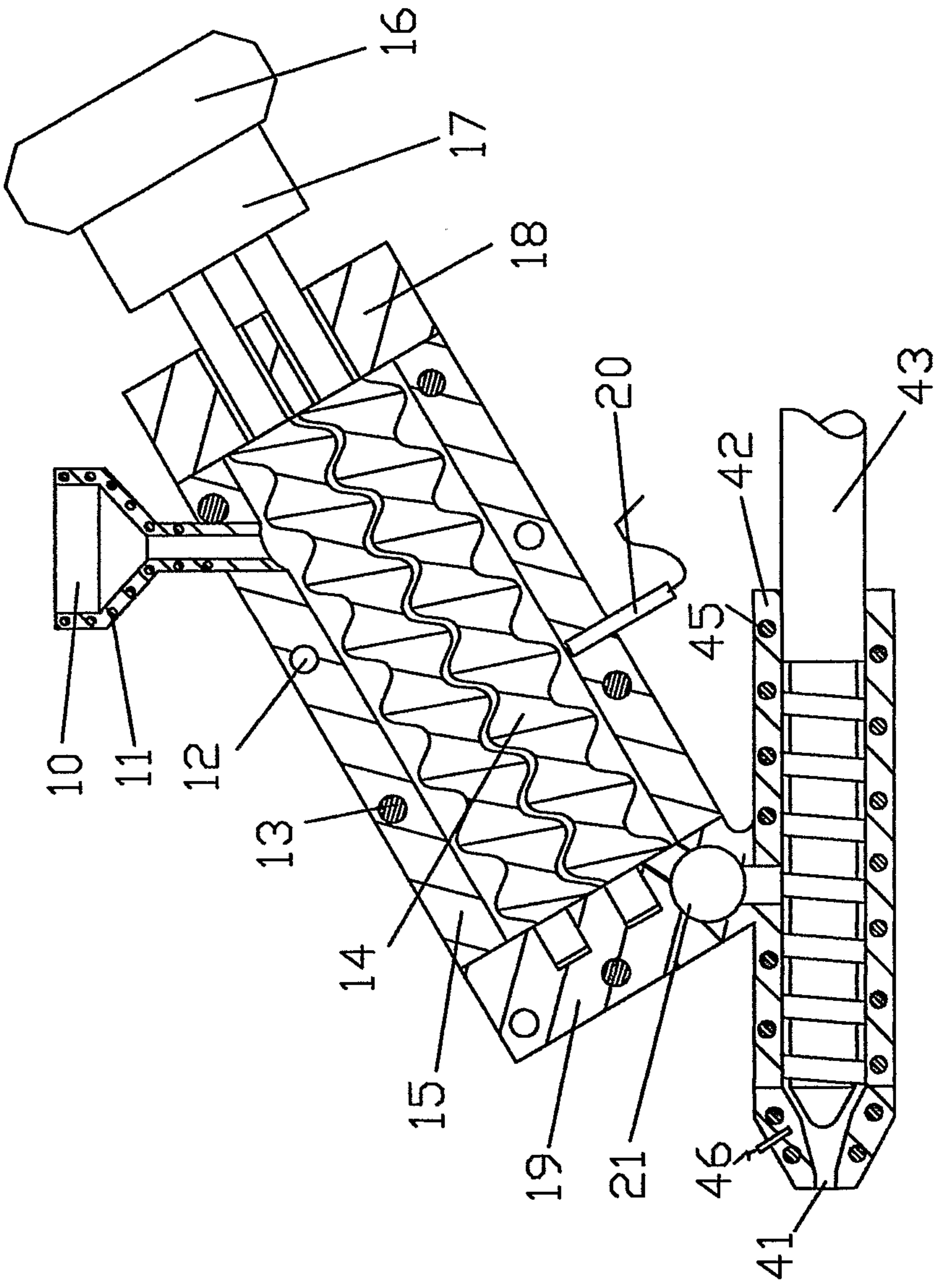


Fig. 5

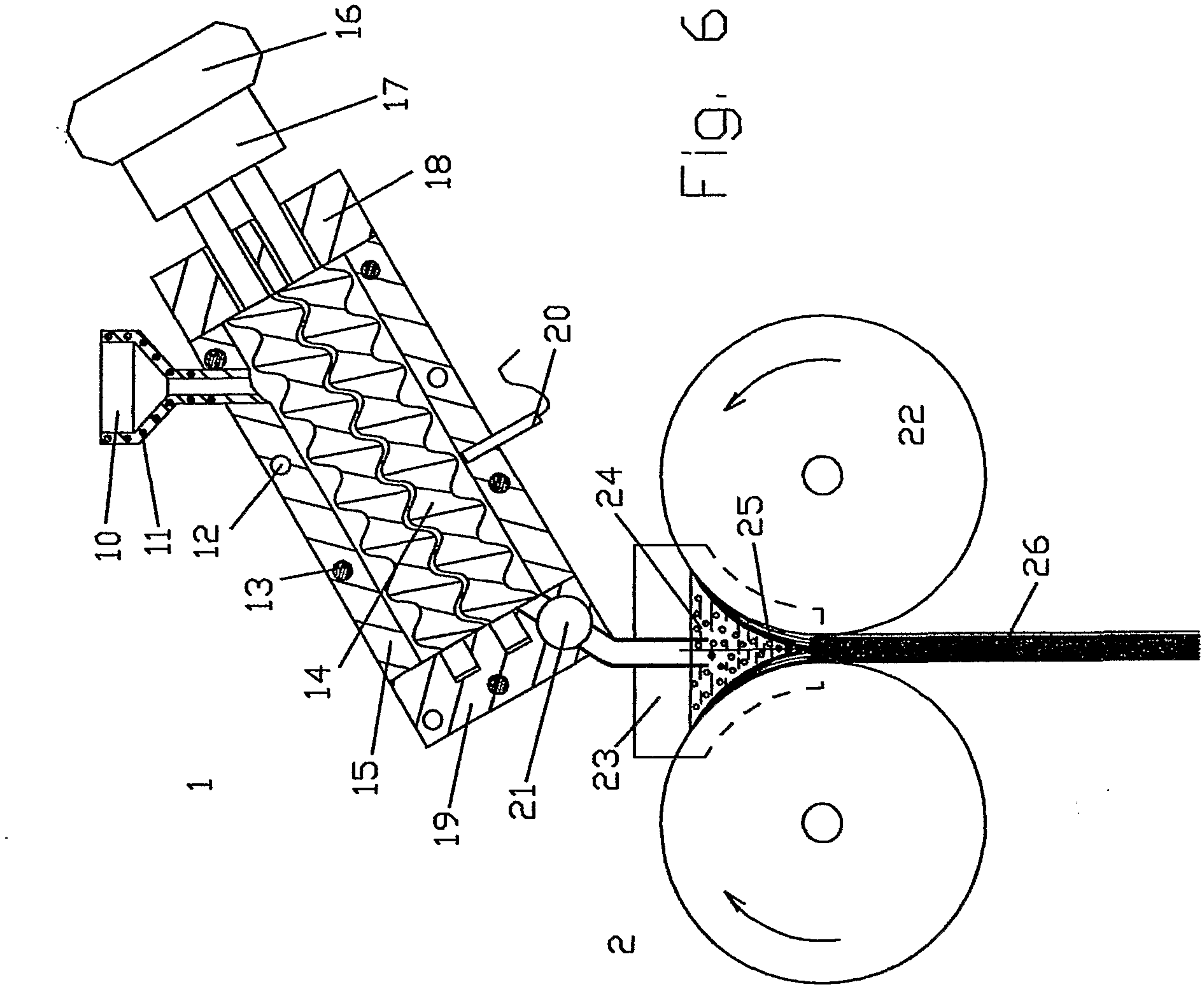
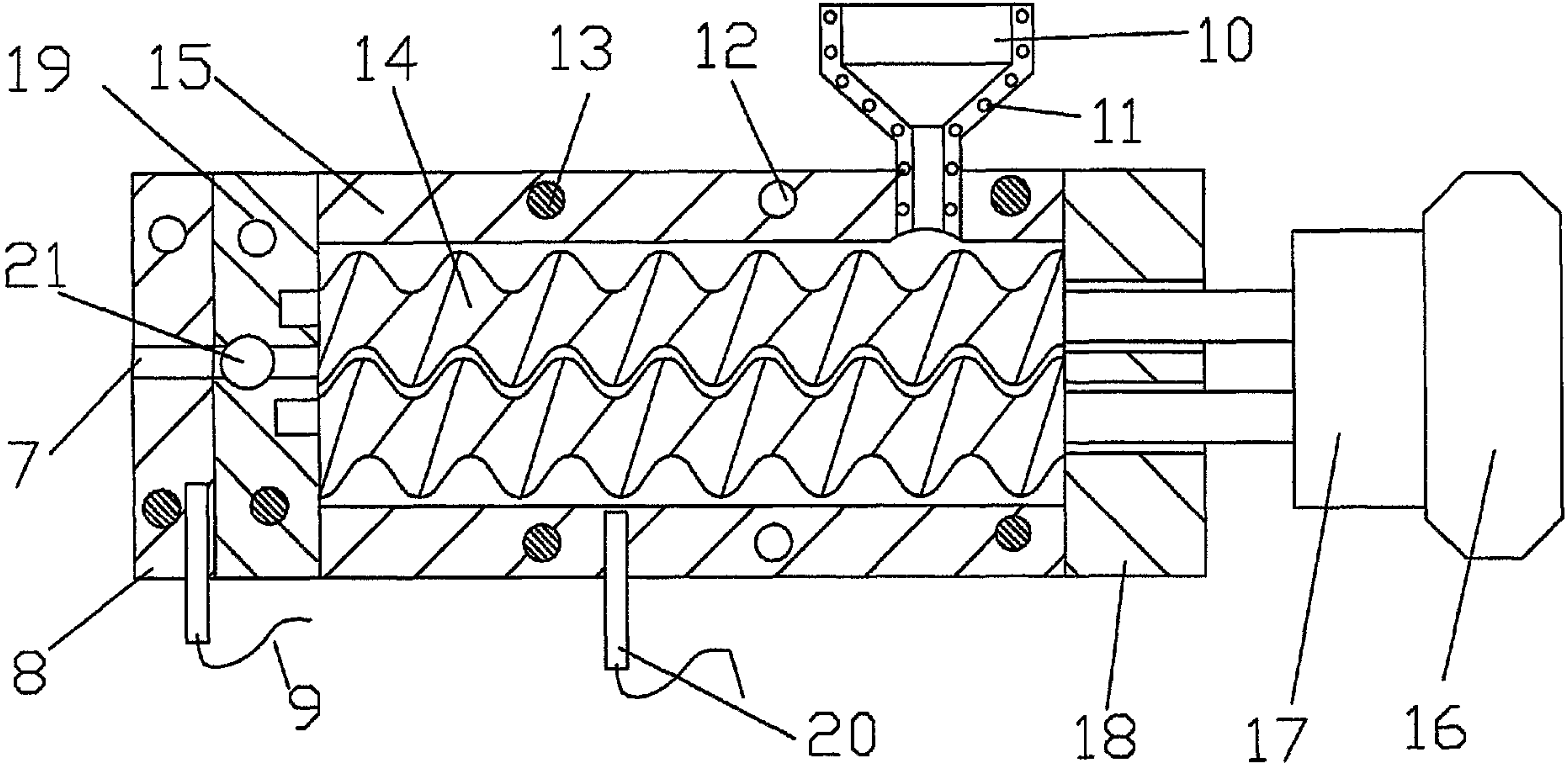


Fig. 6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