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CA 2255904 C 2002/07/30

(11)(21) 2 255 904

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) Date de dépôt PCT/PCT Filing Date: 1996/06/07
(87) Date publication PCT/PCT Publication Date: 1996/12/19
(45) Date de délivrance/Issue Date: 2002/07/30
(85) Entrée phase nationale/National Entry: 1998/11/23
(86) N° demande PCT/PCT Application No.: US 1996/009612
(87) N° publication PCT/PCT Publication No.: 1996/041073
(30) Priorité/Priority: 1995/06/07 (08/480,663) US

(51) Cl.Int.^{6}/Int.Cl.^{6} F02C 3/14, F02C 5/02, F02C 6/00
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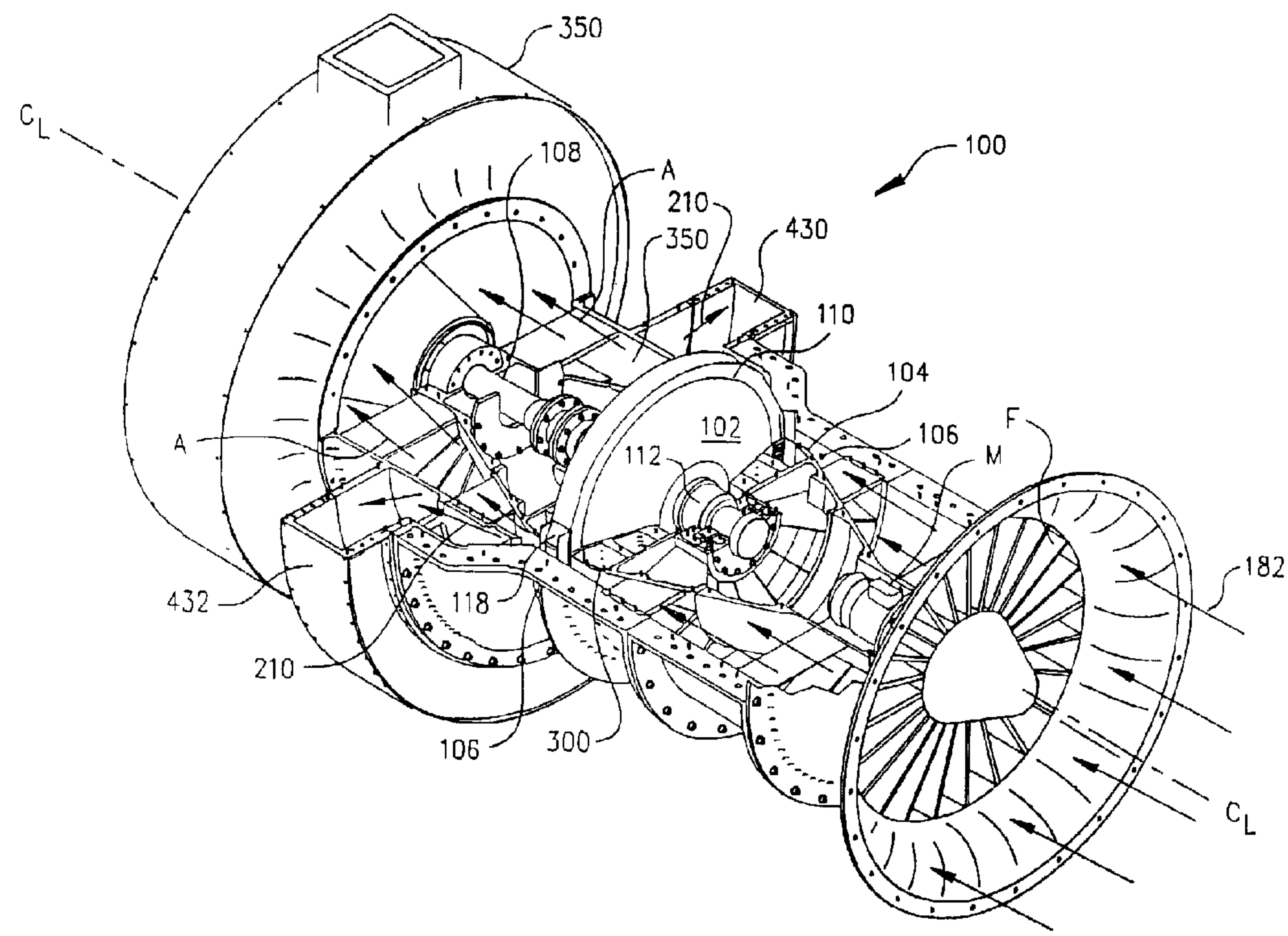
(54) Titre : AMELIORATIONS D'UN PROCEDE ET D'UN APPAREIL DE PRODUCTION DE PUISSANCE
(54) Title: IMPROVED METHOD AND APPARATUS FOR POWER GENERATION



(57) Abrégé/Abstract:
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PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : F02C 3/14, 5/02, 6/00	A1	(11) International Publication Number: WO 96/41073 (43) International Publication Date: 19 December 1996 (19.12.96)

(21) International Application Number: PCT/US96/09612

(22) International Filing Date: 7 June 1996 (07.06.96)

(30) Priority Data:
08/480,663 7 June 1995 (07.06.95) US

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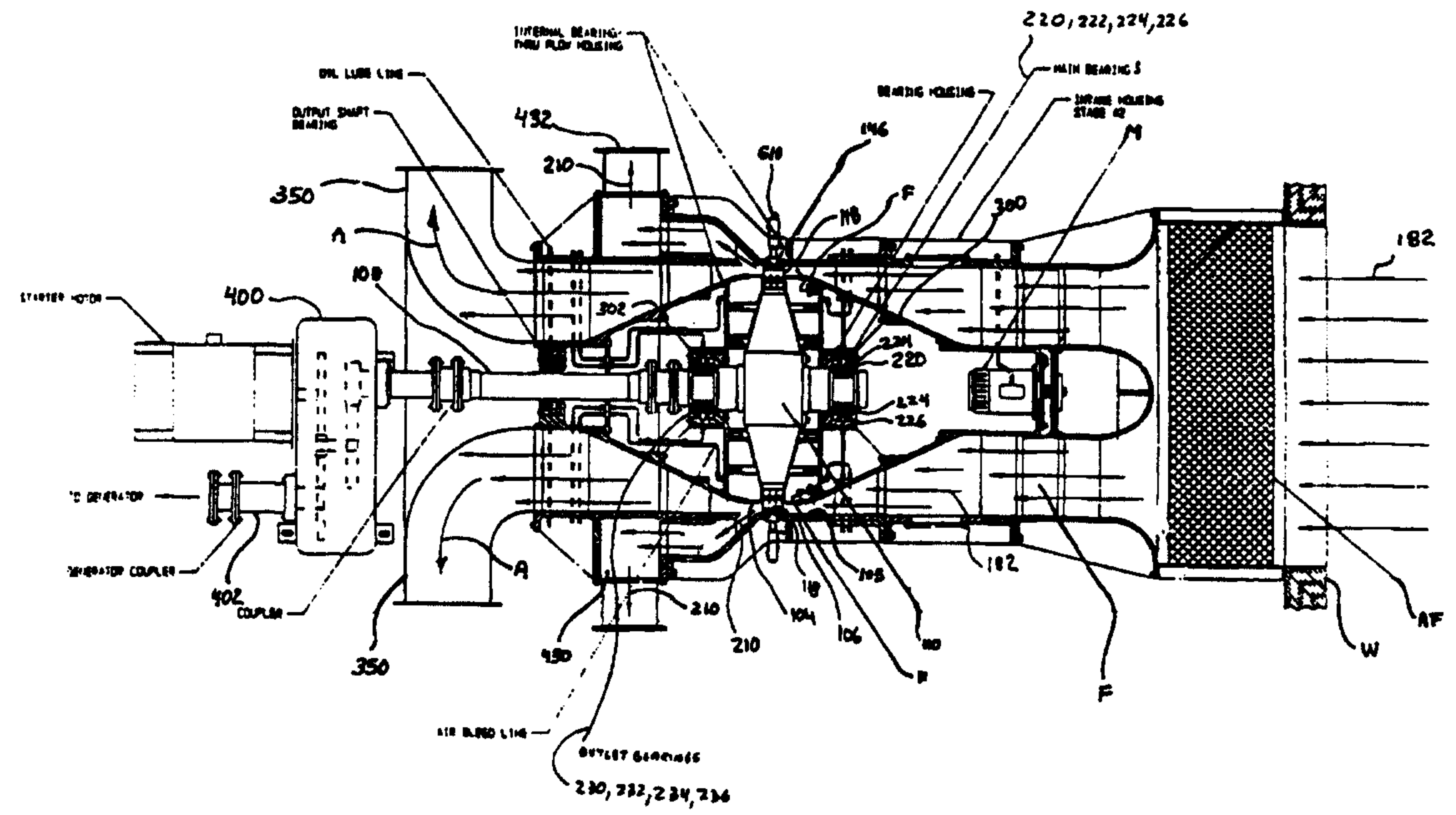
(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, ES, FI, GB, GE, HU, JP, KE, KG, KP, KR, KZ, LK, LT, LU, LV, MD, MG, MN, MW, NO, NZ, PL, PT, RO, RU, SD, SE, SI, SK, TJ, TT, UA, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.
With amended claims and statement.

(54) Title: IMPROVED METHOD AND APPARATUS FOR POWER GENERATION



(57) Abstract

A method and apparatus using partially unshrouded type supersonic ramjet thrust module(s) (118) at the periphery of a low aerodynamic drag tapered disc rotor (114) is disclosed. An unshrouded ramjet inlet (120) compresses an impinging inlet air stream by utilizing the thrust module inlet structures and an adjacent housing sidewall (105, 106). Fuel is oxidized in the ramjet thrust module(s) producing combustion gases which rotate the ramjet at supersonic velocities about a shaft (108) for power generation. The enthalpy in the escaping combustion gases is substantially segregated in an outlet duct (430) and may be utilized thermally via a heat exchanger (440). Efficient mixing in the inlet shock and short residence times in the combustion chamber enabling low nitrogen oxides emissions to be achieved.

IMPROVED METHOD AND APPARATUS FOR POWER GENERATION

TECHNICAL FIELD OF THE INVENTION

My invention relates to a novel, revolutionary apparatus and method for the generation of electrical and mechanical power while achieving very low emission rates of nitrogen oxides. More particularly, my invention relates to a power plant driven by ramjet engine thrust modules, and to novel rotors designed to withstand the extremely high tensile stress encountered while rotatably securing such thrust modules. Power plants of that character are particularly useful for generation of electrical and mechanical power at efficiencies substantially improved over power plants currently in widespread commercial use.

BACKGROUND OF THE INVENTION

A continuing demand exists for a simple, highly efficient and inexpensive thermal power plant which can reliably provide electrical and mechanical power. A variety of medium size electrical and/or mechanical power plants could substantially benefit from a prime mover which provides a significant improvement from currently known efficiencies. Such medium size mechanical or electrical power plants - largely in the 10 to 100 megawatt range - are required in a wide range of industrial applications, including rail locomotives, marine power systems, aircraft engines, and stationary electric power generating units. Power plants in this general size range are also well suited to use in industrial and utility cogeneration facilities. Such facilities are increasingly employed to service thermal power needs while simultaneously generating electrical power.

Power plant designs which are now commonly utilized in co-generation applications include (a) gas turbines, driven by the combustion of natural gas, fuel oil, or other fuels, which capture the thermal and kinetic energy from the combustion gases, (b) steam turbines, driven by the steam which is generated in boilers from the combustion of coal, fuel oil, natural gas, solid waste, or other fuels, and (c) large scale reciprocating engines, usually diesel cycle and typically fired with fuel oils.

Of the currently available power plant technologies, diesel fueled reciprocating and advanced turbine engines have the highest efficiency levels. Efficiencies often range from 25% to 40%, based on net work produced when compared to the energy value of the fuel source. Unfortunately, with respect to the reciprocating engines, at power output levels greater than approximately 1 megawatt, the size of the pistons and other engine components required become almost unmanageably large, and as a result, widespread commercial use of such larger sized reciprocating engine systems has not been accomplished.

Gas turbines perform more reliably than reciprocating engines, and are therefore frequently employed in plants which have higher power output levels. However, because gas turbines are only moderately efficient in converting fuel to electrical energy, gas turbine powered plants are most effectively employed in co-generation systems where both electrical and thermal energy can be utilized. In that way, the moderate efficiency of a gas turbine can in part be counterbalanced by increasing the overall cycle efficiency.

Fossil fueled steam turbine electrical power generation systems are also of fairly low efficiency, often in the range of 30% to 40%. Such systems are commonly employed in both utility and industrial applications for base load electrical power generation. This is primarily due to the high reliability of such systems. However, like gas turbine equipment, steam turbine equipment is most advantageously employed in situations where both mechanical and thermal energy may be utilized, thus increasing overall cycle efficiency.

Because of their modest efficiency in conversion of fuel input to electrical output, the most widely used types of power plants, namely gas turbines and combustion powered steam turbine systems, depend upon co-generation in industrial settings to achieve acceptable costs of production for electricity. Therefore, it can be appreciated that it would be desirable to achieve reduced costs of electrical production by generating electrical power at higher overall efficiency rates than is commonly achieved today.

SUMMARY

I have now invented, and disclose herein, improved details for the design of a novel, revolutionary power plant. My power plant design is based on the use of a ramjet engine as the prime mover, and has greatly increased efficiencies when compared to those heretofore used power plants of which I am aware. Unlike many power plants commonly in use today, my power plant design is simple, compact, relatively inexpensive, easy to install and to service, and is otherwise superior to currently operating plants of which I am aware.

My novel power plants have a unique low aerodynamic drag rotor portion. The rotor is preferably constructed utilizing a disc of high strength composite materials. It can be operated at rotating speeds well above those which would induce tensile and compressive strains that would cause materials such as conventional steel or titanium alloys to fail in structures of similar shape.

The aerodynamic design used in my power plant overcomes two important and serious problems. First, at the supersonic tip speeds at which my device operates, the aerodynamic design minimizes drag. Thus, it

minimizes parasitic losses to the power plant due to the drag resulting from the movement of the rotor through an airstream. This is important commercially because it enables a power plant to avoid large parasitic losses that undesirably consume fuel and reduce overall efficiency. Second, the materials design and specification provides the necessary tensile and compressive strength, where needed in the rotor, to prevent internal separation of the rotor by virtue of the centrifugal and centripetal forces acting on the rotor materials.

I have now developed a novel rotor design for use in combination with a ramjet driven power generation system. In one embodiment, the rotor section comprises a solid disc. The rotor section rotates in a housing which uses boundary layer removal via way of air injection on the rotor face.

Attached to the periphery of the rotor are inboard portions of ramjet engine thrust modules. The inboard portions of ramjet engines are situated so as to engage and to compress that portion of the airstream which is impinged by the ramjet upon its rotation about the aforementioned output shaft portions between the inboard portion of the ramjet engine and the outboard housing wall. I have also provided in my design a feature to insure that a relatively clean airstream (free of the ramjet's own wake turbulence) will be encountered by the rotating ramjet. This is accomplished by rotating the inboard ramjet portion in a supplied air plenum which is oriented generally perpendicular to the aforementioned axis of rotation, and circulating therethrough an airstream which replaces the gases scooped up by the ramjet compression and sweeps away its aerodynamic wake.

Fuel is injected from the interior housing wall, by adding it to the air which is to be captured and compressed at the ramjet inlet. The fuel may be conveniently provided to the ramjet engine combustion chamber through use of fuel supply passageways communicating between the fuel source and the interior housing. The fuel injection ports allow fuel to enter the air stream to be mixed with the inlet air before it arrives at the ramjet engine combustion chamber. The combustion gases formed by oxidation of the fuel escape rearwardly from the ramjet nozzle, thrusting the ramjet tangentially, thus turning the rotor and the output shaft portions. The power generated by the turning shaft may be used directly in mechanical form, or may be used to power an electrical generator and thus generate electricity.

The unique rotor structure and ramjet structure provided enables this power generation apparatus to operate at supersonic velocities, and preferably, at high supersonic velocities, when compared to prior devices of which I am aware. For example, ramjet operation should proceed in excess of Mach 1, and normally, in excess of Mach 2. For improved performance, preferably, operation of the ramjet should occur in a range from approximately Mach 2 to approximately Mach 4.5. More preferably, operation of the ramjet should occur in the range from about at least Mach 3 to about Mach 4.5 or thereabouts. Most preferably, the operation of the ramjet should occur in the Mach 3.5 range.

Preferably, exhaust combustion gases from the ramjet are substantially separated from the outbound air stream travelling through the supplied air plenum. In my improved cogeneration plant design, the combustion exhaust gas duct is used to collect and discharge the exhaust gas stream to a conduit for transport to a heat exchanger, where the gases may be cooled by way of heating up a heat transfer fluid, such as water, in which case the production of hot water or steam results. The heat transfer fluid may be utilized for thermal purposes, or for mechanical purposes, such as driving a steam turbine.

Ultimately, the cooled combustion gases are exhausted to the ambient air. However, by way of the unique technique of completely mixing combustion gas in the supersonic shocks between the ramjet inlet ramps, and due to the short residence time in the combustor, my novel power plant minimizes production of nitrogen oxide to emission levels well below those currently achieved in the industry. Further, variations in the air flow configuration and in provision of the fuel supply may be made by those skilled in the art without departing from the teachings hereof. Finally, in addition to the foregoing, my novel power plant is simple, durable, and relatively inexpensive to manufacture.

OBJECTS, ADVANTAGES, AND FEATURES OF THE INVENTION

From the foregoing, it will be apparent to the reader that one important and primary object of the present invention resides in the provision of novel, improved mechanical devices to generate mechanical and electrical power.

More specifically, an important object of my invention is to provide a ramjet driven power generation plant which is capable of withstanding the stress and strain of high speed rotation, so as to reliably provide a method of power generation at high efficiency.

Other important but more specific objects of the invention reside in the provision of power generation plants as described in the preceding paragraph which:

allow the generation of power to be done in a simple, direct manner;

have a minimum of mechanical parts;

avoid complex subsystems;

require less physical space than existing technology power plants;

are easy to construct, to start, and to service;

have high efficiency rates; that is, to provide high heat and high work outputs relative to the heating value of fuel input to the power plant;

in conjunction with the preceding object, provide lower power costs to the power plant operator and thus to the power purchaser than is presently the case;

cleanly burns fossil fuels;

in conjunction with the just mentioned object, results in fewer negative environmental impacts than most power generation facilities currently in use;

have a fuel supply design which efficiently supplies a ramjet;

have a rotating element with a structure able to withstand the stresses and strains of rotating at very high tip speeds; and which

have a rotating element design which provides operation with minimal aerodynamic drag.

A feature of one embodiment of the present invention is the use of a novel aerodynamic design configuration which provides minimal aerodynamic drag at high rotational design tip speeds, thereby enabling the power plant to minimize parasitic losses, with the resulting advantage of high overall cycle efficiencies.

Another feature of the present invention is the use of a high strength rotor structure.

Other important objects, features, and additional advantages of my invention will become apparent to those skilled in the art from the foregoing and from the detailed description which follows and the appended claims, in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

In the drawing, identical structures shown in the several figures will be referred to by identical reference numerals without further mention.

FIG. 1 provides a cut-away perspective view of the rotating assembly of my novel power plant apparatus, showing rotating output shaft portion affixed to a rotor and rotatably secured therewith, with the rotor having (i) a central hub, (ii) a tapered disc portion, (iii) a and unshrouded thrust module. Additionally, an exhaust combustion gas duct is illustrated.

FIG. 2 is a top plan view with a partial cross section, looking downward at the various components of my power plant.

FIG. 3 is a perspective view showing an enlarged detail of the rotor for my power plant apparatus, showing the location of the integrally constructed ramjet thrust module inboard portion, a central hub, and a rotating output shaft portions.

FIG. 4 is a cross sectional view of a rotor and housing, showing additional detail with respect to the air injection system used to reduce boundary layer drag on the rotor.

FIG. 5 is a partial cross sectional view, similar to that shown in FIG. 4, but providing still further detail of the air injection system used for simultaneous cooling and boundary layer drag reduction.

FIG. 6 is a side view of the rotor construction, showing the use of a non-circular disk with an external segmented cooling cap and integral thrust module, and showing the wall structure which forms the outboard portion of the thrust module as the unshrouded thrust module rotates therein.

FIG. 7 is similar to FIG. 6, but showing only the rotor, thrust module inboard portions, and cooling cap.

FIG. 8 provides a perspective view of the unshrouded thrust module, showing the structural layout which allows cooling.

FIG. 9 is a top plan view of the unshrouded thrust module, further illustrating the layout of the cooling passageways.

FIG. 10 is a perspective view of the rotor cooling caps, showing the location of cooling passageways.

FIG. 11 is a diagrammatic illustration of the operation of a segmented annular gate valve, showing an annular gate valve in a closed position.

FIG. 12 is a diagrammatic illustration of the operation of the segmented annular gate valve first set forth in FIG. 11, showing an annular gate valve in an open position.

FIG. 13 is a side elevation view of a power plant constructed using my supersonic ramjet thrust module in conjunction with a conventional electrical generator set and steam turbine.

FIG. 14 is a plan view of a power plant constructed using my supersonic ramjet thrust module in conjunction with a conventional electrical generator set and steam turbine, as first illustrated in FIG. 13 above.

DESCRIPTION OF INVENTION

Prime Mover for Power Plant

Referring now to the drawing, FIG. 1 depicts a partial cut-away perspective view of my novel power plant 100. Rotating assembly 102 (at respective portions thereof) revolves in close proximity to the fixed inboard housing 104 and to the inner surface 105 of stationary circumferential outboard housing 106, along a central axis C^L of rotation. As illustrated, the rotating assembly 102 includes an output shaft 108 which provides and defines the axis of rotation. The shaft 108 is affixed to rotor 110 at a central hub 112, and rotatably secured therewith.

As is most clearly evident in FIGS. 6 or 7, the rotor 110 is comprised of four basic sections, (i) a central hub 112, (ii) a solid tapered primary disc portion 114, (iii) cooling and protective rotor cap rim segments 116, and (iv) an unshrouded thrust module 118.

The ramjet construction and operation provided in my power plant 100 is unique. The unshrouded (or alternately partially shrouded) integral thrust modules 118 must work with the interior wall 105 of the outboard housing 106 in order to achieve compression in incoming air. This is seen in FIGS. 6 and 8, for example, where the ramjet thrust module 118 inlet includes a first ramp 120 which performs the bulk of compression of inlet air flow 122.

A pair of inlet structures 130, preferably substantially parallel to the spin axis of rotor 110, provides the necessary containment and ramp surface 132 for compression of incoming air along the the ramjet thrust module 118 inlet. However, on the outboard side 134, thrust module has a slot opening defined by first 136 and second 138 inlet walls. These inlet walls, and corresponding trailing edge portions 140 and 142 which form outlet walls, allows the use of the surface 105 of peripheral housing wall 106, and complementary surface 144 (if any) of gate valve 146 as the remaining inlet air compression surface for the ramjet thrust module 118.

The importance of the development of my unique, unshrouded ramjet thrust module 118 will become further evident when the method of starting my ramjet driven power plant 100 is discussed hereinbelow.

Turning now to FIG. 2, the overall structure of the prime mover in my power plant is further illustrated in a partial cross-sectional view. Ramjet thrust modules 118 oxidize a fuel supplied thereto by injectors I and thus create a propulsive thrust from the exhaust gases 210 which are thereby created. Ideally, ramjet thrust modules 118 utilize oxygen from the incoming airflow 182 (from an ambient air supply at the plant site), as an oxidant source. Intake air 182 is preferably provided motor M driven high speed intake fan F, which cleans intake air through an intake air filter AF. Airflow 182 which is not consumed becomes part of the cool air flow and exits the cool air A plenum 350 as described below. Ramjet thrust modules 118 are integrally provided at the outer reaches of rotor 110, so that the propulsive effect of the ramjet thrust modules 118 can be utilized to turn a rotating assembly, including rotor 110, central hub 112, the output shaft 108, so as to allow the ramjets 118, output shaft 108, and rotor 110, to rotate together as a single rotating assembly with respect to stationary circumferential inboard support structure or housing 104.

The rotating assembly 10 (see FIGS. 2 or 4) are rotatably secured in an operating position by a fixed support structure or inboard housing 104 in a manner suitable for extremely high speed operation of the rotating assembly, particularly for operation in the range of 10,000 to 20,000 rpm, or higher. In this regard, suitable inlet side bearings 220, 222, 224, 226, and outlet side bearings 230, 232, 234, and 236, or suitable variations thereof, must provide adequate bearing support for high speed rotation and thrust, with minimum friction. The detailed bearing and lubrication systems may be provided by any convenient means by those knowledgeable in high speed rotating machinery, and need not be further discussed herein.

Inboard housing 104 includes several important features which are provided to reduce aerodynamic drag, particularly on the inboard, solid rotor face portions 240. First, an inlet side inboard housing portion 300 is provided to smooth inlet air flow 182 as it approaches the thrust modules 118. Referring to FIG. 4, a complementary outlet side inboard housing portion 302 is provided to smooth exit flow of sweep air. An inlet side, substantially annular rotor housing 310 with rotor side surface 312, and an outlet side, substantially annular rotor housing 314 with rotor side surface 316 are provided. The solid face portions 240 of rotor 110 rotates so that rotor side surfaces 312 and 316 are in close proximity to rotor solid face portion 240.

Injection air 250 for boundary layer control is provided through a plurality of apertures 252 in the outboard portion 254 of surface 312, and in the outboard portion 256 of surface 316. Air 250 impacts face 240 of rotor and then sweeps outward, cooling rotor cap segments 116, as well as the thrust module 118.

Adequate velocity of the air flowing through the boundary layer injection apertures 252 may be determined by those knowledgeable in the art and to whom this specification is addressed.

The structural design and material systems used for the rotor 110 is critical because of the centrifugal loads induced by the extreme speed with which the rotor turns. The rotor 110 for the proposed power plant are anticipated to optimally turn at speeds between 10,000 and 20,000 rpm. Newly developed metal matrix composites do provide acceptable specific strength characteristics and can survive the required loads. The safety margin available when using such materials can be increased by increasing the material taper ratio, and when using such technique, other materials of construction, including suitable composite carbon devices, become feasible. Preferably, in order to minimize the actual loading to the extent practical, the rotor means should be built with high strength materials in shapes which have large material taper ratios. This basically means that at increasing radial station, (further from the axis of rotation), the rotor means should become increasingly slender or thin. Fundamentally, reduction of rotating mass results in reduction of the encountered stress operating at the center of rotation.

Attention is now directed to FIGS. 13 and 14, where my power plant is illustrated in conjunction with necessary power generation equipment. Intake air 182 flows past turbine room wall W and through fan F as described above, and fuel is consumed in thrust module 118, to provide thrust to turn shaft 108. The shaft 108 acts in conventional fashion to transmit mechanical power to the primary gear-box 400. The gear-box 400 reduces the output shaft 108 speed to a sufficiently low level to accommodate the capabilities of the desired application. In FIGS. 13 and 14, the primary gear-box 400 is connected by shaft 402 to primary electrical generator 404, suited to generate electrical power for transmission to a power grid or other electrical load. However, shaft 402 could be applied directly to do desired mechanical work.

A secondary gear-box 410 from a steam turbine 410 is also shown connected by shaft 406 to generator 404.

Also shown in FIGS. 12 and 13 is the use of combustion exhaust gases 210 from ramjets 118 in a cogeneration system. As shown, the exhaust gases are conveniently collected by an exhaust gas duct 430. The exhaust gas duct 430 substantially surrounds and laterally encloses the through air plenum 350. Exhaust gases 210 are directed slightly outward toward a second housing sidewall 432 due to the rotational motion of the ramjet thrust modules and the direction of their exhaust vector, and are largely collected in exhaust gas duct 430 without substantial cooling of the same by mixing with the supplied air vent stream passing through plenum 350. The exhaust gases are sent through duct 430 to a heat exchanger 440, through which a secondary working fluid or coolant 442 is circulated. In the usual design, the working fluid 442 will be water. The water can be heated to high pressure steam, and can thereafter be used: (a) to drive a steam turbine, for (i) shaft work or (ii) to drive an electrical generator, or (b) as process heat. The hot exhaust gases 210 from the ramjets 118 flow through heat exchanger 440, thus heating the fluid 442 therein. It may be convenient to design the heat exchanger system 440 as a boiler so that the fluid 442 changes state, i.e., water becomes steam, as it is heated, and in such cases the stream indicated as coolant out will be steam, suitable for use in heating, or in mechanical applications as illustrated with steam provided to a steam turbine 410 to produce shaft work, and thence to a condenser 452, before return through liquid line R to the heat exchanger via pump 454. The turbine shaft 460 may be sent through a gearbox 462 for use as shaft work in electric generator 404.

Turning now to FIGS. 11 and 12, in order to establish the desired internal shock structure in thrust module 118 for startup, the inflow must either be accelerated to a Mach number greater than the design

Mach number and then reduced after starting to the design Mach number, or the throat area must be temporarily increased to "swallow" the shock structure and thus induce startup. Depending upon the contraction ratio and Mach number, it may be impossible to increase the inflow Mach number to a sufficiently high level so as to start the inlet.

However, I have developed an alternative, unique variable geometry mechanism to decrease the through airflow through ramjet 118, thus allowing startup at lower Mach numbers. While the exact requirements can be calculated from this disclosure by those skilled in the art, it must be pointed out that the exact requirements will be based on a set of specific assumptions regarding thrust module size, free stream conditions, and fuel source. Also, component performance levels must be predicted consistent with well established test or theoretical data for the inlet, transition section, combustor, and nozzle.

As seen in FIGS. 11 and 12, a series of variable position annular gate valves 146 are provided around the edge of peripheral wall 106. For starting, the annular gate valves 146 are opened in the direction of reference arrow 602 as shown in FIG. 12, forming a gap 603, so that a portion of the incoming air which is being compressed against wall surface 105 can escape outwardly in the direction of arrows 604 and 606. The unique unshrouded ramjet 118 allows this escapement of bypass air 604 and 606. Once the ramjet 118 has "swallowed" the inlet shock structure, then the gate valve(s) 146 can be closed by actuator 610, as illustrated in FIG. 11. I have shown a hydraulic actuator 610 with shaft 612, mounted by bracket 614. Any convenient mechanical, electrical, or hydraulic actuator may be utilized as convenient for this purpose.

Because the ramjet thrust determines the overall power plant output, the thrust from the ramjet is an important figure of merit for overall plant output levels. The ramjet thrust levels and the overall plant output levels increase in direct proportion with the mass captured and processed by the ramjet. Thus, doubling the inlet area and mass capture results in doubling the thrust generated, and thus results in doubling the power output of the system.

The combustor temperature is a critical factor as combustor temperature varies with varying throttle settings. Combustor temperature must be balanced with inflow rate and thrust module materials so as to maintain structural integrity in the combustor walls. To accommodate this design requirement, cast silicon carbide combustion chambers have been utilized as set forth in FIGS. 8 and 9. This combustion chamber is made of a material with a desirable high temperature capability, selected from candidate materials include hot isostatic pressed alumina, silicon nitride, zirconia, beryllia, and silicon carbide. Ideally, the ramjet combustion chamber 118 is manufactured as a monolithic, solid cast part.

Finally, even though high combustion temperatures are experienced, my design allows extremely low nitrogen oxide output. This is because of the short residence times at the high combustion temperatures, and because the fuel is extremely well mixed. Residence times are determined by various design conditions, but as illustrated, a relatively small flow through residence time of 0.24 microseconds is expected. Fuel injected is being thoroughly mixed in by the shock front, and a well mixed air/fuel front enters the combustion chamber 118. This shock-boundry layer interaction premixing technique is a unique approach for achieving a near perfectly premixed conditions and low nitrogen oxides emission. Thus, nitrogen dioxide emissions are limited by limiting the size of highly non-equilibrium free-radical zones in the combustor. NOx emissions are estimated to be less than 5 ppm, or EI is less than 0.5 grams of nitrogen dioxide per kilogram of fuel.

The method and apparatus for producing mechanical, electrical, and thermal power as described above provides a revolutionary, compact, easily constructed, cost effective power plant. The output from this power plant can be used in conjunction with existing power delivery systems, and represents a significant option for reducing air emissions by combustion of clean burning fuels. Further, given the efficiencies, dramatically less fuel will be consumed per unit of electrical, mechanical, or thermal energy generated.

It will thus be seen that the objects set forth above, including those made apparent from the proceeding description, are efficiently attained, and, since certain changes may be made in carrying out the above method and in construction of the apparatus and in practicing the methods set forth without departing from the scope of the invention, it is to be understood that the invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. For example, while I have set forth an exemplary design utilizing a tapered disk configuration, other embodiments, such as a tri-rotor or quad-rotor (three or four "spokes," respectively extending from a central hub) are also feasible. Also, note that as taught, for example in FIG. 7, the rotor does not have to be symmetrical, but can be of varying radius to accomodate the thrust module 118 placement.

The present embodiments are therefore to be considered in all respects as illustrative and not as restrictive. Accordingly, the scope of the invention should be determined not by the foregoing description and the embodiments illustrated, but by the appended claims, and consequently all changes, variations, and alternative embodiments which come within the meaning and range of equivalents of the appended claims are therefore intended to be embraced therein.

CLAIMS

1. Apparatus for generation of power, said apparatus comprising:

(a) an air inlet for supply of combustion air;

(b) a fuel inlet for supply of oxidizable fuel;

(c) a rotor, said rotor having a central axis and adapted for rotary motion thereabout, said rotor extending radially outward from said central axis to an outer extremity;

(d) a stationary peripheral wall, said wall positioned

(i) radially outward from said central axis, and

(ii) very slightly radially outward from said outer extremity of said rotor;

(e) one or more ramjets, said one or more ramjets comprising

(i) a rotating portion affixed at said outer extremity of said rotor, and

(ii) a stationary peripheral wall portion,

(f) wherein said rotating portion and said stationary peripheral wall portion of each of said one or more ramjets cooperate to compress therebetween a portion of said combustion air, to facilitate oxidation of said fuel supplied to said one or more ramjets and to generate combustion gases therefrom, and thereby develop thrust from said combustion gases to effect rotary motion of said rotor about said axis of rotation.

2. The apparatus of claim 1, further comprising at least one output shaft portion, said at least one output shaft portion affixed to said rotor at, and extending outwardly

from said rotor along, said central axis of rotation, for rotation with and by said rotor.

3. The apparatus of claim 1, wherein at least a portion of each of said one or more ramjets is provided in an unshrouded configuration, and wherein at least a portion of said stationary peripheral wall cooperates with the outer reaches of each of said one or more ramjets, so that during rotation about said axis of rotation, said rotating portion of each of said one or more ramjets spins adjacent to said stationary peripheral wall in a close fitting fashion, and wherein a ramjet thrust is created between

   (a) said rotating portion of each of said one or more ramjets, and

   (b) said stationary peripheral wall.

4. The apparatus as set forth in claim 1, wherein said stationary peripheral wall portion further comprises one or more outlet passages for providing communication between said air inlet and an external pressure relief location, said one or more outlet passages located radially outward from said one or more ramjets as said rotor is rotated about said central axis of rotation, said one or more outlet passages adapted to allow escape of at least a portion of said combustion air being compressed by said one or more ramjets.

5. The apparatus as set forth in claim 1, wherein each of said one or more ramjets utilize at least a portion of said stationary peripheral wall for inlet compression of both air and fuel.

6. The apparatus as set forth in claim 1, wherein each of said one or more ramjets utilize at least a portion of said

stationary peripheral wall for expansion of escaping combustion gases.

7. The apparatus of claim 1 wherein each of said one or more ramjets operates at an inlet velocity at least Mach 2.0.

8. The apparatus of claim one, wherein each of said one or more ramjets operates at an inlet velocity of at least Mach 3.0.

9. The apparatus of claim 1 wherein each of said one or more ramjets operates at an inlet velocity between Mach 3.0 and Mach 4.5.

10. The apparatus of claim 1 wherein each of said one or more ramjets operates at an inlet velocity of approximately Mach 3.5.

11. The apparatus as set forth in claim 1, further comprising at least one valve, said at least one valve being operatively located along a circumferential portion of said stationary peripheral wall, and wherein said valve is located in a position radially outward from and closely adjacent to said one or more ramjets as said one or more ramjets rotates thereby, said valve adapted to be moved from

(a) an open position wherein a portion of the combustion air being compressed by said one or more ramjets escapes through said valve, to

(b) a closed position wherein essentially no escapement of the combustion air is provided therethrough.

12. An apparatus for generating power, comprising:

(a) a first housing means, said first housing means comprising a stationary peripheral wall portion and an air supply plenum;

(b) an output means, said output means comprising at least one shaft portion, said at least one shaft portion rotatably secured about an axis of rotation by said first housing means;

(c) a rotor means, said rotor means secured to said output means, so that said rotor may rotate with said output means;

(d) an exhaust outlet passageway, said exhaust gas outlet passageway adjacent to, and, at least partially formed in, said stationary peripheral wall portion, said exhaust outlet passageway providing fluid communication between said air supply plenum and at least one peripheral exhaust gas collection chamber located radially outward from said axis of rotation of said rotor;

(e) a ramjet means, said ramjet means integrally formed between an unshrouded thrust module and said stationary peripheral wall portion, said ramjet means operating at an inlet velocity of at least Mach 1, and said ramjet means further characterized in that said stationary peripheral wall portion is located in close proximity to said unshrouded thrust module when said ramjet means passes adjacent to a given location on said stationary peripheral wall portion, whereby said ramjet means relies on at least a portion of said stationary peripheral wall portion to assist in compression of an inlet air stream into said ramjet means;

(f) said apparatus adapted to oxidize fuel in said ramjet means to generate combustion gases to produce thrust from said ramjet means so as to rotate said ramjet means, rotor means, and output means, to thereby provide power output from said apparatus.

13. The apparatus of claim 12 wherein said ramjet means operates at an inlet velocity of at least Mach 2.0.

14. The apparatus of claim 12, wherein said ramjet means operates at an inlet velocity of at least Mach 3.0.

15. The apparatus of claim 12 wherein said ramjet means operates at an inlet velocity between Mach 3.0 and Mach 4.5.

16. The apparatus of claim 12 wherein said ramjet means operates at an inlet velocity of approximately Mach 3.5.

17. The apparatus of claim 12, wherein said ramjet means further comprises a silicon carbide combustion chamber on said thrust module.

18. The apparatus as set forth in claim 17, wherein said silicon carbide combustion chamber comprises a monolithic silicon carbide portion.

19. The apparatus as set forth in claim 17, wherein said silicon carbide combustion chamber comprises a replaceable cast silicon carbide monostructure insert.

20. A method of generating power, comprising:

(a) providing one or more thrust modules rotatably secured with respect to an outboard housing;

(b) supplying to said one or more thrust modules an airstream containing an oxidant and an oxidizable fuel;

(c) oxidizing said fuel between said one or more thrust modules and said outboard housing, to

(i) generate combustion gases which escape therefrom, to

(ii) generate a motive force by thrust reaction of said combustion gases escaping from between

(A) each of said one or more thrust modules, and

(B) at least a portion of said outboard housing;

(d) propelling said one or more thrust modules at an inlet velocity in excess of Mach 1.0 through said supplied airstream by way of said motive force, said one or more thrust modules characterized in that each of said one or more thrust modules relies on at least a portion of said outboard housing to assist in compression of a portion of said supplied airstream as each of said one or more thrust modules passes adjacent thereto;

(e) turning an output shaft operatively connected to said one or more thrust modules;

(f) whereby power is provided at said output shaft.

21. The method as recited in claim 20 wherein the inlet velocity of said one or more thrust modules is at least Mach 2.0.

22. The method as recited in claim 20, wherein the inlet velocity of said one or more thrust modules is at least Mach 3.0.

23. The method as recited in claim 20 wherein the operational inlet velocity of said one or more thrust modules is between Mach 3.0 and Mach 4.5.

24. The method as recited in claim 20 wherein the operational inlet velocity of said one or more thrust modules is approximately Mach 3.5.

25. The method as recited in claim 20, wherein said fuel is selected from the group comprising gaseous hydrocarbon fuels.

26. The method as recited in claim 25, wherein said fuel is essentially natural gas.

27. The method as recited in claim 20, wherein the step of supplying fuel comprises injecting said fuel into a portion of said supplied airstream radially inward of said outboard housing at a point prior to compression of said portion of said supplied airstream between said outboard housing and any one of said one or more thrust modules.

28. The method as recited in claim 20, wherein said method of generating power further comprises the step of generating electricity.

29. The method as recited in claim 28, wherein the step of generating electricity comprises operatively connecting an electrical generator to said output shaft.

30. The method of generating power as recited in claim 20, wherein said method further includes the step of recovering thermal energy from said combustion gases.

31. The method as recited in claim 30, wherein said thermal energy recovery step comprises transfer of said thermal energy from said combustion gases to a secondary working fluid.

32. The method as recited in claim 31, wherein said secondary working fluid is water, and wherein steam is produced by heating said water.

33. The method as recited in claim 31, wherein said thermal energy recovery step comprises indirect heating of said secondary working fluid by said combustion gases.

34. The method as recited in claim 33, further comprising the step of directing said secondary working fluid to a turbine having a working shaft and generating power by rotation of said turbine by said secondary working fluid, to produce shaft work from said turbine.

35. The method as recited in claim 34, further comprising the step of generating electricity from said shaft work of said turbine.

36. The method as recited in claim 20, further comprising the step of minimizing aerodynamic drag as said one or more thrust modules rotates at supersonic speed.

37. The method as recited in claim 36, wherein said one or more thrust modules are rotatably secured to said output shaft via a rotor, said rotor having an inlet side surface and an outlet side surface and wherein the step of minimizing aerodynamic drag comprises controlling boundary layer drag on said rotor inlet side surface and outlet side surface of said rotor.

38. The method as set forth in claim 37, wherein the step of minimizing aerodynamic drag by controlling boundary layer drag on said rotor inlet side surface and said rotor outlet side surface comprises:

(a) providing an inlet housing with an inlet rotor side surface in close proximity to at least a substantial portion of said inlet side surface of said rotor; and

(b) providing an outlet housing with an outlet rotor side surface in close proximity to at least a substantial portion of said outlet side surface of said rotor.

39. The method of generating power as recited in claim 20, wherein the step of providing an oxidant to said one or more thrust modules is provided by oxygen present in said supplied airstream and wherein said supplied airstream is provided through a supplied air plenum formed between said outboard housing and a stationary inboard housing and wherein each of said one or more thrust modules are circumferentially spaced apart so as to engage said supplied airstream substantially free of turbulence from the previous passage through a given circumferential location of any said one or more thrust modules.

40. An apparatus for generating power, comprising:

(a) an inboard housing and a circumferential peripheral wall housing, between which inlet air and fuel is supplied;

(b) an output shaft, said output shaft rotatably secured about a central axis;

(c) a rotor, said rotor securely affixed to said output shaft;

(d) at least one ramjet, said at least one ramjet

(i) comprising an inboard portion securely affixed to said rotor, said inboard portion further comprising a compression ramp;

(ii) utilizing said circumferential peripheral wall housing as an outboard portion, so that said circumferential peripheral wall housing acts as a retaining surface against which said inlet air is compressed by said compression ramp of said inboard portion of said at least one ramjet.

41. The apparatus of claim 40 wherein said at least one ramjet operates at an inlet velocity of at least Mach 2.0.

42. The apparatus of claim 40, wherein said at least one ramjet operates at an inlet velocity of at least Mach 3.0.

43. The apparatus of claim 40 wherein said at least one ramjet operates at an inlet velocity of between Mach 3.0 and Mach 4.5.

44. The apparatus of claim 40 wherein said at least one ramjet operates at an inlet velocity of approximately Mach 3.5.

45. The apparatus of claim 40, wherein said output shaft is rotatably secured to said at least one ramjet by a rotor constructed of a high strength material.

46. The apparatus of claim 40, wherein at increasing radius from said central axis and for at least a substantial portion of said rotor in increasing radial location, said rotor is tapered.

47. The apparatus of claim 40, wherein said rotor
 (a) comprises a high strength material; and
 (b) has a large material taper ratio.

48. The apparatus of claim 45, wherein said rotor comprises a carbon composite.

49. The apparatus of claim 45, wherein said rotor comprises a metal matrix composite.

50. The apparatus as set forth in claim 40, wherein said inboard portion of each of said at least one ramjets further comprises a pair of inlet structures, said inlet structures located on opposing sides of said compression ramp, said inlet structures adapted to contain therebetween

said inlet air, as said inlet air is compressed against said circumferential peripheral wall housing by said compression ramp.

51. The apparatus as set forth in claim 40, wherein said rotor further comprises, along the circumference thereof, a plurality of ventilatable rotor caps.

52. The apparatus as set forth in claim 40, wherein said rotor further comprises an inlet side surface and an outlet side surface, said apparatus further comprising

(a) an inlet housing with an inlet rotor side surface in close proximity to at least a substantial portion of said inlet side surface of said rotor, and

(b) an outlet housing with a outlet rotor side surface in close proximity to at least a substantial portion of said outlet side surface of said rotor,

(c) said inlet housing in close proximity to said inlet side surface of said rotor, and said outlet housing in close proximity to said outlet side surface of said rotor, to thereby minimizing aerodynamic drag on said rotor, by minimizing boundary layer drag on said rotor inlet side surface and on said rotor outlet side surface.

53. The method as set forth in claim 20, wherein said fuel and said oxidant are thoroughly mixed before compression of said airstream containing said fuel and said oxidant.

54. The method as set forth in claim 20, wherein combustion of said fuel and said oxidant occurs during a short residence time at high combustion temperatures.

55. The method as set forth in claim 54, wherein said high combustion temperature of said fuel occurs for only about 0.24 microseconds.

56. The method as set forth in claim 54, wherein said high combustion temperature of said fuel occurs for less than 0.24 microseconds.

57. The method as set forth in claim 53, wherein said combustion gases comprise less than ten parts per million of nitrogen oxides.

58. The method as set forth in claim 53, wherein said combustion gases comprise less than five parts per million of nitrogen oxides.

59. An apparatus for generating power, comprising:

(a) an inboard housing and a circumferential peripheral wall housing, between which inlet air and fuel is supplied;

(b) an output shaft, said output shaft rotatably secured about a central axis;

(c) a rotor, said rotor

(i) securely affixed to said output shaft; and

(ii) said rotor, at increasing radius from said central axis and for at least a substantial portion of said rotor in increasing radial location, is tapered; and

(iii) said rotor further comprising an inlet side surface and an outlet side surface;

(d) at least one ramjet, said at least one ramjet

(i) comprising an inboard portion securely affixed to said rotor, said inboard portion further comprising a compression ramp;

(ii) utilizing said circumferential peripheral wall housing as an outboard portion, so that said circumferential peripheral wall housing acts as a retaining surface against which said inlet air is compressed by said compression ramp of said inboard portion of said at least one ramjet,

(iii) operating at an inlet velocity in excess of Mach 1,

(iv) said inboard portion of each of said at least one ramjets further comprising a pair of inlet structures, said inlet structures located on opposing sides of said compression ramp, said inlet structures adapted to contain therebetween said inlet air, as said inlet air is compressed against said circumferential peripheral wall housing by said compression ramp;

(e) an inlet housing with an inlet rotor side surface in close proximity to at least a substantial portion of said inlet side surface of said rotor;

(f) an outlet housing with a outlet rotor side surface in close proximity to at least a substantial portion of said outlet side surface of said rotor; and

(g) wherein said inlet housing is in close proximity to said inlet side surface of said rotor, and said outlet housing is in close proximity to said outlet side surface of said rotor, to thereby minimizing aerodynamic drag on said rotor, by minimizing boundary layer drag on said rotor inlet side surface and on said rotor outlet side surface.

60. The apparatus of claim 59 wherein said at least one ramjet operates at an inlet velocity of at least Mach 2.0.

61. The apparatus of claim 59, wherein said at least one ramjet operates at an inlet velocity of at least Mach 3.0.

62. The apparatus of claim 59 wherein said at least one ramjet operates at an inlet velocity of between Mach 3.0 and Mach 4.5.

63. An apparatus for generating power, comprising:
   (e) a circumferential wall, against which inlet air and fuel is supplied;
   (f) an output shaft, said output shaft rotatably secured about a central axis;
   (g) a rotor, said rotor securely affixed to said output shaft;
   (h) at least one ramjet, said at least one ramjet
      (i) comprising a compression portion, said compression portion securely affixed to said rotor;
      (ii) utilizing said circumferential wall as a compression resistance portion, so that said circumferential wall acts as a retaining surface against which said inlet air is compressed circumfluently by said compression ramp portion of said at least one ramjet.

64. The apparatus of claim 63 where in said at least one ramjet operates at an inlet velocity of at least Mach 2.0.

65. The apparatus of claim 63, wherein said at least one ramjet operates at an inlet velocity of at least Mach 3.0.

66. The apparatus of claim 63 wherein said at least one ramjet operates at an inlet velocity of between Mach 3.0 and Mach 4.5.

67. The apparatus of claim 63 wherein said at least one ramjet operates at an inlet velocity of approximately Mach 3.5.

68. The apparatus of claim 63, wherein said output shaft is rotatably secured to said at least one ramjet by a rotor constructed of a high strength material.

69. The apparatus of claim 63, wherein at increasing radius from said central axis and for at least a substantial

portion of said rotor in increasing radial location, said rotor is tapered.

70. The apparatus of claim 63, wherein said rotor
   (a) comprises a high strength material; and
   (b) has a large material taper ratio.

71. The apparatus of claim 68, wherein said rotor comprises a carbon composite.

72. The apparatus of claim 68, wherein said rotor comprises a metal matrix composite.

73. The apparatus as set forth in claim 63, wherein said compression portion of each of said at least one ramjets further comprises a pair of inlet structures, said inlet structures located on opposing sides of said compression portion, said inlet structures adapted to contain therebetween said inlet air, as said inlet air is compressed against said circumferential peripheral wall by said compression portion.

74. The apparatus as set forth in claim 63, wherein said rotor further comprises a plurality of ventilatable rotor caps.

75. The apparatus as set forth in claim 63, wherein said rotor further comprises an inlet side surface and an outlet side surface, said apparatus further comprising:
   (a) an inlet housing with an inlet rotor side surface in close proximity to at least a substantial portion of said inlet side surface of said rotor; and
   (b) an outlet housing with an outlet rotor side surface in close proximity to at least a substantial portion of said outlet side surface of said rotor;
   (c) said inlet housing in close proximity to at least a substantial portion of said inlet side surface of said

rotor and said outlet housing in close proximity to said outlet side surface of said rotor, thereby minimizing aerodynamic drag on said rotor by minimizing boundary layer drag on said rotor inlet side surface and on said rotor outlet side surface.

76. An apparatus for generating power, comprising:

(a) a circumferential wall, against which inlet air and fuel is supplied;

(b) an output shaft, said output shaft rotatably secured about a central axis;

(c) a rotor, said rotor

(i) securely affixed to said output shaft; and

(ii) said rotor, at increasing radius from said central axis and for at least a substantial portion of said rotor in increasing radial location, is tapered; and

(iii) said rotor further comprising an inlet side surface and an outlet side surface;

(d) at least one ramjet, said at least one ramjet

(i) comprising a compression portion affixed to said rotor, said compression portion further comprising a compression ramp;

(ii) utilizing said circumferential wall as a retaining surface against which said inlet air is compressed by said compression ramp of said at least one ramjet;

(iii) operating at an inlet velocity in excess of Mach 1;

(iv) said compression portion of each of said at least one ramjets further comprising a pair of inlet structures, said inlet structures located on opposing sides of said compression ramp, said inlet structures adapted to contain therebetween said inlet air, as said inlet air is compressed in circumfluently against said circumferential wall by said compression ramp;

(e) an inlet housing with an inlet rotor side surface in close proximity to at least a substantial portion of said inlet side surface of said rotor;

(f) an outlet housing with a outlet rotor side surface in close proximity to at least a substantial portion of said outlet side surface of said rotor; and

(g) wherein said inlet housing is in close proximity to said inlet side surface of said rotor, and said outlet housing is in close proximity to said outlet side surface of said rotor, minimizing aerodynamic drag on said rotor by minimizing boundary layer drag on said rotor inlet side surface and on said rotor outlet side surface.

77. The apparatus of claim 76 wherein said at least one ramjet operates at an inlet velocity of at least Mach 2.0.

78. The apparatus of claim 76, wherein said at least one ramjet operates at an inlet velocity of at least Mach 3.0.

79. The apparatus of claim 76 wherein said at least one ramjet operates at an inlet velocity of between Mach 3.0 and Mach 4.5.

80. The apparatus as set forth in claim 63 or in claim 76, wherein said circumferential wall is stationary.

81. A method of generating power, comprising:

(g) providing one or more thrust modules rotatably secured with respect to a circumferential wall;

(h) supplying to said one or more thrust modules an airstream containing an oxidant and an oxidizable fuel;

(i) oxidizing said fuel between said one or more thrust modules and said circumferential wall, to

(iii) generate combustion gases which escape therefrom, to

(iv) generate a motive force by thrust reaction of said combustion gases escaping from between

(C) each of said one or more thrust modules, and

(D) at least a portion of said circumferential wall;

(j) propelling said one or more thrust modules at an inlet velocity in excess of Mach 1.0 through said supplied airstream by way of said motive force, said one or more thrust modules characterized in that each of said one or more thrust modules relies on at least a portion of said circumferential wall to assist in compression of a portion of said supplied airstream as each of said one or more thrust modules passes adjacent thereto;

(k) turning an output shaft operatively connected to said one or more thrust modules;

(l) whereby power is provided at said output shaft.

82. The method as recited in claim 81 wherein the inlet velocity of said one or more thrust modules is at least Mach 2.0.

83. The method as recited in claim 81, wherein the inlet velocity of said one or more thrust modules is at least Mach 3.0.

84. The method as recited in claim 81 wherein the cperational inlet velocity of said one or more thrust modules is between Mach 3.0 and Mach 4.5.

85. The method as recited in claim 81 wherein the operational inlet velocity of said one or more thrust modules is approximately Mach 3.5.

86. The method as recited in claim 81, wherein said fuel is selected from the group comprising gaseous hydrocarbon fuels.

87. The method as recited in claim 81, wherein said fuel is essentially natural gas.

88. The method as recited in claim 81, wherein the step of supplying fuel comprises injecting said fuel into a portion of said supplied airstream at a point prior to compression of said portion of said supplied airstream between said circumferential wall and any one of said one or more thrust modules.

89. The method as recited in claim 81, wherein said method of generating power further comprises the step of generating electricity.

90. The method as recited in claim 89, wherein the step of generating electricity comprises operatively connecting an electrical generator to said output shaft.

91. The method of generating power as recited in claim 81, wherein said method further includes the step of recovering thermal energy from said combustion gases.

92. The method as recited in claim 91, wherein said thermal energy recovery step comprises transfer of said thermal energy from said combustion gases to a secondary working fluid.

93. The method as recited in claim 92, wherein said secondary working fluid is water, and wherein steam is produced by heating said water.

94. The method as recited in claim 92, wherein said thermal energy recovery step comprises indirect heating of said secondary working fluid by said combustion gases.

95. The method as recited claim 94, further comprising the step directing said secondary working fluid to a turbine having a working shaft, and generating power by rotation of said turbine by said secondary working fluid, to produce shaft work from said turbine.

96. The method as recited in claim 95, further comprising the step of generating electricity from said shaft work of said turbine.

97. The method as recited in claim 81, further comprising the step of minimizing aerodynamic drag as said one or more thrust modules rotates at supersonic speed.

98. The method as recited in claim 97, wherein said one or more thrust modules are rotatably secured to said output shaft via a rotor, said rotor having an inlet side surface and an outlet side surface, and wherein the step of minimizing aerodynamic drag comprises controlling boundary layer drag on said rotor inlet side surface and outlet side surface of said rotor.

99. The method as set forth in claim 98, wherein the step of minimizing aerodynamic drag by controlling boundary layer

drag on said rotor inlet side surface and said rotor outlet side surface comprises

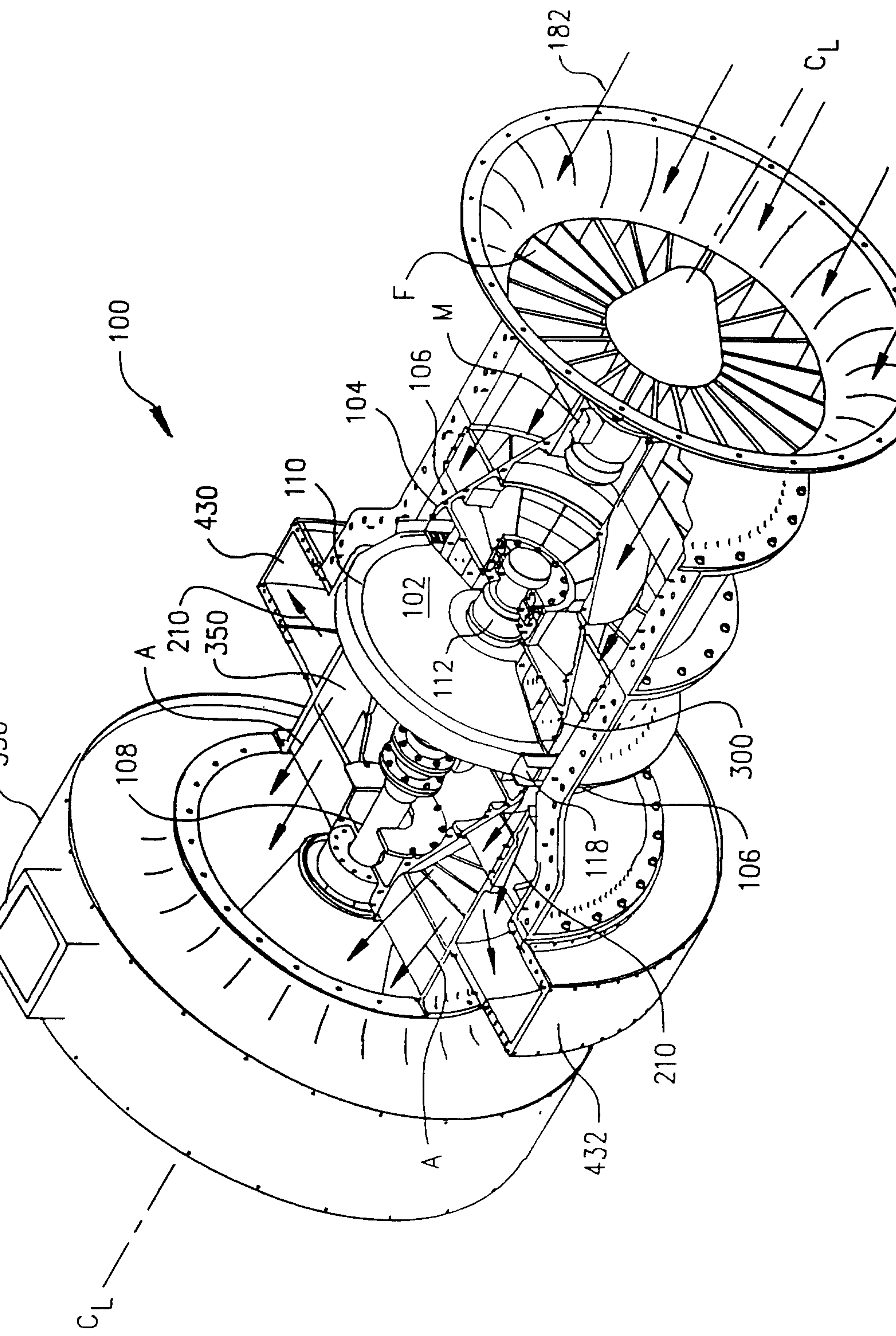
(c) providing an inlet housing with an inlet rotor side surface in close proximity to at least a substantial portion of said inlet side surface of said rotor, and

(d) providing an outlet housing with a outlet rotor side surface in close proximity to at least a substantial portion of said outlet side surface of said rotor.

100. The method as recited in claim of claim 81, wherein the step of providing an oxidant to said one or more thrust modules is provided by oxygen present in said supplied airstream, and wherein said supplied airstream is provided adjacent said circumferential wall, and wherein each of said one or more thrust modules are circumferentially spaced apart so as to engage said supplied airstream substantially free of turbulence from the previous passage through a given circumferential location of any one said one or more thrust modules.

101. The method as recited in claim 81, wherein said circumferential wall is stationary.

FIG. 1



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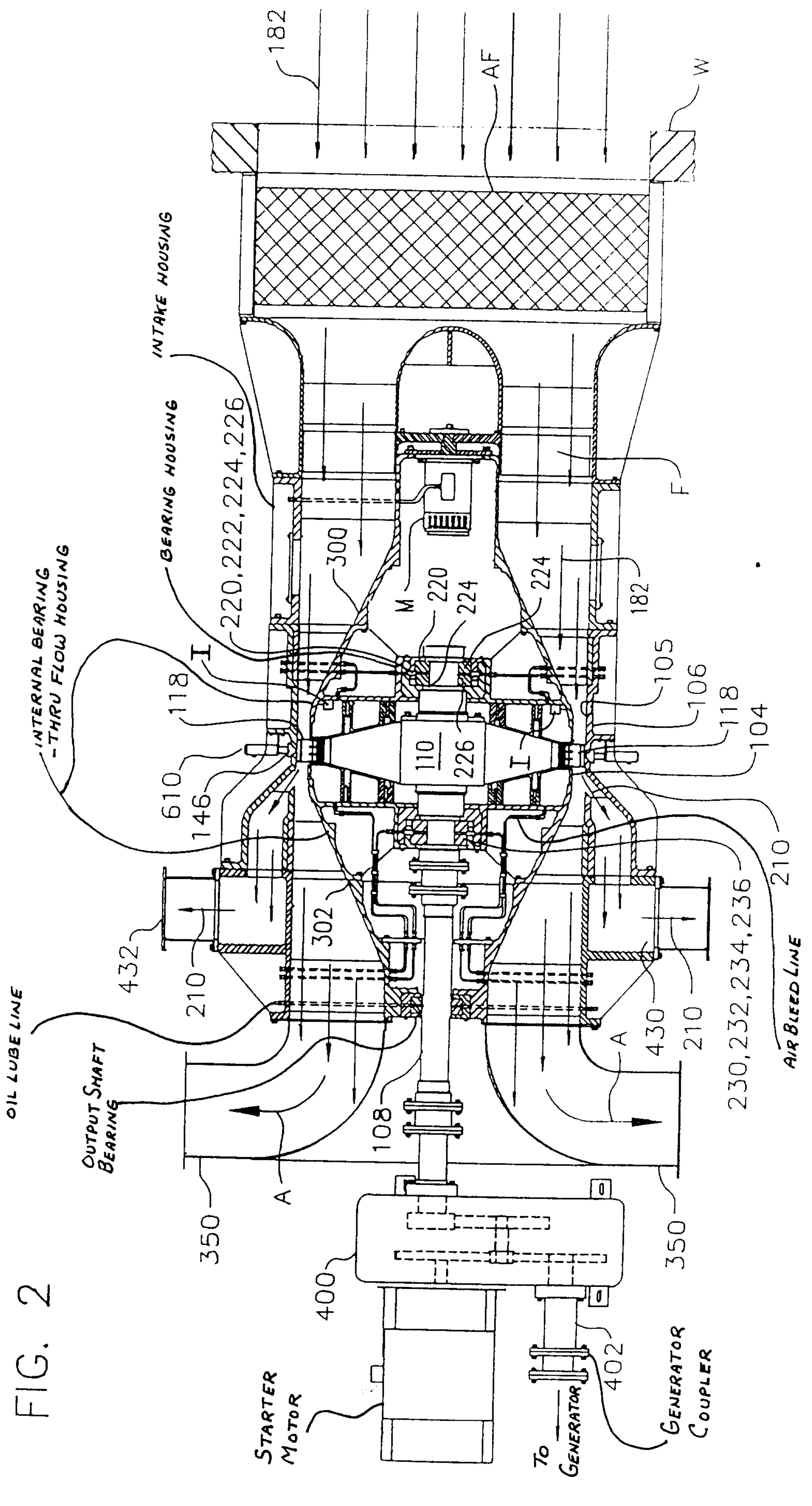

FIG. 2

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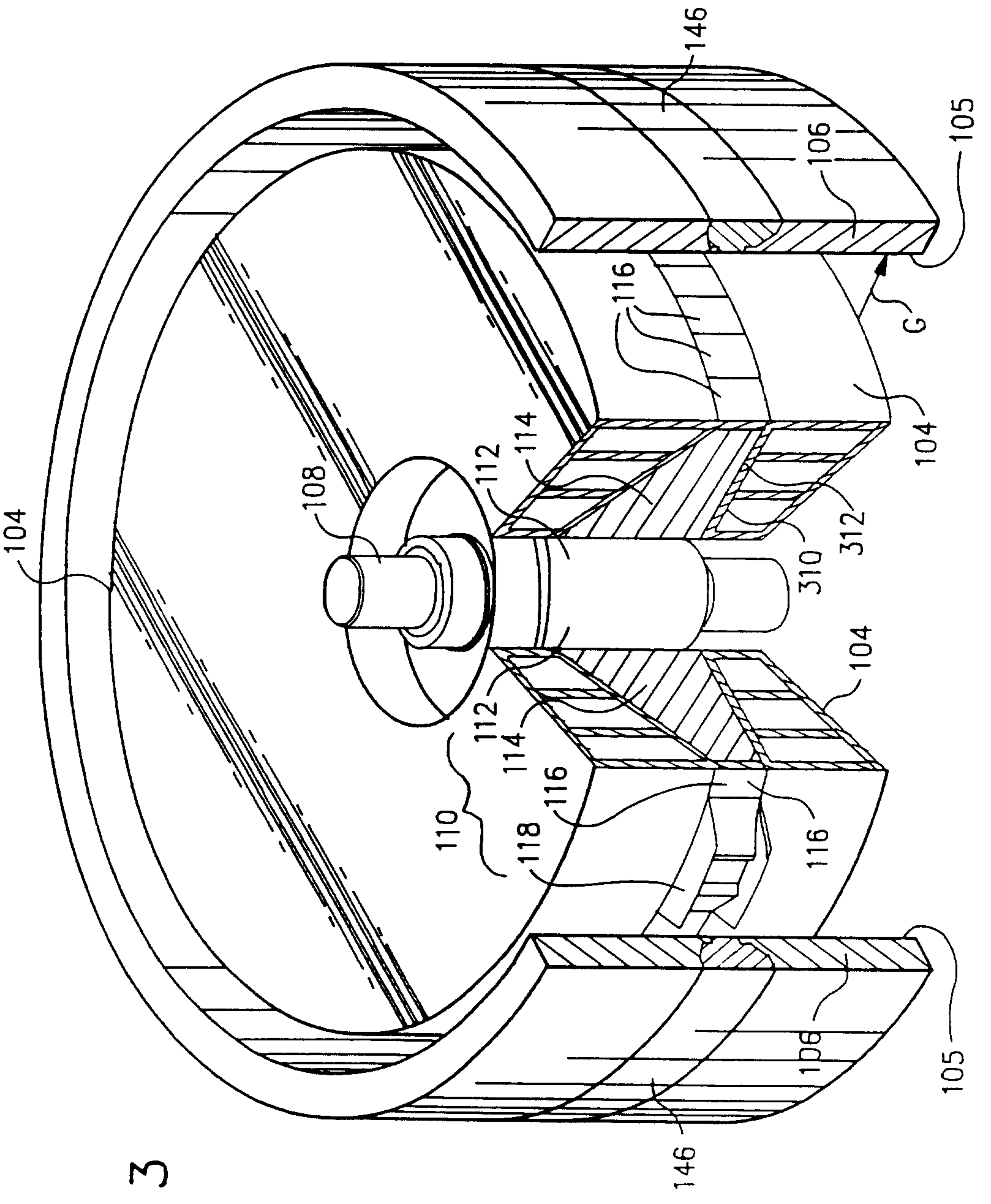
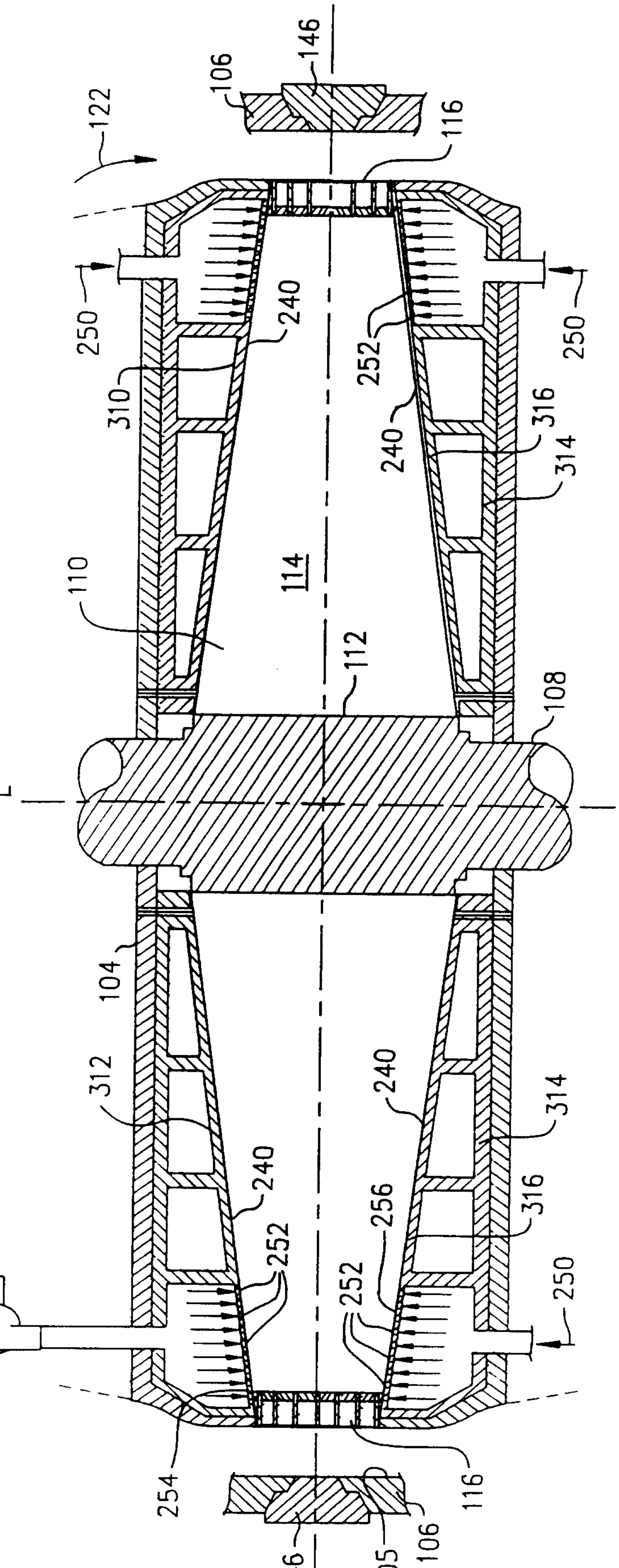


FIG. 3

FIG. 4



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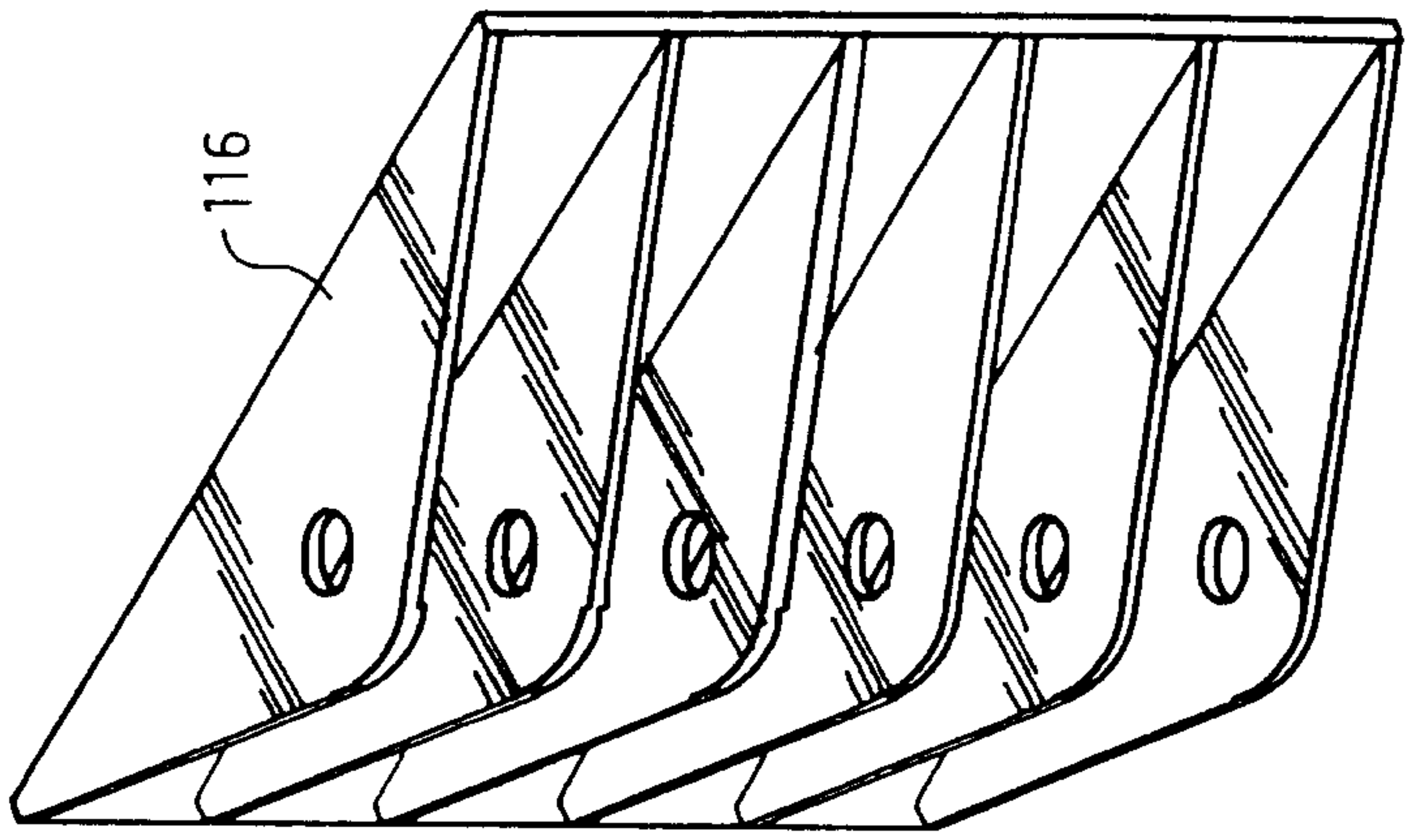

FIG. 10

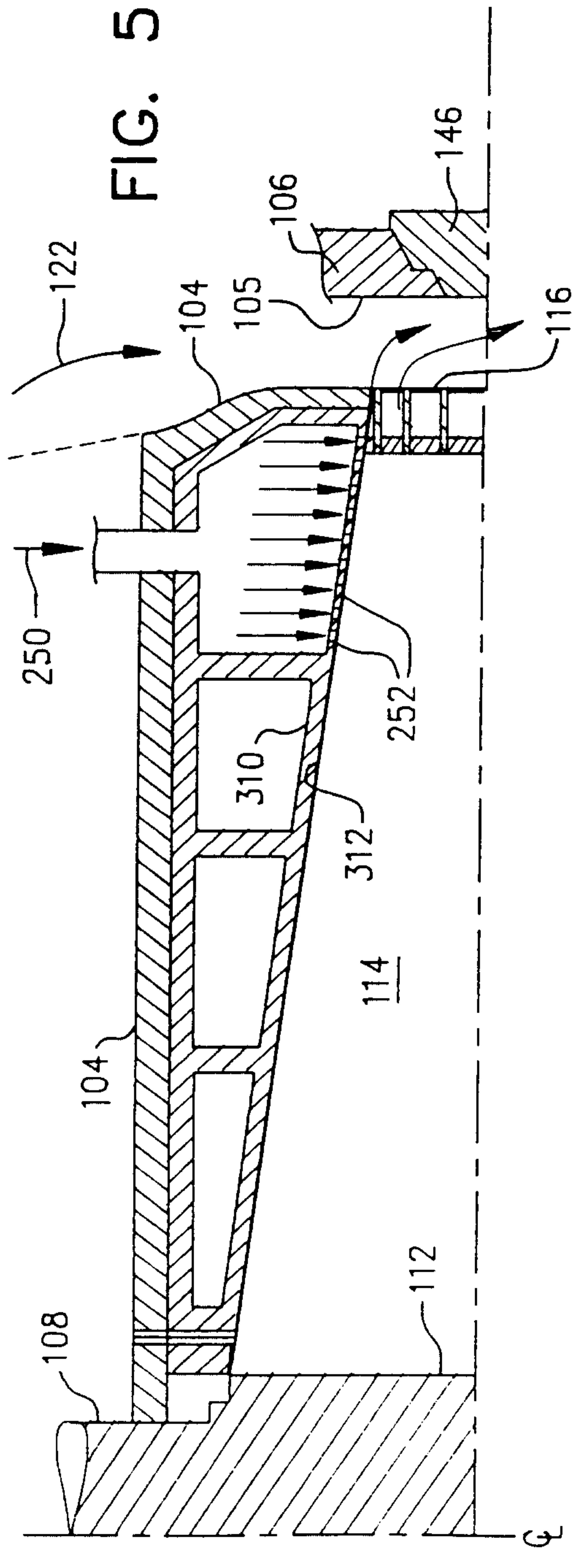

FIG. 5

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FIG. 6

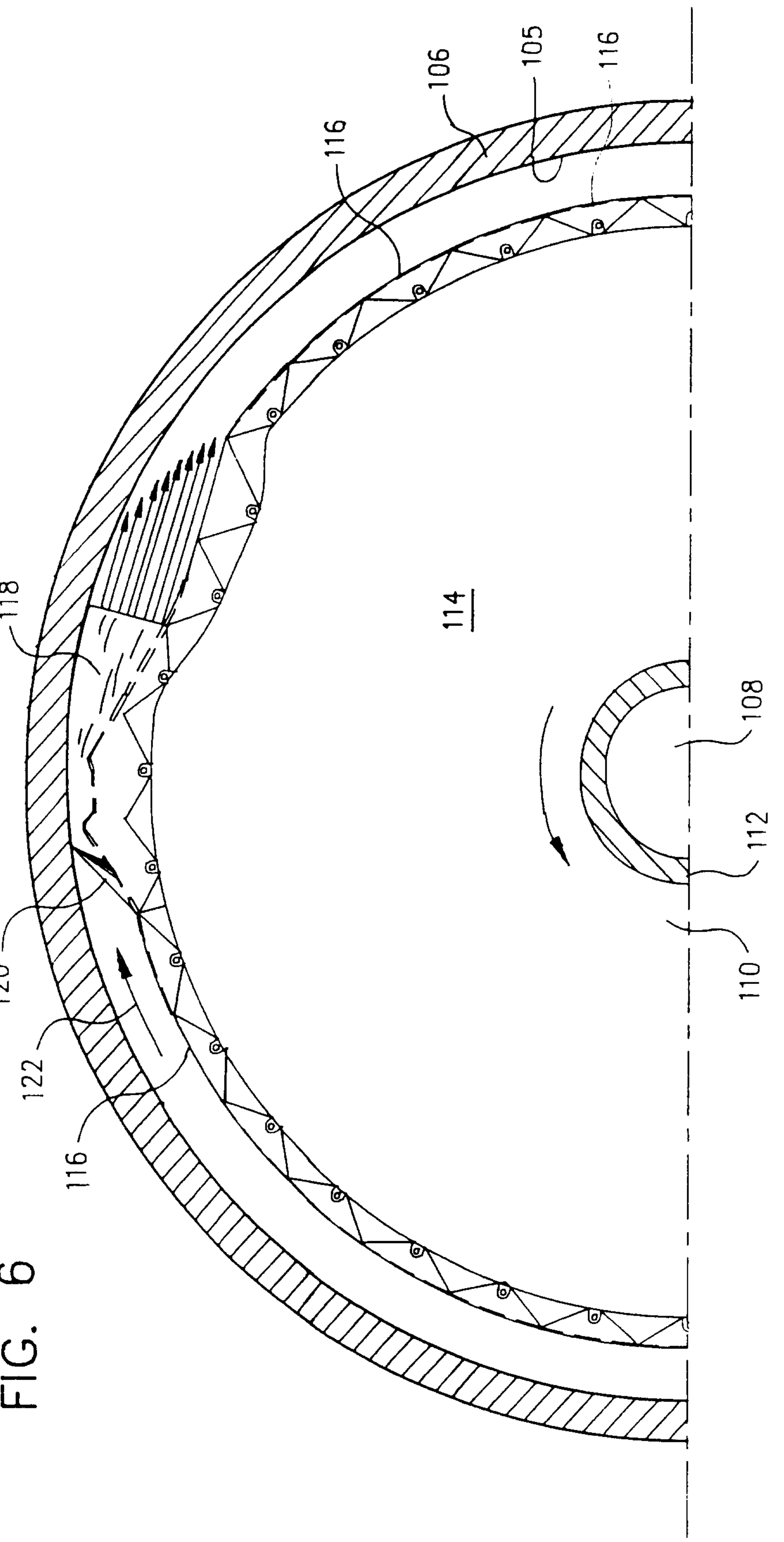

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FIG. 7

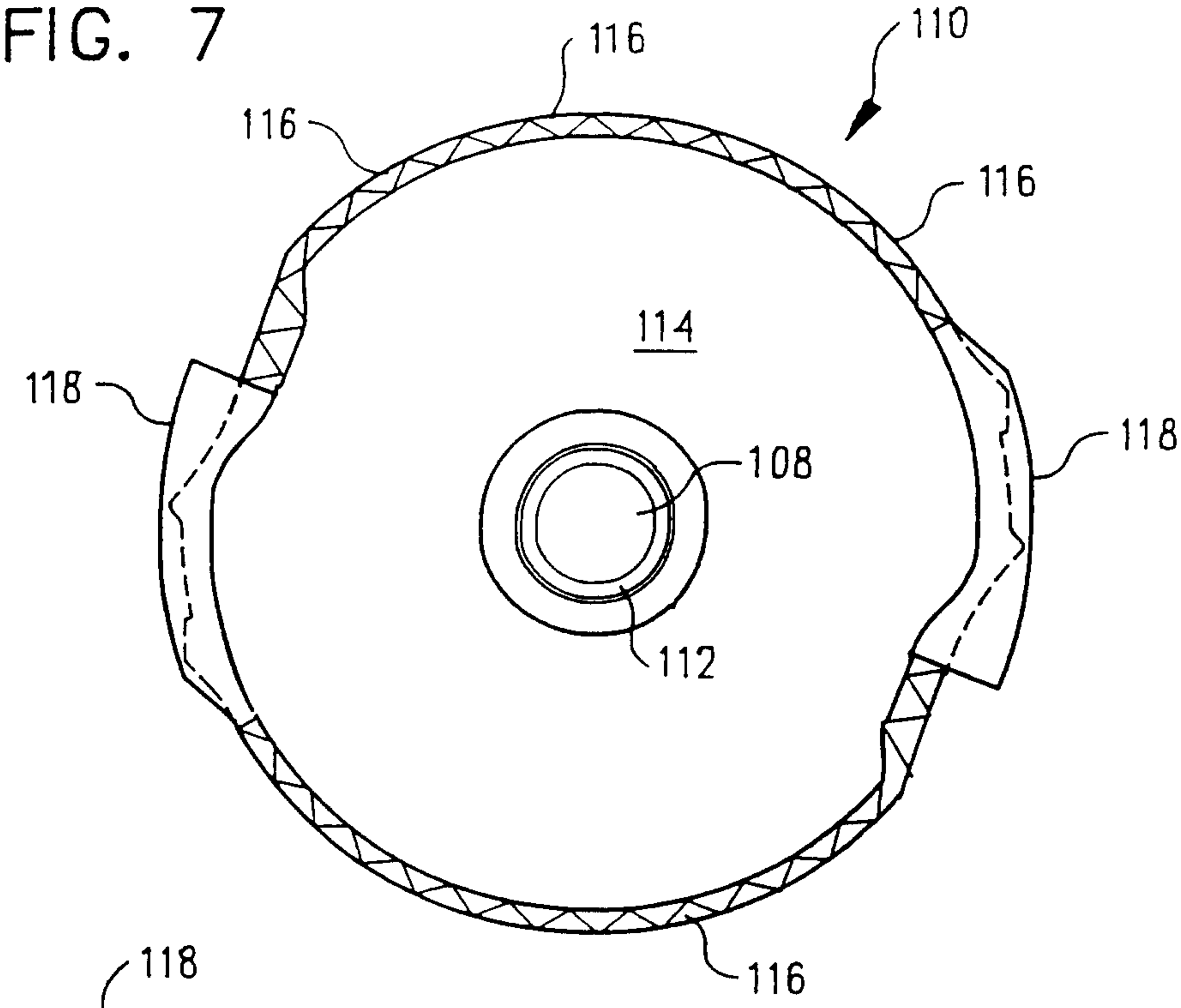

FIG. 9

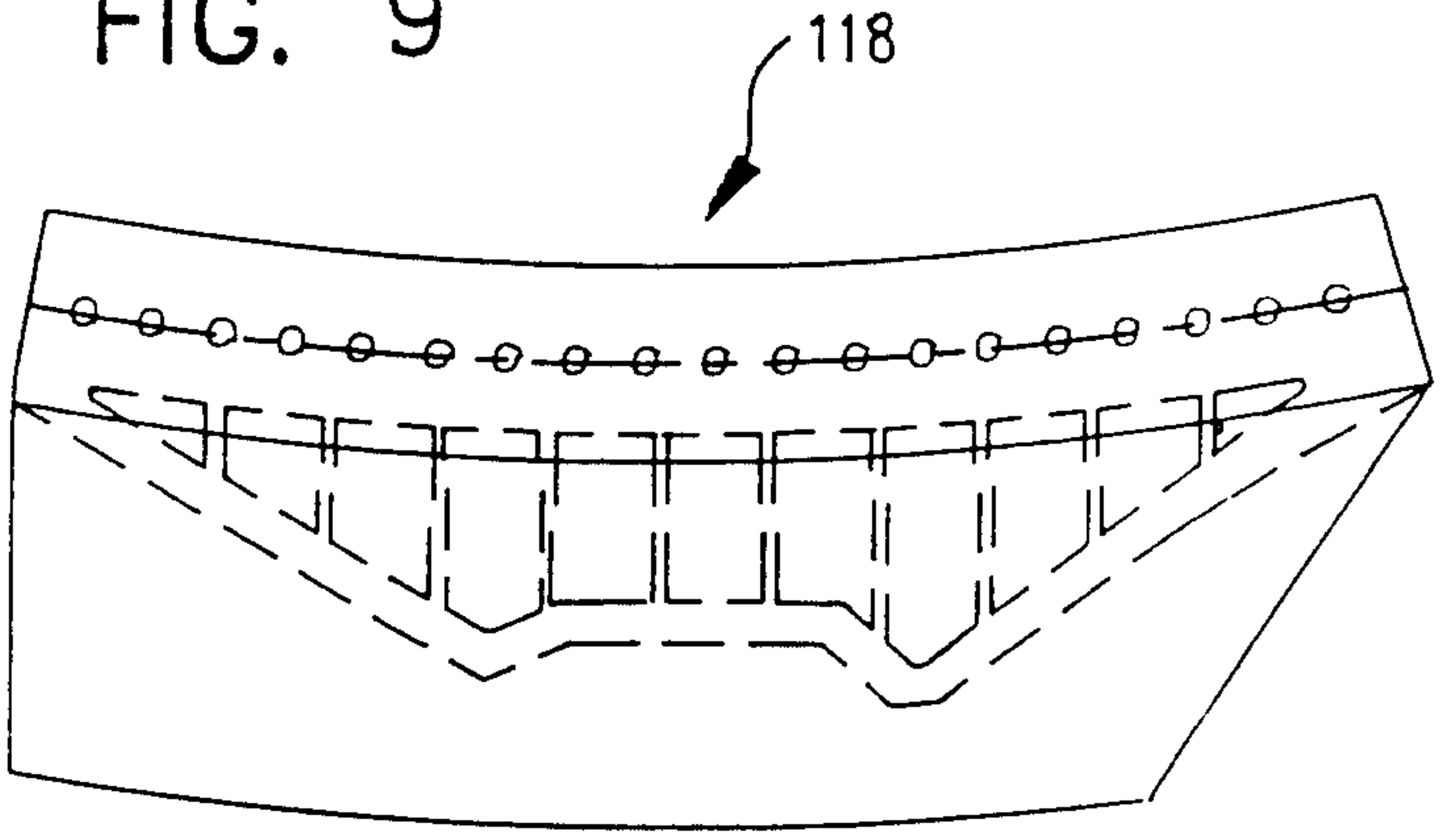

FIG. 8

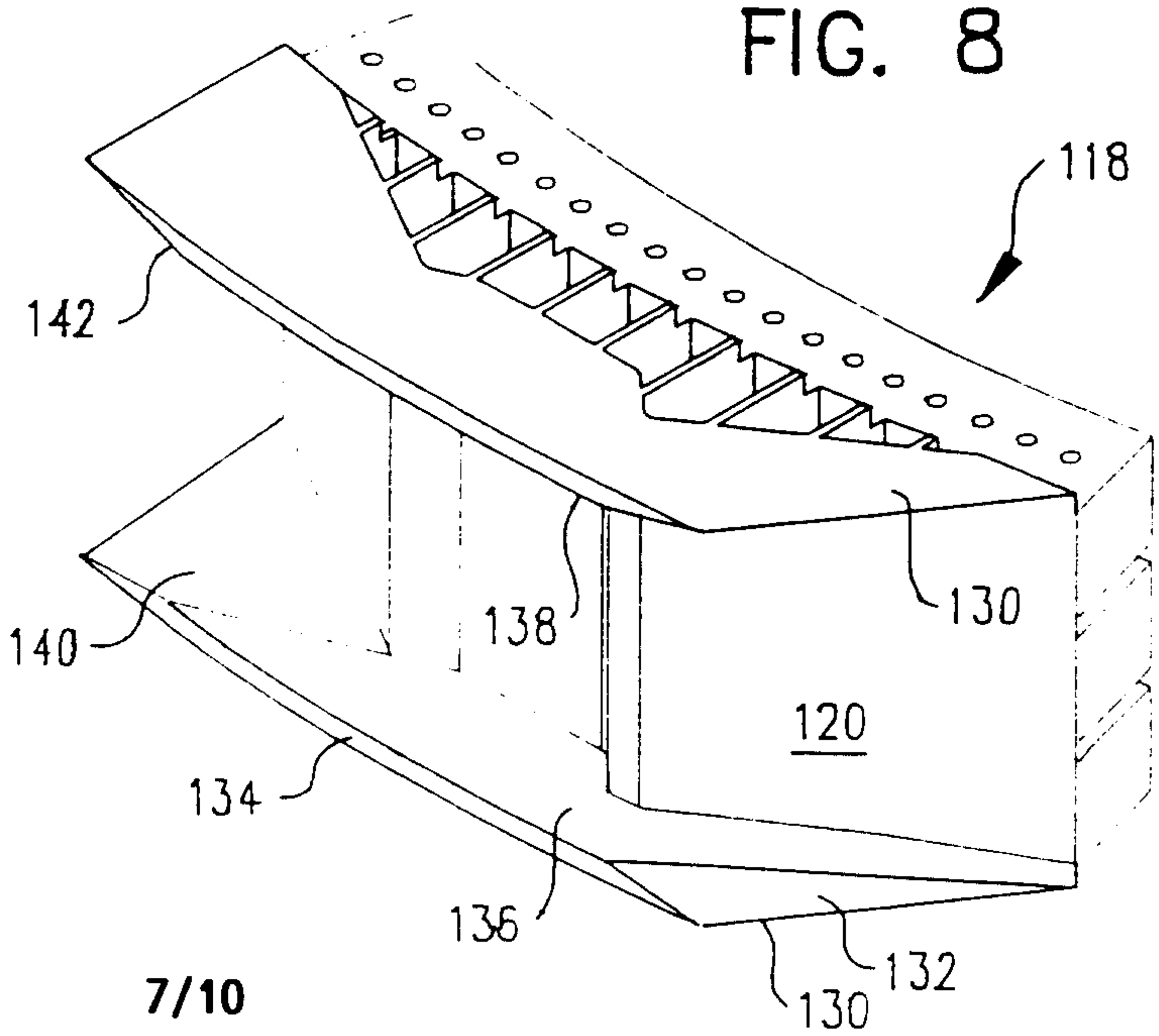

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FIG. 11

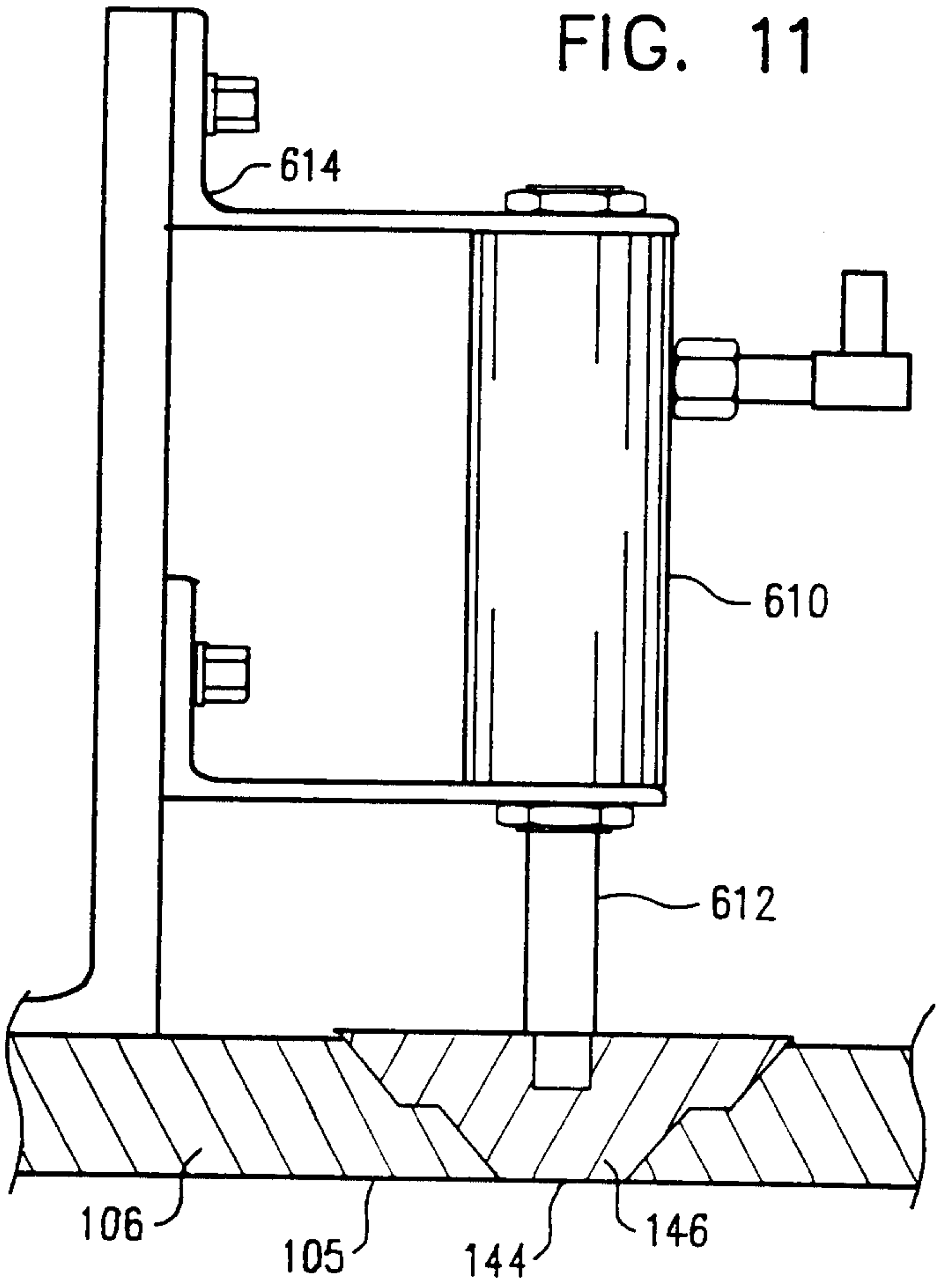
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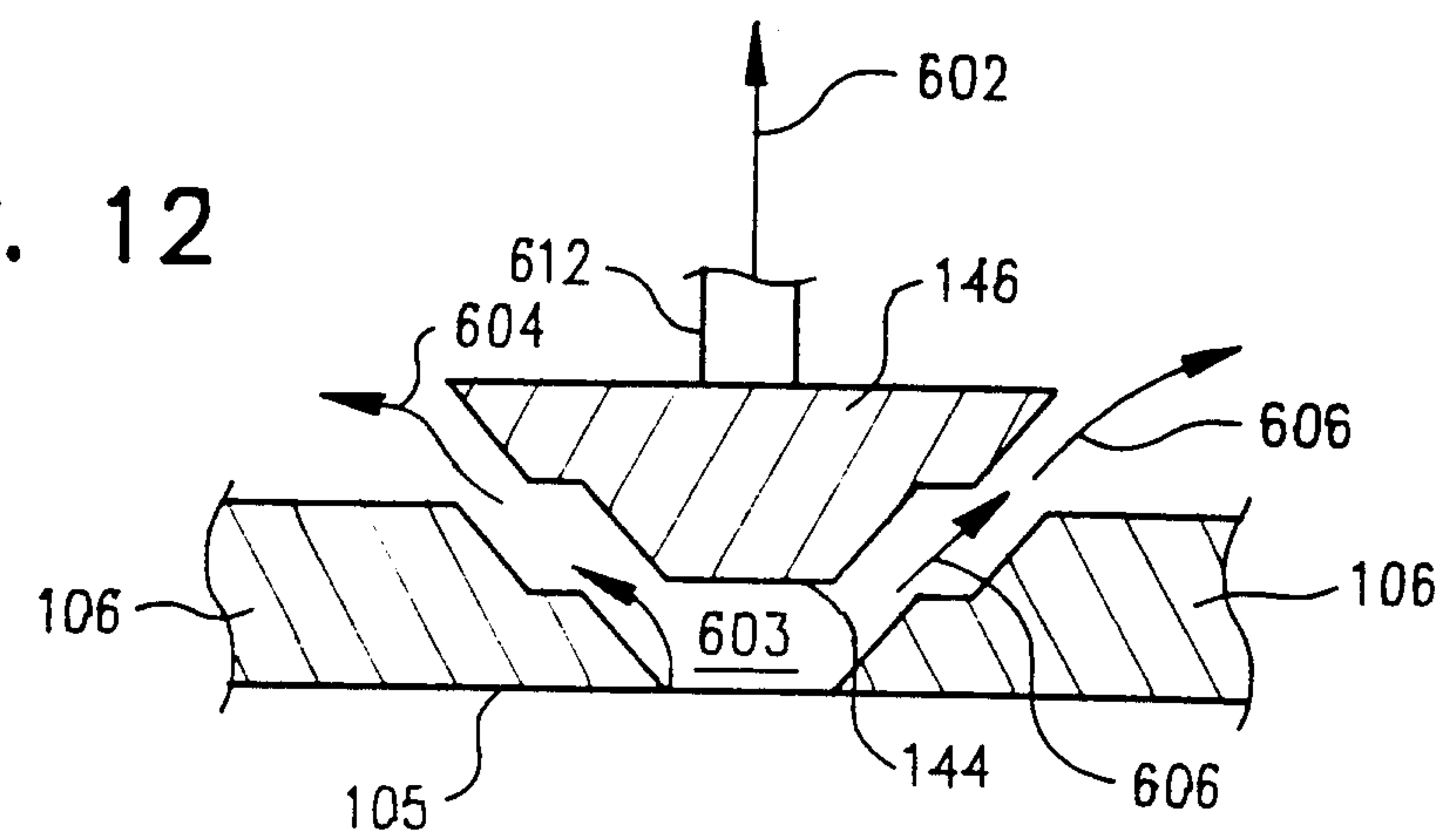
FIG. 12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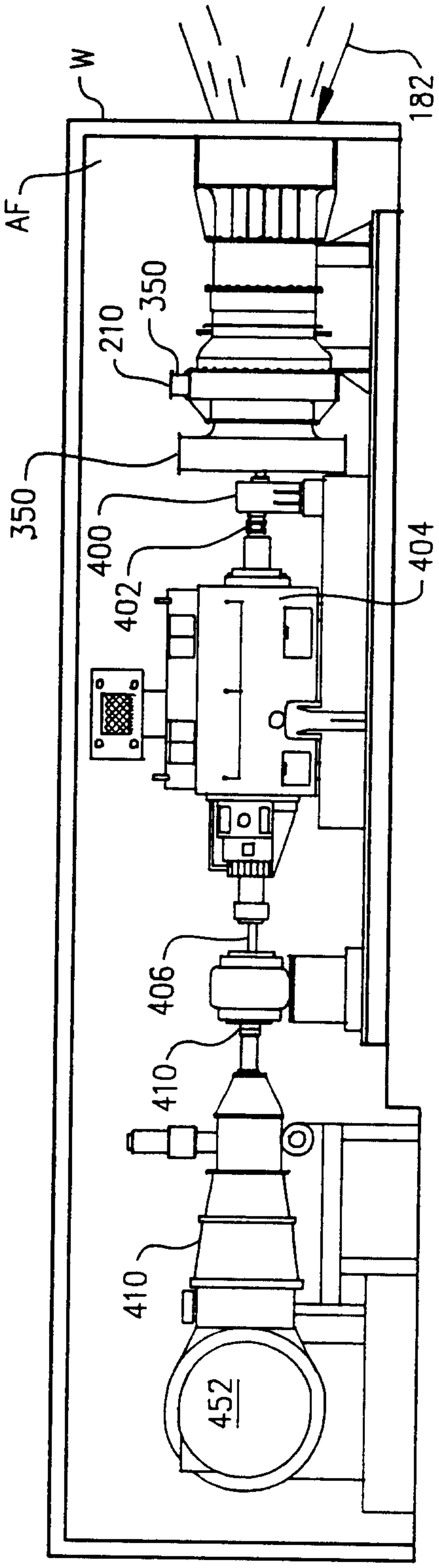
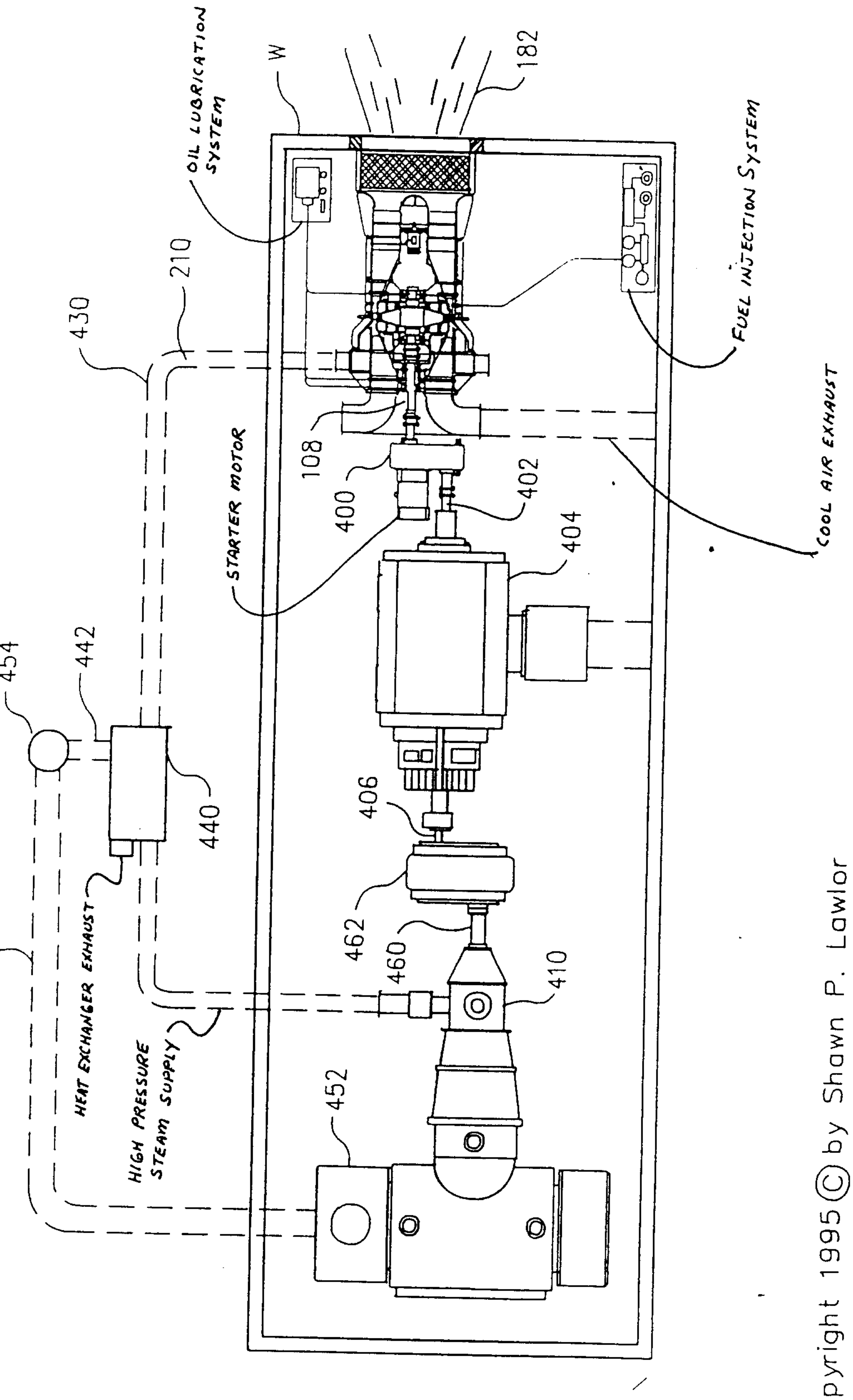


FIG. 13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FUEL INJECTION SYSTEM
COOL AIR EXHAUST
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402
404
STARTER MOTOR
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406
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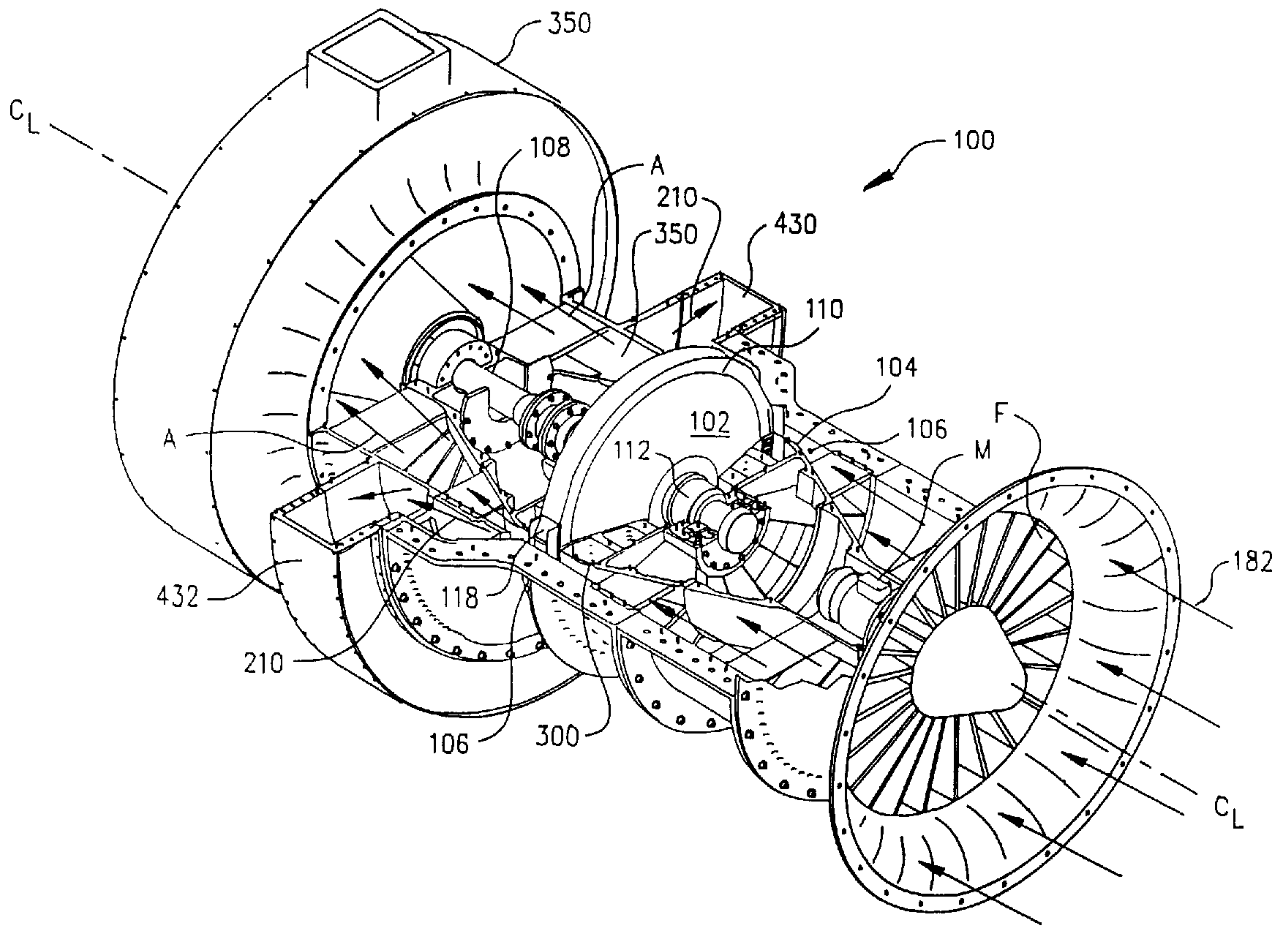
460
410
R
HEAT EXCHANGER EXHAUST
HIGH PRESSURE STEAM SUPPLY
452

FIG. 14



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