United States Patent [19]

Bechtold

[11] **3,769,796**

[45] **Nov. 6, 1973**

[54] **ROTARY HEAT ENGINES**

[75] Inventor: **Max F. Bechtold,** Kennett Square, Pa.

[73] Assignee: **E.I. du Pont de Nemours and Company,** Wilmington, Del.

[22] Filed: **Feb. 10, 1971**

[21] Appl. No.: **206,779**

[52] **U.S. Cl.** **60/108,** 122/11, 74/789

[51] **Int. Cl.** **F01k 11/00,** F01k 11/02

[58] **Field of Search** 60/108, 95; 122/11; 74/789

[56] **References Cited**

UNITED STATES PATENTS

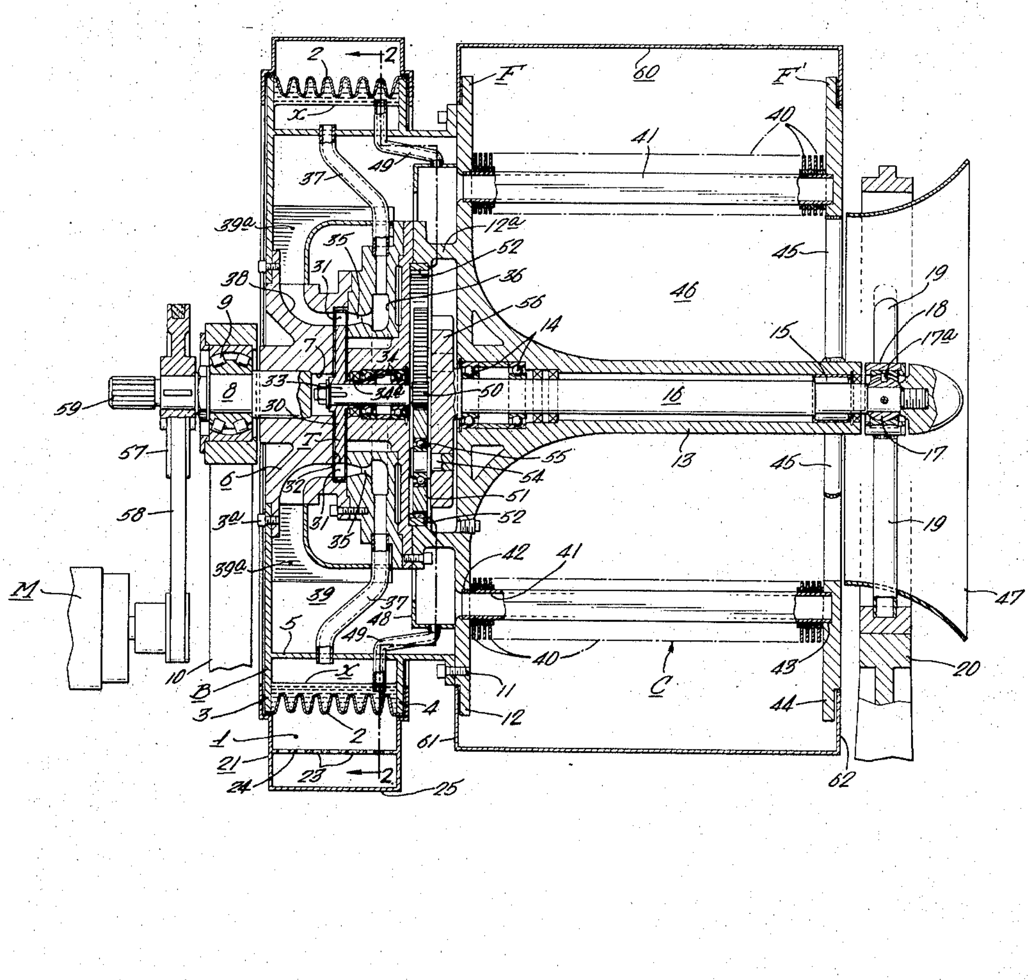
2,525,804	10/1950	Kellogg	60/108 R X
2,576,284	11/1951	Crocchi	60/108 R X
2,583,872	1/1952	Newcomb	60/108 R
2,810,304	10/1957	Ball	74/789
3,613,368	10/1971	Doerner	60/95 R

Primary Examiner—Martin P. Schwadron
Assistant Examiner—H. Burks
Attorney—Dexter N. Shaw et al.

[57] **ABSTRACT**

A rotary closed Rankine cycle engine including rotary closed housing containing a boiler and an expander, and a condenser connected to the housing, all rotatable as a unit about a common axis. The boiler is of annular construction and the housing and boiler are rotationally driven at a predetermined speed to maintain in the boiler an annular body of liquid having a liquid/vapor interface spaced a predetermined distance radially outward from the engine axis. The condenser is mounted coaxially adjacent the housing to rotate therewith as a unit about the engine axis. The expander actuates a coaxial driving member in the rotary housing and an occluded fixed ratio gear train mounted coaxially within the rotatable housing is driven by the expander driving member and connected to and communicating with the rotary housing-boiler-condenser unit to rotationally drive the latter at said predetermined speed. An external drive member is connected to the rotary housing and rotationally driven thereby, and means is provided opposing the reaction torque generated by the internal gear train so that the power output of the expander is transmitted directly to the rotary housing and the external drive member.

26 Claims, 16 Drawing Figures



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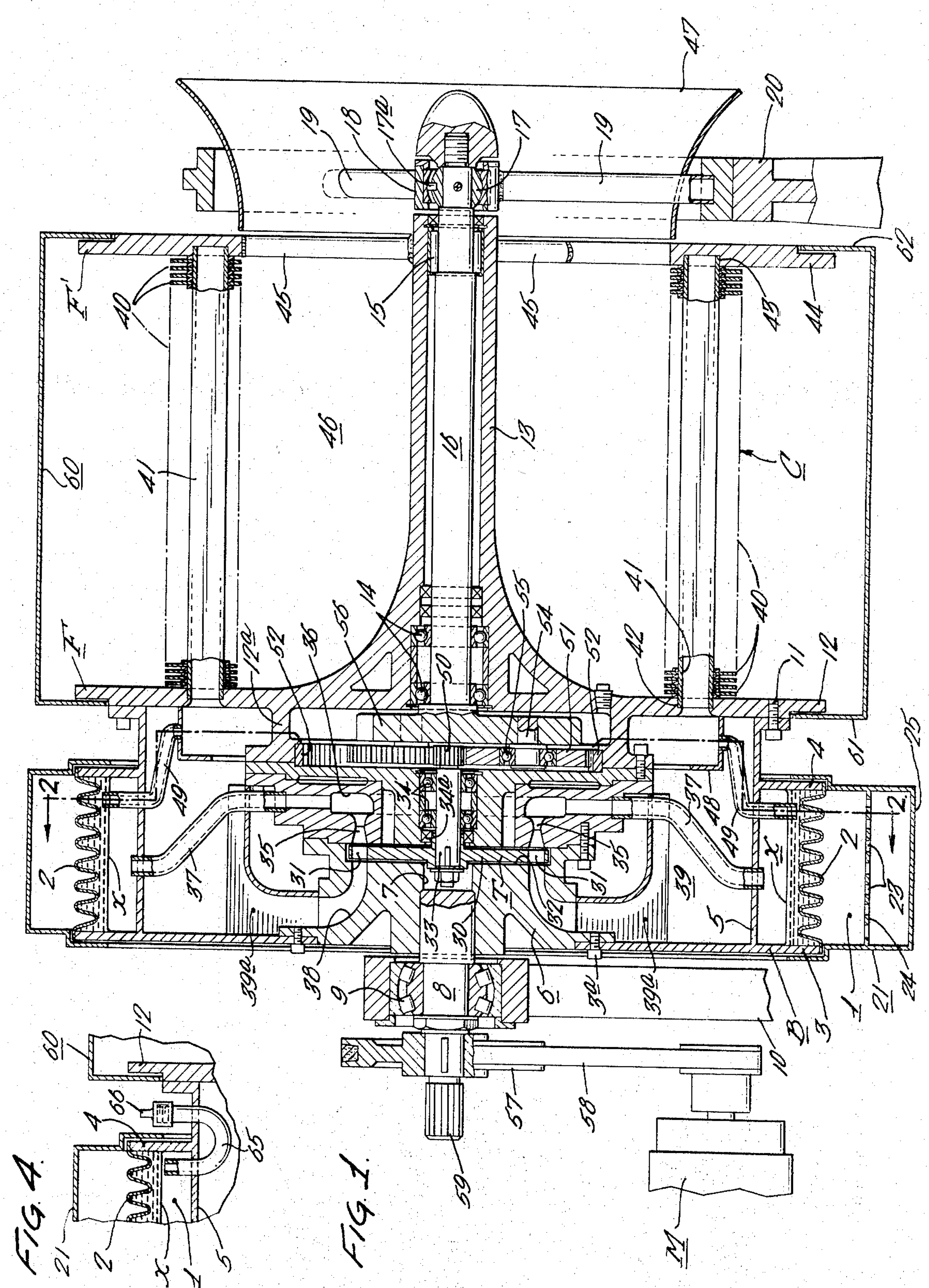

FIG. 1.

FIG. 4.

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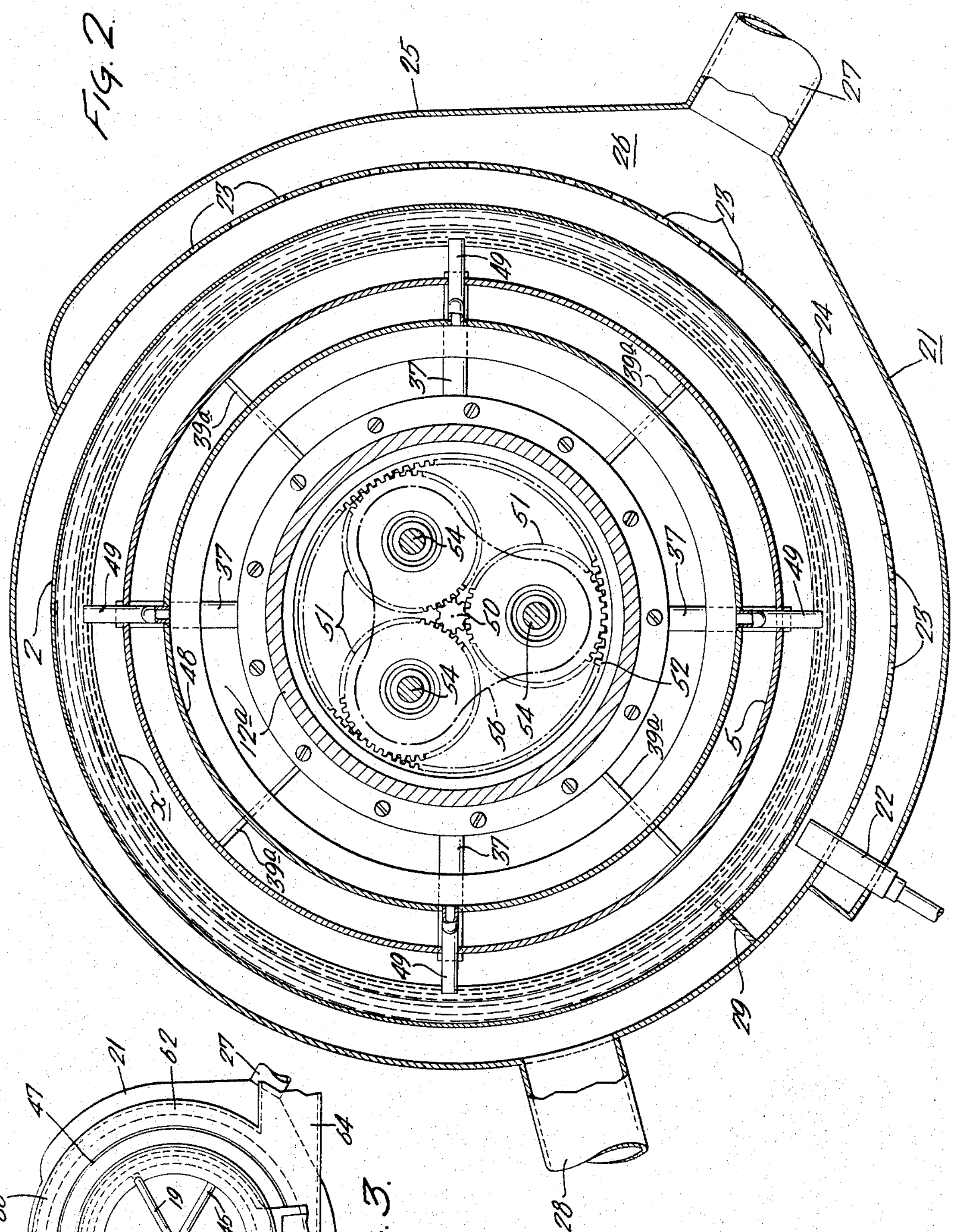
FIG. 2



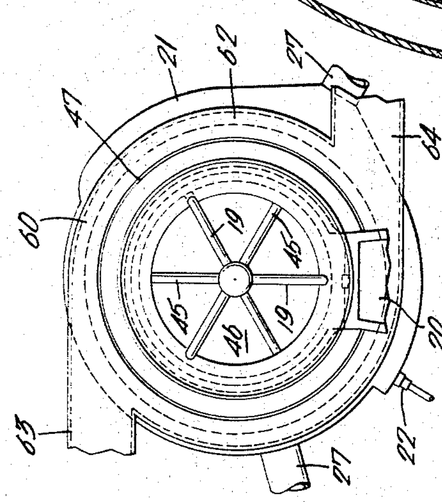


FIG. 3.

FIG. 5.

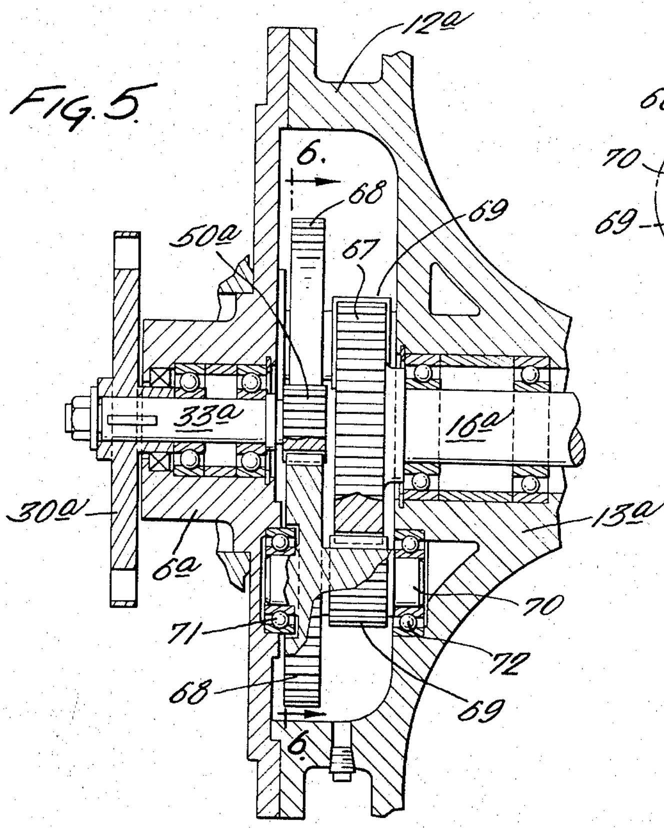


FIG. 6.

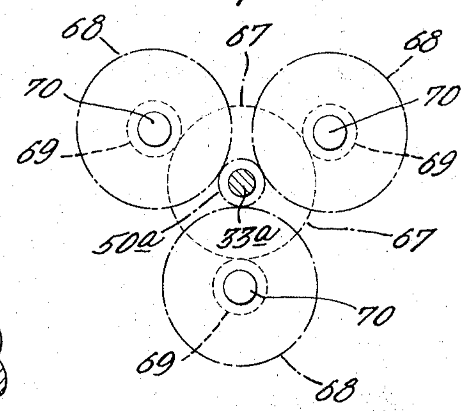


FIG. 7.

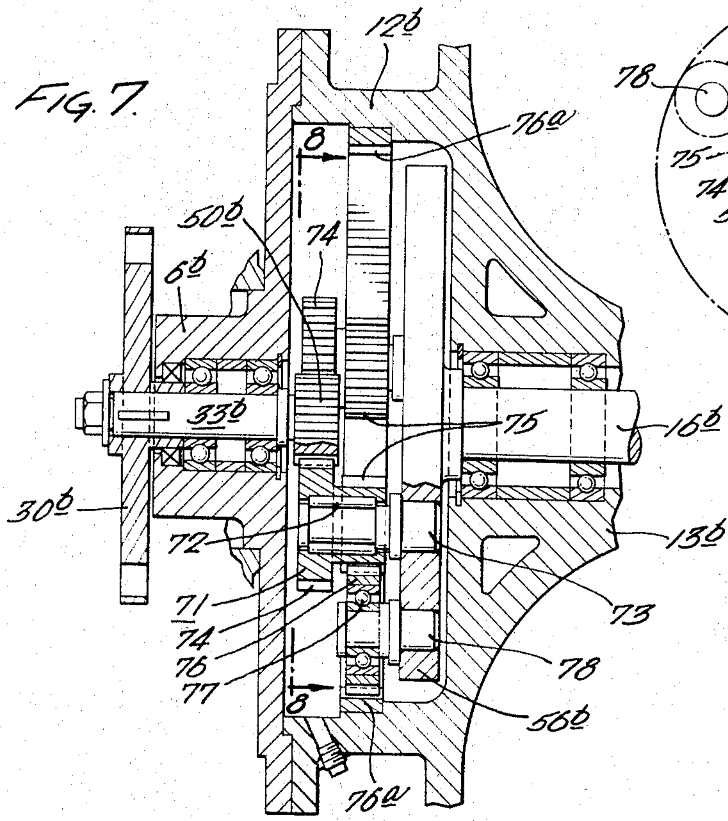
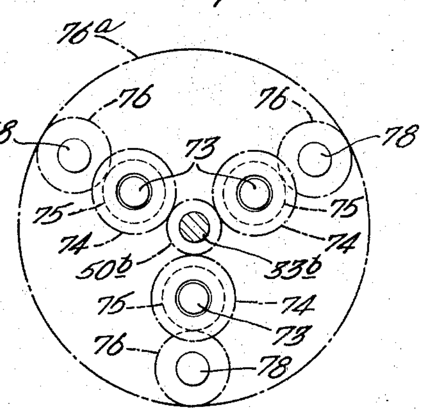
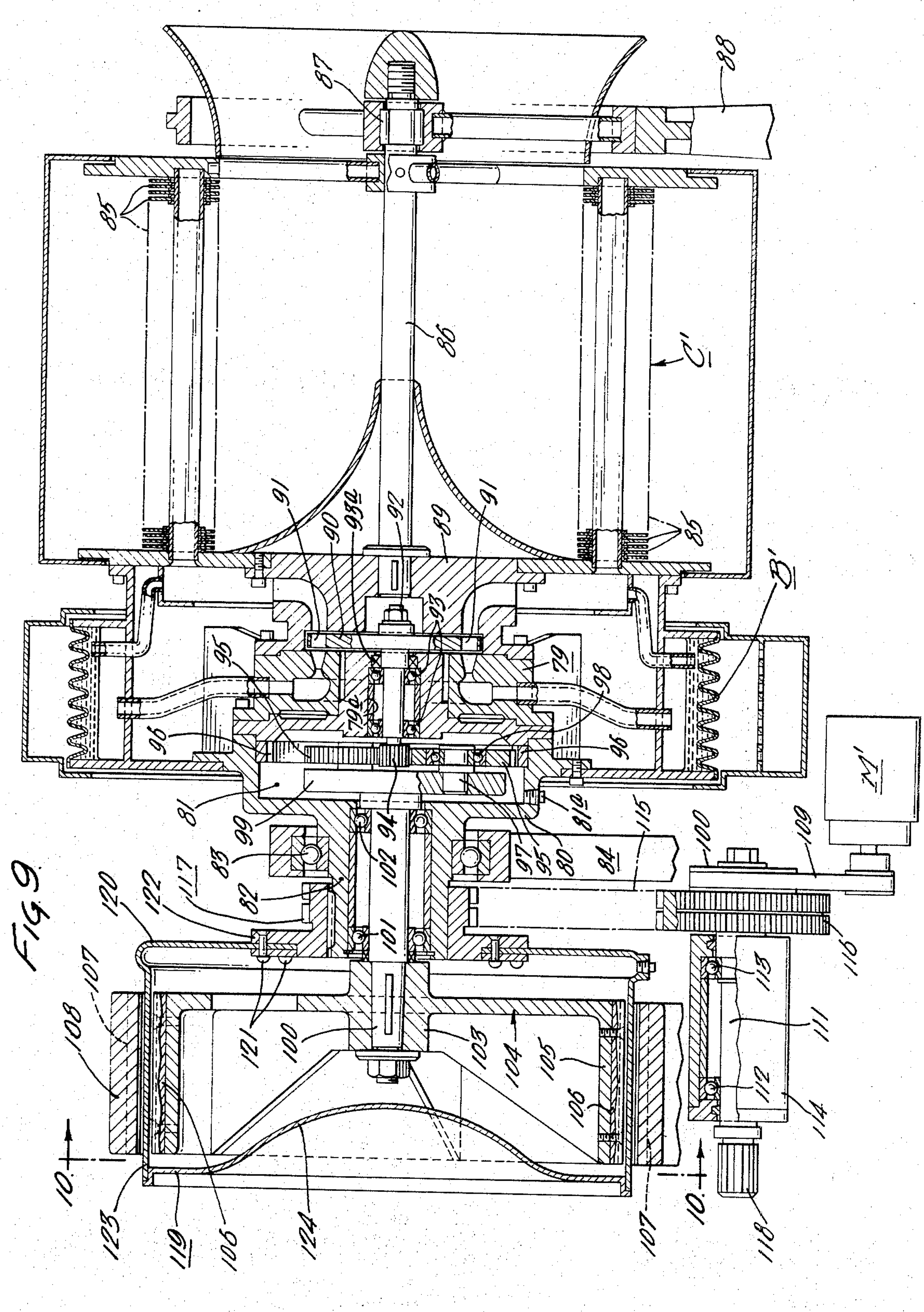


FIG. 8.





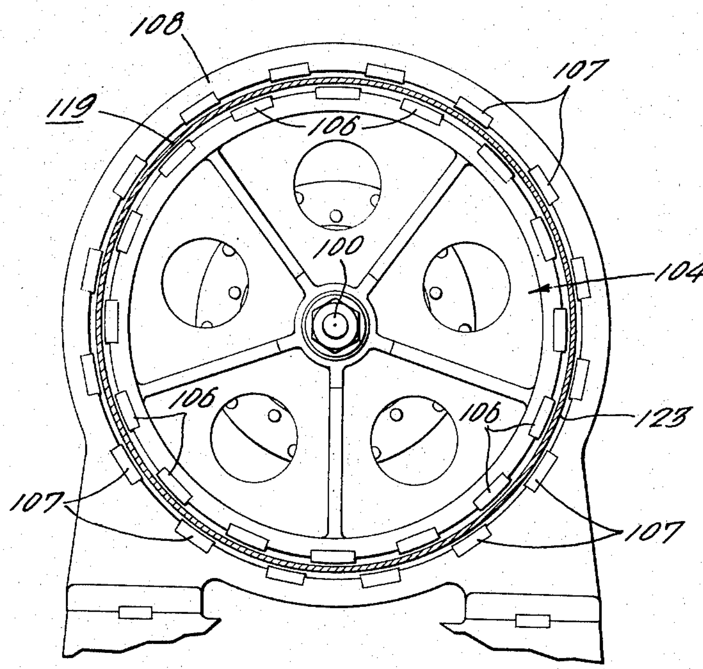


FIG. 10.

FIG. 12.

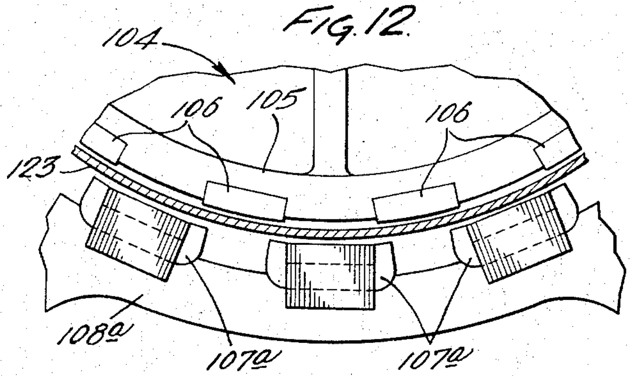


FIG. 11.

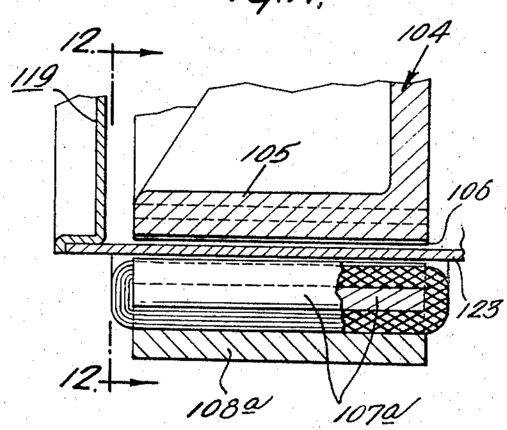


FIG. 13.

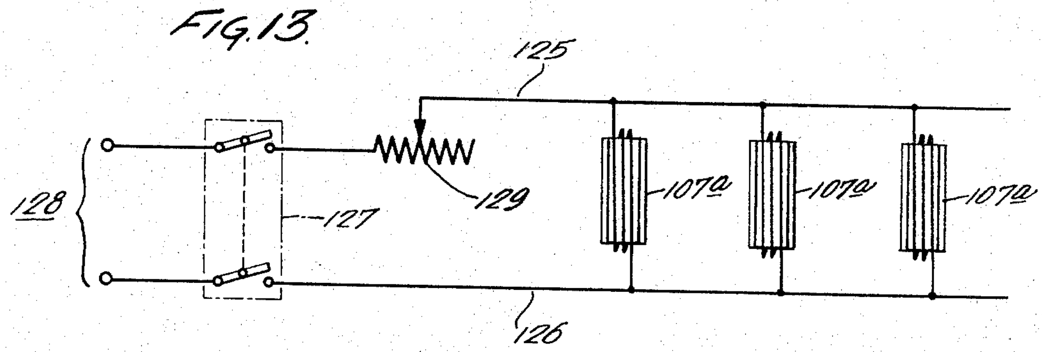


FIG. 14

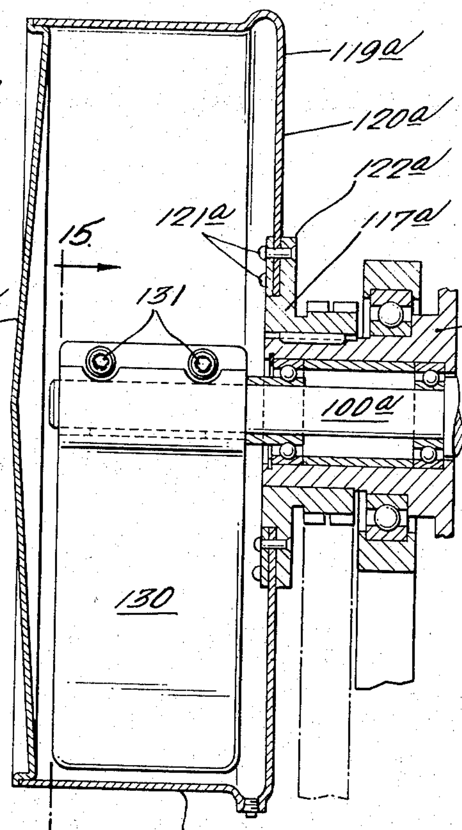


FIG. 15

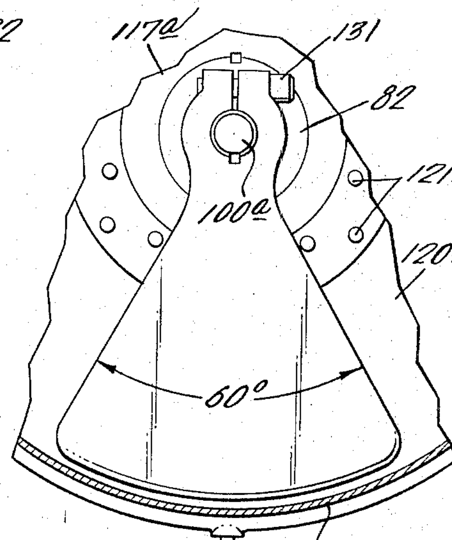
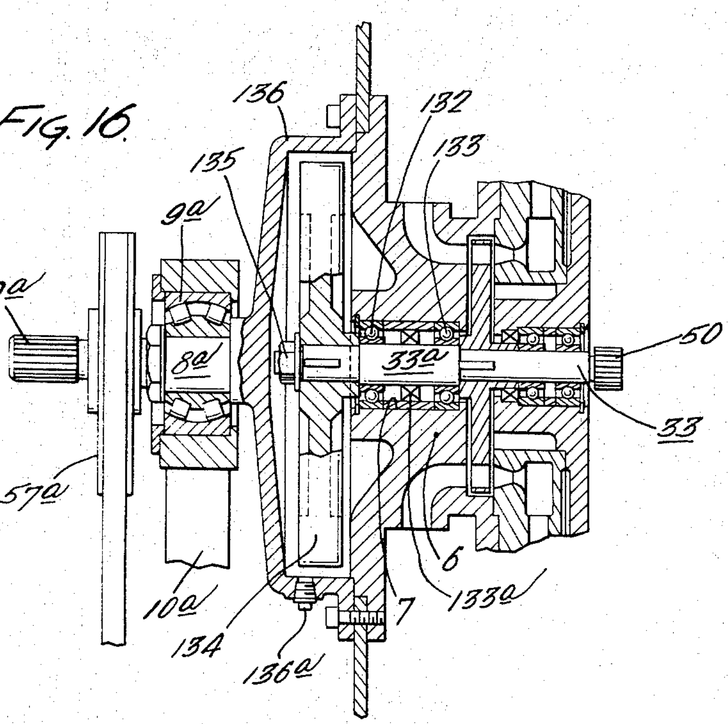


FIG. 16



ROTARY HEAT ENGINES

This invention relates to rotary heat engines, and more particularly to rotary heat engines of the closed Rankine cycle type especially adapted for use with high molecular weight power fluids.

Rotary heat engines of the type set forth comprising a rotatable closed housing, containing an annular boiler with attached internal condenser unit and an expander are known in the art. An example of such an engine is disclosed in U.S. Pat. No. 3,613,368 issued Oct. 19, 1971. Prior to the present invention, and as shown in the aforesaid patent, it has been the practice to rotationally drive the rotary boiler-condenser unit independently of the primary power output of the engine, for example, by means of a rotary power source that is entirely separate and apart from the Rankine engine. Such an arrangement is comparatively complex and requires the provision of an independent rotary power source for continuously driving the boiler-condenser unit that is in addition to and indirectly split from the total power developed by the Rankine engine. Moreover, in such an arrangement, particularly when the expander is a turbine operating substantially below optimum speed, the provision of some means, such as a brake, is required to absorb or use the excess power delivered to the rotary boiler-condenser unit over that required to rotationally drive said unit. Furthermore, control systems for such an arrangement are complex.

According to the present invention, the rotary housing boiler-condenser unit of the Rankine engine is internally coupled mechanically to the internal expander driving member so that, except at start-up of the engine, the housing-boiler-condenser unit is rotationally driven continuously by the primary power output generated by the engine. The principal advantage of the present invention lies in its simplicity and the fact that the proportion of the total power generated required to rotationally drive the housing-boiler-condenser unit is automatically split-off from the total power developed by the engine and the balance of the power is applied directly to the external load on the engine.

More particularly, the present invention contemplates the internal mechanical coupling of the rotary housing-boiler-condenser unit to the internal expander driving members through an internal fixed-ratio gear train so that the boiler-condenser unit is rotationally driven at a constant ratio to the speed of the expander. An advantage of this is that when the expander is a full admission nozzle turbine, the turbine can operate at substantially constant speed with the power output of the engine controlled by regulation of the rate that fuel is supplied to the combustion chamber to heat the boiler liquid. Thus, the expander will operate at peak efficiency at all power levels. Moreover, engine accessories are driven at constant speed independent of the engine power level. The efficient coupling of the mechanical power developed between the internal expander and rotary housing-boiler-condenser unit to the load provided by the present invention solves one of the major difficulties in adapting a rotary closed Rankine cycle engine to vehicular and other mobile propulsion applications. Furthermore, the invention provides for power take-off at reasonable speeds, eliminates the necessity for high speed shaft seals through the closed rotary housing, and substantially reduces windage losses and noise customarily associated with gearing-down high speed expanders, such as turbines, exteriorly of the engine.

With the foregoing in mind, an object of the invention is to provide a rotary heat engine of the type described comprising a closed rotary housing and boiler having an internal expander and an internal mechanical coupling between the expander driving member and housing to rotationally drive the latter, together with means cooperable with the mechanical coupling opposing the generated reaction torque so that the power output of the internal expander is transmitted directly to the rotary housing.

Another object of the invention is to provide a rotary heat engine embodying the foregoing features wherein the mechanical coupling between the expander driving member and rotary housing-boiler-condenser unit is a fixed-ratio gear train constructed and arranged to rotationally drive the engine at a predetermined constant speed.

Still another object of the invention is to provide a rotary heat engine in accordance with the foregoing wherein the fixed-ratio gear train coupling the internal expander driving member and rotary housing-boiler-condenser unit comprises a coaxial first gear driven by said driving member, a second gear carried by said boiler-condenser unit for rotationally driving the latter, and at least one intermediate gear.

A further object of the invention is to provide a rotary heat engine as set forth having novel means cooperable with at least one gear of the occluded gear train to generate a counter torque force opposing or anchoring the reaction torque generated by said occluded fixed-ratio gear train.

A still further object of the invention is to provide a rotary heat engine as set forth having means selectively operable to eliminate the counter torque force opposing the reaction torque of the gear train during start-up of the engine and to selectively control such counter torque force during operation after start-up to provide slip or rotation relative to the reaction torque and thereby vary the speed of rotation of the rotary housing-boiler-condenser unit below the designed predetermined constant speed normally provided by the fixed-ratio gear train as desired.

These and other objects of the invention and the various features and details of construction and operation thereof are hereinafter set forth and described with reference to the accompanying drawings, in which:

FIG. 1 is a vertical sectional view diametrically through a rotary heat engine embodying the present invention;

FIG. 2 is a transverse sectional view on line 2—2, FIG. 1;

FIG. 3 is an end elevational view in reduced scale, from the right hand end of the engine as viewed in FIG. 1;

FIG. 4 is a detached fragmentary sectional view diametrically through the engine;

FIG. 5 is a fragmentary sectional view diametrically through the engine showing a second arrangement of fixed-ratio gear train;

FIG. 6 is a schematic view from line 6—6, FIG. 5;

FIG. 7 is a fragmentary sectional view similar to FIG. 5 showing a third arrangement of fixed-ratio gear train;

FIG. 8 is a schematic view from line 8—8, FIG. 7;

FIG. 9 is a vertical sectional view diametrically through a rotary engine employing magnetic means for counteracting the reaction torque generated by the engine;

FIG. **10** is a sectional view, in reduced scale, on line **10—10**, FIG. **9**;

FIG. **11** is a fragmentary sectional view diametrically through the engine of FIG. **9** showing an alternate coupling arrangement employing electromagnets;

FIG. **12** is a sectional view taken on line **12—12**, FIG. **11**;

FIG. **13** is a schematic diagram of an electric circuit for the electromagnets of FIGS. **11** and **12**,

FIG. **14** is a fragmentary vertical sectional view diametrically through the rotary engine of FIG. **9** illustrating a modification thereof for counteracting the reaction torque generated by the engine;

FIG. **15** is a transverse section on line **15—15**, FIG. **14**; and

FIG. **16** is a fragmentary vertical sectional view diametrically through the engine of FIG. **1** illustrating the adaptation of a flywheel to the turbine drive shaft.

Referring now to the drawings, and more particularly to FIG. **1** thereof, a rotary engine in the form of a closed Rankine cycle power system embodying the present invention comprises a rotary housing and boiler B, a suitable internal expander such as, for example, a turbine T, a rotary condenser C coupled to the rotary, housing -and boiler for rotation therewith as a unit, and an internal occluded fixed-ratio gear train driven by the expander and connected to the rotary housing-boiler-condenser unit to rotationally drive the latter at a predetermined speed, as hereinafter set forth and described.

In the embodiment of the invention shown in FIG. **1** of the drawings, the rotary boiler B comprises a cylindrical chamber **1** defined by an outer continuous circumferentially extending wall **2**, side walls **3** and **4**, and an inner cylindrical wall **5**. Preferably, the outer circumferential wall **2** of the boiler chamber is configurated or contoured, for example as shown, to provide an expanded or extended thermal conductive surface area in accordance with the invention disclosed in the copending application of Philip J. Rennolds, Ser. No. 128,076 filed Mar. 25, 1971, now U.S. Pat. No. 3,690,302

The boiler chamber wall **3** extends radially inward beyond the wall **5** and is connected at its inner end, as by bolts **3***a*, to an annular hub structure **6** disposed coaxially with respect to and internally of the boiler B. The hub **6** houses the turbine T as described hereinafter. The hub **6** has a central bore **7** extending axially therethrough and mounted coaxially in the outer end thereof is a shaft **8** that is secured in the hub **6** for rotation therewith. The shaft **8** is rotatably journalled in a bearing **9** that is mounted in a fixed standard or support **10**.

The inner cylindrical wall **5** of the boiler extends axially beyond the boiler chamber wall **4** as shown, and is fixedly secured, as by bolts **11**, to the peripheral portion of the adjacent surface of a radially extending coaxial circular plate or disk **12** that projects outwardly from the inner end of a coaxially extending tubular shaft **13**. The tubular shaft **13** and plate **12** are rotatably mounted by means of bearings **14** and **15** upon a coaxially extending stationary shaft **16** that has its outer end mounted in a spherical bearing **17** housed in a hub structure **18** supported coaxially of the engine by means of radial spokes **19** from a fixed support **20**. The shaft **16** is secured against rotation by means of a radial pin **17***a*.

From the foregoing description and the drawings, it will be apparent that the cylindrical rotary housing-boiler B and internal hub structure **6** together with the tubular shaft **13** and plate **12** constitute a unitary closed housing structure that is rotatably mounted by means of the bearings **9**, **14** and **15** for coaxial rotation as a unit about the engine axis.

The rotary housing-boiler is adapted to be driven about its axis at a predetermined speed of rotation calculated to create the centrifugal force necessary to dispose and maintain the selected boiler liquid therein uniformly distributed circumferentially about and in contact with the inner surface of the outer peripheral wall **2** of the boiler with a liquid/vapor interface, designated x in FIG. **1**, that is highly stable and essentially cylindrical and concentric with the axis of rotation with the boiler. Essentially the liquid/vapor interface x is disposed at a predetermined radius from the rotation axis of the boiler to provide high boiling heat fluxes in excess of those obtainable at ambient gravity.

The annular body of liquid in the boiler may be heated to the required boiling temperature to vaporize the same, for example, by the combustion of a suitable fuel-air mixture in a stationary combustion box **21** that circumscribes the rotatable boiling chamber **1**. Fuel for combustion is discharged into the combustion box **21** from a nozzle **22** at the required rate and pressure, and air for mixture with the fuel is discharged into the combustion box through a plurality of ports **23** in the peripheral wall **24**. A hood structure **25** defines a plenum chamber **26** into which the air is supplied through a duct **27** at the pressure and volume required for efficient combustion of the fuel to heat the liquid in the boiler casing to the desired temperature. The residual combustion gases are discharged through an exhaust duct **28**,and a stationary transverse baffle **29**, configurated for complementary interfitting cooperation with the configuration of the boiler peripheral wall **2**, is mounted intermediate the fuel nozzle **22** and outlet duct **28** to control recirculation of the combustion gases.

In the illustrated embodiment of the invention, the internal expander, in the form of a turbine T, is of the single stage type comprising a rotor **30** having a series of turbine blades **31** arranged peripherally thereabout. The turbine rotor **30** is received within an annular recess **32** provided in the hub structure **6** and is mounted for coaxial rotation independently of the boiler B on a shaft **33** that is rotationally supported within bore **7** of the hub **6** by means of bearings **34**. An annular series of nozzles **35** is provided in the hub **6** coaxially adjacent the turbine rotor **30** and in confronting relation to the blades **31** thereof. An annular high pressure vapor manifold **36** is provided in the hub structure **6** and leads to the nozzles **35**. High pressure vapor is supplied from the boiler chamber **1** to the manifold **36** by a plurality of vapor tubes **37** arranged in equally spaced relation circumferentially of the axis to insure rotational balance in the boiler. The high pressure vapor is discharged from the manifold **36** through the nozzles **35** and impinges upon the blades **31** to drive the turbine rotor **30** and its shaft **33** at the desired speed of rotation. A seal **34***a* is provided on the shaft **33** inwardly adjacent the turbine rotor **30** to minimize migration of the pressure vapor from the turbine along shaft **33**.

An annular diffuser **38** is provided in the hub **6** to receive the exhaust vapor from the expander, such as turbine T, and the inlet opening thereto is disposed in confronting relation to the turbine blades **31** at the opposite side thereof from the nozzles **35.** Exhaust vapor entering the diffuser **38** is discharged into an annular exhaust chamber **39** in closed rotary housing from which it passes into the condenser C. A plurality of axially extending radial partitions or baffles **39***a* is provided in the exhaust chamber **39** and arranged in equally spaced relation circumferentially about the engine axis. These baffles **39***a* function to maintain the angular velocity of the exhaust vapor at that of the rotating boiler-condenser unit and to direct the vapor toward and into the heat exchange tubes **41** of the condenser C.

In the illustrated embodiment of the invention the condenser C comprises a coaxial array of annular radial fins **40** and axial heat exchange tubes **41** mounted at the opposite side of the plate **12** from the boiler for rotation with boiler B, plate **12** and shaft **13** as a unit. The fins **40** consist of separate or independent annular disk elements supported and secured in predetermined equally spaced parallel relation with respect to one another by means of the plurality of heat exchange tubes or pipes **41** that extend longitudinally through the fins **40** parallel with respect to the rotational axis thereof. The fins **40** and tubes **41** are fabricated of metal having high thermal conductivity such as, for example, copper or aluminum, and said fins preferably are bonded to said heat exchange tubes **41** by brazing, soldering or the like, to provide maximum thermal conductivity therebetween.

The tubes or pipes **41** are arranged in rotationally balanced spaced relation circumferentially of the fins **40** and the inner ends of the tubes **41** are mounted and secured in corresponding openings **42** provided through the plate **12** so that the interiors of the tubes **41** are in communication with the interior of the vapor chamber **39.** The outer ends of the tubes **41** are mounted and secured in recesses **43** provided in an annular end ring **44** that is disposed coaxially adjacent the outermost of the fins **40** and supported from the tubular shaft **13** by circumferentially spaced radial spokes **45.** Thus, the condenser C and boiler B are rotatable as a unit about their common axis.

The inner peripheral edges of the fins **40** define internally thereof a coaxial inlet chamber **46** for the cooling fluid to be discharged outwardly by and between the plurality of rotating fins **40** as hereinafter set forth. The inner diameter of the ring **44** is substantially the same as the inner diameter of the adjacent group of fins **40** so as not to restrict the flow of fluid into the chamber **46,** and an outwardly flared or bell-shaped fluid intake member **47** is fixedly supported by the spokes **19** from the stationary support **20** in coaxial relation outwardly adjacent the end ring **44** as shown in FIG. **1.**

The axial spacing or distance between the adjacent fins **40** is determined with relation to the rotational speed at which the boiler-condenser unit is driven and to the inner and outer radii of said fins so as to utilize the viscous properties of the cooling fluid and the shear forces exerted thereon by the rotating fins **40** to convey and accelerate the fluid radially outward between said fins in accordance with the invention set forth and described in the copending application for U. S. Pat. of William A. Doerner, filed Jan. 28, 1971, Ser. No. 110,478, now abandoned in favor of continuation-in-part application Ser. No. 307,612, filed Nov. 17, 1972. The outer radius of both the plate **12** and the ring **44** is the same and is such that the plate **12** and ring **44** extend radially outward beyond the fins **40** a distance to provide radial flange portions F and F′ operable to augment fluid flow outwardly between the fins **40** as described in the copending application of Stanley B. Levy, Ser. No. 180,733 filed Sept. 15, 1971. Also, fluid flow augmentation blades of the type and construction shown and described in said Levy application S. N. 180,733 can be provided when desired in any particular engine installation.

The turbine exhaust vapor discharged to the chamber **39** passes into the heat exchange tubes **41** where the vapor is condensed by heat exchange with a cooling fluid, such as ambient air, discharged outwardly between the array of fins **40** as previously described. The condensate thus formed in the tubes **41** flows into an annular collector **48** from which it is discharged radially by centrifugal force generated by rotation of the condenser C, through a plurality of conduits **49** and returned to the boiler chamber **1.**

As previously stated, the particular feature of the present invention resides in the provision of a novel mechanical coupling between the internal expander and rotary housing boiler-condenser unit so that during operation of the engine, after start-up, the housing-boiler-condenser unit is rotationally driven continuously by the primary power output generated by the engine. According to the present invention this is accomplished by means of an internal occluded fixed-ratio gear train arranged coaxially of the engine axis and interiorly of the rotary housing-boiler-condenser unit. The term fixed-ratio gear train used in this specification and the appended claims is not limited to a gear train embodying intermeshing toothed gear elements and is intended to include other gear trains of fixed-ratio wherein the driving connection between the elements of the train, for example, is by frictional engagement between said elements, or otherwise, so long as there is provided the desired fixed-ratio of speed reduction between the turbine shaft **33** and the rotary housing-boiler-condenser unit.

In the embodiment of the invention shown in FIGS. **1** and **2,** the gear train is in the form of a planetary gear system comprising a sun gear **50** fixedly mounted on and driven by the turbine shaft **33.** Meshed with the sun gray **50** is a plurality of planetary gears **51** that are also meshed with a circumscribing annular ring gear **52.** The ring gear **52** is fixedly mounted on and carried by an annular flange **12***a* that is formed integral with and projects axially from the adjacent face of the plate **12.** In the present embodiment, as shown in FIG. **2,** three planetary gears **51** are provided and arranged in equally spaced relation circumferentially about the engine axis. Each of the planetary gears **51** is rotatably mounted on a stub shaft **54** by means of a bearing **55** and each stub shaft **54** is fixedly mounted in a stationary spider portion **56** provided at the inner end of the stationary shaft **16.** By this construction the axes of the planetary gears **51** are fixedly positioned so that they do not rotate or move circumferentially relative to or about the engine axis. Thus the full power output of the engine expander is transmitted from the driving sun-gear **50** through the planetary gears **51** directly to the driven ring gear **52** on the rotary housing-boiler-condenser unit at the fixed-speed ratio of the particular gear train.

Lubrication of gears, bearings and other moving parts in the foregoing embodiment of the invention, as well as in the several embodiments hereinafter described, can be provided as desired or necessary in accordance with practices well known in the art.

In operation of the engine, it will be apparent at start-up that there will be no pressure vapor generated by the rotary housing-boiler to drive the internal expander and in turn the boiler-condenser unit. Consequently, at start-up it is necessary to independently drive the boiler-condenser unit at the designed predetermined speed of rotation to establish and maintain the liquid/vapor interface x in the boiler chamber **1** until the annular body of liquid in the boiler is heated to the temperature to produce the desired pressure vapor to drive the turbine T. This may be accomplished for example, by means of a starter motor M driving a pulley **57** fixed on shaft **8** through a belt or chain **58**. Means such as a clutch (not shown), can be provided for breaking the drive between motor M and pulley **57** when the engine attains normal operation, or the motor can continue to be driven by the rotating boiler-condenser unit and shaft **8** and function as a generator operable, for example, for charging a battery that powers accessories such as the starter motor, lights and the like. A power take-off **59** or other suitable driving connection is provided at the outer end of the output shaft **8** which may be used to drive any selected equipment or machinery such as, for example, a wheeled vehicle, boat, or otherwise, as desired.

In normal operation of the rotary engine, with the annular body of liquid in the boiler chamber **1** heated to the required temperature and pressure by combustion of the fuel-air mixture in chamber **21**, the pressure vapor generated in the boiler is discharged inwardly through the tubes **37** to manifold **36** and thence through the nozzles **35** into impinging contact against the turbine blades **31** thereby driving the turbine rotor **30** and shaft **33** at the desired predetermined speed of rotation. The shaft **33** through the occluded gear train previously described drives the rotary housing-boiler-condenser unit and the shaft **8** at a predetermined speed of rotation relative to the speed of shaft **33** determined by the fixed ratio of the gear train. In the embodiment of the invention shown in FIGS. **1** and **2** the direction of rotation of the housing-boiler-condenser unit and its shaft **8** is opposite the direction of rotation of the drive shaft **33**.

The exhaust vapor from the turbine enters the diffuser numeral **38** and is discharged therefrom through housing chamber **39** into the heat exchange tubes **41** where it is condensed by the cooling fluid discharged outwardly between the fins **40** as previously described. The condensate flows outwardly from the tubes **41** into the collector **48** from which it is returned to the boiler chamber **1** through tubes **49** at a controlled rate equal to the rate of vaporization of the boiler liquid.

A plenum chamber may be provided for the heat exchange fluid discharged outwardly through the array of fins **40**. Such a plenum chamber may comprise a stationary cylindrical wall **60** circumscribing the array of fins and enclosed by spaced apart end wall portions **61** and **62** that closely interfit with the outer edge portions of the rotating plate **12** and ring **44**, respectively. The plenum chamber preferably is provided with a pair of diametrically disposed tangentially extending fluid outlets **63** and **64**, respectively, as shown in FIG. **3** of the drawings.

As shown in FIG. **4** of the drawings, a U-shaped tube **65** having a threaded cap closure **66** may be provided circumferentially of the boiler B and arranged as shown for use either as a fill tube for charging the boiler with working liquid or for periodically evacuating the boiler-condenser system to remove small percentages of air or other non-condensable vapors that may become entrained in the working fluid of the boiler-condenser system.

The invention, of course, is not limited to the precise fixed ratio gear train shown in FIGS. **1** and **2**, and other gear arrangements may be employed as desired. For example, and referring to FIGS. **5** and **6** of the drawings, there is shown a fixed-ratio gear train comprising a rotationally driven sun gear **50**a on the shaft **33**a driven by the turbine rotor **30**a. A stationary sun gear **67** is mounted coaxially at the inner end of the stationary shaft **16**a and driving connection to the rotary housing-boiler-condenser unit is provided by a plurality of pairs of gears **68** and **69** that are meshed, respectively, with the driven sun gear **50**a and the stationary sun gear **67**. Each pair of gears **68** and **69** is fixedly mounted coaxially upon a stub shaft **70** and each of the latter has its opposite ends rotationally journalled, by means of bearings **71** and **72**, in the adjacent face of plate portion **12**a of the rotatable shaft **13**a and the rotatable hub structure **6**a of the boiler B, respectively. In operation, the driven sun gear **50**a drives the gears **68** on stub shaft **70** thereby rotationally driving the latter and the gears **69** thereon rotationally about the fixed gear **67** so that the housing-boiler-condenser unit is rotationally driven about the engine axis at the desired speed in the direction opposite the direction of rotation of the turbine rotor **30**a and its shaft **33**a.

Another gear arrangement is shown in FIGS. **7** and **8** which may be employed for driving the housing-boiler-condenser unit in the same direction of rotation as the turbine **30**b and its shaft **33**b. In this arrangement, the driven sun gear **50**b drives a plurality of compound gears **71** each rotationally mounted by means of a bearing **72** on a stub shaft **73** that is fixedly mounted in the stationary spider **56**b at the inner end of the non-rotatable shaft **16**b. As shown, the sun gear **50**b is meshed with and rotationally drives the larger diameter gear **74** of each compound gear **71**, and the smaller diameter gear **75** thereof drives a gear **76** rotationally mounted by a bearing **77** on a stub shaft **78** that is also fixedly mounted in the stationary spider **56**b radially outward from the corresponding stub shaft **73**. The gear **76** in turn is meshed with and rotationally drives a ring gear **76**a that is mounted on an inwardly extending flange portion of the plate **12**b at the inner end of the rotatable shaft **13**b thereby rotationally driving the latter and the boiler-condenser unit at the desired speed in the same direction of rotation as the turbine shaft **33**b.

As in the embodiment of the invention shown in FIG. **1**, in the embodiments shown in FIGS. **5** and **7** of the drawings, the gear train is housed within a closed chamber having a plug located peripherally therein for periodically draining any vapor condensate therefrom.

In the several embodiments of the invention previously described, the reaction torque of the gear train is mechanically opposed or resisted by a fixedly positioned member at the inner end of the non-rotatable shaft **16**, **16***a* or **16***b*, as the case may be. The invention, however, is not limited to such arrangements and other means may be provided for holding or resisting the reaction torque of the gear train.

For example, the reaction torque of the gear train may be opposed or resisted by magnetic means and such an arrangement may be employed to advantage in medium power rotary engines and particularly in installations where it may be desirable to enclose the engine in an hermetically sealed casing or housing. One embodiment of a rotary engine wherein the reaction torque is opposed by means of magnets is shown in FIGS. **9** and **10** of the drawings.

Referring to FIG. **9**, the annular cylindrical housing and boiler B′ has a coaxial central hub structure **79** similar to that previously described and this hub structure includes axially off-set wall portions **80** defining an enclosed gear chamber **81** at the opposite side of the hub **79** from the condenser C′. The wall portions **80** terminate inwardly in a projecting coaxial tubular shaft portion **82** that is rotatably mounted by means of a bearing **83** in a fixed standard or support **84.** The condenser C′, constructed substantially as previously described, includes an array of spaced parallel annular fins **85** supported coaxially of the engine by a shaft **86** that has its outer end rotatably mounted by a bearing **87** in a fixed standard or support structure **88.** The inner end of the shaft **86** is fixedly connected to the adjacent member **89** of the housing-boiler-condenser hub structure. Thus the boiler-condenser is rotatably mounted by the bearings **83** and **87** for coaxial rotation as a unit about the engine axis.

A turbine rotor **90** having a series of turbine blades **91** is received within a recess provided in the hub **79** and is mounted for coaxial rotation independently of the housing-boiler-condenser unit on a shaft **92** that is rotationally supported by bearings **93** in the bore **79***a* of the hub **79.** A seal **93***a* is provided on the shaft **92** adjacent the turbine rotor **90** to minimize migration of pressure vapor along the shaft **92** to the gear chamber **81** where it would condense, and a drain plug **81***a* is provided in the peripheral wall of chamber **81** for periodic removal of vapor condensate therefrom.

In the embodiment illustrated in FIG. **9**, the internal occluded gear train comprises a sun gear **94** fixedly mounted on and driven by the turbine shaft **92.** The sun gear **94** drives a plurality of planetary gears **95** that in turn drive a circumscribing ring gear **96** mounted on and carried by the boiler hub structure **79.** In the present embodiment, as in the engine first described, three planetary gears **95** are provided and arranged in equally spaced relation circumferentially about the engine axis. Each planetary gear **95** is rotatably mounted on a stub shaft **97** by means of a bearing **98** and each stub shaft **97** is fixedly mounted in a spider portion **99** provided at the inner end of a coaxial shaft **100** that is rotationally journalled by means of bearings **101,102** within the rotatably mounted tubular shaft **82** of the boiler-condenser unit.

In accordance with this particular embodiment of the invention, the reaction torque of the gear train is opposed and the shaft **100** and spider **99** are restrained against rotation about the engine axis by means of cooperating pairs of magnets. Mounted on the outer end of the shaft **100** is the hub **103** of a wheel-like member **104** having a coaxial cylindrical flange or rim **105** of predetermined diameter. The hub **103** is keyed or otherwise secured against rotation relative to the shaft **100.** Fixedly mounted in predetermined equally spaced relation circumferentially about the outer surface of the flange **105** is a plurality of magnets **106** (see FIG. **10**) adapted for magnetic coupling with a corresponding plurality of magnets **107** disposed in radially spaced concentric relation circumferentially about the magnets **106** and mounted on the interior surface of a fixed cylindrical support structure **108.** The members **104** and **108** or the portions thereof in which the magnets **106** and **107** are mounted must be of non-magnetic material.

By this construction, axes of the stub shafts **97** are held in position so that the planetary gears **95** do not rotate or move circumferentially about the engine axis. Thus, the full power output of the expander is transmitted from the driving sun gear **95** directly to the driven ring gear **96** on the rotary housing-boiler-condenser unit thereby rotationally driving the latter at a fixed-speed ratio of the gear train.

As previously stated, at start-up of the engine it is necessary to independently drive the housing-boiler-condenser unit until generation of the boiler pressure vapor required to drive the turbine rotor **90** at the desired speed of rotation. This may be accomplished by a motor M′ driving a belt **109** that in turn drives a pulley **100** keyed or otherwise secured upon a drive shaft **111** which is rotatably mounted by bearings **112,113** in a fixed or stationary support **114.** A driving connection between the shaft **111** and the tubular shaft **82** of the rotary housing-boiler-condenser unit is provided by a chain **115** from a sprocket **116** secured on the shaft **111** and a sprocket **117** keyed on the said shaft **82.** A power take-off **118** or other suitable driving connection is provided at the opposite end of the shaft **111.**

The wheel member **104** and the magnets **106** are enclosed within a lightweight vapor-proof housing or casing **119** that is rotatable with the housing-boiler-condenser unit and provided for the purpose of preventing leakage of pressure vapor from the turbine to the ambient atmosphere along shaft **100** thereby eliminating the necessity for providing elaborate and costly pressure vapor seals about the shaft **100.** As shown in FIG. **9**, the housing **119** comprises an inner wall portion **120** secured as at **121** to a flange **122** on the pulley **117** on shaft **82,** a peripheral wall portion **123** extending axially between the series of magnets **106** and **107** and an outer wall portion **124.** An annular sump is provided at the junction of the inner and peripheral wall portions **120** and **123** of the housing **119** for collecting the condensate of any pressure vapor that may migrate past the seal **93***a* and find its way along the shaft **100** into said housing **119** and a threaded plug is provided in the sump for periodically draining off condensate that may be collected therein. The housing or casing **119** is fabricated of non-magnetic material of high electrical resistance such as, for example, fibre reinforced plastic material so as to minimize eddy current losses and also not affect the magnetic field between cooperating pairs of magnets **106** and **107.**

As a typical example of the operation of the magnets in the embodiment of the invention shown in FIGS. **9** and **10,** the sixteen cooperatively disposed pairs of magnets **106** and **107** each composed of barium ferrite having dimensions of 1×3×11 centimeters and circularly arranged on a **13** inch diameter provide a counter torque force sufficient to oppose or anchor a reaction torque of 50 ft.lbs. at a fixed-speed gear train ratio of 11.5 to 1, which is the rated torque output of a 20 hp engine made in accordance with the present invention.

In certain engines it may be desirable to provide means selectively operable for eliminating or disconnecting the countertorque force that anchors or opposes the reaction torque of the gear train during start-up of the engine in order substantially to reduce the load on the starting motor and enable the use of lower powered starting motors than otherwise would be required. Also, it may be desirable to provide for selective control of the counter torque force during normal engine operation to provide slip or rotation relative to the reaction torque of the engine and thereby variably reduce the speed at which the housing-boiler-condenser unit is rotationally driven with respect to the designed predetermined constant speed normally provided by the fixed-ratio gear train.

In the embodiment of the invention shown in FIGS. **9** and **10**, these results may be accomplished, for example, by providing electromagnets **107***a* in the fixed support structure **108***a* in lieu of the magnets **107** for cooperation with core members **106***a* of suitable ferrous material, as shown in FIGS. **11** and **12** of the drawings. As shown in FIG. **13**, the electromagnets **107***a* are connected in parallel relation between the conductors **125** and **126** of an electric circuit that are connected through a double pole single throw switch **127** to a suitable source of electrical energy **128.** A rheostat or other suitable infinite control switch **129** is connected in the conductor **125** between the switch **127** and magnets **107***a*.

By this arrangement, with switch **127** open, the electromagnets **107***a* are deenergized so that there is zero counter torque force opposing the reaction torque of the engine and, with the switch **127** closed, the control **129** can be selectively operated to vary the magnetic field intensity in the magnets **107***a* to provide the desired relative slip or fixation of the planetary gears **95** about the engine axis under the influence of the reaction torque generated by the engine.

Similar operation and results can be obtained in the embodiments of the invention shown in FIGS. **1, 5** and **7** of the drawings by providing a suitable clutch mechanism (not shown), for example, between the shaft **16** and spider **56** (FIG. **1**), the shaft **16***a* and gear **67** (FIG. **5**) and shaft **16***b* and spider **56***b* (FIG. **7**).

Still other arrangements may be provided for generating a counter torque force in opposition to the reaction torque generated by the engine. For example, in engines in the lower power ranges a pendulum of predetermined density, dimensions and location may be employed for generating an effective counter torque force. This may be accomplished, for example, in a rotary engine of the construction shown in FIG. **9**, simply by substituting a suitable pendulum for the wheel member **104** on the shaft **100** and the magnets **106** and **107**, as shown in FIGS. **14** and **15** of the drawings.

Referring to FIGS. **14** and **15**, the reaction torque of the engine gear train is opposed and the gear shaft **100***a* that is journalled in the tubular shaft portion **82** of the rotary boiler-condenser unit of the engine may be effectively restrained against rotation about the engine axis by means of a pendulum **130** fixedly mounted on the outer end portion of said shaft **100***a* by means of bolts **131.** The pendulum is of predetermined density, dimensions and location to generate the desired holding force against the engine reaction torque and, as a typical example, a lead pendulum **130** in the configuration of a 60° triangle as shown, having a radius of 8 inches, an axial length of 8.5 inches and weighing 117 lbs. will provide a counter torque force sufficient to oppose or anchor a reaction torque of 50 ft. lbs. at a fixed-speed gear train ratio of 11.5 to 1, which is the rated torque output of a 20 hp engine of the present invention.

For the reasons previously described, the pendulum **130** is enclosed within a vapor-proof housing **119***a* that is rotatable with the housing-boiler-condenser unit. As shown in FIG. **14** the housing **119***a* comprises an inner wall **120***a* secured at **121***a* to a flange **122***a* on the pulley **117***a* on the shaft **82,** a peripheral wall portion **123***a* and an outer wall portion **124***a*. As previously described, a vapor condensate sump with drain is provided at the juncture of the inner and peripheral wall portions **120***a* and **123***a* of the housing **119***a*.

In the several embodiments of rotary engines shown and described, the rotationally driven components (turbine and housing-boiler-condenser unit) provide an inherent rotational kinetic energy storage system that is highly useful to the performance of the engine, and the energy storage capacity or capability of the engine can be materially increased by the addition of a suitable flywheel on the high-speed turbine shaft of the engine.

This may be accomplished, for example, as illustrated in FIG. **16** of the drawings, which is a fragmentary sectional view of an engine of the construction and arrangement shown in FIG. **1.** Referring to FIG. **16,** the turbine driven shaft **33,** having the sun gear **50** thereon, is extended axially in the opposite direction as indicated at **33***a* and journalled in the bore **7** of hub structure **6** by bearings **132** and **133.** A flywheel **134** of predetermined dimensions and weight is keyed upon the outer end of the shaft extension **33***a* and secured thereon by a nut **135** so that the flywheel **134** is rotationally driven by the turbine **30** at the designed speed of rotation.

The flywheel **134** is enclosed within a housing **136** secured coaxially endwise of the rotary housing-boiler-condenser unit and rotatable therewith. A seal **133***a* is provided on the shaft **33***a* to minimize migration of pressure vapor from the turbine to the flywheel housing **136** where it would condense, and a threaded plug **136***a* is provided in the peripheral wall of the housing for periodically draining collected condensate therefrom. A drive shaft portion **8***a* is formed on the housing **136** coaxially endwise thereof and is journalled by bearing **9***a* in a fixed standard or support **10***a*. A drive pulley **57***a* for the start-up motor is keyed on the outer end of said shaft **8***a* and power take-off connection **59***a* is provided at the extremity of the shaft.

As previously stated, the addition of the flywheel on the high speed turbine shaft further increases the energy storage capability of the engine. For example, a turbine speed flywheel weighing 0.692 lb./hp (that is, a 69.2 lb. flywheel for a 100 hp engine) will increase the rotational kinetic energy storage capability of the engine by a factor of 3.

With the foregoing flywheel, the rotating engine is capable of bringing a 3,500 lb. vehicle travelling at 45 mph to a stop without braking and storing all of the vehicular energy if the engine is permitted to overspeed by 15 percent. This ability to efficiently store kinetic energy by dynamic braking increases the system efficiency.

Conversely, an increase of 25 hp is available from the engine for 10 seconds with the foregoing flywheel with a drop in engine speed of only 10 percent. This increase in power is independent of any changes in fuel setting, and such capability of the engine makes essentially instantaneous response available. The stored kinetic energy of the engine supplies instantaneously the power demand while the engine system adjusts to the new power level and reestablishes the engine speed.

For a typical example of the construction and operation of a closed Rankine cycle rotary engine embodying the present invention, an engine constructed as shown and described having an output of 20 hp at the turbine shaft **33** comprises a boiler having a mean internal diameter of 19.375 inches and an axial internal length of 3.625 inches. The diameter of the turbine rotor **30** at mid-height of the blades **31** is 4.301 inches, and the fins **40** of the condenser C have an outer diameter of 14.00 inches and an inner diameter of 10.50 inches. The axial length of the series of fins **40** is 10.50 inches and the spacing between adjacent fins **40** is 0.032 inches. The housing-boiler-condenser assembly is rotationally driven at a speed in the fixed ratio of 1 to 11.50 with respect to the turbine rotor speed through the occluded gear train and the latter is constructed and arranged in the embodiment of FIG. **1** to rotationally drive the housing-boiler-condenser assembly in the direction opposite the direction of rotation of the turbine rotor **30** and shaft **33**.

Using as the boiler power fluid a high molecular weight fluid, such as trichlorotrifluorobenzene described and claimed in my U. S. Pat. No. 3,702,534, issued Nov. 14, 1972. the specifications for a typical operation of the described engine are as follows:

Boiler temperature (°F.)	620.00
Boiler pressure (psia)	150.00
Turbine speed (rpm) (relative to nozzles)	30000.00
Boiler-Condenser speed (rpm)	2400.00
Condenser temperature (°F.)	303.00
Condenser pressure (psia)	3.30
Power Fluid flow rate, lb/sec.	0.638
Rankine cycle efficiency (no regeneration)	0.196

From the foregoing it will be apparent that the present invention provides a novel rotary heat engine of the closed Rankine cycle type wherein the rotary housing-boiler-condenser unit is internally coupled mechanically to the internal expander driving member so that the housing-boiler-condenser unit is rotationally driven continuously by the primary power output generated by the engine with the proportion of the power required to drive the boiler-condenser unit being automatically split-off from the total power developed and the balance of the power applied directly to the external load on the engine. Also, by utilizing a fixed-ratio gear train for mechanically coupling the rotary housing-boiler-condenser unit to the expander driving members, the housing-boiler -condenser unit is rotationally driven at a constant ratio to the speed of the expander, and engine accessories likewise are driven at a constant speed independent of the engine power level. Furthermore, a rotary engine according to the present invention permits power take-off at reasonable speeds, eliminates the necessity for high speed shaft seals, and substantially reduces windage losses and noise.

Thus, the engine of the present invention is especially useful for driving constant speed devices and equipment such as, for example, electric generators and similar equipment and, in combination with power transmission mechanisms such as, for example of the hydromechanical, toroidal disk, variable pitch pulley and like types that receive power at constant speed and variable torque and provide power output of variable torque and speed, is ideally suited for driving vehicles such as automobiles and the like.

While certain embodiments of rotary engines made according to the present invention have been shown and described, it is not intended to limit the invention to such disclosures and it is contemplated that changes and modifications may be made and incorporated as desired or required, within the scope of the following claims.

I claim:

1. A rotary closed Rankine cycle engine comprising:

a closed cylindrical housing rotatable about its axis and containing an annular boiler, said housing and boiler adapted to be rotated at a predetermined speed to maintain an annular liquid body about the inner peripheral surface of said boiler with a liquid/vapor interface spaced a predetermined distance radially outward from said axis,

means to heat the liquid body in the boiler to generate pressure vapor therein,

an expander coaxially within said closed housing for extracting work from said pressure vapor and including a coaxially rotatable driving member actuated thereby,

a condenser for the exhaust vapor from the expander mounted coaxially adjacent and communicating with the closed housing forming a sealed chamber and rotatable therewith as a unit,

means for returning vapor condensate from the condenser to the boiler,

an occluded fixed ratio gear train mounted coaxially within the rotary closed housing and interconnected between the expander driving member and said closed housing operable to rotationally drive the latter and said boiler about said axis at said predetermined speed,

an external drive member fixedly carried by and rotatable with the rotary closed housing coaxially thereof for driving equipment connected thereto,

and means cooperable with the occluded gear train opposing the reaction torque generated thereby so that the full power output of the expander is transmitted directly to the rotary housing and said external drive member.

2. A rotary engine as claimed in claim **1** wherein the means cooperable with the gear train for generating the counter torque force comprises means for anchoring at least one of the gears in the gear train against relative rotation circumferentially about the engine axis.

3. A rotary engine as claimed in claim **2** wherein the gear anchoring means comprises stationary nonrotatable means fixedly positioning the gear circumferentially with respect to the engine axis.

4. A rotary engine as claimed in claim **2** wherein the gear anchoring means comprises a magnetic coupling between the gear and a stationary non-rotatable member operable to anchor said gear circumferentially with respect to the engine axis.

5. A rotary engine as claimed in claim 2 wherein the gear anchoring means comprises a pendulum member connected to the gear and having predetermined density and dimensions operable to anchor said gear circumferentially with respect to the engine axis.

6. A rotary engine as claimed in claim 1 comprising means variably controlling the generated counter torque force in relation to the generated engine reaction torque.

7. A rotary engine as claimed in claim 2 comprising means for variably controlling the gear anchoring means to provide relative rotation of the gear circumferentially about the engine axis.

8. A rotary engine as claimed in claim 1 wherein the gear train includes a first gear coaxially of the engine axis driven by the expander driving member,
a second gear fixedly mounted on the boiler-condenser unit to rotationally drive the latter,
and a third gear anchored against rotation circumferentially of the engine axis.

9. A rotary engine as claimed in claim 8 wherein the means anchoring the third gear comprises a stationary member on which said third gear is rotatably mounted.

10. A rotary engine as claimed in claim 8 wherein the means anchoring the third gear comprises rotatable means mounting said third gear and magnetic coupling means between said mounting means and a stationary non-rotatable member operable to anchor the gear against rotation about the engine axis.

11. A rotary engine as claimed in claim 8 wherein the means anchoring the third gear comprises coaxial rotatable means mounting said third gear and a pendulum member of predetermined density, dimensions and location mounted on said rotable member.

12. A rotary engine as claimed in claim 1 comprising a flywheel fixedly mounted on the coaxially rotatable driving member of the expander and having predetermined dimensions and weight operable to materially increase the energy storage capacity of the engine.

13. An engine as claimed in claim 1 wherein the expander comprises a turbine having a series of nozzles rotatable with the boiler-condenser unit, and a driven rotor and shaft mounted for rotation coaxially of the engine axis.

14. A rotary engine as claimed in claim 4 comprising means for selectively varying the magnetic field intensity of the magnetic coupling between the gear and stationary member to variably control the counter torque anchoring force in relation to the reaction torque of the engine and provide predetermined relative rotation of the gear about the engine axis.

15. A rotary engine as claimed in claim 4 wherein the magnetic coupling includes electromagnetic means and means for selectively controlling the current to said electromagnetic means for varying the magnetic field intensity of said coupling and thereby the counter torque anchoring force in relation to the engine reaction torque thereby effecting predetermined relative rotation of the gear about the engine axis.

16. A rotary engine as claimed in claim 13 wherein the gear train includes a first gear mounted coaxially on the turbine rotor shaft, a circumscribing ring gear mounted on the boiler-condenser unit, a plurality of intermediate gears providing driving connection from said first gear to said second gear, means rotationally mounting each of said intermediate gears, and means anchoring said intermediate gear mounting means against rotation about the engine axis.

17. A rotary engine as claimed in claim 16 wherein the means anchoring the intermediate gear mounting means comprises a stationary non-rotatable means fixedly positioning said gear mounting means circumferentially with respect to the engine axis.

18. A rotary engine as claimed in claim 16 wherein the anchoring means for the intermediate gear mounting means comprises a magnetic coupling between the latter and a stationary non-rotatable member.

19. A rotary engine as claimed in claim 16 wherein the anchoring means for the intermediate gear mounting means comprises a pendulum member connected to said mounting means and having predetermined density, dimensions and location operable to anchor the mounting means circumferentially with respect to the engine axis.

20. A rotary engine as claimed in claim 16 comprising a flywheel fixedly mounted coaxially on the turbine rotor shaft and having predetermined dimensions and weight operable to materially increase the energy storage capacity of the engine.

21. A rotary engine as claimed in claim 16 comprising means for variably controlling the anchoring means for said intermediate gear mounting means to provide relative rotation of the latter about the engine axis.

22. A rotary engine as claimed in claim 18 comprising means for selectively varying the magnetic field intensity of the magnetic coupling between the gear mounting and stationary member to variably control the anchoring force in relation to the reaction torque of the engine and provide predetermined relative rotation of the mounting means and gears about the engine axis.

23. A rotary engine as claimed in claim 18 wherein the magnetic coupling includes electromagnetic means and means for selectively controlling the current to said electromagnetic means for varying the magnetic field intensity of said coupling and thereby the anchoring force in relation to the engine reaction torque to provide predetermined relative rotation of the mounting means and gears about the engine axis.

24. A rotary engine as claimed in claim 10 comprising means for selectively varying the magnetic field intensity of the magnetic coupling between the gear and stationary member to variably control the counter torque anchoring force in relation to the reaction torque of the engine and provide predetermined relative rotation of the gear about the engine axis.

25. A rotary engine as claimed in claim 10 wherein the magnetic coupling includes electromagnetic means and means for selectively controlling the current to said electromagnetic means for varying the magnetic field intensity of said coupling and thereby the counter torque anchoring force in relation to the engine reaction torque thereby effecting predetermined relative rotation of the gear about the engine axis.

26. An engine as claimed in claim 10 wherein the expander comprises a turbine having a series of nozzles rotatable with the boiler-condenser unit, and a driven rotor and shaft mounted for rotation coaxially of the engine axis on which the said first gear is mounted.

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