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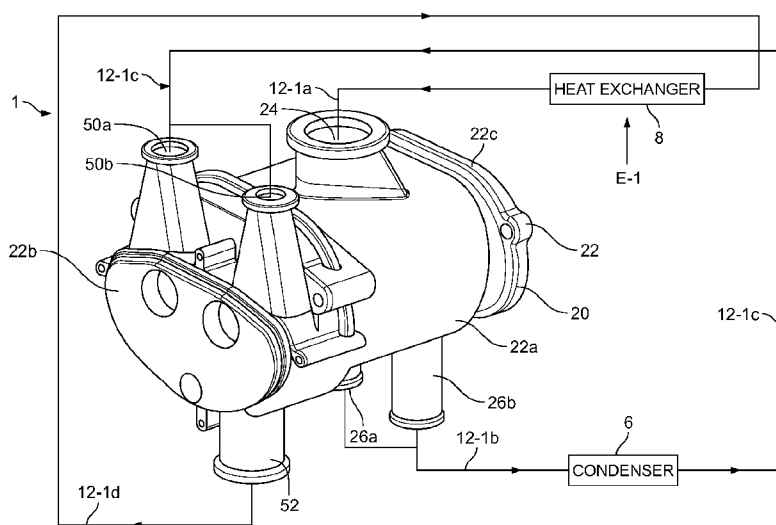


FIG. 1

(57) Abstract: In one aspect, an integrated expander and pump assembly is disclosed that includes: a housing defining an internal chamber and a pair of parallel helical rotors disposed within the housing internal chamber. The assembly can include a first working fluid inlet and a first working fluid outlet between which the working fluid is expanded by the rotors. The assembly can also include a second working fluid inlet and a second working fluid outlet between which the working fluid is pumped by the rotors.

INTEGRATED EXPANDER-PUMP ASSEMBLY

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is being filed on June 14, 2016 as a PCT International Patent Application and claims the benefit of U.S. Patent Application Serial No. 62/175,675, filed on June 15, 2015, the disclosure of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to a volumetric fluid expander with an integral pump used for power generation.

BACKGROUND

[0003] Volumetric expanders can be utilized to recover waste heat from a power plant, such as an internal combustion engine. In one application, waste heat from a power plant is recovered by expanding a working fluid heated by the exhaust gases from the power plant through the expander.

SUMMARY

[0004] In one aspect, an integrated expander and pump assembly is disclosed that includes: a housing defining an internal chamber; a pair of parallel helical rotors disposed within the housing internal chamber, the rotors being configured to operate in a counter rotating non-contacting arrangement, each of the rotors having a first end and a second end; a first working fluid inlet for receiving a superheated or partially saturated working fluid; a first working fluid outlet for discharging the working fluid after the working fluid has been expanded by the pair of rotors; a second working fluid inlet for receiving the working fluid from the first working fluid outlet; and a second working fluid outlet for discharging the working fluid after the working fluid has been pumped by the pair of rotors. The first working fluid outlet can include a first outlet port and a second outlet port and the second working fluid inlet can include a first inlet port and a second inlet port.

[0005] An energy recovery system for a power plant including the above described integrated expander and pump assembly is also disclosed. The system can further include a heat exchanger for transferring heat from the power plant to the working fluid leaving the second outlet port and entering the first working fluid inlet; and a condenser for

condensing the working fluid leaving the first working fluid outlet and entering the second working fluid inlet.

[0006] A method for operating an energy recovery system is also disclosed, which can include the steps of heating a working fluid with a heat exchanger that is in fluid communication with a power plant; expanding the working fluid to have a lower pressure and temperature by passing the working fluid through a pair of rotors within an expander between a first inlet and a first outlet; condensing the expanded working fluid to at least a partially condensed state; reintroducing the at least partially condensed working fluid back into the expander at a second inlet; and pumping the working fluid with the pair of rotors to a second outlet to the heat exchanger.

DRAWINGS

[0007] Figure 1 is a schematic perspective view of an integrated expander pump assembly within a working fluid circuit in accordance with the present invention.

[0008] Figure 2 is a schematic exploded perspective view of the integrated expander pump assembly shown in Figure 1.

[0009] Figure 3 is a schematic see-through perspective view of the integrated expander pump assembly shown in Figure 1.

[0010] Figure 4 is a schematic see-through perspective view of the integrated expander pump assembly shown in Figure 1.

[0011] Figure 5 is schematic cross-sectional view of an expander having features in common with the integrated expander pump assembly shown in Figure 1.

[0012] Figure 6 is a schematic see-through perspective view of an example expander having features in common with the integrated expander pump assembly shown in Figure 1.

[0013] Figure 7 is a schematic cross-sectional side view of the rotors of the integrated expander pump assembly shown in Figure 1.

DETAILED DESCRIPTION

[0014] The expander 20 is shown schematically at Figures 5 and 6. This section will describe general operational features and concepts of the expander 20. In general, the volumetric energy recovery device or expander 20 relies upon the kinetic energy and static pressure of a working fluid to rotate an output shaft 38. The expander 20 may be an energy recovery device 20 wherein the working fluid 12-1 is reduced in temperature and pressure between an inlet and an outlet. In such instances, device 20 may be referred to as an expander or expander, as so presented in the following paragraphs.

[0015] The expander 20 has a housing 22 with a fluid inlet 24 and a fluid outlet 26 through which the working fluid 12-1 undergoes a pressure drop to transfer energy to the output shaft 38. The output shaft 38 is driven by synchronously connected first and second interleaved counter-rotating rotors 30, 32 which are disposed in a cavity 28 of the housing 22. Each of the rotors 30, 32 has lobes that are twisted or helically disposed along the length of the rotors 30, 32. Upon rotation of the rotors 30, 32, the lobes at least partially seal the working fluid 12-1 against an interior side of the housing at which point expansion of the working fluid 12-1 only occurs to the extent allowed by leakage which represents an inefficiency in the system. In contrast to some expanders that change the volume of the working fluid when the fluid is sealed, the volume defined between the lobes and the interior side of the housing 22 of device 20 is constant as the working fluid 12-1 traverses the length of the rotors 30, 32. Accordingly, the expander 20 may be referred to as a “volumetric device” as the sealed or partially sealed working fluid volume does not change.

[0016] The expander 20 is shown schematically at Figures 5 and 6. As presented, the expander 20 inlets and outlets are configured for use with a relatively low pressure working fluid, such as a working fluid heated by an exhaust from an internal combustion engine or fuel cell. In one example, the working fluid and expander 20 are part of a Rankine cycle system 1 (see Figure 1) utilizing an organic working fluid. One such type of Rankine system within which the disclosed expander 20 can be used is shown and described in Patent Cooperation Treaty (PCT) International Publication Number WO 2013/130774, the entirety of which is incorporated by reference herein. The expander 20 can also be used in a system in which the working fluid is the coolant for a power plant, such as an internal combustion engine. Such a system is shown and described in PCT

International Patent Application Serial Number PCT/US2015/018372, filed on 03 March 2015 and entitled Coolant Energy and Exhaust Energy Recovery System. The entirety of PCT/US2015/018372 is incorporated by reference herein. The expander 20 may also be used with any type of working fluid (i.e., refrigerant) or system in which the working fluid is in at least a partially liquid state (i.e. at least partially condensed) within the expander 20 and in which the working fluid requires pumping through the circuit. Some applications for expander 20 include internal combustion engine based systems and refrigerant-based data center room cooling systems.

[0017] As shown, the expander 20 includes a housing 22 including an inlet port 24 configured to admit relatively high-pressure working fluid 12-1a from a heat exchanger 8 (see Figure 1). The heat exchanger 8 can be configured to transfer heat to the working fluid from a variety of sources, for example, the heat exchanger 8 can be a heat exchanger between the exhaust flow stream E-1 of an internal combustion engine and the working fluid 12-1. The housing 22 also includes an outlet port 26 configured to discharge working fluid 12-1b to a condenser 6 (see Figure 1) and/or a recuperator (not shown). It is noted that the working fluid 12-1b discharging from the outlet 26 is at a relatively lower pressure than the pressure of the working fluid 12-1a entering at the inlet 24.

[0018] As additionally shown in Figure 6, each rotor 30, 32 is a Roots-type rotor having four lobes, 30-1, 30-2, 30-3, and 30-4 in the case of the rotor 30, and 32-1, 32-2, 32-3, and 32-4 in the case of the rotor 32. Although four lobes are shown for each rotor 30 and 32, each of the two rotors may have any number of lobes that is equal to or greater than two, as long as the number of lobes is the same for both rotors in applications where the rotors are configured as Roots-type rotors. Accordingly, when one lobe of the rotor 30, such as the lobe 30-1 is leading with respect to the inlet port 24, a lobe of the rotor 32, such as the lobe 30-2, is trailing with respect to the inlet port 24, and, therefore with respect to a stream of the high-pressure working fluid 12-1.

[0019] As shown, the first and second rotors 30 and 32 are fixed to respective rotor shafts, the first rotor being fixed to an output shaft 38 and the second rotor being fixed to a shaft 40. Each of the rotor shafts 38, 40 is mounted for rotation on a set of bearings 60/62 and 64/66 about an axis X1, X2, respectively. It is noted that axes X1 and X2 are generally parallel to each other. The first and second rotors 30 and 32 are interleaved and continuously meshed for unitary rotation with each other. With renewed reference to

Figure 5, the expander 20 also includes meshed timing gears 42 and 44, wherein the timing gear 42 is fixed for rotation with the rotor 30, while the timing gear 44 is fixed for rotation with the rotor 32. The timing gears 42, 44 are configured to retain specified position of the rotors 30, 32 and prevent contact between the rotors during operation of the expander 20.

[0020] The output shaft 38 is rotated by the working fluid 12 as the working fluid undergoes expansion from the relatively high-pressure working fluid 12-1 to the relatively low-pressure working fluid 12-2. As may additionally be seen in both Figures 5 and 6, the output shaft 38 extends beyond the boundary of the housing 22. Accordingly, the output shaft 38 is configured to capture the work or power generated by the expander 20 during the expansion of the working fluid 12 that takes place in the rotor cavity 28 between the inlet port 24 and the outlet port 26 and transfer such work as output torque from the expander 20. Although the output shaft 38 is shown as being operatively connected to the first rotor 30, in the alternative the output shaft 38 may be operatively connected to the second rotor 32.

[0021] With reference to Figures 1-4, the expander 20 is shown in detail and in a configuration wherein the working fluid pumping and expansion functions are integrated together into the expander. As shown, the expander housing 22 includes a working fluid inlet 24, a first working fluid outlet 26a associated with rotor 30, and a second working fluid outlet 26b associated with rotor 32. The expander 20 also includes a first pump inlet 50a associated with rotor 30 and a second pump inlet 50b associated with rotor 32. A singular pump outlet 52 is also provided within the housing 22. Each of the inlets 24, 50a, 50b and outlets 26a, 26b, 52 extend into the internal rotor cavity 28 defined by the housing 22. Although two inlets 50a, 50b and two outlets 26a, 26b are shown, it is possible to provide singular inlets and outlets in some configurations.

[0022] As shown at Figure 1, the working fluid outlets 26a, 26b are in fluid communication with the condenser 6, where superheated or partially saturated working fluid 12-1b exiting the expander 20 can be condensed into a fully or partially saturated liquid. From the condenser 6, the working fluid 12-1c is directed to the pump inlets 50a, 50b. The working fluid 12-1c is then exposed to a length or portion of the rotating rotors 30, 32 which then pump the working fluid 12-1 to the pump outlet 52.

[0023] The provision of two working fluid outlets 26a, 26b for the expanded working fluid allows for the working fluid 12-1 to be evacuated from the cavity 28 in a rotor timing window in a more tightly controlled manner, as compared to that required with a single outlet. By controlling the timing of the fluid outlets 26a, 26b in relation to the inlets 50a, 50b (i.e. specific placement and size of the ports into the cavity 28), it is possible to maximize the degree to which the expanded working fluid is exhausted from the rotors before the pumped fluid is introduced into the rotors 30, 32 and cavity 28. This is an advantageous configuration that maximizes performance. The control of the port timing also results in the portion of the rotors 30, 32 performing the pumping function to be more easily separated from the portion performing the expansion functions, as schematically illustrated at Figure 7.

[0024] Referring to Figure 2, it can be seen that the housing 22 includes a first housing part 22a and a mating second housing part 22b that together define the cavity 28. The housing 22 also includes a cover plate 22c. As shown, the second housing part 22b has an end face 55 that faces the ends of the rotors 30, 32. The end face 55 includes a first inlet port 56a in fluid communication with the first inlet 50a, a second inlet port 56b in fluid communication with the second inlet 50b, and an outlet port 58 in fluid communication with the outlet 52. In this configuration, the provision of two pump inlet ports 56a, 56b at the location shown allows for the working fluid 12-1 to be effectively directed to the end faces of the rotors 30, 32, which are generally parallel to end face 55, and into the closed volume defined between the interior housing wall and the lobes of the rotors 30, 32 in a balanced manner. As such, the two pumped fluid streams can be individually pumped around the perimeter of the cavity 28 and towards the centrally located outlet port 58.

[0025] In one aspect, the fluid 12-1 entering ports 50a, 50b, referenced as fluid 12-1c in the drawings, is at a relatively lower temperature than the fluid 12-1 entering the inlet port 24 which is referenced as fluid 12-1a in the drawings. This is due to the circumstance that the port 24 receives fluid 12-1a from the heat exchanger 8, which is specifically designed to raise the temperature of the working fluid 12-1, while the ports 50a, 50b receive fluid 12-1c that has already been expanded by the expander 20 and routed through the condenser 6. In one example, the fluid 12-1a entering the inlet port 24 could be about 250°C while the fluid 12-1c entering the inlet ports 50a, 50b could be about 30°C. As

such, the pumped fluid received at inlet ports 50a, 50b, which is subsequently exposed to the housing 22 and the rotors 30, 32 can have a beneficial performance effect on the expander 20 in limiting thermal expansion of the housing 22 and rotors 30, 32. In one embodiment, this cooling effect more easily allows for the housing 22 and rotors 30, 32 to be constructed of aluminum.

[0026] Additionally, as the fluid streams entering inlets 50a, 50b and 24 are intermixed within the cavity 28 to some degree, the expander 20 itself acts as a recuperator in that the pumped fluid 12-1d leaving outlet 52 and entering exchanger 8 will have been pre-heated to some degree while the fluid 12-1d leaving the outlets 26a, 26b will have been beneficially cooled to reduce the heat load in the condenser 6. Another beneficial aspect of the disclosed configuration is that the working fluid 12-1c entering the cavity 28 via ports 50a, 50b is primarily in a liquid state (i.e. at least partially condensed) and can act to seal the clearance gaps between the rotors 30, 32 and the interior side of the housing 22 that forms the cavity 28. This sealing effect reduces leakage losses of the fluid passing from inlet 24 to outlets 26a, 26b and thus improves the overall efficiency of the expander 20. Yet another benefit of the integrated expander and pump design is that the fluid being pumped from ports 50a, 50b to outlet 52 will not harm the rotors 30, 32 if the fluid is not a saturated liquid. As such, the rotors 30, 32 can pump a multiple phase fluid, albeit at a reduced pumping efficiency.

[0027] As the expander 20 is configured to simultaneously operate as an expander and a pump with the same set of rotors 30, 32, it is advantageous in some configurations to reduce the rotational speed of the rotors 30, 32 in comparison to an expander which only performs an expansion function. For example, a pure expander configuration might have an operating point of 8,000 revolutions per minute (rpm) while the disclosed configuration may have a corresponding operating point of 2,000 rpm. This reduced rotational rate can enable the rotors 30, 32 to more effectively pump fluid from ports 50a, 50b to outlet 52.

WHAT IS CLAIMED IS:

1. An integrated expander and pump assembly comprising:
 - a. a housing defining an internal chamber;
 - b. a pair of parallel helical rotors disposed within the housing internal chamber, the rotors being configured to operate in a counter rotating arrangement, each of the rotors having a first end and a second end;
 - c. a first working fluid inlet for receiving a superheated or partially saturated working fluid;
 - d. a first working fluid outlet for discharging the working fluid after the working fluid has been expanded by the pair of rotors;
 - e. a second working fluid inlet for receiving the working fluid in at least a partially condensed state from the first working fluid outlet; and
 - f. a second working fluid outlet for discharging the working fluid after the working fluid has been pumped by the pair of rotors.
2. The integrated expander and pump assembly of claim 1, wherein the first working fluid outlet includes a first outlet port and a second outlet port.
3. The integrated expander and pump assembly of claim 1 or 2, wherein the second working fluid inlet includes a first inlet port and a second inlet port.
4. The integrated expander and pump assembly of claim 3, wherein the first inlet port extends to a first opening in an end wall of the housing that is in fluid communication with a first rotor of the pair of rotors and the second inlet port extends to a second opening in the housing end wall that is in fluid communication with a second rotor of the pair of rotors.
5. The integrated expander and pump assembly of claim 4, wherein the end wall is generally parallel to first end faces of the pair of helical rotors.
6. The integrated expander and pump assembly of any of the above claims, wherein each of the pair of rotors is a Roots-type rotor such that the rotors have an equal number of non-contacting lobes.

7. The integrated expander and pump assembly of claim 6, wherein each of the rotors has three lobes.
8. An energy recovery system for a power plant comprising:
 - a. the integrated expander and pump assembly of claim 1;
 - b. a heat exchanger for transferring heat from the power plant to the working fluid leaving the second outlet port and entering the first working fluid inlet; and
 - c. a condenser for condensing the working fluid leaving the first working fluid outlet and entering the second working fluid inlet.
9. The energy recovery system of claim 8, wherein the heat exchanger transfers heat from an exhaust flow stream from the power plant to the working fluid.
10. The energy recovery system of claim 8 or 9, wherein the power plant is an internal combustion engine.
11. The energy recovery system of any of claims 8-10, wherein the first working fluid outlet includes a first outlet port and a second outlet port.
12. The energy recovery system of any of claims 8-11, wherein the second working fluid inlet includes a first inlet port and a second inlet port.
13. The energy recovery system of claim 12, wherein the first inlet port extends to a first opening in an end wall of the housing that is in fluid communication with a first rotor of the pair of rotors and the second inlet port extends to a second opening in the housing end wall that is in fluid communication with a second rotor of the pair of rotors.
14. The energy recovery system of any of claims 8-13, wherein each of the pair of rotors is a Roots-type rotor such that the rotors have an equal number of non-contacting lobes.
15. The energy recovery system of claim 14, wherein each of the rotors has three lobes.

16. A method for operating an energy recovery system comprising:
 - a. heating a working fluid with a heat exchanger that is in fluid communication with a power plant;
 - b. expanding the working fluid to have a lower pressure and temperature by passing the working fluid through a pair of rotors within an expander between a first inlet and a first outlet;
 - c. condensing the expanded working fluid to at least a partially condensed state;
 - d. reintroducing the at least partially condensed working fluid back into the expander at a second inlet; and
 - e. pumping the working fluid with the pair of rotors to a second outlet to the heat exchanger.
17. The method of claim 16, wherein the first outlet includes a first outlet associated with a first rotor and a second outlet associated with a second rotor.
18. The method of claim 17, wherein the second inlet includes a first inlet associated with the first rotor and a second inlet associated with the second rotor.

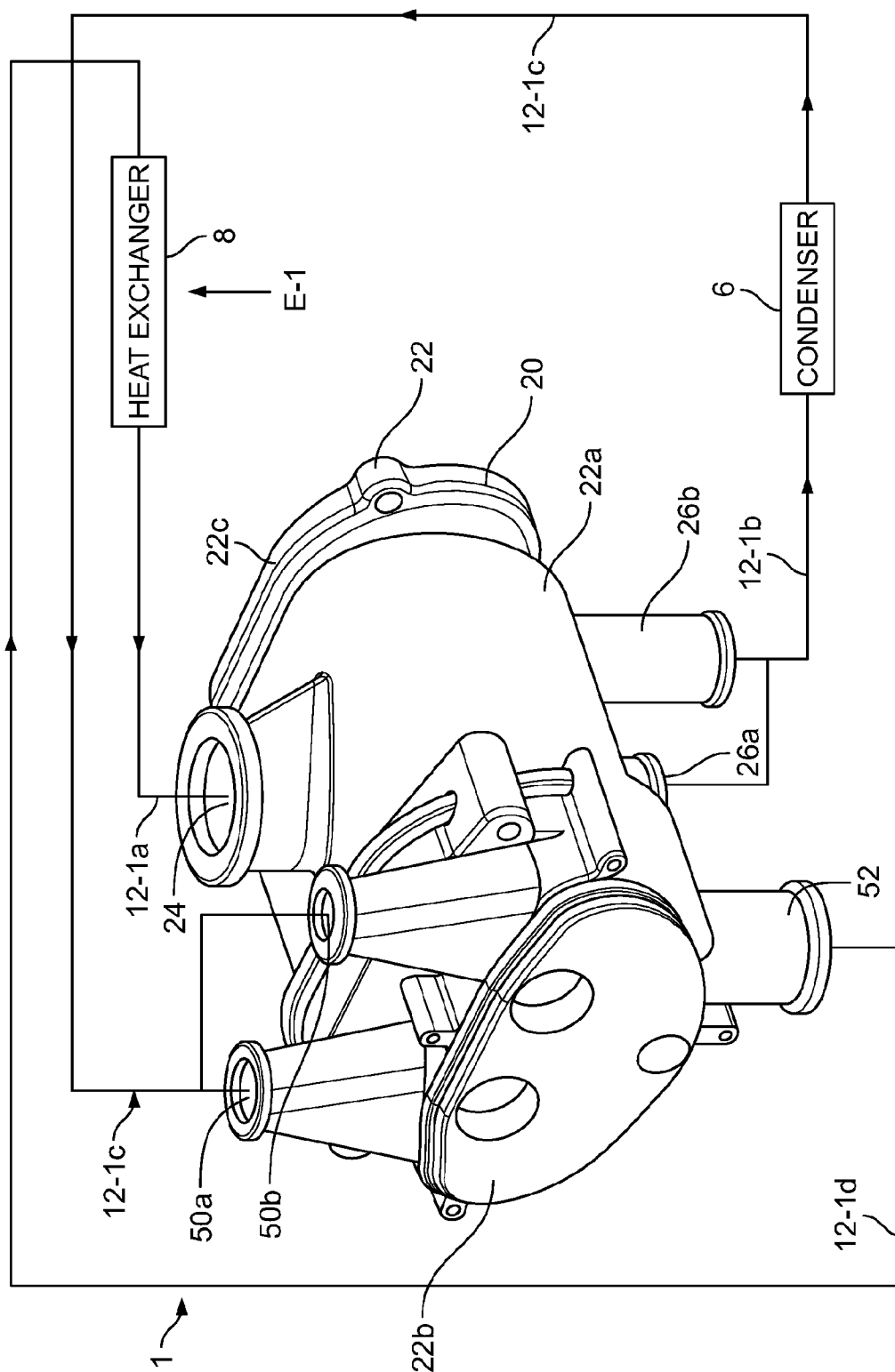


FIG. 1

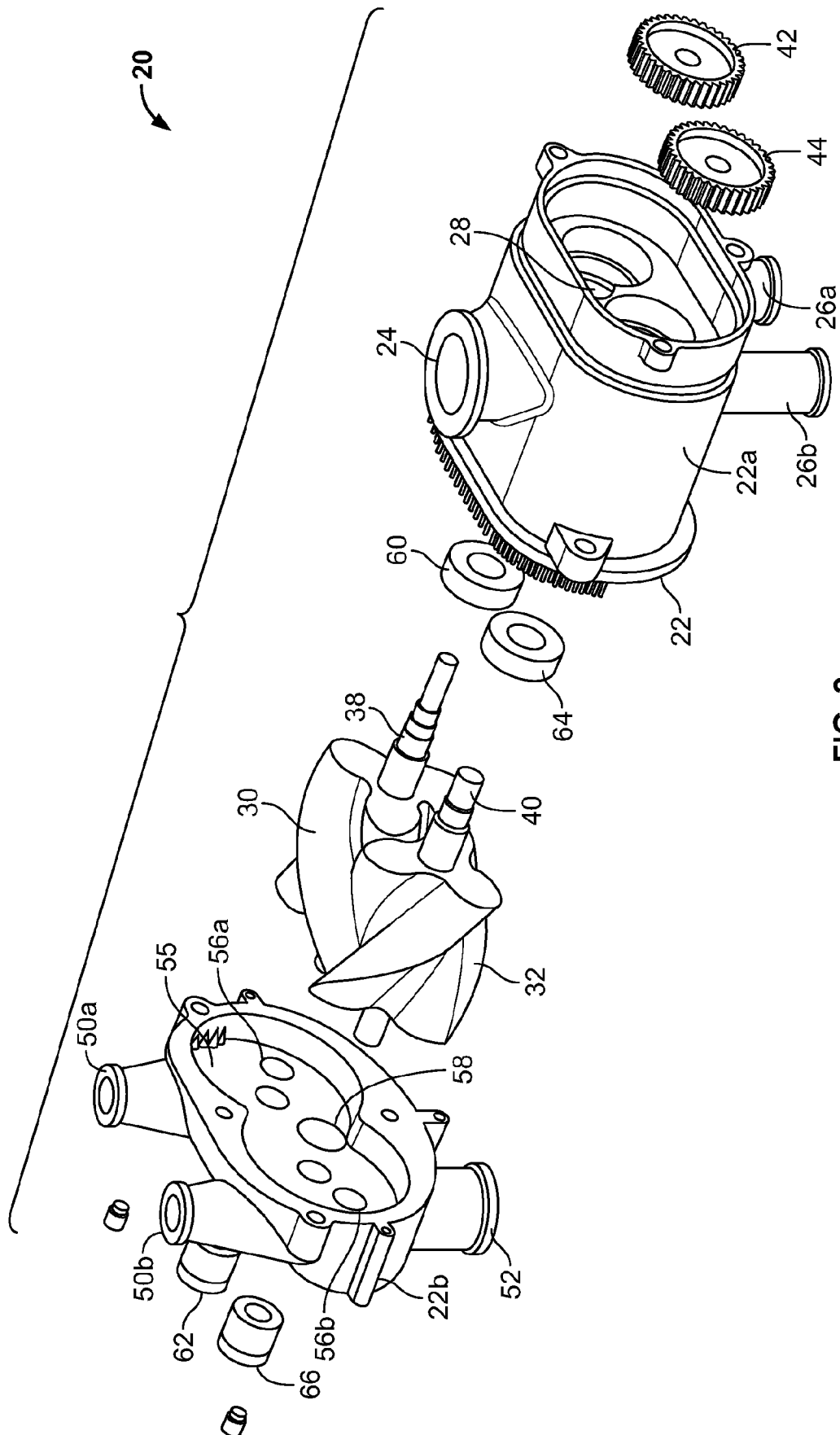


FIG. 2

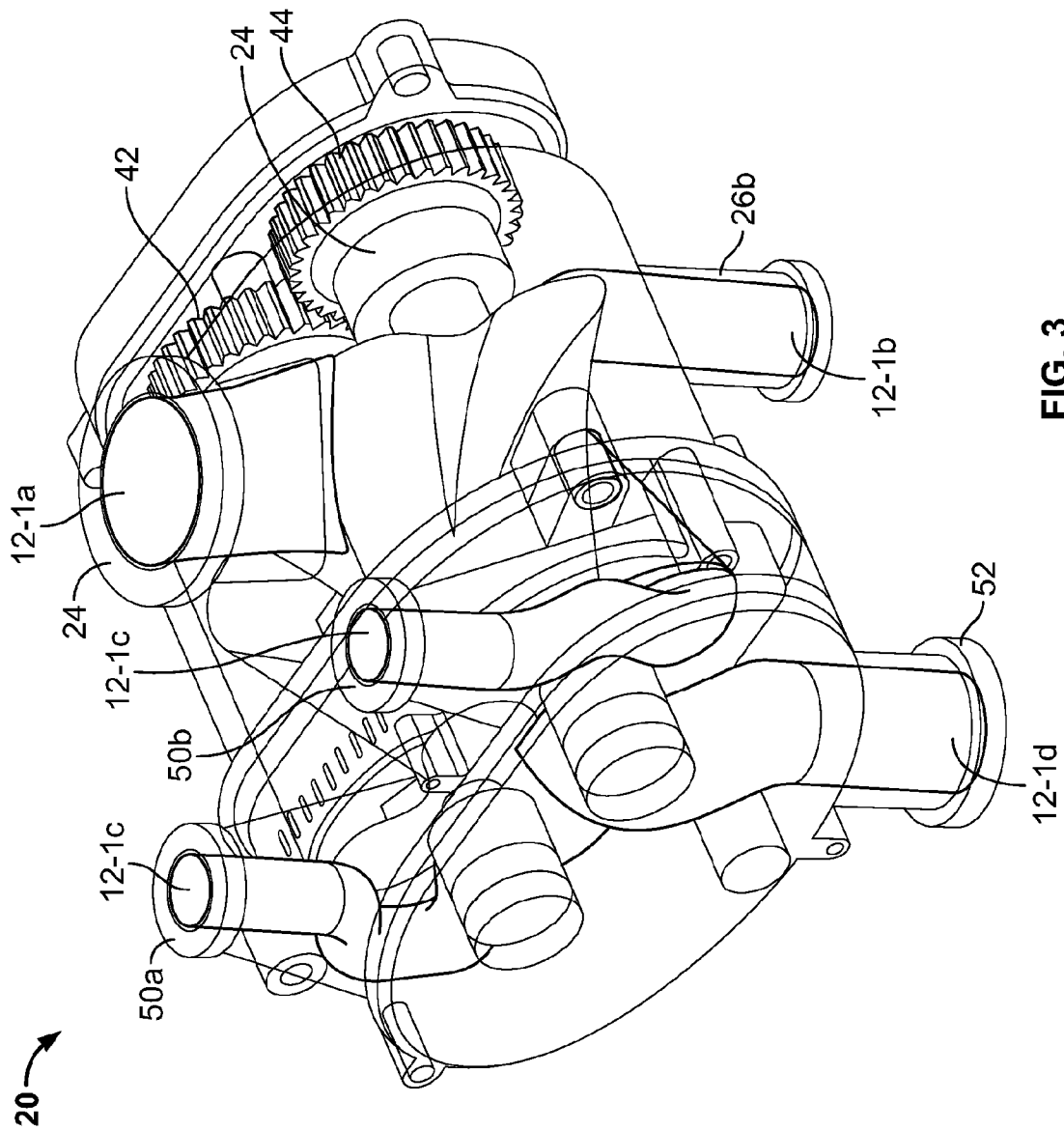


FIG. 3

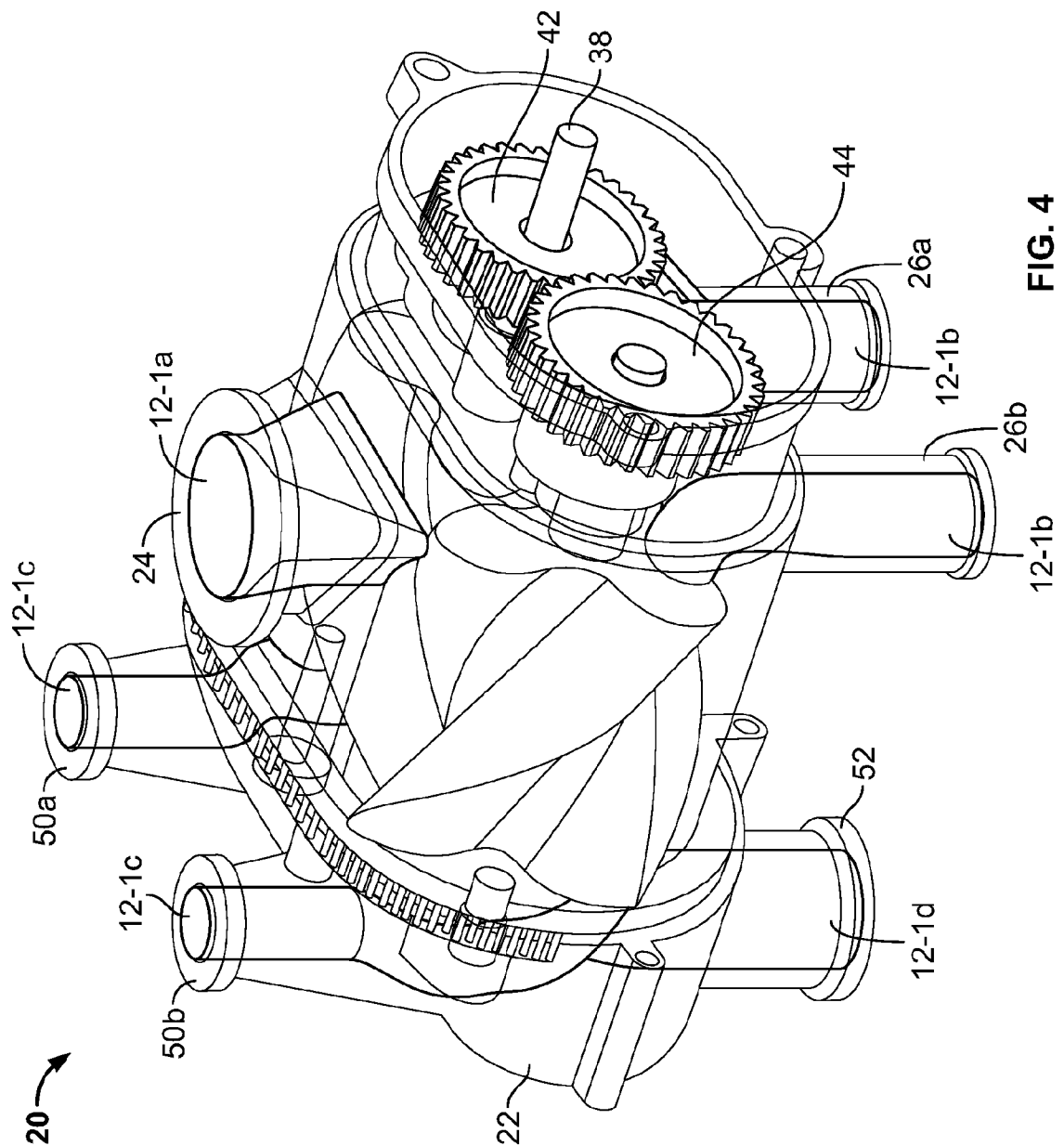


FIG. 4

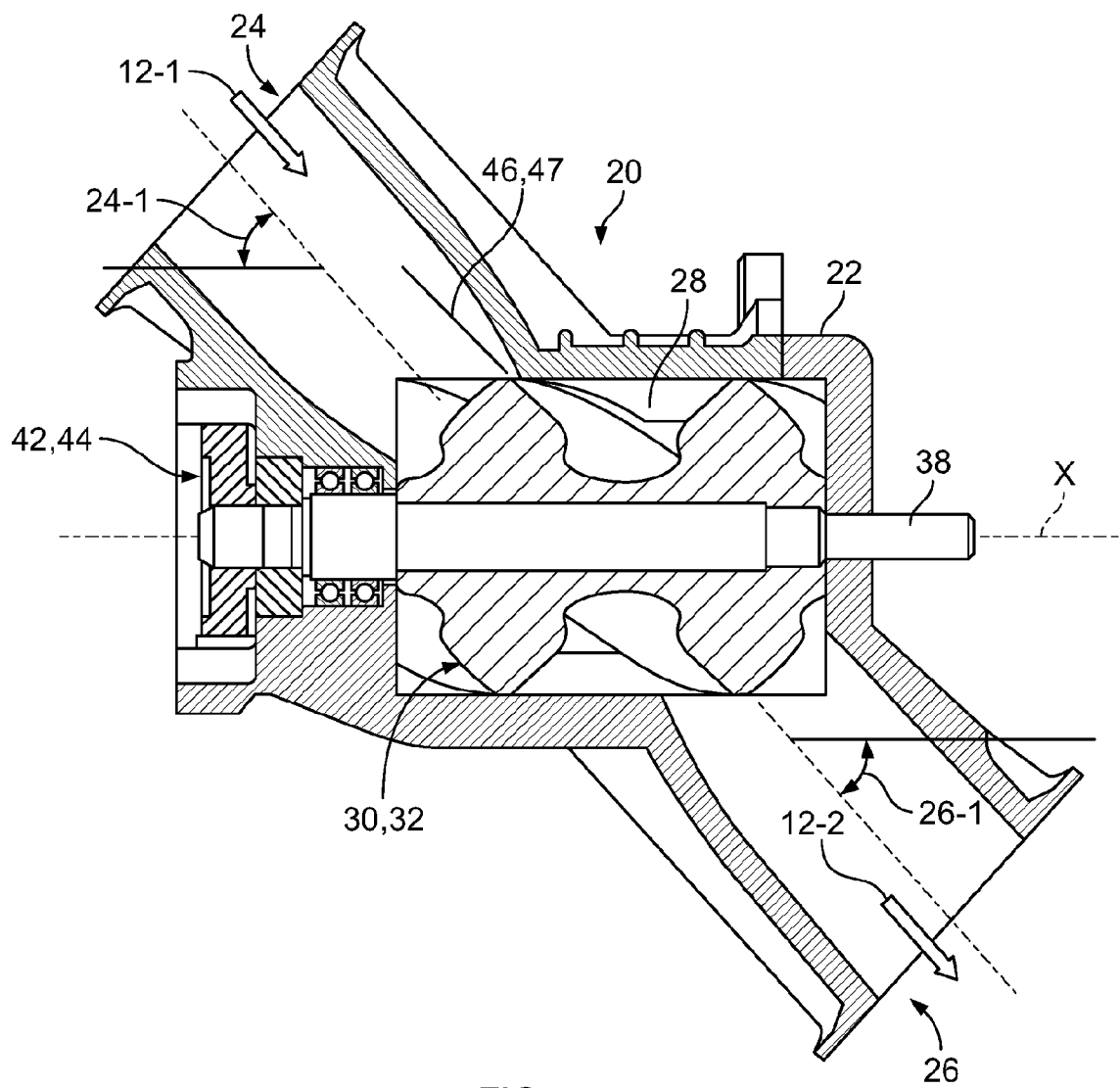


FIG. 5

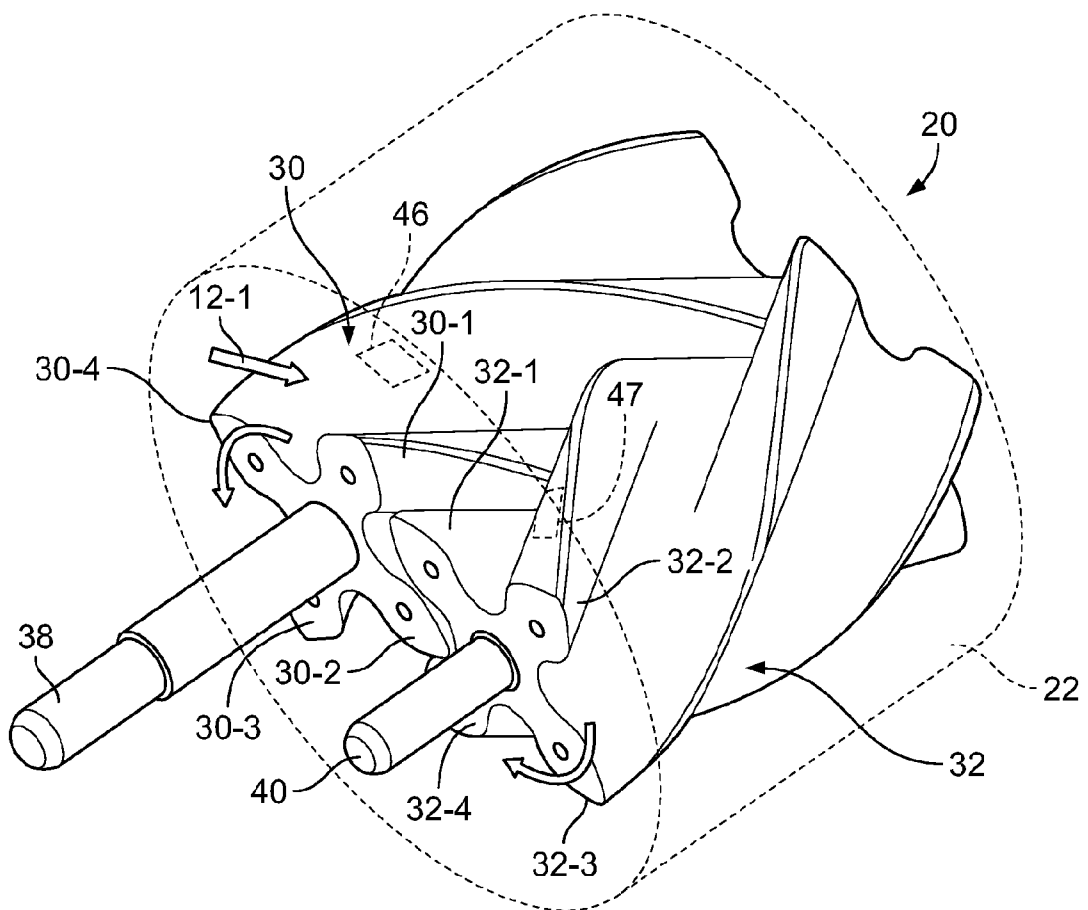


FIG. 6

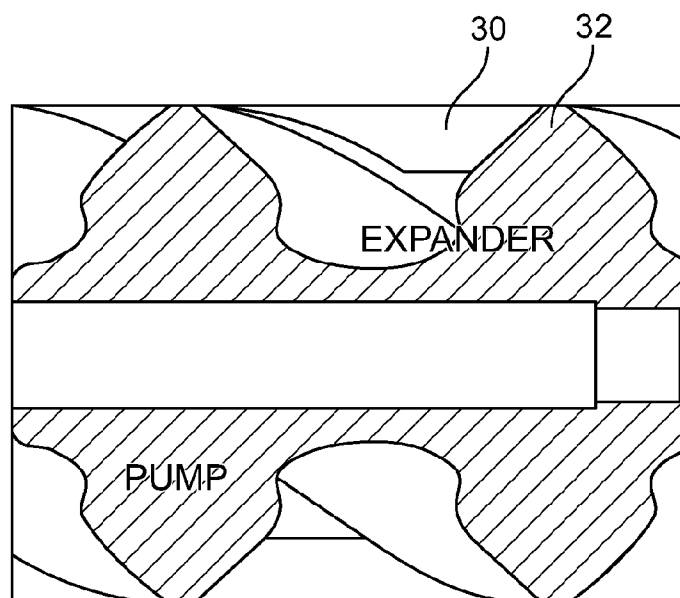


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/037359**A. CLASSIFICATION OF SUBJECT MATTER****F02G 5/02(2006.01)I, F01N 5/02(2006.01)I, F04C 2/08(2006.01)I**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F02G 5/02; F01K 23/10; F02B 73/00; F02C 3/04; F01D 25/18; F01D 15/10; F01K 25/00; F01N 5/02; F04C 2/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & keywords: expander, heat exchanger, condenser, inlet, outlet and rotor

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2014-0190172 A1 (MAIER, WILLIAM C.) 10 July 2014 See abstract, paragraphs [0017]-[0023], claim 1 and figure 1.	1-15
A		16-18
Y	US 2014-0260245 A1 (EATON CORPORATION) 18 September 2014 See abstract, paragraphs [0025]-[0040], claims 1, 9 and figures 1-3, 7-9.	1-15
A	US 2012-0073289 A1 (AST et al.) 29 March 2012 See abstract, paragraphs [0016]-[0026] and figures 1-4.	1-18
A	US 2014-0159369 A1 (KABUSHIKI KAISHA KOBE SEIKO SHO (KOBE STEEL, LTD.)) 12 June 2014 See abstract, paragraphs [0037]-[0052], claim 1 and figures 1-4.	1-18
A	US 8820082 B2 (YOSHIMURA, SHOJI) 02 September 2014 See abstract, column 6, line 3 - column 8, line 41 and figures 1-5.	1-18



Further documents are listed in the continuation of Box C.



See patent family annex.

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189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea



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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/037359

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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