(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 489 595 A1

(12) **EUROPEAN PATENT APPLICATION**

published in accordance with Art. 153(4) EPC

(43) Date of publication:
29.05.2019 Bulletin 2019/22

(21) Application number: **18845398.9**

(22) Date of filing: **02.05.2018**

(51) Int Cl.:
F25B 9/10 *(2006.01)*

(86) International application number:
PCT/CN2018/085286

(87) International publication number:
WO 2019/041869 (07.03.2019 Gazette 2019/10)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **31.08.2017 CN 201710766787**

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(54) WAVE ROTOR-BASED MULTI-STAGE REFRIGERATOR

(57) It is a kind of multistage wave rotor refrigerator which could be used in the field of gas expansion refrigeration. The refrigerator is mainly composed of a casing, a left end cover, a right end cover, a wave rotor, a central shaft, a high pressure inlet nozzle, a medium pressure outlet nozzle and a drive mechanism. Within the structure of the refrigerator, 2-8 times unsteady expansion of gas could get realized, which improves the refrigeration efficiency under large pressure ratio. Extending the structure of the refrigerator and changing the structure of end cover could help realize multistage expansion refrigeration of gas. The double opening structure of oscillation tubes could help the refrigerator work regularly with high moisture content of gas. This refrigerator is a gas expansion refrigeration device that uses moving unsteady pressure waves in oscillation tubes to realize the separation of the heat and cold of gas. Improvement of refrigeration efficiency could be done by recycling expansion work in the form of pressure energy that formed by expansion of high pressure gas.

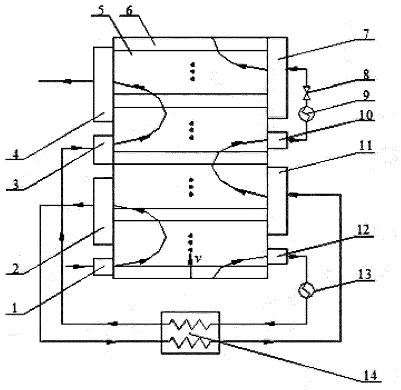

Fig. 1

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Description

Technical field

[0001] The invention relates to a multistage wave rotor refrigeration machine which belongs to the technical field of gas expansion refrigeration.

Background technique

[0002] The gas wave refrigeration technology rose since the 1980s. The gas wave expansion refrigeration machine uses unsteady flow of the gas in the oscillation tube to separate the heat and cold.

[0003] At present, the gas wave refrigeration technology is mainly used in the liquefaction and separation of mixed gas, light hydrocarbon recovery of liquefied petroleum gas, liquefaction of natural gas, generation of low temperature air source and other fields. The gas wave refrigerator has the advantages of easy operation, easy maintenance and high reliability compared with the ordinary turbo expander. The natural gas treatment process often needs depressurization, cooling and dehydration treatment.When the required pressure drop is large, the ordinary single-stage gas wave refrigerator is difficult to meet the operating conditions. Therefore, it is necessary to invent a multistage gas wave refrigerator to meet the demand of refrigeration under the condition of large pressure ratio.

[0004] Most of the gas wave refrigerators belong to the single stage unsteady expansion refrigeration system(such as the Chinese patent 87101903.5, 89213744.4, 90222999.0 and so on). The expansion ratio is generally ranges from 2 to 4. If larger cooling temperature drop is needed, the isentropic refrigeration efficiency will decrease considerably. Therefore, it is necessary to invent a multistage refrigerator to meet the demand of refrigeration under the condition of large pressure ratio. There is only one type of multistage gas wave refrigerator (the Chinese patent 96115022.X) until now, which employs single opening oscillation tube. Although multistage refrigeration can be realized under large pressure ratio in the gas wave refrigerator of single opening oscillation tubes, the phenomenon of liquid accumulation may make the oscillation tube ruptured in the process of operating. And large bulk of the machine and slow heat dissipation in the working process are also disadvantages.

[0005] If several gas wave refrigerators are connected in series to realize refrigeration, expansion ratio of each machine could be decreased a lot. However, the pressure energy of the gas can’t be effectively recovered and the series connection of refrigerators leads to large investment and the occupation. And the overall efficiency will reduce when the match between different stages of refrigerators is not good. Therefore, the invention of a refrigerator that can achieve efficient refrigeration at high pressure ratio, recover the pressure energy effectively and avoid the generation of liquid during the operation becomes a key issue of current gas wave refrigeration technology.

Invention content

[0006] The invention provides a kind of multistage wave rotor refrigerator to overcome the existing technology problems. About the structure of the machine, there are 30-280 oscillation tubes parallel to the axis in the circumferential direction of the wave rotor, which can realize 2-8 times unsteady expansion in the wave rotor to achieve gas cooling under a large pressure ratio.In this way, the expansion work produced by the expansion of the high pressure gas is recovered in the form of pressure energy to improve refrigeration efficiency. The oscillation tube with the form of double opening can effectively control the trend of liquid motion to avoid the liquid accumulation problems.

[0007] The technical scheme of the present invention is that: a multistage wave rotor refrigerator includes a casing, a left end cover, a right end cover, a wave rotor, a central shaft, a high pressure inlet nozzle, a medium pressure outlet nozzle and a drive mechanism. The wave rotor is fixed to the circular disk of the central shaft by bolts. The wave rotor is placed in the casing whose left side is set with a left end cover and a right side a right end cover. Between the left end cover and the left side of central shaft there are two bearings behave as support. Another two bearings behave as support between the right end cover and the right side of central shaft. Oscillation tubes with constant cross-section are set in the wave rotor in circumferential direction. On the left end cover there are first high pressure inlet chamber of 2-8 stages, second low temperature outlet chamber of 2-8 stages, second high pressure inlet chamber of 2-8 stages and first low temperature outlet chamber of 2-8 stages in order. On the right end cover (25) there are second medium pressure outlet chamber of 2-8 stages, first low pressure inlet chamber of 2-8 stages, first medium pressure outlet chamber of 2-8 stages and second low pressure inlet chamber of 2-8 stages in order. The high pressure inlet nozzles of 2-8 stages are fixed on the left end cover by bolts, and the medium pressure outlet nozzles of 2-8 stages on the right end cover. The circumferential central line of high pressure inlet nozzles and medium pressure outlet nozzles is the same as the circumferential central line of end faces of oscillation tubes. The clearance fitting between stationary nozzles surface plane and rotary wave rotor surface plane needs to be controlled. The drive mechanism is an electromotor that drives the wave rotor on the central shaft to rotate in the casing through a coupling.

[0008] There are 2-8 high-pressure inlet nozzles in the refrigerator, which could help realize unsteady expansion of gas 2-8 times.

[0009] In the wave rotor of refrigerator there are 30-280 oscillation tubes.

[0010] The beneficial effects of the present invention include that it simplifies the structure of machine and it is conducive to be installed and adjusted. The wave rotor of refrigerator of double opening oscillation tubes is mainly composed of a casing, a left end cover, a right end cover, a wave rotor, a central shaft, a high pressure inlet nozzle, a medium pressure outlet nozzle and a drive mechanism. The wave rotor and the central shaft are combined into a whole and rotate synchronously.

[0011] The gas wave rotor refrigerator can reduce the temperature and pressure of the gas after 2-8 times expansion, which realizes 2-8 stages gas refrigeration. At the same time expansion ratio ranging from 4 to 20 could be realized that makes the machine more suitable for gas refrigeration under large pressure ratio.

[0012] The refrigerator can transmit the expansion work generated by the expansion of high pressure gas to the low pressure gas expanded by itself in the oscillation tube through the shock wave, which raises the pressure level of the gas. The gas whose pressure rises could be expanded again in the device.The expansion work is recovered in the form of pressure energy, which greatly reduces the overall cooling pressure loss of the system and improves the refrigeration efficiency of the system.

[0013] According to the present invention, the high temperature gas exhausted from the medium pressure chamber of the gas wave refrigerator could be cooled by external cooler, which effectively improves the heat dissipation efficiency.

[0014] The gas wave refrigerator uses double opening oscillation tubes. When the moisture content of the gas is high, the gas would be condensed during the cooling process in oscillation tubes. Then the condensed liquid can discharge through both sides of oscillation tubes. So the refrigerator can work with liquid.

Illustrating the drawings

[0015]

Figure 1 shows the working procedure of a two-stage wave rotor refrigerator.

Figure 2 shows the structure of a two-stage wave rotor refrigerator.

Figure 3 shows the structure of left end cover of a two-stage wave rotor refrigerator.

Figure 4 shows the structure of right end cover of a two-stage wave rotor refrigerator.

Figure 5 is the A-A section view in Figure 2.

Figure 6 is the B-B section view in Figure 2.

Figure 7 is the structure schematic diagram of the left end cover structure of a two-stage wave rotor refrigerator.

Figure 8 is the structure schematic diagram of the left end cover structure of a six-stage wave rotor refrigerator.

Figure 9 is the structure schematic diagram of the left end cover structure of an eight-stage wave rotor refrigerator.

[0016] In the Figures: 1.first high pressure inlet nozzle of two stages, 2.first low temperature outlet chamber of two stages, 3. second high pressure inlet nozzle of two stages, 4. second low temperature outlet chamber of two stages, 5.wave rotor, 6.oscillation tube, 7.second low pressure inlet chamber of two stages, 8.throttle valve, 9.first stage cooler, 10.first medium pressure outlet nozzle of two stages, 11.first low pressure inlet chamber of two stages, 12.second medium pressure outlet nozzle of two stages,13.second stage cooler, 14.first stage heat exchanger, 15.second high pressure inlet chamber of two stages, 16.left bearing end cover, 17.bearings, 18. first high pressure inlet chamber of two stages, 19.left end cover, 20.casing, 21.second medium pressure outlet chamber of two stages, 22.electromotor, 23.coupling, 24.right bearing end cover, 25.right end cover, 26.first medium pressure outlet chamber of two stages, 27.bolts, 28.central shaft, 28a.circular disk, a_{10}.first high pressure inlet chamber of six stages, a_{11}.first low temperature outlet chamber of six stages, a_{20}.second high pressure inlet chamber of six stages, a_{21}. second low temperature outlet chamber of six stages, a_{30}.third high pressure inlet chamber of six stages, a_{31}.third low temperature outlet chamber of six stages, a_{40}.fourth high pressure inlet chamber of six stages, a_{41}.fourth low temperature outlet chamber of six stages, a_{50}.fifth high pressure inlet chamber of six stages, a_{51}.fifth low temperature outlet chamber of six stages, a_{60}.sixth high pressure inlet chamber of six stages,a_{61}.sixth low temperature outlet chamber of six stages, b_{10}.first high pressure inlet chamber of eight stages, bu.first low temperature outlet chamber of eight stages, b_{20}.second high pressure inlet chamber of eight stages, b_{21}.second low temperature outlet chamber of eight stages, b_{30}.third high pressure inlet chamber of eight stages, b_{31}.third low temperature outlet chamber of eight stages, b_{40}.fourth high pressure inlet chamber of eight stages, b_{41}. fourth low temperature outlet chamber of eight stages, b_{50}.fifth high pressure inlet chamber of eight stages, b_{51}.fifth low temperature outlet chamber of eight stages, b_{60}.sixth high pressure inlet chamber of eight stages, b_{61}.sixth low temperature outlet chamber of eight stages, b_{70}.seventh high pressure inlet chamber of eight stages, b_{71}.seventh low temperature outlet chamber of eight stages, b_{80}.eighth high pressure inlet chamber of eight stages, b_{81}.eighth low temperature outlet chamber of eight stages.

Detailed description

[0017] The two-stage refrigerator is introduced particularly according to the figures and the detailed description:

Figures 2, 3, 4, 5 and 6 show the structure of a two-stage wave rotor refrigerator. In the figures, a multistage wave rotor refrigerator includes a casing 20, a left end cover 19, a right end cover 25, a wave rotor 5, a central shaft

28, high pressure inlet nozzles, medium pressure outlet nozzles and a drive mechanism. The wave rotor 5 is fixed to the circular disk 28a of the central shaft 28 by bolts 27. The wave rotor 5 is composed of 30-280 oscillation tubes 6 of equal section. On the left end cover 19 there are first high pressure inlet chamber of two stages 18, second low temperature outlet chamber of two stages 4, second high pressure inlet chamber of two stages 15 and first low temperature outlet chamber of two stages 2 in order. On the right end cover 25 there are second medium pressure outlet chamber of two stages 21, first low pressure inlet chamber of two stages 11, first medium pressure outlet chamber of two stages 26 and second low pressure inlet chamber of two stages 7 in order. The first high pressure inlet nozzle of two stages 1 and the second high pressure inlet nozzle of two stages 3 are respectively fixed to the left end cover 19 by bolts. The first medium pressure outlet nozzle of two stages 10 and the second medium pressure outlet nozzle of two stages 12 are respectively fixed to the right end cover 25 by bolts. The circumferential central line of nozzles above is the same as the circumferential central line of end faces of oscillation tubes 6. The drive mechanism is an electromotor 22 that drives the wave rotor 5 on the central shaft 28to rotate in the casing 20 through a coupling 23. The clearance fitting between stationary nozzles surface plane and rotary wave rotor 5 surface plane needs to be controlled.

[0018] Figure 1 shows the working procedure of a two-stage wave rotor refrigerator. While working, the electromotor 22 drives the wave rotor 5 to rotate through the central shaft 28 then the high pressure gas enters the first high pressure inlet chamber of two stages 18.After that the gas enters the left side of oscillation tubes 6 via the first high pressure inlet nozzle of two stages 1. The injected high pressure gas transmits the expansion work in the form of shock wave to the low pressure gas in the oscillation tubes 6, so that temperature and pressure of the gas in the oscillation tubes 6 rises. So that the pressure level of the gas rises.Then the gas is discharged by the second medium pressure outlet nozzle of two stages 12. At last, after cooled by second stage cooler 13, the gas enters the first stage heat exchanger 14 to exchange the cold with the gas whose temperature is reduced after being expanded.

[0019] The temperature of medium pressure gas decreases after the gas exchanging the cold then the gas gets injected into the oscillation tubes 6 by second high pressure inlet nozzle of two stages 3 to get expanded a second time making the temperature of gas lower. Motivated by pressure drop, the gas is exhausted out of the system via second low temperature outlet chamber of two stages 4 of which the position is confirmed by calculating matching of nozzles. After heat exchanging, another flux of gas flows back to the oscillation tubes 6 via first low pressure inlet chamber of two stages 11.At this time the high pressure gas from the second high pressure inlet nozzle of two stages 3gets expanded and transmits the expansion work in the form of shock wave to the gas in the oscillation tubes 6.The temperature and pressure of the gas in the oscillation tubes 6 rise and then the gas becomes medium pressure gas which then flows into first medium pressure outlet chamber of two stages 26 via first medium pressure outlet nozzle of two stages 10 and get exhausted out of oscillation tubes 6. The pressure and temperature of medium pressure gas decreases after flowing via throttle valve 8 and first stage cooler 9. Then the gas flows back to oscillation tubes 6 via second low pressure inlet chamber of two stages 7. After one period rotating of wave rotor 5, oscillation tubes 6 get connected with first high pressure inlet nozzle of two stages 1 one more time and low pressure gas prepares for attaining pressure energy next time.

[0020] Figure 7 shows the left end cover structure of a two-stage wave rotor refrigerator. The first high pressure inlet chamber of two stages 18 and the second high pressure inlet chamber of two stages 15 are symmetrically set on the left end cover. Second low temperature outlet chamber of two stages 4 and first low temperature outlet chamber of two stages 2 are symmetrically set on the left end cover where high pressure inlet chambers and low temperature outlet chambers are cross-distributed.

[0021] Figure 8 shows the left end cover structure of a six-stage wave rotor refrigerator. There are first high pressure inlet chamber of six stages a_{10}, first low temperature outlet chamber of six stages a_{11}, second high pressure inlet chamber of six stages a_{20}, second low temperature outlet chamber of six stages a_{21}, third high pressure inlet chamber of six stages a_{30}, third low temperature outlet chamber of six stages a_{31}, fourth high pressure inlet chamber of six stages a_{40}, fourth low temperature outlet chamber of six stages a_{41}, fifth high pressure inlet chamber of six stages a_{50}, fifth low temperature outlet chamber of six stages a_{51}, sixth high pressure inlet chamber of six stages a_{60}, sixth low temperature outlet chamber of six stages a_{61}. They were symmetrically located on the left end cover where the high pressure inlet chambers and the low temperature outlet chambers are cross-distributed. The structure of the right end cover of the six-stage wave rotor refrigerator is similar to that of the left end cover. The working process of the six-stage refrigerator is similar to that of the two-stage refrigerator.

[0022] Figure 9 shows the left end cover structure of an eight-stage wave rotor refrigerator. There are first high pressure inlet chamber of eight stages b_{10}, first low temperature outlet chamber of eight stages b_{11}, second high pressure inlet chamber of eight stages b_{20}, second low temperature outlet chamber of eight stages b_{21}, third high pressure inlet chamber of eight stages b_{30}, third low temperature outlet chamber of eight stages b_{31}, fourth high pressure inlet chamber of eight stages b_{40}, fourth low temperature outlet chamber b_{41}, fifth high pressure inlet chamber of eight stages b_{50}, fifth low temperature outlet chamber of eight stages b_{51}, sixth high pressure inlet chamber of eight stages b_{60}, sixth low temperature outlet chamber of eight stages b_{61}, seventh high pressure inlet chamber of eight stages b_{70}, seventh low temperature outlet chamber of eight stages b_{71}, eighth high pressure inlet chamber of eight stages b_{80}, eighth low temperature outlet chamber of eight stages b_{81}. They were symmetrically located in the left end cover where the high pressure inlet chambers and the low temperature outlet chambers are cross-distributed. The structure of the right end cover of the eight-stage wave rotor refrigerator is similar to that of the left end cover. The working process of the eight-stage refrigerator is similar to that of the two-stage refrigerator.

Claims

1. A multistage wave rotor refrigerator including a casing (20), a left end cover (19) and a right end cover (25); the characteristics of the refrigerator include a wave rotor (5), a central shaft (28), high pressure inlet nozzles, medium pressure outlet nozzles and a drive mechanism; the wave rotor (5) is fixed on the circular disk (28a) of central shaft (28) through bolts (27); the wave rotor (5) is placed in the casing (20) whose left side is set with the left end cover (19) and right side the right end cover (25); between the left end cover (19) and the left side of central shaft (28) there are two bearings (17) behave as support; another two bearings (17) behave as support between the right end cover (25) and the right side of central shaft (28); oscillation tubes (6) with constant cross-section are set in the wave rotor (5) in circumferential direction; On the left end cover (19) there are first high pressure inlet chamber of 2-8 stages, second low temperature outlet chamber of 2-8 stages, second high pressure inlet chamber of 2-8 stages and first low temperature outlet chamber of 2-8 stages in order; on the right end cover (25) there are second medium pressure outlet chamber of 2-8 stages, first low pressure inlet chamber of 2-8 stages, medium pressure outlet chamber of 2-8 stages and second low pressure inlet chamber of 2-8 stages in order; the high pressure inlet nozzles of 2-8 stages are fixed on the left end cover (19) by bolts, and the medium pressure outlet nozzles of 2-8 stages on the right end cover (25); the circumferential central line of high pressure inlet nozzles and medium pressure outlet nozzles is the same as the circumferential central line of end faces of oscillation tubes (6); the clearance fitting between stationary nozzles surface plane and rotary wave rotor (5) surface plane needs to be controlled; The drive mechanism is an electromotor (22) that drives the wave rotor (5) on the central shaft (28) to rotate in the casing (20) through a coupling (23).

2. The multistage wave rotor refrigerator according to the claim 1, the characteristics include that as for two-stage wave rotor refrigerator, on the left end cover (19) there are a first high pressure inlet chamber of two stages(18), a second low temperature outlet chamber of two stages (4), a second high pressure inlet chamber of two stages (15), a first low temperature outlet chamber of two stages (2) in order; on the right end cover (25) there are a second medium pressure outlet chamber of two stages (21), a first low pressure inlet chamber of two stages (11), a first medium pressure outlet chamber of two stages (26) and a second low pressure inlet chamber of two stages (7) in order; the first high pressure inlet nozzle of two stages (1) and the second high pressure inlet nozzle of two stages (3) are respectively fixed on the left end cover (19) by bolts; the first medium pressure outlet nozzle of two stages (10) and the second medium pressure outlet nozzle of two stages (12) are respectively fixed on the right end cover (25) by bolts(27).

3. The multistage wave rotor refrigerator according to the claim 1, the characteristics include that the wave rotor refrigerator has 2-8 high pressure inlet nozzles which can realize 2-8 times unsteady expansion of gas in the refrigerator.

4. The multistage wave rotor refrigerator according to the claim 1, the characteristics include that in the wave rotor (5) refrigerator there are 30-280 oscillation tubes (6).

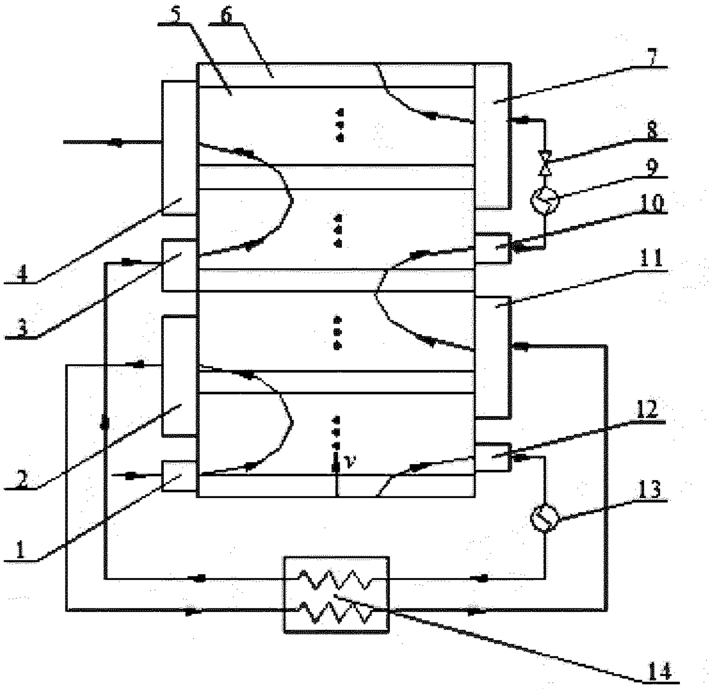
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Fig. 1

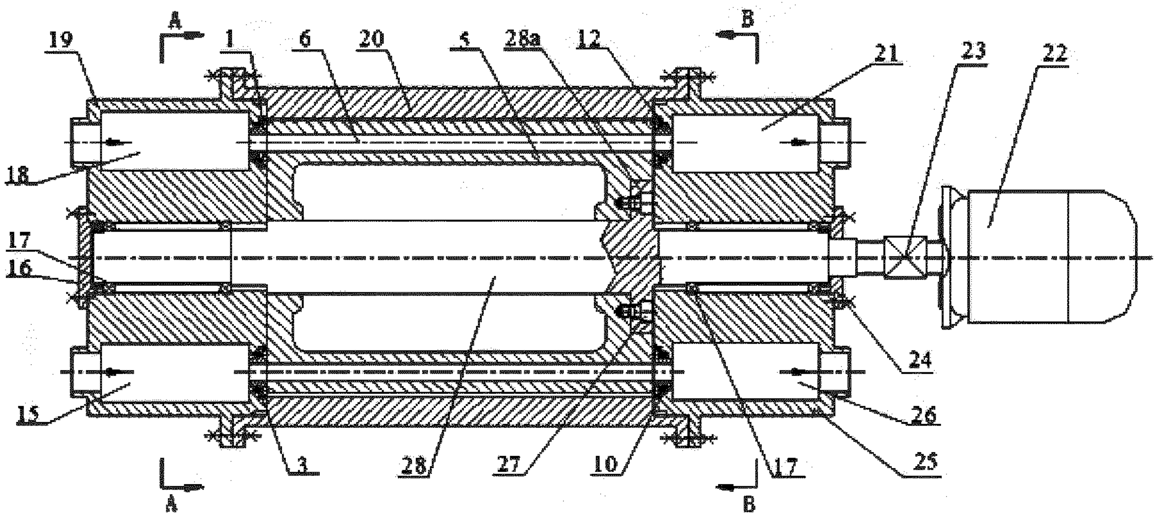
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Fig. 2

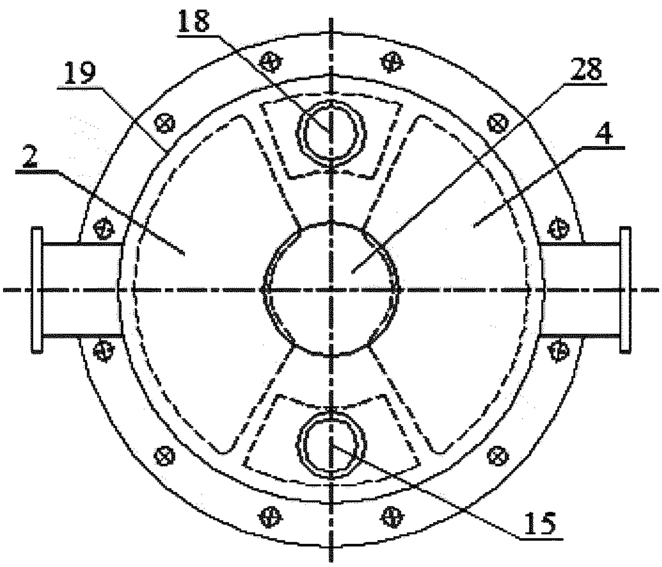

Fig. 3

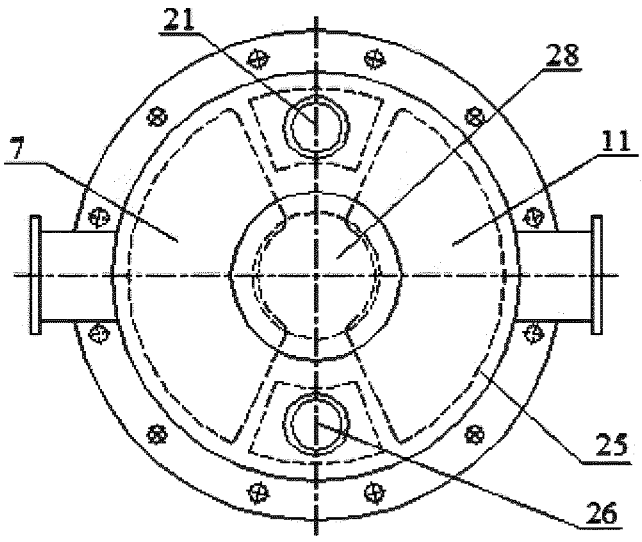

Fig. 4

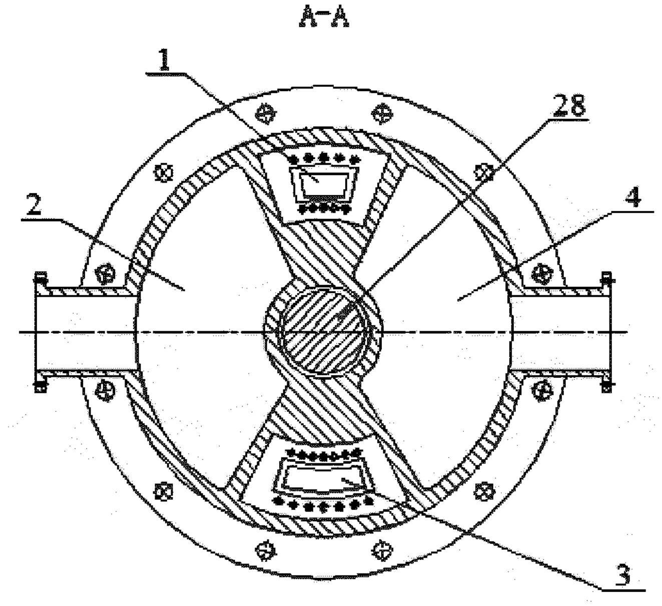

Fig. 5

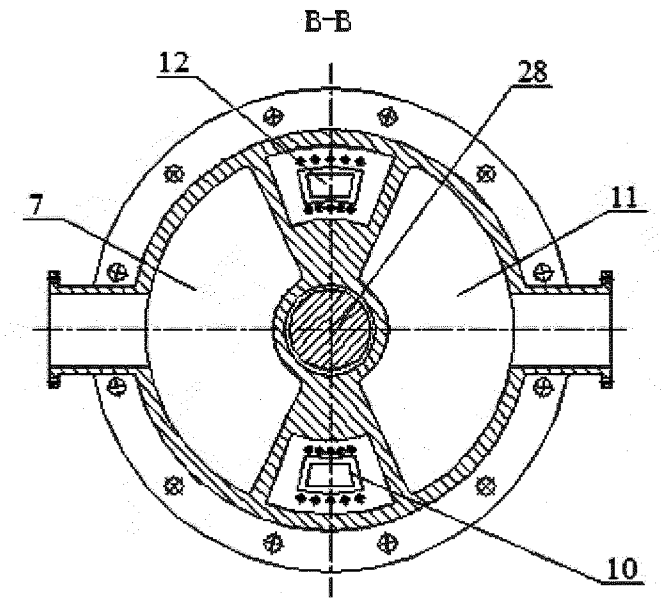

Fig. 6

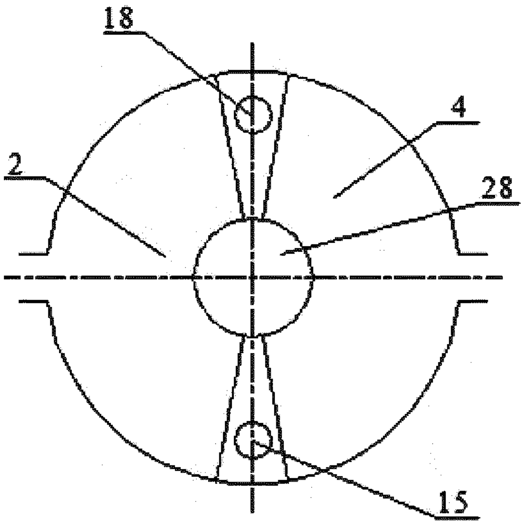

Fig. 7

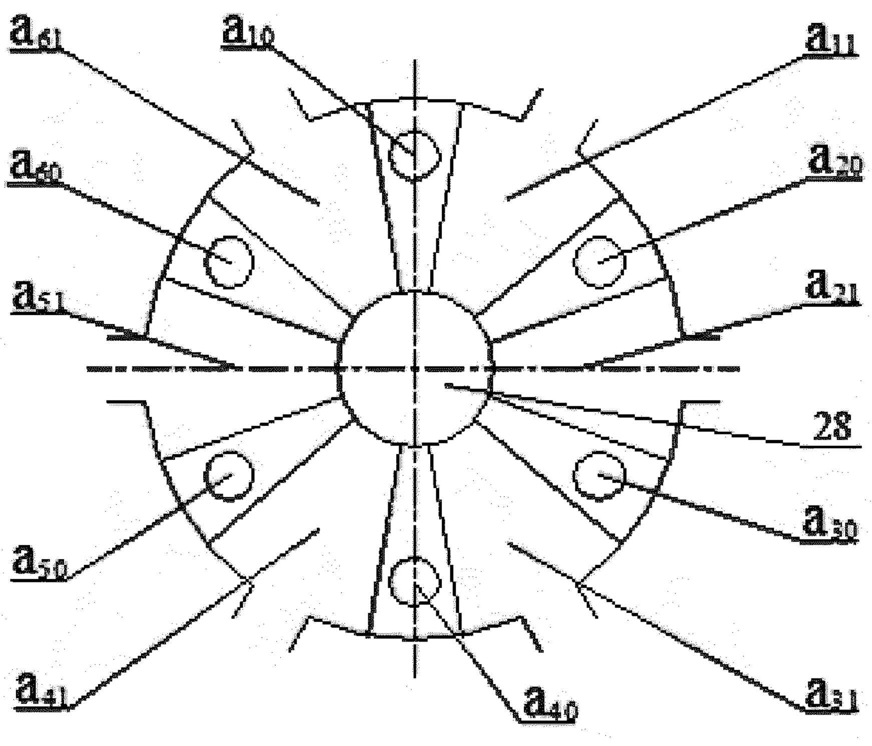

Fig. 8

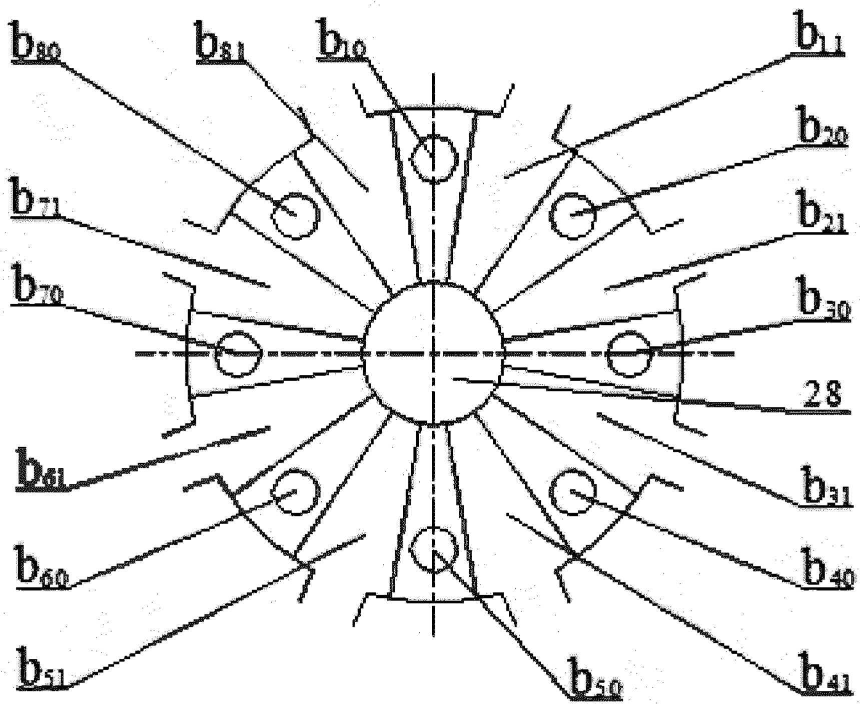
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Fig. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2018/085286

A. CLASSIFICATION OF SUBJECT MATTER

F25B 9/10 (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)

F25B 7 F25B 9 F25B 27 F25B 23

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

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

CNABS, CNTXT, CNKI, DWPI, SIPOABS: 波 膨胀 级 管 wave expan+ stage tube pipe conduit

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	CN 207247611 U (DALIAN UNIVERSITY OF TECHNOLOGY) 17 April 2018 (17.04.2018), description, paragraphs [0025]-[0031], and figures 1-9	1-4
PX	CN 107367084 A (DALIAN UNIVERSITY OF TECHNOLOGY) 21 November 2017 (21.11.2017), description, paragraphs [0025]-[0031], and figures 1-9	1-4
A	CN 101290174 A (DALIAN UNIVERSITY OF TECHNOLOGY) 22 October 2008 (22.10.2008), description, specific embodiment, and figure 1	1-4
A	CN 1171541 A (DALIAN UNIVERSITY OF TECHNOLOGY) 28 January 1998 (28.01.1998), entire document	1-4
A	US 5412950 A (ZHIMIN HU) 09 May 1995 (09.05.1995), entire document	1-4

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
09 July 2018	16 July 2018

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Form PCT/ISA /210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2018/085286

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
CN 207247611 U	17 April 2018	None	
CN 107367084 A	21 November 2017	None	
CN 101290174 A	22 October 2008	CN 100575816 C	30 December 2009
CN 1171541 A	28 January 1998	CN 1085824 C	29 May 2002
US 5412950 A	09 May 1995	None	

Form PCT/ISA /210 (patent family annex) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- CN 87101903 **[0004]**
- CN 89213744 **[0004]**
- CN 90222999 **[0004]**
- CN 96115022X **[0004]**