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(54) Title of the Invention: **Improvements in refrigeration**
Abstract Title: **A cryogenic engine driven refrigeration system**

(57) A cryogenic engine system 310 and a refrigeration system 360 which are coupled such that the cryogenic engine drives the refrigeration system. The cryogenic engine preferably has a driving means comprising a drive shaft 330 or drive shafts, coupled together and drives the compressor 368 of the refrigeration system. The refrigeration cycle comprises a compressor 368 and an expander 372. Both the cryo-genic engine and the refrigeration system have heat exchangers 318, 322, 326, 370. The cryo-engine is preferably thermally coupled to the refrigeration system so that heat generated by the refrigerator is used to expand the working fluid in the cryo-engine and the cryo-engines working fluid acts as a heat sink for the refrigerator, by combining the heat exchangers of the two systems (fig 5). The cryo engine includes a tank 314 and at least one expander 320, 324 to output mechanical work from the working fluid via the drive means. The expanders may be reciprocating expanders or turbine expanders.

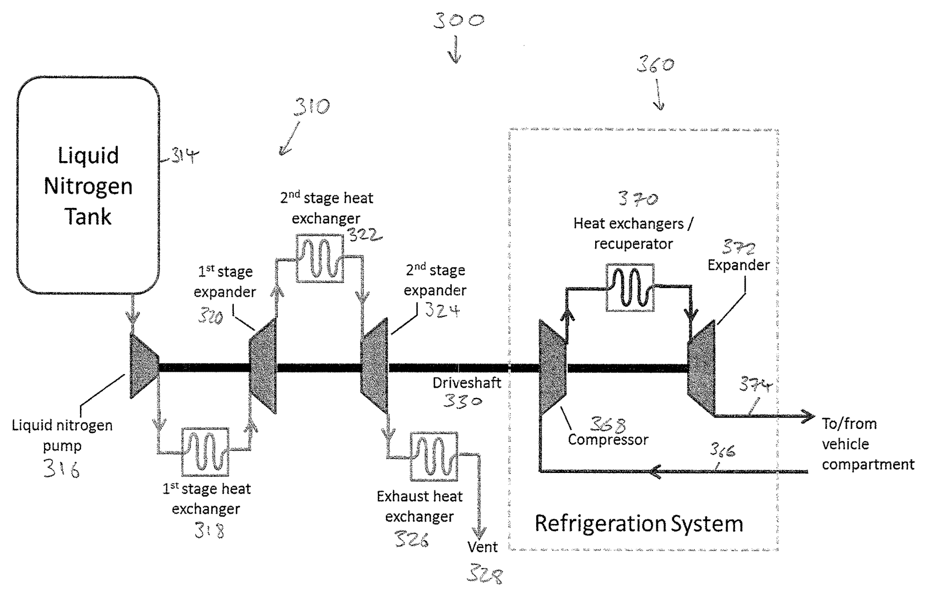

Fig. 4

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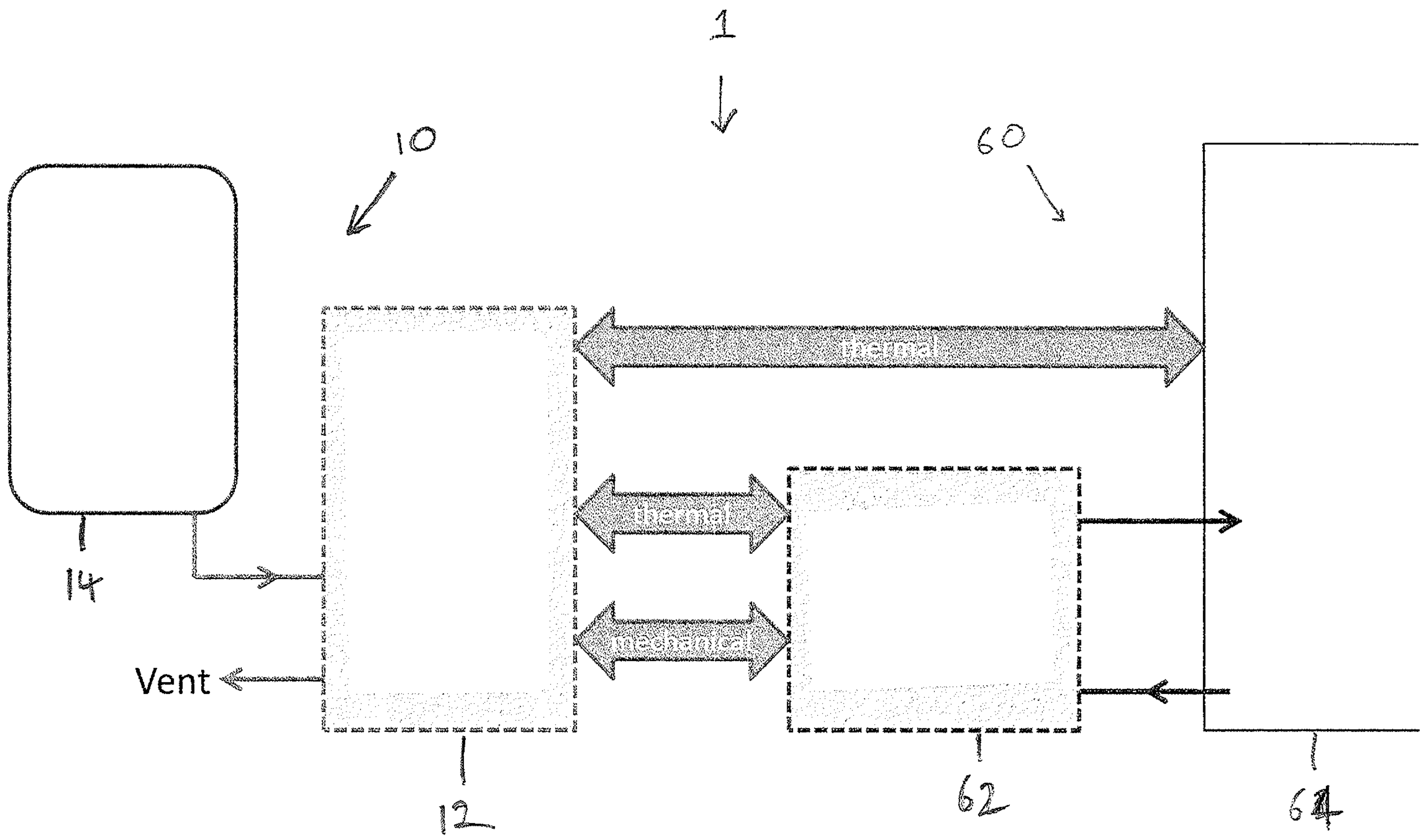


Fig. 1

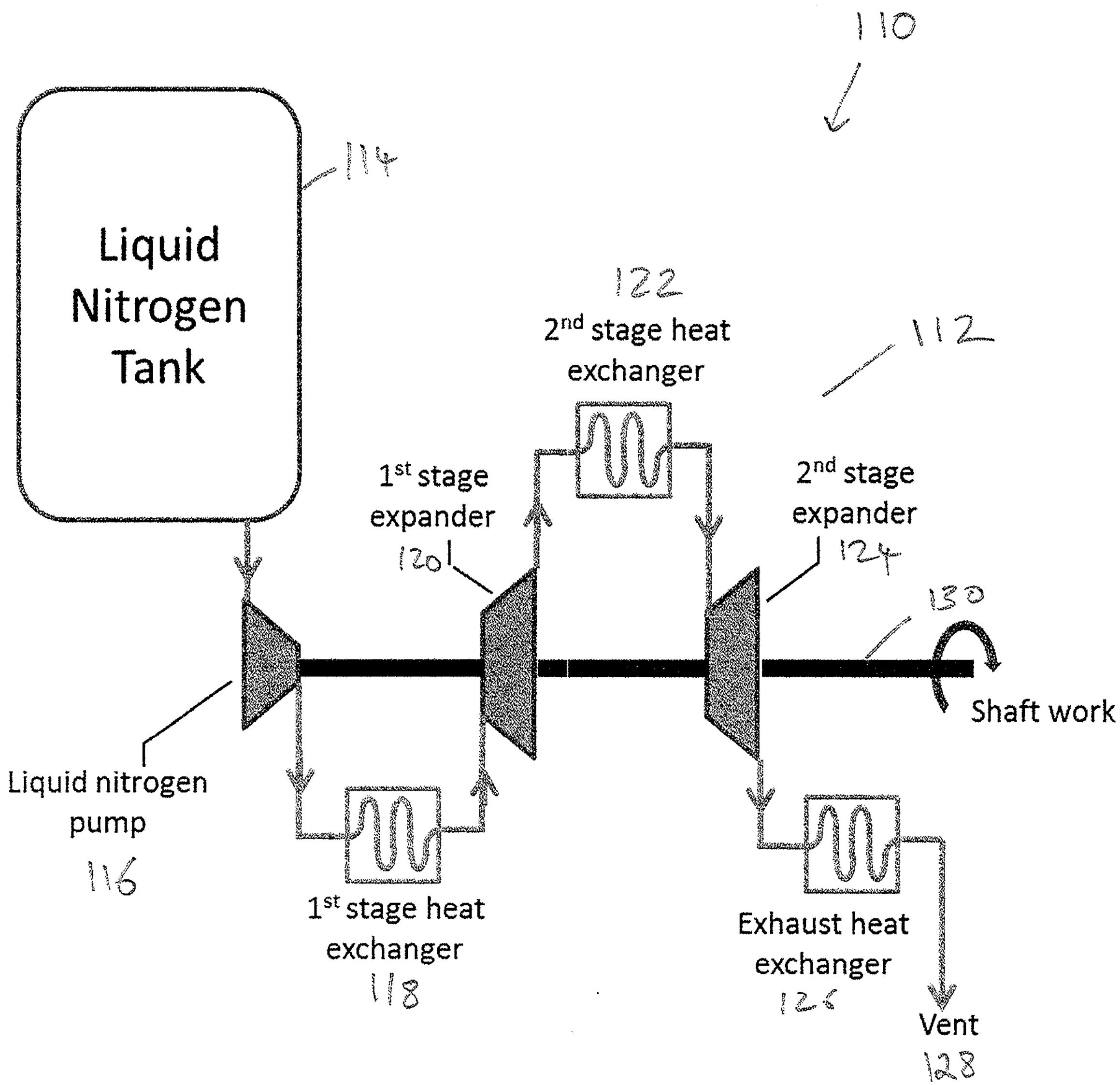
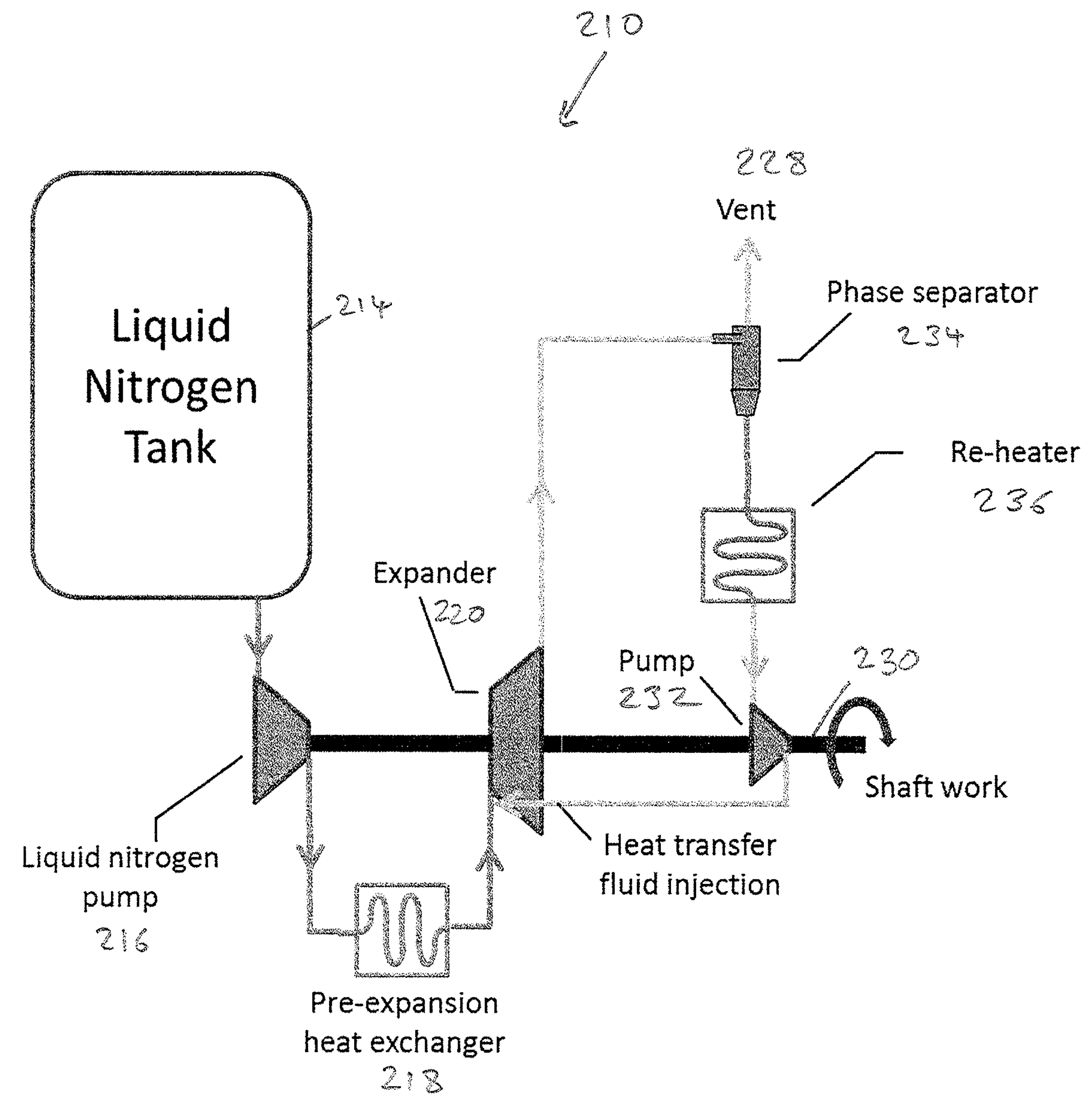

110
112
Liquid Nitrogen Tank
114
Liquid nitrogen pump
116
1st stage heat exchanger
118
1st stage expander
120
2nd stage heat exchanger
122
2nd stage expander
124
Exhaust heat exchanger
126
Vent
128
130
Shaft work

Fig. 2



210
228
Vent
Liquid Nitrogen Tank
214
Phase separator
234
Re-heater
236
Expander
220
Pump
232
230
Shaft work
Liquid nitrogen pump
216
Heat transfer fluid injection
Pre-expansion heat exchanger
218

Fig. 3

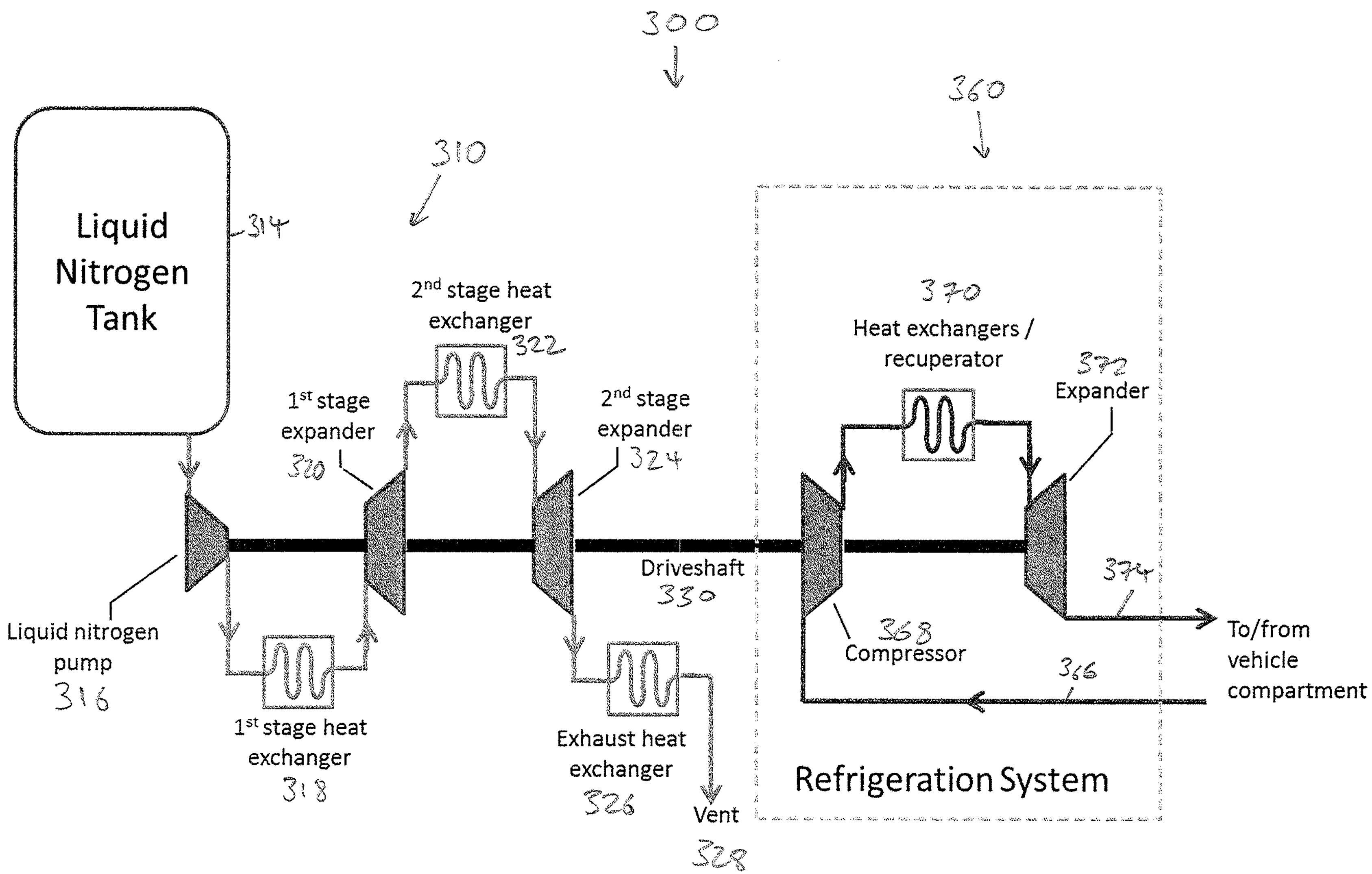

300
310
360
Liquid Nitrogen Tank
314
Liquid nitrogen pump
316
1st stage expander
320
1st stage heat exchanger
318
2nd stage heat exchanger
322
2nd stage expander
324
Exhaust heat exchanger
326
Vent
328
Driveshaft
330
Refrigeration System
370
Heat exchangers / recuperator
372
Expander
368
Compressor
374
366
To/from vehicle compartment

Fig. 4

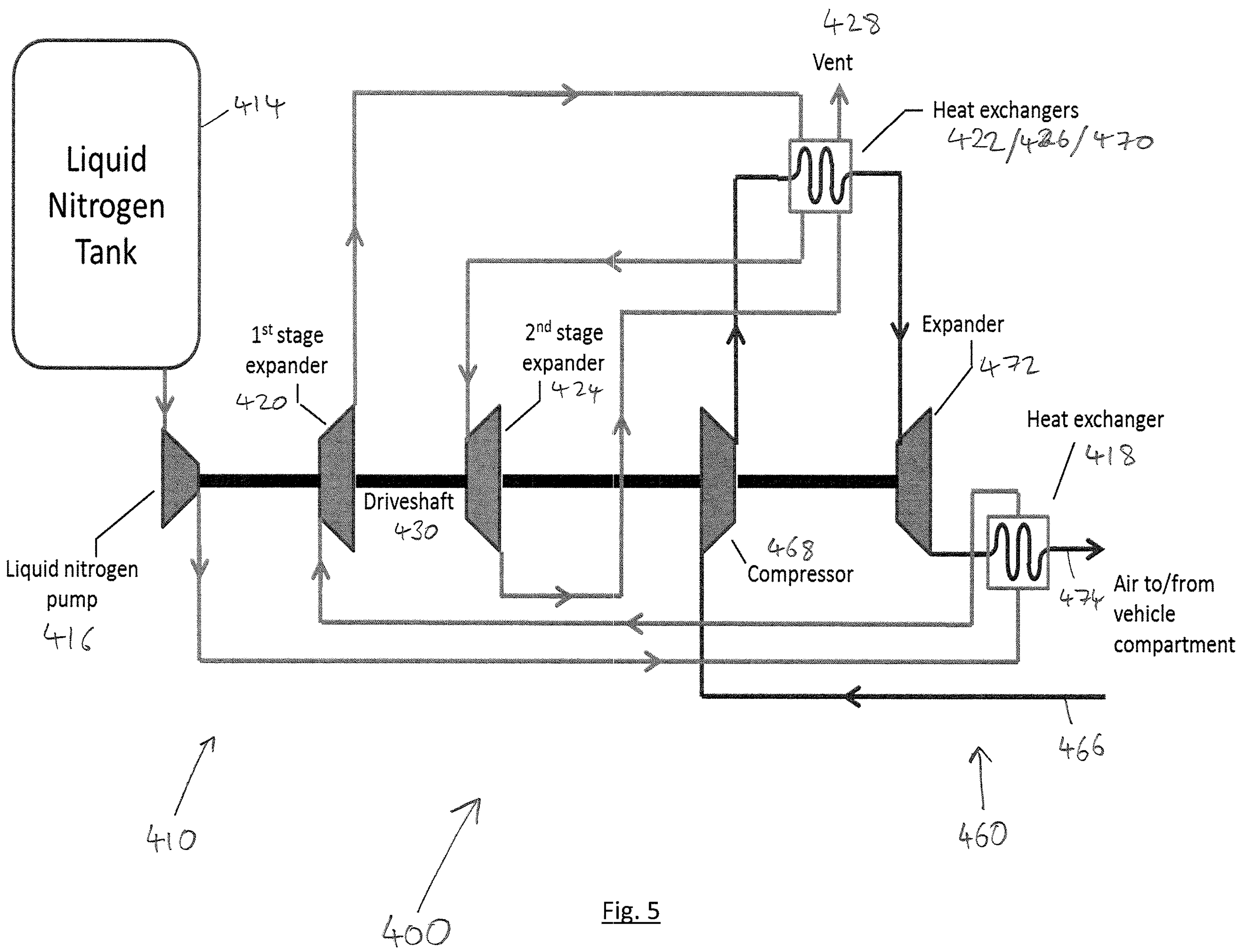

Liquid Nitrogen Tank
414
Liquid nitrogen pump
416
1st stage expander
420
Driveshaft
430
2nd stage expander
424
468
Compressor
Expander
472
Heat exchanger
418
Heat exchangers
422/426/470
Vent
428
Air to/from vehicle compartment
474
466
410
400
460

Fig. 5

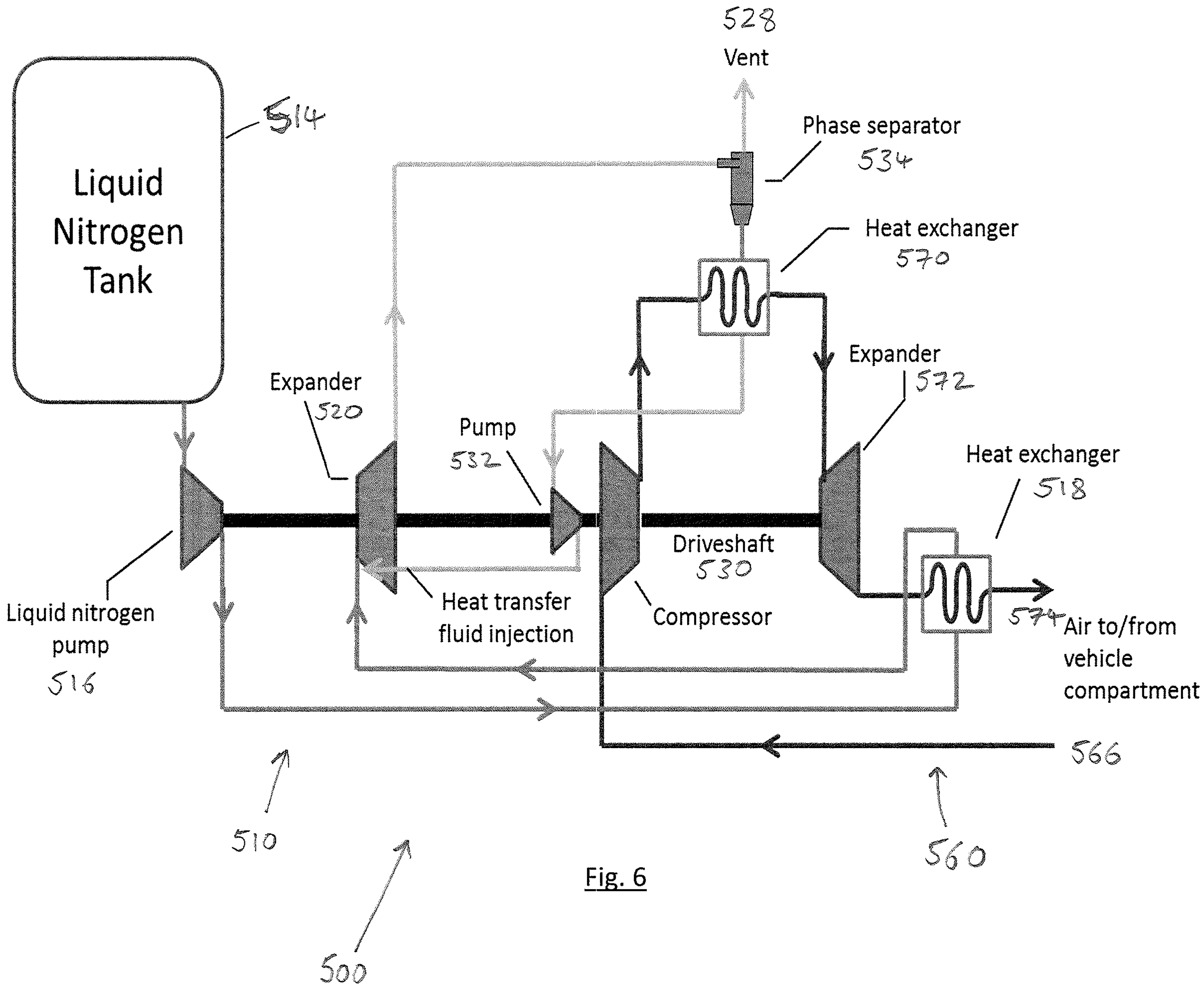

528
Vent
Phase separator
534
Heat exchanger
570
Liquid
Nitrogen
Tank
514
Expander
520
Pump
532
Expander
572
Heat exchanger
518
Driveshaft
530
Liquid nitrogen
pump
516
Heat transfer
fluid injection
Compressor
574
Air to/from
vehicle
compartment
566
510
560
500

Fig. 6

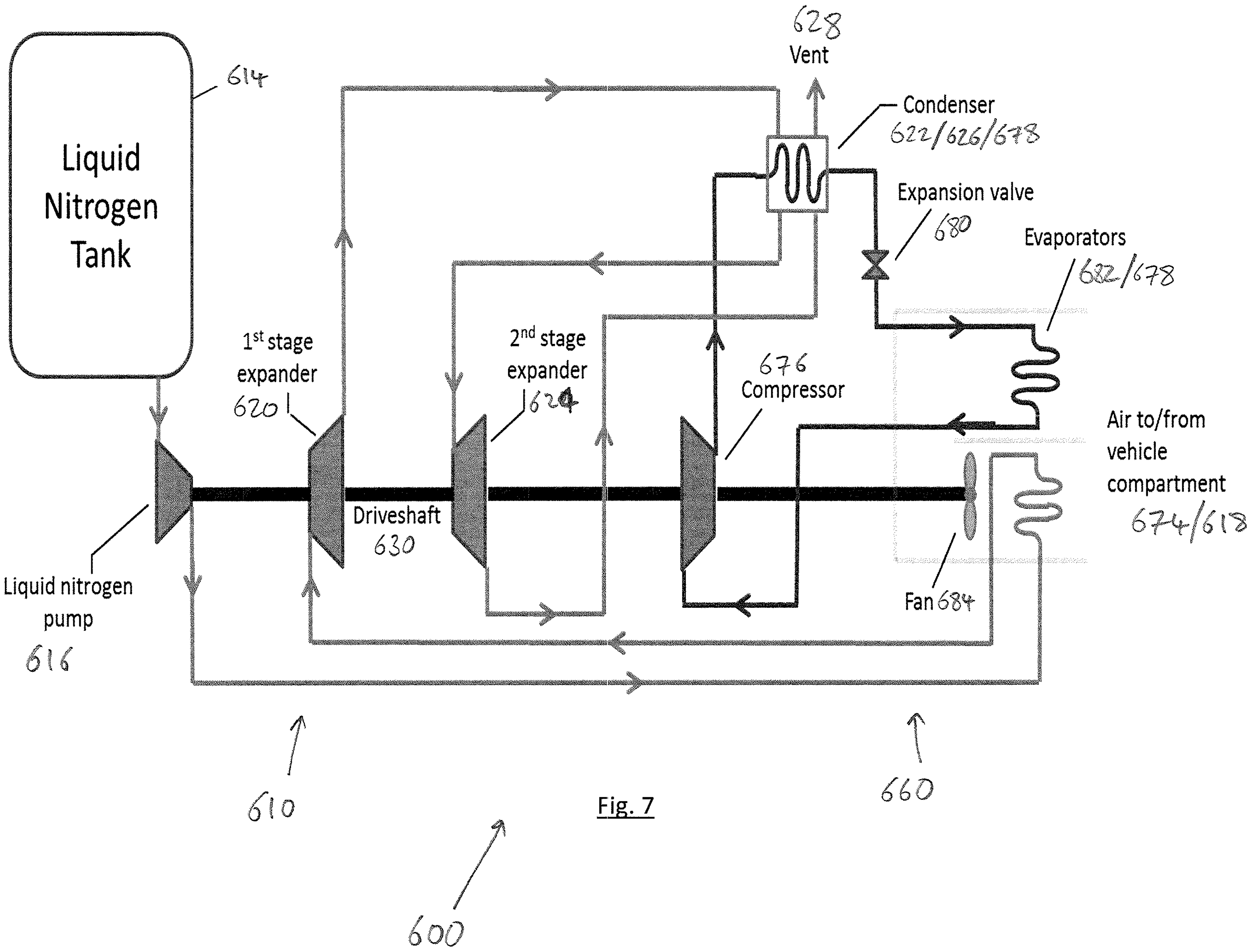

Liquid Nitrogen Tank
614
Liquid nitrogen pump
616
1st stage expander
620
Driveshaft
630
2nd stage expander
624
676
Compressor
628
Vent
Condenser
622/626/678
Expansion valve
680
Evaporators
682/678
Air to/from vehicle compartment
674/618
Fan 684
610
660
600

Fig. 7

Improvements in Refrigeration

Field of the Invention

The invention relates to a system comprising a cryogenic engine and a refrigeration system.

Background of the Invention

The majority of vehicle transport refrigeration systems in use today are powered by an internal combustion engine running on diesel fuel, either directly with an auxiliary generator mounted on the refrigerated trailer, or indirectly by taking power from the tractor engine unit mechanically or electrically via an alternator. Cooling is then attained through using that power to drive a standard closed loop refrigeration cycle.

Typically, both the power take-off and refrigeration unit are over specified for the level of cooling typically required to maintain the compartment temperature in transit. This is for a number of reasons:

i) The refrigeration unit must be capable of cooling down the container after the doors have been opened;

ii) The insulation performance of such cold compartments degrades by 3 - 5 % per year, increasing the cooling power required through the lifecycle; and

iii) APT mandate that the refrigeration unit must be able to extract heat at 1.35 to 1.75 times the heat transfer through the container wall at a 30 °C ambient temperature.

The result of this is that the refrigeration units on mobile vehicles spend much of their operational lives running at an inefficient point. The consequence of this is that coefficients of performance of mobile refrigeration units are typically quite low compared to other cooling equipment (e.g. approximately 0.5 for frozen compartments at -20 °C to 1.5-1.75 for compartments refrigerated to 3 °C).

Currently, it is estimated that approximately 0.05% of total greenhouse gas emissions in the UK come from the refrigeration equipment used for food transportation. This is a small proportion but represents a significant quantity. Consequently, there is a need to reduce emissions from refrigerated transport units. The inefficient use of hydrocarbon fuels for these refrigeration units is also disadvantageous and so a method of reducing their consumption in this application is required.

A number of alternative cooling methods have been proposed. These include energy storage via fuel cells or battery electric for which the cost, infrastructure and charge time drawbacks are known to be undesirable. Eutectic beams employing phase change materials have been used to store cold, but these impose a significant weight penalty. Adsorption and absorption methods utilising tractor power unit waste heat are known but tend to be bulky and rely on high quality heat from the tractor power unit which may not be available at idle. Air cycle refrigeration systems using air from the cold compartment as the working fluid remove the need for refrigerants, but still require a power source.

Various cryogenic systems have been described whereby a cryogenic fluid such as liquid nitrogen is stored in an insulated vessel and used as a source of cold. These can be grouped generally as systems which use the cryogen directly by spraying it into the cold compartment, as described in WO 2011/126581 and US 3699694, systems that use the cryogen indirectly via a heat exchanger, as described in WO 2010/128233 and WO 01/53764, or a mixture of both. It is also known to use a cryogen with an independently powered refrigeration cycle to reduce the quantity of cryogen that must be carried. In EP 0599612, the cryogen exchanges heat directly with the refrigerant in a slurry tank. The potential for using a heated or vent vapour from indirect heat exchange to drive an air displacement fan has been considered in WO 2007/116382 and EP 0599626.

However, direct use of the cryogen can pose an asphyxiation hazard with many choices of cryogenic fluid. Moreover, existing cooling systems using cryogenic substances are inefficient. Therefore, there exists a need for a commercially-viable, efficient, safe and sustainable cooling system employing the beneficial properties of cryogenic substances.

It is an aim of the invention to address the above problems.

Summary of the Invention

In accordance with a first aspect of the present invention, there is provided a system comprising:

a cryogenic engine system; and

a refrigeration system,

wherein the cryogenic engine system and the refrigeration system are coupled with each other such that the cryogenic engine system drives the refrigeration system.

An advantage of coupling a cryogenic engine system with a refrigeration system is that the refrigeration system can be downsized and used only for maintaining the unit temperature, whilst the cryogenic fluid can also be used directly to achieve benefits such as fast temperature pull down and quiet operation.

The cryogenic engine system may comprise a driving means, such as a drive shaft, or a plurality of drive shafts which are coupled with each other, for example via an electrical coupling. The cryogenic engine system and the refrigeration system may be mechanically coupled with each other such that the cryogenic engine system is configured to drive the refrigeration system via the driving means.

Therefore, various components of the refrigeration system can be driven by the driving means (e.g. drive shaft(s)) of a cryogenic engine system.

The cryogenic engine system and the refrigeration system may be thermally coupled with each other such that heat generated by the refrigeration system is used to expand working fluid in the cryogenic engine system. The cryogenic engine system and the refrigeration system may also be thermally coupled with each other such that working fluid in the cryogenic engine system acts as a heat sink for removing heat from the refrigeration system. The working fluid in the cryogenic engine system may exchange heat directly or indirectly (via a further fluid or fluids) with the refrigeration compartment.

The cryogenic engine system may comprise:

a tank for storing working fluid;

a first expander in fluid communication with the tank and configured to expand the working fluid so as to output mechanical work via the driving means; and

a first heat exchanger in fluid communication with the tank and the first expander and configured to transfer heat to the working fluid before the working fluid is delivered to the first expander.

The cryogenic engine system may further comprise a first pump configured to pressurise the working fluid then introduce the working fluid into the first heat exchanger. The pump may be driven by the driving means.

In one embodiment, the cryogenic engine system may further comprise a second heat exchanger in fluid communication with the first expander.

The cryogenic engine system may further comprise a second expander in fluid communication with the second heat exchanger and configured to expand the working fluid so as to output mechanical work via the driving means, wherein the second heat exchanger is configured to transfer heat to the working fluid before the working fluid is delivered to the second expander.

The cryogenic engine system may further comprise an exhaust heat exchanger and a vent for expelling working fluid from the cryogenic engine system after the working fluid has passed through the expander(s).

In another embodiment, the first expander may be configured to mix the working fluid with a heat transfer fluid, and the cryogenic engine system may further comprise:

a phase separator in communication with the first expander for separating working fluid from heat transfer fluid after expansion;

a re-heater for re-heating the heat transfer fluid; and

a second pump for returning heat transfer fluid to the first expander.

The phase separator may be a cyclonic phase separator. The second pump may be driven by the driving means.

The cryogenic engine system may further comprise a vent for expelling working fluid from the cryogenic engine system after the working fluid has passed through the expander(s).

At least one of the expander(s) may be a reciprocating expander. Alternatively or additionally, at least one of the expander(s) may be a turbine expander.

The refrigeration system may comprise a refrigeration cycle configured to cool a refrigeration compartment. The refrigeration cycle may be an air cycle.

The refrigeration cycle may comprise:

a first conduit for removing air from a refrigeration compartment;

a compressor;

a refrigerator heat exchanger for heating air in the refrigeration cycle prior to expansion;

an expander; and

a second conduit for returning cold air to a refrigeration compartment.

The compressor of the refrigeration cycle may be driven by the driving means.

At least one heat exchanger of the cryogenic engine system may be coupled with at least one heat exchanger of the refrigeration system.

For example, at least one of a second heat exchanger and an exhaust heat exchanger of the cryogenic engine system may be coupled with the refrigerator heat exchanger.

Alternatively, both of the second heat exchanger and the exhaust heat exchanger of the cryogenic engine system may be coupled with the refrigerator heat exchanger.

At least one heat exchanger of the cryogenic engine system may be coupled with at least one conduit of the refrigeration cycle.

For example, the first heat exchanger of the cryogenic engine system may be coupled with the second conduit of the refrigeration cycle.

The refrigeration cycle may be a vapour compression cycle.

The refrigeration cycle may comprise:

a first conduit for removing air from a refrigeration compartment;
a compressor;
a condenser;
an expansion valve; an evaporator;
a second conduit for returning cold air to a refrigeration compartment; and
a fan for circulating air from the refrigeration compartment through the first and/or second conduit for cooling.

The fan and/or the compressor may be driven by a driving means of the cryogenic engine system.

At least one of the second heat exchanger and the exhaust heat exchanger of the cryogenic engine system may be coupled with the condenser of the refrigeration cycle. Alternatively or additionally, both of the second heat exchanger and the exhaust heat exchanger of the cryogenic engine system may be coupled with the condenser of the refrigeration cycle.

The first heat exchanger of the cryogenic engine system and the evaporator of the refrigeration cycle may be configured to exchange heat with air from the refrigeration compartment.

The system may further comprise a first transfer means extending between a tank of the cryogen engine system and a refrigeration compartment of the refrigeration system for transferring working fluid directly from the tank to the refrigeration compartment.

The system may further comprise a second transfer means extending between a vent or exhaust of the cryogenic engine system and a refrigeration compartment of the refrigeration system for transferring working fluid from the vent or exhaust to the refrigeration compartment.

At least one heat exchanger may be configured to employ ambient cooling by exchanging heat with the atmosphere.

The working fluid of the cryogenic engine system may comprise a cryogenic fluid.

The working fluid of the cryogenic engine system may comprise at least one of liquid nitrogen, liquid air, liquified natural gas, carbon dioxide, oxygen, argon, compressed air or compressed natural gas.

The cryogenic engine system may be configured to drive at least one further system outside the refrigeration system.

Brief Description of the Drawings

The invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a box diagram of a system according to the invention;

Figure 2 is a schematic view of a cryogenic engine system according to a first embodiment of the invention;

Figure 3 is a schematic view of a cryogenic engine system according to a second embodiment of the invention;

Figure 4 is a schematic view of the cryogenic engine system shown in Figure 2 and a first exemplary refrigeration system;

Figure 5 is a schematic view of a system comprising the cryogenic engine system shown in Figure 2 and the first exemplary refrigeration system;

Figure 6 is a schematic view of a system comprising the cryogenic engine system shown in Figure 3 and the first exemplary refrigeration system; and

Figure 7 is a schematic view of a system comprising the cryogenic engine system shown in Figure 2 and a second exemplary refrigeration system.

In the drawings, like features are denoted by like reference numerals.

Detailed Description of the Drawings

Fig. 1 shows a box diagram of a system 1 according to an embodiment of the invention. The system 1 comprises a cryogenic engine system 10 and a refrigeration system 60. The cryogenic engine system 10 comprises a thermodynamic power cycle 12 and a tank 14 for storing a cryogenic working fluid, such as liquid nitrogen, or a mixture of cryogenic fluids, such as liquid air. The skilled person will understand that any other suitable cryogenic working fluid could equally be used. The refrigeration system 60 comprises a refrigeration cycle 62 which is used to refrigerate a refrigeration compartment 64.

As shown in Fig. 1, the cryogenic engine system 10 and the refrigeration system 60 are mechanically and/or thermally coupled with each other. The cryogenic engine system 10 is mechanically coupled to the refrigeration cycle 62 of the refrigeration system 60, and is thermally coupled with the refrigeration cycle 62 and/or directly with the refrigeration compartment 64. The mechanical coupling means that the cryogenic engine system 10 mechanically drives the refrigeration cycle 62. Alternatively, the mechanical coupling can allow the cryogenic engine system to drive an electricity generator for driving the refrigeration system. The thermal coupling means that heat generated by the refrigeration system 60 is used to expand working fluid in the cryogenic engine system 10, and cooling (a result of cryogenic working fluid) in the cryogenic engine system 10 acts as a heat sink for removing heat from the refrigeration system 60.

Fig. 2 shows a cryogenic engine system 110 according to a first embodiment of the invention. A thermodynamic power cycle 112 of the cryogenic engine system 110 involves the delivery of pressurised cryogenic working fluid (e.g. liquid nitrogen) from an insulated storage tank 114. This is achieved using a cryogenic pump 116 mounted within the tank 114 or externally, or by tank pressurisation via a heating circuit for example. Liquid nitrogen is delivered to a first heat exchanger 118 for indirect heat transfer in which the liquid nitrogen is vaporised to nitrogen gas and heated prior to being expanded in a first expander 120. As the expansion is near adiabatic there is a drop in nitrogen gas temperature. Cold is therefore captured before and after each expansion stage. The first expansion is followed by any number of subsequent stages involving a further heat exchanger and expansion. The embodiment shown in Fig. 2 comprises a second heat exchanger 122 and a second expander 124. The nitrogen gas is also passed through a further indirect exhaust heat exchanger 126 after the final expansion, prior to venting to the atmosphere via a vent 128. The expanders in each stage are of the reciprocating or turbine types generating power through a driving means shown in the figures in the form of a drive shaft 130. Mechanical power output via the drive shaft 130 is used to power other devices or systems, such as a refrigeration system, as described in detail hereafter.

Although the driving means is described herein as a drive shaft, the skilled person will understand that alternative mechanical driving means could be used. Moreover, hydraulic or electrical pumps or motors and other non-mechanical driving means could also be used. Intermediate storage means, such as a battery, can also be provided. Additionally, each expander could be coupled with a separate driving means or drive shaft, in which case the drive shafts are coupled with each other, for example by an electrical coupling.

Fig. 3 shows a cryogenic engine system 210 according to a second embodiment of the invention. The cryogenic engine system 210 comprises a tank 214, a first pump 216, a first heat exchanger 218, a first expander 220 and a vent 228, as described above with reference to Fig. 2. However, in this embodiment, direct contact heat transfer is used to transfer heat to the nitrogen using a heat transfer fluid (such as glycol, water, refrigerant or air) which is introduced into the first expander 220 using a second pump 232. The nitrogen is therefore heated within the first expander 220 by the heat transfer fluid and may be vaporised. After expansion, the heat transfer fluid is separated from the nitrogen by a cyclonic or other phase separator 234, with the nitrogen gas vented to the atmosphere through the vent 228. Once separated from the nitrogen, the heat transfer fluid is passed through a re-heater 236 and pumped back to the first expander 220 by the second pump 232 for reuse.

In the embodiment shown in Fig. 3, the second pump 232 is driven by a drive shaft 230 which outputs mechanical power from the first expander 220. However, any other conveniently-located power source could equally be used. The expander 220 may again be of the reciprocating or turbine type and consist of multiple or single stages generating power output through the drive shaft 230. Alternatively, each expander may output mechanical work via its own separate drive shaft, in which case the drive shafts are coupled with each other, for example by an electrical coupling.

As shown in Fig. 2 and Fig. 3, the work output by the drive shaft from expansion stages is used to drive the first pump. In the embodiments of the system of the present invention shown in Figures 5 to 7, the mechanical power generated by the expansions and output by the drive shaft is used to drive a refrigeration cycle of a refrigeration system to cool a refrigeration compartment. The refrigeration system is of any known arrangement that can make use of shaft power, such as vapour-compression or air cycle type.

Fig. 4 shows a system 300 comprising a cryogenic engine system 310 like that shown in Fig. 2 coupled mechanically via a drive shaft 330 to a refrigeration system 360. The refrigeration system 360 comprises an air cycle comprising a first conduit 366 for removing air from a refrigeration compartment, a compressor 368, a refrigerator heat exchanger 370, an expander 372, and a second conduit 374 for returning cold air to a refrigeration compartment. Fig. 4 shows that the drive shaft 330 drives the compressor 368 of the refrigeration system 360. The expander 372 of the refrigeration system assists with driving of the drive shaft 330.

It is also advantageous to achieve thermal coupling, as well as mechanical coupling, between the cryogenic engine system and the refrigeration system. Figs. 5 to 7 show embodiments of the invention which achieve this advantage. In these embodiments, heat exchangers in the cryogenic engine system are coupled with those in the refrigeration cycle through appropriate pipework or other means of interface. The purpose of this is to scavenge heat from the refrigeration cycle to warm the cryogenic fluid in the cryogenic engine system ready for expansion. Heat may also come from the atmosphere (ambient heat) or any other source like from an IC engine. The other benefit of this approach is to enhance heat rejection from the refrigeration system, thereby improving the refrigeration properties of the system. It can be beneficial for this heat transfer to be additional to heat transfer with the environment in a combined heat exchanger/radiator.

Fig. 5 shows a system 400 comprising a cryogenic engine system 410 (like that described above with reference to Fig. 2) having a two-stage thermodynamic power cycle coupled to an air cycle refrigeration system, as described with reference to Fig. 4. Second 422 and exhaust 426 heat exchangers of the cryogenic engine system are thermally coupled with a heat exchanger 470 on the hot side of the refrigeration air cycle. This may be additional, or used to replace heat exchange with the atmosphere in the refrigeration cycle. A first stage heat exchanger 418 (or vaporiser) is coupled with a return air flow 474 (i.e. cold air being returned to the refrigeration compartment) to allow further cooling of the return air by the cryogen before return to the cold compartment. If the cryogenic fluid is liquid air it may also be preferable to vent cold exhaust directly to the compartment. As described previously, a first pump 416 of the cryogenic engine system 410, and a compressor 468 of the refrigeration cycle 460 are all driven by a drive shaft 430 which outputs mechanical work provided by the expanders of the cryogenic engine system 410. The expander 472 of the refrigeration system assists with driving the drive shaft 430.

Fig. 6 shows a similar system 500 to Fig. 5, but with the cryogenic engine system replaced with a system 510 like that shown in Fig. 3. In this arrangement, a heat transfer fluid is used to heat nitrogen in the cryogenic engine system 510 during expansion in a first expander 520, and beneficially a heat transfer fluid re-heat uses heat from the hot side of the air cycle of the refrigeration system. This allows for higher than ambient temperatures in the nitrogen expansion, increasing the work output of the power cycle of the cryogenic engine system 510.

Fig. 7 shows a further embodiment in which a cryogenic engine system 610 like that described above with reference to Fig. 2 is coupled with a vapour compression refrigeration cycle 660 comprising a first conduit 666 for removing air from a refrigeration compartment, a compressor 676, a condenser 678, an expansion valve 680, an evaporator 682, a second conduit 674 for returning cold air to a refrigeration compartment, and a fan 684 for circulating air from the refrigeration compartment through the first and/or second conduit for cooling. Second 622 and exhaust 626 heat exchangers are thermally coupled with the condenser 678 of the refrigeration cycle. A first stage heat exchanger 618 and the evaporator 682 are arranged so as to sequentially exchange heat with cold air from a refrigeration compartment. As described previously, a first pump 616 of the cryogenic engine cycle, and the compressor 676 of the refrigeration cycle are driven by a drive shaft 630 which outputs mechanical work provided by the expanders of the cryogenic engine system 610. The fan 684 driving air flow over the cooling coils is also powered by the drive shaft 630.

In all of the above-described embodiments, the shaft power from the cryogenic engine output by the drive shaft or drive shafts (assisted by any expanders within the refrigeration system) is used to drive the compressors, pumps and any fans in the refrigeration cycle. In an alternative embodiment, all or part of the shaft power output by the drive shaft is used as an auxiliary power source and thus used, for example, to drive an alternator for lighting or control purposes or used as a primary source to supply power to the tractor.

Examples of applications for the system of the present invention include refrigerated trailers for heavy goods vehicle, refrigeration systems for light goods vehicles and vans and systems for refrigerated containers used in shipping. The system is also beneficial for some classes of static refrigerated containers and buildings. In all of the aforementioned applications, the term refrigerated applies to any sub-ambient holding temperature including but not limited to the standard temperature for transport of perishable produce (~0 °C) and for frozen produce (~-20 °C). There are also potential applications for this invention for all classes of air conditioning systems especially those installed in transport applications.

The present invention has been described above in exemplary form with reference to the accompanying drawings which represent embodiments of the invention. It will be understood that many different embodiments of the invention exist, and that these embodiments all fall within the scope of the invention as defined by the following claims.

Claims

1. A system comprising:

a cryogenic engine system; and

a refrigeration system,

wherein the cryogenic engine system and the refrigeration system are coupled with each other such that the cryogenic engine system drives the refrigeration system.

2. A system according to claim 1, wherein:

the cryogenic engine system comprises a driving means; and

the cryogenic engine system and the refrigeration system are mechanically coupled with each other such that the cryogenic engine system is configured to drive the refrigeration system via the driving means.

3. A system according to claim 2, wherein the driving means comprises at least one drive shaft.

4. A system according to claim 3, wherein the driving means comprises a plurality of drive shafts which are coupled with each other.

5. A system according to claim 4, wherein the drive shafts are electrically coupled with each other.

6. A system according to any of the preceding claims, wherein the cryogenic engine system and the refrigeration system are thermally coupled with each other such that heat generated by the refrigeration system is used to expand working fluid in the cryogenic engine system.

7. A system according to any of the preceding claims, wherein the cryogenic engine system and the refrigeration system are thermally coupled with each other such that working fluid in the cryogenic engine system acts as a heat sink for removing heat from the refrigeration system.

8. A system according to any of claims 2 to 7, wherein the cryogenic engine system comprises:

a tank for storing a working fluid;

a first expander in fluid communication with the tank and configured to expand the working fluid so as to output mechanical work via the driving means; and

a first heat exchanger in fluid communication with the tank and the first expander and configured to transfer heat to the working fluid before the working fluid is delivered to the first expander.

9. A system according to claim 8, wherein the cryogenic engine system further comprises a first pump configured to introduce working fluid into the first heat exchanger.

10. A system according to claim 9, wherein the first pump is driven by the driving means.

11. A system according to any of claims 8 to 10, wherein the cryogenic engine system further comprises a second heat exchanger in fluid communication with the first expander.

12. A system according to any of claims 8 to 11, wherein the cryogenic engine system further comprises a second expander in fluid communication with the second heat exchanger and configured to expand the working fluid so as to output mechanical work via the driving means, wherein the second heat exchanger is configured to transfer heat to the working fluid before the working fluid is delivered to the second expander.

13. A system according to any of claims 8 to 12, wherein the cryogenic engine system further comprises an exhaust heat exchanger and a vent for expelling working fluid from the cryogenic engine system after the working fluid has passed through the expander(s).

14. A system according to any of claims 8 to 10, wherein the first expander is configured to mix the working fluid with a heat transfer fluid, and wherein the cryogenic engine system further comprises:

a phase separator in communication with the first expander for separating working fluid from heat transfer fluid after expansion;

a re-heater for re-heating the heat transfer fluid; and

a second pump for returning heat transfer fluid to the first expander.

15. A system according to claim 14, wherein the phase separator is a cyclonic phase separator.

16. A system according to claim 14 or claim 15, wherein the second pump is driven by the driving means.

17. A system according to any of claims 14 to 16, wherein the cryogenic engine system further comprises a vent for expelling working fluid from the cryogenic engine system after the working fluid has passed through the expander(s).

18. A system according to any one of claims 8 to 17, wherein at least one of the expander(s) is a reciprocating expander.

19. A system according to any one of claims 8 to 18, wherein at least one of the expander(s) is a turbine expander.

20. A system according to any preceding claim, wherein the refrigeration system comprises a refrigeration cycle configured to cool a refrigeration compartment.

21. A system according to claim 20, wherein the refrigeration cycle is an air cycle.

22. A system according to claim 21, wherein the refrigeration cycle comprises:

a first conduit for removing air from a refrigeration compartment;

a compressor;

a refrigerator heat exchanger for heating air in the refrigeration cycle prior to expansion;

an expander; and

a second conduit for returning cold air to a refrigeration compartment.

23. A system according to claim 22, wherein the compressor of the refrigeration cycle is driven by a driving means of the cryogenic engine system.

24. A system according to claim 22 or claim 23, wherein at least one heat exchanger of the cryogenic engine system is coupled with at least one heat exchanger of the refrigeration system.

25. A system according to any of claims 22 to 25, wherein at least one of a second heat exchanger and an exhaust heat exchanger of the cryogenic engine system is coupled with the refrigerator heat exchanger.

26. A system according to claim 25, wherein both of the second heat exchanger and the exhaust heat exchanger of the cryogenic engine system are coupled with the refrigerator heat exchanger.

27. A system according to any of claims 22 to 26, wherein at least one heat exchanger of the cryogenic engine system is coupled with at least one conduit of the refrigeration cycle.

28. A system according to any of claims 22 to 27, wherein a first heat exchanger of the cryogenic engine system is coupled with the second conduit of the refrigeration cycle.

29. A system according to any of claims 1 to 20, wherein the refrigeration cycle is a vapour compression cycle.

30. A system according to claim 29, wherein the refrigeration cycle comprises:

a first conduit for removing air from a refrigeration compartment;
a compressor;
a condenser;
an expansion valve;
an evaporator;
a second conduit for returning cold air to a refrigeration compartment; and
a fan for circulating air from the refrigeration compartment through the first and/or second conduit for cooling.

31. A system according to claim 30, wherein the compressor and/or the fan are driven by a driving means of the cryogenic engine system.

32. A system according to claim 30 or claim 31, wherein at least one of a second heat exchanger and an exhaust heat exchanger of the cryogenic engine system is coupled with the condenser of the refrigeration cycle.

33. A system according to claim 32, wherein both of the second heat exchanger and the exhaust heat exchanger of the cryogenic engine system are coupled with the condenser of the refrigeration cycle.

34. A system according to any of claims 30 to 33, wherein a first heat exchanger of the cryogenic engine system and the evaporator of the refrigeration cycle are configured to exchange heat with air from the refrigeration compartment.

35. A system according to any of the preceding claims, further comprising a first transfer means extending between a tank of the cryogen engine system and a refrigeration compartment of

the refrigeration system for transferring working fluid directly from the tank to the refrigeration compartment.

36. A system according to any of the preceding claims, further comprising a second transfer means extending between a vent or exhaust of the cryogenic engine system and a refrigeration compartment of the refrigeration system for transferring working fluid from the vent or exhaust to the refrigeration compartment.

37. A system according to any of the preceding claims, wherein at least one heat exchanger is configured to employ ambient cooling by exchanging heat with the atmosphere.

38. A system according to any of the preceding claims, wherein the working fluid of the cryogenic engine system comprises a cryogenic fluid.

39. A system according to any of the preceding claims, wherein the cryogenic engine system is configured to drive at least one further system outside the refrigeration system.

40. A system according to any of the preceding claims, wherein the working fluid of the cryogenic engine system comprises at least one of liquid nitrogen, liquid air, liquified natural gas, carbon dioxide, oxygen, argon, compressed air or compressed natural gas.

41. A system substantially as hereinbefore described with reference to Figure 4.

42. A system substantially as hereinbefore described with reference to Figure 5.

43. A system substantially as hereinbefore described with reference to Figure 6.

44. A system substantially as hereinbefore described with reference to Figure 7.

Application No: GB1220788.2 **Examiner:** Mr Colin Walker

Claims searched: 1 to 44 **Date of search:** 24 May 2013

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
Y	1 to 44	US3842333 A (HENCEY et al) - See figures and column 2 line 29 to column 3 line 37.
Y	1 to 44	US4311917 A (HENCEY et al) - See figures and column 6 lines 4 to 22.
Y	1 to 44	WO2007/003912 A2 (DEARMAN) - See figures and paragraphs 7 to 13.
Y	1 to 44	US6349787 B1 (DAKHIL) - See figures and paragraphs 7 to 9.
Y	1 to 44	US2006/000228 A1 (FISHER) - See figures and paragraphs 4 to 8.
Y	1 to 44	US2010/319375 A1 (MATSUBARA et al) - See figures and paragraphs 7 and 8.
Y	1 to 44	US2008/314059 A1 (HARKNESS et al) - See figures and paragraphs 2, and 19 in particular.
Y	1 to 44	US2006/042296 A1 (LUDWIG et al) - See figures and paragraphs 4 to 6.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

F01K; F25B

The following online and other databases have been used in the preparation of this search report

Online : WPI, EPODOC

International Classification:

Subclass	Subgroup	Valid From
F25B	0011/00	01/01/2006
F01K	0025/10	01/01/2006
F25B	0027/00	01/01/2006