

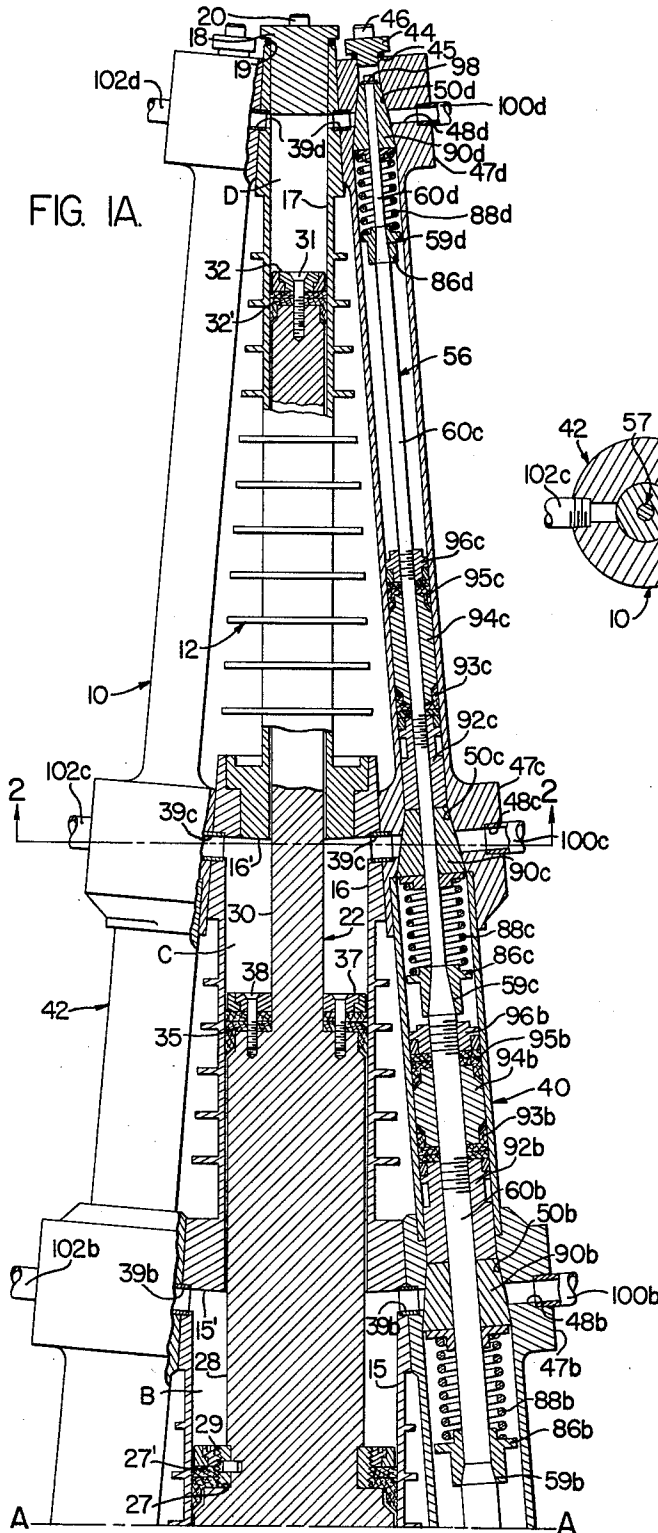
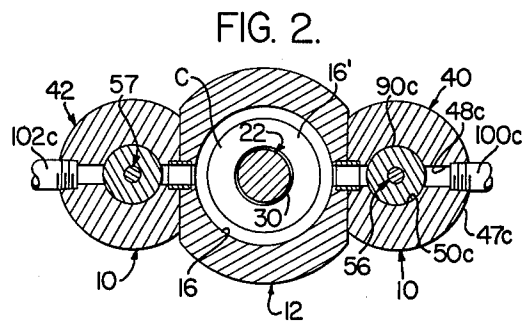
May 5, 1964

S. C. COLLINS
EXPANSION ENGINE

3,131,547

Filed March 27, 1962

3 Sheets-Sheet 1



INVENTOR:
SAMUEL C. COLLINS

BY *Louis J. Reganelli*
AGENT

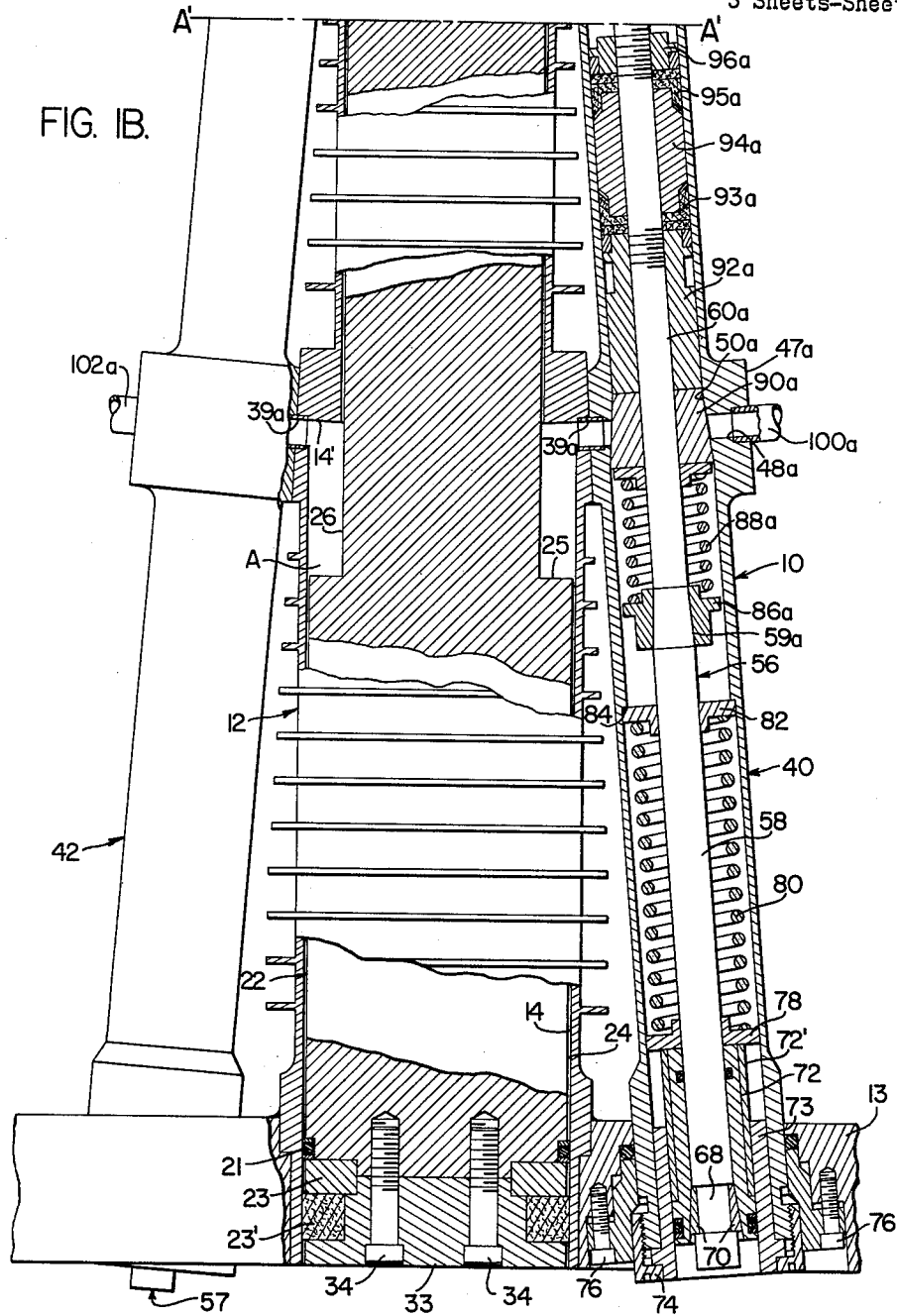
May 5, 1964

S. C. COLLINS
EXPANSION ENGINE

3,131,547

Filed March 27, 1962

3 Sheets-Sheet 2



INVENTOR:
BY SAMUEL C. COLLINS

Samuel C. Collins
AGENT

May 5, 1964

S. C. COLLINS
EXPANSION ENGINE

3,131,547

Filed March 27, 1962

3 Sheets-Sheet 3

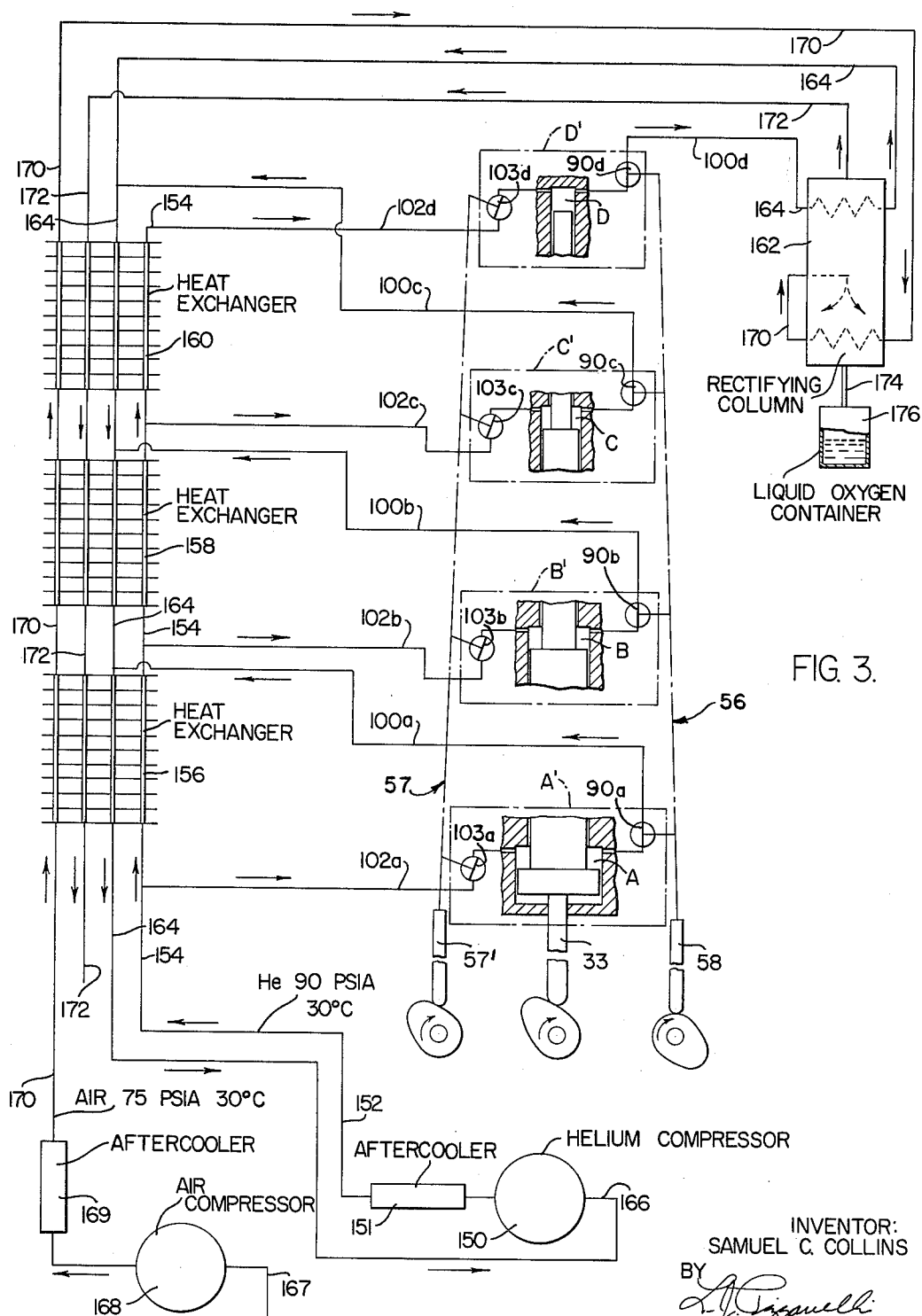


FIG. 3.

INVENTOR:
SAMUEL C. COLLINS
BY *Samuel C. Collins*
AGENT

1

3,131,547

EXPANSION ENGINE

Samuel C. Collins, Belmont, Mass., assignor to Joy Manufacturing Company, Pittsburgh, Pa., a corporation of Pennsylvania

Filed Mar. 27, 1962, Ser. No. 182,859

13 Claims. (Cl. 62—86)

This invention relates to an expansion device and more particularly to a multiple chamber, cryogenic, expansion engine for the production of low temperatures as in the liquefaction of normally gaseous elements such as hydrogen, helium, nitrogen, and oxygen.

In the field of cryogenics, it has been the general practice to employ multiple cylinder expansion engines to extract energy from progressively colder portions of compressed fluid. Although such devices have served the purpose, they have not proved entirely satisfactory under all conditions of service for the reasons that considerable difficulty has been experienced in providing an efficient seal between the cylinders and their associated pistons especially in the colder parts of such apparatus and difficulties encountered in preventing thermal energy transfer from the warmer parts of the apparatus to the colder parts.

The general purpose of this invention is to provide an expansion engine which embraces all the advantages of similarly employed multiple cylinder engines and possesses none of the aforescribed disadvantages. To attain this, the present invention contemplates the use of a unique stepped cylinder which in conjunction with a stepped piston provides multiple expansion chambers within the single stepped cylinder, all of which expansion chambers operate at substantially the same fluid pressure thereby greatly reducing the need for piston to cylinder sealing arrangements between the expansion chambers and restricting the sealing problem to a single piston seal at the warm end of the expansion engine. The use of the stepped cylinder stepped piston arrangement also precludes locating parts of the apparatus having large temperature differences next to each other and as a consequence reduces thermal energy leakage from the warmer parts of the apparatus to the colder parts. It is to be noted that the single stepped cylinder and stepped piston of the expansion device of the present invention replace the multiple cylinders and pistons of earlier devices, respectively, with no reduction in the number of available expansion chambers provided by multiple cylinder devices of the prior art.

It is therefore an object of this invention to provide a new and improved expansion device.

It is another object of the invention to provide a new and improved expansion device having multiple expansion chambers.

It is a further object of this invention to provide a new and improved expansion engine having multiple expansion chamber portions within a single stepped cylinder.

A specific object of this invention is to provide a new and improved expansion engine having multiple expansion chamber portions within a single stepped cylinder provided with a single stepped piston to provide more efficient piston to cylinder sealing arrangements and to reduce thermal energy transfer from one portion of this device to another.

It is another specific object of this invention to provide a new and improved expansion engine having multiple expansion chamber portions within a single stepped cylinder having a plurality of different diameters preceding seriatim from a large diameter at the relatively warm end of a cryogenic expansion engine through successively

2

smaller diameters to a smallest diameter at the relatively cold end of the cryogenic expansion engine, and also having a stepped piston suitably fitted to the above mentioned successively reduced diameters so as to provide a plurality of piston equipped expansion chamber portions to provide the effect of multiple cylinder expansion within a single cylinder device.

These and other objects and advantages of this invention will be readily apparent from consideration of the following description and drawings, in which:

FIG. 1 is a partially sectioned elevational view of an expansion engine constructed according to the principles of this invention, FIG. 1 being made up of FIG. 1A and FIG. 1B assembled so that line A—A at the bottom of FIG. 1A coincides with line A'—A' at the top of FIG. 1B;

FIG. 2 is a sectional view taken substantially on line 2—2 of FIG. 1A; and

FIG. 3 is a diagrammatic view of the piping connection of a cryogenic apparatus incorporating the expansion engine of this invention.

In FIG. 1 there is shown, in partial axial section, an expansion engine 10, constructed according to the principles of this invention, comprising an elongated, hollow, stepped, upward tapering, cylinder member 12 rigidly secured to a laterally extended cylinder base 13 mounted on a cam shaft housing (not shown). The cylinder member 12 has a stepped axial bore therethrough, with progressively smaller diameter cylinder portions beginning with the largest diameter portion 14 at the bottom, extending upwardly through the base 13, and progressing through intermediate diameter portions 15 and 16, respectively, to a smallest diameter portion 17 at the top of the cylinder member 12. The top end of the smallest cylinder portion 17 is closed and rendered fluid tight by a headed cylindrical plug 18 and a ring type, flexible, sealing element 19, the cylindrical portion of plug 18 being rigidly but removably secured, within the top end of cylinder portion 17, by threaded retaining elements such as cap screws 20. The relative diameters of the different cylinder portions are determined by thermodynamic considerations hereinafter more fully explained.

Located within the axial bore of the cylinder member 12 is an elongated, stepped cylindrical, solid piston member 22, made of phenolic resin or similar material preferably reinforced by a fibrous material such as paper or cloth and having progressively smaller cylindrical portions beginning with the largest diameter portion 24 at the bottom of the piston and progressing upwardly through intermediate diameter portions 26 and 28, respectively, to a smallest diameter portion 30 forming the uppermost portion of the piston 22. The cylindrical portions 24, 26, 28 and 30 are closely slidably received by the cylinder portions 14, 15, 16 and 17, respectively, and are adapted to reciprocate therein in the usual piston and cylinder relationship.

The clearance between cylinder and piston is approximately .004 in. on the diameter, as compared with approximately .0004 in. in machines of the prior art, obviating contact thermal energy transfer from piston 22 to the cylinder 12 and return as the piston 22 reciprocates in the cylinder 12.

The bottom surface of piston 22 is an inwardly stepped cylindrical surface mating with an outwardly stepped upper surface of a stepped cylindrical cap member 33 removably secured to the lower end of the piston 22 by a plurality of threaded retaining elements such as cap screws 34 which are threadedly received by metallic inserts (not shown) in the lower end portion of the piston 22. The stepped cylindrical surfaces of the bottom of the piston 22 and of the cap 33 form a stepped groove which closely receives and supports a plurality of flexible,

piston sealing elements comprising a rubber O ring 21, a plastic ring 23 and a leather packing 23', in a manner well known in the art. The lower cylindrical portion 24 of the piston 22 terminates upwardly in an annular shoulder 25 at the bottom end of the intermediate cylindrical portion 26 and the lower cylinder portion 14 of the stepped cylindrical bore terminates upwardly in a substantially annular stepped surface 14'. The length of the lower cylindrical portion 24 is such that when the bottom surface of the cap 32 is coplanar with the bottom end of the cylinder member 12, the shoulder 25 is downwardly spaced from the stepped surface 14', by a distance substantially equal to but slightly greater than the distance hereinafter designated the desired stroke of the pistons, forming an expansion chamber A.

The lower intermediate cylindrical portion 26 of the piston 22 terminates upwardly in a formed shoulder 27 at the bottom end of the upper intermediate portion 28. The shoulder 27 is adapted to receive and support flexible sealing elements 27' to prevent leakage of fluid along the periphery of the lower intermediate portion 26, which sealing elements 27' are secured in position by a threaded retaining ring 29 in a manner well known in the art, so that the flexible sealing elements 27' are carried back and forth with the piston 22 as it reciprocates in the cylinder as is known. The retaining ring 29 is spaced downwardly from a substantially annular step surface 15' to form a second expansion chamber B. In the same manner the upper intermediate cylindrical portion 28 of the piston 22 terminates upwardly in a formed shoulder provided with flexible sealing elements 35 and retaining elements 36 and 37. The retaining element 37 is in the form of a flat ring suitably provided with suitable bores parallel to its axis through which suitable threaded retaining elements such as cap screws 38 threadedly engaged in the shoulder portion of the cylindrical portion 28 removably secure the retaining elements 36 and 38 against said shoulder forming a third expansion chamber C, upwardly terminating in an annular step surface 16'.

At the top end of the smallest cylindrical portion 30, of the piston 22, similar, though smaller, retaining elements 32 and sealing elements 32' are removably secured to the top end of piston 22 by a cap screw 31 threadedly engaged with the upper end of the piston 22 forming expansion chamber D between the retaining elements 32 and the bottom surface of plug 18. The respective lengths of the cylindrical portions 26, 28 and 30 are such that the retaining elements at the upper end of each cylindrical portion, respectively, are downwardly spaced from the upper end of the hollow cylindrical portion in which they are located by an amount equal to the stroke of the engine so that an expansion chamber is formed in each cylindrical portion of the cylinder member 12, which has an axial length equal to the stroke of the engine. All of these expansion chambers, A through D, will be substantially, completely filled by the piston 22 and its associated reciprocating parts when piston 22 is at the top of its stroke.

At the top end portion of each expansion chamber, A through D, respectively, there is a diametrical pair of substantially radial bores or ports 39a, b, c and d, respectively, communicating through the surface of the cylinder member 12 with a pair of elongated, hollow, valve body members 40 and 42, respectively. Which body members 40 and 42 are made up of coaxial cylindrical portions of progressively smaller diameters beginning with the largest at the bottom and having the smallest diameter cylindrical portions at the top of the valve body members 40 and 42. The axes of the body members 40 and 42 are coplanar with the axis of the cylinder member 12, but preferably canted inwardly at the top so that the valve body members 40 and 42 closely follow the generally upward tapering exterior profile of the cylinder member 12. Since the two valve bodies 40 and 42 are in all respects

the same except for being shown in FIG. 1 as mirror images of each other, only the one to the right, referred to in a later operation description as exhaust valve body 40, will be described. The valve body 40 extends upwardly from the lower surface of the cylinder base 13 to a point downwardly adjacent the upper end of the cylinder member 12 and contacts the exterior surface of the cylinder member 12 in spaced areas surrounding the expansion chamber ports 39a, b, c and d, respectively, the valve body 40 has a radially enlarged portion 47a, b, c or d at each of these regions and is provided with a diametrical bore 48a, b, c or d communicating therethrough from the outside of the valve body 40, through the ports 39, into the expansion chambers A, B, C or D, respectively. The inside of the valve body 40 forms an axially extended series of coaxial cylindrical bores of progressively smaller diameter from the bottom of the valve body 40 to its top surface. Each of the coaxial bores upwardly terminates in one of the hereinbefore mentioned radially enlarged portions 47 of the valve body 40 and forms an upwardly tapering valve seat 50a, b, c or d which extends above and below the diametrical bore 48 in that region and connects one of the coaxial bores with the next smaller one above it. At the extreme upper end of the valve body 40 the valve seat in that enlarged region 47d terminates in a coaxial bore which reaches to the upper surface of the valve body 40 and is sealed by a headed cylindrical plug 44 and ring type seal member 45 removably secured in fluid tight relationship with the topmost coaxial bore by threadedly engaged, threaded retaining members such as cap screws 46.

Within the valve body 40 and positioned coaxially therewith is an elongated, generally cylindrical, valve actuating, member or rod 56 extending from a point upwardly adjacent the bottom end of the valve body 40 to a point slightly downwardly spaced from the bottom surface of the plug 44 at the top of the valve body 40. The valve rod 56 comprises a plurality of elongated cylindrical sections of progressively smaller diameters beginning at the bottom with the largest diameter portion 58 and progressing upwardly through successively smaller diameters 60a, 60b and 60c, respectively, to the smallest diameter portion 60d at the top end portion of the valve rod 56. Transition from the largest diameter 58 to the next smaller diameter 60a is accomplished by an upwardly tapering portion 59a downwardly spaced from the diametrical bore 48a associated with the top of the expansion chamber A and the further reductions in diameter are accomplished in the same manner by upwardly tapering portions 59b, c and d, of the valve rod 56, downwardly spaced from their respective diametrical bores with tapered portion 59b downwardly spaced from diametrical bore 48b, 59c, similarly related to 48c and tapered portion 59d downwardly spaced from diametrical bore 48d.

Near the bottom end of the valve rod 56 is a shallow circumferential groove in which two, upwardly tapering, internally semi-cylindrical, valve keepers 70 are seated to secure upon the rod 56 hollow cylindrical valve spring seat retainer 72 and guide member 72' in a manner well known in the art. The retainer 72 and guide member 72' are slidably received in and guided by a hollow cylindrical guide bushing 73 removably secured in the lower end of the valve body 40 by a hollow cylindrical, ring type, threaded retainer 74, threadedly engaged with external threads on the valve body 40. The valve body 40 is rigidly but removably secured in the cylinder base 13 by a plurality of cap screws 76 threadedly engaged with the cylinder base 13.

A disc type spring seat 78 is slidably received by the valve rod 56 and biased against the retainer 72 by an elongated, compression type, cylindrical spring 80 coaxial with the rod 56 and engaging at its upper end with a disc type spring stop 82, which is in turn abuttingly engaged with an internal circumferential shoulder 84 in the valve body 40. It is to be noted that the spring seat

5

78 is freely, axially, slidable within the valve body 40 and that the spring 80 biases the valve rod 56 downwardly within the valve body 40, so that to have the valve rod 56 and the valve body 40 in the relative positions, as illustrated in FIG. 1, an upwardly biasing force must be applied to the bottom end of the valve rod 56 by a cam operated push rod 58' (see FIG. 3) or other device. The largest diameter portion 58 of the valve rod 56 extends upwardly through the spring stop 82 so that the tapered portion 59a is spaced upwardly of the spring stop 82. An inwardly tapered spring seat 86a is seated upon the tapered portion 59a and supports a cylindrical compression type valve spring 88a which in turn engages and upwardly biases and upwardly tapered, frusto-conical, non-metallic valve 90a slidably received by the valve rod 56 and externally engaged in fluid tight relationship with the valve seat 50a so that, in the position shown, the diametrical bore 48a is effectively sealed against the passage of fluids. It is to be appreciated that downward motion of the valve 90a will disengage it from the seat 50a and establish a circumferential path about the valve 90a to allow fluid flow through the diametrical bore 48a into or out of the expansion chamber A as desired. The valve 90a is axially located upon the valve rod 56 by an internally threaded, externally cylindrical valve adjusting element 92a slidably received within the valve body 40. The adjusting element 92a supports, on its upper surface, a sealing element 93a upwardly terminating in a cup which is positioned and guided by seal guide elements 94a, slidably received upon the valve rod 56 and within the valve body 40, in turn supporting and guiding further sealing elements 95a which are abuttingly engaged and secured in position on valve rod 56 by an adjustable, internally threaded, externally cylindrical seal locating nut 96a. It is to be noted that rotation of the adjusting element 92a on the valve rod 56 will result in adjusting the location of the valve 90a on the rod 56, and that suitable rotation of the nut 96a can be applied to maintain the abutting relationship of the seals 95a and 93a with the seal guide element 94a. It is to be further noted that parts similar in design and function but varying slightly in size and angle of taper are associated in similar manner with the intermediate expansion chambers B and C, respectively, and the top expansion chamber D; and that such parts are given the same numerical designation with an appropriate letter to indicate the chamber with which they are respectively related. It is further to be noted that the valve 90d associated with the expansion chamber D is not provided with an adjusting element or sealing elements 92, 93, 94 and 95 but is abuttingly engaged by a slotted retaining element 98, suitably engaged in a suitable circumferential groove (not shown) downwardly adjacent the top end of the valve rod 56 so that the valve 90d slidably received by the cylindrical portion 60d of the valve rod 56 is free to move downwardly along the rod against the biasing of spring 88d. Adjustment of the valves of this expansion engine 10 is accomplished by trial insertion of the valve rod 56 together with its valves and associated parts during which inspection shows whether all of the valves are seating simultaneously or not. Proper adjustment of the adjusting elements 92a, b and c in conjunction with the upward biasing force of the valve springs 88a, b and c is accomplished when, upon insertion of the valve rod assembly, all of the valves 90 engage the valve seats 50 at the same time. When the proper adjustments of the adjusting elements 92 have been achieved, the nuts 96a, b and c are tightened to hold the seals and lock the adjusting elements 92 in place. It is to be realized that the use of the valve springs 88 makes it possible for the upward camming motion of the valve rod 56 to be somewhat in excess of the amount of upward motion necessary to close the valves without causing damage or interfering with the proper functioning of the engine.

Each of the outlet bores 48 in the enlarged portions 47

6

of the valve body 40 is provided with a fluid conducting outlet conduit 100a, b, c, or d, respectively, individually communicating when their valves are open with the chambers A, B, C or D, respectively, as shown in FIG. 1. In an entirely similar manner, analogous diametrical bores in the enlarged portions of valve body 42 are provided with inlet connections 102a, b, c, and d, respectively, similarly controlled by valve action, provided by an inlet valve rod 57 having inlet valves 103a, b, c, and d secured thereon (see FIG. 3) to all inlet of fluids to their respective expansion chambers A, B, C and D when activated by a cam operated push rod 57'.

FIGURE 3 is a schematic representation of a cryogenic apparatus for the production of liquid oxygen and is shown solely for the purpose of exemplifying the utility of the expansion engine of this invention. In the FIGURE 3 four (4) rectangular boxes A', B', C' and D' schematically represent the expansion chambers A, B, C and D, respectively, together with their associated valves and will hereinafter be designated as expansion engine stages A', B', C' and D. The outlet conduits 100a, b, c and d and the inlet conditions 102a, b, c and d are the same as those shown and described in FIG. 1. The cryogenic apparatus of FIG. 3 also comprises a helium compressor 150 equipped to deliver high pressure helium through an aftercooler 151 to a conduit 152 communicating with inlet conduit 102a, a branch 154 of conduit 152 passes through a heat exchanger 156 and thereafter communicates with inlet conduit 102b. In similar manner the conduit 154 subsequently passes through a heat exchanger 158 thereafter communicating with inlet conduit 102c and then passes through a heat exchanger 160 and thereafter communicates with inlet conduit 102d. Outlet conduit 100d communicates with a conduit 164 which passes through a top portion of a rectifying column 162 of a type well known in the art. After exiting from the rectifying column 162, the conduit 164 communicates with the outlet conduit 100c and thereafter passes through the heat exchanger 160, communicates with outlet conduit 100b, passes through heat exchanger 158, communicates with outlet conduit 100a, and passes through heat exchanger 156, in that order, and exiting therefrom connects with an inlet conduit 166 of the compressor 150.

Other parts shown in FIG. 3 comprise an air handling system having an air compressor 168 provided with an atmospheric inlet conduit 167 and discharging through an outlet aftercooler 169 and through an outlet conduit 170 which passes in succession through the heat exchangers 156, 158, and 160 and through the bottom portion of the rectifying column 170. The outlet conduit 170 emerges from a lower side portion of the rectifying column 162 and passing upwardly therealong re-enters the rectifying column 162 in a central portion and there terminates as an air supply for the rectifying column 162. The rectifying column 162 is provided with an outlet conduit 172 emerging from its top surface which passes successively through heat exchangers 160, 158 and 156 and terminates in an end portion open to the atmosphere after emerging from the heat exchanger 156.

To operate this device the expansion engine 10 is mounted upon a shaft housing (not shown) which is provided with a cam shaft, having three (3) cams, and three (3) push rods abuttingly engaged with the valve rods 57, 56 and the piston cap member 33 to provide axial reciprocating motion thereto. The cam shaft is provided with a flywheel and an energy consuming device such as a generator or brake (also not shown). The cams are rigidly secured to the cam shaft so that all three rotate simultaneously but with their lobes in different positions to give proper timing to the valves in relation to the motion of the piston 22. The position of piston 22, illustrated in FIG. 1, is the extreme downward position allowable in this device and will hereinafter be referred to as the bottom dead-center position. The other extreme position of the piston with expansion chambers A, B, C and D sub-

stantially completely occupied by their respective piston portions and associated parts will be hereinafter referred to as the top dead-center position and is more definitely described by the fact that the shoulder 25 will be downwardly adjacent the stepped surface 14' with the expansion chamber A almost completely filled by the lower portion 24 of the piston 22.

With the piston 22 in its top dead-center position the inlet valve rod 57 is in a slightly downwardly displaced position so that the inlet valves 103a, b, c and d associated with the inlet conduits 102a, 102b, 102c and 102d are slightly open. Highly compressed helium at a pressure of approximately 90 lbs. per square inch will flow from the compressor 150 through the after-cooler 151, the conduit 152 and the inlet connection 102a into the expansion chamber A. Pressure of the helium gas on shoulder 25 will cause the piston to begin to move downwardly, rotating the cam shaft, further opening the valves on the valve rod 57 and allowing the helium to begin to expand. As the piston 22 moves downwardly it continues to rotate the cam shaft which in turn causes the inlet valve rod 57 to be cammed upwardly closing the inlet valve before the piston 22 reaches its bottom dead-center position. When the piston 22 reaches its bottom dead-center position continued rotation of the flywheel mounted on the cam shaft causes the piston 22 to begin to return upwardly toward its top dead-center position and rotates the cam associated with the outlet valve rod 56 to allow the valve rod 56 to be biased downwardly by the spring 30 opening the valves 90a, 90b, 90c and 90d. With the valve 90a in the open position the helium is exhausted from the chamber A through the outlet conduit 100a. Applying these same actions to the expansion chambers B, C and D it will be seen that the expansion engine 10 provides for the four (4) stages of expansion A', B', C' and D' as shown in FIG. 3. Referring to FIG. 3 it will be seen that all of the inlet conduits 102 are connected to a common conduit 154 so that all of the expansion chambers are subjected to substantially the same inlet pressure. In like manner the outlet conduits 100 are all connected to a common outlet conduit 164 so that the outlet pressures of all the chambers are substantially equal to each other. Since all of the chambers are operating at substantially the same pressures, there is almost no tendency for leakage to occur between any two of the chambers, which is one of the great advantages inherent in the expansion engine of this invention. The expansion chamber D is effectively sealed from the atmosphere by the plug 44 and the seal 45 which are solidly engaged with the upper end of cylinder member 12. Thus, the only active piston seals which have any substantial pressure difference to contain are the O rings 21 and the leather packing 23' at the bottom of the largest cylindrical portion 24, and these seals are operating at a temperature very nearly that of the ambient atmosphere as distinguished from the operating temperatures of the expansion chambers B, C, and D which in cryogenic devices of this kind must necessarily be much lower than that of the ambient atmosphere. Thus, the low temperature piston sealing problems common to machines of the prior art are almost completely eliminated in the expansion engine 10 of this invention.

To continue with the operation of this device it is, of course, obvious that when the piston 22 reaches the top dead-center position the cam associated with valve rod 56 raises the valve rod 56 until all of the valves 90 are closed while at the same time allowing the valve rod 57 to be biased downwardly by its associated spring to open the valves 103a, b, c and d in the valve body 42 and begin repetition of the hereinbefore described cycle.

Referring again to FIG. 3 it will be seen that the compressed helium furnished to stage A' and allowed to expand therein with consequent reduction in temperature and loss of energy is exhausted through the outlet conduit 100a and passing into the conduit 164, absorbs energy within the heat exchanger 156, lowering the temperature

of the exchanger 156, and thence returns to the helium compressor 150 through its inlet connection 166. As the helium in the expanded low pressure state passes through the heat exchanger 156 it absorbs energy from a portion of the compressed helium passing through the conduit 154 inwardly to the other stages, B', C' and D'. A portion of this cooled compressed helium enters the stage B' through the inlet connection 102b and after expanding and further cooling passes through the outlet conduit 100b into the common outlet conduit 164 and passes outwardly through the heat exchangers 158 and 156, cooling both, through the inlet connection 166 into the compressor 150. A third portion of the compressed helium having passed through the heat exchangers 156 and 158, in each of which it is somewhat cooled, now passes into the stage C' and in similar manner is expanded and cooled and passes out of the stage C' through the outlet conduit 100c and into the common outlet conduit 164 through which it passes internally of the heat exchangers 160, 158, 156, cooling all three, in succession, and returns to the helium compressor 150 through its inlet connection 166. A fourth portion of the compressed helium having passed through the heat exchangers 156, 158 and 160, losing heat successively in each one of these exchangers, enters the stage D' at a very low temperature and is there further expanded and cooled and exhausting through the outlet conduit 100d is used in the top portion of the rectifying column 162 to provide the extremely low temperatures needed for the liquefying of oxygen, nitrogen or other gases. The fourth portion of gas returns, of course, through the common outlet line 164 passing internally through the heat exchangers 168, 158, 156, cooling each, and returns to the helium compressor 160 through its inlet connection 166.

The air compressor 168 furnishes compressed air taken into the compressor through the inlet connection 167 and exhausted from the compressor 168 through the after-cooler 169 so that the compressor outlet conduit 170 carries a stream of air through the heat exchangers 156, 158 and 160 in succession which heat exchangers cool the air to lower and lower temperatures so that it passes through the bottom portion of the rectifying column at a temperature low enough to liquify oxygen. The air in conduit 170 then passes out of the rectifying column and upwardly along side it to be discharged inwardly into the intermediate portion of the rectifying column 162 in a manner well known in the art. In the rectifying column of the present example the oxygen of the air is liquefied and gathering at the bottom of the rectifying column 162 is drained off through a liquid conducting conduit 174 and collected in a suitable container 176. The remaining constituents of the air, largely nitrogen, pass upwardly through the rectifying column 162 and out through its outlet 172 to pass outward internally of the heat exchangers 160, 158 and 156 absorbing heat from the incoming stream of air in the conduit 170 and of helium in the conduit 154. For further description of the apparatus and operation associated with liquefaction refer to U.S. Patent No. 2,458,894.

It is to be noted that the stroke of the piston is constant for all the chambers of the expansion engine 10 and that the relative rates of flow through the engine in the various chambers is such that, for a given expansion ratio, refrigeration is provided in conjunction with the outflowing main stream of helium to cool the inflowing mass of helium traversing the associated heat exchanger by an amount approximately equal to the temperature drop in that portion of the expansion engine. It is this consideration which determines the diameters of the various portions of the piston 22 and cylinder member 12. The respective lengths of the piston portions 24, 26, 28 and 30 are determined first of all by the shortest practical length which will prevent excessive thermal energy transfer from one chamber to the next at the desired temperature difference, and are further determined by the differences in

diameter which give a particular angle to the valve bodies 40 and 42 which must be maintained throughout the length of these valve bodies so that all portions thereof are axially aligned. In some cases it will be found preferable to make the valve bodies 40 and 42 parallel to each other and normal to the base 13 to facilitate machining. In such case the lengths of the cylinder portions will be entirely determined by considerations of thermal energy transfer from one expansion chamber to the other.

Further advantages inherent in the expansion engine 10 of this invention reside in the absolute synchronization of the piston action and valve action in all of the chambers and in the mounting of the expansion engine 10 on the cam shaft housing. Since only compression members such as push rods are required to operate the engine 10, dismounting the engine is much simpler than in prior art devices in which tension members must be disconnected.

Although the operation of the expansion engine 10 has been exemplified in a process of oxygen liquefaction it is to be appreciated that, with another piping circuit and related components, the engine of this invention can be used in the production of far lower temperatures such as those needed for liquefaction of hydrogen or helium. Indeed the advantages hereinabove cited as inherent in the design of expansion engine 10 will become more valuable as lower temperatures are produced.

Having described a preferred embodiment of this invention in accordance with the Patent Statutes, it is to be realized that modifications thereof may be made without departing from the broad spirit of this invention. Accordingly, it is respectfully requested that this invention be interpreted as broadly as possible and be limited only by the prior art.

I claim:

1. A method of operating a multistage expansion engine for a cryogenic process comprising, connecting a plurality of expansion chamber portions of a single chamber to the discharge of a compressor, simultaneously admitting pressure fluid from such compressor discharge to all of such chamber portions to move a single piston in one direction, simultaneously discharging such fluid from such chambers by moving such piston in a direction opposite to said one direction.

2. A method of operating an expansion engine for a cryogenic process having a single expansion chamber with a plurality of chamber portions comprising, simultaneously admitting pressure fluid from the discharge of a compressor to all of such chamber portions to move a piston in one direction, simultaneously discharging such fluid from such chamber portions by moving such piston in a direction opposite to said one direction.

3. An expansion engine for a cryogenic apparatus comprising, a single chamber with a plurality of chamber portions having a piston means reciprocably disposed in said chamber, inlet and outlet conduit means for said chamber portions respectively, valve means located in said inlet and outlet conduit means respectively being alternately simultaneously operable for admitting and discharging, respectively, pressure fluid to said chamber portions, and drive means for reciprocating said piston and said valve means in timed relation.

4. An expansion engine for a cryogenic apparatus comprising, a member having a chamber in the form of a stepped bore and a unitary stepped piston means reciprocably disposed therein which forms a plurality of expandable chamber portions, inlet and outlet conduit means for said chamber portions respectively, valve means located in said inlet and outlet conduit means respectively being intermittently simultaneously operable for admitting and discharging, respectively, pressure fluid to said chamber portions, and drive means for reciprocating said piston and said valve means in sequentially timed relation.

5. An expansion engine for a cryogenic apparatus comprising a cylinder having coaxial, axially extending, communicating bores of progressively reduced diameter; a

piston having coaxial axially extending portions simultaneously cooperable with said bores for forming chamber portions having reciprocably movable boundary walls; each of such chamber portions having a fluid inlet and outlet conduit; valve means cooperable with said inlets and said outlets respectively for allowing simultaneous admission and subsequently simultaneous ejection, respectively, of fluid from such chamber portions; and means for operating said piston and said valve means in timed relation.

6. An expansion engine for a cryogenic apparatus comprising a cylinder having coaxial, axially extending, communicating bores of progressively reduced diameter; a piston having coaxial axially extending portions simultaneously cooperable with said bores for forming chamber portions having reciprocably movable boundary walls; each such chamber portions having a fluid inlet and outlet conduit; simultaneously intermittently operable valve means for said inlet and simultaneously intermittently operable valve means for said outlet; and means for operating said piston and said valve means in timed relation, for permitting pressure fluid to be discharged to all of said chamber portions simultaneously to expand such fluid and move said piston in one direction, and for subsequently moving said piston in a direction opposite to said one direction and permitting substantially simultaneous discharge of such expanded fluid from said chambers.

7. An expansion engine for a cryogenic apparatus comprising a cylinder having coaxial, axially extending, communicating bores of progressively reduced diameter; a piston having coaxial axially extending portions simultaneously cooperable with said bores for forming chamber portions having reciprocably movable boundary walls; each of such chamber portions having a fluid inlet and outlet conduit; simultaneously intermittently operable inlet valve means and simultaneously intermittently operable outlet valve means; and means for operating said piston and said valve means in timed relation; said inlet and said outlet valve means being connected to elongated reciprocable operating members respectively which when actuated by said operating means sequentially opens and closes said inlet and said outlet valve means in timed relation.

8. An expansion engine for a cryogenic apparatus comprising, an elongated tubular member having coaxial axially extending communicating bores being of progressively decreasing diameter from one end thereof, an elongated piston having portions of decreasing diameter from one end thereof corresponding in number and size to said bores, said piston being reciprocably mounted in said tubular member for forming a plurality of tandem expandable chamber portions, each of said chamber portions having inlet and outlet fluid passageways, inlet valve means located in said inlet passageways respectively being simultaneously operable to admit pressure fluid to said chamber portions, outlet valve means located in said outlet passageways respectively being simultaneously operable to allow discharge of said fluid from said chamber portion.

9. An expansion engine for a cryogenic apparatus comprising, an elongated tubular member having coaxial axially extending communicating bores being of progressively decreasing diameter from one end thereof, an elongated piston having portions of decreasing diameter from one end thereof corresponding in number and size to said bores, said piston being reciprocably mounted in said tubular member for forming a plurality of tandem expandable chamber portions, each of said chamber portions having inlet and outlet fluid passageways, inlet valve means located in said inlet passageways respectively being simultaneously operable to admit pressure fluid to said chamber portions for effecting expansion of said fluid in all of said chamber portions simultaneously, outlet valve means located in said outlet passageways respectively being simultaneously operable to allow discharge of said

11

fluid from said chamber portions, and means for actuating said inlet and said outlet valve means alternately.

10. A cryogenic apparatus comprising, a unitary tandem expansion engine having a single chamber with a plurality of chamber portions operable to simultaneously receive and subsequently simultaneously discharge a working fluid; said expansion engine having the inlets and outlets of said chamber portions connected to the discharge and the return, respectively, of a compressor.

11. A cryogenic apparatus comprising, a unitary tandem expansion engine having a single chamber with a plurality of chamber portions operable to simultaneously receive and subsequently simultaneously discharge respectively a working fluid, said expansion engine having the inlets and outlets of said chamber portions connected to the discharge and the return, respectively, of a compressor, heat exchange means located between said chambers for incrementally transferring energy to the fluid discharged by said chambers from the fluid received by said chambers.

12. A cryogenic apparatus comprising, a unitary tandem expansion engine having a single chamber with a plurality of chamber portions operable to simultaneously receive and subsequently simultaneously discharge respectively a working fluid, said expansion engine having the inlets and outlets of said chamber portions connected to the discharge and the return, respectively, of a compressor, simultaneously operable inlet valve means, simul-

12

taneously operable outlet valve means, and means for operating said inlet and said outlet valve means in a predetermined time relation, said expansion engine having said chamber portions formed by a tubular member having a stepped bore and a stepped piston reciprocally disposed therein.

13. An expansion engine for a cryogenic apparatus comprising; an elongated tubular member having coaxial axially extending communicating bores being of progressively decreasing diameter from one end thereof; an elongated piston having portions of decreasing diameter from one end thereof corresponding in number and size to said bores; said piston being reciprocally mounted in said tubular member for forming a plurality of tandem expandible chamber portions; said piston being formed so that said portions of decreasing diameter, respectively, are of relatively greatly reduced diameter with respect to said bores corresponding thereto for avoiding contact therebetween in order to obviate contact heat transfer between said tubular member and said piston.

References Cited in the file of this patent

UNITED STATES PATENTS

741,536	Norberg	Oct. 13, 1903
1,124,340	Sebald	Jan. 12, 1915
2,458,894	Collins	Jan. 11, 1949
2,916,205	Litz	Dec. 8, 1959
3,010,641	Peregrine	Nov. 28, 1961