Feb. 9, 1965 J. E. FLEURY 3,168,805

THERMAL POWER ELEMENT

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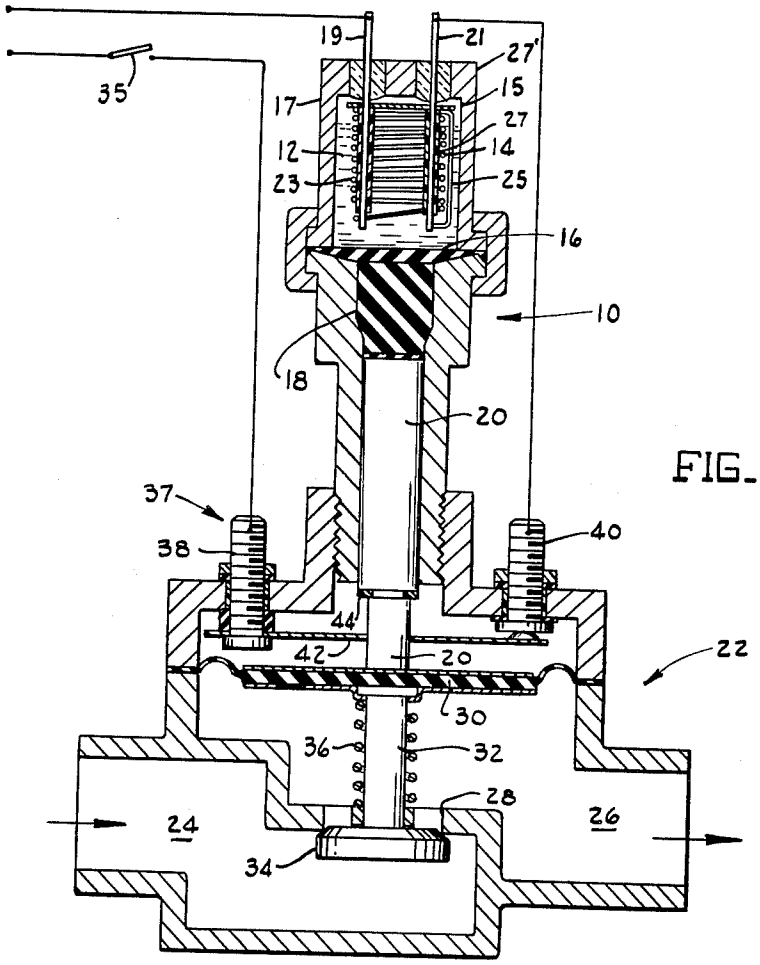


FIG_1

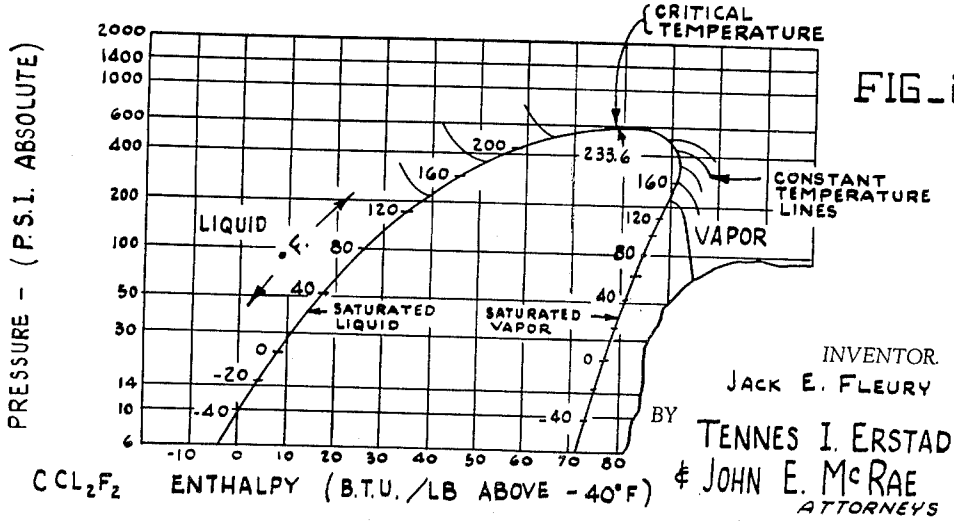


FIG_2

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THERMAL POWER ELEMENT

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This invention relates to power elements of the type which comprise a casing having an internal chamber and a piston arranged to move into and out of the casing in accordance with variations in chamber volume.

In such power elements the internal chamber is commonly charged with a material having a high coefficient of thermal expansion, such as wax, so that when the material is heated (as by an electric resistance heater) the piston moves forward out of the casing; when the expansion material is cooled, as by the ambient atmosphere, the piston returns into the casing under the influence of the external load against which the piston is working. The load can be any device which it is desired to control by mechanical motion, as for example a liquid valve.

One object of the present invention is to provide a power element wherein the forward piston stroke is obtained with a relatively small heat input, thereby necessitating only a relatively small subtraction of heat to effect the reverse cooling stroke.

An additional object is to provide a power element having a relatively fast piston motion, both on the heating stroke and on the cooling stroke.

Another object is to provide a power element wherein the expansion material is conditioned to undergo rapid cooling, thereby facilitating a rapid piston return stroke.

A further object is to provide a power element wherein the expansion material is utilized near its critical temperature such that each incremental heat input produces a relatively large pressure change in the expansion material.

A still further object is to provide a power element wherein the expansion material is effective to move the piston outwardly only after the material has reached a relatively high temperature, whereby the subsequent cooling cycle is accomplished by a relatively large temperature differential between the expansion material and the ambient atmosphere.

Other objects of this invention will appear from the following description and appended claims, reference being had to the accompanying drawings forming a part of this specification wherein like reference characters designate corresponding parts in the several views.

In the drawings:

FIGURE 1 is a sectional view taken through a power element of this invention and showing same in position for opening and closing a conventional liquid valve;

FIG. 2 is a chart plotting the pressure-enthalpy characteristic of the expansion material utilized in the FIG. 1 power element.

Before explaining the present invention in detail, it is to be understood that the invention is not limited in its application to the details of construction and arrangement of parts illustrated in the accompanying drawings, since the invention is capable of other embodiments and of being practiced or carried out in various ways. Also, it is to be understood that the phraseology or terminology employed herein is for the purpose of description and not of limitation.

Referring in greater detail to the drawings, there is shown a power element **10** having a charge of thermally expansible material **12** which is arranged to be heated by an electric resistance heater **14**, whereby to develop a fluid pressure on the flexible diaphragm **16**. Diaphragm **16** in

turn transmits the pressure to a squeezable rubber plug **18** which is arranged above a piston **20**.

The resistance heater may be varied as to design. However, as shown, the heater includes two pin-like terminals **19** and **21**, and a generally cylindrical coil of resistance wire **23** wrapped therearound so that one end of the wire connects directly with terminal **19** and the other end extends along the wall of casing **17**, as at **25**, before connecting with terminal **21**. Each terminal pin is preferably provided with a sleeve-like insulator **27**.

As semi-schematically shown in the drawing, power element **10** is mounted atop a liquid valve **22** which is provided with an inlet chamber **24**, an outlet chamber **26**, and a port **28**. The piston **20** of the power element is arranged to engage the diaphragm seal **30** which is interconnected with a stem **32** and poppet valve element **34**. Thus, thermal expansion of material **12** causes a downward movement of piston **20** and a corresponding movement of valve element **34**. Upon cooling of the expansion material the valve element may be returned to its closed position by the liquid pressure in inlet **24** and/or the compression spring **36**. Thus, assuming a continually large liquid head in inlet **24**, the diaphragm **30** (because of its relatively large area compared to the port area) tends to move the valve element **34** to the closed position.

Preferably, although not necessarily, electric heater **14** is in circuit with a first on-off control switch **35**, and a second limit switch **37**. Switch **37** includes a first terminal **38**, a second terminal **40**, and a switch blade **42** having a portion thereof in registry with the shoulder formed by dielectric washer **44**. With such an arrangement, when heater **14** is energized the resultant expansion of material **12** causes the piston to be moved downwardly until the shoulder at **44** engages the blade **42** and thus interrupts the circuit between terminals **38** and **40**, thereby de-energizing the heater. With switch **35** in a closed condition the piston **20** will cycle rapidly a very short distance under the control of limit switch **37**.

As will be evident, when the heater is de-energized by switch **35** the ambient atmosphere surrounding the power element casing **17** acts to cool material **12** and thus permits the power element piston **20** to return to its illustrated position under the influence of spring **36** and/or the liquid pressure in inlet chamber **24**.

In the illustrated power element the expansion material **12** may consist of dichlorodifluoromethane (CCl_2F_2) which is a common material obtainable, for example, from the Du Pont Company under the tradename "Freon 12." As indicated in FIG. 1, the CCl_2F_2 is initially charged into chamber **15** in a liquid condition so as to occupy only a fractional part of the chamber **15** volume. At one atmosphere pressure the CCl_2F_2 boils at approximately —21° F., and the charging operation is therefore preferably carried out at this temperature or slightly therebelow. Preferably the charging operation is carried out in a manner to exclude air from chamber **15**. This may be accomplished either by charging under vacuum or at a temperature high enough to allow the formation of CCl_2F_2 vapor in the casing. For example, with cup element **27'** disposed in an upright position dissociated from the other components, liquid CCl_2F_2 may be sprayed into the cup element to produce a mild vaporizing action therein. The CCl_2F_2 vapor is heavier than air so that it sits in the cup and excludes the air from the cup interior. After charging the cup element may be assembled with the other casing parts to form the completed casing.

CCl_2F_2 is of interest as a power element expansion material because it has a relatively low specific heat, relatively low critical temperature, and relatively large pressure change per unit temperature change at temperatures near its critical temperature. Another material having similar advantageous properties is methyl alcohol.

The term "critical temperature" is used herein to indicate the temperature above which it is impossible for the material to remain liquid whether pressure is impressed thereon. The critical volume is the specific volume of the material existing at the critical temperature.

As known in the art, any material when in the liquid state has attactive forces between its molecules which predominate over the translational kinetic energy forces which tend to separate the molecules. The kinetic energy forces increase with increasing temperature, and when they predminate over the intermolecular attractive forces the material is vaporized. At relatively low temperatures pressure may be applied to force the molecules toward one another in spite of the kinetic energy forces; thus the pressure brings the molecules close enough together so that the intermolecular attractive forces can hold the material in a liquid condition. However when the temperature is increased above a critical value it is impossible by the application of high pressures to overcome the kinetic energy forces; the kinetic energy forces predominate as though the intermolecular forces were not present. For this reason, when the material approaches or reaches its critical temperature each unit temperature change is potentially capable of producing a relatively large free kinetic energy change and large pressure change. In the present invention this characteristic is utilized to produce a power element having improved operating efficiency.

As before stated, one suitable expansion material which lends itself to operation near its critical temperature is CCl_2F_2. In FIG. 2 there is shown a chart which plots the pressure against enthalpy for CCl_2F_2. It will be seen that when the material is in a saturated liquid condition, at relatively low temperatures each unit temperature change is accompanied by a relatively small pressure change, whereas in higher temperature ranges each unit temperature change effects a relatively large pressure change.

In the lower temperature ranges, as for example from 80° F. to 120° F., the rate of pressure change is relatively low, being in the neighborhood of about 2 p.s.i. per degree F. change. In the temperature range from 200° to the critical temperature of 233.6° the pressure changes from about 430 p.s.i. to about 597 p.s.i. which represents an average rate of pressure change of about 5 p.s.i. per degree F. At temperatures above the critical temperature the rate of pressure change per unit temperature change is relatively high, being in the neighborhood of 10 p.s.i. per degree F. change or higher.

I have found that if the power element is fully charged with liquid CCl_2F_2 the thermal expansion results in volume increase while the material is still in a relatively low temperature condition; operation is then on pure liquid expansion where the piston motion per unit temperature change is relatively small. However, I have noted that if power element chamber **15** is only partially charged with liquid CCl_2F_2 the substantially vacant or vapor space in the chamber will absorb the initial low temperature expansion so that pressure development will be delayed until the material is in a relatively high temperature condition. By thus delaying the pressure development I am able to operate at temperatures above 200 degrees F. (near the critical temperature) where the rate of pressure change per unit temperature change is relatively high.

Operating near the critical temperature is advantageous in producing a relatively rapid outward stroke of the piston. Additionally the high operating temperatures create a relatively large temperature differential between the CCl_2F_2 and the ambient atmosphere so that rapid cooling takes place when heater **14** is de-energized; this promotes a rapid return stroke of the piston. A rapid return stroke is also promoted by the fact that a relatively small quantity of material **12** is present in chamber **15**. Thus, with small amounts of material **12** less heat is needed to be subtracted from the material to attain a desired state of cooling and pressure reduction.

The exact quantity of expansion material needed to be

charged into chamber **15** is dependent on several factors, including the nature of the material, the required pressure to be applied on diaphragm **16**, and the required increase in chamber volume necessary for the desired piston stroke. When working with CCl_2F_2 and a power element needing an internal pressure of 1,000 p.s.i. and a twenty percent increase in chamber volume, I have found that chamber **15** may be initially charged about one-half to two-thirds full with liquid CCl_2F_2. Such a charge leaves sufficient vacant space in the chamber so that the operating stroke of the piston takes place in a temperature range somewhat above 200° F., which is the preferred operating range.

In one experimental arrangement the power element was constructed to have a piston diameter of about one-quarter inch and a piston stroke of about two-tenths inch. The piston was provided with an external load of about thirty-five pounds, and the frictional resistance offered by plug **18** was about fifteen pounds; thus the total load was about fifty pounds. The internal pressure in chamber **15** necessary to produce a satisfactory piston movement is approximately 1,000 p.s.i.

To evaluate the performance of this experimental power element the element was charged with differing quantities of CCl_2F_2, and measurements taken of the temperatures and piston stroke times. The temperatures were taken with thermocouples applied to the outer surface of cup **27**.

In power elements having internal resistance heaters the piston stroke time is different in the same element, depending on how frequently the element is cycled For example, if the element is cycled for a one minute period during every fifteen operational minutes, the walls of the element will tend to rise only a few degrees above room temperature throughout each cycle, and the piston will have a relatively slow outstroke and fast return stroke; this allows the electrically-produced heat to be easily dissipated through the power element walls. If on the other hand the element is cycled substantially continuously the walls of the element will tend to have a higher average temperature which tends to promote a relatively fast outstroke and slow return stroke. In the case of the described experimental power element the piston stroke times were measured both with the element cycled only infrequently and with the element cycled continuously.

With the power element charged with liquid CCl_2F_2 to about forty-one percent of the chamber volume the cold element cycled out in about fifteen seconds and back in about five seconds; after a period of continuous cycling the piston outstroke time dropped to about eight seconds, and the return stroke time increased to about twelve seconds. The piston started its outstroke at about 233° F., and completed its outstroke at about 250° F.

With the power element charged with liquid CCl_2F_2 to about fifty-eight percent of the chamber volume the cycle times were about the same as with the forty-one percent charge. However the temperatures were somewhat reduced, ranging from 222° F. at the start of the piston outstroke to about 240° F. at completion of the piston outstroke.

With the power element charged with liquid CCl_2F_2 to about seventy-one percent of the chamber volume the cycle times were considerably increased to values in excess of thirty seconds. The piston began its outstroke at about 166° F. and completed its outstroke at about 190° F.

With the power element charged with liquid CCl_2F_2 to about seventy-eight percent of the chamber volume the piston stroke times were further increased, especially on the cooling stroke. On the heating stroke the piston began its movement at about 140° F.

Of the various charges tested to fifty-eight percent charge appears to be the most satisfactory from the standpoint of quick operating times and safe operational temperatures. The forty-one percent charge attains a relatively high temperature which could in some arrangements cause breakdown of the rubber parts and/or decomposi-

tion of the CCl_2F_2 after a period of service; this is especially true since the temperatures within the CCl_2F_2 are somewhat higher than those registered on the power element outer surface. The seventy-one percent and seventy-eight percent charges are believed unsatisfactory for many applications because of their long operating times. On the basis of experimental evidence a partial charge of fifty percent to sixty-five percent appears to be most practical.

The partially charged CCl_2F_2 element is believed to represent considerable improvement over known constructions. For example, wax-charged elements and water-charged elements have under generally similar loads required relatively long piston forward stroke times in the neighborhood of one minute, and return stroke times of thirty seconds to one minute or more. Oil-charged elements have in certain instances had response times varying from one minute to three or four minutes. In such elements the usable expansions have been obtained at temperatures appreciably below the critical temperature of the charged material, and it was therefore not possible to achieve the high internal pressures and response times which characterize the operation of the described element.

During the description reference has been made particularly to the material CCl_2F_2. This material is particularly useful because it has a relatively low critical temperature and low specific heat. It is contemplated however that other materials might be employed while still practicing the invention. One material which is of some interest is methyl alcohol.

It is contemplated that the invention can be utilized in other power element constructions than the one specifically shown in the drawing. For example, it is possible to locate the heated portion of the element remote from the diaphragm-plug portion, in which case the heated portion can be provided with a capillary tube connection to the diaphragm chamber portion. Such an arrangement is advantageous in achieving low diaphragm temperatures.

As previously noted, the invention has as its principal objects the provision of a power element which can be operated with a relatively small heat input and which attains a relatively high operating temperature and pressure near or above the critical temperature and pressure, whereby to promote a rapid piston forward stroke and a rapid piston return stroke under high load conditions. By utilizing the concepts of this invention it is believed that these objects have been achieved.

What is claimed is:

1. In a heat-actuated power element having a chamber-forming casing, a loaded power member extending from said casing, and a thermal expansion substance within the chamber: the improvement comprising the thermal expansion substance filling only a predetermined fractional portion of the chamber in a liquid condition when the power element is below its operating temperature range; the power member having a loading which prevents substantial power member motion until the chamber pressure reaches a predetermined value; and the expansion liquid substance having an expansion up to its critical temperature which produces a chamber pressure less than said predetermined pressure, whereby substantial motion is produced only as the critical temperature is approached.

2. In a heat-actuated power element having a chamber-forming casing, an electric heater within said casing for heating the chamber interior, a loaded piston extending from said casing, and a thermal expansion substance within the chamber; the improvement comprising the utilization of dichlorodifluoromethane as the thermal expansion substance, said substance having a mass which causes it to occupy approximately sixty percent of the chamber volume when in a liquid condition at its normal boiling point; the piston having a loading which requires an internal chamber pressure of approximately 1,000 p.s.i. for the attainment of outward piston motion, whereby energization of the electric heater effects piston movement only after the chamber temperature is above 200° F.

3. In a heat-actuated power element having a chamber-forming casing, a loaded power member extending from said casing, and a thermal expansion substance within the chamber: the improvement comprising the thermal expansion substance occupying between 50% and 65% of the chamber volume when in a liquid condition at its normal boiling point; the power member having a loading which prevents substantial power member motion until the chamber pressure reaches a predetermined value; and the expansion liquid substance having an expansion up to its critical temperature which produces a chamber pressure less than said predetermined pressure, whereby substantial motion is produced only as the critical temperature is approached.

4. In a heat-actuated power element having a chamber-forming casing a loaded power member extending from said casing, and a thermal expansion substance within the chamber: the improvement comprising the thermal expansion substance occupying approximately 60% of the chamber volume when in a liquid condition at its normal boiling point; the power member having a loading which prevents substantial power member motion until the chamber pressure reaches a predetermined value; and the expansion liquid substance having an expansion up to its critical temperature which produces a chamber pressure less than said predetermined pressure, whereby substantial motion is produced only as the critical temperature is approached.

5. In a heat-actuated power element having a chamber-forming casing, a loaded power member extending from said casing, a thermal expansion substance within the chamber, an electrical resistance heating element within the chamber for causing the expansion substance to move the power member in one direction, and electrical switch means controlling the heating element in response to said one direction movement of the power member whereby to permit the expansion substance to cool and allow the loading to return the power member in the opposite direction: the improvement comprising the thermal expansion substance filling only a predetermined fractional portion of the chamber in a liquid condition when the power element is below its operating temperature range; the power member having a loading which prevents substantial power member motion until the chamber pressure reaches a predetermined value; and the expansion liquid substance having an expansion up to its critical temperature which produces a chamber pressure less than the predetermined pressure, whereby substantial motion is produced only as the critical temperature is approached.

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