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(54) Joule-Thomson cryostat

(57) A load temperature regulated, adaptive-orifice, Joule-Thomson cryostat which controls refrigeration output by servo-controlled gas flow regulation at the Joule-Thomson cryostat expansion, or throttling, orifice. The mechanism consists of a variable aperture needle valve 19 with an expansion orifice that is controlled by a miniature, electrically driven transducer 41, using closed-loop feedback control 59 which monitors 51 the temperature at or on a thermal load point and adjusts the gas throughput so as to maintain a desired cold temperature constant at the load 15.

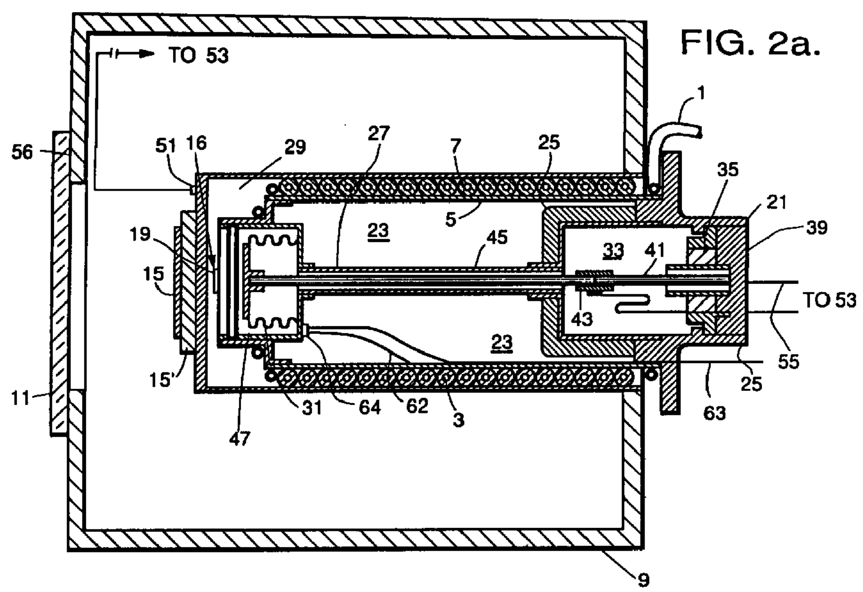

FIG. 2a.

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Description

BACKGROUND OF THE INVENTION

Field of the Invention:

The present invention relates to Joule-Thomson cryostats. More specifically, the present invention relates systems and techniques for improving the performance of Joule-Thomson cryostats.

While the present invention is described herein with reference to illustrative embodiments for particular applications, it should be understood that the invention is not limited thereto. Those having ordinary skill in the art and access to the teachings provided herein will recognize additional modifications, applications, and embodiments within the scope thereof and additional fields in which the present invention would be of significant utility.

Description of the Related Art:

A cryostat is an apparatus which provides a localized low-temperature environment in which operations or measurements may be carried out under controlled temperature conditions. Cryostats are used to provide cooling of infrared detectors in guided missiles, for example, where detectors and associated electronic components are often crowded into a small containment package. Cryostats are also used in superconductor systems where controlled very low temperatures are required for superconductive activity.

A Joule-Thomson cryostat is a cooling device that uses a valve (known in the art as a "Joule-Thomson valve") through which a high pressure gas is allowed to expand via an irreversible throttling process in which enthalpy is conserved, resulting in lowering of its temperature.

The simplest form of a conventional Joule-Thomson cryostat typically had a fixed-size orifice in the heat exchanger at the cold end of the cryostat such that cooling by the cryostat was unregulated. The input pressure and internal gas flow dynamics established the flow parameters of the coolant through the cryostat. Although the conventional Joule-Thomson cryostat is a simple apparatus in that it has no moving parts, the inherent, uncontrolled flow characteristics make the fixed-orifice type cryostat unsuitable for many applications where rapid cool-down and long cooling durations from a limited size gas supply source are required. Rapid cool-down requires high rate gas flow and a large size orifice, while long cooling durations require low gas flow rates and a small size orifice. These two conditions cannot be simultaneously met in a fixed orifice cryostat.

Since approximately the 1950's, demand-flow Joule- Thomson cryostats with internal, passive, thermostatic control of variable orifice size have been used. These cryostats have the ability to start cool-down with the maximum orifice size, thereby providing high rate gas flow and refrigeration for rapid cool-down. After cool-down is achieved, the orifice size is reduced for minimal gas flow rate and refrigeration necessary for the thermal load. A thermostatic element within the mandrel of the apparatus provides self-regulation of gas flow based upon the temperature in and around the gas plenum chamber. The cooling rate is proportional to the mass flow rate of gas through the cryostat. The thermostatic element, which can be a gas-filled bellows or a segment of material which contracts or expands based upon temperature, is coupled to a demand-flow needle valve mechanism. As the temperature drops, the bellows is adapted to contract and cause the needle to extend into and partially close the Joule-Thompson orifice. At the predetermined critical temperature, the bellows thermostat mechanism can close the needle valve entirely. As the temperature rises, the bellows expands again and actuates the valve mechanism, allowing new coolant flow through the orifice and ultimately to the heat load.

While the self-regulating demand-flow cryostat provides control over coolant flow, there are still limitations which can make it unacceptable in systems where temperature fluctuations can be critical to operations.

The thermostat bellows mechanism (and similar substitute devices that rely upon expansion and contraction of materials, such as certain plastics) are inherently subject to large performance tolerances. This can result in instabilities and fluctuations in the critical on-off temperature point for the needle valve. Therefore, such cryostats have been found to be non- proportional in their gas flow regulation over the expected full range of operation.

Additionally, the same cryostat will react differently using different cryogens. Thus, the system performance will be dependent upon the specific cryogen in use during any single operation. If a substitute coolant is used in place of that for which the thermal contraction link is designed, the cryostat will seek the design set temperature and may repeatedly fail.

Furthermore, temperature waves within the expansion chamber can result in thermal cycling of the bellows mechanism. Moreover, in rocketry environments, the mechanism will be subject to the effects of acceleration and deceleration. In infrared detector cooling, instability in the detector due to fluctuations in refrigeration by the cryostat may result in a type of thermal noise, known as thermophonics, produced in a coupled video display.

Pooling of the liquid gas when a saturated condition within the plenum chamber is reached can also seriously affect the performance of the cryostat needle valve operation if the liquid pool moves under the influence of environmental forces. This can result in a rapid vaporization or impedance to gas flow in the low pressure side of the heat exchanger and consequent liquid vapor pressure changes and a sudden opening of the needle valve. Another operational limitation is encountered when an extended thermal load is used. The temperature of the gas plenum chamber cools down before the remote extremities of the thermal load and causes the needle valve to prematurely close before the load is entirely cooled down.

Any of these exemplary conditional aspects can result in a premature closing or undesired variations in the needle valve positioning and gas flow rate. This forces a manufacturing design of a multiplicity of Joule-Thomson cryostat components tailored to both heat load factors and coolant parameters.

Thus, there is a need for an active mechanism for cryostats which can use the sensed temperature of the thermal load, and not just the gas plenum chamber temperature, to adjust the gas expansion valve orifice size setting from maximum opening during cool-down to a reduced minimal opening for sustained cooling of the thermal load. Furthermore, there is a need for an active mechanism for cryostats to provide stable, time-averaged, proportional control of the gas expansion valve orifice size for stable gas flow and, therefore, stable refrigeration rate and temperature control. Ideally, this control should be able to adjust to changing heat load and input pressure conditions, as well as changing thermal environments in a continuous, gradual and non-abrupt manner, which maintains a stable cold temperature. Ideally, this control should be able to work with multiple coolant gases and provide a stable cold temperature and optimal performance. In addition, there is a need for an active mechanism for cryostats that minimizes susceptibility to temperature fluctuations caused by outside environmental effects, such as inertial accelerations, or to internal thermal waves, or to pressure variations within the plenum chamber.

SUMMARY OF THE INVENTION

The need in the art is addressed by the present invention which provides an active gas throttling mechanism for a cryostat, using a needle valve controlled, Joule-Thomson effect cryostat to cool a heat load. The inventive apparatus includes an actuator device connected, to a needle valve, for controlling the flow of a coolant therethrough. A temperature sensor is connected to the heat load in proximity thereto. The sensor provides a signal indicative of sensed temperature. A servo-controller receives the signal and regulates the flow of coolant to the actuator device in response thereto.

In operation, the invention provides a closed-loop method for controlling refrigeration of a thermal load by a Joule-Thomson effect cryostat comprising the steps of: (a) sensing proximate temperature of the thermal load, (b) transmitting a first signal related to the proximate temperature, (c) converting the signal to a second signal for regulating flow of coolant in the cryostat, and (d) adjusting the flow of coolant in direct relation to the first signal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a cross-sectional, plan (side) view of a typical conventional cryostat.

FIG. 1B is a cross-section, plan view (side) of a typical demand-flow needle valve as utilized in the typical conventional cryostat of FIG 1A.

FIG. 2A is a depiction of the present invention in a cross-section, plan view (side) as incorporated in a Joule-Thomson cryostat.

FIG. 2B is a detail depiction of a portion of the present invention as shown in FIG. 2A.

FIG. 3 is a schematic diagram of the present invention as shown in FIG. 2A.

FIG. 4 is a schematic flow chart diagram of the operation of the present invention as shown in FIGS. 2 and 3.

FIG. 5 is an alternative embodiment of the present invention as shown in FIG. 2A.

FIG. 6 is a schematic flow chart diagram of the operation of the alternative embodiment of the present invention as shown in FIG. 5.

DESCRIPTION OF THE INVENTION

A typical conventional Joule-Thomson cryostat 10 is shown in FIGS. 1A and 1B. A coolant, such as high pressure argon or nitrogen gas or even air, is introduced through a gas inlet fitting 1 into a recuperative heat exchanger 3 that encompasses a support mandrel 5 inside a cold finger section 7 of a dewar package 9. The heat exchanger 3 basically comprises counterflow finned metal tubing 4 wrapped around the mandrel 5, that allows the high pressure gas to cool significantly as it moves toward the lower end of the cold finger section 7. The heat exchanger tubing 4 terminates in an orifice 16 at the lower end of the mandrel 5, commonly referred to as the cold end of the cryostat. The orifice 16 acts as a Joule-Thomson gas throttling valve. As the gas passes through the orifice 16 and enters the surrounding gas plenum chamber 29, it expands to a low pressure gas and creates a liquid form. The evaporated liquid and low pressure gas are used to cool the thermal load 15 which is located adjacent the dewar window 11. The cooling of the load is accomplished by a liquid coolant spray from the orifice 16 onto the portion of cold finger 7 positioned in contact with thermal load 15. The gas from the chamber 29 is recycled through another low pressure branch of the heat exchanger 3 before exiting into the atmosphere through exit port 13 at the upper, of warm end, of the cryostat 10.

As mentioned above, the simplest form of a conventional Joule-Thomson cryostat typically had a fixed-size orifice 16 in the heat exchanger 3 at the cold end of the cryostat such that cooling by the cryostat was unregulated. The input pressure and internal gas flow dynamics established the flow parameters of the coolant through the cryostat. While a simple apparatus in that it has no moving parts, the inherent, uncontrolled flow characteristics make the fixed-orifice type cryostat unsuitable for many applications where rapid cool-down and long cooling durations from a limited size gas supply source are required. Rapid cool-down requires high rate gas flow and a large size orifice, while long cooling durations require low gas flow rates and a small size orifice. These two conditions cannot be simultaneously met in a fixed orifice cryostat.

Since approximately the 1950's, demand-flow Joule- Thomson cryostats with internal, passive, thermostatic control of variable orifice size have been used as shown in FIG. 1B. These cryostats have the ability to start cool-down with the maximum orifice size, thereby providing high rate gas flow and refrigeration for rapid cool-down. After cool-down is achieved, the orifice size is reduced for minimal gas flow rate and refrigeration necessary for the thermal load.

A thermostatic element within the mandrel 5 provides self-regulation of gas flow based upon the temperature in and around the gas plenum chamber 29. The cooling rate is proportional to the mass flow rate of gas through the cryostat. The thermostatic element, which can be a gas- filled bellows or a segment of material which contracts or expands based upon temperature, is coupled to a demand-flow needle valve mechanism 19. As the temperature drops, the bellows is adapted to contract and cause the needle to extend into and partially close the Joule-Thomson orifice 16. At the predetermined critical temperature, the bellows thermostat mechanism 17 can close the needle valve 19 entirely. As the temperature rises, the bellows expands again and actuates the valve mechanism 19, allowing new coolant flow through the orifice and ultimately to the heat load 15.

As mentioned above, while the self-regulating demand-flow cryostat provides control over coolant flow, there are still limitations which can make it unacceptable in systems where temperature fluctuations can be critical to operations.

The thermostat bellows mechanism 17 (and similar substitute devices that rely upon expansion and contraction of materials, such as certain plastics) are inherently subject to large performance tolerances. This can result in instabilities and fluctuations in the critical on-off temperature point for the needle valve. Therefore, such cryostats have been found to be non- proportional in their gas flow regulation over the expected full range of operation.

Additionally, the same cryostat will react differently using different cryogens. Thus, the system performance will be dependent upon the specific cryogen in use during any single operation. If a substitute coolant is used in place of that for which the thermal contraction link is designed, the cryostat will seek the design set temperature and may repeatedly fail.

Furthermore, temperature waves within the expansion chamber can result in thermal cycling of the bellows mechanism. Moreover, in rocketry environments, the mechanism will be subject to the effects of acceleration and deceleration. In infrared detector cooling, instability in the detector due to fluctuations in refrigeration by the cryostat may result in a type of thermal noise, known as thermophonics, produced in a coupled video display.

Pooling of the liquid gas when a saturated condition within the plenum chamber 29 is reached can also seriously affect the performance of the cryostat needle valve operation if the liquid pool moves under the influence of environmental forces. This can result in a rapid vaporization or impedance to gas flow in the low pressure side of the heat exchanger 3 and consequent liquid vapor pressure changes and a sudden opening of the needle valve 19.

Another operational limitation is encountered when an extended thermal load 15 is used. The temperature of the gas plenum chamber 29 cools down before the remote extremities of the thermal load 15 and causes the needle valve 19 to prematurely close before the load is entirely cooled down.

Any of these exemplary conditional aspects can result in a premature closing or undesired variations in the needle valve positioning and gas flow rate. This forces a manufacturing design of a multiplicity of Joule-Thomson cryostat components tailored to both heat load factors and coolant parameters.

Thus, there is a need for an active mechanism for cryostats which can use the sensed temperature of the thermal load, and not just the gas plenum chamber temperature, to adjust the gas expansion valve orifice size setting from maximum opening during cool-down to a reduced minimal opening for sustained cooling of the thermal load.

Furthermore, there is a need for an active mechanism for cryostats to provide stable, time-averaged, proportional control of the gas expansion valve orifice size for stable gas flow and, therefore, stable refrigeration rate and temperature control. Ideally, this control should be able to adjust to changing heat load and input pressure conditions, as well as changing thermal environments in a continuous, gradual and non- abrupt manner, which maintains a stable cold temperature. Ideally, this control should be able to work with multiple coolant gases and provide a stable cold temperature and optimal performance.

Furthermore, there is a need for an active mechanism for cryostats that minimizes susceptibility to temperature fluctuations caused by outside environmental effects, such as inertial accelerations, or to internal thermal waves, or to pressure variations within the plenum chamber.

The present invention addresses these needs. The present invention is adaptable to a configuration of a cryostat of the type shown in FIG. 1A. FIG. 2A shows the invention as incorporated into such a Joule-Thomson cryostat.

The invention is contained within the cold finger 7 of the vacuum dewar container 9 of like manner to the prior art of FIG. 1A.

Referring back to FIG. 2A, a mandrel cap member 21 seals a mandrel chamber 23. Generally, the cap member 21 comprises an encapsulated thermal foam insulation 25, such as polyurethane, to prevent thermal leakage from the chamber 23.

A sealed sheath tubing 27, preferably made of stainless steel or the like, runs the from the cap member 21 the length of the mandrel chamber 23 and openly connects within a coolant plenum chamber 29 at the cold end of the cryostat. The coolant plenum chamber 29 houses a fixedly mounted bellows spring 31. In the preferred embodiment, a low mass, high spring constant device is used for the bellows spring 31.

Within a cap chamber 33 of the mandrel cap 21 is seated an electrical feedthrough connector 35. In the preferred embodiment, this is a glass-to-metal feedthrough connector 35. The feedthrough connector 35 has an electrical lead 55 terminating externally of the mandrel cap 21. A bellows spring actuator mechanism is terminated at a first end 39 in the feedthrough connector 35. The bellows spring actuator comprises a first section, which, in the preferred embodiment, is a biometal wire rod 41. The rod 41 extends through the length of the mandrel cap 21 toward the sheath tubing 27 and is coupled at an electrical return junction 43 to a wire rod 45, in the preferred embodiment a steel wire rod. Note that with a relatively sturdy rod 45, the sheath 27 may be eliminated. An electrical return wire 55' coupled to the junction 43 also leads externally of the mandrel cap 21.

The biometal rod 41 acts as a transducer. In the preferred embodiment, the biometal wire rod 41 is a type of titanium-nickel shape memory alloy which contracts during heating when an electrical current is passed through it (known in the art as martensitic-austensitic phase transitioning). Either a small proportional direct current or a pulse-width modulated electric current may be provided through the rod 41 via the pair of electrical leads 55, 55'. The rod 41 thus acts as a miniature transducer for translating motion, using the attached steel wire rod 45, to a needle valve 19 in the coolant plenum chamber 29. Alternatives to the biometal could be a solid-state electromagnetic device, such as a solenoid or magnetostrictive alloy, or another solid-state electromechanical device, such as a piezoelectric transducer. The application of the cryostat may dictate which alternative is most appropriate. In FIG. 2A, electrical current is applied to the wire rod 41 through feedthrough connector 35 (FIG. 3). Current is also supplied by wires 62 and 63 to a heating element 64.

Referring also to FIG. 2B, the steel wire rod 45, connected to the biometal wire rod 41 at the electrical return junction 43, runs through the sheath tubing 27 to a bellows compression plate 47 connected to the movable end of the bellows spring 31.

The bellows spring 31 is connected to a needle valve mechanism 19 within the coolant plenum chamber 29 via bellows pressure plate 47. The combination of spring 31 and pressure plate connected through the steel wire rod 45 to the biometal rod 41 forms a valve actuator device. As shown in FIG. 2B, the needle valve mechanism 19 and connection bellows spring 31 is similar or identical to that recognized by a person skilled in the art as exemplified in FIG. 1B.

Returning to FIG. 2A, a thermal sensor 51 is mounted on, or adjacent, a thermal load mounting platform 15' (which may be integral with the particular load). In the preferred embodiment, a silicon diode temperature sensor 51 is fixedly mounted on the heat load platform 15' in close proximity to the load 15.

A commercially available sensor such as the IN914 diode manufactured by Texas Instruments is suitable for use in the present invention. Transistor-type sensors may alternatively be employed in the invention. The sensor 51 is mounted so as to be sensitive to the ambient temperature of the load environment rather than the temperature within the plenum chamber 29.

Referring now to FIG. 3, the invention is represented in a schematic diagram to assist understanding of its operation.

The heat load 15 that requires temperature control, for example, a missile infrared detector or focal plane array, is fixedly mounted on a thermal load platform 15'. The platform 15' is in turn located adjacent to the cryostat near an orifice 16 as shown in FIG. 2A.

A servo-controller actuator 53 is coupled by electrical leads 55, 55'(return) to the bellows spring actuator 57 and thermal sensor 51. As shown by arrows designated Qx, there are various sources of heat comprising the load. The load 15 and its platform 15', Qfpa and other load environment heat contributors are shown as Qrad, Qcond and even Qvalve, representing heat generated from the valve actuator itself Heat to be extracted by the cryostat is shown a -Qcryo. The temperature sensor 51 provides feedback from the load 15, 15' environment to a servo-controller 53 of the valve control actuator 57. The operational parameters of the servo-controller 53 are designed to control the dimensional length of the biometal rod 41 based upon the sensed temperature. Servo-controller actuator 53 current, being coupled to the biometal wire rod 41 by the electrical leads 55, 55' drives the transducer action of the biometal wire rod 41. In turn, the steel wire rod 45 attached to the biometal wire rod 41 controls the bellows spring 31 and, thus, the Joule-Thomson orifice of the needle valve 19 and, therefore, the flow of the coolant to the load 15.

The method of operation is depicted in the block diagram designated FIG. 4. Designated as reference numeral 101, the servo-controller 53 of the valve control actuator 57 is activated at the time when the coolant gas is input through the gas inlet fitting 1 into the heat exchanger 3. The current to the biometal rod 41 is turned on to reach a predetermined temperature which is just below the phase transition temperature of the preselected biometal material used in rod 41. During the cool down phase of a refrigeration cycle, the needle valve 19 is normally wide open to maximize gas flow and refrigeration effectiveness. Designated by reference numeral 103, when the load temperature approaches its predetermined reference value, the temperature sensor 51 provides a temperature error feedback signal to the servo-controller 59 of the valve control actuator 57, as shown by reference numeral 105. The servo-controller 59 in turn begins to generate an additional current into the biometal wire rod 41 via electrical lead 55 and feedthrough connector 35. As the rod 41 heats, the biometal material contracts. This contraction, transmitted through the steel wire rod 37 and bellows pressure plate 47 throttles the coupled needle into the valve orifice and reduces gas flow and, therefore, the Joule-Thomson cryostat refrigeration effect.

The gas flow cut back continues until the load temperature rises above the reference level which is detected by the thermal sensor 51. As a result, the current to the biometal wire 41 is cut back, causing the reverse reaction and opening the orifice of the needle valve 19 to produce more refrigeration. The temperature may oscillate but only until the temperature error signal is properly nulled to zero when the feedback through the valve control actuator 57 has adjusted the needle valve 19 orifice to a size where the refrigeration rate matches the thermal load within the desired reference temperature range.

FIG. 5 shows an alternative embodiment of the valve control actuator 57 to include a fine servo-controller 61 coupled to the temperature sensor 51 by electrical lead pair 56. Also shown, the fine servo-controller element 61 drives a heating element 64 located inside the cold end of the cryostat chamber 23 or, as shown on FIG. 5, is alternatively mounted near the heat load 15. The function of the second fine servo-controller element 61 is to add any additional necessary heat to maintain the load temperature within a finer tolerance reference temperature range for the specific load.

Similarly, the operation of the alternative embodiment of FIG. 5 is depicted in the block diagram of FIG. 6. Thus, a secondary servo loop with feedback uses small amounts of electrical heater power added to the thermal load to maintain the temperature constant within tighter tolerances.

In this manner, active, servo-controlled cryogenic refrigeration to maintain a substantially steady-state temperature environment for a thermal load is accomplished with a non-saturated cryogen operating mode. In the non-saturated cryogen operating mode, excess liquid cryogen is not produced and, therefore, there is no pooling of liquid cryogen in the plenum chamber 29. As the present invention operates in the non-saturated mode, the invention should operate over a wide range of ambient environmental pressure, including in space vacuum, since there is no dominant dependency on the cryogen boiling pressure or temperature as long as the reference temperature is higher than the range of cryogen boiling points.

This invention is also capable of operating in the saturated to near-saturated operating mode. For example, by using a servo-control reference temperature slightly above the liquid cryogen boiling temperature, but converting the servo-controller from a null search mode to a mode that delivers a fixed predetermined output current when the threshold temperature is reached, the cryostat would be made to operate with the orifice reduced but fixed, during sustained cooling, to produce a slight excess of liquid cryogen.

Because of these features, the invention is useful in Joule-Thomson cryo-systems which provide fast cool down and long duration cooling from minimal size and weight gas supply systems, for example, in missile systems.

The present invention has been described herein with reference to a particular embodiment for a particular application. Those having ordinary skill in the art and access to the present teachings will recognize additional modifications, applications and embodiments within the scope thereof.

It is therefore intended by the appended claims to cover any and all such applications, modifications and embodiments within the scope of the present invention.

Claims

1. A throttling mechanism for a cryostat, using a needle valve controlled, Joule-Thomson effect cryostat to cool a heat load (15), said throttling mechanism comprising:

   first means (31), connected to said needle valve (19), for controlling the flow of a coolant therethrough;
   second means (51), connected to the thermal load (15), for sensing temperature in proximity to said load (15) and providing a signal indicative of sensed temperature; and
   third means (41, 45) for receiving said signal and for regulating said first means (31) in response thereto.

2. The mechanism as set forth in Claim 1 wherein said means for controlling the flow of coolant further comprises:
   a transducer means (41) for receiving a regulating signal and
   a needle valve actuator means (57), connected on a distal end of said transducer means, for imparting motion to a needle in said needle valve.

3. The mechanism as set forth in Claim 1 wherein said means for sensing temperature further comprises a silicon diode temperature sensor (51).

4. The mechanism as set forth in Claim 1 wherein said means for regulating further comprises:
   a Servo-controller (53) adapted to receive said signal from said means for sensing temperature (51) and to provide an output signal in

response thereto and

a transducer actuator means (41, 45) adapted to receive said output signal from said servo-controller (53) for providing an actuation signal to said means for controlling the flow of coolant in response thereto.

5. The mechanism as set forth in Claim 2 wherein said transducer means further comprises:

a transducer element (41) which expands or contracts in reaction to said regulating signal and

a translating means (45), connected to said transducer means on a first end thereof and said needle valve actuator means on a distal end thereof, for translating transducer expansion and contraction to said needle valve (19).

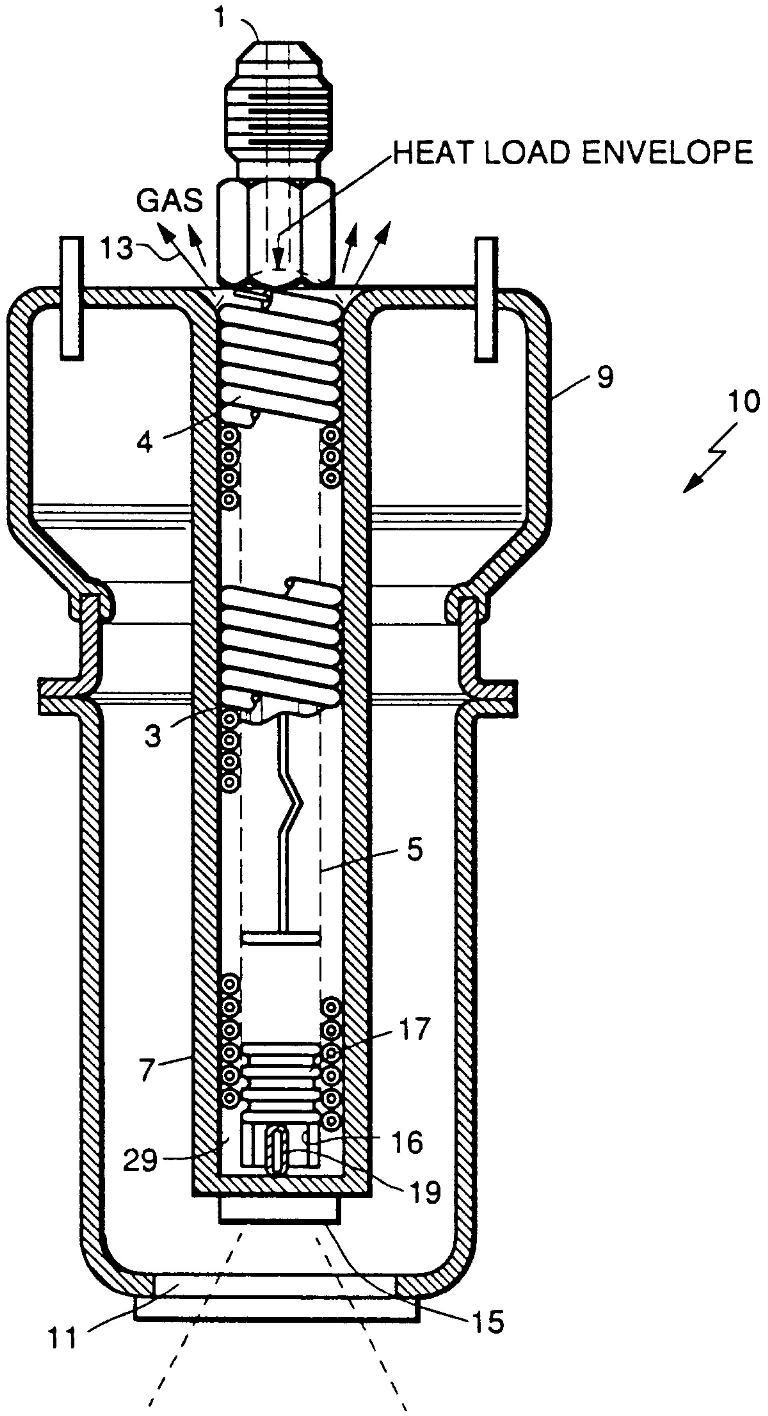


FIG. 1.
(PRIOR ART)

FIG. 2a.

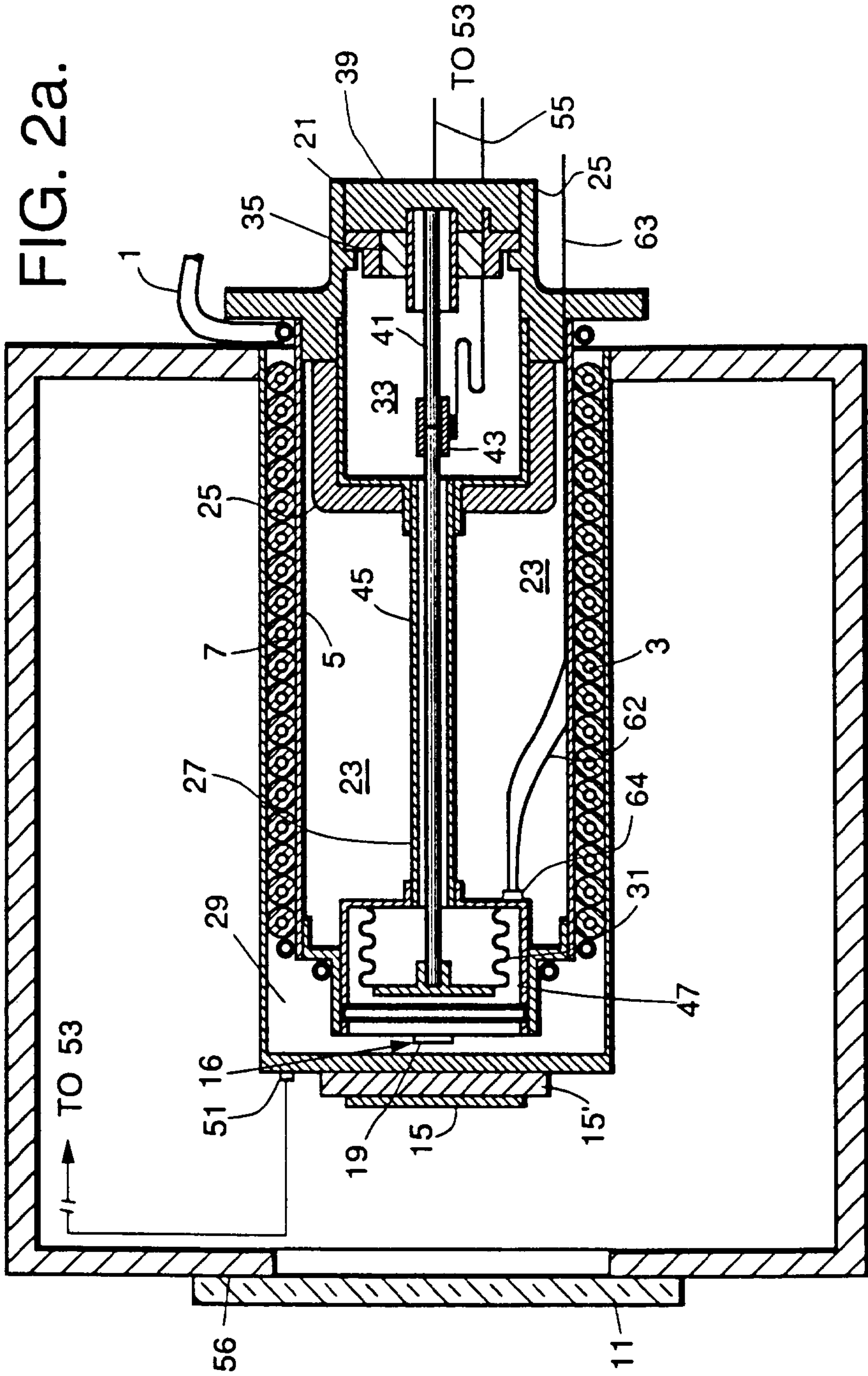
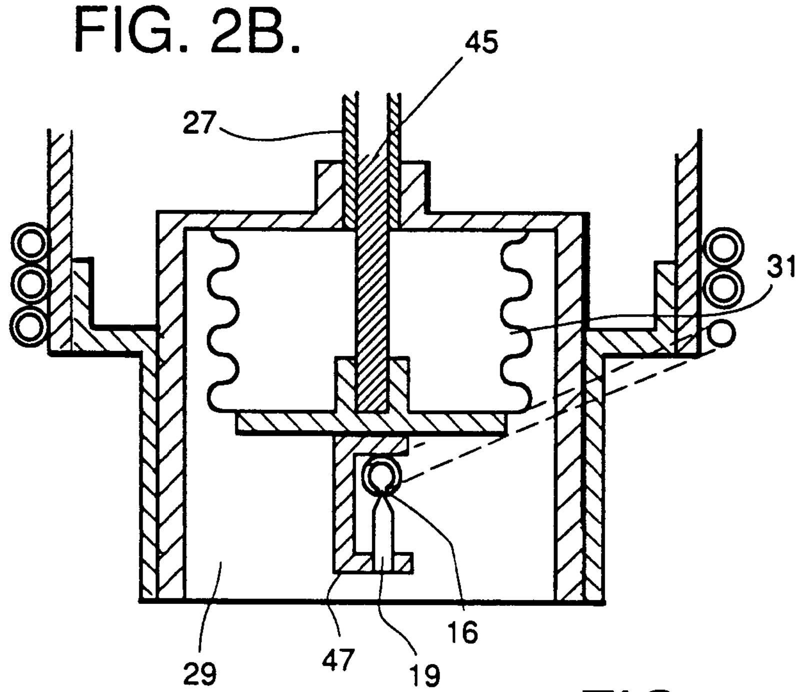

TO 53
39
55
21
25
35
63
1
41
33
43
9
25
45
23
7
5
3
62
23
27
64
31
29
47
TO 53
16
51
19
15
15'
56
11

FIG. 2B.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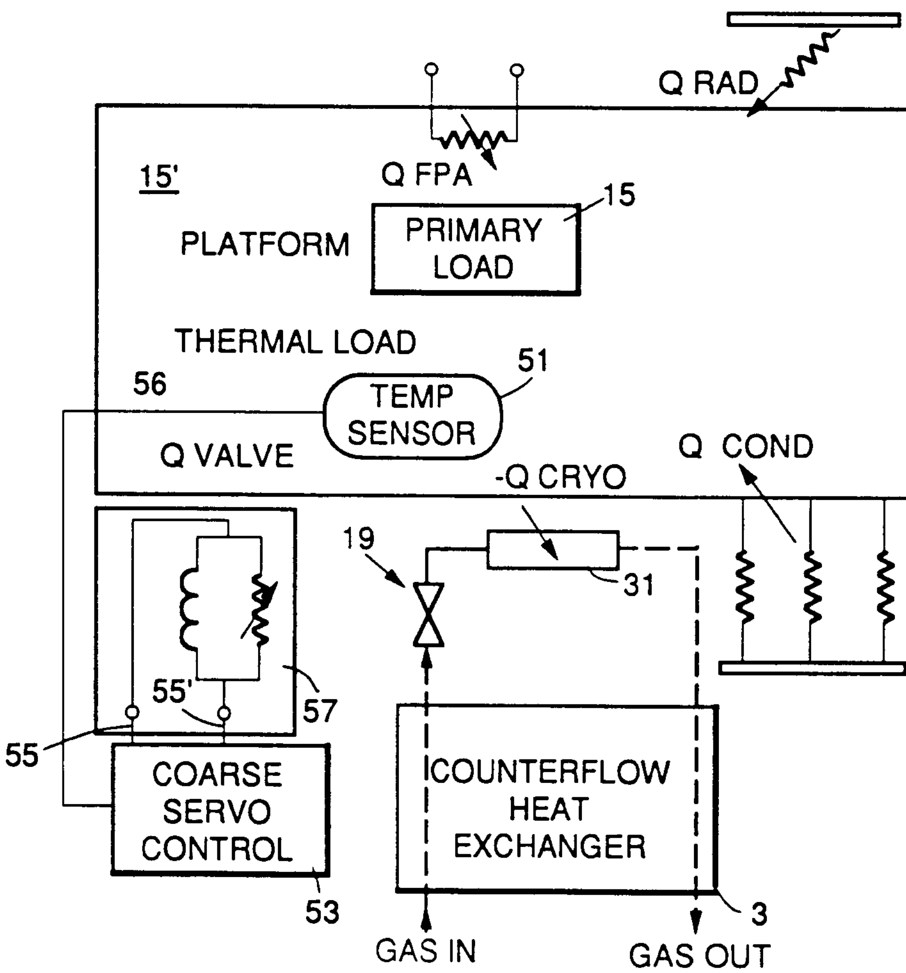
31
29
47
19
16

FIG. 3.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15'
Q FPA
PLATFORM
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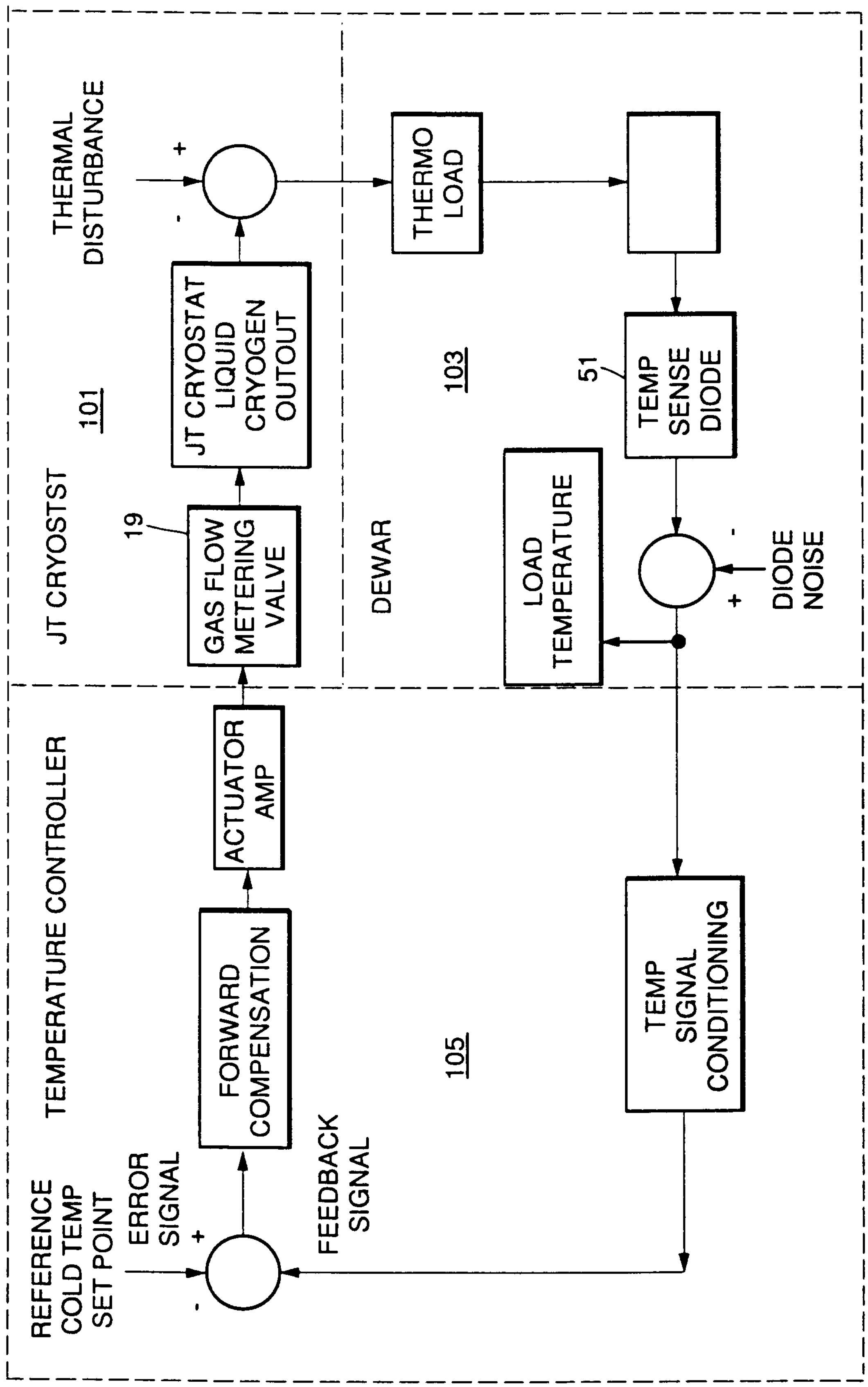
LOAD
15
THERMAL LOAD
51
56
TEMP
SENSOR
Q VALVE
Q COND
-Q CRYO
19
31
55'
57
55
COARSE
SERVO
CONTROL
53
COUNTERFLOW
HEAT
EXCHANGER
3
GAS IN
GAS OUT

FIG. 4.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+
-
19
GAS FLOW METERING VALVE
JT CRYOSTAT LIQUID CRYOGEN OUTOUT
DEWAR
103
THERMO LOAD
51
TEMP SENSE DIODE
LOAD TEMPERATURE
-
+
DIODE NOISE
TEMPERATURE CONTROLLER
105
REFERENCE COLD TEMP SET POINT
ERROR SIGNAL
+
-
FORWARD COMPENSATION
ACTUATOR AMP
FEEDBACK SIGNAL
TEMP SIGNAL CONDITIONING

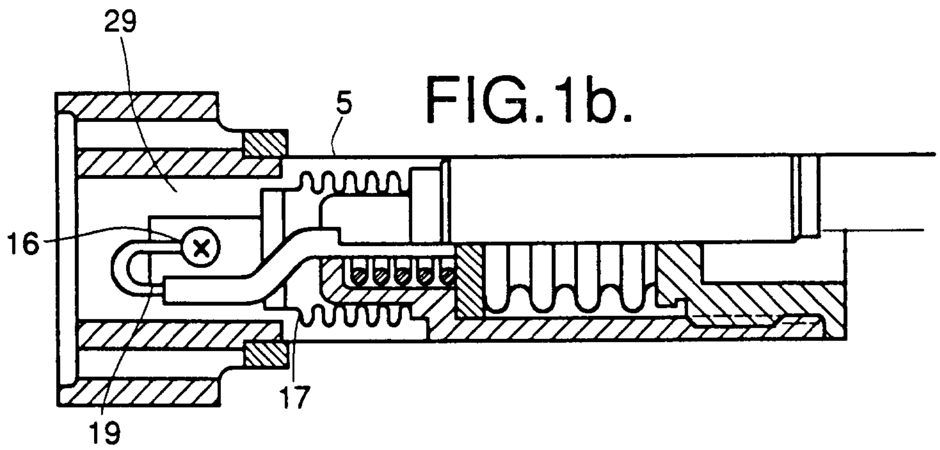
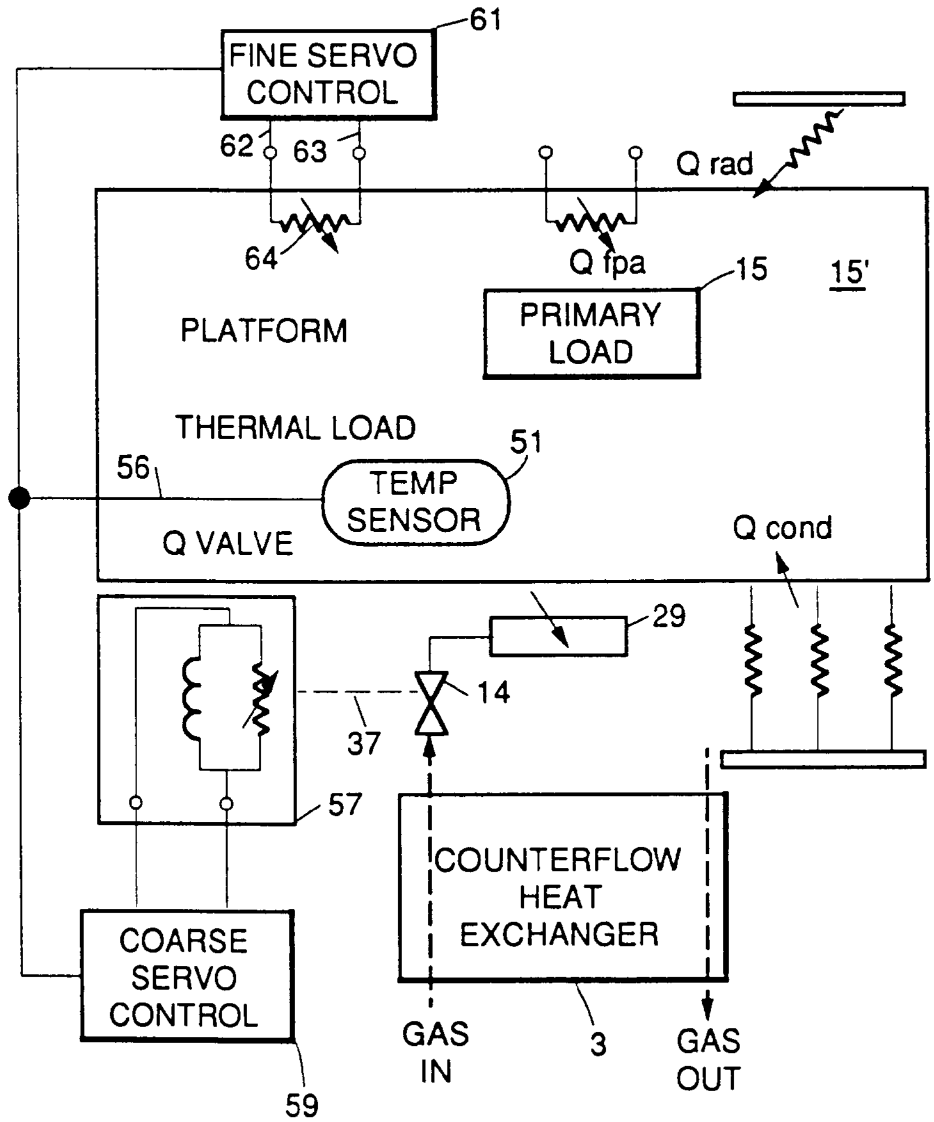

29
5
16
17
19

FIG.1b.

FIG. 5.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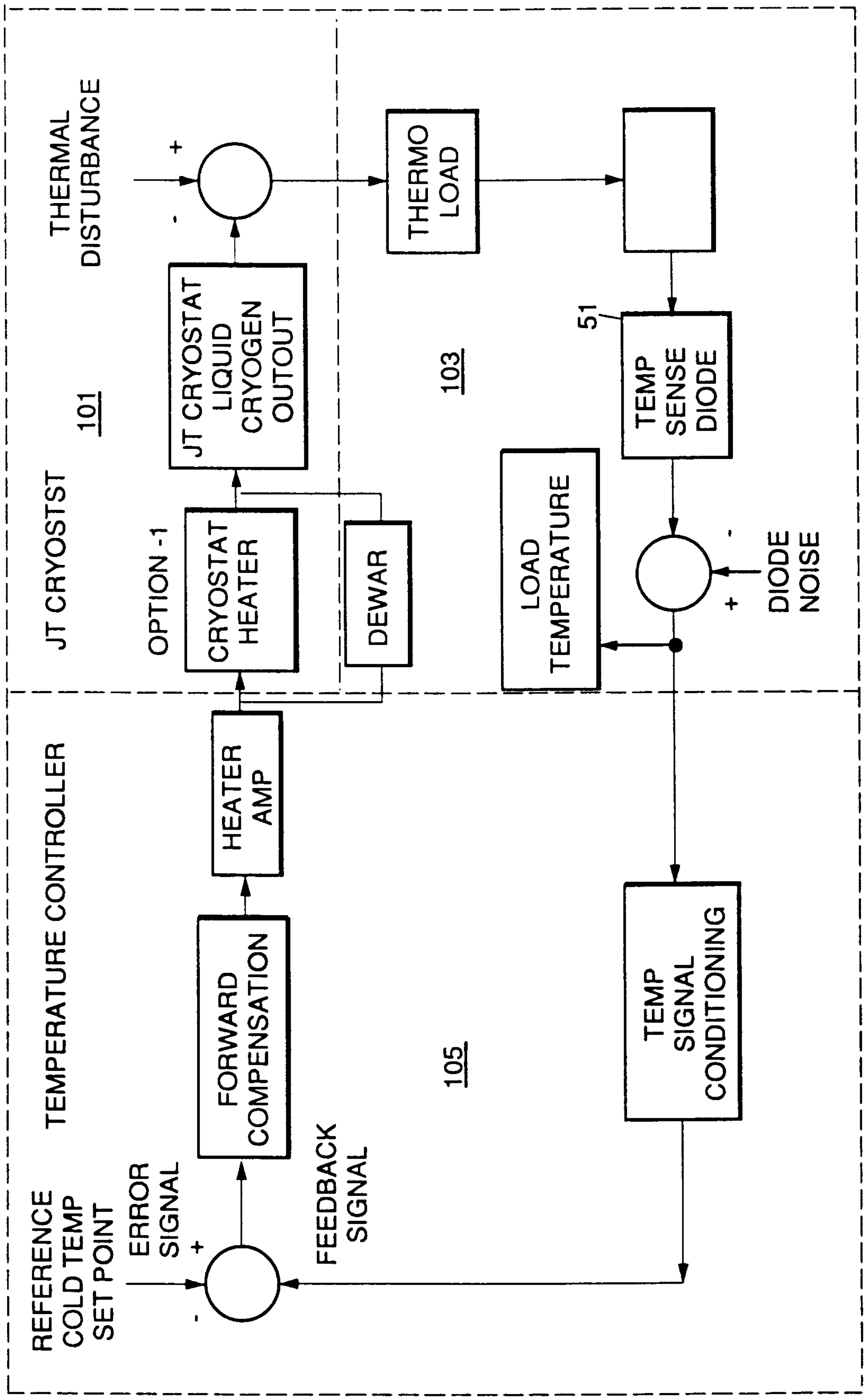
Q rad
64
Q fpa
15
15'
PLATFORM
PRIMARY LOAD
THERMAL LOAD
51
56
TEMP SENSOR
Q VALVE
Q cond
29
14
37
57
COUNTERFLOW HEAT EXCHANGER
COARSE SERVO CONTROL
GAS IN
3
GAS OUT
59

FIG. 6.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REFERENCE COLD TEMP SET POINT
ERROR SIGNAL
+
-
FEEDBACK SIGNAL
FORWARD COMPENSATION
HEATER AMP
TEMP SIGNAL CONDITIONING
JT CRYOSTST
101
OPTION -1
CRYOSTAT HEATER
DEWAR
JT CRYOSTAT LIQUID CRYOGEN OUTOUT
THERMAL DISTURBANCE
+
-
THERMO LOAD
103
51
TEMP SENSE DIODE
LOAD TEMPERATURE
DIODE NOISE
+
-