March 30, 1965 H. A. DINTER, JR 3,175,762

CENTRIFUGE

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FIG 1

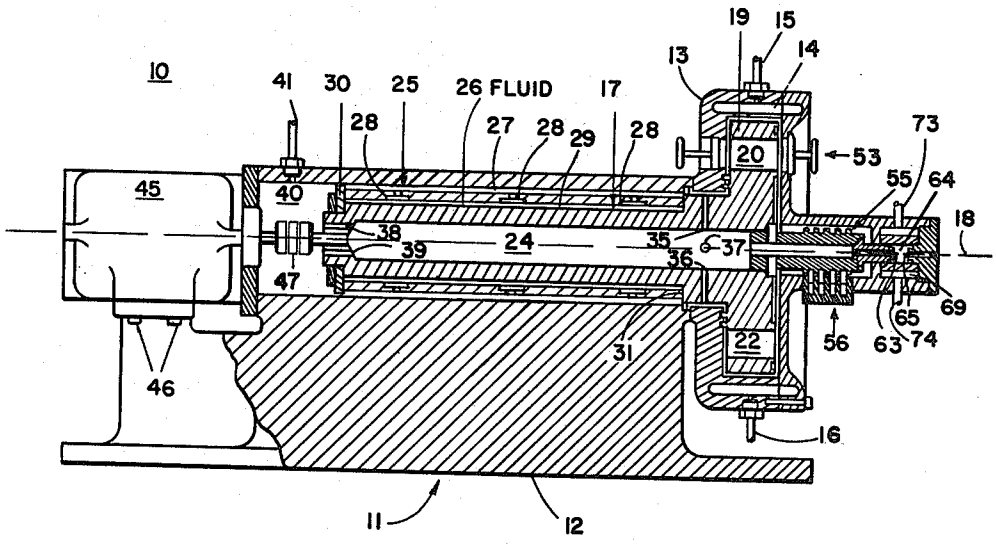
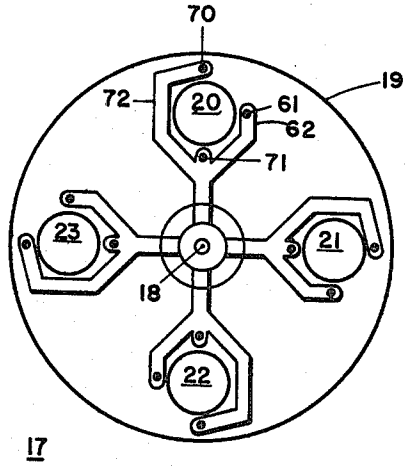


FIG. 2



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FIG. 3

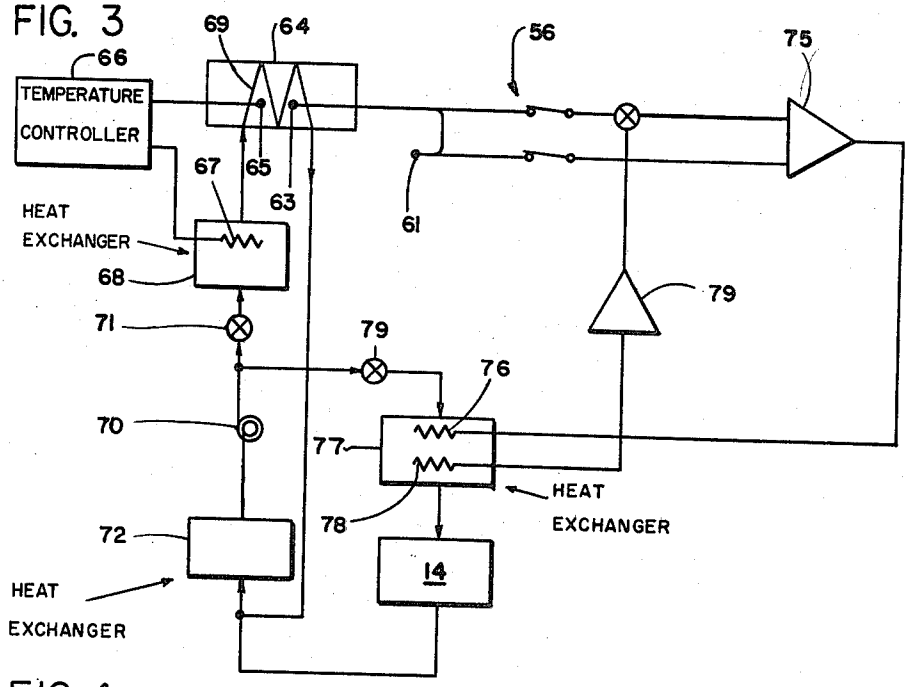
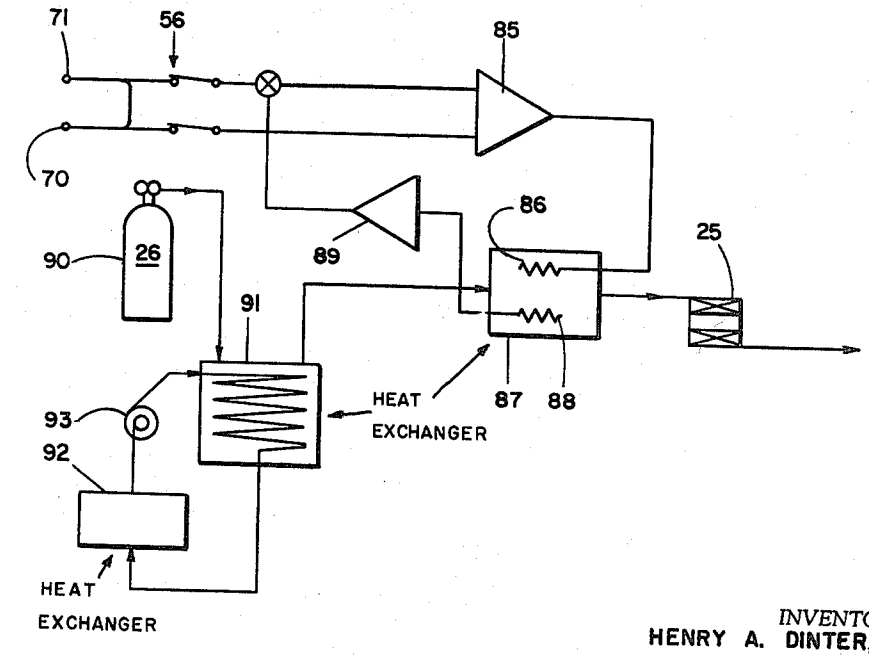


FIG 4



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CENTRIFUGE

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3 Claims. (Cl. 233—11)

This invention pertains to control apparatus and more particularly to that type of control apparatus generally referred to as a centrifuge.

The applicant's unique centrifuge has special application to the field of biological research, although it is not limited to this type of application. The applicant's unique centrifuge provides fluid bearing support of the rotatable element and precise temperature control of the specimen cavities therein. The applicant has provided a temperature control means in which the average temperature of the specimen cavity is controlled to a precise temperature and the temperature gradient across the specimen cavity is substantially eliminated.

It is therefore an object of this invention to provide an improved control apparatus.

This and other objects of the invention will become apparent from a study of the accompanying specification and claims in conjunction with the drawings in which:

FIGURE 1 is a schematic elevation view partially in cross section of the applicant's centrifuge;

FIGURE 2 is a schematic end view of the rotatable element of the applicant's centrifuge;

FIGURE 3 is a schematic diagram of the average temperature control system of the applicant's centrifuge; and

FIGURE 4 is a schematic diagram of the temperature gradient control system of the applicant's centrifuge.

Referring now to FIGURE 1, reference numeral 10 generally depicts the applicant's unique centrifuge. A housing means is identified by reference numeral 11. Housing means 11 consists of a base portion 12 and a temperature lag portion 13. Base portion 12 may be fabricated of stabilized cast steel or other suitable material. Temperature lag portion 13 is fabricated out of copper in the embodiment illustrated because of its superior heat transfer characteristics. Temperature lag portion 13 contains an annular fluid cavity 14 therein. An input connector 15 connects cavity 14 to a heat exchange fluid source (not shown). An output connector 16 connects cavity 14 to a heat exchanger and to a fluid pump (not shown).

A rotatable element or shaft means 17 is mounted upon housing means 11 so as to rotate about an axis 18. Rotatable element 17 has an enlarged radius section 19 thereon. Enlarged radius section 19 contains four specimen cavities therein symmetrically located about axis 18. The cavities are identified by reference numerals 20, 21, 22 and 23 and are illustrated in FIGURE 2. It should be pointed out that the applicant does not wish to be limited to any specific number of cavities; a single cavity or a plurality of cavities may be utilized. It should also be pointed out that although rotatable means 17 is fabricated from a single bar of stainless steel, in the embodiment illustrated, it is possible to construct the rotatable means 17 out of two or more component parts. A cylindrical central chamber 24 is located within rotatable element 17 concentric with axis 18 and having an axial extent substantially equal to the axial extent of rotatable element 17. An instrumentation spindle 55 is attached to the end of rotatable element 17 contiguous enlarged radius section

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19. Spindle 55 provides a mounting means for certain elements of the temperature control means to be explained hereinafter.

The rotatable element 17 is mounted upon housing 11 by means of a fluid, gas or hydrostatic bearing means 25. A fluid 26 which supports the rotatable element 17 is introduced from a suitable source (not shown) into an annular distribution manifold 27. Fluid 26 flows from manifold 27 through a plurality of radial orifices to a plurality of pressure pads 28. Fluid 26 flows into a radial bearing clearance 29 from the pressure pads so as to provide radial support of the rotatable element 17. Thrust support is provided for rotatable element 17 as fluid 26 leaves clearance 29 past an end restrictor 30 and an end restrictor 31 upon rotatable element 17. Fluid 26 flows from clearance 29 through a plurality of radial orifices 35, 36 and 37 into central chamber 24 of rotatable element 17. Fluid 26 flows through central chamber 24 from right to left as viewed in FIGURE 1, and exhausts from chamber 24 through a plurality of axial orifices 38 and 39. A chamber 40 is provided between the end of rotatable element 17 and housing means 11. Fluid 26 flows from chamber 24 into chamber 40 through orifices 38 and 39. A portion of fluid 26 flows from clearance 29 past end restriction 30 into chamber 40. Fluid 26 exhausts from chamber 40 through an outlet connector 41.

A drive motor 45 is provided to rotate the rotatable element 17. Drive motor 45 may be of any suitable hysteresis synchronous motor type designed to operate at a particular angular velocity. It is possible to utilize a drive motor designed to operate at a plurality of definite angular velocities. Drive motor 45 is attached to housing means 11 by means of bolts 46 and is coupled to rotatable element 12 by means of a flexible coupling 47.

Means are provided, as at 53, to utilize an optical pickoff arrangement. Although the optical pickoff means forms no part of the present invention it should be noted that the overall design of the applicant's unique centrifuge provides an optical path which is unimpeded by any parts of the centrifuge.

Referring now to FIGURE 2 a thermocouple 61 is imbedded in enlarged radius section 19 of rotatable element 17 adjacent to cavity 20. Thermocouple 61 monitors the average temperature of cavity 20 in one embodiment of the applicant's invention. Leads from thermocouple 61 (not shown) are positioned within a lead path 62 and connect thermocouple 61 in opposed series relationship with a thermocouple 63 mounted upon rotatable element 17 contiguous with axis 18. Thermocouple 61 and thermocouple 63 form a differential thermocouple. Thermocouple 63 is rigidly attached to and rotates with rotatable element 17. Thermocouple 63 is positioned within a chamber 64 within temperature lag portion 13 of housing means 11. Chamber 64 is heated or cooled by a heat exchange fluid flowing through a fluid cavity 69 within temperature lag portion 13 of housing 11 and contiguous chamber 64. The heat exchange fluid enters cavity 69 by means of a connector 73 and exhausts from cavity 69 by means of a connector 74. A thermocouple 65 is mounted upon temperature lag portion 13 of housing 11 and within chamber 64 adjacent to thermocouple 63. Thus thermocouple 63 and thermocouple 65 sense the same temperature.

A temperature controller 66 utilizes the output voltage from the differential thermocouples 61, 63, to control the

temperature of a heat exchange fluid which controls the temperature of chamber 64. The temperature of chamber 64 is set at a desired temperature. This temperature is monitored by thermocouple 65 and controlled by the temperature controller 66 and a heat exchange fluid. A difference in temperature between thermocouple 63 (which is at the same temperature as thermocouple 65) and thermocouple 61 results in an output voltage which is indicative of the temperature differential between cavity 20 and chamber 64. The output voltage of differential thermocouple 61, 63 is utilized to control the temperature of a heat exchange fluid which is introduced into cavity 14 within housing 11 so as to maintain the average temperature of cavity 20 at the particular value desired. By so controlling the average temperature of cavity 20, the average temperature of cavities 21, 22 and 23 is also controlled. Because of the symmetrical construction of centrifuge 10, each cavity will have the same average temperature as cavity 20.

It is also possible to utilize a separate thermocouple for each cavity. In this embodiment, the thermocouples would be connected in a series relationship. This results in an output signal of a higher magnitude than is obtained when utilizing a single thermocouple. The thermocouples of controlling the average temperature of cavities 21, 22 and 23 will be identical to thermocouple 61. Consequently no further discussion of this alternate embodiment is deemed necessary.

A thermocouple 70 is imbedded near the periphery of enlarged radius section 19 of rotatable element 17 and adjacent to cavity 20. A thermocouple 71 is imbedded within enlarged radius section 19 of rotatable element 17 adjacent to cavity 20 but displaced radially inward from thermocouple 70. As illustrated in FIGURE 2, thermocouples 70 and 71 are disposed on opposite sides of cavity 20. Thermocouple 70 and thermocouple 71 are connected in opposed series relationship so as to form a differential thermocouple. The leads (not shown) of thermocouple 70 and thermocouple 71 are positioned within a lead path 72 to conduct the output voltage to spindle 55. The output voltage from differential thermocouple 70, 71 is indicative of the temperature difference or temperature gradient across cavity 20. The output voltage of differential thermocouple 70, 71 is utilized to conduct the output voltage to spindle 55. The output voltage from differential thermocouple 70, 71 is utilized to control the temperature of fluid 26 of fluid bearing means 25. A change in temperature of fluid 26 results in a change in temperature of that portion of rotatable element 17 in contact with fluid 26. This change in temperature is conducted radially outward through enlarged radius section 19 of rotatable element 17 so as to substantially eliminate any temperature gradient existing across cavity 20. By so controlling the temperature gradient across cavity 20, the temperature gradient across cavities 21, 22 and 23 is also controlled. Because of the symmetrical construction of centrifuge 10, each cavity will be controlled the same as cavity 20.

It is also possible to utilize a separate set of thermocouples for each cavity. In this embodiment, each set of thermocouples would be connected in a series relationship. This results in an output signal of a higher magnitude than is obtained when utilizing a single set of thermocouples. The thermocouples for controlling the temperature gradient across cavities 21, 22 and 23 will be identical to the thermocouples 61, 63. Consequently, no further discussion of this alternate embodiment is deemed necessary,

A plurality of slip rings 56 are provided between spindle 55 and housing 11 so that the output voltage of differential thermocouple 61, 63 and differential thermocouple 70, 71 may be conducted from rotatable element 17 to the stationary housing 11.

The operation of the temperature control means of the applicant's centrifuge can best be explained with reference to FIGURES 3 and 4. FIGURE 3 is a schematic diagram of the means for controlling the average temperature of cavities 20, 21, 22 and 23. The temperature in chamber 64 is monitored by thermocouple 65. The output voltage of thermocouple 65 is connected to a temperature controller 66 which in turn functions to control the energization of a heater 67 of a heat exchanger 68. A heat exchange fluid is pumped by means of a pump 70 through a valve 71 into heat exchanger 68. When a sufficient amount of heat has been added to the heat exchange fluid it is pumped to a cavity surrounding chamber 64 to control the temperature thereof. The heat exchange fluid leaves chamber 64 and is conducted through a refrigeration unit or heat exchanger 72. The heat exchange fluid is connected from fluid heat exchanger 72 to the pump means 70 to complete a first fluid loop.

As pointed out previously, the average temperature of cavity 20 is sensed by thermocouple 61 which is differentially connected to thermocouple 63. The average temperature desired for cavity 20 is the temperature at which chamber 64 is maintained. Thermocouple 65 and thermocouple 63 are positioned adjacent to one another within chamber 64 and sense the same temperature. Consequently, should thermocouple 61 sense a different temperature than thermocouple 63 an output voltage is generated which is indicative of the difference in temperature between thermocouple 61 and thermocouple 63. Stated otherwise, the output voltage is indicative of the temperature differential between cavity 20 and chamber 64. The output voltage from differential thermocouple 61, 63 is conducted through slip ring means 56 to an amplifier means 75. The output of amplifier means 75 is utilized to control a heater element 76 within a heat exchanger 77. A feedback sensor 78 is also positioned within heat exchanger 77. The output of feedback sensor 78 is connected to an amplifier 79. The output of amplifier 79 is connected to the input of amplifier 75 so as to complete the servo loop.

Heat exchange fluid is also directed from pump 70 through a valve 79 and into heat exchanger 77 where a certain amount of heat is added to the fluid by means of energization of heater element 76. Heater 76 is controlled by the output voltage of differential thermocouple means 61, 63. Heat exchange fluid flows from heat exchanger 77 to annular chamber 14 in temperature lag portion 13 of housing 11. The fluid flows from annular chamber 14 back to heat exchanger 72 where it is cooled and then back to pump 70 to complete a second fluid loop.

In summary, chamber 64 is set at a desired temperature and maintained at this temperature by means of a heat exchange fluid. A difference between the average temperature of cavity 20 and the temperature of chamber 64 results in an output voltage from differential thermocouple 61, 63 which is utilized to control the temperature of a heat exchange fluid so as to drive the average temperature of cavity 20 to the desired temperature (the temperature of chamber 64).

The means controlling the temperature gradient of cavities 20–23 is illustrated in FIGURE 4. As hereinbefore discussed, thermocouple 70 and thermocouple 71 are connected to form a differential thermocouple. The output voltage generated by differential thermocouple 70, 71 is indicative of a temperature differential therebetween. The output signal of differential thermocouple 70, 71 is conducted through slip ring means 56 to the input of an amplifier means 85. The output of amplifier means 85 controls the energization of a heater means 86 of a heater exchanger 87. A feedback sensor 88 is also contained within heat exchanger 87. The output of feedback sensor 88 is connected to the input of an amplifier means 89. The output of amplifier means 89 is connected back to the input of amplifier means 85 so as to complete the servo loop.

A supply 90 of fluid 26, for example, hydrogen, for

fluid bearing means 25 is provided at the required pressure. Fluid 26 is supplied to a heat exchanger 91 where it is cooled somewhat below the desired temperature. The fluid 26 is cooled by means of a heat exchanger or refrigeration unit 92 which circulates a coolant through heat exchanger 91 by means of a pump 93. A temperature control thermostat and related items for heat exchanger 91 are not illustrated in FIGURE 4. The fluid 26 is conducted from heat exchanger 91 in a cool state and is conducted to a heat exchanger 87. If a temperature differential exists between differential thermocouple 70, 71 the output voltage therefrom will be utilized to energize heater 86 so as to heat fluid 26 to the correct temperature. Fluid 26 is conducted from heat exchanger 87 to bearing means 25, circulates therethrough, and is expelled out of outlet connector 41. It should be noted that the fluid 26 is cooled sufficiently to counteract the heat added to rotatable element 17 due to the viscous shear of the fluid 26.

Thus the applicant has provided a unique centrifuge in which the rotatable element is supported by means of a fluid bearing in which he provides temperature control means to control the average temperature of the specimen cavity and the temperature gradient across the specimen cavity. The temperature gradient is substantially eliminated by utilizing the fluid of the fluid bearing means.

While I have shown and described a specific embodiment of this invention, further modifications and improvements will occur to those skilled in the art. I desire it to be understood, therefore, that this invention is not limited to the particular form shown and I intend in the appended claims to cover all modifications which do not depart from the spirit and scope of this invention.

I claim:

1. An apparatus of the class described: housing means; a shaft element having an enlarged radius section thereon, said shaft element being positioned within said housing means; hydrostatic bearing means rotatably supporting said shaft element for rotation about an axis, said hydrostatic bearing means utilizing a first fluid; means for rotating said shaft about said axis; said housing means having an annular cavity therein surrounding said enlarged radius section of said shaft element; said housing means having a chamber therein contiguous one end of said shaft element; said enlarged radius section having a specimen cavity therein; means for controlilng the average temperature of said specimen cavity including a first thermocouple positioned contiguous said specimen cavity and a second thermocouple positioned upon said shaft and within said chamber, said first thermocouple being connected to said second thermocouple so as to provide a first output signal indicative of the temperature differential between said specimen cavity and said chamber; said means for controlling the average temperature further including means responsive to said first output signal for controlling the temperature of a second fluid adapted to flow through said annular cavity within said housing means, a change in temperature of said second fluid being effective to change the average temperature of said specimen cavity; means for controlling the temperature gradient across said specimen cavity including a third thermocouple and a fourth thermocouple positioned contiguous to and on opposite sides of said specimen cavity, said third thermocouple being connected to said fourth thermocouple so as to provide a second output signal indicative of the temperature gradient across said specimen cavity; and said means for controlling the temperature gradient further including means responsive to said second output signal for controlling the temperature of said first fluid to said hydrostatic bearing means, a change in the temperature of said first fluid being effective to reduce the temperature gradient across said specimen cavity.

2. An apparatus of the class described: housing means; a shaft element having a first section thereon, said shaft element being positioned within said housing means; hydrostatic bearing means rotatably supporting said shaft element for rotation about an axis, said hydrostatic bearing means utilizing a first fluid; means for rotating said shaft about said axis; said housing means having an annular cavity therein surrounding said first section of said shaft element; said housing means having a chamber therein; said first section having a specimen cavity therein; means for controlling the average temperature of said specimen cavity including a first sensor means positioned contiguous said specimen cavity and a second sensor means positioned upon said shaft and within said chamber, said first sensor means being connected to said second sensor means so as to provide a first output signal indicative of the temperature differential between said specimen cavity and said chamber; said means for controlling the average temperature further including means responsive to said first output signal for controlling the temperature of a second fluid adapted to flow through said anunular cavity within said housing means, the temperature of said second fluid being effective to control the average temperature of said specimen cavity; means for controlling the temperature gradient across said specimen cavity including a third sensor means and a fourth sensor means positioned contiguous to and on opposite sides of said specimen cavity, said third sensor means being connected to said fourth sensor means so as to provide a second output signal indicative of the temperature gradient across said specimen cavity; and said means for controlling the temperature gradient further including means responsive to said second output signal for controlling the temperature of said first fluid to said hydrostatic bearing means; the temperature of said first fluid being effective to control the temperature gradient across said specimen cavity.

3. An apparatus of the class described: housing means; a shaft element having a first section thereon, said shaft element being positioned within said housing means; hydrostatic bearing means supporting said shaft element for rotation about an axis, said hydrostatic bearing means utilizing a first fluid; means for rotating said shaft about said axis; said housing means having an annular cavity therein surrounding said first section of said shaft element; said housing means having a chamber therein; said first section having a specimen cavity therein; means for controlling the average temperature of said specimen cavity including a first sensor means positioned contiguous said specimen cavity and a second sensor means positioned upon said shaft and within said chamber, said first sensor means being connected to said second sensor means so as to provide a first output signal indicative of the temperature differential between said specimen cavity and said chamber; said means for controlling the average temperature further including means responsive to said first output signal for controlling the temperature of a second fluid adapted to flow through said annular cavity within said housing means so as to control the average temperature of said specimen cavity; means for controlling the temperature gradient across said specimen cavity including a third sensor means and a fourth sensor means positioned contiguous to and on opposite sides of said specimen cavity, said third sensor means being connected to said fourth sensor means so as to provide a second output signal indicative of the temperature gradient across said specimen cavity; and said means for controlling the temperature gradient further including means responsive to said second output signal for controlling the temperature of said first fluid to said hydrostatic bearing so as to reduce the temperature gradient across said specimen cavity.

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