May 9, 1961 R. G. MINER ET AL 2,983,111

REFRIGERATION MACHINE AND METHOD OF CONTROLLING SAME

Filed Nov. 17, 1958 2 Sheets-Sheet 1

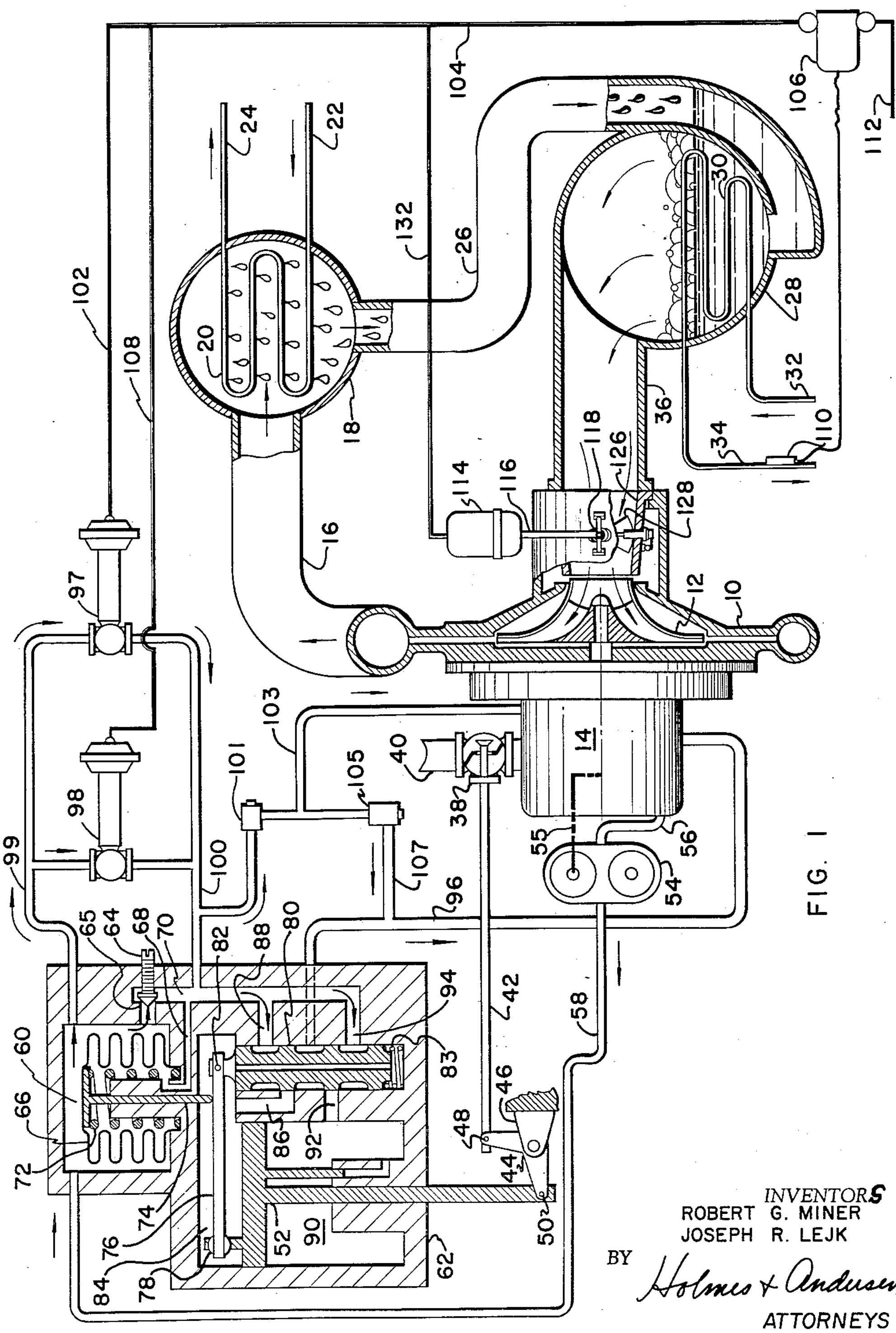

FIG. 1

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REFRIGERATION MACHINE AND METHOD OF CONTROLLING SAME

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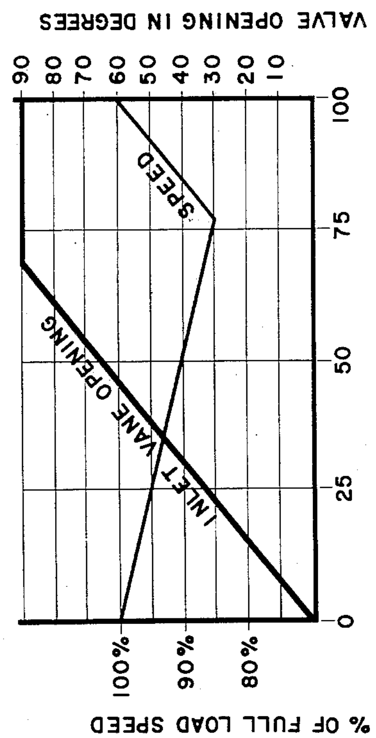

FIG. 3

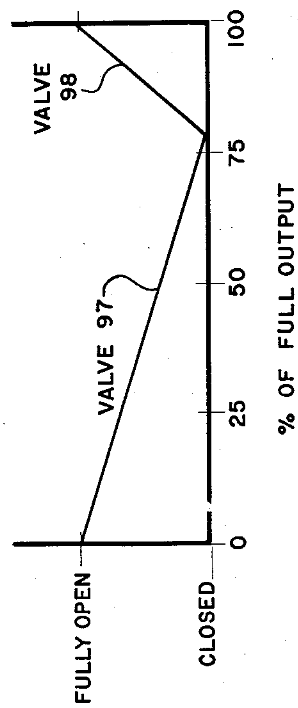

FIG. 4

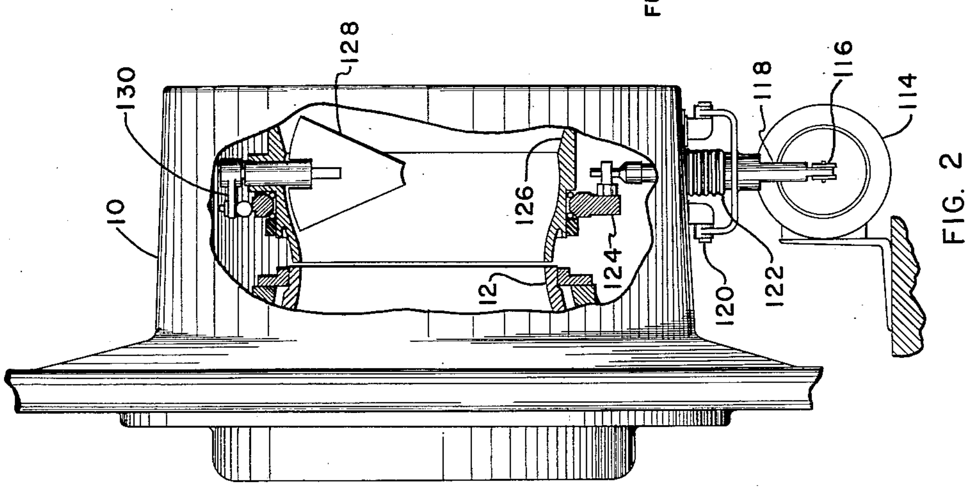

FIG. 2

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REFRIGERATION MACHINE AND METHOD OF CONTROLLING SAME

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This invention relates to a refrigeration machine having a turbine driven centrifugal compressor and to a method of controlling such machine.

With refrigeration machines of this type, it is important to be able to vary the output from full capacity to a small percentage of full capacity with good efficiency over the range and without developing in the compressor a condition of surge. Surge is an unstable condition during which the gas periodically flows through the compressor in a direction from the discharge to the suction.

It is an object of this invention to provide a control for turbine driven centrifugal compressors which will economize on the use of the steam or other motive fluid.

It is another object of the invention to provide a control which reduces the output of the compressor from full output by first reducing the speed, secondly, further reducing the output by closing the prerotation inlet guide vanes while simultaneously increasing the speed.

It is another object of the invention to provide a method of controlling a refrigeration machine to conserve the use of motive fluid and to avoid surging conditions.

Other objects and advantages of the invention will appear as the specification proceeds to describe the invention with reference to the accompanying drawings in which:

Fig. 1 is a diagrammatic view of the refrigeration machine and control system of this invention;

Fig. 2 is a partial view of the compressor partly in section on an axial plane;

Fig. 3 is a diagram showing the cycle of operation of the governor and the inlet vanes; and

Fig. 4 is a diagram showing the cycle of operation of the valves which determine the speed at which the governor controls.

Referring now to Fig. 1, a compressor **10** has an impeller **12** which is driven by a turbine **14**. The compressor **10** discharges refrigerant gas under pressure to a conduit **16** through which the gas flows into a condenser **18**. The condenser **18** has a coil **20** which receives water or other cooling fluid from a source **22**. The cooling water is discharged from the coil **20** through a conduit **24**. The condensed refrigerant flows from the condenser **18** through a conduit **26** to an evaporator **28** which is preferably of the shell and tube type in which a secondary refrigerant liquid such as chilled water or brine flows through the tubes **30**. The chilled water or brine from a refrigeration load flows to the evaporator **28** through conduit **32** and returns from the evaporator **28** to the refrigeration load through a conduit **34**. The refrigerant liquid in the evaporator **28** boils to form gas which passes through suction pipe **36** to the compressor **12**.

Steam or other motive fluid flows to the turbine **14** through a valve **38** from a source **40**. A rod **42** actuates the valve **38**. The rod **42** moves to the right as viewed in Fig. 1 to open the valve **38**. A bell crank **44** is pivotally mounted on a fixed abutment **46** and has one arm pivotally secured at **48** to rod **42** and the other arm pivotally secured at **50** to the piston **52**.

An oil pump **54** is driven by the shaft of the turbine **14** as indicated by line **55** and receives oil through conduit **56**. The pump **54** discharges the oil under pressure to conduit **58** which conducts the oil to the bellows chamber **60** of the governor **62**. A valve member **64** is in threaded engagement with the body of the governor **62** and is adjustable to determine the flow of oil from the bellows chamber **60** through orifice **65**. A bellows **66** is mounted in the bellows chamber **60** and has its interior connected by passageway **68** to the passageway **70** downstream from the orifice **65**. A spring **72** opposes the force of the oil pressure on the outside of the bellows **66**. A stem **74** is secured to the bellows **66** and acts upon a lever **76** pivoted at **78** on the piston **52**. A pilot valve **80** is pivotally secured to lever **76** at **82**. A spring **83** acts to raise pilot valve **80**. Movement of the valve **80** to one position connects fluid pressure to the chamber **84** through passageways **86**, **88**, and **70**. Movement of valve **80** to another position connects fluid pressure to the chamber **90** through passageways **92**, **94**, and **70**. Fluid from chambers **84** and **90** exhausts through conduit **96** under the control of the valve **80**. It is thus seen that the pressure drop across the orifice **65** determines the amount that the bellows **66** is compressed, that the extent of the bellows **66** determines the position of the valve **80** and that the valve **80** determins the position of the piston **52**. Upward movement of piston **52** opens steam valve **38** and downward movement closes steam valve **38**. Should the speed rise, the pressure drop across the orifice **65** is increased and the bellows **66** lowers, forcing the valve **80** down admitting oil to the top of the piston **52**, which forces it downward to reduce the opening of valve **38**. Reduction of opening of valve **38** brings the speed back to the control point. The reverse action would occur if the speed tended to decrease below the control point.

If the valve member **64** is adjusted to reduce the opening of orifice **65**, the pressure drop across orifice **65** would be increased forcing the bellows **66** downward until equilibrium is restored at a new lower speed.

In order to control the speed of operation of the turbine **14**, pneumatically controlled valves **97** and **98** are connected to receive fluid from bellows chamber **60** through conduit **99**. Fluid from valves **97** and **98** flows through conduit **100** to passageway **70** and to pressure relief valve **101** which may be set to regulate the pressure at about 45 pounds per sq. in.

From the pressure relief valve **101**, the fluid passes through a conduit **103** to the bearings of the turbine **14** and to a pressure relief valve **105** which is set to regulate the pressure in conduit **103** at about 15 pounds per sq. in. From pressure relief valve **105**, the fluid flows through conduit **107** to conduit **96** which conducts the fluid back to the turbine **14**.

Valve **97** is connected by conduits **102** and **104** to a pneumatic thermostat **106**. Valve **98** is connected by conduits **108** and **104** to pneumatic thermostat **106**. Pneumatic thermostat **106** has a bulb **110** in temperature sensing relationship with conduit **34** which conducts chilled water from the evaporator **28** to the refrigeration load. It should be understood that the temperature of the leaving chilled water is close to the temperature of the evaporator and that the bulb **110** could be mounted in the evaporator, if desired, so that it is responsive to evaporator temperature. The pneumatic thermostat is connected to a source of compressed air **112**.

A fluid cylinder **114** has a piston rod **116** which is pivotally connected to a lever **118**. As shown in Fig. 2, lever **118** is pivoted to the compressor casing at **120**. Lever **118** extends into the compressor casing and a bellows **122** provides a flexible seal between the casing and the lever **118**. The inner end of lever **118** is pivotally mounted on a ring **124** which is rotatably mounted on inlet 126. A plurality of radially arranged prerotation inlet guide vanes 128 are pivotally mounted in inlet 126. Each guide vane 128 has a crank 130 secured thereto. Cranks 130 are pivotally secured to ring 124 so that rotation of ring 124 rotates all of the vanes 128 in unison. The vanes 128 are adjustable to positions in which they are at right angles to the path of flow and substantially prevent flow of gas thus reducing the capacity of the machine to substantially zero. The prerotation guide vanes 128 may be adjusted to angles such that they guide the refrigerant gas partially in the direction of flow into the impeller, thus causing the machine to operate at some capacity less than full capacity. The vanes 128 may be adjusted to positions in which they are substantially in planes radial to the axis of the inlet so that there is substantially no prerotation of the gas. Under this condition, the machine operates at substantially full capacity. It is thus seen that the vanes 128 operate to provide variable throttling means in the suction passageway to the compressor impeller 12. Fluid cylinder 114 receives fluid pressure from thermostat 106 through conduits 132 and 104.

The method of operation of the device will now be described. Let us assume that the machine is operating at full capacity and the temperature of the chilled water in conduit 34 falls slightly indicating that less capacity is required. Bulb 110 senses this drop in temperature and causes thermostat 106 to transmit a lower pressure through conduit 104, and normally closed valve 98 gradually closes because the pressure in conduit 108 is always the same as that in conduit 104. The reduced flow of fluid from bellows chamber 60 through conduit 99 and valve 98 increases the pressure in bellows chamber 60 and consequently bellows 66 is compressed against the force of spring 72. Stem 74, lever 76 and valve 80 are therefore lowered. When valve 80 moves downwardly, more fluid is admitted above the piston 52 and more fluid is exhausted from below the piston 52. Consequently, piston 52 moves downwardly and through bell crank 44 and rod 42 moves steam valve 38 toward closed position. Movement of steam valve 38 toward closed position reduces the speed of the turbine and consequently the output of the compressor is reduced.

At full load, the pressure in conduit 104 from thermostat is about 18 pounds. Valve 98 reaches fully closed position at about 13 pounds and the output of the compressor is slightly greater than 75% of full output.

A further drop in temperature of the water in conduit 34 indicates that a further reduction in capacity is required and thermostat 106 reduces the pressure in conduit 104 below 13 pounds. As the pressure in conduit 104 falls below 13 pounds, fluid cylinder 114 gradually closes the inlet vanes 126 to reduce the output of the compressor, and normally open valve 97 gradually opens to increase the speed of the compressor. When the fluid pressure from thermostat 106 drops to three pounds, the vanes 126 are fully closed and the valve 97 is fully open with the result that the turbine is operating at full speed. When the pressure from thermostat 106 tends to drop below three pounds indicating that refrigeration is not required, mechanism (not shown) shuts down the machine.

Although we have described specifically a preferred embodiment of our invention, we contemplate that changes may be made without departing from the scope or spirit of our invention and we desire to be limited only by the claims.

We claim:

1. A control system for a refrigeration machine having a centrifugal compressor, a condenser connected to receive compressed refrigerant from said compressor, an evaporator for removing heat from a heat exchange fluid, said evaporator being connected to said condenser to receive condensed refrigerant from said condenser, conduit for conducting refrigerant from said evaporator to said compressor, means for throttling the flow of refrigerant to said compressor, a turbine connected to drive said compressor, a governor for controlling the speed of said turbine, means responsive to the temperature of the heat exchange fluid of said evaporator for adjusting said governor to control the turbine at a different speed and means responsive to the temperature of the heat exchange fluid of said evaporator for varying the effectiveness of said throttling means to vary the output of the compressor.

2. A control system for a refrigeration machine having a centrifugal compressor, a condenser connected to reecive compressed refrigerant from said compressor, an evaporator for removing heat from a heat exchange fluid, said evaporator being connected to said condenser to receive condensed refrigerant from said condenser, conduit for conducting refrigerant from said evaporator to said compressor, prerotation angularly adjustable guide vanes in said conduit adjacent said compressor, a turbine connected to drive said compressor, a governor for controlling the speed of said turbine, means responsive to the temperature of the heat exchange fluid of said evaporator for adjusting said governor to control the turbine at a different speed and means responsive to the temperature of the heat exchange fluid of said evaporator for adjusting the inlet guide vanes to vary the output of the compressor.

3. In a refrigeration system, a centrifugal compressor, a condenser connected to said compressor to receive compressed refrigerant from said compressor, an evaporator connected to said condenser to receive condensed refrigerant from said condenser, means for conducting a heat exchange fluid to be cooled through said evaporator, conduit for conducting refrigerant from said evaporator to said compressor, prerotation angularly adjustable guide vanes mounted in said conduit adjacent said compressor, a turbine connected to drive said compressor, a valve for controlling the flow of driving fluid to said turbine, a governor responsive to the speed of said turbine to control the position of said valve to control the speed of said turbine, means responsive to the temperature of heat exchange fluid of said evaporator for adjusting said governor to vary the speed at which said governor controls the turbine, and means responsive to the temperature of the heat exchange fluid of said evaporator for angularly adjusting said angularly adjustable prerotation guide vanes to vary the output of the compressor.

4. In a refrigeration system, a centrifugal compressor, a condenser connected to said compressor to receive compressed refrigerant from said compressor, an evaporator connected to said condenser to receive condenser refrigerant from said condenser, means for conducting a heat exchange fluid to be cooled through said evaporator, conduit for conducting refrigerant from said evaporator to said compressor, prerotation angularly adjustable guide vanes mounted in said conduit adjacent said compressor, a turbine connected to drive said compressor, a valve for for controlling the flow of driving fluid to said turbine, a governor responsive to the speed of said turbine to control the position of said valve to control the speed of said turbine, fluid means responsive to the temperature of heat exchange fluid of said evaporator for adjusting said governor to vary the speed at which said governor controls the turbine, and fluid means responsive to the temperature of the heat exchange fluid of said evaporator for angularly adjusting said angularly adjustable prerotation guide vanes to vary the output of the compressor.

5. A method of controlling the output of a refrigeration machine having a turbine driven centrifugal compressor comprising reducing the speed of the compressor to reduce its output from substantially full output to a partial output and then further reducing the output of

the machine by throttling the flow of the refrigerant entering the impeller of the compressor while simultaneously increasing the speed of the compressor.

6. A method of controlling the output of a refrigeration machine having a turbine driven centrifugal compressor comprising reducing the speed of the compressor to reduce its output from substantially full output to a partial output and then further reducing the output of the machine by causing the refrigerant entering the compressor to prerotate in the direction of rotation of the compressor while simultaneously increasing the speed of the compressor.

7. A control system for a refrigeration machine having a centrifugal compressor, a condenser connected to receive compressed refrigerant from said compressor, an evaporator for removing heat from a fluid, said evaporator being connected to said condenser to receive condensed refrigerant from said condenser, conduit for conducting refrigerant from said evaporator to said compressor, a turbine connected to drive said compressor, a valve for controlling the flow of motive fluid to said turbine, a pump driven by said turbine for circulating hydraulic fluid, a hydraulic cylinder connected to receive hydraulic fluid from said pump, a piston operating in said cylinder and operatively connected to said valve, means responsive to the magnitude of the speed of rotation of said turbine for controlling the pressure of hydraulic fluid in said cylinder to position said piston in said cylinder and means responsive to the temperature of said evaporator for adjusting said last mentioned means to vary the position of said piston in said cylinder and thereby vary the position of said valve.

8. A control system for a refrigeration machine having a centrifugal compressor, a condenser connected to receive compressed refrigerant from said compressor, an evaporator for removing heat from a fluid, said evaporator being connected to said condenser to receive condensed refrigerant from said condenser, conduit for conducting refrigerant from said evaporator to said compressor, a turbine connected to drive said compressor, a valve for controlling the flow of motive fluid to said turbine, a pump driven by said turbine for circulating hydraulic fluid, a hydraulic cylinder connected to receive hydraulic fluid from said pump, a piston operating in said cylinder and operatively connected to said valve, means responsive to the pressure of hydraulic fluid delivered by said pump for controlling the pressure of hydraulic fluid in said cylinder to position said piston in said cylinder and means responsive to the temperature of said evaporator for adjusting said last mentioned means to vary the position of said piston in said cylinder and thereby vary the position of said valve.

9. A control system for a refrigeration machine having a centrifugal compressor, a condenser connected to receive compressed refrigerant from said compressor, an evaporator for removing heat from a heat exchange fluid, said evaporator being connected to said condenser to receive condensed refrigerant from said condenser, conduit for conducting refrigerant from said evaporator to said compressor, a turbine connected to drive said compressor, valve means for controlling the flow of motive fluid to said turbine, a lubricating system for said turbine, a pump driven by said turbine for circulating lubricant in said lubricating system, a hydraulic cylinder connected to receive lubricant from said pump, a piston operating in said cylinder and operatively connected to said valve, means responsive to the pressure of lubricant delivered by said pump for positioning said piston and means responsive to the temperature of said evaporator for adjusting said last mentioned means to vary the position of said piston and thereby vary the position of said valve.

10. The invention set forth in claim 9 including adjustable means for throttling the flow of refrigerant to said compressor and means responsive to the temperature of said evaporator for adjusting said throttling means to vary the effectiveness of said throttling means.

11. A control system for a refrigeration machine having a centrifugal compressor, a condenser connected to receive compressed refrigerant from said compressor, an evaporator for removing heat from a fluid, said evaporator being connected to said condenser to receive condensed refrigerant from said condenser, conduit for conducting refrigerant from said evaporator to said compressor, adjustable means for throttling the flow of refrigerant to said compressor, a turbine connected to drive said compressor, a valve for controlling the flow of motive fluid to said turbine, a pump driven by said turbine for circulating hydraulic fluid, a hydraulic cylinder connected to receive hydraulic fluid from said pump, a piston operating in said cylinder and operatively connected to said valve, means responsive to the pressure of hydraulic fluid delivered by said pump for controlling the pressure of hydraulic fluid in said cylinder to position said piston in said cylinder, means responsive to the temperature of said evaporator for adjusting said last mentioned means to vary the position of said piston in said cylinder and thereby vary the position of said valve and means responsive to the temperature of said evaporator for adjusting said throttling means to vary the effectiveness of said throttling means.

References Cited in the file of this patent

UNITED STATES PATENTS

1,268,079	Banner	June 4, 1918
2,817,213	Miner	Dec. 24, 1957