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(54) **SYSTEM AND METHOD FOR MAP-INTERPOLATION BASED CONTROL OF EJECTORS IN AN EJECTOR REFRIGERATION CIRCUIT**

(57) A system (101) for map-interpolation based control of ejectors (101) in an ejector refrigeration circuit includes a controller (104) coupled to each of the ejectors and adapted to generate maps (200, 200A, 200B, 200C) based on predefined conditions. The controller identifies a first map (200A) associated with a first temperature of a heat rejecting heat exchanger (105) and a second map (200B) associated with a second temperature of the heat rejecting heat exchanger. The controller predicts an opening percentage of the first ejector from at least one of opening percentages indicated in the first map and opening percentages indicated in the second map. Finally, the controller adjusts the opening percentage of the first ejector based on the predicted opening percentage.

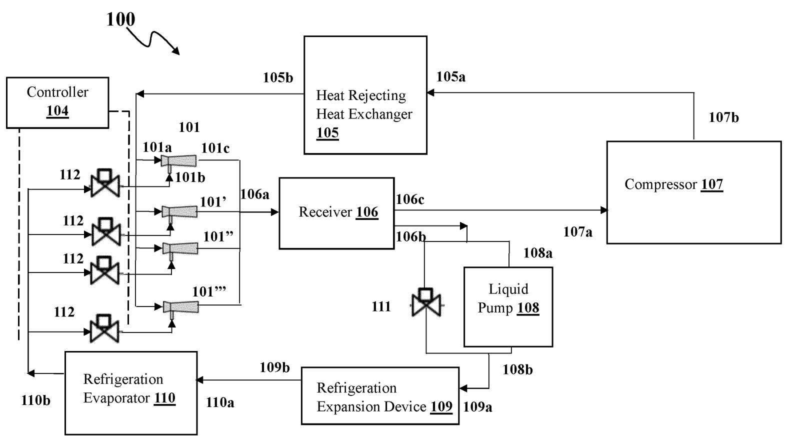

FIG. 1A

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Description

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 63/591,576 filed on October 19, 2023, which is incorporated by reference herein in its entirety.

FIELD OF THE INVENTION

[0002] The invention generally relates to ejector refrigeration circuits. More particularly, the invention relates to a system for controlling a plurality of ejectors in an ejector refrigeration circuit.

BACKGROUND

[0003] Ejectors are sometimes used to improve overall efficiency of commercial refrigeration systems. The ejectors improve efficiency in the refrigeration system by utilizing a high pressure to help compress a low pressure gas, instead of relying solely on a compressor.

[0004] Typically, the ejectors may be located between an outlet of a heat rejecting heat exchanger and an inlet of a receiver tank. The ejectors include a primary high pressure inlet, a secondary low pressure inlet, and an outlet. When an ejector is used as part of the refrigeration system, the cooled refrigerant from the heat rejecting heat exchanger enters each of the ejectors at the high pressure inlet and is expanded to a lower pressure at the outlet of each of the ejectors. At the outlet of the ejectors, the refrigerant flow will typically be both liquid and gaseous phase. The gaseous phase will be fed back to a compressor, while the liquid phase is fed through another expansion valve and then the evaporator. The fluid that leaves the evaporator then flows to the low pressure inlet of the ejector. The inclusion of the ejectors reduces a load on the compressor as the compressor can operate at a lower pressure difference and use less energy since the ejectors have partially compressed the refrigerant vapors to the intermediate pressure level.

[0005] Existing control systems dynamically control the ejectors in a multi-ejector refrigeration circuit. However, when the ejectors are operated, if the high pressure fluid and the outlet fluid flow back to the secondary low pressure inlet, a large loss of compressor efficiency will result. Therefore, an improved ejector control system that optimizes machine performance while avoiding ejector reverse flow is desirable.

SUMMARY

[0006] This summary is provided to introduce a selection of concepts in a simplified format that are further described in the detailed description of the embodiments of the invention. This summary is not intended to identify key or essential inventive concepts of the invention, nor is it intended for determining the scope of the invention.

[0007] In accordance with a first aspect of the present invention, a system for map-interpolation based control of a plurality of ejectors in an ejector refrigeration circuit, is provided. The system includes a plurality of ejectors and a controller coupled to each of the plurality of ejectors. Each of the plurality of ejectors include a primary high pressure input port, a secondary low pressure input port, and an output port. The controller is adapted to generate a plurality of maps based on a set of predefined conditions, such that each of the plurality of maps is associated with a corresponding temperature of a heat rejecting heat exchanger. Next, the controller identifies a first map from the plurality of maps associated with a first temperature of the heat rejecting heat exchanger and an input signal indicative of a flow rate of a refrigerant fluid through the first ejector. The controller then identifies a second map from the plurality of maps associated with a second temperature of the heat rejecting heat exchanger. Subsequently, the controller predicts an opening percentage of the first ejector from at least one of a plurality of opening percentages indicated in the first map and a plurality of opening percentages indicated in the second map. Finally, the controller adjusts the opening percentage of the first ejector based on the predicted opening percentage.

[0008] Optionally, the step of predicting the opening percentage includes identifying a first opening percentage from the plurality of opening percentages indicated in the first map and a second opening percentage from the plurality of opening percentages indicated in the second map. Then, the step includes performing a linear interpolation to fit a line between the identified first opening percentage and the identified second opening percentage. Next, the step of predicting the opening percentage includes identifying a slope of the line as a rate-of-change of the flow rate of the refrigerant fluid through the first ejector. Finally, the opening percentage is predicted 'at which the first ejector is to be maintained based on interpolation of the identified slope when the heat rejecting heat exchanger is at an intermediate temperature between the first temperature and the second temperature.

[0009] Optionally, each of the plurality of maps indicates a rate of change of the flow rate of the refrigerant fluid through each of the plurality of ejectors based on a change in the opening percentage of each of the plurality of ejectors during the corresponding temperature of the heat rejecting heat exchanger.

[0010] Optionally, each of the plurality of maps includes a plurality of stages and the opening percentage of at least the first ejector from the plurality of ejectors is greater than zero in each of the plurality of stages.

[0011] Optionally, the plurality of stages includes at least a first stage, a second stage, and a third stage. In the first stage, the opening percentage of the plurality of ejectors excluding the first ejector equals zero. In the second stage, the opening percentage of the plurality of ejectors excluding the first ejector and a second ejector equals zero. In the third stage, the opening percentage of the plurality of ejectors excluding the first ejector, the second ejector, and a third ejector equals zero.

[0012] Optionally, when transitioning between the plurality of stages of a first map, the controller is further configured to perform an extrapolation to fit a line to the plurality of opening percentages lying within a predefined hysteresis band indicated in the first map. Next, the controller identifies a slope of the line as a rate-of-change of the flow rate of the refrigerant fluid through the first ejector. Subsequently, the controller predicts the opening percentage at which the plurality of ejectors is to be maintained based on interpolation of the identified slope.

[0013] Optionally, the set of predefined conditions includes:

A) the opening percentages of the plurality of ejectors increase within a stage;

B) when switching between the plurality of stages of each of the plurality of maps, the opening percentages of the plurality of ejectors are adjusted to keep the flow rate of the refrigerant fluid constant;

C) when switching between the plurality of stages of each of the plurality of maps, the opening percentages of the plurality of ejectors are greater than zero; and

D) a flow rate of the refrigerant fluid through the secondary low pressure input port of each of the plurality of ejectors is greater than zero.

[0014] Optionally, the plurality of ejectors are controllable variable ejectors connected in a parallel configuration.

[0015] Optionally, the ejector refrigeration circuit includes a high pressure ejector circuit and a refrigerating evaporator flow path. The high pressure ejector circuit includes, in a direction of flow of a circulating refrigerant, the heat rejecting heat exchanger having an inlet side and an outlet side, the plurality of ejectors, a receiver, and at least one compressor. Each of the plurality of ejectors have the primary high pressure input port, the secondary low pressure input port, and the output port, such that the primary high pressure input port is in fluid communication with the outlet side of the heat rejecting heat exchanger. The receiver includes an inlet, a liquid outlet, and a gas outlet. The inlet is in fluid communication with the output port of each of the plurality of ejectors. The at least one compressor includes an inlet side and an outlet side. The inlet side of the at least one compressor is in fluid communication with the gas outlet of the receiver and the outlet side of the at least one compressor is in fluid communication with the inlet side of the heat rejecting heat exchanger. The refrigerating evaporator flow path includes, in the direction of flow of the circulating refrigerant, a liquid pump, at least one refrigeration expansion device, and at least one refrigeration evaporator. The liquid pump includes an inlet side and an outlet side such that the inlet side is in fluid communication with the liquid outlet of the receiver. The at least one refrigeration expansion device includes an inlet side and an outlet side. The inlet side of the at least one refrigeration expansion device is in fluid communication with the outlet side of the liquid pump. The at least one refrigeration evaporator includes an inlet side and an outlet side. The inlet side is in fluid communication with the outlet side of the at least one refrigeration expansion device and the outlet side is in fluid communication with the secondary low pressure input port of each of the plurality of ejectors.

[0016] Optionally, the liquid pump includes a bypass-line having a switchable bypass valve for allowing refrigerant to selectively bypass the liquid pump by opening the switchable bypass valve.

[0017] In accordance with a second aspect of the present invention, a method for map-interpolation based control of a plurality of ejectors in an ejector refrigeration circuit, is also provided. The method includes generating, via a controller, a plurality of maps based on a set of predefined conditions, each of the plurality of maps associated with a corresponding temperature of a heat rejecting heat exchanger. Next, the controller identifies a first map from the plurality of maps associated with a first temperature of the heat rejecting heat exchanger and an input signal indicative of a flow rate of a refrigerant fluid through the first ejector. Then, the controller identifies a second map from the plurality of maps associated with a second temperature of the heat rejecting heat exchanger. Next, the controller predicts an opening percentage of the first ejector from at least one of a plurality of opening percentages indicated in the first map and a plurality of opening percentages indicated in the second map. Finally, the controller adjusts the opening percentage of the first ejector based on the predicted opening percentage.

[0018] Optionally, the step of predicting the opening percentage includes identifying a first opening percentage from the plurality of opening percentages indicated in the first map and a second opening percentage from the plurality of opening percentages indicated in the second map. Second, the step includes performing a linear interpolation to fit a line between the identified first opening percentage and the identified second opening percentage. Next, the step of predicting the opening percentage includes identifying a slope of the line as a rate-of-change of the flow rate of the refrigerant fluid through the first ejector. Finally, the opening percentage is predicted 'at which the first ejector is to be maintained based on interpolation of the identified slope when the heat rejecting heat exchanger is at the intermediate temperature between the first temperature and the second temperature.

[0019] Optionally, each of the plurality of maps indicates a rate of change of the flow rate of the refrigerant fluid through each of the plurality of ejectors based on a change in the opening percentage of each of the plurality of ejectors during the corresponding temperature of the heat rejecting heat exchanger.

[0020] Optionally, each of the plurality of maps comprises a plurality of stages and the opening percentage of at least the first ejector from the plurality of ejectors is greater than zero in each of the plurality of stages.

[0021] Optionally, the plurality of stages includes at least a first stage, a second stage, and a third stage. In the first stage, the opening percentage of the plurality of ejectors excluding the first ejector equals zero. In the second stage, the opening percentage of the plurality of ejectors excluding the first ejector and a second ejector equals zero. In the third stage, the opening percentage of the plurality of ejectors excluding the first ejector, the second ejector, and a third ejector equals zero.

[0022] Optionally, when transitioning between the plurality of stages of a first map, the controller is further configured to perform an extrapolation to fit a line to the plurality of opening percentages lying within a predefined hysteresis band indicated in the first map. Next, the controller is configured to identify a slope of the line as a rate-of-change of the flow rate of the refrigerant fluid through the first ejector. Subsequently, the controller is configured to predict the opening percentage at which the plurality of ejectors is to be maintained based on interpolation of the identified slope.

[0023] Optionally, the set of predefined conditions includes:

A) the opening percentages of the plurality of ejectors increase within a stage;

B) when switching between the plurality of stages of each of the plurality of maps, the opening percentages of the plurality of ejectors are adjusted to keep the flow rate of the refrigerant fluid constant;

C) when switching between the plurality of stages of each of the plurality of maps, the opening percentages of the plurality of ejectors are greater than zero; and

D) a flow rate of the refrigerant fluid through the secondary low pressure input port of each of the plurality of ejectors is greater than zero.

[0024] Optionally, each of the plurality of ejectors include a primary high pressure input port, a secondary low pressure input port, and an output port.

[0025] Optionally, the ejector refrigeration circuit includes a high pressure ejector circuit and a refrigerating evaporator flow path. The high pressure ejector circuit includes, in a direction of flow of a circulating refrigerant, the heat rejecting heat exchanger having an inlet side and an outlet side, the plurality of ejectors, a receiver, and at least one compressor. Each of the plurality of ejectors have the primary high pressure input port, the secondary low pressure input port, and the output port, such that the primary high pressure input port is in fluid communication with the outlet side of the heat rejecting heat exchanger. The receiver includes an inlet, a liquid outlet, and a gas outlet. The inlet is in fluid communication with the output port of each of the plurality of ejectors. The at least one compressor includes an inlet side and an outlet side. The inlet side of the at least one compressor is in fluid communication with the gas outlet of the receiver and the outlet side of the at least one compressor is in fluid communication with the inlet side of the heat rejecting heat exchanger. The refrigerating evaporator flow path includes, in the direction of flow of the circulating refrigerant, a liquid pump, at least one refrigeration expansion device, and at least one refrigeration evaporator. The liquid pump includes an inlet side and an outlet side such that the inlet side is in fluid communication with the liquid outlet of the receiver. The at least one refrigeration expansion device includes an inlet side and an outlet side. The inlet side of the at least one refrigeration expansion device is in fluid communication with the outlet side of the liquid pump. The at least one refrigeration evaporator includes an inlet side and an outlet side. The inlet side is in fluid communication with the outlet side of the at least one refrigeration expansion device and the outlet side is in fluid communication with the secondary low pressure input port of each of the plurality of ejectors.

[0026] Optionally, the liquid pump includes a bypass-line having a switchable bypass valve allowing refrigerant to selectively bypass the liquid pump by opening the switchable bypass valve.

[0027] To further clarify the advantages and features of the methods, systems, and apparatuses, a more particular description of the methods, systems, and apparatuses will be rendered by reference to specific embodiments thereof, which are illustrated in the appended drawings. It is appreciated that these drawings depict only typical embodiments of the invention and are therefore not to be considered limiting of its scope. The embodiments of the invention will be described and explained with additional specificity and detail with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] These and other features, aspects, and advantages of the invention will become better understood when the following detailed description is read with reference to the accompanying exemplary drawings in which like characters represent like parts throughout the drawings, wherein:

FIG. 1A exemplarily illustrates a schematic view of a system for map-interpolation based control of a plurality of ejectors in an ejector refrigeration circuit;

FIG. 1B exemplarily illustrates a schematic sectional view of a controllable ejector employed in the exemplary embodiment shown in **FIG. 1A;**

FIG. 2A exemplarily illustrates a schematic view of a plurality of maps generated by a controller of the system shown in **FIG. 1A;**

FIG. 2B exemplarily illustrates a schematic view of a map interpolation method implemented between a first map associated with a first temperature and a second map associated with a second temperature of the heat rejecting heat exchanger that is generated by the controller of the system shown in **FIG. 1A;**

FIG. 2C exemplarily illustrates a schematic view of a stage switch method using the first map associated with the first temperature of the heat rejecting heat exchanger that is generated by the controller of the system shown in **FIG. 1A;** and

FIG. 3 exemplarily illustrates a flowchart indicating a method for map-interpolation based control of the plurality of ejectors in the ejector refrigeration circuit.

[0029] Further, skilled artisans will appreciate that elements in the drawings are illustrated for simplicity and may not have necessarily been drawn to scale. For example, the flow charts illustrate the method in terms of the most prominent steps involved to help to improve understanding of aspects of the invention. Furthermore, in terms of the construction of the device, one or more components of the device may have been represented in the drawings by conventional symbols, and the drawings may show only those specific details that are pertinent to understanding the embodiments of the invention so as not to obscure the drawings with details that will be readily apparent to those of ordinary skill in the art having the benefit of the description herein.

DETAILED DESCRIPTION

[0030] For the purpose of promoting an understanding of the principles of the invention, reference will now be made to the various embodiments and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, such alterations and further modifications in the illustrated system, and such further applications of the principles of the invention as illustrated therein being contemplated as would normally occur to one skilled in the art to which the invention relates.

[0031] It will be understood by those skilled in the art that the foregoing general description and the following detailed description are explanatory of the invention and are not intended to be restrictive thereof.

[0032] Reference throughout this specification to "an aspect", "another aspect" or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. Thus, appearances of the phrase "in an embodiment", "in another embodiment", "some embodiments", "one or more embodiments" and similar language throughout this specification may, but do not necessarily, all refer to the same embodiment.

[0033] The terms "comprises", "comprising", or any other variations thereof, are intended to cover a non-exclusive inclusion, such that a process or method that comprises a list of steps does not include only those steps but may include other steps not expressly listed or inherent to such process or method. Similarly, one or more devices or sub-systems or elements or structures or components proceeded by "comprises... a" does not, without more constraints, preclude the existence of other devices or other sub-systems or other elements or other structures or other components or additional devices or additional sub-systems or additional elements or additional structures or additional components.

[0034] Embodiments of the invention will be described below in detail with reference to the accompanying drawings.

[0035] **FIG. 1A** exemplarily illustrates a schematic view of a system 100 for map-interpolation based control of a plurality of ejectors 101 in an ejector refrigeration circuit according to one or more embodiments of the invention. It may be appreciated that the components of the system 100 are described in the detailed description of **FIG.** 1 and the algorithm or process flow of the map-interpolation based control of the plurality of ejectors 101 are described in the detailed description of **FIG. 2B.**

[0036] In an exemplary embodiment according to the invention, the ejector refrigeration circuit includes a high pressure ejector circuit including, in the direction of flow of a circulating refrigerant, a heat rejecting heat exchanger 105, the plurality of ejectors 101, a receiver 106, and at least one compressor 107. The ejector refrigeration circuit also includes a refrigerating evaporator flow path including, in the direction of flow of the circulating refrigerant, a liquid pump 108, at least one refrigeration expansion device 109, and at least one refrigeration evaporator 110.

[0037] The heat rejecting heat exchanger 105 includes an inlet side 105a and an outlet side 105b. The heat rejecting heat exchanger 105 may also be interchangeably referred to as a gas cooler unit or a condenser. The heat rejecting heat exchanger 105 is configured for transferring heat from the refrigerant to the environment thereby reducing the superheat of the refrigerant. In an embodiment, the heat rejecting heat exchanger 105 may include one or more fans for blowing air through the heat rejecting heat exchanger 105 to enhance the transfer of heat from the refrigerant to the environment. The type and number of the fans used may be adjusted based on the type of the condenser used, etc. The cooled refrigerant leaving the heat rejecting heat exchanger 105 at the outlet side 105b is delivered via a high pressure input line and an optional service valve to a primary high pressure input port 101a of the plurality of ejectors 101.

[0038] The plurality of ejectors 101 is adapted to expand the refrigerant to a reduced medium pressure level. Each of the plurality of ejectors 101 includes the primary high pressure input port 101a, a secondary low pressure input port 101b, and an output port 101c. The primary high pressure input port 101a is in fluid communication with the outlet side 105b of the heat rejecting heat exchanger 105. The expanded refrigerant leaves the ejectors 101 through a respective ejector output port 101c and is delivered to an inlet 106a of the receiver 106. Moreover, the receiver 106 includes a liquid outlet 106b and a gas outlet 106c, and the inlet 106a is in fluid communication with the output port 101c of each of the plurality of ejectors 101. Within the receiver 106, the refrigerant is separated by means of gravity into a liquid portion collecting at a bottom part of the receiver 106 and a gas phase portion collecting in an upper part of the receiver 106. The gas phase portion of the refrigerant leaves the receiver 106 through the gas outlet 106c provided at the upper part of the receiver 106 and is delivered to the inlet side 107a of the at least one compressor 107 completing the refrigerant cycle of the high pressure ejector circuit.

[0039] The at least one compressor 107 includes the inlet side 107a and an outlet side 107b. The inlet side 107a of the at least one compressor 107 is in fluid communication with the gas outlet 106c of the receiver 106 and the outlet side 107b of the at least one compressor 107 is in fluid communication with the inlet side 105a of the heat rejecting heat exchanger 105.

[0040] The liquid pump 108 includes an inlet side 108a and an outlet side 108b. The inlet side 108a is in fluid communication with the liquid outlet 106b of the receiver 106. In an embodiment, the liquid pump 108 may be located below the receiver 106. Arranging the liquid pump 108 below the receiver 106 allows using the forces of gravity for supplying the liquid refrigerant from the receiver 106 to the inlet side 108a of the liquid pump 108. The liquid pump 108 also includes a bypass-line including a switchable bypass valve 111 allowing refrigerant to selectively bypass the liquid pump 108 by opening the switchable bypass valve 111. In an embodiment, separate liquid pumps 108 and (optional) bypass-lines may be provided allowing to adjust the pressure of the liquid refrigerant independently.

[0041] The at least one refrigeration expansion device 109 includes an inlet side 109a and an outlet side 109b. The inlet side 109a of the at least one refrigeration expansion device 109 is in fluid communication with the outlet side 108b of the liquid pump 108. The at least one refrigeration evaporator 110 includes an inlet side 110a and an outlet side 110b. The inlet side 110a is in fluid communication with the outlet side 109b of the at least one refrigeration expansion device 109 and the outlet side 110b is in fluid communication with the secondary low pressure input port 101b of each of the plurality of ejectors 101.

[0042] The system 100 includes a controller 104 coupled to each of the plurality of ejectors 101 having the primary high pressure input port 101a, the secondary low pressure input port 101b, and the output port 101c. In an embodiment, each of the plurality of ejectors 101 are controllable variable ejectors 101 as disclosed in the detailed description of FIG. **1B.** Hereinafter, the "ejector 101" may interchangeably be referred to as the "controllable variable ejector 101". Moreover, the plurality of ejectors 101 may be connected in parallel to each other or in a parallel configuration.

[0043] The plurality of ejectors 101 may have different capacities or may all be of the same capacity. In another embodiment, a first group of ejectors 101 from the plurality of ejectors 101 may have equal capacities and a second group of ejectors 101 from the plurality of ejectors 101 may have equal capacities such that the capacities of the second group are greater than the first group of ejectors 101. In yet another embodiment, the first group of ejectors 101 from the plurality of ejectors 101 may have equal capacities and the second group of ejectors 101 from the plurality of ejectors 101 may have equal capacities such that the capacities of the first group are greater than the second group of ejectors 101.

[0044] If the plurality of ejectors 101 used are controllable variable ejectors 101, the plurality of ejectors 101 may have opening percentages that are adjustable by actuating a needle 126, shown in FIG. 1B, of the plurality of ejectors 101 by the controller 104. As used herein, the term "opening percentage" is defined and described in detail in the detailed description of FIG. 1B. Alternatively, each of the plurality of ejectors 101 used may be controllable variable ejectors 101 with a flow valve 112 upstream of the secondary low pressure input port 101b. In an embodiment, the controller 104 is adapted to open the flow valve 112 to permit refrigerant flow and adapted to close the flow valve 112 to prevent refrigerant flow. In such an implementation, the controller 104 actuates the flow valve 112 between an ON and OFF position to permit or prevent a refrigerant flow towards the secondary low pressure input port 101b of the respective ejector 101.

[0045] As used herein, the "controller 104" may be configured to control the at least one compressor 107, the liquid pump 108, the flow valves 112, and/or the plurality of ejectors 101 if at least one ejector 101 of the plurality of ejectors 101 are variable. The controller 104 is adapted to control the plurality of ejectors 101 based on a plurality of generated maps that are described in detail in the detailed description of **FIG. 2A-2C** for enhancing the Coefficient of Performance (COP) of the ejector refrigeration circuit as efficiently as possible. In an embodiment, the controller 104 may refer to a single controller 104 or may be construed to encompass one or a combination of microprocessors, suitable logic, circuits, printed circuit boards (PCB), audio interfaces, visual interfaces, haptic interfaces, or the like. The controller 104 may include, but is not limited to, a microcontroller, a Reduced Instruction Set Computing (RISC) processor, an Application-Specific Integrated Circuit (ASIC) processor, a Complex Instruction Set Computing (CISC) processor, a central processing unit (CPU), a graphics processing unit (GPU), a state machine, and/or other processing units or circuits.

[0046] The controller 104 may also include suitable logic, circuits, interfaces, and/or code that may be configured to execute a set of instructions stored in a memory unit. In an exemplary implementation of the memory unit, the memory unit may include, but is not limited to, Electrically Erasable Programmable Read-only Memory (EEPROM), Random Access Memory (RAM), Read Only Memory (ROM), Hard Disk Drive (HDD), Flash memory, Solid-State Drive (SSD), and/or CPU cache memory.

[0047] The controller 104 may also include a communication unit adapted to communicate with a computing device via a communication network. The communication unit may be configured of, for example, a telematic transceiver (DCM), a mayday battery, a GPS, a data communication module ASSY, a telephone microphone ASSY, and a telephone antenna ASSY. The communication network may include, but is not limited to, a Wide Area Network (WAN), a cellular network, such as a 3G, 4G, or 5G network, an Internet-based mobile ad hoc networks (IMANET), etc. The communication network may also include wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, radio frequency (RF), microwave, infrared (IR) and other wireless media. In an embodiment, the computing device may be implemented as a portion of a small-form factor portable (or mobile) electronic device such as a cell phone, a personal data assistant (PDA), a personal media player device, a wireless web-watch device, a personal headset device, an application specific device, or a hybrid device that include any of the above functions.

[0048] In an exemplary embodiment, the controller 104 may receive power from a suitably coupled power source (not shown). For example, a battery or a power source may be electrically coupled to supply electrical power to the controller 104. In an embodiment, the power source may be, for example, a battery, such as a rechargeable battery or a non-rechargeable battery. Examples of suitable batteries include, for example, a lithium battery (such as a lithium-ion battery), a nickel battery (such as a nickel-cadmium battery), and an alkaline battery.

[0049] **FIG. 1B** exemplarily illustrates a schematic sectional view of the controllable variable ejector 101 as it may be employed in the exemplary embodiment shown in **FIG.** 1A. Each of the plurality of ejectors 101 includes the primary high pressure input port 101a, the secondary low pressure input port 101b, and the output port 101c. The ejector 101 is formed by a motive nozzle 113 nested within an outer member 114. The primary high pressure input port 101a forms the inlet to the motive nozzle 113. The outlet of the outer member 114 provides the output port 101c of the ejector 101. A primary refrigerant flow 115 enters the primary high pressure input port 101a and then passes into a convergent section 116 of the motive nozzle 113. The primary refrigerant flow 115 then passes through a throat section 117 and a divergent expansion section 118 to an outlet 119 of the motive nozzle 113. The motive nozzle 113 accelerates the primary refrigerant flow 115 and decreases the pressure of the primary refrigerant flow 115. The secondary low pressure input port 101b forms an inlet of the outer member 114. The pressure reduction caused to the primary flow by the motive nozzle 113 draws a secondary flow 120 into the outer member 114. The outer member 114 includes a mixer having a convergent section 121 and an elongate throat or mixing section 122. The outer member 114 also has a divergent section or diffuser 123 downstream of the elongate throat or mixing section 122. The outlet 119 of the motive nozzle 113 is positioned within the convergent section 121. As the primary refrigerant flow 115 exits the outlet 119, the primary refrigerant flow 115 begins to mix with the secondary flow 120 with further mixing occurring through the elongated throat or mixing section 122 which provides a mixing zone. Thus, respective primary and secondary flow paths respectively extend from the primary high pressure input port 101a and the secondary low pressure input port 101b to the output port 101c, merging at the exit.

[0050] In operation, the primary refrigerant flow 115 may be supercritical upon entering the controllable variable ejector 101 and subcritical upon exiting the motive nozzle 113. The secondary flow 120 may be gaseous or a mixture of gas with a smaller amount of liquid upon entering the secondary low pressure input port 101b. The resulting combined flow 124 is a liquid/vapor mixture and decelerates and recovers pressure in the diffuser 123 while remaining a mixture.

[0051] The controllability of the controllable variable ejector 101 is provided by a needle valve 125 having a needle 126 and an actuator 127. The actuator 127 is adapted to move a tip portion 128 of the needle 126 into and out of the throat section 117 of the motive nozzle 113 to modulate the primary refrigerant flow 115 through the motive nozzle 113 and, in turn, the controllable variable ejector 101 overall. In an embodiment, each of the plurality of ejectors 101 may have throat sections 117 having different diameters. Alternatively, each of the plurality of ejectors 101 may have throat sections 117 having equal diameters. As used throughout this document, the term "opening percentage" refers to the percentage of opening of the throat section 117. When the tip portion 128 of the needle 126 moves into the throat section 117, the opening percentage reduces to zero percent. Similarly, when the tip portion 128 moves completely out of the throat section 117, the opening percentage increases to 100 percent. Therefore, by actuating the tip portion of the needle 126 into and out of the throat section 117 of the motive nozzle 113, the opening percentage of the throat section 117 is controlled to range between 0-100 percent, such that the opening percentage of zero percent restricts the primary refrigerant flow 115 completely and the opening percentage of 100 percent allows the primary refrigerant flow 115 completely.

[0052] In an embodiment, the actuators 127 may be an electric actuator, for example, a solenoid or the like. The controller 104 disclosed in the detailed description of **FIG.**

1A may be coupled to the actuator 127 and other controllable components of the controllable variable ejector 101 using hardwired or wireless communication paths. The controller 104 may store a mathematical model to estimate the suction and motive flow rate. As such, the controller 104 may extract signals from sensors such as temperature sensors, pressure sensors, and the like to determine one or more parameters for use in the mathematical model. For example, the controller uses a motive Pressure, a motive temperature, a diameter of an Ejector needle opening, a diffuser Pressure, a Suction Pressure, etc. to estimate the suction flow rates and motive flow rates dynamically during operation.

[0053] **FIG. 2A** exemplarily illustrates a schematic view of the plurality of maps 200, 200A, 200B, 200C generated by the controller 104 of the system 100 shown in **FIG. 1A.** The controller 104 is coupled to each of the plurality of ejectors 101 of the system 100. As an example, the controller 104 is shown to generate the maps 200, 200A, 200B, and 200C based on a set of predefined conditions.

[0054] Each of the maps 200, 200A, 200B, 200C include a plurality of stages 201, 202, 203. For example, in the first stage 201, only the first ejector 101' is open. In the second stage 202, the first ejector 101' and the second ejector 101" are open. In the third stage 203, the first ejector 101', the second ejector 101", and the third ejector 101‴ are open. The number of stages 201, 202, 203 may be the same as the number of ejectors 101. As shown in **FIG. 2B,** in the illustrated embodiment, three stages 201, 202, 203 are depicted with respect to three ejectors 101', 101", 101‴. It may be appreciated that the number of ejectors 101 may be two, three, more than three, or in extreme cases only one. As such, the number of stages may also include two stages, three stages or, in extreme cases, a single stage. Therefore, the number of stages is equal to the number of ejectors.

[0055] In an embodiment, the set of predefined conditions may be a set of constraints that include at least the following:

(A) the opening percentages of the plurality of ejectors 101 increase within a stage. This means the opening percentages of the plurality of ejectors 101 cannot decrease within a stage.

(b) When switching between the plurality of stages 201, 202, 203 of each of the plurality of maps 200, 200A, 200B, 200C, the opening percentages of the plurality of ejectors 101 are adjusted to keep the flow rate of the refrigerant fluid constant. This means the cumulative refrigerant fluid exiting the plurality of ejectors 101 may be kept constant irrespective of the number of ejectors 101 being closed or opened.

(c) When switching between the plurality of stages 201, 202, 203 of each of the plurality of maps 200, 200A, 200B, 200C, the opening percentages of the plurality of ejectors 101 are greater than zero. This means once an ejector 101 from the plurality of ejectors 101 is opened during any stage, the same ejector 101 cannot be closed in any subsequent stage; and

(d) A flow rate of the refrigerant fluid through the secondary low pressure input port 101b of each of the plurality of ejectors 101 is greater than zero.

[0056] In an embodiment, each of the plurality of maps 200, 200A, 200B, 200C are associated with a corresponding temperature of the heat rejecting heat exchanger 105. For example, the map 200 is generated for a temperature of 277.1K of the heat rejecting heat exchanger 105, the map 200A is generated for a temperature of 289.1K of the heat rejecting heat exchanger 105, the map 200B is generated for a temperature of 301.1K of the heat rejecting heat exchanger 105, the map 200C is generated for a temperature of 313.1K of the heat rejecting heat exchanger 105, and so on. Each of the plurality of maps 200, 200A, 200B, 200C indicates a rate of change of the flow rate of the refrigerant fluid through each of the plurality of ejectors 101 based on a change in the opening percentage of each of the plurality of ejectors 101 during the corresponding temperature of the heat rejecting heat exchanger 105.

[0057] Each of the plurality of maps 200, 200A, 200B, 200C comprises the plurality of stages 201, 202, 203. During the first stage 201, the opening percentage of only the first ejector 101' is greater than zero. This means the first ejector 101' is open while the second ejector 101" and the third ejector 101‴ remain closed. During the second stage 202, the opening percentage of the plurality of ejectors 101 excluding the first ejector 101' and the second ejector 101" equals zero. This means the first ejector 101' and the second ejector 101" are open while the third ejector 101‴ remains closed. Similarly, during the third stage 203, the opening percentage of the plurality of ejectors 101 excluding the first ejector 101', the second ejector 101", and the third ejector 101‴ equals zero. This means the first ejector 101', the second ejector 101", and the third ejector 101‴ are open while any remaining ejectors are closed. Therefore, in each of the maps 200, 200a, 200b, 200c the opening percentage of at least the first ejector 101' from the plurality of ejectors 101 is greater than zero in each of the plurality of stages 201, 202, 203.

[0058] As an example, when the temperature of the heat rejecting heat exchanger 105 reaches 289.1K, the controller 104 identifies the first map 200A from the plurality of maps 200, 200A, 200B, 200C. The controller 104 also receives an input signal from the first ejector 101' indicative of a flow rate of a refrigerant fluid through the first ejector 101'. The controller 104 adjusts the opening percentages of the plurality of ejectors 101 based on the identified first map 200A.

[0059] **FIG. 2B** exemplarily illustrates a schematic view of a map interpolation method implemented between the first map 200A and the second map 200B. In the map interpolation method, an interpolation line L is drawn between the first map 200A associated with the first temperature GCT' and the second map 200B associated with the second temperature GCT" of the heat rejecting heat exchanger 105 that is generated by the controller 104 of the system 100 shown in **FIG. 1A.** It may be appreciated that although the embodiment disclosed in **FIG. 2B** shows a linear curve, the plurality of the maps 200, 200A, 200B, and 200C may include non-linear curves without departing from the scope of this invention.

[0060] As already described in **FIG. 2A,** the controller 104 is shown to generate the maps 200, 200A, 200B, and 200C based on the set of predefined conditions. During operation of the system 100, the temperature of the heat rejecting heat exchanger 105 increases or decreases and accordingly the map corresponding to the instantaneous temperature is identified and selected. For example, when the heat rejecting heat exchanger 105 is at the temperature of 277.1K, the map 200 generated for the temperature of 277.1K of the heat rejecting heat exchanger 105 is selected. Similarly, when the heat rejecting heat exchanger 105 is at the temperature of 289.1K, the map 200A generated for the temperature of 289.1K of the heat rejecting heat exchanger 105 is selected and when the heat rejecting heat exchanger 105 is at the temperature of 301.1K, the map 200B generated for the temperature of 301.1K of the heat rejecting heat exchanger 105 is selected, and so on.

[0061] Existing systems utilize algorithms that implement a discrete switch between maps for different temperatures of the heat rejecting heat exchanger 105 causing possible oscillations and system instabilities. This means, for example, if the temperature of the heat rejecting heat exchanger 105 increases from 277.1K to 289.1K, the opening percentages of the plurality of ejectors 101 that are open may change abruptly based on the identified opening percentage according to the map 200A. The proposed algorithm or steps executed by the controller 104 anticipates or predicts the opening percentage of the plurality of ejectors 101 according to the map associated with the instantaneous temperature of the heat rejecting heat exchanger 105. As such, the system 100 provides a smooth transition between maps 200, 200A, 200B, 200C, etc., for different temperatures avoiding any discontinuous behavior.

[0062] In an embodiment, the controller 104 is coupled to each of the plurality of ejectors 101 as exemplarily illustrated in **FIG. 1A.** Each of the plurality of ejectors 101 may include components as disclosed in the detailed description of **FIG. 1B.** Moreover, the controller 104 is adapted to generate the plurality of maps 200, 200A, 200B, 200C, etc., based on the set of predefined conditions as described in the detailed description of **FIG. 2A.** Each of the plurality of maps 200, 200A, 200B, 200C may be associated with a corresponding temperature of the heat rejecting heat exchanger 105.

[0063] When the temperature of the heat rejecting heat exchanger 105 begins to change, the controller 104 identifies a first map, for example, 200A from the plurality of maps 200, 200A, 200B, 200C, associated with the first temperature GCT' of the heat rejecting heat exchanger 105 and an input signal indicative of a flow rate of the refrigerant fluid through the first ejector 101'. The first temperature may be 289.1K and may be the instantaneous temperature of the heat rejecting heat exchanger 105 from which the temperature changes to the second temperature GCT" 301.1K. When the heat rejecting heat exchanger 105 is at an intermediate temperature GCT‴ between the first temperature GCT' and the second temperature GCT", the controller 104 dynamically predicts an intermediate opening percentage OD‴ between the known opening percentages OD' associated with the first map 200A and the known opening percentages OD" associated with the second map 200B.

[0064] The controller 104 predicts the intermediate opening percentage OD‴ of the first ejector 101' from a plurality of opening percentages indicated in the second map when the heat rejecting heat exchanger is at the intermediate temperature GCT‴ between the first temperature GCT' and the second temperature GCT". Finally, the controller 104 adjusts the opening percentage of the first ejector 101' based on the predicted opening percentage before the heat rejecting heat exchanger 105 reaches the second temperature 289.1K. It may be appreciated that although the steps mentioned herein are described in relation to the "first ejector 101' ", the steps disclosed herein may be implemented by any of the remaining plurality of ejectors 101 of the system 100.

[0065] The step of predicting the opening percentage includes identifying a first opening percentage from the plurality of opening percentages indicated in the first map 200A and a second opening percentage from the plurality of opening percentages indicated in the second map 200B. Next, the step includes performing a linear interpolation to fit a line L between the identified first opening percentage and the identified second opening percentage. The controller 104 then identifies a slope of the line L as a rate-of-change of the flow rate of the refrigerant fluid through the first ejector 101'. Finally, the controller 104 predicts the opening percentage OD‴ at which the first ejector 101' is to be maintained when the heat rejecting heat exchanger 105 is at the intermediate temperature GCT‴ based on interpolation of the identified slope.

[0066] **FIG. 2C** exemplarily illustrates a schematic view of a stage switch method using the first map 200A associated with the first temperature GCT' of the heat rejecting heat exchanger 105 that is generated by the controller 104 of the system 100 shown in **FIG. 1A.** As shown in **FIG. 2C,** the map 200A includes the plurality of stages 201, 202, 203. **FIG. 2C** illustrates a second scenario in which the system 100 switches between stages 202 and 203. For example, in the stage 202 which is the second stage, the first ejector 101' and the second ejector 101" are open. When the system 100 transitions from the second stage 202 to the third stage 203, the third ejector 101‴ becomes open. During this transition, sometimes the system 100 falls back to the second stage 202 within a predefined hysteresis band H. If the system 100 falls back to the second stage 202 to a zone beyond the predefined hysteresis band H, the system 100 remains in the second stage 202. Alternatively, if the system 100 is in the third stage 203 and transitioning to the second stage 202, the system 100 is initially at point 1 and transitioning to point 3 in the second stage 202. Now, the system 100 tries to fall back to a point 2 triggering the stage switch to the third stage 203, but since the system 100 is still within the predefined hysteresis band H, the system 100 remains in the second stage 202 reaching the point 4 by extrapolating the stage 202. The system 100 remains in the second stage 202 until the system 100 crosses a point 5 of the predefined hysteresis band H. When the system 100 is at point 6, the system 100 is completely crossed into the third stage 203.

[0067] However, if the system 100 is within the predefined hysteresis band H, the controller 104 is further configured to perform an extrapolation to fit a line L' to the plurality of opening percentages lying within the predefined hysteresis band H indicated in the first map 200A. The controller 104 then identifies a slope of the line L' as a rate-of-change of the flow rate of the refrigerant fluid through the first ejector 101' if the stage switch is between the second stage 202 and the third stage 203 as shown in **FIG. 2C.** Finally, the controller 104 predicts the opening percentage at which the first ejector 101' is to be maintained based on interpolation of the identified slope. Alternatively, if the system 100 stays within the predefined hysteresis band H and moves back in the direction of stage 203, the controller 104 is further configured to perform an extrapolation of the stage 202. Next, the controller 104 identifies openings of the first ejector 101' for the right side of the predefined hysteresis band H based on performed extrapolation. Finally, when the system 100 goes beyond the right-side band of the predefined hysteresis band H, the controller 104 stops extrapolating the second stage 202, performs the stage switch to the third stage 203, and adjusts the opening percentage of the first ejector 101' to match the opening percentage defined by the third stage 203. Moreover, during the stage switch, the implementation of the predefined hysteresis band H makes the system 100 more robust during the stage switch and when a jump in the high pressure is expected. In certain embodiments of the present invention, the predefined hysteresis band H may be user defined.

[0068] It may be appreciated that although the embodiment disclosed in **FIG. 2C** shows a linear curve, each of the stages 201, 202, 203 of the plurality of maps 200, 200A, 200B, and 200C may include non-linear curves without departing from the scope of this invention. In such embodiments, different types of extrapolation methods may be used to predict the opening percentages when the system 100 switches between the different stages, for example, 201, 202, 203, etc. Therefore, in such embodiments, the system 100 extrapolates the opening percentages within the predefined hysteresis band H. As such, extrapolation methods that are known in the art, for example, but not limited to, linear extrapolation methods, polynomial extrapolation methods, conic extrapolation methods, etc., that help in predicting the opening percentages during the stage switch fall within the scope of this invention.

[0069] **FIG. 3** exemplarily illustrates a flowchart indicating a method 300 for map-interpolation based control of the plurality of ejectors 101 in the ejector refrigeration circuit. While the steps of **FIG. 3** are shown and described in a particular sequence, the steps may occur in variations to the sequence in accordance with various embodiments of the invention. Further, the details related to various steps of **FIG. 3,** which are already covered in the description related to **FIGS. 1A-2** are not discussed again in detail here for the sake of brevity. The method 300 for controlling the plurality of ejectors in an ejector refrigeration circuit, is disclosed.

[0070] At Step 301, the controller 104 generates the plurality of maps 200, 200A, 200B, 200C as shown in **FIG. 2** based on the set of predefined conditions described in the detailed description of **FIG. 2A.** Each of the plurality of maps 200, 200A, 200B, 200C, is associated with a corresponding temperature of the heat rejecting heat exchanger 105. The generation of the plurality of maps 200, 200A, 200B, 200C for different temperatures of the heat rejecting heat exchanger 105 ensures the optimization of the ejector control over the entire working range of the heat rejecting heat exchanger 105.

[0071] At Step 303, the controller 104 identifies the first map 200 from the plurality of maps 200, 200A, 200B, 200C associated with the first temperature, for example 277.1K, of the heat rejecting heat exchanger 105 and the input signal from the first ejector 101' indicative of the flow rate of the refrigerant fluid through the first ejector 101'. This feature advantageously allows the ejector control to be adjusted based on changes in the temperature of the heat rejecting heat exchanger 105. This means any fluctuation or variation in the temperature of the heat rejecting heat exchanger 105 will not adversely affect the ejector control of the system 100.

[0072] At Step 305, the controller 104 identifies the second map 200A from the plurality of maps 200, 200A, 200B, 200C associated with the second temperature, for example 289.1 K, of the heat rejecting heat exchanger 105.

[0073] At Step 307, the controller 104 predicts an opening percentage of the first ejector from a plurality of opening percentages indicated in the first map 200A and a plurality of opening percentages indicated in the second map 200A when the heat rejecting heat exchanger 105 is at an intermediate temperature between the first temperature and the second temperature.

[0074] In an embodiment, the step of predicting the opening percentage includes in the map interpolation method, firstly, identifying a first opening percentage from the plurality of opening percentages indicated in the first map 200A and a second opening percentage from the plurality of opening percentages indicated in the second map 200B. Secondly, the step includes of predicting the opening percentage includes performing a linear interpolation to fit a line L between the identified first opening percentage and the identified second opening percentage. Next, the controller identifies a slope of the line L as a rate-of-change of the flow rate of the refrigerant fluid through the first ejector 101'. Finally, the controller 104 predicts the opening percentage at which the first ejector 101' is to be maintained when the heat rejecting heat exchanger 105 is at the intermediate temperature based on interpolation of the identified slope.

[0075] In an embodiment, when transitioning between the plurality of stages using the stage switch method, for example, 201, 202, 203, etc., of the first map 200A, the step of predicting includes the controller 104 being configured to perform an extrapolation to fit a line L' to the plurality of opening percentages lying within a predefined hysteresis band H indicated in the first map 200A. Next, the controller 104 identifies a slope of the line as a rate-of-change of the flow rate of the refrigerant fluid through the first ejector 101'. Subsequently, the controller 104 predicts the opening percentage at which the plurality of ejectors 101', 101", 101‴ is to be maintained based on interpolation of the identified slope.

[0076] At Step 309, the controller 104 adjusts the opening percentage of the first ejector 101' based on the predicted opening percentage before the heat rejecting heat exchanger 105 reaches the second temperature.

[0077] **The** system 100, disclosed herein, ensures the overall machine behavior is more robust by minimizing the number of ON/OFF switches. This is because the set of predefined conditions includes the constraint that the ejector 101' opened in the first stage 201 cannot be closed in subsequent stages 202 or 203. Moreover, within a stage, the opening percentage of the ejectors 101 always increase. Furthermore, during the stage switch, the implementation of the predefined hysteresis band H makes the system 100 more robust by reducing the number of stage switches (i.e., opening degree jumps) when a jump in the high pressure is expected.

[0078] While specific language has been used to describe the subject matter, any limitations arising on account thereto, are not intended. As would be apparent to a person in the art, various working modifications may be made to the method in order to implement the inventive concept as taught herein. The drawings and the foregoing description give examples of embodiments. Those skilled in the art will appreciate that one or more of the described elements may well be combined into a single functional element. Alternatively, certain elements may be split into multiple functional elements. Elements from one embodiment may be added to another embodiment.

Claims

1. A system (100) for map-interpolation based control of a plurality of ejectors (101) in an ejector refrigeration circuit, the system comprising:

   a plurality of ejectors, each of the plurality of ejectors having a primary high pressure input port (101a), a secondary low pressure input port (101b), and an output port (101 c); and
   a controller (104) coupled to each of the plurality of ejectors, the controller adapted to:

      generate a plurality of maps (200, 200A, 200B, 200C) based on a set of predefined conditions, each of the plurality of maps associated with a corresponding temperature of a heat rejecting heat exchanger;
      identify a first map (200A) from the plurality of maps associated with a first temperature of the heat rejecting heat exchanger and an input signal indicative of a flow rate of a refrigerant fluid through the first ejector;
      identify a second map (200B) from the plurality of maps associated with a second temperature of the heat rejecting heat exchanger;
      predict an opening percentage of the first ejector from at least one of a plurality of opening percentages indicated in the first map and a plurality of opening percentages indicated in the second map; and
      adjust the opening percentage of the first ejector based on the predicted opening percentage.

2. The system according to claim 1,

   wherein predicting the opening percentage comprises:

      identifying a first opening percentage from the plurality of opening percentages indicated in the first map and a second opening percentage from the plurality of opening percentages indicated in the second map;
      performing a linear interpolation to fit a line between the identified first opening percentage and the identified second opening percentage;
      identifying a slope of the line as a rate-of-change of the flow rate of the refrigerant fluid through the first ejector; and
      predicting the opening percentage at which the first ejector is to be maintained based on interpolation of the identified slope when the heat rejecting heat exchanger is at an intermediate temperature between the first tem-

perature and the second temperature,

and/or, wherein each of the plurality of maps indicates a rate of change of the flow rate of the refrigerant fluid through each of the plurality of ejectors based on a change in the opening percentage of each of the plurality of ejectors during the corresponding temperature of the heat rejecting heat exchanger.

3. The system according to claim 1 or 2, wherein each of the plurality of maps comprises a plurality of stages and the opening percentage of at least the first ejector from the plurality of ejectors is greater than zero in each of the plurality of stages.

4. The system according to claim 3, wherein the plurality of stages comprises at least:

a first stage, wherein the opening percentage of the plurality of ejectors excluding the first ejector equals zero;
a second stage, wherein the opening percentage of the plurality of ejectors excluding the first ejector and a second ejector equals zero; and
a third stage, wherein the opening percentage of the plurality of ejectors excluding the first ejector, the second ejector, and a third ejector equals zero,
and/or, wherein when transitioning between the plurality of stages of a first map, the controller is further configured to:
perform an extrapolation to fit a line to the plurality of opening percentages lying within a predefined hysteresis band indicated in the first map;
identify a slope of the line as a rate-of-change of the flow rate of the refrigerant fluid through the first ejector; and
predict the opening percentage at which the plurality of ejectors is to be maintained based on interpolation of the identified slope.

5. The system according to any preceding claim, wherein the set of predefined conditions comprises:

the opening percentages of the plurality of ejectors increase within a stage;
when switching between the plurality of stages of each of the plurality of maps, the opening percentages of the plurality of ejectors are adjusted to keep the flow rate of the refrigerant fluid constant;
when switching between the plurality of stages of each of the plurality of maps, the opening percentages of the plurality of ejectors are greater than zero; and
a flow rate of the refrigerant fluid through the secondary low pressure input port of each of the plurality of ejectors is greater than zero,
and/or, wherein the plurality of ejectors are controllable variable ejectors connected in a parallel configuration.

6. The system according to any preceding claim, wherein the ejector refrigeration circuit comprises:

a high pressure ejector circuit comprising in a direction of flow of a circulating refrigerant:

the heat rejecting heat exchanger having an inlet side (105a) and an outlet side (105b);
the plurality of ejectors, each of the plurality of ejectors having the primary high pressure input port, the secondary low pressure input port, and the output port, wherein the primary high pressure input port is in fluid communication with the outlet side of the heat rejecting heat exchanger;
a receiver (106), having an inlet (106a), a liquid outlet (106b), and a gas outlet (106c), the inlet in fluid communication with the output port of each of the plurality of ejectors;
at least one compressor (107) having an inlet side (107a) and an outlet side (107b), the inlet side of the at least one compressor in fluid communication with the gas outlet of the receiver and the outlet side of the at least one compressor in fluid communication with the inlet side of the heat rejecting heat exchanger; and

a refrigerating evaporator flow path comprising in the direction of flow of the circulating refrigerant:

a liquid pump (108) having an inlet side (108a) and an outlet side (108b), the inlet side in fluid communication with the liquid outlet of the receiver;
at least one refrigeration expansion device (109) having an inlet side (109a) and an outlet side (109b), the inlet side of the at least one refrigeration expansion device in fluid communication with the outlet side of the liquid pump; and
at least one refrigeration evaporator (110) having an inlet side (110a) and an outlet side (110b), the inlet side in fluid communication with the outlet side of the at least one refrigeration expansion device and the outlet side in fluid communication with the secondary low pressure input port of each of the plurality of ejectors.

7. The system according to claim 6, wherein the liquid pump comprises a bypass-line having a switchable bypass valve (111) for allowing refrigerant to selectively bypass the liquid pump by opening the switchable bypass valve.

8. A method for map-interpolation based control of a plurality of ejectors in an ejector refrigeration circuit, the method comprising:

generating, via a controller, a plurality of maps based on a set of predefined conditions, each of the plurality of maps associated with a corresponding temperature of a heat rejecting heat exchanger;
identifying, via the controller, a first map from the plurality of maps associated with a first temperature of the heat rejecting heat exchanger and an input signal indicative of a flow rate of a refrigerant fluid through the first ejector; and
identifying, via the controller, a second map from the plurality of maps associated with a second temperature of the heat rejecting heat exchanger;
predicting, via the controller, an opening percentage of the first ejector from at least one of a plurality of opening percentages indicated in the first map and a plurality of opening percentages indicated in the second map; and
adjusting, via the controller, the opening percentage of the first ejector based on the predicted opening percentage.

9. The method according to claim 8, wherein predicting the opening percentage comprises:

identifying a first opening percentage from the plurality of opening percentages indicated in the first map and a second opening percentage from the plurality of opening percentages indicated in the second map;
performing a linear interpolation to fit a line between the identified first opening percentage and the identified second opening percentage;
identifying a slope of the line as a rate-of-change of the flow rate of the refrigerant fluid through the first ejector; and
predicting the opening percentage at which the first ejector is to be maintained based on interpolation of the identified slope when the heat rejecting heat exchanger is at an intermediate temperature between the first temperature and the second temperature.

10. The method according to claim 8 or 9, wherein each of the plurality of maps indicates a rate of change of the flow rate of the refrigerant fluid through each of the plurality of ejectors based on a change in the opening percentage of each of the plurality of ejectors during the corresponding temperature of the heat rejecting heat exchanger.

11. The method according to any of claims 8 to 10, wherein each of the plurality of maps comprises a plurality of stages and the opening percentage of at least the first ejector from the plurality of ejectors is greater than zero in each of the plurality of stages.

12. The method according to claim 11, wherein the plurality of stages comprises at least:

a first stage, wherein the opening percentage of the plurality of ejectors excluding the first ejector equals zero;
a second stage, wherein the opening percentage of the plurality of ejectors excluding the first ejector and a second ejector equals zero; and
a third stage, wherein the opening percentage of the plurality of ejectors excluding the first ejector, the second ejector, and a third ejector equals zero.

13. The method according to claim 11 or 12, wherein when transitioning between the plurality of stages of a first map, the controller is further configured to:

perform an extrapolation to fit a line to the plurality of opening percentages lying within a predefined hysteresis band indicated in the first map;
identify a slope of the line as a rate-of-change of the flow rate of the refrigerant fluid through the first ejector; and
predict the opening percentage at which the plurality of ejectors is to be maintained based on interpolation of the identified slope.

14. The method according to any of claims 8 to 13,

wherein the set of predefined conditions comprise:

the opening percentages of the plurality of ejectors increase within a stage;
when switching between the plurality of stages of each of the plurality of maps, the opening percentages of the plurality of ejectors are adjusted to keep the flow rate of the refrigerant fluid constant;
when switching between the plurality of stages of each of the plurality of maps, the opening percentages of the plurality of ejectors are greater than zero; and
a flow rate of the refrigerant fluid through a secondary low pressure input port of each of the plurality of ejectors is greater than zero,

and/or, wherein each of the plurality of ejectors comprise a primary high pressure input port, a secondary low pressure input port, and an output port.

15. The method according to any of claims 8 to 14, wherein the ejector refrigeration circuit comprises:

a high pressure ejector circuit comprising in the direction of flow of a circulating refrigerant:

the heat rejecting heat exchanger having an inlet side and an outlet side;
the plurality of ejectors, each of the plurality of ejectors having the primary high pressure input port, the secondary low pressure input port, and the output port, wherein the primary high pressure input port is in fluid communication with the outlet side of the heat rejecting heat exchanger;
a receiver, having an inlet, a liquid outlet, and a gas outlet, the inlet in fluid communication with the output port of each of the plurality of ejectors;
at least one compressor having an inlet side and an outlet side, the inlet side of the at least one compressor in fluid communication with the gas outlet of the receiver and the outlet side of the at least one compressor in fluid

communication with the inlet side of the heat rejecting heat exchanger; and
a refrigerating evaporator flow path comprising in the direction of flow of the circulating refrigerant:

a liquid pump having an inlet side and an outlet side, the inlet side in fluid communication with the liquid outlet of the receiver;
at least one refrigeration expansion device having an inlet side and an outlet side, the inlet side of the at least one refrigeration expansion device in fluid communication with the outlet side of the liquid pump; and
at least one refrigeration evaporator having an inlet side and an outlet side, the inlet side in fluid communication with the outlet side of the at least one refrigeration expansion device and the outlet side in fluid communication with the secondary low pressure input port of each of the plurality of ejectors,

optionally, wherein the liquid pump comprises a bypass-line including a switchable bypass valve allowing refrigerant to selectively bypass the liquid pump by opening the switchable bypass valve.

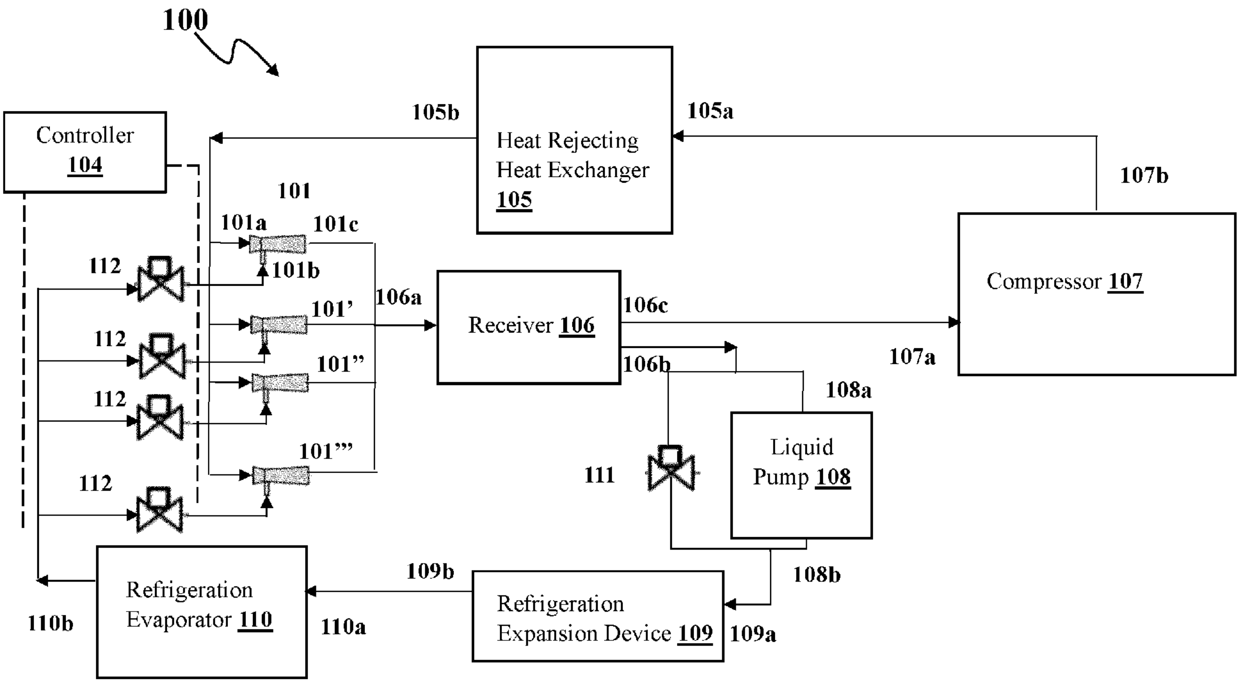
100
Controller 104
Heat Rejecting Heat Exchanger 105
105b
105a
107b
101
101a
101c
101b
112
112
112
112
101'
101"
101'''
106a
Receiver 106
106c
106b
107a
Compressor 107
108a
Liquid Pump 108
111
108b
109b
Refrigeration Evaporator 110
110b
110a
Refrigeration Expansion Device 109
109a

FIG. 1A

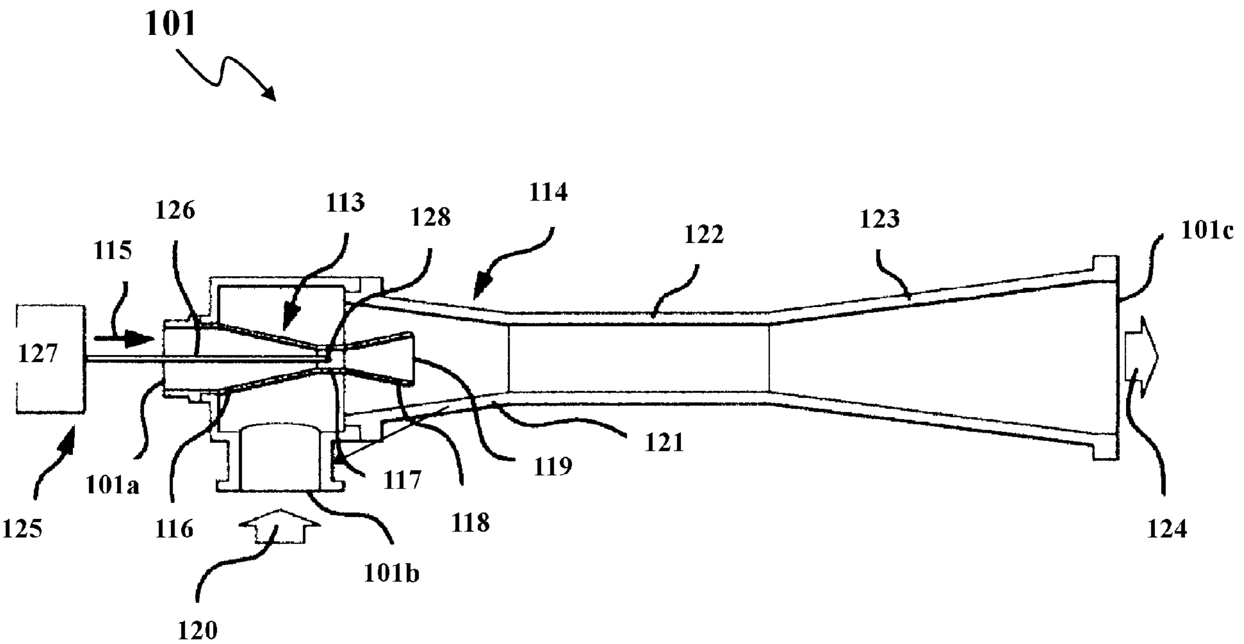
101
126
113
128
114
122
123
101c
115
127
101a
116
117
118
119
121
124
125
120
101b

FIG. 1B

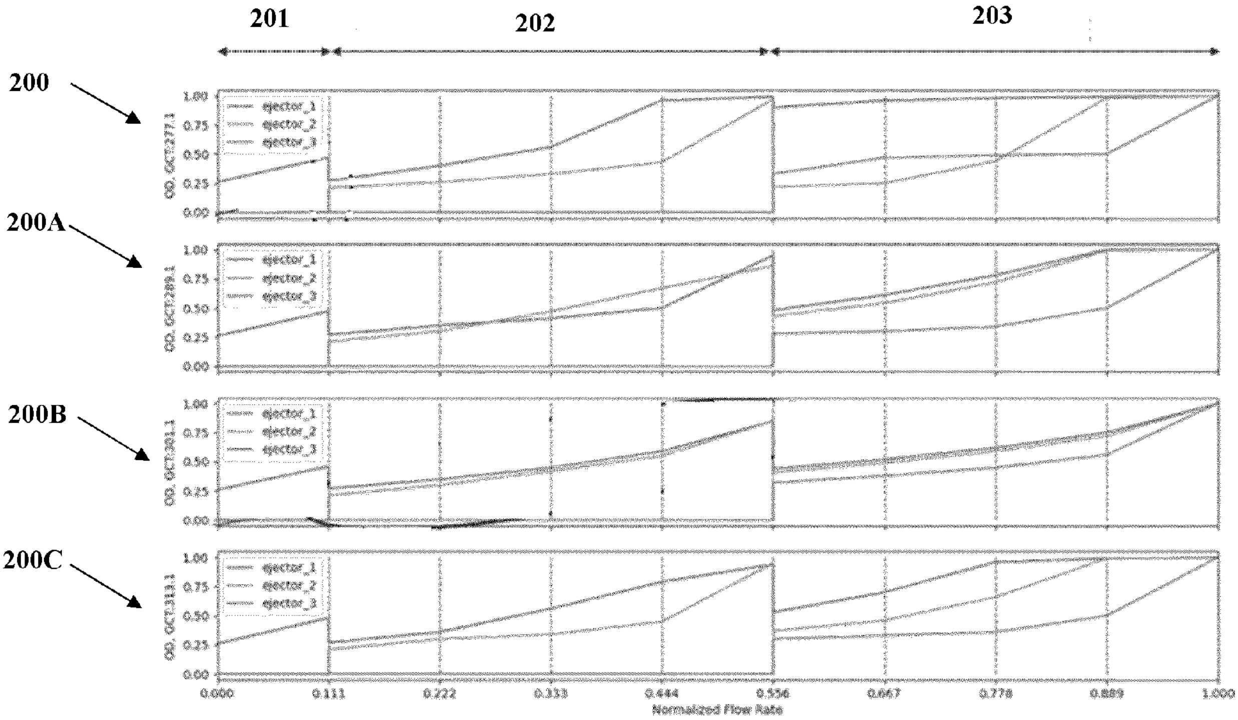
201
202
203
200
200A
200B
200C
ejector_1
ejector_2
ejector_3
1.00
0.75
0.50
0.25
0.00
0.000
0.111
0.222
0.333
0.444
0.556
0.667
0.778
0.889
1.000
Normalized Flow Rate

FIG. 2A

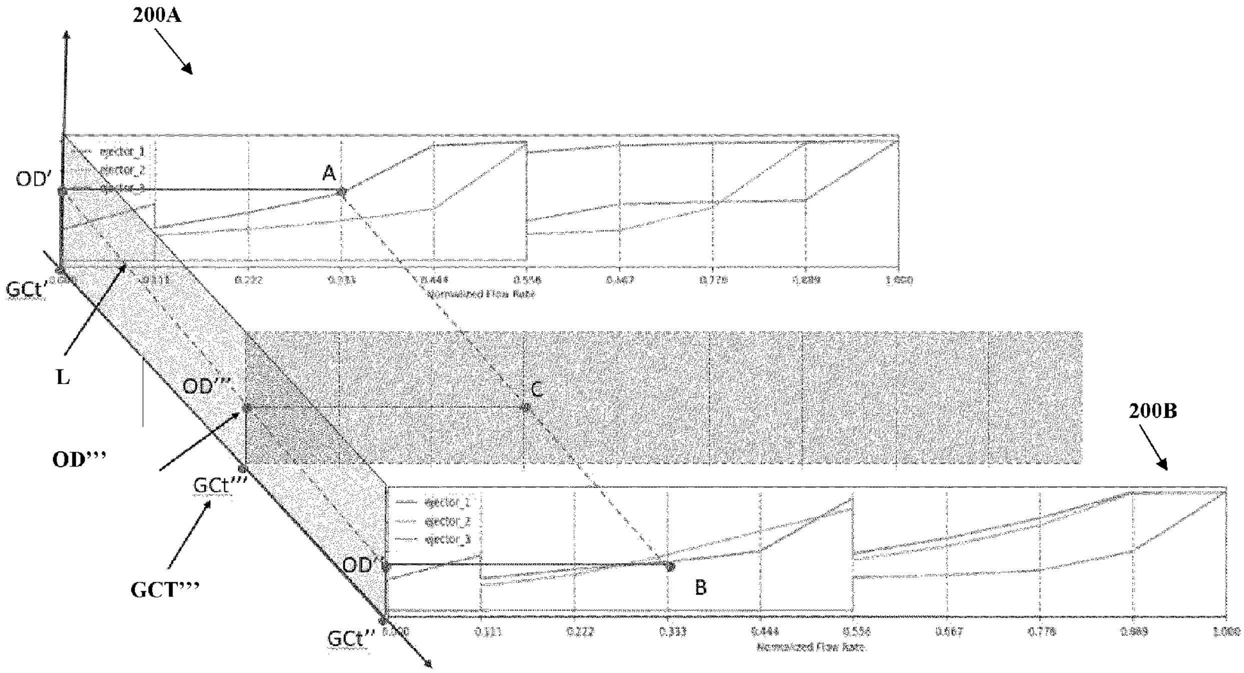
200A
OD'
A
GCt'
L
OD'''
C
200B
OD'''
GCt'''
GCT'''
OD'
B
GCt''
ejector_1
ejector_2
ejector_3
Normalized Flow Rate

FIG. 2B

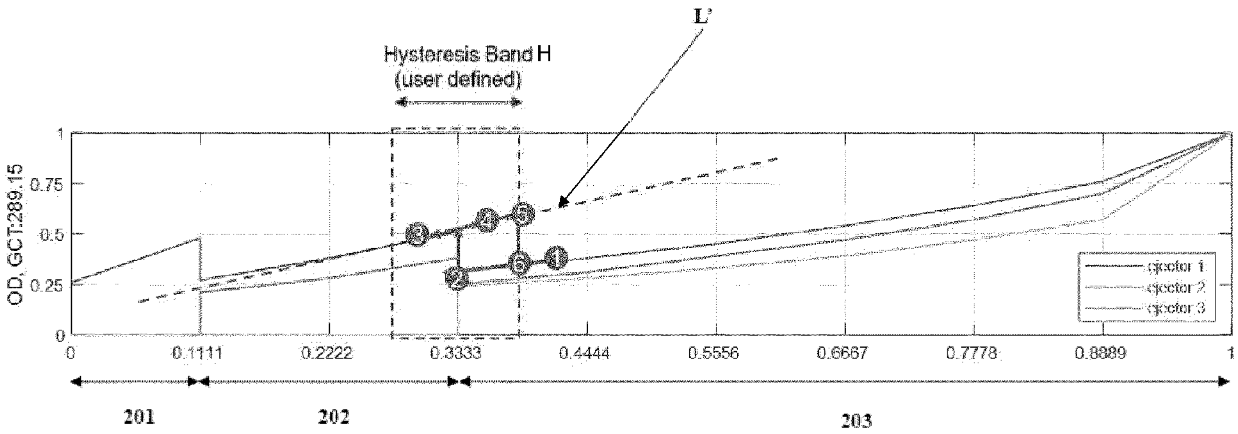
L'
Hysteresis Band H
(user defined)
OD, GCT:289.15
1
0.75
0.5
0.25
0
0
0.1111
0.2222
0.3333
0.4444
0.5556
0.6667
0.7778
0.8889
1
201
202
203
1
2
3
4
5
6

FIG. 2C

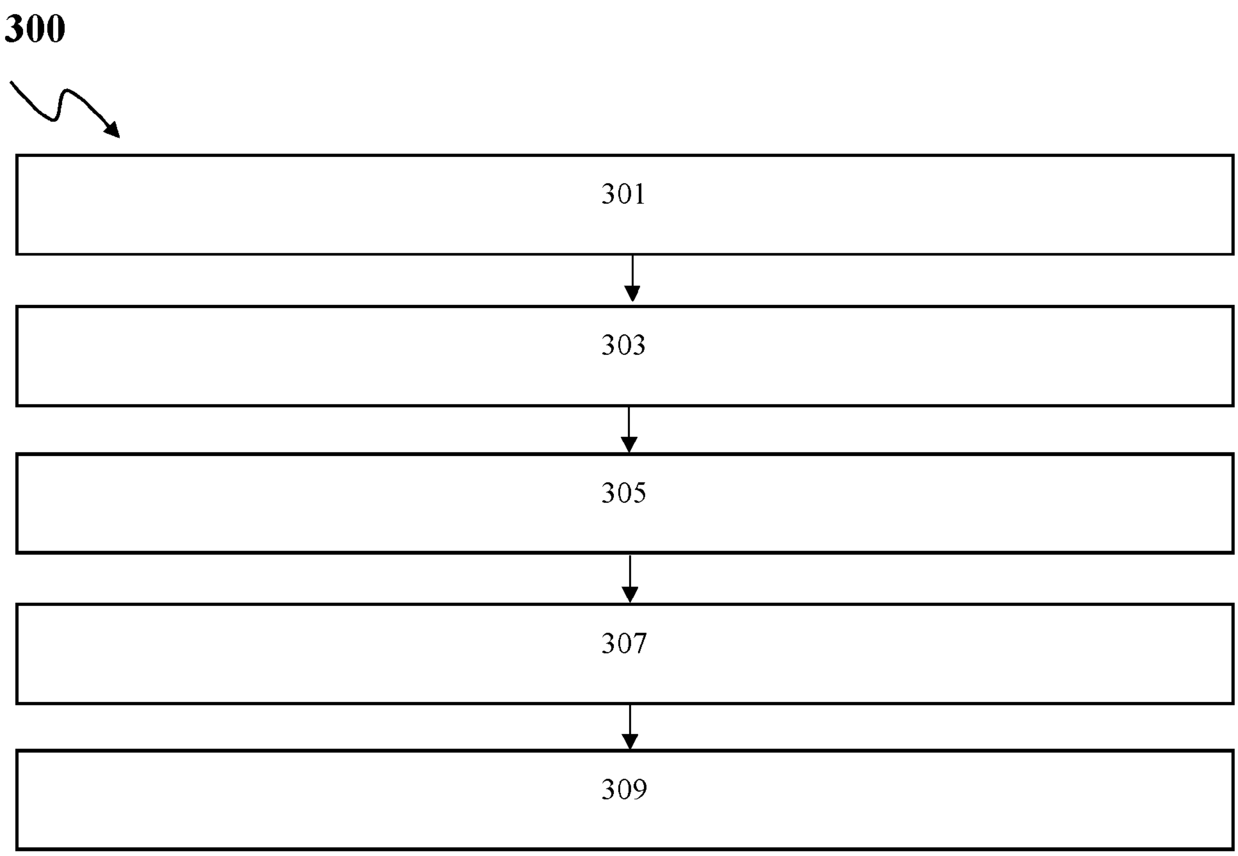

FIG. 3

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EUROPEAN SEARCH REPORT

Application Number
EP 24 20 7866

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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F25B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	19 February 2025	Amous, Moez

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