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(54) METHOD OF CONTROLLING A DEVICE INCLUDING HILSCH-RANQUE VORTEX TUBES

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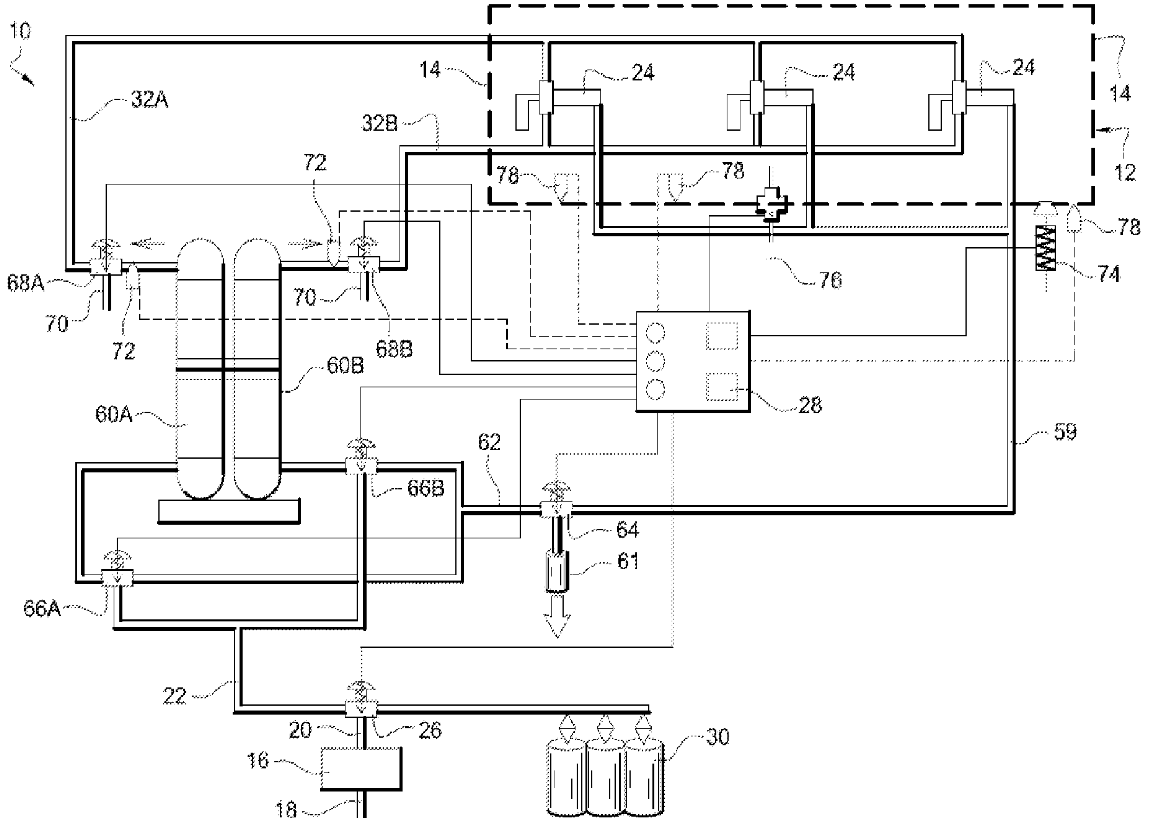
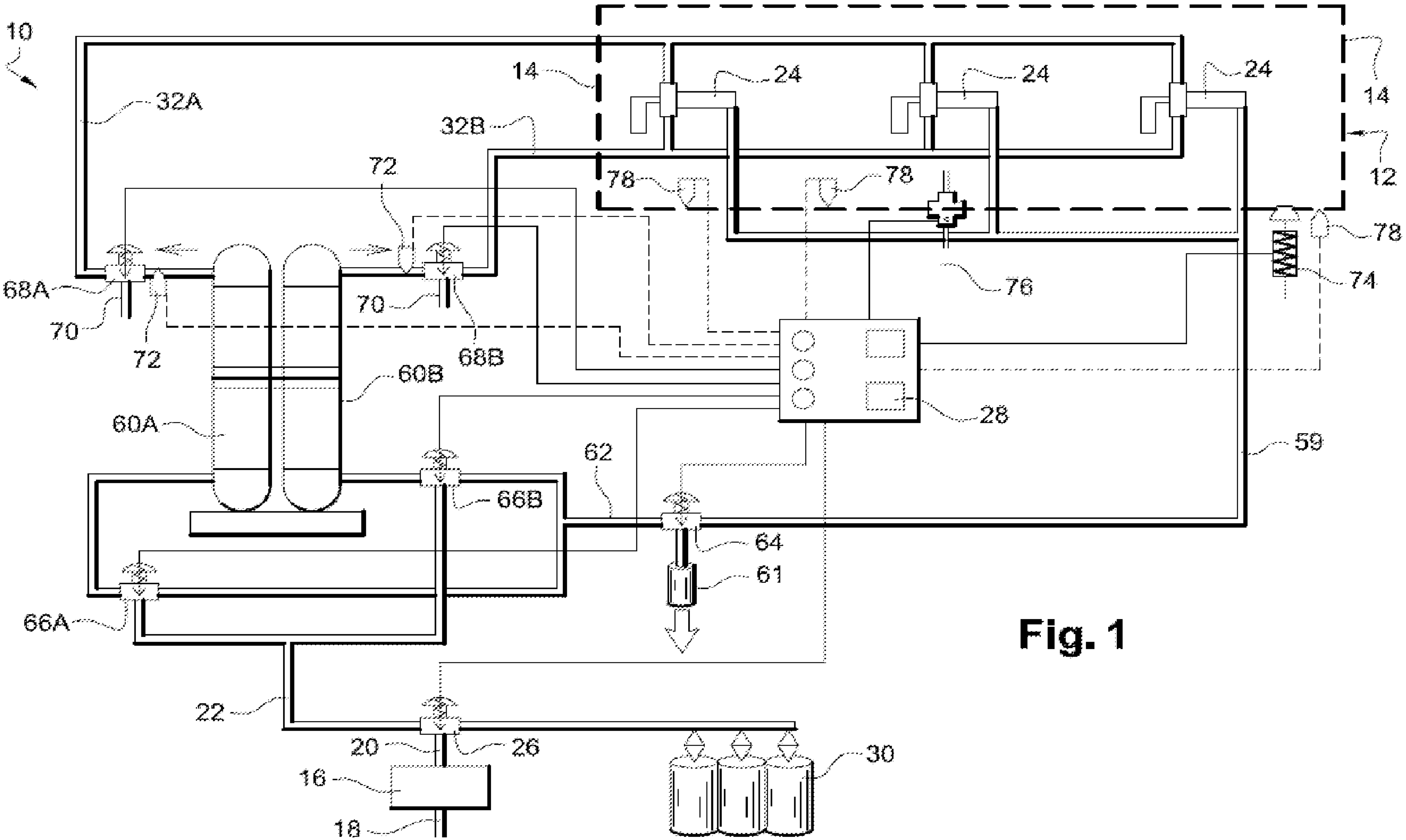
(57) **ABSTRACT**

A method of controlling a device for air conditioning (**80**) or cooling by refrigeration (**10**) or heating the interior of a sealed chamber (**12**), the device (**10**, **80**) including at least one compressed air source (**16**, **30**) which supplies at least one Hilsch-Ranque tube (**24**), called "vortex" tube, with compressed air at an injection pressure (P_{inj}), is characterized in that a tapered relief valve (**48**) of the tube (**24**) is preset so that the first (FC) and second (FF) fractions of cold and hot air are constant while the method is running and in that it includes a step (E**3**, C**4**) for controlling the compressed air injection pressure (P_{inj}). A device for implementing such a method is also described.

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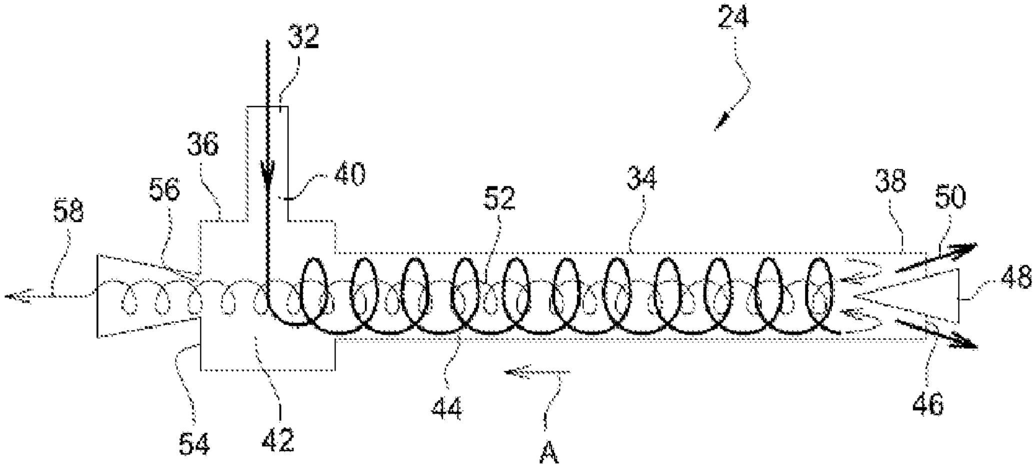
32A
14
24
24
24
14
32B
72
78
78
12
78
68A
70
72
70
68B
76
74
60B
60A
28
62
59
66B
64
61
66A
22
20
26
30
16
18

Fig. 1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24
36
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34
38
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58
56
52
48
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42
44
46
A

Fig. 2

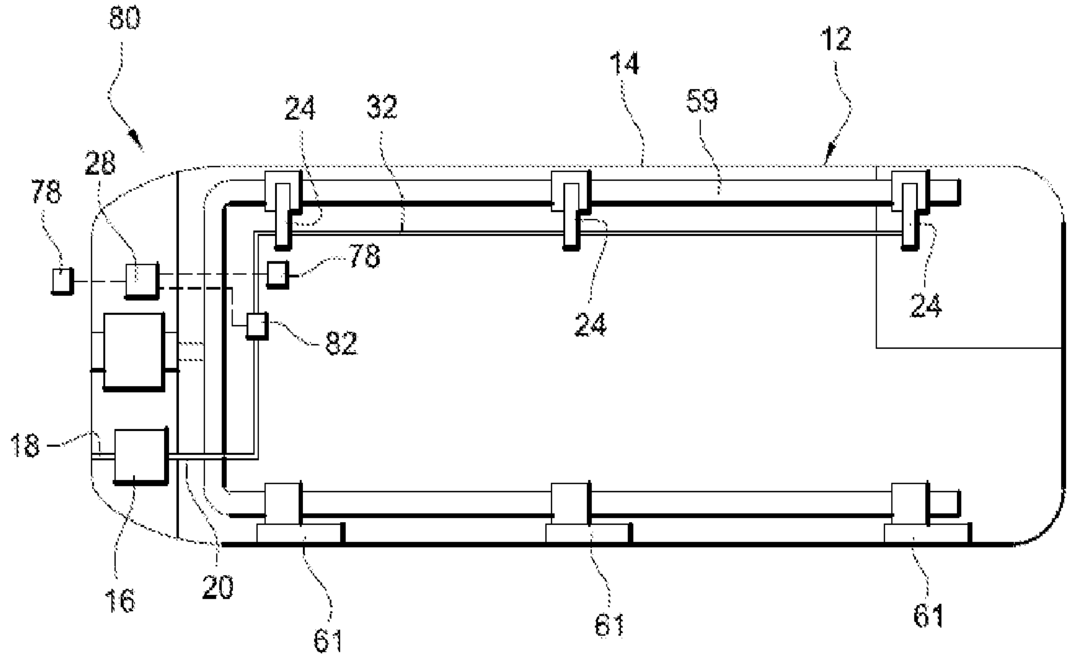
80
12
14
59
24
32
28
78
78
24
24
82
18
16
20
61
61
61

Fig. 4

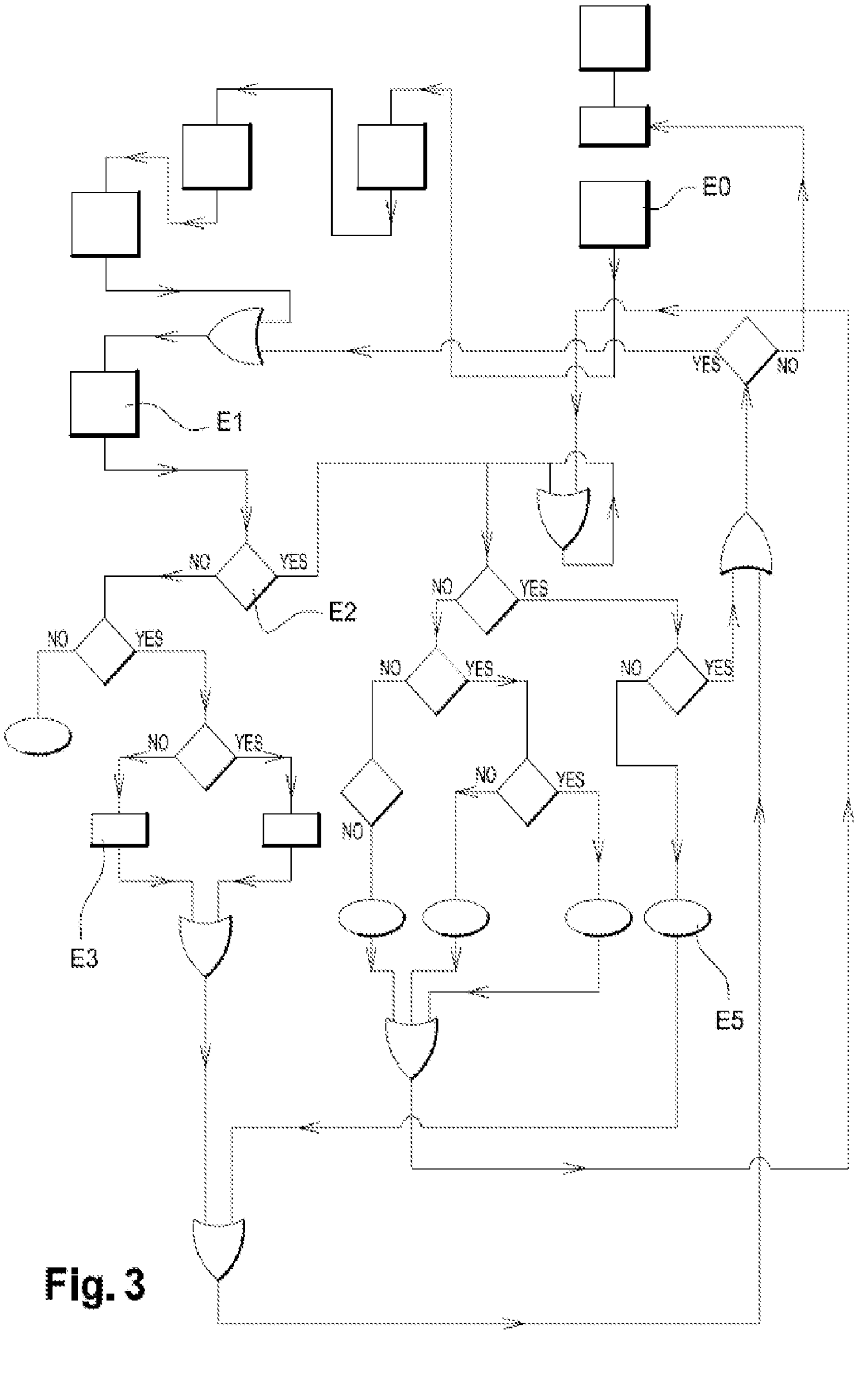
E0
E1
NO
YES
E2
NO
YES
YES
NO
NO
YES
NO
YES
NO
YES
NO
YES
NO
NO
YES
E3
E5

Fig. 3

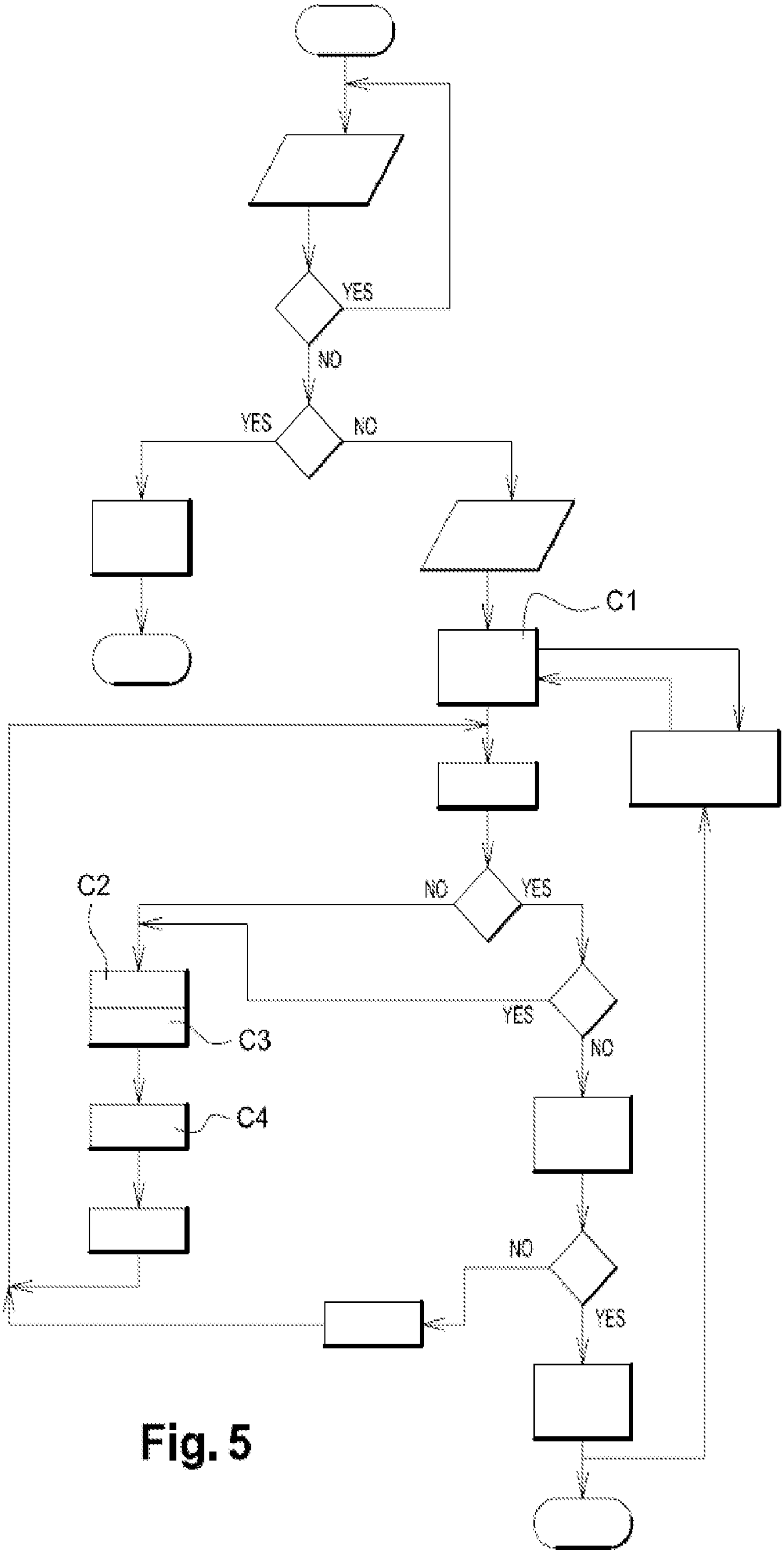

Fig. 5

METHOD OF CONTROLLING A DEVICE INCLUDING HILSCH-RANQUE VORTEX TUBES

[0001] The invention relates to a method of controlling a device for air conditioning or cooling the interior of a sealed chamber including at least one Hilsch-Ranque tube.

[0002] The invention relates more particularly to a method of controlling a device for air conditioning or cooling by refrigeration or heating the interior of a sealed chamber, the device comprising at least one compressed air source which supplies at least one Hilsch-Ranque tube, called "vortex" tube, with compressed air at an injection pressure, the Hilsch-Ranque vortex tube comprising:

[0003] at least one tangential orifice for injecting compressed air inside the Hilsch-Ranque vortex tube which is arranged close to a first end of the Hilsch-Ranque vortex tube, the injected air forming a first incoming stream of swirling air towards a second end (**38**) of the Hilsch-Ranque vortex tube;

[0004] a tapered relief valve which partially blocks off a first expulsion orifice of the second end of the Hilsch-Ranque vortex tube so that a first fraction of the incoming hot air stream is expelled outside the chamber while a second fraction of the air stream is reflected towards the first end of the Hilsch-Ranque vortex tube forming a second concentric swirling air stream inside the first swirling stream, the reflected air stream being cooled by heat exchange with the incoming air stream;

[0005] a "cold" outlet orifice for the reflected air which is arranged at the first end of the Hilsch-Ranque vortex tube so as to allow the second fraction of the cold air stream to leave inside the chamber.

[0006] The air conditioning or cooling devices generally use heat-transfer fluids considered as pollutants such as chlorofluorocarbons (CFC).

[0007] To overcome this problem, the production of cold air by using tubes called Hilsch-Ranque vortex tubes is known, as disclosed, for example, in the document U.S. Pat. No. 1,952,281.

[0008] The regulation of the temperature inside a chamber cooled or air conditioned by such devices is generally controlled by acting on the cold air flow leaving the first end of the tube. This is done by adjusting the fraction of hot air expelled through the second end of the tube by acting on the tapered relief valve.

[0009] However, such a control method entails acting on the tapered relief valve through the intermediary of a motor. Such a device therefore includes moving parts which are likely to be prematurely worn.

[0010] Now, it is essential, in particular for the cooling device, to have a robust and reliable device. In practice, if a failure occurs on a cooling device for a cold room, the cold subsystem, which ensures that the cooled elements are well conserved, risks being broken.

[0011] Furthermore, such a control method induces a superfluous energy consumption, in particular for compressing the injected air, because, in the event of a weak cold air flow, a large fraction, called hot fraction, of the injected air is expelled as pure loss through the expulsion orifice of the second end of the tube.

[0012] To overcome these problems, the invention proposes a control method of the type described previously, characterized in that the tapered relief valve is preset so that the first fraction of hot air and the second fraction of cold air are constant while the method is running and in that it comprises a step for controlling the compressed air injection pressure.

[0013] According to other characteristics of the invention:

[0014] the outlet temperature of the cold air stream is controlled by acting only on the injection pressure of the air into the Hilsch-Ranque vortex tube according to a predetermined control law;

[0015] the method comprises a step for calculating the outlet temperature of the cold air stream prior to the step for controlling the injection pressure during which said outlet temperature is calculated by subtracting a predetermined constant value from the compressed air injection temperature,

[0016] and the method also comprises a step for correcting the calculated cold air stream outlet temperature, which is triggered when said outlet temperature during the preliminary calculation step is less than a minimum temperature and during which the outlet temperature is corrected so as to be greater than or equal to said minimum temperature;

[0017] the compressed air source is an air compressor which sucks in ambient air from outside the chamber, the injection temperature being proportional to the external temperature of the chamber;

[0018] the chamber is a passenger compartment of a motor vehicle in which the air conditioning device is installed and the air compressor is driven by the heat engine of the motor vehicle through the intermediary of a hydraulic pump and a hydraulic motor;

[0019] the injection pressure is controlled by pulses at an injection pressure which is predetermined, the duration of each pulse being determined in such a way that the chamber is maintained at a setpoint temperature;

[0020] the duration of each pulse is determined as a function of the ambient temperature inside the chamber, of the injection temperature of compressed air into the Hilsch-Ranque vortex tube, and of the setpoint temperature;

[0021] the duration of each pulse is determined by taking into account the balance between the sum of the heat losses through the walls of the chamber per time unit and the quantity of heat to be removed to cool the air inside the chamber to the setpoint temperature, and the quantity of heat likely to be absorbed by the cold air leaving each Hilsch-Ranque vortex tube for said time unit;

[0022] the air is dried by drying means before its injection into each Hilsch-Ranque vortex tube so that its dew point is less than the air outlet temperature.

[0023] The invention also relates to a device for implementing the method produced according to the teachings of the invention, characterized in that it comprises a plurality of Hilsch-Ranque vortex tubes which are fed in parallel by at least one common compressed air source and in that each Hilsch-Ranque vortex tube includes a tapered relief valve that can be adjusted only manually.

[0024] Other features and benefits will become apparent while reading the detailed description that follows, for an understanding of which reference should be made to the appended drawings in which:

[0025] FIG. **1** is a diagram which represents a cooling device installed in a refrigerated transport vehicle;

[0026] FIG. **2** is an axial cross-sectional view which represents a Hilsch-Ranque vortex tube;

[0027] FIG. **3** is a block diagram which represents a method of controlling the refrigerating cooling device of FIG. **1**;

[0028] FIG. **4** is a diagram which represents an air conditioning device installed on board a motor vehicle;

[0029] FIG. **5** is a block diagram which represents a method of controlling the air conditioning device of FIG. **4**.

[0030] Hereinafter in the description, elements that have identical, analogous or similar functions will be designated by the same reference numbers.

[0031] Hereinafter in the description, an axial orientation directed from back to front indicated by the arrow "A" in FIG. **2** will be adopted in a non-limiting manner.

[0032] FIG. **1** represents a refrigerating cooling device **10** which is intended to cool a hermetically sealed chamber **12**. The sealed chamber **12** is in this case formed by a cold chamber of a refrigerated transport motor vehicle (not represented) in which the cooling device **10** is installed.

[0033] According to a non-represented variant of the invention, the cooling device **10** is also adapted to cool an immobile refrigerating chamber.

[0034] The chamber **12** is sealed horizontally in all directions by four vertical walls **14** and vertically in both directions by a top wall (not represented) and by a bottom wall (not represented).

[0035] The walls **14** are equipped with means of thermally insulating the chamber **12** from the outside. The thermal insulation means are characterized by their general thermal transmission coefficient "K".

[0036] One of the walls of the cold chamber is also equipped with an access door (not represented) that is thermally insulated and is likely to be sealed hermetically.

[0037] The chamber **12** is intended to be maintained at a setpoint temperature "θ_c" by the cooling device **10**. The setpoint temperature "θ_c" is, for example, less than 0° C. The setpoint temperature "θ_c" is, for example, −25° C.

[0038] The cooling device **10** includes at least one compressed air source. The cooling device **10** in this case includes two compressed air sources.

[0039] A first compressed air source **16** is formed by an air compressor **16** which is driven by an electric motor or heat engine. The motor is advantageously autonomous and independent of the engine (not represented) pulling the vehicle in order to ensure continuous operation of the air compressor **16** even when the engine pulling the motor vehicle is stopped.

[0040] The air compressor **16** includes a suction duct **18** through which the air outside the chamber **12** is sucked in, and it includes a discharge duct **20** through which the compressed air is discharged from the air compressor **16**. The air compressor **16** is, for example, selected for the air to be compressed at a constant pressure between 7.5 and 10.5 bar.

[0041] The discharge duct **20** is connected to a duct **22** supplying Hilsch-Ranque vortex tubes **24** through the intermediary of a three-way supply valve **26** controlled by an electronic control unit **28**.

[0042] A second compressed air source **30** is formed by air accumulators **30**, such as cylinders. The air accumulators **30** are, for example, capable of storing 300 litres of compressed air at a pressure of 300 bar.

[0043] This second compressed air source **30** is reserved for backup use, enabling the cooling device **10** to operate when the air compressor **16** has failed. Thus, it is possible to act on the air compressor **16** and avoid breaking the cold subsystem.

[0044] The air accumulators **30** are also connected to the supply duct **22** through the intermediary of the third way of the supply valve **26**.

[0045] The supply valve **26** can thus occupy a first position in which the supply duct **22** is fed with compressed air only by the air compressor **16**, a second position in which the supply duct **22** is fed with compressed air only by the air accumulators **30**, and a third total closure position in which the supply duct **22** is totally cut off from both compressed air sources **16**, **30**.

[0046] The cooling device **10** includes a plurality of Hilsch-Ranque vortex tubes **24** which are supplied in parallel by at least one supply circuit **32** supplied with compressed air by the supply duct **22**.

[0047] The cooling device **10** includes, for example, three Hilsch-Ranque vortex tubes **24**. It will, however, be understood that this number is given purely way of example and that the cooling device **10** is likely to include at least one Hilsch-Ranque vortex tube **24**.

[0048] Because of the humidity of the air sucked in by the air compressor **16**, and as will be explained in more detail hereinbelow, the cooling device **10** here includes two parallel compressed air supply circuits **32**A, **32**B. The Hilsch-Ranque vortex tubes **24** are likely to be supplied alternately by one then the other of the supply circuits **32**A, **32**B.

[0049] In a non-limiting manner, there are three Hilsch-Ranque vortex tubes **24**. They are all identical, so hereinafter just one of these tubes **24** will be described.

[0050] A Hilsch-Ranque vortex tube **24** is represented in more detail in FIG. **2**. It comprises a tubular body **34** which is cylindrical of revolution with longitudinal axis which comprises a first front end **36** and a second rear end **38**.

[0051] A tangential orifice **40** for injecting compressed air inside the tubular body **34** is arranged close to the first front end **36** in an inlet chamber **42**. The injection orifice **40** is arranged so that the injected air forms an incoming swirling air stream **44** towards the second rear end **38** of the tubular body **34**.

[0052] The inlet chamber **42** is also configured so as to provoke an acceleration of the rotation of the injected compressed air. Under the effect of the centrifugal force, the air pressure at the periphery of the tubular body **34** increases, and a depression is formed inside the incoming swirling air stream **44**.

[0053] The rear end **38** of the tubular body **34** is open through an expulsion orifice **46**. A tapered relief valve **48** partially blocks off the expulsion orifice **46** of the second rear end **38** of the tubular body **34**. The tapered relief valve **48** presents a tapered front face coaxial to the tubular body **34** so that the top of the cone is facing towards the interior of the tubular body **34**. The diameter of the base is substantially equal to the diameter of the expulsion orifice **46**.

[0054] The tapered relief valve **48** can be set axially, for example by means of a screw (not represented), so as to be able to axially separate the periphery of the base of the tapered relief valve **48** from the edge of the expulsion orifice **46**.

[0055] A first fraction "FC" of the incoming swirling air stream **44** is expelled outside the chamber **12** through the space reserved between the tapered relief valve **48** and the edge of the expulsion orifice **46** in the form of a hot air stream **50** while a second fraction "FF" of the incoming swirling air stream **44** is reflected towards the front end **36** of the tubular body **34**, forming a second concentric swirling air stream **52** inside the first incoming swirling air stream **44**.

[0056] The reflected swirling air stream **52** is cooled by heat transfer radially towards the incoming swirling air stream **44**.

[0057] The first front end **36** of the tubular body **34** is sealed by a radial wall **54** in which is formed an outlet orifice **56**, called cold orifice, so as to allow the second fraction "FF" of the reflected swirling air stream **52** to leave in the form of a cold air stream **58** inside the chamber **12**.

[0058] Such a Hilsch-Ranque vortex tube **24** operates under the action of the injected compressed air with air rotation speeds that are, for example, of the order of 500000 to 1000000 revolutions/min. These rotation speeds provoke air jet noises which are advantageously muffled by fitting a silencer to the rear expulsion orifice **46** for the hot air stream **50**.

[0059] As a variant, or in combination, a silencer can be arranged at the front outlet orifice **56** of the cold air stream **58**.

[0060] The outlet temperature "θ_{SF}" of the cold air stream **58** depends mainly on three parameters, which are the injection pressure "P_{inj}", the air injection temperature "θ_{inj}" and the fraction "FC" of the hot air stream **50** expelled through the tapered relief valve **48**.

[0061] As a general rule, the temperature drop between the air injection temperature "θ_{inj}" and the cold outlet temperature "θ_{SF}" is globally inversely proportional to the injection pressure "P_{inj}".

[0062] The hot air stream **50** expelled by the Hilsch-Ranque vortex tubes **24** is expelled outside the chamber **12** through the intermediary of an exhaust duct **59** which includes inlet orifices which are each connected to an expulsion orifice **46** of an associated Hilsch-Ranque vortex tube **24** and an exhaust orifice **61** which is arranged outside the refrigerating chamber **12**.

[0063] For a refrigerating cooling application, the outlet temperature "θ_{SF}" of the cold air stream **58** is generally less than 0° C. Now, the compressed air includes a percentage humidity such that the outlet temperature "θ_{SF}" of the cold air stream **58** leaving the Hilsch-Ranque vortex tube **24** is less than the dew point. This humidity then risks being condensed and then forming ice inside the chamber **12**.

[0064] To avoid this problem, an air dryer **60**A, **60**B is inserted into each supply circuit **32**A, **32**B so that the compressed air is dried before being injected into the Hilsch-Ranque vortex tubes **24**. Thus, the air will be dried so that its dew point is lowered below the cold air outlet temperature "θ_{SF}", for example the dew point of the dried air is −40° C.

[0065] The air driers **60**A, **60**B have to be regularly regenerated in order to expel the retained humidity water in steam form. By having two parallel supply circuits **32**A, **32**B, it is possible to regenerate the air drier **60**A, **60**B of a supply circuit **32**A, **32**B while the Hilsch-Ranque tubes **24** are supplied by the other supply circuit **32**B, **32**A.

[0066] In the interests of optimizing the overall energy consumption of the cooling device **10**, the heat used to evaporate the humidity is supplied by the hot air stream **50** expelled by the Hilsch-Ranque vortex tubes **24**.

[0067] The hot air stream **50** is led to the air driers **60**A, **60**B through a tap duct **62** which is top connected to the exhaust duct **59**. The tap duct **62** includes a fork in order to supply in parallel each of the two reheating circuits upstream of the associated air drier **60**A, **60**B.

[0068] The hot air stream **50** is intended to enter into the air drier **60**A, **60**B via the same inlet orifice as the compressed air. Thus, each reheating circuit is connected to an associated supply circuit **32**A, **32**B upstream of the associated air drier **60**A, **60**B.

[0069] The tapping of the hot air stream **50** in the tap duct **62** is controlled by a three-way tap valve **64** which is arranged at the connection between the exhaust duct **59** and the tap duct **62**.

[0070] Then, the switching of the duly diverted hot air stream **50** to one or other of the air driers **60**A, **60**B is controlled by a three-way regulation valve **66**A, **66**B which is arranged at the connection between each supply circuit **32**A, **32**B and tap duct **62**. The regulation valves **66**A, **66**B are controlled between a supply position in which the hot air stream **50** is completely blocked, the compressed air supplying the associated air drier **60**A, **60**B, and a drying position in which a mixture of compressed air and hot air stream **50** supplies the associated air drier **60**A, **60**B.

[0071] The moist hot air stream **50** leaving the regenerated air drier **60**A, **60**B is then discharged outside the refrigerating chamber **12** without being injected into the Hilsch-Ranque vortex tubes **24**. To this end, a three-way discharge valve **68**A, **68**B is arranged in each supply circuit **32**A, **32**B downstream of the air drier **60**A, **60**B. The discharge valves **68**A, **68**B include a discharge orifice **70** which is connected to the exterior of the chamber **12**. The discharge valve **68**A, **68**B is likely to occupy a regeneration position in which the air that arrives from the air drier **60**A, **60**B is entirely diverted to the discharge orifice **70** and a supply position in which the air that arrives from the air driver **60**A, **60**B is entirely directed to the injection orifice **40** of the Hilsch-Ranque vortex tubes **24**.

[0072] Furthermore, to monitor the effectiveness of the air driers **60**A, **60**B, each supply circuit **32**A, **32**B is provided with a hygrostat **72** for measuring the humidity ratio "TH" of the air circulating in the associated supply circuit **32**A, **32**B downstream of the air driers **60**A, **60**B. Each hygrostat **72** is likely to send the electronic control unit **28** a signal representative of the measured humidity ratio "TH".

[0073] Moreover, the air introduced inside the chamber **12** through the intermediary of the cooling device **10** is likely to increase the air pressure inside the chamber **12** which is hermetically sealed. To avoid having the pressure increase too much, a solenoid valve **74** is provided, which is controlled between a position in which it blocks a balancing orifice of a wall of the chamber **12** and a decompression position in which the pressurized cold ambient air can leave towards the exterior through the balancing orifice under the effect of the pressure difference between the inside and the outside of the chamber **12**.

[0074] The solenoid valve **74** is controlled by the electronic control unit **28** according to the measurements made by a differential pressure stat **76** which is arranged in a wall of the refrigerating chamber **12** and which measures the differential pressure "ΔP" between the inside and the outside of the chamber **12**. The differential pressure stat **76** can send a signal representative of the measurement of the differential pressure "ΔP" to the electronic control unit **28**.

[0075] Thus, when the measured differential pressure "ΔP" between the pressure inside the chamber **12** and the pressure outside the chamber **12** exceeds an overpressure threshold, the solenoid valve **74** is controlled to its decompression position so as to expel the air causing the overpressure.

[0076] The solenoid valve **74** is controlled to its blocking position when the measured differential pressure "ΔP" between the inside and the outside of the chamber **12** is less than or equal to a second safety threshold. The safety threshold is chosen so that the pressure inside the chamber **12** is always greater than the pressure outside in order to avoid the hot outside air penetrating inside the chamber **12** through the balancing orifice.

[0077] The invention proposes a control method in which the compressed air source **16**, **30** is controlled by the electronic control unit **28**.

[0078] To implement the method set up according to the teachings of the invention, the tapered relief valve **48** is preset in such a way that the first "FC" and second "FF" air fractions are constant while the method is running. The tapered relief valve **48** is set as a preliminary step according to the maximum flow rate of the cold air current **58** likely to be produced.

[0079] Thus, the method set up according to the teachings of the invention does not entail acting on the structural elements that form the Hilsch-Ranque tubes **24**. This is all the more beneficial when the cooling device **10** includes a plurality of Hilsch-Ranque vortex tubes **24**.

[0080] The tapered relief valve **48** is, for example, set in such a way that the flow of hot air stream **50** expelled through the expulsion orifice **46** is equal to the flow of cold air stream **58** leaving through the cold outlet orifice **56**, in other words, the first "FC" and second "FF" air fractions are equal to 50%.

[0081] The outlet temperature "θ_{SF}" of the cold air stream **58** is controlled by acting solely on the injection pressure "P_{inj}" of the compressed air into the Hilsch-Ranque vortex tube **24** according to a predetermined control law.

[0082] In this application for refrigeration cooling, the injection pressure "P_{inj}" is more particularly controlled by pulses at an injection pressure "P_{inj}" which is predetermined in such a way that the ambient temperature "θ_{int}" inside the chamber **12** is maintained equal to a setpoint temperature "θ_c".

[0083] Hereinafter, the ambient temperature inside the chamber **12** will be called internal temperature "θ_{int}".

[0084] At the time of the pulses, the outlet temperature "θ_{SF}" of the cold air stream **58** is determined according to a number of parameters. As an example, the parameters can be set as follows:

[0085] the injection pressure "P_{inj}" is set at 7 or 10 bar according to the type of air compression **16** used;

[0086] the injection temperature is set at 21° C.;

[0087] the hot "FC" and cold "FF" air stream fractions are set at 50% by presetting the tapered relief valve **48**.

[0088] Thus, the outlet temperature "θ_{SF}" of the cold air stream **58**, at the time of the pulses, is predetermined. The air compressor **16** is, for example, selected so that the outlet temperature "θ_{SF}" is substantially equal to −30° C. for an injection temperature "θ_{inj}" of approximately 21° C. The temperature of the hot air stream **50** is, for example, equal to 120° C.

[0089] The duration "t" of each pulse is determined according to internal temperature "θ_{int}", the injection temperature "θ_{inj}" of compressed air into the Hilsch-Ranque vortex tube **24**, and the setpoint temperature "θ_c".

[0090] More particularly, the duration "t" of the pulse is determined by taking into account the following equation "EQ1":

$$Q_{m,of}=Q_{dep}+Q_{ref} \qquad \text{"EQ1":}$$

in which $Q_{m,af}$ represents the quantity of heat likely to be absorbed by the cold air stream **58** leaving the Hilsch-Ranque vortex tube **24** for a time unit "t";

[0091] Q_{dep} represents the heat loss through the walls of the chamber **12** for said time unit "t"; and

[0092] Q_{ref} represents the quantity of heat to be removed to cool the ambient air inside the chamber **12** to the setpoint temperature "θ_c".

[0093] The heat loss Q_{dep} through the walls of the chamber **12** is calculated according to the following equation "EQ2" which is well known to those skilled in the art:

$$Q_{dep}=K\cdot S_T\cdot(\theta_{ext}-\theta_C)\cdot t \qquad \text{"EQ2":}$$

in which "K" represents the general thermal transmission coefficient of the walls of the chamber **12** expressed in W/m^2. K;

[0094] S_T represents the surface area of the walls in m^2;

[0095] θ_{ext} represents the ambient temperature of the air outside the chamber **1 2** in K, hereinafter called external temperature;

[0096] "θ_c" represents the setpoint temperature in Kelvin.

[0097] The quantity of heat Q_{ref} to be removed to cool the ambient air inside the chamber **12** is calculated according to the following equation "EQ3" which is well known to those skilled in the art:

$$Q_{ref}=\rho_{int}\cdot V\cdot C_p\cdot(\theta_{int}-\theta_C) \qquad \text{"EQ3":}$$

in which ρ_{int} represents the density of the ambient air inside the chamber **12** expressed in kg/m^3;

[0098] V represents the volume of the chamber **12** expressed in m^3;

[0099] C_p represents the specific heat of the air at constant pressure expressed in kJ/kg;

[0100] θ_{int} represents the internal temperature expressed in K;

[0101] "θ_c" represents the setpoint temperature in K.

[0102] The quantity of heat $Q_{m,af}$ likely to be absorbed by the cold air stream **58** is calculated according to the following equation "EQ4":

$$Q_{m,af}=\mu\cdot\rho_{af}\cdot q_{m,e}\cdot h_{af}\cdot t \qquad \text{"EQ4":}$$

in which μ represents the efficiency of the compressed air source;

[0103] ρ_{af} represents the density of the cold air leaving the Hilsch-Ranque vortex tube **24** expressed in kg/m^3;

[0104] $q_{m,e}$ represents the mass flow of cold air expressed in kg/s;

[0105] h_{af} represents the quantity of heat likely to be absorbed by a kilogram of cold air leaving the Hilsch-Ranque vortex tube **24** expressed in fg/kg;

[0106] t represents the time expressed in seconds.

[0107] From balance equation "EQ1", it is possible to find the duration "t" of a compressed air injection pulse for the inside temperature "θ_{int}" to be equal to the setpoint temperature "θ_c" according to the following equation "EQ5":

$$t=\frac{\rho_{int}\cdot V\cdot C_p\cdot(\theta_{int}-\theta_{int}^c)}{\mu\cdot\rho_{af}\cdot q_{m,e}\cdot h_{af}-K\cdot S_T\cdot(\theta_{ext}-\theta_{int}^c)} \qquad \text{"EQ5"}$$

[0108] It will be observed that, to be able to calculate the duration "t" of the pulse, in addition to the constants that are established beforehand according to the physical properties of the air or the specifications of the compressed air source, it is necessary to know the parameter values that are likely to change during the method. These parameters are the external temperature "θ_{ext}", the inside temperature "θ_{int}" and the setpoint temperature "θ_c".

[0109] The setpoint temperature "θ_c" can be predefined or indeed set by the user for example by means of an appropriate interface for entering data into the electronic control unit **28**.

[0110] The inside "θ_{int}" and outside "θ_{ext}" temperatures are measured by at least two thermal probes **78** that are arranged respectively inside and outside the refrigerating chamber **12**. Each thermal probe **78** comprises means for transmitting a signal representative of the measured temperature to the electronic control unit **28**.

[0111] The table below represents the pulse durations "t" in seconds of the cooling device **10** controlled according to the inventive method according to the external temperature "θ_{ext}" and the internal temperature "θ_{int}" to achieve a setpoint temperature "θ_c" of −25° C. for a refrigerating chamber **12** with a volume of 12 m^3 and made of a highly insulating material having a general thermal transmission coefficient "K" less than 0.35 kcal/m^2.K.

	θext									
Θint	25	26	28	30	32	34	35	36	38	40
−25	0	0	0	0	0	0	0	0	0	0
−24	3	3	3	3	3	3	3	3	3	3
−23	5	5	5	5	5	5	5	5	5	5
−22	8	8	8	8	8	8	8	8	8	8
−21	10	10	10	10	10	10	11	11	11	11
−20	13	13	13	13	13	13	13	13	13	13
−19	15	15	15	15	16	16	16	16	16	16
−18	18	18	18	18	18	18	18	18	18	18
−17	20	20	20	21	21	21	21	21	21	21
−16	23	23	23	23	23	23	23	23	23	23
−15	25	25	25	25	26	26	26	26	26	26
−14	28	28	28	28	28	28	28	28	28	28
−13	30	30	30	30	30	31	31	31	31	31
−12	32	32	33	33	33	33	33	33	33	33
−11	35	35	35	35	35	35	35	35	36	36
−10	37	37	37	37	38	38	38	38	38	38
−9	39	39	40	40	40	40	40	40	40	41
−8	42	42	42	42	42	42	43	43	43	43
−7	44	44	44	44	45	45	45	45	45	45
−6	46	46	47	47	47	47	47	47	47	48

[0112] The method of controlling the refrigerating cooling device **10** is represented in FIG. **3**. When the method is running, all the control and comparison actions are performed by the electronic control unit **28**.

[0113] On the initialization "E**0**" of the method, the setpoint temperature "θ_c" is given as a parameter of the electronic control unit **28**.

[0114] In a first measurement step "E**1**", the measurements of the internal temperature "θ_{int}", of the external temperature "θ_{ext}", of the differential pressure "ΔP" and of the humidity ratio "TH" are transmitted to the electronic control unit **28**.

[0115] Then, in a second comparison step "E**2**", the internal temperature "θ_{int}" is compared with the setpoint temperature "θ_c".

[0116] If the internal temperature "θ_{int}" is less than the setpoint temperature "θ_c", the internal temperature "θ_{int}" is compared to an alarm temperature "θ_{al}" above which the cold subsystem risks being broken.

[0117] If the alarm temperature "θ_{al}" is exceeded, an alarm is triggered.

[0118] If the internal temperature "θ_{int}" is between the setpoint temperature "θ_c" and the alarm temperature "θ_{al}", a third step for controlling the injection pressure "E**3**" is triggered during which the Hilsch-Ranque vortex tubes **24** are supplied with compressed air by the air compressor **16**.

[0119] The duration "t" of the injected compressed air pulse is calculated by the electronic control unit **28** as explained previously in such a way that the internal temperature "θ_{int}" once again becomes equal to the setpoint temperature "θ_c".

[0120] When the duration "t" of the pulse is exceeded, the supply valve **26** is controlled to its total closure position. Thus, the Hilsch-Ranque vortex tubes **24** are no longer supplied with compressed air.

[0121] Then, the method returns to the first measurement step "E**1**".

[0122] From the second comparison step "E**2**", when the internal temperature "θ_{int}" is less than or equal to the setpoint temperature "θ_c", the method triggers a fourth step "E**4**" for checking the pressure that is triggered when the differential pressure "ΔP" between inside and the outside of the chamber **12** exceeds the set overpressure threshold. During this step, the solenoid valve **74** is controlled in such a way that the differential pressure "ΔP" is equal to the safety threshold.

[0123] When the differential pressure "ΔP" is less than the overpressure threshold, and the humidity ratio "TH" inside the chamber **12** is greater than an icing threshold, a fifth step "E**5**" for regeneration of the air driers **60**A, **60**B is triggered. During this step, the tap **64**, discharge **68**A, **68**B and regulator **66**A, **66**B valves are controlled in such a way as to regenerate one and then the other of the air driers **60**A, **60**B.

[0124] The method implemented according to the teachings of the invention makes it possible to very effectively cool a refrigerating chamber **12** through the intermediary of Hilsch-Ranque vortex tubes **24** by acting solely on the compressed air injection pressure "P_{inj}".

[0125] This is particularly advantageous because the cooling method does not entail acting individually on the tapered relief valve **48** on each of the Hilsch-Ranque vortex tubes **24**, but by acting in a centralized manner on the compressed air source which is common to all the Hilsch-Ranque vortex tubes **24**. Thus, the cooling device **10** is less costly to manufacture and is easy to control.

[0126] According to a second embodiment of the invention, a similar method can be applied to an air conditioning device equipped with Hilsch-Ranque vortex tubes **24**.

[0127] FIG. **4** represents an air conditioning device **80** which is intended to cool a sealed chamber **12**. The chamber **12** is in this case formed by the passenger compartment of a motor vehicle, such as a bus, in which the air conditioning device **80** is installed.

[0128] According to a variant that is not represented of the invention, the air conditioning device is designed in such a way as to be able to be installed in a lift cabin in order to be able to air-condition its interior.

[0129] According to another variant that is not represented of the invention, the air conditioning device is also adapted for immobile applications, such as the air conditioning of rooms of a building.

[0130] The chamber **12** of the vehicle is sealed by four vertical walls **14**, by a bottom wall (not represented) and by a top wall (not represented).

[0131] As for the first embodiment, the air conditioning device **80** mainly comprises a compressed air source which supplies, through the intermediary of a supply circuit **32**A, **32**B, a plurality of Hilsch-Ranque vortex tubes **24**. An exhaust duct **59** routes the hot air stream **50** expelled by the

Hilsch-Ranque vortex tubes **24** to an exhaust orifice **61** which discharges outside the chamber **12**.

[0132] The compressed air source is in this case formed by an air compressor **16** which is driven by an autonomous electric motor (not represented). The electric motor is, for example, supplied by an electricity accumulator which is regularly recharged by an alternator driven by the heat engine of the motor vehicle.

[0133] According to an unrepresented variant of the invention, the air compressor is driven by the heat engine of the motor vehicle through the intermediary of a hydraulic pump and a hydraulic motor.

[0134] The air is sucked by the air compressor **16** outside the chamber **12** via a suction duct **18**.

[0135] Advantageously, the air compressor **16** is selected in such a way as to ensure the renewal of the air of the passenger compartment according to the maximum number of people that the motor vehicle is likely to transport simultaneously. In practice, a passenger enclosed in the chamber **12** consumes an air flow rate that is, for example, approximately 4 m^3/h. This flow rate has to be multiplied by the maximum number of people that the vehicle can transport simultaneously, for example 100 people. The air available in the chamber **12** depends on the volume of the chamber.

[0136] To avoid suffocation, the air must be renewed according to a renewal rate "τ_r" calculated according to the following equation "EQ6":

$$\tau_r = \frac{q_{vs}}{V_u} \qquad \text{"EQ6"}$$

in which "q_{vs}" represents the air flow rate expired by the maximum number of passengers that the passenger compartment of the vehicle is likely to contain simultaneously, expressed in m^3/h;

[0137] V_u represents the volume of the passenger compartment expressed in m^3.

[0138] From this calculation, the selected air compressor **16** is, for example, likely to output 0.84 m^3/h to ensure the renewal of the air.

[0139] Concerning an air conditioning device **80**, the objective is in this case to cool the internal temperature "θ_{int}" of the chamber **12** by a few degrees relative to the external temperature "θ_{ext}", in particular when the external temperature "θ_{ext}" is considered to be hot, for example above 25° C. For example, the air conditioning device **80** is designed for the internal temperature "θ_{int}" to be 6° C. less than the external temperature "θ_{ext}".

[0140] Advantageously, the cold air stream is blown at the height of the head of an individual of average size, considering the population that is likely to be present inside the chamber. Thus, the heads of the individuals are cooled as a priority, because that is where the hypothalamus, which is the human body's thermal regulator, is located. This is a principle that we call "Human Occipital Cooling" (abbreviated HOC).

[0141] To be able to know the internal temperature "θ_{int}", a thermal probe **78** is arranged inside the chamber **12**.

[0142] This objective is reached by maintaining the outlet temperature "θ_{SF}" of the cold air stream **58** leaving the Hilsch-Ranque vortex tubes **24** as close as possible to the dew point, which is in this case 0° C., without this outlet temperature "θ_{SF}" of the cold air stream **58** being less than the dew point.

[0143] The temperature of the hot air stream **50** is then, for example, equal to 120° C.

[0144] Since the outlet temperature "θ_{SF}" of the cold air stream **58** blown through the cold outlet orifice **56** of the Hilsch-Ranque vortex tubes **24** is greater than the dew point of the air in normal atmospheric conditions, the device does not include an air drier **60**A, **60**B, and it includes only a single supply circuit **32**.

[0145] The air conditioning device **80** is controlled according to a control method in which, in a manner similar to that described in the first embodiment, the outlet temperature "θ_{SF}" of the cold air stream **58** is controlled by acting only on the injection pressure "P_{inj}" of the air in the Hilsch-Ranque vortex tube **24** according to a predetermined control law.

[0146] However, unlike the first embodiment, the compressed air is in this case injected continuously and not by pulses.

[0147] Furthermore, the outlet temperature "θ_{SF}" of the cold air stream **58** is automatically regulated by the electronic control unit **28** by varying the injection pressure "P_{inj}" of the compressed air so that the outlet temperature "θ_{SF}" is always greater than or equal to a minimum temperature "θ_{min}", for example 0° C., to avoid condensation of the humidity present in the cold air stream at the outlet of the Hilsch-Ranque vortex tube. To this end, the air conditioning device **80** includes a pneumatic regulator-expansion valve **82** which is inserted in the supply circuit **32** to adjust the injection pressure "P_{inj}" of the compressed air. The regulator-expansion valve **82** is controlled by the electronic control unit **28**.

[0148] It will be recalled that the parameters that influence the outlet temperature "θ_{SF}" of the cold air stream **58** are as follows:

[0149] the setting of the tapered relief valve **48** which determines the fraction "FF" of air reflected towards the outlet of the Hilsch-Ranque vortex tube **24**;

[0150] the injection temperature "θ_{inj}" of the compressed air;

[0151] the injection pressure "P_{inj}" of the compressed air.

[0152] In the inventive control method, the tapered relief valve **48** is preset so that the fraction "FF" of reflected air remains constant throughout the method. For an air conditioning device **80**, this fraction "FF" of reflected air is, for example, equal to 70%.

[0153] The injection temperature "θ_{inj}" of the air is generally equal to the external temperature "θ_{ext}" of the air when it is sucked into the air compressor **16** to which must be added a constant which is, for example, equal to 10° C. or 15° C. according to the type of air compressor **16** used. To be able to know the injection temperature, the air conditioning device **80** therefore includes a temperature probe **78** which can transmit to the electronic control unit **28** a signal representative of the measured external temperature "θ_{ext}", from which it is possible to know the injection temperature "θ_{inj}".

[0154] The maximum injection pressure "P_{max}" at which the air can be injected depends on the selected air compressor **16** as indicated previously. The maximum injection pressure "P_{max}" is for example, equal to 8 bar.

[0155] In the method implemented according to the teachings of the invention, the air compressor **16** permanently compresses the air at the maximum pressure "P_{max}", then, the injection pressure "P_{inj}" is regulated by controlling the regulator-expansion valve **82**.

[0156] Thus, the injection pressure "P_{inj}" of the air can be controlled in an injection pressure range between 1 and 8 bar.

Bearing in mind that the temperature drop "ΔT" between the injection temperature "θ_{inj}" and the outlet temperature "θ_{SF}" of the cold air stream **58** is inversely proportional to the pressure "P_{inj}" of the injected compressed air, the limitation of the injection pressure "P_{inj}" to **8** bar means ipso facto that the temperature drop "ΔT" will also be limited. The maximum temperature drop is, for example, 41° C.

[0157] The fraction "FF" of reflected air being constant, it is possible to deduce the injection pressure "P_{inj}" of the air by using the following equation "EQ7":

$$\Delta T=-0.0397\cdot(P_{inj})^4+0.8377\cdot(P_{inj})^3-6.5497\cdot(P_{inj})^2+24.912\cdot(P_{inj})-5.3973 \quad \text{"EQ7":}$$

in which "ΔT" represents the temperature drop between the injection temperature "θ_{inj}" and the cold outlet temperature "θ_{SF}"; and "P_{inj}" represents the injection pressure of the compressed air.

[0158] This equation "EQ7" is here obtained by interpolation, for example by the least squares method, based on a table of values supplied by the manufacturer of the Hilsch-Ranque vortex tubes **24**. It is in this case a fourth degree polynomial.

[0159] This equation "EQ7" is a correct approximation for an injection temperature "θ_{inj}" equal to a reference temperature "θ_{ref}" which is in this case equal to 21° C. When the injection temperature "θ_{inj}" differs from this reference temperature "θ_{ref}", it is possible to multiply the measured temperature drop "ΔT" by a correction factor which is equal to the injection temperature "θ_{inj}" divided by the reference temperature "θ_{ref}".

[0160] Such an approximation is sufficient to implement the air conditioning function of the air conditioning device **80** while retaining sufficient precision for the outlet temperature "θ_{SF}" of the cold air stream **58** not to fall below the minimum temperature "θ_{mi}n" of 0° C.

[0161] The control method of the air conditioning device **80** is now described.

[0162] In a first measurement step "C**1**" the external temperature "θ_{ext}" and the internal temperature "θ_{int}" are measured by the thermal probes **78** and transmitted to the electronic control unit **28**.

[0163] Then, a second step "C**2**" for calculating the outlet temperature "θ_{SF}" of the cold air stream **58** is triggered when the difference between the external temperature "θ_{ext}" and the internal temperature "θ_{int}" is less than a comfort value which is, for example, 7° C. During this step, the outlet temperature "θ_{SF}" is calculated by subtracting a predetermined constant value from a measurement of the injection temperature "θ_{inj}" of the compressed air.

[0164] The predetermined constant value is defined according to the characteristics of the selected air compressor **16**, and notably according to the maximum injection pressure "P_{max}" at which the air can be compressed. This constant value is more particularly equal to the maximum temperature drop "ΔT" that it is possible to obtain with the air compressor **16** and which is, for example, equal to 41° C. In other words, the outlet temperature "θ_{SF}" of the cold air stream **58** cannot be more than 41° C. less than the injection temperature "θ_{inj}" of the air, this temperature drop "ΔT" being obtained for the maximum injection pressure "P_{max}".

[0165] Then, a subsequent third step "C**3**" for correcting the outlet temperature "θ_{SF}" of the cold air stream **58** calculated during the second calculation step "C**2**" is triggered when said outlet temperature "θ_{SF}" is less than the minimum temperature "θ_{min}" of 0° C. The outlet temperature "θ_{SF}" is corrected so as to be greater than or equal to said minimum temperature "θ_{min}" $_{of}$0° C.

[0166] The minimum temperature "θ_{min}" is in this case set at 0° C. It can of course change according to the atmospheric conditions in which the motor vehicle is required to operate.

[0167] According to the result of this last step "C**3**", the temperature drop "ΔT" between the injection temperature "θ_{inj}" and the desired outlet temperature "θ_{SF}" of the cold air stream **58** is known.

[0168] The injection pressure "P_{inj}" of the compressed air is then calculated by the resolution of the interpolation equation "EQ7" in a fourth control step "C**4**". When this equation "EQ7" allows a number of injection pressures "P_{inj}" as a solution, the highest injection pressure "P_{inj}" that is within the pressure range of the air compressor **16** is retained by the electronic control unit **28**.

[0169] Then, the electronic control unit **28** drives the regulator-expansion valve **82** so that the injection pressure "P_{inj}" of the compressed air is effectively equal to the calculated injection pressure.

[0170] Then, the method is repeated, for example, at the end of a time delay which is, for example, equal to 60 seconds.

[0171] Thanks to the method implemented according to the teachings of the invention, it is therefore possible to control in a centralized way a plurality of Hilsch-Ranque vortex tubes by acting only on the injection pressure "P_{inj}". Such a method is less costly and simple to implement.

[0172] According to a third embodiment of the invention that is not represented, the devices explained in the initial embodiments of the invention can also be used as heating devices by routing the hot air stream **50** expelled from the Hilsch-Ranque vortex tube **24** to the place or the object to be heated.

[0173] For example, the exhaust duct **59** of the air conditioning device **80** includes an orifice opening out inside the chamber **12**. The orifice is blocked off by a controlled valve. When it is necessary to heat the chamber **12**, the valve is then controlled to open.

[0174] The temperature of the hot air stream **50** can equally be calculated according to the injection pressure "P_{inj}" of the compressed air and the injection temperature "θ_{inj}" of the compressed air. Thus, it is possible to control the temperature of the hot air stream **50** by acting only on the injection pressure "P_{inj}" of the air through the intermediary of the electronic control unit **28**.

[0175] It will be understood that these embodiments are given by way of indication and that the control method is applicable to any device of the same type including Hilsch-Ranque vortex tubes that is used to cool or heat a chamber or any element.

1. Method of controlling a device for air conditioning (**80**) or cooling by refrigeration (**10**) or heating the interior of a sealed chamber (**12**), the device (**10**, **80**) comprising at least one compressed air source (**16**, **30**) which supplies at least one Hilsch-Ranque tube (**24**), called "vortex" tube, with compressed air at an injection pressure (P_{inj}), the Hilsch-Ranque vortex tube (**24**) comprising:

at least one tangential orifice (**40**) for injecting compressed air into the Hilsch-Ranque vortex tube (**24**) which is arranged close to a first end (**36**) of the Hilsch-Ranque vortex tube, the injected air forming a first incoming stream of swirling air (**44**) towards a second end (**38**) of the Hilsch-Ranque vortex tube;

a tapered relief valve (**48**) which partially blocks off a first expulsion orifice (**46**) of the second end (**38**) of the Hilsch-Ranque vortex tube so that a first fraction (FC) of the incoming hot air stream (**44**) is expelled outside the chamber (**12**) while a second fraction (FF) of the air stream is reflected towards the first end (**36**) of the Hilsch-Ranque vortex tube forming a second concentric swirling air stream (**52**) inside the first swirling stream (**44**), the reflected air stream (**52**) being cooled by heat exchange with the incoming air stream (**44**);

a "cold" outlet orifice (**56**) for the reflected air (**52**) which is arranged at the first end (**36**) of the Hilsch-Ranque vortex tube so as to allow the second fraction (FF) of the cold air stream (**52**) to leave inside the chamber (**12**);

characterized in that the tapered relief valve (**48**) is preset so that the first (FC) and second (FF) fractions of air are constant while the method is running and in that it comprises a step (E**3**, C**4**) for controlling the compressed air injection pressure (P_{inj}).

2. Control method according to claim **1**, characterized in that the outlet temperature (θ_{SF}) of the cold air stream is controlled by acting only on the injection pressure (P_{inj}) of the air into the Hilsch-Ranque vortex tube (**24**) according to a predetermined control law (EQ7).

3. Control method according to claim **1**, characterized in that it comprises a step (C**2**) for calculating the outlet temperature (θ_{SF}) of the cold air stream prior to the step for controlling the injection pressure (C**4**) during which said outlet temperature (θ_{SF}) is calculated by subtracting a predetermined constant value from the compressed air injection temperature (θ_{inj}),

and in that it comprises a step for correcting (C**3**) the calculated cold air stream outlet temperature (θ_{SF}), which is triggered when said outlet temperature (θ_{SF}) during the preliminary calculation step (C**2**) is less than a minimum temperature (θ_{min}) and during which the outlet temperature (θ_{SF}) is corrected so as to be greater than or equal to said minimum temperature (θ_{min}).

4. Control method according to claim **3**, characterized in that the compressed air source (**16**) is an air compressor which sucks in ambient air from outside the chamber (**12**), and in that the injection temperature (θ_{inj}) is proportional to the external temperature (θ_{ext}) of the chamber (**12**).

5. Control method according to claim **4**, characterized in that the chamber (**12**) is a passenger compartment of a motor vehicle in which the air conditioning device (**80**) is installed and in that the air compressor (**16**) is driven by the heat engine of the motor vehicle through the intermediary of a hydraulic pump and a hydraulic motor.

6. Control method according to claim **2**, characterized in that the injection pressure (P_{inj}) is controlled by pulses at an injection pressure (P_{inj}) which is predetermined, the duration (t) of each pulse being determined in such a way that the chamber (**12**) is maintained at a setpoint temperature (θ_c).

7. Method according to claim **6**, characterized in that the duration (t) of each pulse is determined as a function of the ambient temperature inside the chamber (θ_{int}), of the injection temperature of compressed air into the Hilsch-Ranque vortex tube (θ_{inj}), and of the setpoint temperature (θ_c).

8. Control method according to claim **7**, characterized in that the duration (t) of each pulse is determined by taking into account the balance (EQ1) between:

the sum of the heat losses (Q_{dep}) through the walls of the chamber (**12**) per time unit and the quantity of heat to be removed (Q_{ref}) to cool the air inside the chamber (**12**) to the setpoint temperature (θ_c), and

the quantity of heat ($Q_{m,af}$) likely to be absorbed by the cold air leaving each Hilsch-Ranque vortex tube (**24**) for said time unit.

9. Method according to claim **7**, characterized in that the air is dried by drying means (**60**A, **60**B) before its injection into each Hilsch-Ranque vortex tube (**24**) so that its dew point is less than the air outlet temperature (θ_{SF}).

10. Device (**10**, **80**) for implementing the method according to claim **1**, characterized in that it comprises a plurality of Hilsch-Ranque vortex tubes (**24**) which are fed in parallel by at least one common compressed air source (**16**, **30**) and in that each Hilsch-Ranque vortex tube (**24**) includes a tapered relief valve (**48**) that can be adjusted only manually.

11. Method according to claim **8**, characterized in that the air is dried by drying means (**60**A, **60**B) before its injection into each Hilsch-Ranque vortex tube (**24**) so that its dew point is less than the air outlet temperature (θ_{SF}).

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