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(12) (19) (CA) **Demande-Application**

(21) (A1) **2,313,788**
(22) 2000/07/12
(43) 2001/01/30

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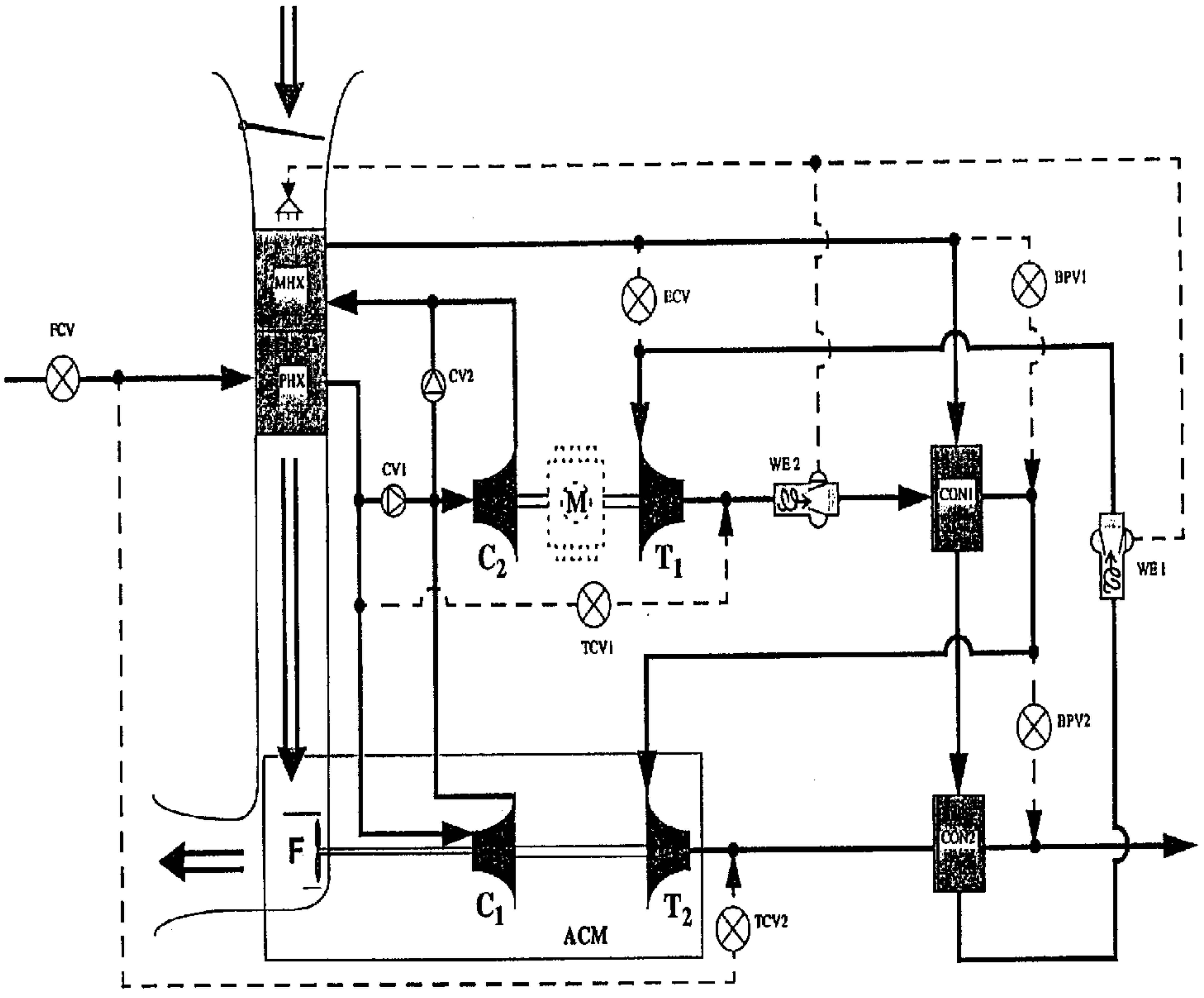
(51) Int.Cl.^{7} B64D 13/00
(30) 1999/07/30 (199 35 918.0) DE

(54) SYSTEME DE CONDITIONNEMENT D'AIR POUR CABINE D'AVION

(54) AIR-CONDITIONING SYSTEM FOR AIRPLANE CABINS



(57) An air-conditioning system in particular for aircraft is proposed wherein pressurized, moisture-containing air is conditioned for air-conditioning the cabin. The pressurized air is compressed further in two separate stages, dehumidified in a high-pressure water extraction cycle and subsequently expanded in one or two turbine stages. Depending on the design one can thereby achieve ice-free conditioned air or a high efficiency of the air-conditioning-system, in particular if two turbine stages are provided and the energy gained in the particular turbine stages is utilized regeneratively, distributed over the compressor stages.

Abstract

An air-conditioning system in particular for aircraft is proposed wherein pressurized, moisture-containing air is conditioned for air-conditioning the cabin. The pressurized air is compressed further in two separate stages, dehumidified in a high-pressure water extraction cycle and subsequently expanded in one or two turbine stages. Depending on the design one can thereby achieve ice-free conditioned air or a high efficiency of the air-conditioning-system, in particular if two turbine stages are provided and the energy gained in the particular turbine stages is utilized regeneratively, distributed over the compressor stages.

Air-conditioning system for airplane cabins

This invention relates to an air-conditioning system for conditioning moisture-containing, pressurized air for air-conditioning a room, in particular for air-conditioning airplane cabins, and to a corresponding method.

Fresh air for air-conditioning airplane cabins is conditioned from the air (known as bleed) bled off the engine at high pressure and high temperature. Air-conditioning systems draw the necessary cooling power out of the pressure and temperature potential of the engine air. In the course of the fresh-air conditioning process the bleed is cooled, dehumidified and expanded to the cabin pressure of 1 bar in ground operation or about 0.8 bars in flight operation. Special value is attached in fresh-air conditioning to dehumidification in order to prevent icing of individual components of the air-conditioning system and ice crystallization in the fresh air to be conditioned. The necessity of dehumidification exists mainly in ground operation, however, because in flight operation, i.e. at high altitudes, ambient air and thus the bled-off engine air is already extremely dry.

With reference to Fig. 4 an air-conditioning system will be described in the following as is used in present-day Airbus and Boeing passenger airplanes, for example the A330/340 and Boe 757/767.

Via flow control valve *FCV* the amount of bleed required for supplying fresh air to the cabin is bled off an engine at about 2 bars and 200°C. In ground operation bleed is withdrawn from an auxiliary engine at about 3 bars. The bleed is first passed through primary heat exchanger *PHX* and cooled to about 100°C. Then the bleed is compressed further in compressor *C* to about 4.5 bars and 160°C and cooled again to about 45°C in main heat exchanger *MHX*. The high pressure of 4.5 bars is necessary to be able to realize a high degree of dehumidification in the following water extraction cycle. This air cycle system is therefore also known as a "high-pressure water extraction cycle".

The high-pressure water extraction cycle comprises condenser *CON*, as proposed in EP 0 019 492 A3, and water extractor *WE* following condenser *CON*. Compressed, cooled bleed is cooled in condenser *CON* by about $\Delta T = -15K$, condensed water is then extracted in water extractor *WE*, and the thus dehumidified air is subsequently expanded in turbine *T* to the cabin pressure of about 1 bar, the temperature at the turbine outlet being about -30°C. Thus conditioned bleed, before being mixed as fresh air with recirculated cabin air in a mixing chamber, is passed through condenser *CON* of the high-pressure water extraction cycle in heat-exchanging fashion in order to cool the compressed, cooled bleed to the temperature necessary for water extraction in water extractor *WE*. Air expanded in turbine *T* and cooled is thereby accordingly heated again by $\Delta T = +15K$ to about -15°C.

The conditioned air is then mixed with recirculated cabin air in a mixing chamber (not shown). Temperature control valve *TCV* can be used to increase the temperature at the turbine outlet to obtain an optimum mixing temperature with the admixed, recirculated cabin air. For this purpose part of the bleed precooled in primary heat exchanger *PHX* is branched off and resupplied to the conditioned air stream after turbine *T*.

The high-pressure water extraction cycle has, in addition to condenser *CON*, heat exchanger *REH* (reheater) preceding condenser *CON*. Compressed, cooled bleed is first passed through heat exchanger *REH* before entering condenser *CON*, and subsequently the dehumidified air is passed through heat exchanger *REH* before entering turbine *T*. Heat exchanger *REH* has substantially the function of heating the dehumidified air by about $\Delta T = 5K$ and vaporizing residual moisture while simultaneously recovering energy before air enters the turbine. Residual moisture in the form of fine droplets can destroy the turbine surfaces since air almost reaches the speed of sound in turbine *T*. A second function of heat exchanger *REH* is to relieve condenser *CON* by cooling compressed, cooled bleed before it enters condenser *CON* by $\Delta T = -5K$.

It is typical of such an air-conditioning system that the energy gained in turbine *T* is used to drive compressor *C*, on the one hand, and fan *F*, on the other. All three wheels, that is turbine/compressor/fan, are disposed on a common shaft and form air cycle machine *ACM*, also known as a three-wheel machine Fan *F* conveys a cooling air stream branched off from ambient air through a cooling shaft in which primary and main heat exchangers *PHX*, *MHX* are disposed. Fan *F* must be driven actively by turbine *T* in particular in ground operation. In flight operation ram air suffices, it being optionally throttled by a valve at the cooling shaft inlet.

The overall system is designed for ground operation at an ambient temperature of 38°C. In order to optimize the effectiveness of the heat-exchange process in the cooling shaft, water gained in the high-pressure water extraction cycle is supplied at a temperature of about $T = 20°C$ and a pressure of 3.5 bars in the cooling shaft inlet in fine droplets to be vaporized therein, thereby improving the effectiveness of the heat exchangers.

In case air cycle machine *ACM* fails completely, for example because the necessary mass flow rate of compressed air is not attainable for fulfilling the parameters necessary for the system to work, bypass valve *BPV* is provided for bypassing turbine *T*. In this case check valve *CV* opens automatically since an overpressure triggering check valve *CV* builds up before compressor *C* as turbine *T* is not driven. The opening of check valve *CV* causes compressor *C* to be bypassed or "short-circuited". In this state, fresh air is supplied directly through primary and main heat exchangers *PHX*, *MHX* to the mixing chamber following the air-conditioning system to be mixed with recirculated cabin air.

As mentioned at the outset, icing in the conditioned fresh air is a problem. In order to avoid icing, anti-icing valve *AIV* is provided for directly branching off part of the air bled off the engine and resupplying it to the conditioned air stream after turbine *T*. A further way of avoiding ice is to design the turbine such that no temperatures below 0°C occur at the turbine outlet. However, this latter variant requires much more energy if the same cooling power is to be reached. Therefore, it is preferable to supply hot air at the turbine outlet.

An improved variant of this air-conditioning system provides that air cycle machine *ACM* is extended by a second turbine. This makes the three-wheel machine, turbine/compressor/fan, into a four-wheel machine, turbine/turbine/compressor/fan (US 5,086,622). The second turbine is disposed on a common shaft with the other wheels in order to recycle the energy gained by the turbines into the air-conditioning system, as in the conventional three-wheel system. The second turbine supplements the first turbine such that air dehumidified in the high-pressure water extraction cycle is expanded in two stages, the condenser of the high-pressure water extraction cycle being disposed with the air pipe between the two turbines in heat-exchanging fashion. This is more favorable energetically than the conventional structure of the air-conditioning system because air exiting the first turbine is comparatively warm, preferably above 0°C to avoid ice, and this air is heated in condenser *CON* by for example $\Delta T = +15$ Kelvin to a comparatively high energy level, so that the second turbine can utilize this high energy level to gain energy which gets lost in the conventional system. This system is known in expert circles as a "condensing cycle".

A development of the four-wheel machine is described in WO 99/24318 and generally designated a 2+2-wheel system. The two turbines are accordingly disposed on separate shafts, the first turbine with the compressor and the second turbine with the fan being on a common shaft in each case.

The problem of the present invention is to adapt the above-described air-conditioning system or method so that it can be designed more flexibly and the overall efficiency optimized more easily, in particular to make it adaptable to the particular system requirements more flexibly and therefore better energetically through a greater number of freely selectable system parameters.

A further problem is to provide an air-conditioning system and method with which one can reduce icing during air conditioning.

A further problem is to improve overall efficiency over known systems and methods.

Yet a further problem is to be seen in increasing overall efficiency in particular in flight operation.

These problems are solved by the air-conditioning system and method having the features stated in the independent patent claims and claims dependent thereon.

It is essential to the invention that compression of bleed is effected in two stages. One of the two compression stages procures the energy required for compression in conventional fashion by regenerative utilization of energy gained during expansion of dehumidified air. For this purpose one of the two compressor wheels is disposed on a common shaft with a turbine wheel, for example, so that compressor wheel and turbine wheel, optionally with a fan wheel in addition, form a (first) two-or three-wheel air cycle machine. The compressor wheel of the first compression stage is preferably disposed on a common shaft with the turbine wheel, but it can also be the compressor wheel of the second compressor stage. The other compressor wheel can be driven with energy external to the system for example. This makes it possible to design the (first) air cycle machine such that the compressor and turbine disposed on a common shaft have comparatively high efficiency. This initially results in the compressor power of the air cycle machine being below the compressor power necessary for bringing the engine air to be conditioned to the pressure necessary for air dehumidification. The lacking compressor power is therefore provided by the additional compressor stage. This permits the air-conditioning system to be designed flexibly and the overall efficiency optimized easily.

Due to the second compressor stage it is in particular possible to produce ice-free conditioned air. The invention exploits the fact that at a given temperature the amount of water condensing out of air increases with rising pressure. Since the temperature can only be influenced within limits due to the system, in particular because compressed engine air cooled in the main heat exchanger cannot be cooled below ambient temperature in the cooling shaft (designed for 38°C ambient temperature), a comparatively high compression pressure of ≥ 4.6 bars can be produced with the additional compressor stage to reach the desired high degree of condensation in the high-pressure water extraction cycle. Freedom from ice is reached e.g. at -10°C and 1 bar with < 1.8 g of water per kilogram of dry air.

Instead of having a power source external to the system for the additional compressor, one can also operate the latter regeneratively by effecting not only compression of bleed but also expansion of dehumidified air in two stages, for example in two separate turbines, and utilizing the energy delivered by the turbines for the first compressor stage, on the one hand, and for the second compressor stage, on the other. The air-conditioning system then comprises two machines each having at least a compressor wheel and a turbine wheel on a common shaft. Additionally the fan can be disposed on one shaft and a motor on the other shaft, whereby the motor can also be designed as a generator.

Disposing the compressor and turbine wheels on two separate shafts or in two separate machines permits much more flexible design of the overall system than conventional air-conditioning systems. One attains an optimum design in particular of compressor and turbine.

Freedom from ice can be obtained without any problem in particular when not only compression of bleed but also condensation of moisture contained in the air is effected in two stages in the high-pressure water extraction cycle. For this purpose a first condenser of the high-pressure water extraction cycle is disposed for heat exchange with dehumidified air before the turbine inlet, in case of two-stage expansion before the second turbine inlet, and a second condenser of the high-pressure water extraction cycle for heat exchange with dehumidified and expanded air after the turbine outlet, compressed air being passed through said condensers in heat-exchanging fashion in order to condense water and then extract it. Effectiveness of dehumidification is increased substantially by two-stage condensation. This holds in particular when expansion is also effected in two turbine stages.

When small amounts of ice in the cooling air are no great problem and high efficiency of the overall system is important, it is advantageous to combine two-stage compression with two-stage expansion, compressed air being passed in heat-exchanging fashion through a condenser disposed between first and second turbines to extract moisture. Efficiency can be further improved if dehumidified air is guided past compressed, not yet dehumidified air in heat-exchanging fashion in a reheater before entering the first turbine stage. This relieves the condenser, on the one hand, since compressed air is precooled before entering the condenser. On the other hand, any residual moisture contained in the dehumidified air is vaporized before the first turbine inlet so that the turbine surfaces are protected from being destroyed by water drops. In terms of efficiency this variant is to be ranked the most favorable.

The invention offers the further advantage that it is possible to switch off the additional compressor stage and optionally the turbine stage driving said compressor stage by means of suitable bypass circuits. This is useful in particular in flight operation, when air moisture and freedom from ice of the cooling air play no part so that high compression for the high-pressure water extraction cycle is unnecessary. In flight operation one can completely switch off one of the two machines by opening and/or closing valves, thereby avoiding unnecessary losses and therefore increasing efficiency in flight operation.

Designing the air-conditioning system with two separate machines each comprising compressor and turbine wheel on a common shaft, one of which can be switched off in flight operation, offers further advantages resulting from the fact that a greater pressure ratio is available in ground operation than in flight operation due to the system. This makes it energetically favorable to provide a relatively small turbine nozzle (baffle screen cross section) in ground operation. Said small nozzle is realized by connecting the two turbine stages in series, resulting in a "total nozzle" smaller than each individual nozzle. In flight operation about the same volume flow is required for air-conditioning the airplane cabin despite a lower available pressure ratio, however, so that in flight operation a large nozzle would be necessary for about the same air flow. Since one machine and thus one turbine stage is turned off for the overall system in flight operation, a large nozzle results by reason of the sole remaining turbine of the second turbine stage for the overall system. One can thus increase efficiency in flight operation. This gain in efficiency is preferably utilized for designing the primary and main heat exchangers with minimal overall size and weight, under the constraint that the necessary volume flow rate is just met. In the final effect one can thus achieve a smaller overall size and thus lower total weight of the air-conditioning system by the measure of providing two machines instead of only one machine.

A further advantage resulting when the air-conditioning system has two separate machines each with a coupled compressor and turbine is that if one machine fails at least the other machine still works and the air-conditioning system can be operated further without restriction. With the redundancy required for aircraft, this means that one fewer air conditioner or "pack" per aircraft is necessary, for example only two packs instead of three. As a consequence, the accordingly lower number of components decreases weight, increases the reliability of the installation and reduces expense for maintenance and repair.

Finally, it is to be ascertained that both in ground operation with two machines and in flight operation with one switched-off machine the energy gained during expansion in the turbine or turbines is largely recovered via the two compressor stages (ground operation) or the sole remaining compressor stage (flight operation).

In the following the invention will be described by way of example with reference to Figures 1 to 3, in which:

Figure 1 shows a diagram of an inventive air-conditioning system,

Figure 2 shows a diagram of an improved embodiment of the system of Figure 1, in particular for producing ice-free conditioned air,

Figure 3 shows a diagram of an improved embodiment of the system of Figure 1 with improved efficiency, and

Figure 4 shows an air-conditioning system according to the prior art.

Figure 1 shows an air-conditioning system differing from the air-conditioning system described in Figure 4 with respect to the prior art substantially in that two compressors *C*1 and *C*2 are provided in order to bring bleed cooled in primary heat exchanger *PHX* to the pressure necessary for high-pressure water extraction. Compressors *C*1 and *C*2 are to be designed depending on whether freedom from ice or high efficiency of the air-conditioning system is more important. In Figure 1, compressor *C*1 of the first compressor stage together with turbine *T* and fan *F* form three-wheel machine *ACM*. That is, compressor *C*1 and fan *F* are driven regeneratively by energy gained in turbine *T*. Compressor *C*2 of the second compression stage is operated by separate motor *M*, i.e. by external energy. Check valve *CV*2 opens automatically when compressor *C*2 is blocked or when motor *M* of compressor *C*2 is not switched off in flight operation for example. Check valve *CV*1 opens automatically when air cycle machine *ACM* is blocked or bypass valve *BPV*2 is actively opened.

The air-conditioning system schematically shown in Figure 1 otherwise corresponds fundamentally in structure and function to the system of Figure 4, whereby it should be taken into account that the reheater is not absolutely necessary but of great advantage in particular in case absolute freedom from ice is to be achieved.

Figure 2 shows a further development of the invention. In the air-conditioning system shown schematically therein, dehumidified air is expanded in two stages via turbines *T*1 and *T*2. Energy gained during expansion in turbine *T*1 is utilized regeneratively to drive compressor *C*2, while energy delivered by turbine *T*2 is utilized regeneratively by compressor *C*1, as before. In addition to condenser *CON*1 in the high pressure dewatering cycle, through which condensed bleed is guided in heat-exchanging fashion past dehumidified air expanded in turbine *T*1, second condenser *CON*2 is provided through which air precooled in condenser *CON*1 is guided in heat-exchanging fashion past air expanded by turbine *T*2. Condensers *CON*1 and *CON*2 are especially advantageous when conditioned air is to be free from ice. Otherwise one can do without condenser *CON*2, which one does in particular when high efficiency of the overall system is to be achieved.

Before air expanded in the first turbine stage enters condenser *CON*1, water extractor *WE*2 is advantageously provided in addition to water extractor *WE*1 provided in the high-pressure water extraction cycle. Extracted water is supplied to ram-air heat exchangers *MHX*/*PHX* to be vaporized therein. Water extractor *WE*2 is advantageous in particular when air cycle machine *ACM* is blocked, since the effectiveness of first water extractor *WE*1 is greatly restricted here.

Further, one can open economy valve *ECV* to switch off the high-pressure water extraction cycle, which is useful in particular when air cycle machine *ACM* fails and not enough pressure is available for energetically suitable utilization of the high-pressure water extraction cycle. Water extraction is then effected at low pressure by water extractor *WE*2. Condensers *CON*1 and *CON*2 are inoperative in this case.

As in the air-conditioning system described above, one can switch off the machine comprising turbine *T*1 and compressor *C*2 in particular for flight operation by opening bypass valve *BPV*1. By opening bypass valve *BPV*2 one can also bypass air cycle machine *ACM*, in particular if it fails.

Figure 2 shows optional motor *M*, with which the efficiency of the system can be optimized, by dotted lines on the shaft interconnecting turbine *T*1 and compressor *C*2. One can either make additional energy available to the system. Or, and in particular, one can utilize the motor as a generator in order to supply surplus energy to the board wiring.

While the air-conditioning system shown in Figure 2 is in particular suitable for providing ice-free conditioned air, Figure 3 schematically shows an air-conditioning system having especially favorable efficiency. As described with respect to Figure 4 (prior art), reheater *REH* is disposed before turbine *T*1 and condenser *CON* after turbine *T*1 in heat-exchanging fashion for compressed air to flow through and for condensation of moisture contained therein. Reheater *REH* can fundamentally be omitted, but is advantageous for the reasons stated above. Moisture contained in compressed air is condensed in condenser *CON* at a comparatively high energy level, in contrast to the prior art described in Figure 4, whereby this energy can be utilized in turbine *T*2 as fundamentally proposed in US 5,086,622. However, in US 5,086,622 turbines *T*1 and *T*2 are disposed jointly with compressor *C*1 and fan *F* on a common shaft in a single air cycle machine *ACM*. Since according to the invention compression is divided into two stages, and turbine *T*1 plus compressor *C*2 and turbine *T*2 plus compressor *C*1 each form separate machines, efficiency can be increased further because the design of the air-conditioning system is altogether more variable.

As described in Figure 2, economy valves *ECV*1 and *ECV*2 serve optionally to bypass the high-pressure water extraction cycle. By opening bypass valve *BPV*1 one bypasses the machine comprising turbine *T*1 and compressor *C*2 in flight operation. Bypass valve *BPV*2 accordingly serves to bypass air cycle machine *ACM* if it fails. Both bypass valves can also be used optionally as temperature control valves. Temperature control valve *TCV*2 is likewise optional, while temperature control valve *TCV*4 should preferably be provided in the air-conditioning system. As mentioned above, one can actually omit reheater *REH*, but it is advantageous for the reasons stated at the outset.

Depending on the system requirement and/or to simplify the system, individual valves can be omitted, as mentioned above, or they can be partly combined. In particular one can for example combine valves *ECV*1, *BPV*1 and *ECV*2 into one line with only one valve, resulting in a less complex system altogether. The installation is then optimized for flight operation with a switched-off machine (turbine *T*1/compressor *C*2).

Patent claims

1. A method for conditioning moisture-containing, pressurized air for air-conditioning a passenger plane cabin comprising the following steps:
   - compressing the pressurized air to a higher pressure,
   - dehumidifying the compressed air by condensing and extracting water from the compressed air,
   - expanding the dehumidified air to a lower pressure, thereby gaining process energy which is utilized regeneratively in the step of compressing the pressurized air to the higher pressure, and
   - passing on the conditioned air for air-conditioning the passenger plane cabin,

   characterized in that the step of compressing the pressurized air to a higher pressure is effected in separate first and second compression stages.
2. A method according to claim 1, wherein energy external to the process is supplied in the other of the two compression stages.
3. A method according to claim 1, wherein regenerated process energy is utilized in the other of the two compression stages.
4. A method according to claim 3, wherein expansion of the air is effected in two separate stages by means of first and second turbines, and the energy gained with the first turbine is utilized regeneratively at least partly in the second compression stage and the energy gained with the second turbine at least partly in the first compression stage, or vice versa.
5. A method according to claim 4, wherein water is extracted from the air after expansion of the air in the first turbine stage and before expansion of the air in the second turbine stage.
6. A method according to either of claims 4 and 5, wherein in the condensation step the compressed air is guided in heat-exchanging fashion past the air expanded by the first turbine stage, and cooled.
7. A method according to claim 6, wherein the condensation step is performed in two stages by the compressed air also being guided in heat-exchanging fashion

past the air expanded by the second turbine stage, and cooled.

8. A method according to any of claims 1 to 7, wherein the air is guided in heat-exchanging fashion past the compressed, and heated, after dehumidification and before expansion.

9. A method according to any of claims 4 to 8, wherein at least part of the energy gained during expansion in one of the two turbine stages is converted into electric energy and removed.

10. A method according to any of claims 1 to 9, characterized in that at least part of the process energy gained during expansion of the dehumidified air is utilized to drive a fan (*F*).

11. An air-conditioning system for passenger plane cabins for conditioning moisture-containing, pressurized air for air-conditioning a passenger plane cabin comprising:

    - a compressor device (*C*1, *C*2) for compressing the pressurized air to a higher pressure,
    - a condenser (*CON*; *CON*1, *CON*2) and following water extractor (*WE*; *WE*1, *WE*2) for dehumidifying the compressed air,
    - an expansion device (*T*; *T*1, *T*2) for expanding the dehumidified air to a lower pressure, the expansion device comprising a first turbine (*T*; *T*1, *T*2) coupled with the compressor device (*C*1) for driving the same, and
    - an output line for passing on the conditioned air for air-conditioning the passenger plane cabin,

    characterized in that the compressor device (*C*1, *C*2) is of two-stage construction for further compressing the pressurized air and comprises first and second separately driven compressors (*C*1 and *C*2).

12. An air-conditioning system according to claim 11, wherein the other of the two compressors (*C*2) is driven with external energy (*M*).

13. An air-conditioning system according to claim 11, wherein the expansion device is of two-stage design and comprises a second turbine (*T*1) coupled with the other of the two compressors (C2) for driving the same.

14. An air-conditioning system according to claim 13, characterized in that a water

extractor (*WE*2) is disposed between the two turbines (*T*1, *T*2).

15. An air-conditioning system according to either of claims 13 and 14, wherein a first heat exchanger (*CON*; *CON*1), through which the compressed air is passed in heat-exchanging fashion and cooled, is disposed between the two turbines (*T*1, *T*2).

16. An air-conditioning system according to claim 15, wherein a second heat exchanger (*CON*2), through which the compressed air is passed in heat-exchanging fashion and cooled, is disposed after the second turbine (*T*2).

17. An air-conditioning system according to any of claims 11 to 16, wherein a further heat exchanger (*REH*), through which the dehumidified air is passed and heated, is disposed before the first turbine.

18. An air-conditioning system according to any of claims 11 to 17, wherein a bypass device (*CV*2) is provided for bypassing the other of the two compressors (*C*2).

19. An air-conditioning system according to any of claims 13 to 18, wherein a bypass device (*BPV*1) is provided for bypassing the first turbine (*T*1).

20. An air-conditioning system according to any of claims 11 to 19, wherein a bypass device (*CV*1; *BPV*2) is provided for bypassing one of the two compressors (*C*1).

21. An air-conditioning system according to any of claims 11 to 20, wherein a generator (*M*) coupled with one of the two turbines (*T*1) and producing and removing energy is provided.

22. An air-conditioning system according to any of claims 11 to 21, wherein a fan (*F*) coupled with the other of the two turbines (T2) and driven thereby is provided.

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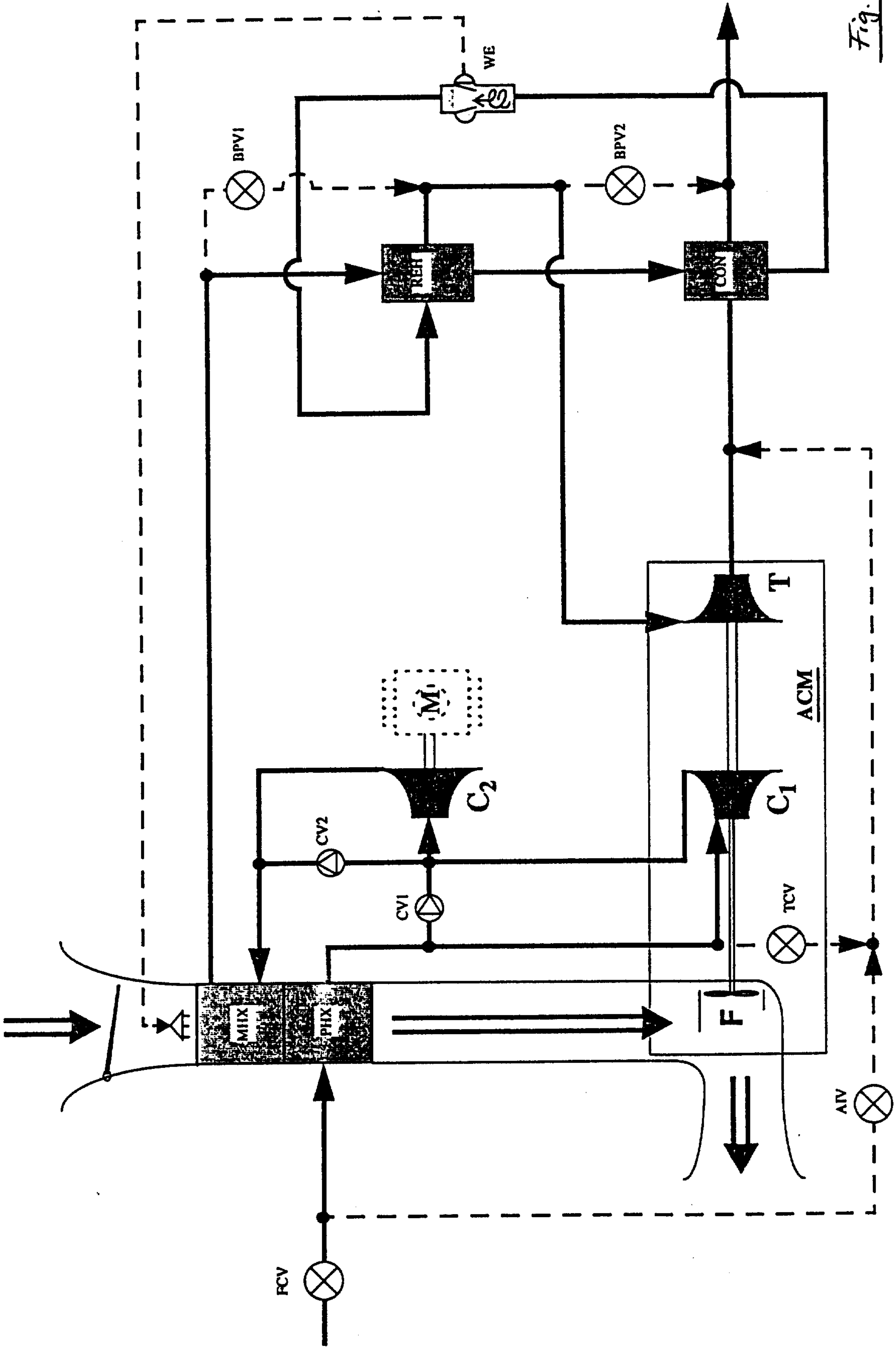

Fig. 1

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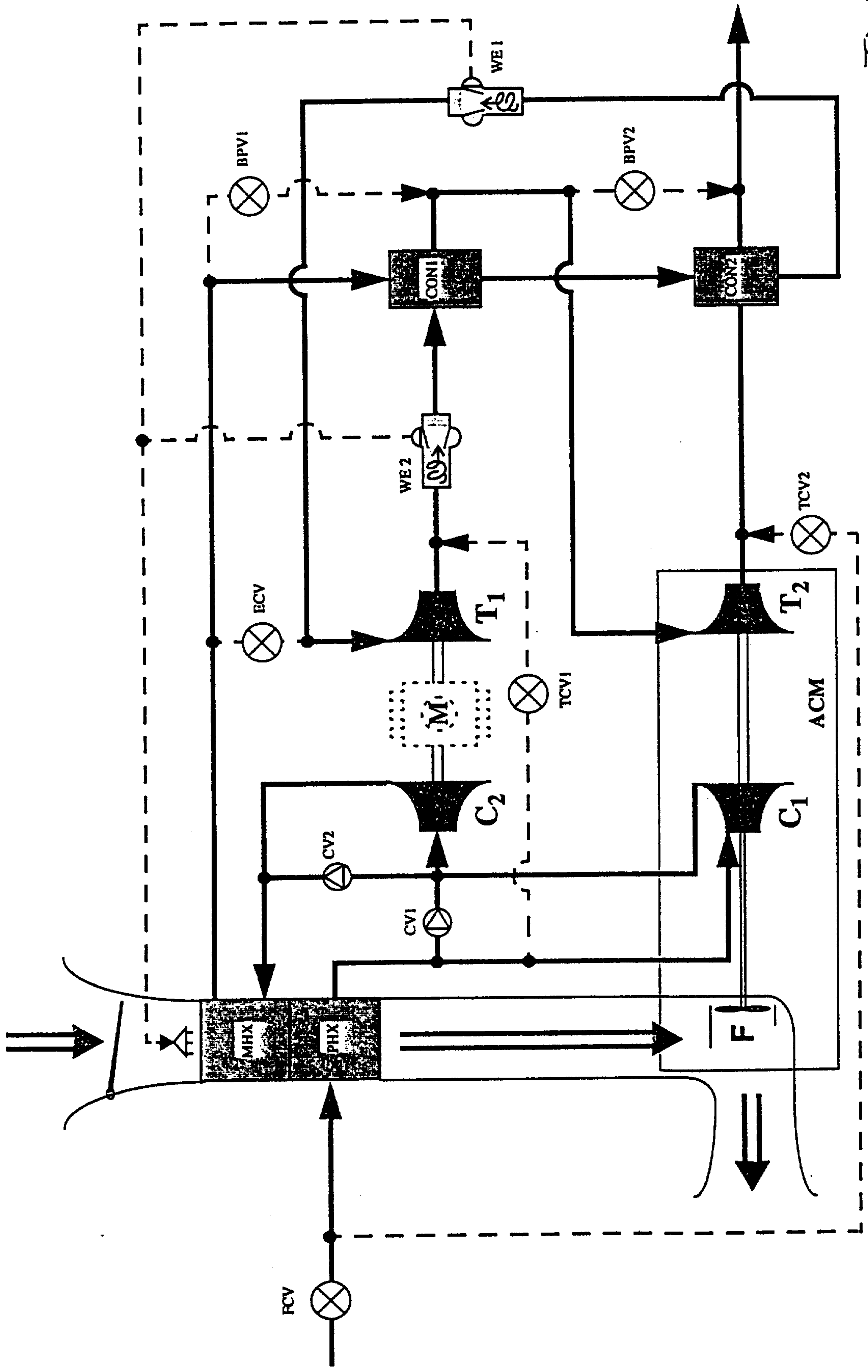
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BPV1
BPV2
CON1
CON2
WE2
ECV
T_1
T_2
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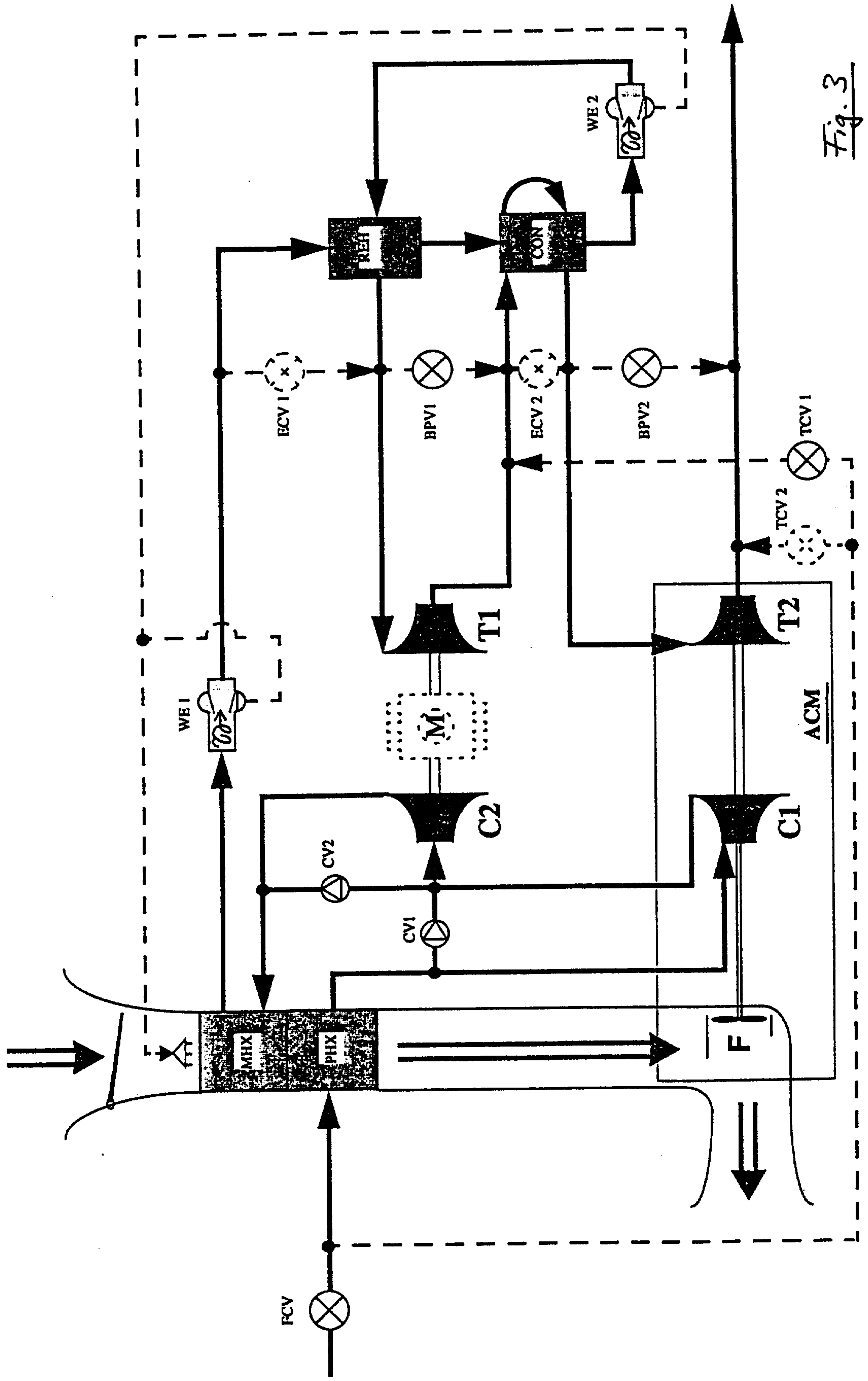
MHX
PHX
F
FCV

Fig. 2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MHX
PHX
F
WE 1
CV1
CV2
C1
C2
M
ACM
T1
T2
ECV 1
BPV1
ECV 2
BPV2
TCV 1
TCV 2
REH
CON
WE 2

Fig. 3

4/4

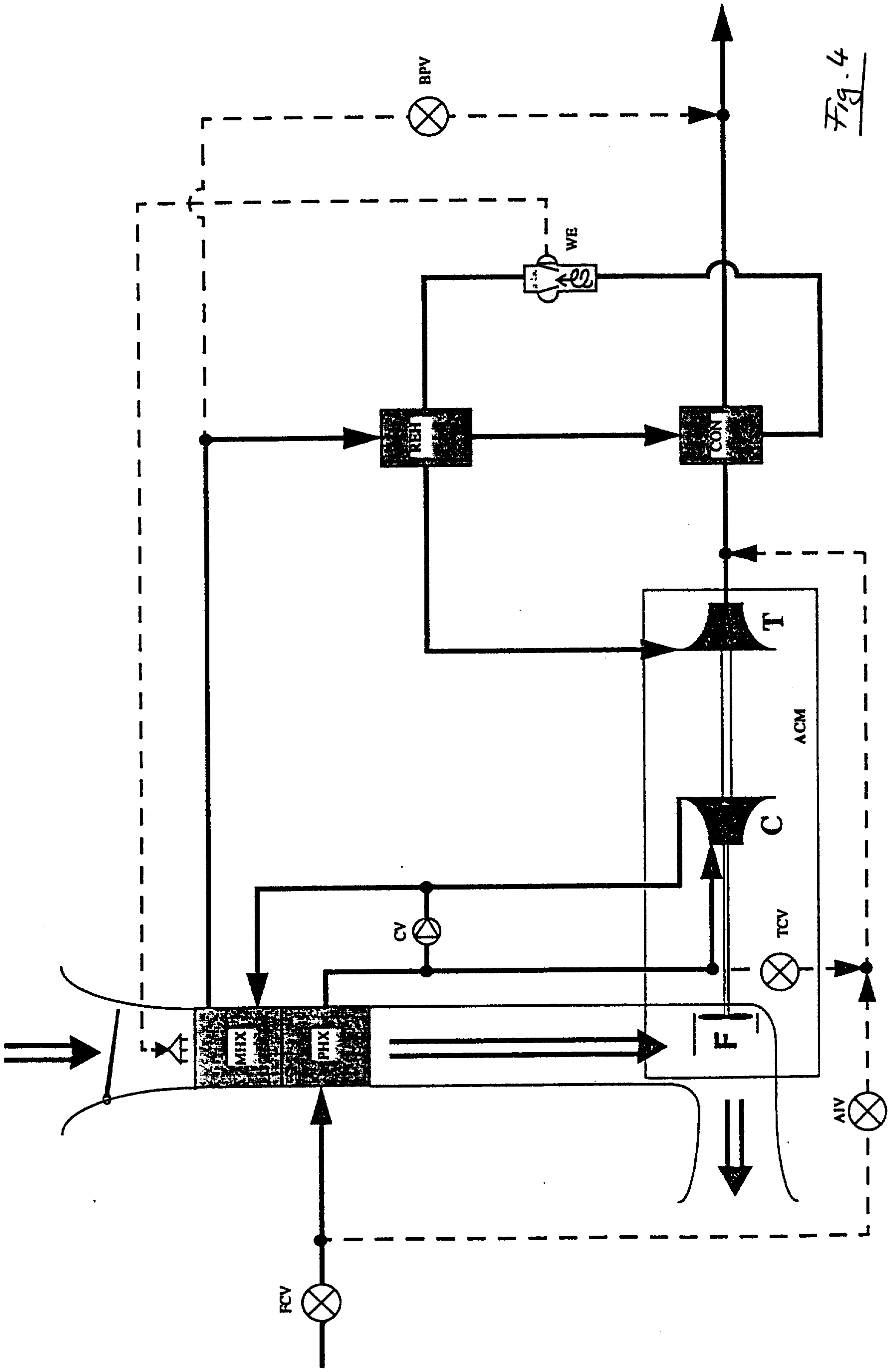
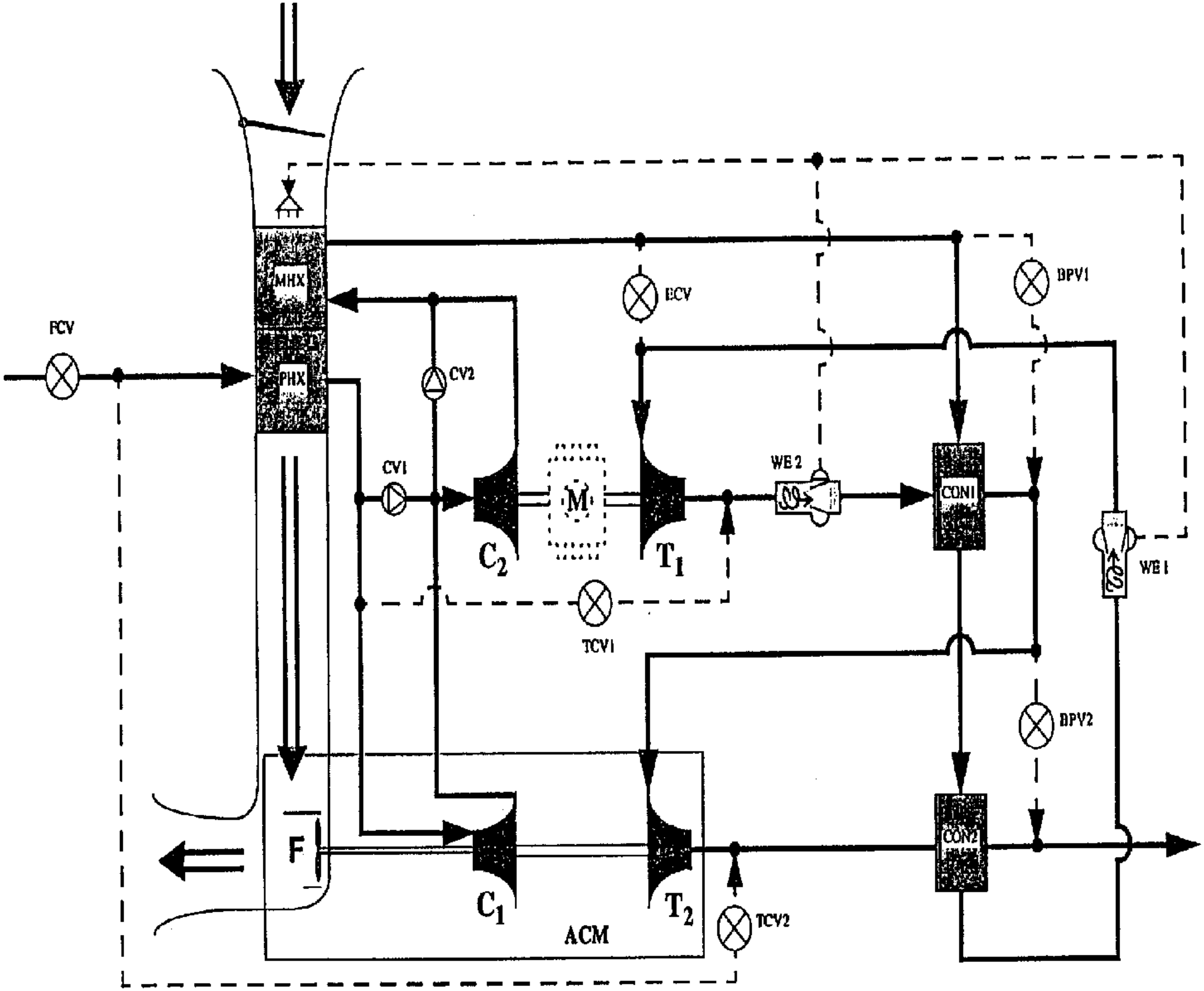


Fig. 4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CON2
F
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ACM
TCV2