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Remarks:
Amended claims in accordance with Rule 137(2) EPC.

(54) **Cryogenic air separation unit and method of operation of a cryogenic air separation unit**

(57) In a process for operating an air separation unit, air to be separated in a cryogenic air separation unit is compressed in one of at least two compressors (MAC1, MAC2), purified, cooled and separated in the air separation unit (19) to produce a fluid product (21) and de-

pending on the temperature of the feed air (3, 5), the degree of humidity of the feed air or the temperature of a cooling water stream (W1, W1', W2, W2'), one of the two compressors is used to provide compressed feed air for the air separation unit.

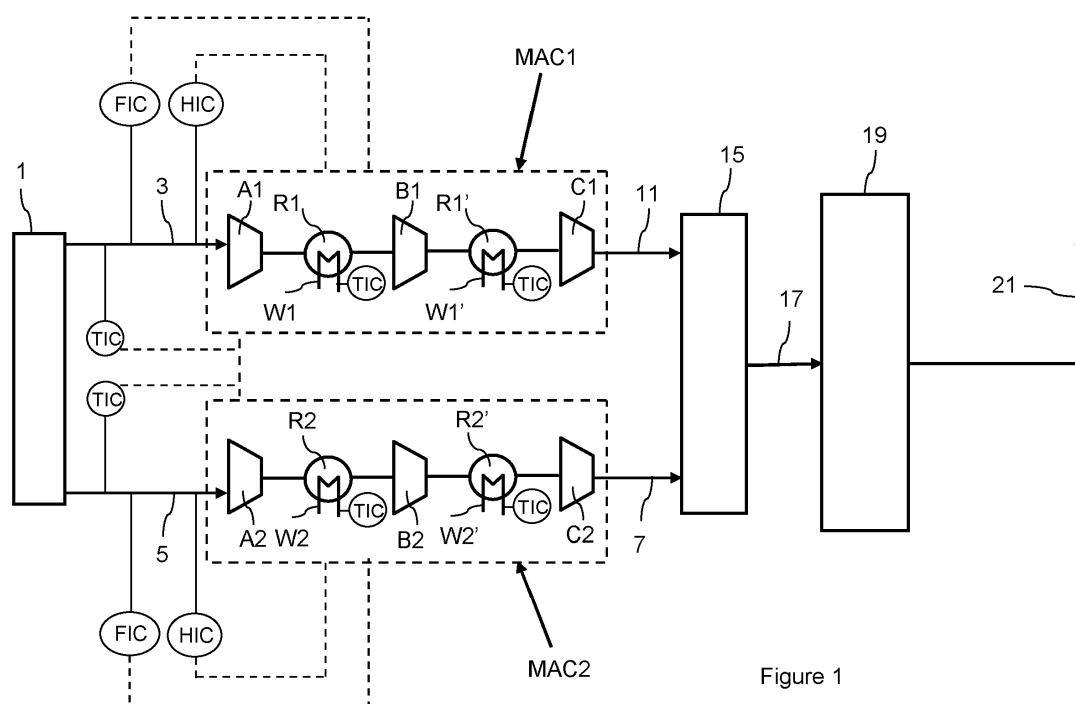


Figure 1

Description

[0001] The present invention relates a cryogenic air separation unit and to a method of operation of a cryogenic air separation unit. In such air separation units, all the air to be separated by distillation is compressed in a compressor, for example a centrifugal compressor. The compressor is typically designed in order to produce the maximum performance (pressure, flow rate) whatever the climatic conditions are. Typically, a compressor will be designed for summer operating conditions (warm air temperature, high relative humidity and high cooling water temperature). Generally, the production of gas or liquid from the air separation unit is not required to vary with the climatic conditions. For geographies where the climatic conditions can vary throughout the year, the machine is designed for an extreme environment which is applicable only a few days per year. For the rest of the year, the machine is over performing, and has to be used in reduced mode, therefore far from its optimum operating point.

[0002] Accordingly, it is an object of this invention to provide an improved method of operating an air separation unit. This method uses a main air compressor configuration for reducing the Total Cost of Ownership of the air separation unit, for example a single column nitrogen generator.

[0003] According to the present invention, there is provided a process for operating an air separation unit wherein air to be separated in a cryogenic air separation unit is compressed in one of at least two compressors, purified, cooled and separated in the air separation unit to produce a fluid product, each compressor comprising at least two stages and cooling being provided between the stages using at least one stream of cooling water wherein:

- i) during a first period, in which the temperature of the air to be compressed is below a first threshold and/or the degree of humidity of the air to be compressed is below a second threshold and/or the temperature of the stream of cooling water is below a third threshold, the air to be separated in the air separation unit is compressed only in a first of the at least two compressors and
- ii) during a second period, in which the temperature of the air to be compressed is above the first threshold and/or the degree of humidity of the air to be compressed is above the second threshold and/or the temperature of the stream of cooling water is above a third threshold, the air to be separated in the air separation unit is compressed only in a second of the at least two compressors.

[0004] According to optional features of the invention:

- during the first period the temperature of the air to be compressed is below the first threshold and dur-

ing the second period the temperature of the air to be compressed is above the first threshold.

- during the first period the degree of humidity of the air to be compressed is below the second threshold and during the second period the degree of humidity of the air to be compressed is above the second threshold.
- during the first period, the temperature of the cooling water stream is below the third threshold and during the second period, the temperature of the cooling water stream is above the third threshold.
- the second compressor is designed to compress a maximum flow of air higher than the maximum flow which the first compressor is designed to compress.
- the first period designates a number of days in the year and the second period the rest of the year.
- at least part of the first period falls during the night
- at least part of the second period falls during the day.
- most or all of the first period falls during the night
- most of the second period falls during the day
- during the first period, the second compressor is capable of operating and during the second period, the first compressor is capable of operating.
- a theoretical value V for the feed air stream is calculated, a value R for the required air stream to produce a required product stream is calculated and when the deviation between R and V exceeds a threshold, the feed air is sent to the second compressor only.

[0005] According to the present invention, there is provided an air separation apparatus comprising at least two main air compressors, each compressor comprising at least two stages, for each compressor a cooler between two stages and means for sending a stream of cooling water to the cooler, a purification unit, a column system, a conduit for sending air from the first of the main air compressors to the purification unit, a further conduit for sending air from the second of the main air compressors to the purification unit, a conduit for sending purified air from the purification unit to the column system and a conduit for removing a product from the column system characterized in that it comprises means for measuring the atmospheric temperature and/or means for measuring the degree of humidity of the air to be compressed and/or means for measuring the temperature of the stream of cooling water, means for starting up the first air compressor and shutting down the second main air compressor if the atmospheric temperature and/or the degree of humidity of the air to be compressed and/or the temperature of the stream of cooling water falls or fall below a threshold or thresholds and means for starting up the second air compressor and shutting down the first main air compressor if the atmospheric temperature and/or the degree of humidity of the air to be compressed and/or the temperature of the stream of cooling water rises or rise above the threshold or thresholds.

[0006] According to other optional features, the apparatus comprises:

- means for measuring the atmospheric temperature and means for starting up the first air compressor and shutting down the second main air compressor if the atmospheric temperature falls below a threshold and means for starting up the second air compressor and shutting down the first main air compressor if the atmospheric temperature rises above the threshold.
- means for measuring the degree of humidity of the air to be compressed and means for starting up the first air compressor and shutting down the second main air compressor if the degree of humidity of the air to be compressed falls below a threshold and means for starting up the second air compressor and shutting down the first main air compressor if the degree of humidity of the air to be compressed rises above the threshold.
- means for measuring the temperature of the cooling water and means for starting up the first air compressor and shutting down the second main air compressor if the temperature of the stream of cooling water falls below a threshold and means for starting up the second air compressor and shutting down the first main air compressor if the temperature of the stream of cooling water rises above the threshold.
- the first and second air compressors are connected so as to send all of the air compressed therein to the column system.
- the apparatus comprises only two air compressors compressing air from atmospheric pressure.

[0007] The invention will be described in detail with reference to the enclosed figure, showing an air separation unit operating according to the invention.

[0008] The air separation unit comprises two main air compressors MAC1, MAC2, a filtration unit 1, a purification unit 15 for removing carbon dioxide and humidity from the air and a cold temperature unit operating at cryogenic temperature and containing a column system. The column system may be a single column nitrogen generator, a double column producing oxygen and/or nitrogen or a triple column. The first main air compressor MAC 1 is composed of three stages in series A1, B1, C1. Between each pair of stages, there is a cooler R1, R1' which is cooled using a stream of cooling water W1, W1'. There is also a final cooler after stage C1 which is not shown. The second main air compressor MAC2 is composed of three stages in series A2, B2, C2. Between each pair of stages, there is a cooler R2, R2' which is cooled using a stream of cooling water W2, W2'. There is also a final cooler after stage C1 which is not shown. The compressors may contain more or less than three stages.

[0009] According to the process, during a first period when the atmospheric temperature is below a first threshold, all the air to be distilled is filtered in filter 1 to form stream 3, stream 3 is compressed in first main air compressor MAC1 to form first compressed air stream 11. The first compressed air stream 11 is purified in a purifi-

cation unit 15 and sent as stream 17 to the cold temperature unit 19 to be separated. A product stream of a given quantity is formed. The product stream 21 may be gaseous oxygen or nitrogen or liquid oxygen or nitrogen. Other products may of course be produced. When the atmospheric temperature is below the first threshold, the second main air compressor MAC2 is not used, though it may be capable of being used, for example in the case of breakdown and/or maintenance of the first main air compressor MAC1.

[0010] During a second period, when the atmospheric temperature is above the first threshold, all the air to be distilled is filtered in filter 1 forming stream 5, stream 5 is compressed in second main air compressor MAC2 to form first compressed air stream 7. The first compressed air stream 7 is purified in the purification unit 15 and sent as stream 17 to the cold temperature unit 19 to be separated. A product stream of a given quantity is formed. When the atmospheric temperature is above the first threshold, the first main air compressor MAC1 is not used, though it may be capable of being used for example in the case of breakdown and/or maintenance of the second main air compressor MAC2. The atmospheric temperature is determined by measuring the temperature of stream 3 and/or stream 5 using element TIC or by measuring the air temperature at some other position (eg in the open air).

[0011] It is also possible to decide whether to use the first or second main air compressor as a function of the degree of humidity. Thus when the degree of humidity of the feed air is below a second threshold, only the first main air compressor is used and when the degree of humidity is above that threshold, only the second air main air compressor is used. Alternatively, it may be required that both the temperature and the degree of humidity be above certain threshold, in order to start using the second main air compressor and stop using the first main air compressor. The degree of humidity may be measured by measuring the humidity of stream 3 and/or stream 5 using element HIC or by measuring the humidity at some other point. A typical value for the humidity threshold might be chosen within the range of 60% to 85%.

[0012] It is also possible to decide whether to use the first or second main air compressor as a function of the cooling water temperature. Thus when the temperature of the cooling water is below a third threshold, only the first main air compressor is used and when the water temperature is above that threshold, only the second air main air compressor is used. A typical value for the cooling water temperature threshold might be 20°C.

[0013] Alternatively, it may be required that both the air temperature and the water temperature be above certain threshold or that both the water temperature and humidity be above given thresholds, or that all three criteria be above given thresholds, in order to start using the second main air compressor and stop using the first main air compressor. The cooling water temperature may be determined by measuring the temperature of at least

one of streams W1, W1', W2, W2' either upstream or downstream of the cooler R1, R1', R2, R2' using element TIC. The cooling water temperature could also be measured in a storage tank for the water.

[0014] A more sophisticated technique to switch between the compressors could involve calculating a theoretical compressed air flow V for stream 3 or 5, based on the feed air temperature and/or feed air humidity and/or the temperature of the cooling water. This would then be compared with a required air stream R needed to produce a required product stream 21, for example nitrogen. When the deviation between V and R exceeds a given value, the process switches from using first compressor MAC1 to second compressor MAC2.

The switch from one compressor to another can of course be done manually.

[0015] The first air compressor is dimensioned to operate for the maximum volumetric flow possible for temperatures below the first threshold or degrees of humidity below the second threshold or cooling water temperature below the third threshold.

[0016] The second air compressor is dimensioned for a maximum flow higher than the maximum flow of the first air compressor. For example, the maximum flow for the second air compressor may be at least 10% higher than for the first main air compressor.

[0017] In certain cases, the second air compressor only operates when the atmospheric temperature is above 35°C, or above 40°C. This may mean that the second air compressor only operates for a few days in the year and the first air compressor operates for all the rest of the year.

[0018] Alternatively, where there is a considerable difference between night temperatures and day temperatures, the first main air compressor may supply all the feed air during the night and the second main air compressor may supply all the feed air during the day. For example, in some countries, the average daytime temperature is above 35°C whereas at night the temperature can fall to 0°C. The cooling water temperature will also probably vary to a large extent. It will be necessary to determine the optimum cut-off temperature when the first main air compressor stops operating and the second main air compressor comes into operation. In these cases, the degree of humidity may or may not also be taken into account.

[0019] It is of course possible to have a first main air compressor which operates only for the coldest days in the winter, supplying all the feed air to an air separation unit and a second main air compressor which operates the rest of the time supplying all the feed air instead of the first main air compressor.

[0020] Since both main air compressors operate at their optimal conditions, the process according to the invention allows an overall energy reduction of about 8~10% (depending on the machine size and operating point of use), and a reduction of up to 10~14% of yearly

operation cost, including savings in liquid nitrogen, for a plant producing nitrogen, because of reduced plant unavailability. This liquid nitrogen would otherwise have needed to be vaporized to provide the maximum amount of product required. Even though the invention requires extra investment, the estimated reduction of TCO is in the range of 2~5%.

[0021] According to the invention, the power consumption of the two main air compressors can be optimized, since their aerodynamic performance is designed for different conditions to avoid long term operation at off-design point as far as possible.

[0022] The first main air compressor is designed for normal climatic conditions and the second main air compressor is designed for extreme climatic conditions

[0023] It is possible to use compressors of the same frame size for the first and second compressor. One of the compressors can then be adapted by altering the aerodynamic design condition and thus a competitive plant power consumption can be proposed.

[0024] The compressor can be adapted by changing pinion rotors, diffusers and inlet covers only, and the other components and equipment such as scroll, bull gear, gearbox, bearing, seal, gas coolers, main motor, oil system, etc. can remain the same for both the first and second main air compressors.

[0025] In this case, spare parts designed for the extreme climatic condition of the second main air compressor may be shared with the first main air compressor.

[0026] In addition to MAC 1 & MAC 2, another aerodynamic design components, which designed for different condition aiming at average climatic condition or lower flow rate/wider turn down operation may be available as capital spares to optimize plant operation and power consumption much more based on what is required. Those capital spares can be installed, either on MAC1 or MAC2 which is in stand-by, to be ready for operation without disturbing plant continuous operation.

[0027] The use of a common filter 1 is not essential. The means for measuring flow and/or humidity and/or temperature may be placed on a common conduit feeding both first and second compressors MAC1, MAC2.

Claims

1. Process for operating an air separation unit wherein air to be separated in a cryogenic air separation unit is compressed in one of at least two compressors, purified, cooled and separated in the air separation unit to produce a fluid product, each compressor comprising at least two stages and cooling being provided between the stages using at least one stream of cooling water wherein:

i) during a first period, in which the temperature of the air to be compressed is below a first threshold and/or the degree of humidity of the

- air to be compressed is below a second threshold and/or the temperature of the stream of cooling water is below a third threshold, the air to be separated in the air separation unit is compressed only in a first of the at least two compressors (MAC1), and
- ii) during a second period, in which the temperature of the air to be compressed is above the first threshold and/or the degree of humidity of the air to be compressed is above the second threshold and/or the temperature of the stream of cooling water is above a third threshold, the air to be separated in the air separation unit is compressed only in a second (MAC2) of the at least two compressors.
2. Process according to Claim 1 wherein during the first period the temperature of the air to be compressed is below the first threshold and during the second period the temperature of the air to be compressed is above the first threshold.
 3. Process according to Claim 1 or 2 wherein during the first period the degree of humidity of the air to be compressed is below the second threshold and during the second period the degree of humidity of the air to be compressed is above the second threshold.
 4. Process according to any preceding claim wherein during the first period, the temperature of the cooling water stream is below the third threshold and during the second period, the temperature of the cooling water stream is above the third threshold.
 5. Process according to any preceding claim wherein the second compressor (MAC2) is designed to compress a maximum flow of air higher than the maximum flow which the first compressor (MAC1) is designed to compress.
 6. Process according to any preceding claim wherein the first period designates a number of days in the year and the second period the rest of the year.
 7. Process according to any preceding claim wherein at least part of the first period falls during the night and at least part of the second period falls during the day.
 8. Process according to any preceding claim wherein during the first period, the second compressor (MAC2) is capable of operating and during the second period, the first compressor (MAC1) is capable of operating.
 9. Process according to any preceding claim wherein a theoretical value V for the feed air stream (3,5) is calculated, a value R for the required air stream to produce a required product stream is calculated and when the deviation between R and V exceeds a threshold, the feed air is sent to the second compressor (MAC2) only.
 10. Air separation apparatus comprising at least two main air compressors (MAC1, MAC2), each compressor comprising at least two stages, for each compressor a cooler (R1, R1', R2, R2') between two stages and means for sending a stream of cooling water (W1, W1', W2, W2') to the cooler, a purification unit (15), a column system (19), a conduit for sending air (11) from the first of the main air compressors to the purification unit, a further conduit (7) for sending air from the second of the main air compressors to the purification unit, a conduit for sending purified air (17) from the purification unit to the column system and a conduit for removing a product (21) from the column system **characterized in that** it comprises means for measuring the atmospheric temperature (TIC) and/or means for measuring the degree of humidity (HIC) of the air to be compressed and/or means for measuring the temperature (TIC) of the stream of cooling water, means for starting up the first air compressor and shutting down the second main air compressor if the atmospheric temperature and/or the degree of humidity of the air to be compressed and/or the temperature of the stream of cooling water falls or fall below a threshold or thresholds and means for starting up the second air compressor and shutting down the first main air compressor if the atmospheric temperature and/or the degree of humidity of the air to be compressed and/or the temperature of the stream of cooling water rises or rise above the threshold or thresholds.
 11. Apparatus according to Claim 10 comprising means for measuring the atmospheric temperature and means for starting up the first air compressor (MAC1) and shutting down the second main air compressor (MAC2) if the atmospheric temperature falls below a threshold and means for starting up the second air compressor and shutting down the first main air compressor if the atmospheric temperature rises above the threshold.
 12. Apparatus according to Claim 10 or 11 comprising means for measuring the degree of humidity of the air to be compressed and means for starting up the first air compressor (MAC1) and shutting down the second main air compressor (MAC2) if the degree of humidity of the air to be compressed falls below a threshold and means for starting up the second air compressor and shutting down the first main air compressor if the degree of humidity of the air to be compressed rises above the threshold.
 13. Apparatus according to Claim 10, 11 or 12 compris-

ing means for measuring the temperature of the cooling water and means for starting up the first air compressor (MAC1) and shutting down the second main air compressor (MAC2) if the temperature of the stream of cooling water falls below a threshold and means for starting up the second air compressor and shutting down the first main air compressor if the temperature of the stream of cooling water rises above the threshold.

14. Apparatus according to any of Claims 10 to 13 wherein the first and second air compressors (MAC1, MAC2) are connected so as to send all of the air compressed therein to the column system (19).
15. Apparatus according to any of Claims 10 to 15 wherein the apparatus comprises only two air compressors (MAC1, MAC2) compressing air from atmospheric pressure.

Amended claims in accordance with Rule 137(2) EPC.

1. Process for operating an air separation unit wherein air to be separated in a cryogenic air separation unit is compressed in one of at least two compressors, purified, cooled and separated in the air separation unit to produce a fluid product, each compressor comprising at least two stages and cooling being provided between the stages using at least one stream of cooling water wherein:

i) during a first period, in which the temperature of the air to be compressed is below a first threshold and/or the degree of humidity of the air to be compressed is below a second threshold and/or the temperature of the stream of cooling water is below a third threshold, the air to be separated in the air separation unit is compressed only in a first of the at least two compressors (MAC1), and

ii) during a second period, in which the temperature of the air to be compressed is above the first threshold and/or the degree of humidity of the air to be compressed is above the second threshold and/or the temperature of the stream of cooling water is above a third threshold, the air to be separated in the air separation unit is compressed only in a second (MAC2) of the at least two compressors.

2. Process according to Claim 1 wherein during the first period the temperature of the air to be compressed is below the first threshold and during the second period the temperature of the air to be compressed is above the first threshold.

3. Process according to Claim 1 or 2 wherein during the first period the degree of humidity of the air to be compressed is below the second threshold and during the second period the degree of humidity of the air to be compressed is above the second threshold.

4. Process according to any preceding claim wherein during the first period, the temperature of the cooling water stream is below the third threshold and during the second period, the temperature of the cooling water stream is above the third threshold.

5. Process according to any preceding claim wherein the second compressor (MAC2) is designed to compress a maximum flow of air higher than the maximum flow which the first compressor (MAC1) is designed to compress.

6. Process according to any preceding claim wherein the first period designates a number of days in the year and the second period the rest of the year.

7. Process according to any preceding claim wherein at least part of the first period falls during the night and at least part of the second period falls during the day.

8. Process according to any preceding claim wherein during the first period, the second compressor (MAC2) is capable of operating and during the second period, the first compressor (MAC1) is capable of operating.

9. Process according to any preceding claim wherein a theoretical value V for the feed air stream (3,5) is calculated, a value R for the required air stream to produce a required product stream is calculated and when the deviation between R and V exceeds a threshold, the feed air is sent to the second compressor (MAC2) only.

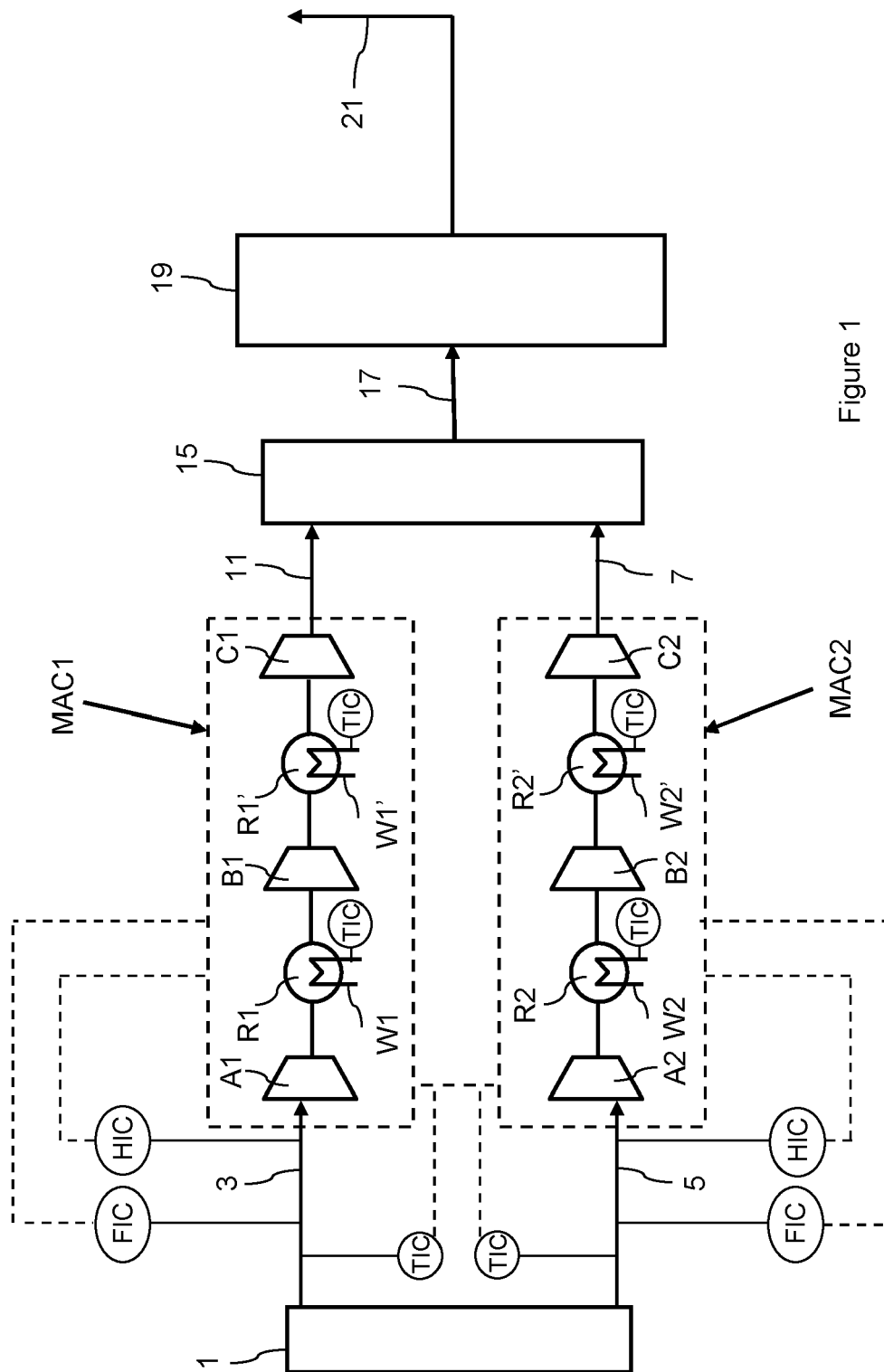


Figure 1



EUROPEAN SEARCH REPORT

Application Number
EP 11 30 6601

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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A	* column 1, line 14 - line 41 * * column 3, line 33 - line 45 * * column 4, line 21 - line 22 * * column 5, line 27 - line 36 * * column 5, line 66 - column 6, line 21 * * figures * * column 9, line 6 - column 11, line 49 *	1-9	
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			TECHNICAL FIELDS SEARCHED (IPC)
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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 24 May 2012	Examiner Harf-Bapin, E
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>			

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EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 11 30 6601

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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24-05-2012

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