

(19)



(11)

EP 2 600 089 B1

(12)

EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention
of the grant of the patent:
03.09.2014 Bulletin 2014/36

(51) Int Cl.:
F25J 3/04 ^(2006.01)

(21) Application number: **11306601.3**

(22) Date of filing: **01.12.2011**

(54) Method of operation of a cryogenic air separation unit

Verfahren zum Betrieb einer kryogenen Lufttrennungseinheit

Procédé de mise en oeuvre d'une unité de séparation d'air cryogénique

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**

(43) Date of publication of application:
05.06.2013 Bulletin 2013/23

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(56) References cited:
**EP-A1- 0 992 275 FR-A1- 2 929 385
JP-A- 2001 116 449 US-A- 6 116 027**

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Description

[0001] The present invention relates to a method of operation of a cryogenic air separation unit. In such methods, 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 (TCO) 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 during 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] The invention will be described in detail with reference to the enclosed figure, showing a method of operating an air separation unit operating according to the invention.

[0006] 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 MAC1 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.

[0007] 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 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. 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 MAC 1.

[0008] 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).

[0009] 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%.

[0010] 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.

[0011] 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.

[0012] 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.

[0013] The switch from one compressor to another can of course be done manually.

[0014] 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.

[0015] 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.

[0016] 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.

[0017] 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.

[0018] 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.

[0019] 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%.

[0020] 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.

[0021] The first main air compressor is designed for normal climatic conditions and the second main air compressor is designed for extreme climatic conditions

[0022] 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.

[0023] 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.

[0024] 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.

[0025] 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.

[0026] 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 com-

pressed 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 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.

Patentansprüche

1. Verfahren zum Betreiben einer Luftabscheidevorrichtung, wobei die in einer Tieftemperatur-Luftabscheidevorrichtung abzuscheidende Luft in einem von wenigstens zwei Verdichtern verdichtet, gereinigt, gekühlt und in der Luftabscheidevorrichtung abgeschieden wird, um ein Fluidzeugnis zu erzeugen, wobei jeder Verdichter wenigstens zwei Stufen umfasst und das Kühlen zwischen den Stufen unter Verwendung wenigstens eines Stroms von Kühlwasser bereitgestellt wird, wobei:

i) während eines ersten Zeitraums, in dem die Temperatur der zu verdichtenden Luft unterhalb eines ersten Schwellenwertes liegt und/oder der Feuchtigkeitsgrad der zu verdichtenden Luft unterhalb eines zweiten Schwellenwertes liegt und/oder die Temperatur des Stroms von Kühlwasser unterhalb eines dritten Schwellenwertes liegt, die in der Luftabscheidevorrichtung abzuscheidende Luft nur in einem ersten (MAC1) der wenigstens zwei Verdichter verdichtet wird und
ii) während eines zweiten Zeitraums, in dem die Temperatur der zu verdichtenden Luft oberhalb des ersten Schwellenwertes liegt und/oder der Feuchtigkeitsgrad der zu verdichtenden Luft oberhalb des zweiten Schwellenwertes liegt und/oder die Temperatur des Stroms von Kühlwasser oberhalb des dritten Schwellenwertes liegt, die in der Luftabscheidevorrichtung abzuscheidende Luft nur in einem zweiten (MAC2) der wenigstens zwei Verdichter verdichtet wird.

2. Verfahren nach Anspruch 1, wobei während des ersten Zeitraums die Temperatur der zu verdichtenden Luft unterhalb des ersten Schwellenwertes liegt und während des zweiten Zeitraums die Temperatur der zu verdichtenden Luft oberhalb des ersten Schwellenwertes liegt.

3. Verfahren nach Anspruch 1 oder 2, wobei während des ersten Zeitraums der Feuchtigkeitsgrad der zu verdichtenden Luft unterhalb des zweiten Schwellenwertes liegt und während des zweiten Zeitraums der Feuchtigkeitsgrad der zu verdichtenden Luft oberhalb des zweiten Schwellenwertes liegt.

4. Verfahren nach einem der vorhergehenden Ansprüche, wobei während des ersten Zeitraums die Temperatur des Stroms von Kühlwasser unterhalb des dritten Schwellenwertes liegt und während des zweiten Zeitraums die Temperatur des Stroms von Kühlwasser oberhalb des dritten Schwellenwertes liegt.

5. Verfahren nach einem der vorhergehenden Ansprüche, wobei der zweite Verdichter (MAC2) dafür ausgelegt ist, einen maximalen Luftstrom zu verdichten,

der höher ist als der maximale Luftstrom, den zu verdichten der erste Verdichter (MAC1) ausgelegt ist.

6. Verfahren nach einem der vorhergehenden Ansprüche, wobei der erste Zeitraum eine Anzahl von Tagen im Jahr und der zweite Zeitraum den Rest des Jahres bezeichnet.

7. Verfahren nach einem der vorhergehenden Ansprüche, wobei wenigstens ein Teil des ersten Zeitraums in die Nacht fällt und wenigstens ein Teil des zweiten Zeitraums in den Tag fällt.

8. Verfahren nach einem der vorhergehenden Ansprüche, wobei während des ersten Zeitraums der zweite Verdichter (MAC2) dazu in der Lage ist zu arbeiten und während des zweiten Zeitraums der erste Verdichter (MAC1) dazu in der Lage ist zu arbeiten.

9. Verfahren nach einem der vorhergehenden Ansprüche, wobei ein theoretischer Wert V für den zugeführten Luftstrom berechnet wird, ein Wert R für den erforderlichen Luftstrom zum Erzeugen eines erforderlichen Produktstroms berechnet wird und, wenn die Abweichung zwischen R und V einen Schwellenwert überschreitet, die zugeführte Luft nur zu dem zweiten Verdichter (MAC2) geschickt wird.

Revendications

1. Procédé d'exploitation d'une unité de séparation d'air dans lequel de l'air à séparer dans une unité de séparation d'air cryogénique est comprimé dans l'un d'au moins deux compresseurs, purifié et refroidi et séparé dans l'unité de séparation d'air afin de produire un produit fluide, chaque compresseur comprenant au moins deux étages et le refroidissement étant assuré entre les étages à l'aide d'au moins un courant d'eau de refroidissement, dans lequel :

i) pendant une première période, au cours de laquelle la température de l'air à comprimer est en dessous d'un premier seuil et/ou le degré d'humidité de l'air à comprimer est en dessous d'un deuxième seuil et/ou la température du courant d'eau de refroidissement est en dessous d'un troisième seuil, l'air à séparer dans unité de séparation d'air est comprimé uniquement dans un premier des au moins deux compresseurs (MAC1), et

ii) pendant une seconde période, au cours de laquelle la température de l'air à comprimer est au-dessus du premier seuil et/ou le degré d'humidité de l'air à comprimer est au-dessus du deuxième seuil et/ou la température du courant d'eau de refroidissement est au-dessus d'un troisième seuil, l'air à séparer dans l'unité de

séparation d'air est comprimé uniquement dans un deuxième (MAC2), des au moins deux compresseurs.

2. Procédé selon la revendication 1, dans lequel pendant la première période, la température de l'air à comprimer est en dessous du premier seuil et pendant la seconde période, la température de l'air à comprimer est au-dessus du premier seuil. 5
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3. Procédé selon la revendication 1 ou 2, dans lequel pendant la première période, le degré d'humidité de l'air à comprimer est en dessous du deuxième seuil et pendant la seconde période, le degré d'humidité de l'air à comprimer est au-dessus du deuxième seuil. 15
4. Procédé selon l'une quelconque des revendications précédentes, dans lequel pendant la première période, la température du courant d'eau de refroidissement est en dessous du troisième seuil et pendant la seconde période, la température du courant d'eau de refroidissement est au-dessus du troisième seuil. 20
5. Procédé selon l'une quelconque des revendications précédentes, dans lequel le deuxième compresseur (MAC2) est conçu pour comprimer un flux d'air maximal supérieur au flux maximal que le premier compresseur (MAC1) est conçu pour comprimer. 25
30
6. Procédé selon l'une quelconque des revendications précédentes, dans lequel la première période désigne un nombre de jours dans l'année et la seconde période le reste de l'année. 35
7. Procédé selon l'une quelconque des revendications précédentes, dans lequel au moins une partie de la première période tombe pendant la nuit et au moins une partie de la seconde période tombe pendant la journée. 40
8. Procédé selon l'une quelconque des revendications précédentes, dans lequel pendant la première période, le deuxième compresseur (MAC2) est capable de fonctionner et pendant la seconde période, le premier compresseur (MAC1) est capable de fonctionner. 45
9. Procédé selon l'une quelconque des revendications précédentes, dans lequel une valeur théorique V pour le courant d'air d'amenée est calculée, une valeur R pour le courant d'air requis afin de produire un courant de produit requis est calculée et lorsque l'écart entre R et V dépasse un seuil, l'air d'amenée est envoyé uniquement au deuxième compresseur (MAC2). 50
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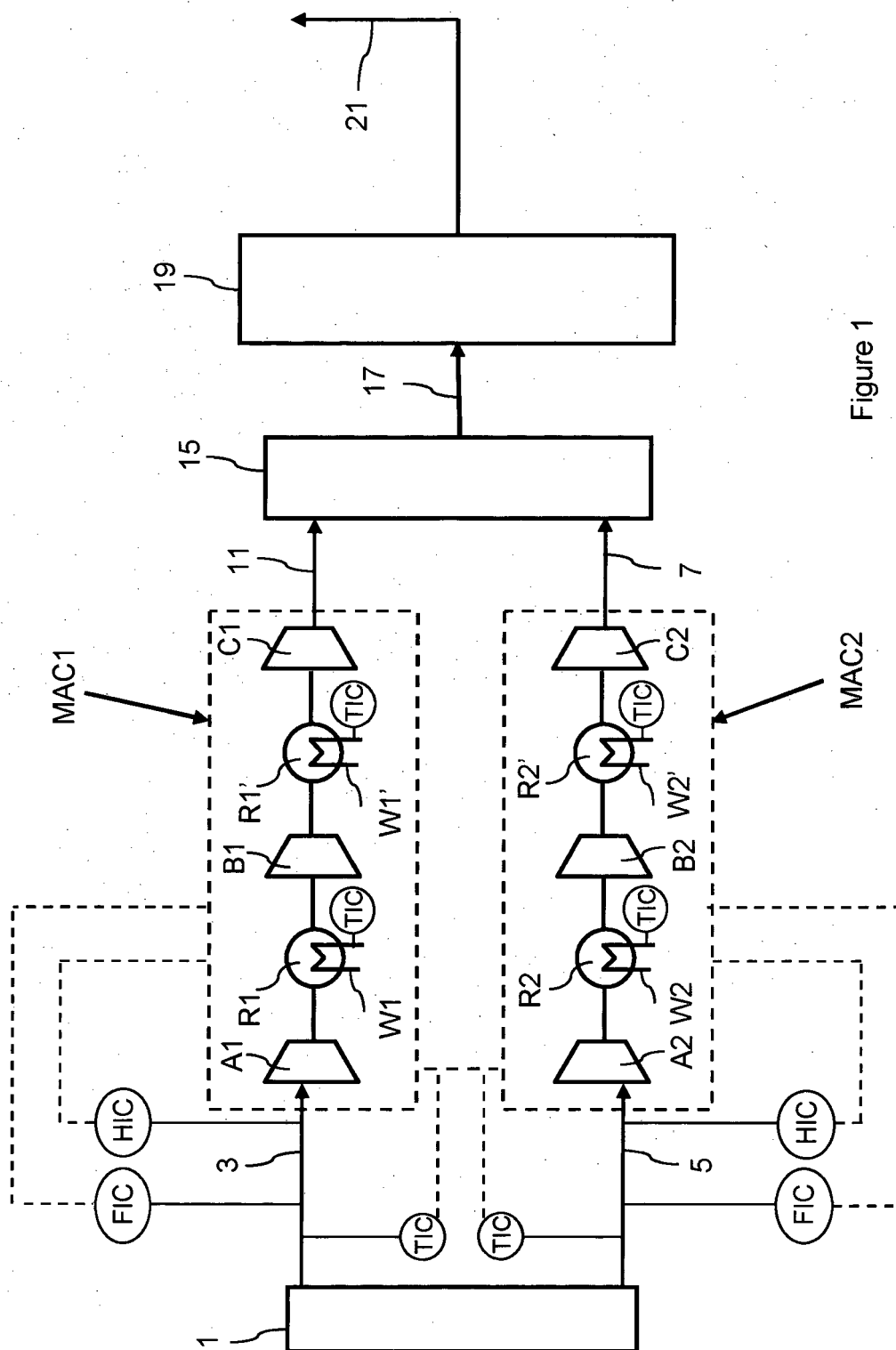


Figure 1