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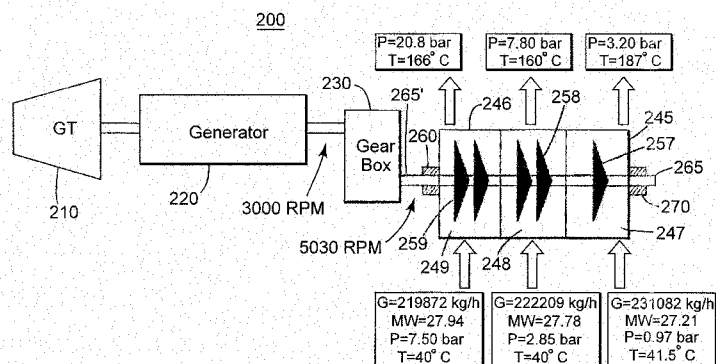
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(54) Title: HIGH PRESSURE RATIO COMPRESSORS WITH MULTIPLE INTERCOOLING AND RELATED METHODS

Figure 2



(57) Abstract: Turbo-compressor/generator trains 200,300 including high pressure ratio compressors with multiple intercooling and related methods are provided. A high pressure ratio compressor 245,345 with multiple intercooling includes a casing 246, 346 with plural chambers 247,248, one or more shafts 265,365 penetrating inside the chambers, and impellers 257,258 mounted on the one or more shafts inside the chambers, respectively. Each chamber has a gas inlet and a gas outlet to allow gas flow to be input into and to be output from the respective chamber. A gas flow is successively compressed in each of the chambers, and is cooled outside the compressor when transferring from one chamber to a next chamber among the plural chambers.



HIGH PRESSURE RATIO COMPRESSORS WITH MULTIPLE INTERCOOLING AND RELATED METHODS

Embodiments of the subject matter disclosed herein generally relate to high pressure
5 ratio compressors with multiple intercooling and related methods; more particularly,
to a turbo-compressor/generator train using a high pressure compressor with multiple
intercooling instead of plural compressors.

One type of turbo-machinery is a centrifugal compressor. Centrifugal compressors
are usually designed in families intended to cover a specific flow range and use. In
10 order to achieve a desired compression ratio, a centrifugal compressor may be
arranged to perform compression one after another. For example, two centrifugal
compressors are typically arranged in a turbo-compressor/generator train 100 as
illustrated in Figure 1. Such turbo-compressor/generator trains may be used for blast
furnaces in the steel industry, natural gas liquefaction, gas reinjection and other oil
15 and gas services.

Five machines are mechanically coupled in the turbo-compressor/generator train 100:
a gas turbine 110, a generator 120, a gear box 130, a first low pressure compressor
140, and a second compressor 150. This type of arrangement is sometimes called a
“single-shaft” configuration.

20 The generator 120 may have a rotation speed of 3000 rotations per minute (RPM).
The gear box 130 is a step-up type of gear, for example, increasing the rotation speed
to ~5000 RPM and transmitting this rotation to the first compressor 140 and to the
second compressor 150.

The first low pressure compressor 140 may be of a double flow type receiving via two
25 inputs the gas flow at an input pressure (e.g., of about 0.97 bar) and an input
temperature (e.g., of about 41.5° C), and outputting the gas flow at an output pressure
(e.g., of about 3.20 bar) and an output temperature (e.g., of about 187° C). The output
gas is then cooled and input to the second compressor 150.

The second compressor 150 may be a two-section type of compressor receiving first

an input gas flow at a first input pressure (e.g., 2.85 bar) and a first input temperature (e.g., of about 40° C) and outputting a first output flow at a first output pressure (e.g., of about 7.90 bar) and a first output temperature (e.g., of about 160° C). This first output flow is then cooled and input to the compressor 150 as a second flow at a
5 second input pressure (e.g., 7.50 bar) and a second input temperature (e.g., of about 40° C). The compressor 150 then outputs a second output flow at a second output pressure (e.g., of about 20.8 bar) and a second output temperature (e.g., of about 166° C).

Note that the second input pressure is slightly lower than the first output pressure, and
10 the third input pressure is slightly lower than the second output pressure. Also, the gas flow may be about 22-230000 kg/h, but flow losses of around 10% may occur during cooling.

In the conventional turbo-compressor/generator train, the compressor has closed and
shrunk fit impellers, the required compression being achieved by splitting the
15 compression process into sub-processes performed inside the two different compressors. Reliability is sub-optimal due to the use of the two different compressors and the transition there-between. Additionally, the cost of the two compressors and the operating costs (footprint) thereof make it attractive to seek using more efficient, cheaper and reliable equipment for the compression.

20 Accordingly, it would be desirable to provide a high pressure compressor with multiple intercooling and related methods that avoid the afore-described problems and drawbacks.

The use of a high pressure air compressor with two levels of intercooling instead of
two compressors in a turbo-compressor/generator train allows removal of one large
25 casing, leading to a benefit in size, cost, overall reliability and footprint.

According to one exemplary embodiment, a high pressure ratio compressor with multiple intercooling used in a turbo-compressor/generator train includes a casing with plural chambers, one or more shafts penetrating inside the chambers, and impellers mounted on the one or more shafts, inside the chambers, respectively. Each

chamber has a gas inlet and a gas outlet to allow gas flow to be input into and to be output from the respective chambers. A gas flow is successively compressed in each of the chambers, and is cooled outside the compressor when transferring from one chamber to the next chamber among the plural chambers.

- 5 According to another embodiment, a turbo-compressor/generator train includes a high pressure ratio compressor with multiple intercooling. The compressor has a casing with plural chambers, one or more shafts penetrating inside the chambers, and impellers mounted on the one or more shafts, inside the chambers, respectively. Each chamber has a gas inlet and a gas outlet to allow gas flow to be input into and to be
- 10 output from the respective chambers. The gas flow is successively compressed in each of the chambers, and is cooled outside the compressor when transferring from one chamber to the next chamber among the plural chambers.

According to another exemplary embodiment, a method of retrofitting a conventional turbo-compressor/generator train includes (A) removing at least two compressors

15 from the conventional turbo-compressor/generator train, and (B) adding a single high pressure ratio compressor with multiple intercooling. The single compressor is configured to achieve the same compression as the removed compressors.

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate one or more embodiments and, together with the description,

20 explain these embodiments. In the drawings:

Figure 1 is a schematic diagram of a conventional turbo-compressor/generator train;

Figure 2 is a schematic diagram of a turbo-compressor/generator train, according to an exemplary embodiment;

Figure 3 is a schematic diagram of a turbo-compressor/generator train, according to

25 another exemplary embodiment; and

Figure 4 is a flowchart illustrating a method for retrofitting a conventional turbo-compressor/generator train, according to an exemplary embodiment.

The following description of the exemplary embodiments refers to the accompanying drawings. The same reference numbers in different drawings identify the same or similar elements. The following detailed description does not limit the invention. Instead, the scope of the invention is defined by the appended claims. The following
5 embodiments are discussed, for simplicity, with regard to the terminology and structure of a turbo-compressor/generator train. However, the embodiments to be discussed next are not limited to these systems, but may be applied to other systems in which plural compressors are used.

Reference throughout the specification to “one embodiment” or “an embodiment”
10 means that a particular feature, structure or characteristic described in connection with an embodiment is included in at least one embodiment of the subject matter disclosed. Thus, the appearance of the phrases “in one embodiment” or “in an embodiment” in various places throughout the specification is not necessarily referring to the same embodiment. Further, the particular features, structures or characteristics may be
15 combined in any suitable manner in one or more embodiments.

In some embodiments, plural impellers are mounted in the same one casing to achieve a more efficient, cheaper and reliable compressor capable of performing the duty of the two compressors in a conventional turbo-compressor/generator train.

A schematic diagram of a turbo-compressor/generator train 200, according to an
20 exemplary embodiment, is illustrated in Figure 2. The turbo-compressor/generator train 200 includes a gas turbine 210, a generator 220, a gear box 230, and a single compressor 245 with multiple cooling. The gas turbine 210, the generator 220, and the gear box 230 may be similar to the gas turbine 110, the generator 120, and the gear box 130 in the conventional turbo-compressor/generator train 100.

25 The compressor 245 is a high pressure ratio compressor with multiple intercooling. The ratio of the output pressure (of the gas flow output from the compressor 245 after being compressed) to the input pressure (of the gas flow input to the compressor 245 for being compressed) may be over 20. Shafts 265 and 265' of the compressor 245 are axially connected and may be supported by plural bearings. In Figure 2, a first
30 bearing 260 is located outside the casing 246 of the compressor 245, on the shaft 265'

at a side of the casing 245 toward the gear box 230. A second bearing 270 is also located outside the casing 246, on the shaft 265 at the opposite side of the casing 246 relative to the side where the first bearing 260 is located.

5 The compressor 245 has three chambers 247, 248 and 249, each chamber having a gas inlet and a gas outlet to allow gas flow to enter and to exit the respective chamber. The gas may be air. The shafts 265 and 265' penetrate through the chambers. Impellers 257, 258 and 259 are mounted on the shafts in chambers 247, 248 and 249, respectively. The impellers 257 and 258 are low pressure components and may be open impeller type. The impeller 259 is a high pressure component and may be of
10 closed impeller type. The low pressure components 257 and 258 may be axially stacked, while the high pressure component 259 may be either stacked type or shrunk fit onto shaft 265'. The shafts 265 and 265' and the impellers 257, 258 and 259 are axially connected to constitute the rotor of compressor 245.

The gas flow enters the first chamber 247 of the compressor 245 having a first input
15 pressure (e.g., of about 0.97 bar) and a first input temperature (e.g., of about 41.5° C), and is output having a first output pressure (e.g., of about 3.20 bar) higher than the first input pressure, and a first output temperature (e.g., of about 187° C) higher than the first input temperature.

20 The output gas is then cooled (i.e., a first cooling outside the compressor) and input into the second chamber 248 of the compressor 245 having a second input pressure (e.g., 2.85 bar) and a second input temperature (e.g., of about 40° C). Inside the second chamber 248, the gas is compressed to be output having a second output pressure (e.g., of about 7.80 bar) higher than the second input pressure, and a second output temperature (e.g., of about 160° C) higher than the second input temperature.

25 The gas flow is then cooled again (i.e., a second cooling outside the compressor) and input into the third chamber 249 of the compressor 245 having a third input pressure (e.g., 7.50 bar) and a second input temperature (e.g., of about 40° C). Inside the third chamber 249, the gas is compressed to be output having a third output pressure (e.g., of about 20.8 bar) higher than the third input pressure, and a third output temperature
30 (e.g., of about 166° C) higher than the third input temperature.

A schematic diagram of a turbo-compressor/generator train 300, according to another exemplary embodiment, is illustrated in Figure 3. The turbo-compressor/generator train 300 includes a gas turbine 310, a generator 320, a gear box 330, and a single compressor 345 with multiple cooling. The gas turbine 310, the generator 320, and the gear box 330 may be similar to the gas turbine 110, the generator 120, and the gear box 130 in the conventional turbo-compressor/generator train 100.

Similar to compressor 245, the compressor 345 is a high pressure ratio compressor with multiple intercooling that may achieve a ratio of the output pressure to the input pressure over 20. The compressor 345 has three chambers 347, 348 and 349, with impellers 357, 358 and 359 mounted on the shaft 365 therein. The gas flow is compressed inside the chambers 347, 348 and 349 in a manner similar to the manner described relative to compressor 245.

The shaft 365 of compressor 345 may be supported by plural bearings. A first bearing 360 is located outside the compressor 345, at a side of the casing 346 of the compressor 345 toward the gear box 330. Different from compressor 245, a second bearing 380 is located inside compressor 345 between chamber 347 and chamber 348 thereof. This arrangement of the bearings allows a higher rotation of the shaft 365, than of shafts 265, 265', for example, up to 7000 RPM.

Conventional turbo-compressor/generator trains may be retrofitted by replacing the two compressors with a single high pressure ratio compressor with multiple intercooling. Figure 4 is a flowchart illustrating a method 400 for retrofitting a conventional turbo-compressor/generator train, according to an exemplary embodiment. The method 400 includes removing at least two compressors from the conventional turbo-compressor/generator train, at S410, and adding a single high pressure ratio compressor with multiple intercooling, at S420. The single compressor is configured to achieve the same compression as the removed compressors.

The single compressor may have multiple chambers inside which a gas flow is compressed. For example, the single compressor may have three chambers. The compressed gas flow is output from two of the chambers to be cooled outside the compressor before being directed into the next chamber.

The method may further include adding at least two bearings to support a shaft of the single compressor. One of the added bearings may be located outside the casing of the single compressor, at a side thereof toward the gear box of the turbo-compressor/generator train. In one embodiment a second bearing may also be located
5 outside the casing of the single compressor, at the opposite side of the casing relative to the side where the first bearing is located. In another embodiment, a second bearing may be located inside the casing of the single compressor. For example, the second bearing may be located between chambers of the compressor.

The disclosed exemplary embodiments provide a turbo-compressor/generator train
10 including a single high pressure compressor with multiple cooling and related methods. It should be understood that this description is not intended to limit the invention. On the contrary, the exemplary embodiments are intended to cover alternatives, modifications and equivalents, which are included in the spirit and scope of the invention as defined by the appended claims. Further, in the detailed
15 description of the exemplary embodiments, numerous specific details are set forth in order to provide a comprehensive understanding of the claimed invention. However, one skilled in the art would understand that various embodiments may be practiced without such specific details.

Although the features and elements of the present exemplary embodiments are
20 described in the embodiments in particular combinations, each feature or element can be used alone without the other features and elements of the embodiments or in various combinations with or without other features and elements disclosed herein.

This written description uses examples of the subject matter disclosed to enable any person skilled in the art to practice the same, including making and using any devices
25 or systems and performing any incorporated methods. The patentable scope of the subject matter is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims.

CLAIMS

1. A high pressure ratio compressor (245, 345) with multiple intercooling used in a turbo-compressor/generator train (200, 300), the compressor comprising:

a casing (246, 346) with plural chambers (247, 248, 249, 347, 348, 349), each chamber having a gas inlet and a gas outlet to allow gas flow to be input into and to be output from the respective chamber;

one or more shafts (265, 265', 365) penetrating inside the chambers; and

impellers (257, 258, 259, 357, 358, 359) mounted on the one or more shafts, inside the chambers, respectively,

wherein a gas flow is successively compressed in each of the chambers, and is cooled outside the casing when transferring from one chamber to a next chamber among the plural chambers.

2. The compressor of claim 1, wherein the compressor is configured to achieve a compression ratio over 20, for a gas flow around 220000 kg/h.

3. The compressor of claim 1 or claim 2, further comprising plural bearings supporting the shaft, wherein one of the plural bearings is located on the shaft outside the casing, at a side of the casing towards a gear box of the turbo-compressor/generator train.

4. The compressor of any preceding claim, wherein another one of the plural bearings is located on the shaft outside the casing, at an opposite side of the casing relative to the side of the casing towards the gear box.

5. The compressor of any preceding claim, wherein another one of the plural bearings is located on the shaft inside the casing, near a wall separating chambers of the compressor.

6. The compressor of any preceding claim, wherein the chambers are arranged in an order corresponding to an output pressure of the gas flow, the another one of the plural bearings being located near the wall separating lower pressure chambers of the compressor, and the one of the plural bearings being located near a chamber corresponding to the highest output pressure.

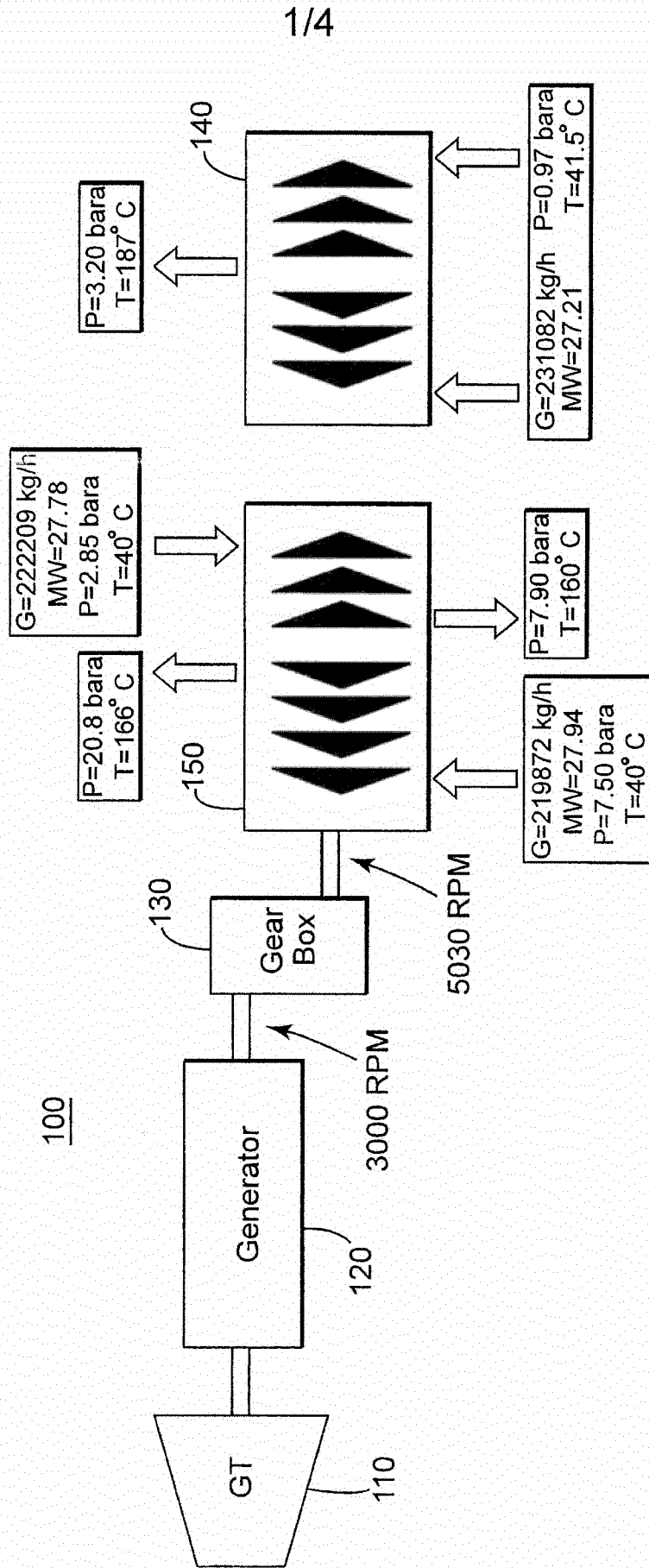
7. The compressor of any preceding claim, wherein the compressor includes three chambers, and pressure of the gas flow output from one chamber drops about 10% while being cooled outside the casing before being input into the next chamber.
8. The compressor of any preceding claim, wherein the compressor is configured to meet at least one of the following conditions:
 - temperatures of the gas flow input in each of the chambers is around 40° C;
 - a ratio of pressure of the gas flow output from each chamber to pressure of the gas flow input in the respective chamber is between 2.5 and 3.5;
 - an input pressure of the gas flow input in a first chamber of the compressor is about 1 bar;
 - an output pressure of the gas flow output from the compressor is about 20.8 bar; and
 - a rotation speed of the one or more shafts is between 5000-7000 RPM.
9. A turbo-compressor/generator train (200, 300) comprising a high pressure ratio compressor (245,345) with multiple intercooling according to any preceding claim.
10. A turbo-compressor/generator train (200, 300), comprising:
 - a high pressure ratio compressor (245, 345) with multiple intercooling including
 - a casing (246, 346) with plural chambers (247, 248, 249, 347, 348, 349), each chamber having a gas inlet and a gas outlet to allow gas flow be input into and to be output from the respective chamber;
 - one or more shafts (265, 265', 365) penetrating inside the chambers; and
 - impellers (257, 258, 259, 357, 358, 359) mounted on the one or more shafts inside the chambers, respectively,
 - wherein a gas flow is successively compressed in each of the chambers, and is cooled outside the casing when transferring from one chamber to a next chamber among the plural chambers.
11. A method (400) of retrofitting a conventional turbo-compressor/generator train, the method comprising:

removing (S410) at least two compressors from the conventional turbo-compressor/generator train; and

adding (S420) a single high pressure ratio compressor with multiple intercooling,

wherein the single compressor is configured to achieve the same compression as the removed compressors.

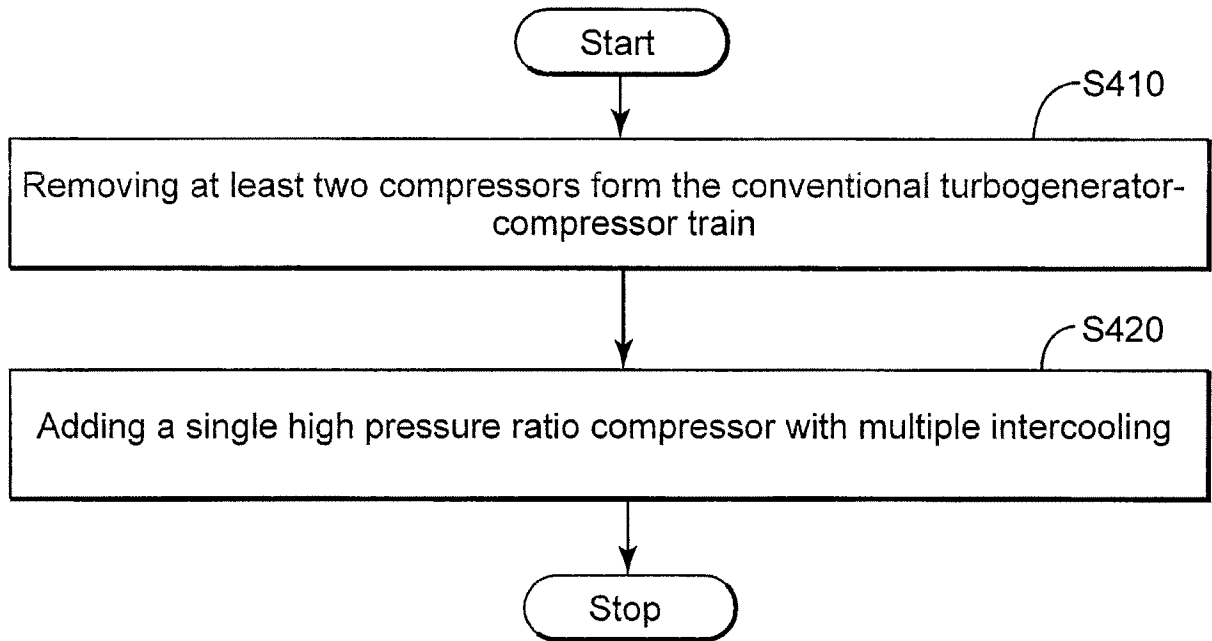
Figure 1



4/4

Figure 4

400



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/061295

A. CLASSIFICATION OF SUBJECT MATTER
 INV. F02C7/143 F04D29/58
 ADD. F02C6/06 F04D17/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
 Minimum documentation searched (classification system followed by classification symbols)
 F02C F04D F01D F25B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
 EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	WO 2006/079438 A1 (SIEMENS AG [DE]; KATHOL ULRICH [DE]) 3 August 2006 (2006-08-03) the whole document page 7, line 14 - page 8, line 14 figures 1,6	1-11
X	DE 14 28 047 A1 (BASF AG) 28 November 1968 (1968-11-28) the whole document page 9, line 14 - page 11, line 12 figure 1	1-3,7-11
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Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

<p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p>
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Date of the actual completion of the international search 4 September 2013	Date of mailing of the international search report 10/09/2013
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INTERNATIONAL SEARCH REPORT

International application No
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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