(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 839 221 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
23.06.2021 Bulletin 2021/25

(51) Int Cl.:
F01K 23/06 (2006.01) *F01K 9/00* (2006.01)

(21) Application number: 19217690.7

(22) Date of filing: 18.12.2019

(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
Designated Extension States:
BA ME
KH MA MD TN

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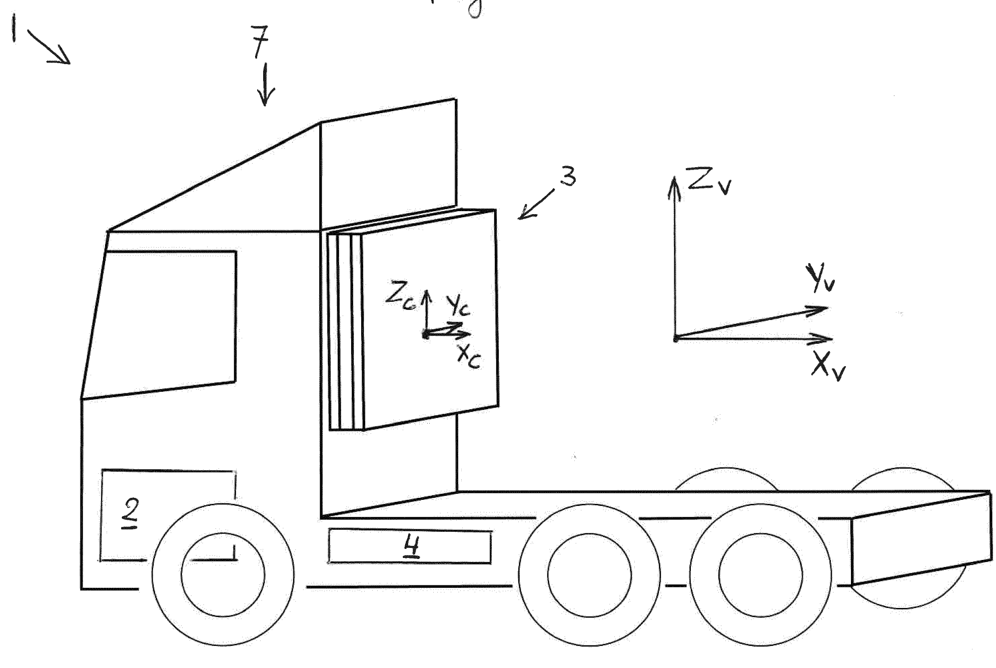
(54) HEAVY-DUTY VEHICLE COMPRISING A COMBUSTION ENGINE

(57) A heavy-duty vehicle (1) comprises an ORC system for waste heat recovery out of flue gas exhausted by the vehicle's combustion engine. The ORC system comprises a condensor (3) which is arranged in the slipstream of the vehicle's base structure (7). The overall width W of the condensor is in the range between 1.0 m and 3.0 m, the overall height H of the condensor is in the range between 1.0 m and 4.0 m, while the overall depth D of the condensor is in the range between 0.05W and 0.30W and in the range between 0.05H and 0.30H. Air-intake and air-outlet openings of the condensor are configured for realizing buoyancy flow of environmental air through the condensor. Thanks to the condensor's location, dimensions and configuration considerable improvements in energy savings are obtained as compared to previously proposed ORC systems for heavy-duty vehicles.

Fig. 1



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Description

[0001] The invention relates to a heavy-duty vehicle comprising a combustion engine. Such a heavy-duty vehicle may for example be a truck having a cabin, or a bus having a passenger compartment.

[0002] In practice, attempts have been made and are still being made to provide a heavy-duty vehicle with an organic rankine cycle system for waste heat recovery out of flue gas exhausted by the combustion engine. As used herein, an organic rankine cycle system is also called "ORC system". In general, an ORC system typically comprises an evaporator, an expansion device (such as a turbine or other expander), a condensor and a working fluid pump. In an ORC system, an organic fluid is used. In the expansion device, the energy is recovered as work, which can be used to perform mechanical work and/or to generate electricity.

[0003] However, ORC systems which have thus far been proposed for incorporation in a heavy-duty vehicle have not yet turned out to be of significant economical interest. The reason is that the energy savings obtained are relatively low as compared to the costs of incorporating such a proposed ORC system in a heavy-duty vehicle. One of the factors therein is that the condensor that has to be used in the ORC system needs considerable cooling, which is achieved via wind-intake opening structures in the heavy-duty vehicle and/or via electrical fans. Applying wind-intake opening structures comes at the price of increased aerodynamic resistance of the vehicle, while the application of electrical fans costs electrical energy. Evidently, these factors cost fuel.

[0004] It is an object of the invention to improve the energy savings obtained when an ORC system for waste heat recovery out of flue gas is incorporated in a heavy-duty vehicle, such as a truck or a bus.

[0005] For that purpose the invention provides a heavy-duty vehicle according to the appended independent claim 1. Preferable embodiments of the invention are provided by the appended dependent claims 2-11.

[0006] Hence the invention provides a heavy-duty vehicle comprising a combustion engine and an organic rankine cycle system for waste heat recovery out of flue gas exhausted by the combustion engine, wherein:

- said organic rankine cycle system is configured for performing organic rankine cycles with an organic working fluid which is heated by said flue gas;
- said organic rankine cycle system comprises a condensor for condensing said organic working fluid by heat transfer with environmental air of the heavy-duty vehicle;
- the heavy-duty vehicle has mutually orthogonal vehicle directions in the form of a vehicle length direction, a vehicle width direction, and a vehicle height direction;
- the condensor has mutually orthogonal condensor directions in the form of a condensor depth direction, a condensor width direction, and a condensor height direction;
- the condensor is arranged in a slipstream of a base structure of the heavy-duty vehicle, said base structure comprising a cabin of a truck in case the heavy-duty vehicle is a truck, or a passenger compartment in case the heavy-duty vehicle is a bus;
- the condensor depth direction is parallel to the vehicle length direction, the condensor width direction is parallel to the vehicle width direction, and the condensor height direction is parallel to the vehicle height direction;
- the condensor has an overall depth D in said condensor depth direction (Xc), an overall width W in said condensor width direction, and an overall height H in said condensor height direction;
- said overall width W has a value in the range $1.0 \text{ m} \leq W \leq 3.0 \text{ m}$;
- said overall height H has a value in the range $1.0 \text{ m} \leq H \leq 4.0 \text{ m}$;
- said overall depth D has a value in the range $0.05W \leq D \leq 0.30W$;
- said overall depth D has a value in the range $0.05H \leq D \leq 0.30H$;
- said condensor has at least one air-intake opening for allowing said environmental air to enter the condensor and at least one air-outlet opening for allowing said environmental air, when entered into and heated inside the condensor, to exit the condensor, wherein said at least one air-intake opening is located at a lower position along said height direction than said at least one air-outlet opening.

[0007] Some surprising key features of the heavy-duty vehicle according to the invention are summarized as follows.

i. The condensor is arranged at a surprising location in the slipstream of the vehicle's base structure.
ii. The values of the overall width W, overall height H and overall depth D of the condensor are forming a surprisingly huge condensor for a heavy-duty vehicle.
iii. Said at least one air-intake opening is surprisingly located at a lower position than said at least one air-outlet opening.

[0008] The combination of these surprising key features (i), (ii) and (iii) allows for a remarkably effective buoyancy flow of environmental air through the condensor. In other words, a kind of chimney effect is created according to which environmental air that is heated inside the condensor automatically rises up. The combination of these key features (i), (ii) and (iii) considerably improves the efficiency of the ORC system of the heavy-duty vehicle, without necessity to use wind-intake opening structures in the heavy-duty vehicle and/or electrical fans for the air-cooling of the condensor. Hence, this is achieved with more or less zero aerodynamic impact and zero electrical energy for cooling. This way the energy savings obtained for a heavy-duty vehicle are improved to such an extent that the present invention makes the application of an ORC system in a heavy-duty vehicle economically worthwile.

[0009] In a preferable embodiment of a heavy-duty vehicle according to the invention, said overall width W has a value in the range 1.5 m $\leq$ W $\leq$ 2.5 m.

[0010] In another preferable embodiment of a heavy-duty vehicle according to the invention, said overall height H has a value in the range 1.5 m $\leq$ H $\leq$ 2.5 m.

[0011] In another preferable embodiment of a heavy-duty vehicle according to the invention, said overall depth D has a value in the range 0.10W $\leq$ D $\leq$ 0.20W.

[0012] In another preferable embodiment of a heavy-duty vehicle according to the invention, said overall depth D has a value in the range 0.10H $\leq$ D $\leq$ 0.20H.

[0013] In another preferable embodiment of a heavy-duty vehicle according to the invention, said condensor comprises a condensor housing containing at least two flat condensing structures configured for containing said organic working fluid and for condensing said organic working fluid contained therein, wherein said at least two flat condensing structures are extending mutually parallel and perpendicularly to said condensor depth direction, and wherein said at least two flat condensing structures are mutually spaced in said condensor depth direction.

[0014] It is remarked that, instead of the last-mentioned preferable embodiment in which the condensor comprises a condensor housing containing at least two flat condensing structures, the condensor of a heavy-duty vehicle according to the invention may, more generally, comprise a condensor housing which contains one, and only one, flat condensing structure which is configured for containing said organic working fluid and for condensing said organic working fluid contained therein, wherein said one, and only one, flat condensing structure is extending perpendicularly to said condensor depth.

[0015] The last-mentioned preferable embodiment in which the condensor comprises a condensor housing containing said at least two flat condensing structures, instead of only one flat condensing structure, has the advantage of improved condensor efficiency, at the price of only restricted additional space requirement for the condensor in the slipstream of the vehicle's base structure.

[0016] In another preferable embodiment of a heavy-duty vehicle according to the invention, said condensor comprises a first interspace in-between two mutually neighbouring ones of said at least two flat condensing structures, wherein said first interspace is configured for containing said environmental air for heating of said environmental air, and wherein said first interspace has a first overall interspace dimension D1 in said condensor depth direction having a value in the range 5 cm $\leq$ D1 $\leq$ 15 cm. This further improves the condensor efficiency.

[0017] In another preferable embodiment of a heavy-duty vehicle according to the invention, said first interspace contains at least two first airfins, which are extending in said condensor height direction, and which are mutually spaced in said condensor width direction, and wherein each of said at least two first airfins is extending in said condensor depth direction in such manner that it is interconnecting said two mutually neighbouring ones of said at least two flat condensing structures. Said at least two first airfins provide for improved heat transfer from the organic working fluid to the environmental air, as well as for improved structural strength of the condensor structure.

[0018] In another preferable embodiment of a heavy-duty vehicle according to the invention, said condensor comprises a second interspace in-between said condensor housing and a neighbouring one of said at least two flat condensing structures, wherein said second interspace is configured for containing said environmental air for heating of said environmental air, and wherein said second interspace has a second overall interspace dimension D2 in said condensor depth direction having a value in the range 1 cm $\leq$ D2 $\leq$ 10 cm. This further improves the condensor efficiency.

[0019] In another preferable embodiment of a heavy-duty vehicle according to the invention, said second interspace contains at least two second airfins, which are extending in said condensor height direction, and which are mutually spaced in said condensor width direction, and wherein each of said at least two second airfins is extending in said condensor depth direction in such manner that it is interconnecting said condensor housing and said neighbouring one of said at least two flat condensing structures. Said at least two second airfins provide for improved heat transfer from the organic working fluid to the environmental air, as well as for improved structural strength of the condensor structure.

[0020] In another preferable embodiment of a heavy-duty vehicle according to the invention, said condensor is a first heat exchanger being assembled within a combined heat exchanging unit that is located in said slipstream of said base structure, and wherein said combined heat exchanging unit further comprises at least one further heat exchanger for heat transfer with environmental air of the heavy-duty vehicle, said at least one further heat exchanger having at least one further air-intake opening for allowing said environmental air to enter said at least one further heat exchanger and at least one further air-outlet opening for allowing said environmental air, when entered into and heated inside the condensor, to exit said at least one further heat exchanger, wherein said at least one further air-intake opening is located at a lower position along said height direction than said at least one further air-outlet opening. Thanks to said combined heat exchanging unit, said at least one further heat exchanger may benefit at least from advantages similar to the advantages of the condensor of the ORC system, i.e. improved efficiency of the at least one further heat exchanger of the heavy-duty vehicle, without necessity to use wind-intake opening structures in the heavy-duty vehicle and/or electrical fans for the air-cooling of the at least one further heat exchanger. It is noted that said at least one further heat exchanger may for example be an engine oil heat exchanger and/or a transmission oil heat exchanger and/or an air-conditioning condensor and/or any other heat exchanger used in a heavy-duty vehicle.

[0021] In the following, the invention is further elucidated with reference to nonlimiting embodiments and with reference to the schematic figures in the appended drawing, in which the following is shown.

Fig. 1 shows, in a perspective view, an example of an embodiment of a heavy-duty vehicle according to the invention.
Fig. 2 shows, in a more detailed perspective view, the condensor of the ORC system of the heavy-duty vehicle of Fig. 1.
Fig. 3 shows the heavy-duty vehicle of Fig. 1 in a side view.
Fig. 4 shows the condensor of Fig. 1 in a cross-section perpendicular to the condensor width direction.
Fig. 5 shows, in a cross-section perpendicular to the condensor width direction, an example in which the condensor of Figs. 1-4 is assembled within an example of an embodiment of the above-mentioned combined heat exchanging unit.

[0022] The reference signs used in Figs. 1-5 are referring to the above-mentioned parts and aspects of the invention, as well as to related parts and aspects, in the following manner.

1	heavy-duty vehicle
2	combustion engine
3	condensor of organic rankine cycle system
3A	further heat exchanger
3B	further heat exchanger
3C	further heat exchanger
4	parts of organic rankine cycle system, other than the condensor
5	organic working fluid
6	environmental air
7	base structure
8	at least one air-intake opening
8A	at least one further air-intake opening
8B	at least one further air-intake opening
8C	at least one further air-intake opening
9	at least one air-outlet opening
9A	at least one further air-outlet opening
9B	at least one further air-outlet opening
9C	at least one further air-outlet opening
10	condensor housing
11	flat condensing structure
12	flat condensing structure
14	combined heat exchanging unit
15	vapour supply pipe
16	T-connection piece
17	liquid discharge pipe structure
21	first interspace
22A	second interspace
22B	second interspace
31	first airfin
32A	second airfin
32B	second airfin
X_C	condensor depth direction
Y_C	condensor width direction
Z_C	condensor height direction
X_V	vehicle length direction
Y_V	vehicle width direction
Z_V	vehicle height direction

[0023] Based on the above introductory description, including the brief description of the drawing figures, and based on the above-listed reference signs used in Figs. 1-5, the examples of Figs. 1-5 are readily self-explanatory. The following extra explanations are given.

[0024] The heavy-duty vehicle 1 of Figs. 1 and 3 is a truck, wherein the base structure 7 of the truck is formed by a cabin and a cabin top deflector mounted on top of the cabin. The ORC system of the vehicle 1 comprises the condensor 3, which is located in the slipstream of the base structure 7. Other parts of the ORC system have been shown and indicated highly schematically by item 4 in Fig. 1. It is noted that, in case the heavy-duty vehicle would be a bus, the condensor can be located in the slipstream on, for example, the backside of the bus.

[0025] In the shown example, the condensor 3 substantially has the shape of a rectangular parallelepiped having the overall depth D, the overall width W and the overall height H as mentioned above. In the perspective view of Fig. 2 and in the side view of Fig. 3 the condensor 3 is shown partly in ghost view, so as to indicate some internal parts within the housing 10 of the condensor 3. The indicated internal parts are the two flat condensing structures 11, 12, the first interspace 21, and the two second interspaces 22A, 22B. In Fig. 2 it is seen that the environmental air 6 enters the condensor 3 via the lower air-intake openings 8 and exits the condensor 3 via the upper air-outlet openings 9. In the first interspace 21 and the two second interspaces 22A, 22B the environmental air 6 is heated by heat transfer from the organic working fluid 5 inside the two flat condensing structures 11, 12.

[0026] In Fig. 2 the reference numerals 5 serve to indicate that the organic working fluid 5 may enter the two flat condensing structures 11, 12 from above in gaseous form and may exit the two flat condensing structures 11, 12 from below in condensed form. This is also illustrated by the cross-sectional view of Fig. 4, which illustrates that, in the shown example, a vapour supply pipe 15 is used that is extending from under the condensor 3 upwardly into and through the first interspace 21 and then connects via a T-connection piece 16 with top inlets of the two flat condensing structures 11, 12. Fig. 4 further illustrates that, in the shown example, a liquid discharge pipe structure 17 is connected to bottom outlets of the two flat condensing structures 11, 12.

[0027] Fig. 2 further indicates upper parts of the first airfins 31, the second airfins 32A and the second airfins 32B, which are extending in the first interspace 21, the second interspace 22A and the second interspace 22B, respectively. In the shown example, although not visibile in Fig. 2, these first and second airfins 31, 32A, 32B are extending in the condensor height direction Z_C along the full height H of the condensor 3.

[0028] Fig. 4 further indicates, for the first interspace 21, the first overall interspace dimension D1; for the second interspace 22A, the value $D2_A$ of the second overall interspace dimension D2; and for the second interspace 22B, the value $D2_B$ of the second overall interspace dimension D2. All these dimensions are as measured in the condensor depth direction X_C.

[0029] Fig. 5 shows the combined heat exchanging unit 14, which comprises the condensor 3 with its at least one air-intake opening 8 and its at least one air-outlet opening 9, wherein the condensor 3 is the condensor of the ORC system of the heavy-vehicle 1. In addition the combined heat exchanging unit 14 comprises the further heat exchanger 3A with its at least one air-intake opening 8A and its at least one air-outlet opening 9A, the further heat exchanger 3B with its at least one air-intake opening 8B and its at least one air-outlet opening 9B, and the further heat exchanger 3C with its at least one air-intake opening 8C and its at least one air-outlet opening 9C. The further heat exchanger 3A may for example be an engine oil heat exchanger. The further heat exchanger 3B may for example be a transmission oil heat exchanger, and the further heat exchanger 3C may for example be an air-conditioning condensor.

Claims

1. A heavy-duty vehicle (1) comprising a combustion engine (2) and an organic rankine cycle system (3, 4) for waste heat recovery out of flue gas exhausted by the combustion engine, wherein:

   - said organic rankine cycle system is configured for performing organic rankine cycles with an organic working fluid (5) which is heated by said flue gas;
   - said organic rankine cycle system comprises a condensor (3) for condensing said organic working fluid by heat transfer with environmental air (6) of the heavy-duty vehicle;
   - the heavy-duty vehicle has mutually orthogonal vehicle directions in the form of a vehicle length direction (X_V), a vehicle width direction (Y_V), and a vehicle height direction (Z_V);
   - the condensor has mutually orthogonal condensor directions in the form of a condensor depth direction (X_C), a condensor width direction (Y_C), and a condensor height direction (Z_C);
   - the condensor is arranged in a slipstream of a base structure (7) of the heavy-duty vehicle, said base structure comprising a cabin of a truck in case the heavy-duty vehicle is a truck, or a passenger compartment in case the heavy-duty vehicle is a bus;
   - the condensor depth direction (X_C) is parallel to the vehicle length direction (X_V), the condensor width direction (YC_c) is parallel to the vehicle width direction (Y_V), and the condensor height direction (Z_C) is parallel to the vehicle height direction (Z_V);
   - the condensor has an overall depth D in said condensor depth direction (X_C), an overall width W in said condensor width direction (Y_C), and an overall height H in said condensor height direction (Z_C);
   - said overall width W has a value in the range $1.0 \text{ m} \leq W \leq 3.0 \text{ m}$;
   - said overall height H has a value in the range $1.0 \text{ m} \leq H \leq 4.0 \text{ m}$;
   - said overall depth D has a value in the range $0.05W \leq D \leq 0.30W$;
   - said overall depth D has a value in the range $0.05H \leq D \leq 0.30H$;
   - said condensor has at least one air-intake opening (8) for allowing said environmental air to enter the condensor and at least one air-outlet opening (9) for allowing said environmental air, when entered into and heated inside the condensor, to exit the condensor, wherein said at least one air-intake opening is located at a lower position along said height direction than said at least one air-outlet opening.

2. A heavy-duty vehicle according to claim 1, wherein said overall width W has a value in the range $1.5 \text{ m} \leq W \leq 2.5 \text{ m}$.

3. A heavy-duty vehicle according to any one of the preceding claims, wherein said overall height H has a value in the range $1.5 \text{ m} \leq H \leq 2.5 \text{ m}$.

4. A heavy-duty vehicle according to any one of the preceding claims, wherein said overall depth D has a value in the range $0.10W \leq D \leq 0.20W$.

5. A heavy-duty vehicle according to any one of the preceding claims, wherein said overall depth D has a value in the range $0.10H \leq D \leq 0.20H$;

6. A heavy-duty vehicle according to any one of the preceding claims, wherein said condensor comprises a condensor housing (10) containing at least two flat condensing structures (11, 12) configured for containing said organic working fluid and for condensing said organic working fluid contained therein, wherein said at least two flat condensing structures

are extending mutually parallel and perpendicularly to said condensor depth direction (X_C), and wherein said at least two flat condensing structures are mutually spaced in said condensor depth direction (X_C).

7. A heavy-duty vehicle according to claim 6, wherein said condensor comprises a first interspace (21) in-between two mutually neighbouring ones of said at least two flat condensing structures, wherein said first interspace is configured for containing said environmental air for heating of said environmental air, and wherein said first interspace has a first overall interspace dimension D1 in said condensor depth direction (X_C) having a value in the range 5 cm ≤ D1 ≤ 15 cm.

8. A heavy-duty vehicle according to claim 7, wherein said first interspace contains at least two first airfins (31), which are extending in said condensor height direction (Z_C), and which are mutually spaced in said condensor width direction (Y_C), and wherein each of said at least two first airfins is extending in said condensor depth direction (X_C) in such manner that it is interconnecting said two mutually neighbouring ones of said at least two flat condensing structures.

9. A heavy-duty vehicle according to any one of claims 6-8, wherein said condensor comprises a second interspace (22A, 22B) in-between the condensor housing and a neighbouring one of said at least two flat condensing structures, wherein said second interspace is configured for containing said environmental air for heating of said environmental air, and wherein said second interspace has a second overall interspace dimension D2 in said condensor depth direction (X_C) having a value in the range 1 cm ≤ D2 ≤ 10 cm.

10. A heavy-duty vehicle according to claim 9, wherein, wherein said second interspace contains at least two second airfins (32A, 32B), which are extending in said condensor height direction (Z_C), and which are mutually spaced in said condensor width direction (Y_C), and wherein each of said at least two second airfins is extending in said condensor depth direction (X_C) in such manner that it is interconnecting said condensor housing and said neighbouring one of said at least two flat condensing structures.

11. A heavy-duty vehicle according to any one of the preceding claims, wherein said condensor is a first heat exchanger being assembled within a combined heat exchanging unit (14) that is located in said slip-stream of said base structure, and wherein said combined heat exchanging unit further comprises at least one further heat exchanger (3A, 3B, 3C) for heat transfer with environmental air of the heavy-duty vehicle, said at least one further heat exchanger having at least one further air-intake opening (8A, 8B, 8C) for allowing said environmental air to enter said at least one further heat exchanger and at least one further air-outlet opening (9A, 9B, 9C) for allowing said environmental air, when entered into and heated inside the condensor, to exit said at least one further heat exchanger, wherein said at least one further air-intake opening is located at a lower position along said height direction than said at least one further air-outlet opening.

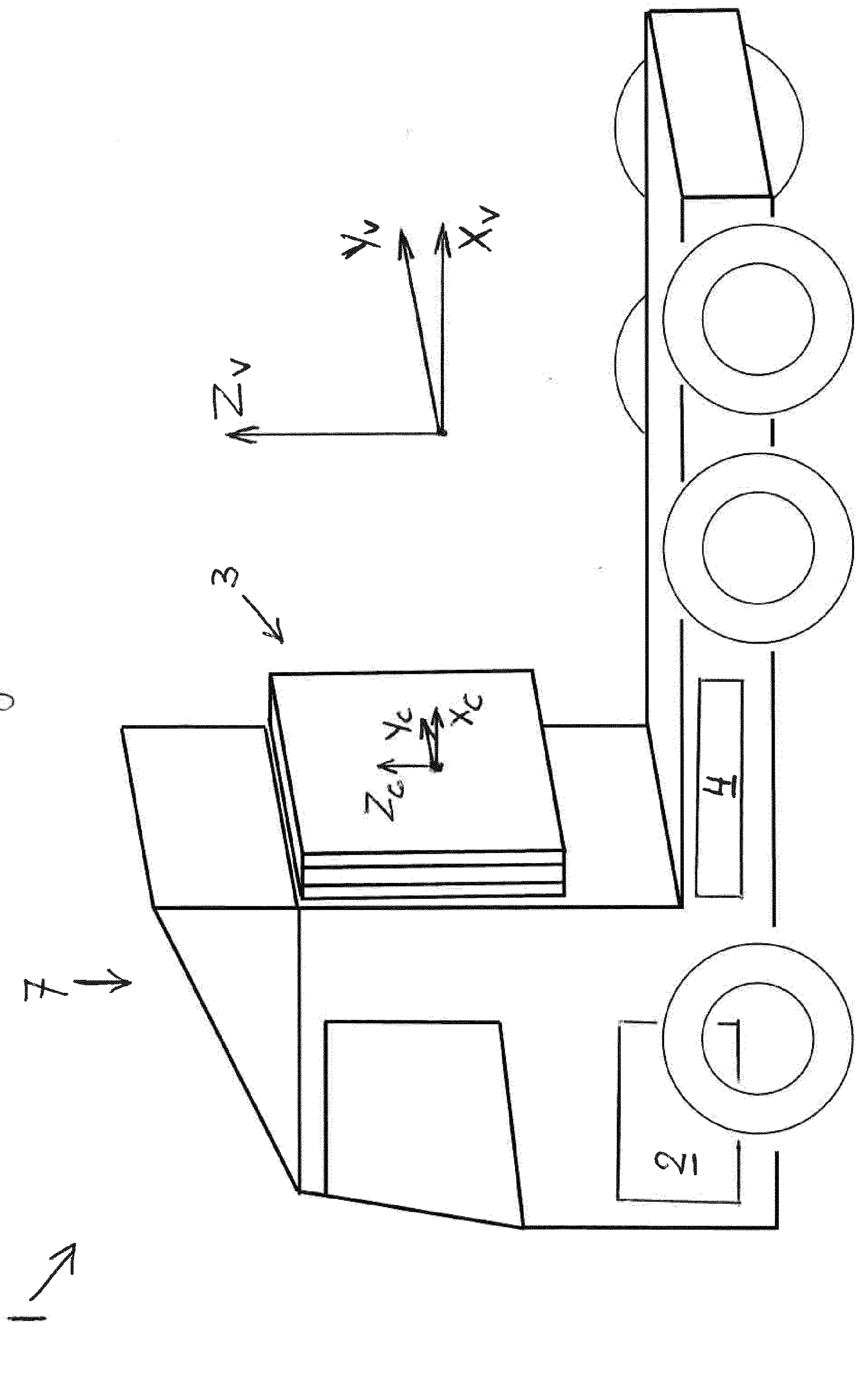


Fig. 1

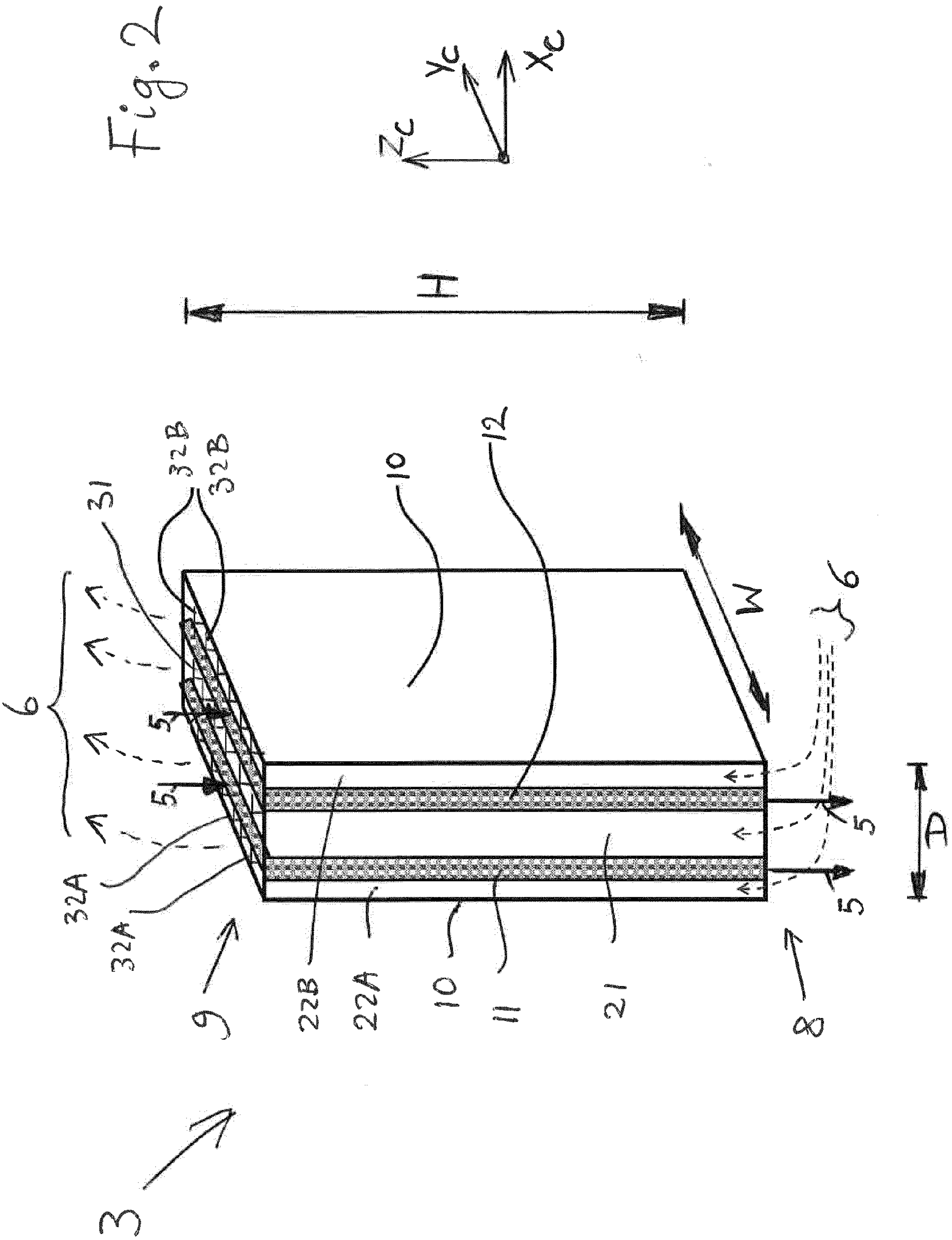


Fig. 2

Fig. 3

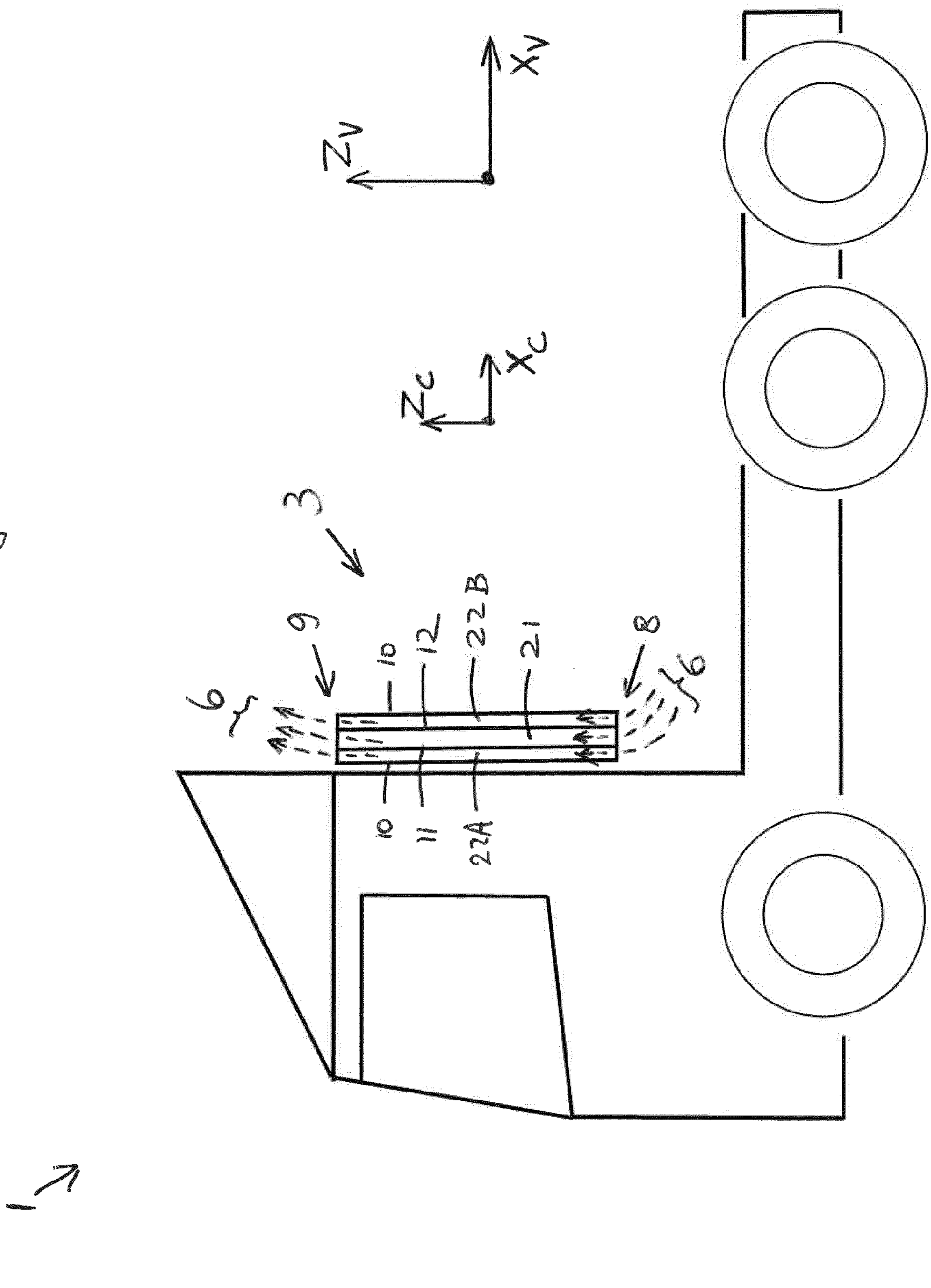


Fig.4

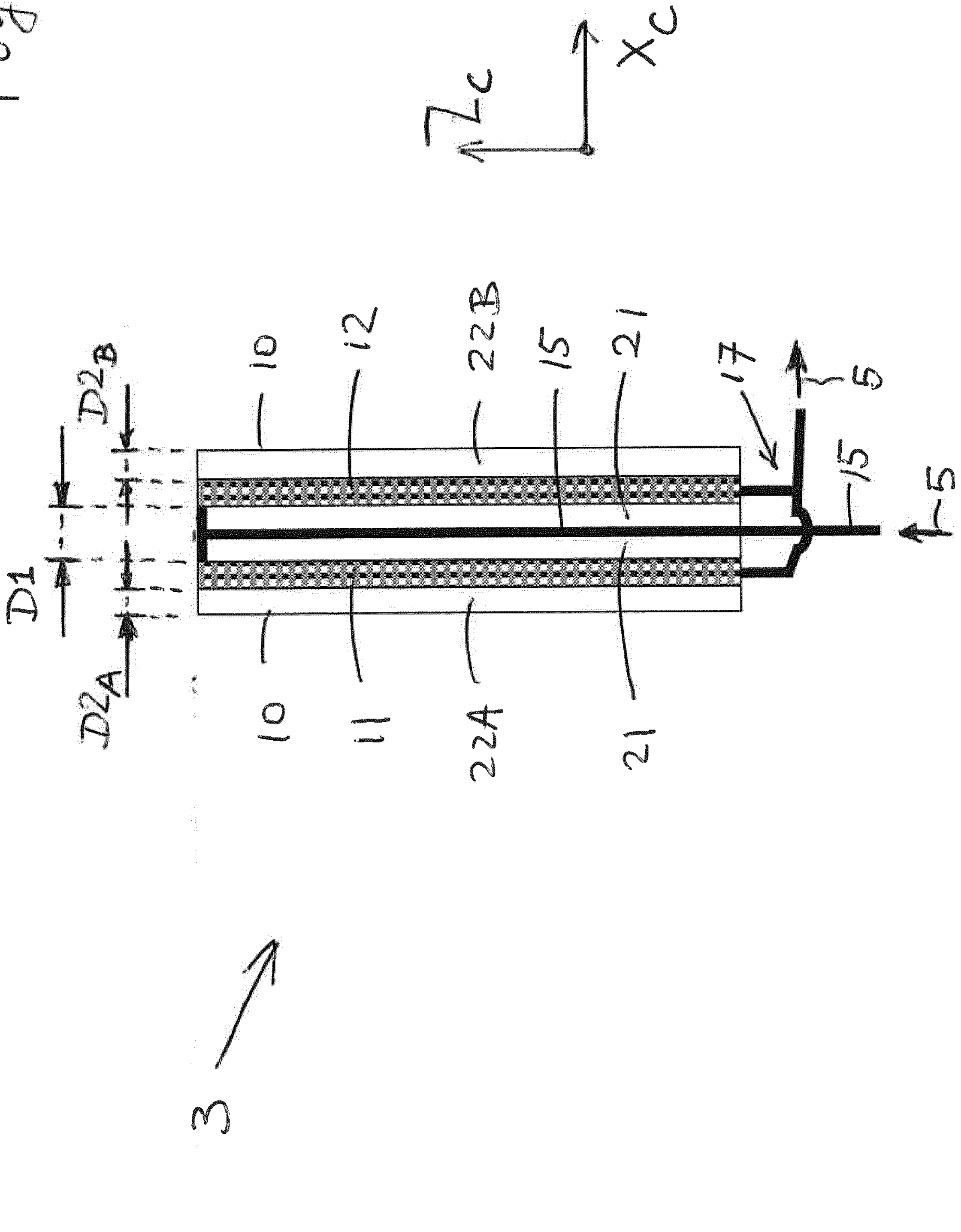
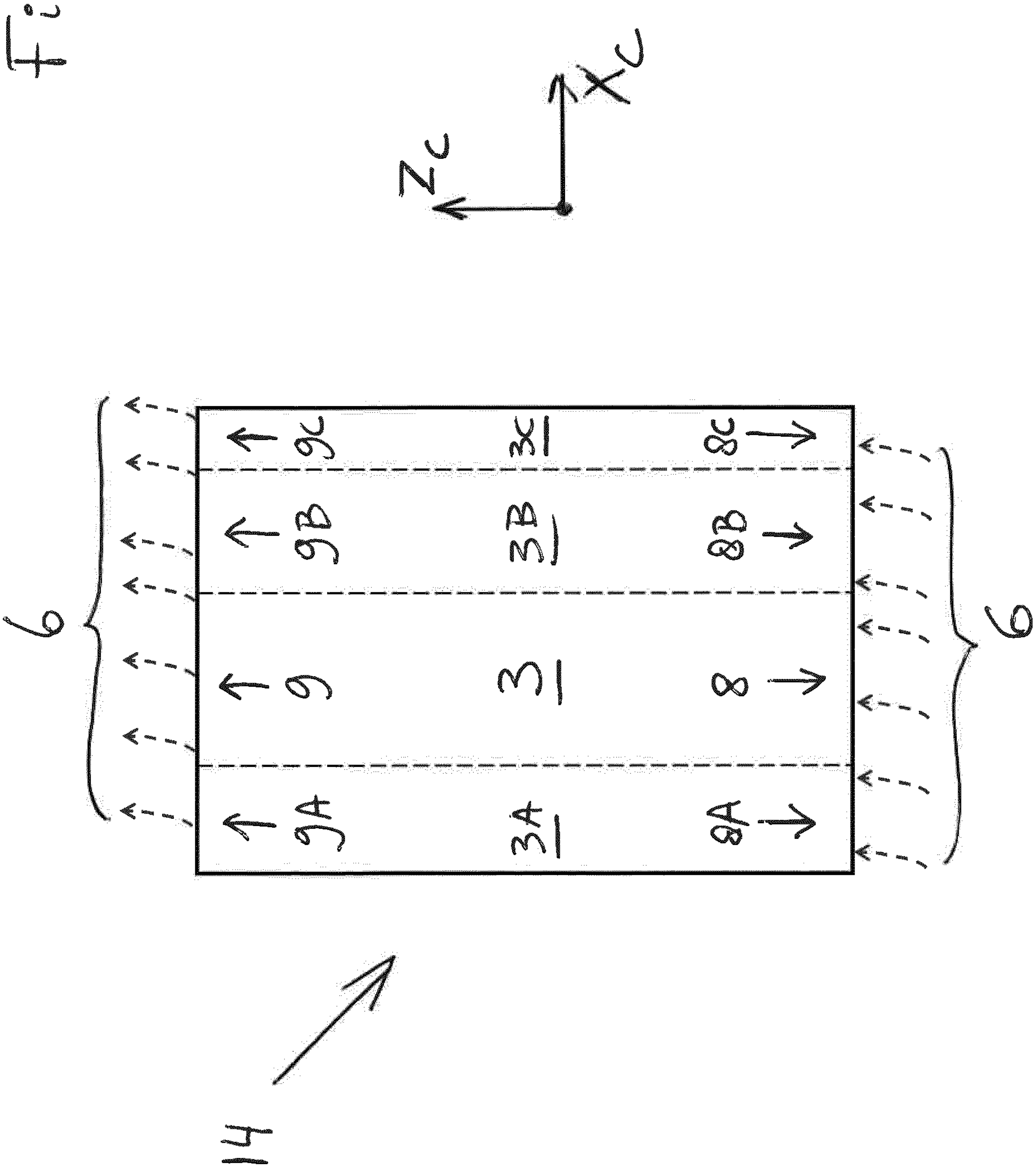


Fig. 5



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EUROPEAN SEARCH REPORT

Application Number
EP 19 21 7690

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	5 June 2020	Röberg, Andreas

CATEGORY OF CITED DOCUMENTS

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EPO FORM P0459

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