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(54) **CENTRIFUGAL COMPRESSOR WITH CASING TREATMENT BYPASS**

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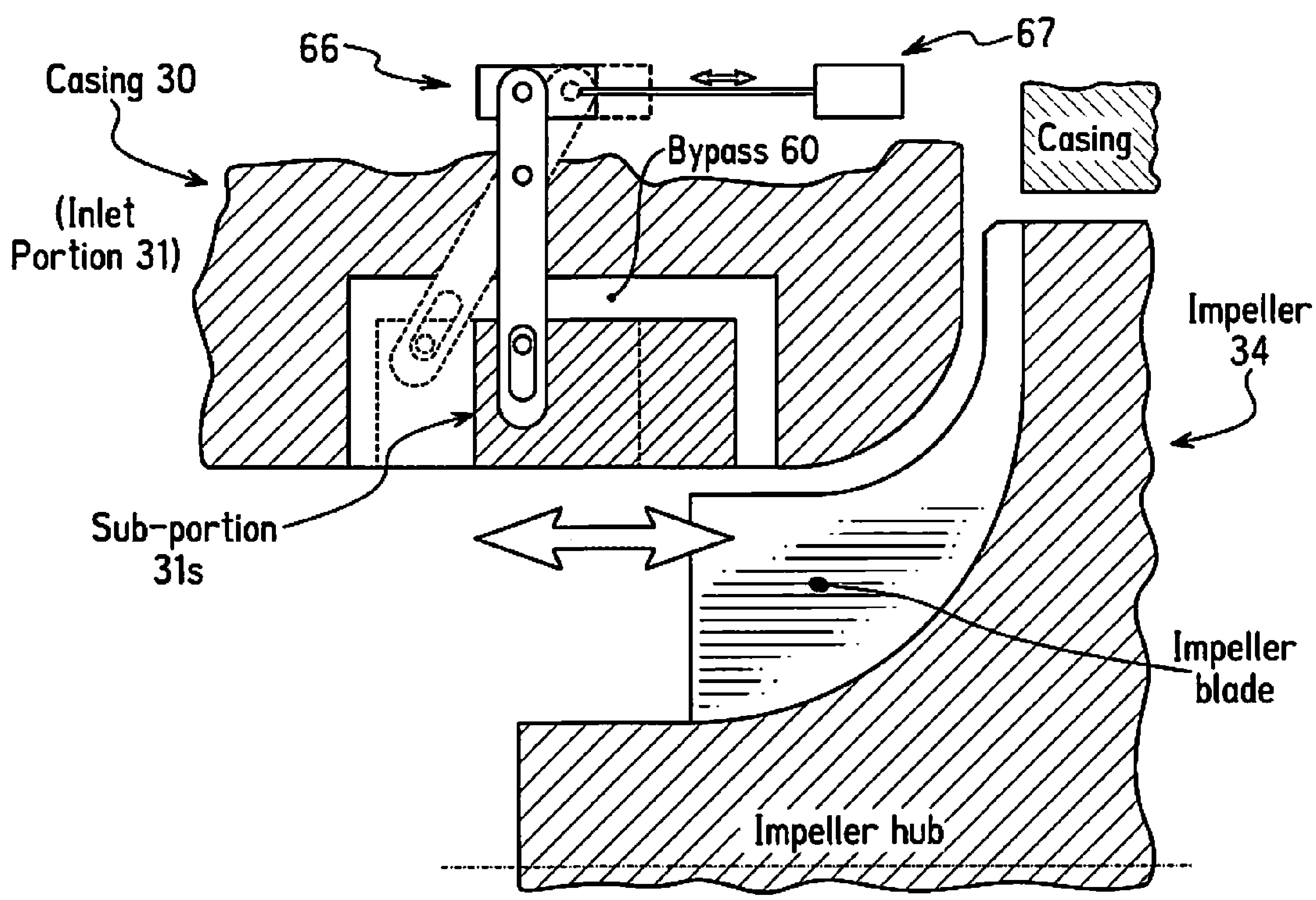
(57) **ABSTRACT**

A centrifugal compressor for a chiller system includes a casing, an inlet guide vane, an impeller disposed downstream of the inlet guide vane, a motor and a diffuser. The casing has inlet and outlet portions with the inlet guide vane disposed in the inlet portion. The impeller is attached to a shaft rotatable about a rotation axis, and the motor rotates the shaft in order to rotate the impeller. The centrifugal compressor further includes a casing treatment bypass having an entrance port and an exit port. The casing treatment bypass injects refrigerant from a gap between the impeller and the inlet portion of the casing toward an area between the impeller and the inlet guide vane. The exit port of the casing treatment bypass is positioned upstream in a direction of a refrigerant flow with respect to the entrance port of the casing treatment bypass.



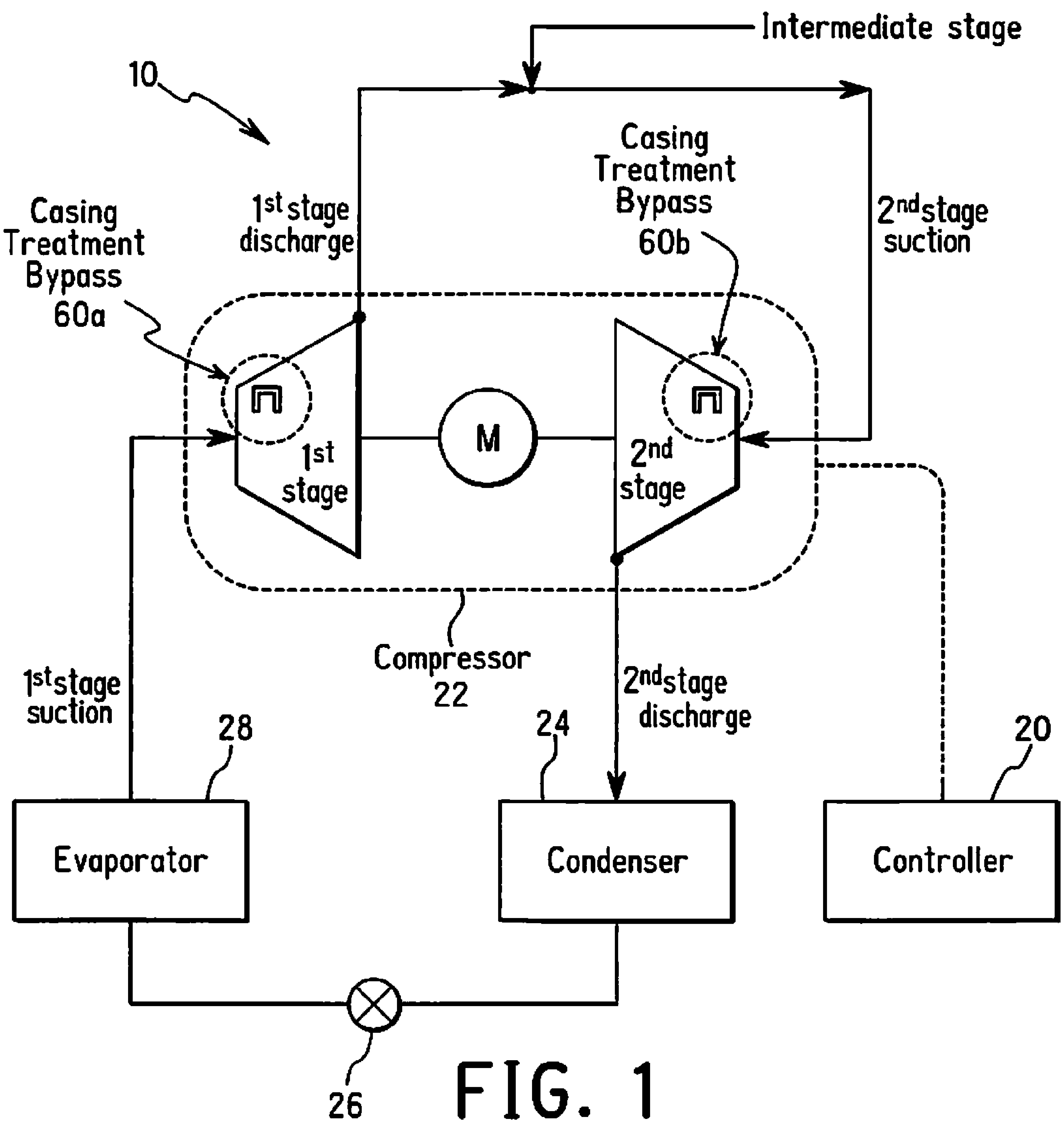

Intermediate stage
10
Casing Treatment Bypass 60b
1st stage discharge
2nd stage suction
Casing Treatment Bypass 60a
M
1st stage
2nd stage
Compressor 22
1st stage suction
2nd stage discharge
28
24
20
Evaporator
Condenser
Controller
26

FIG. 1

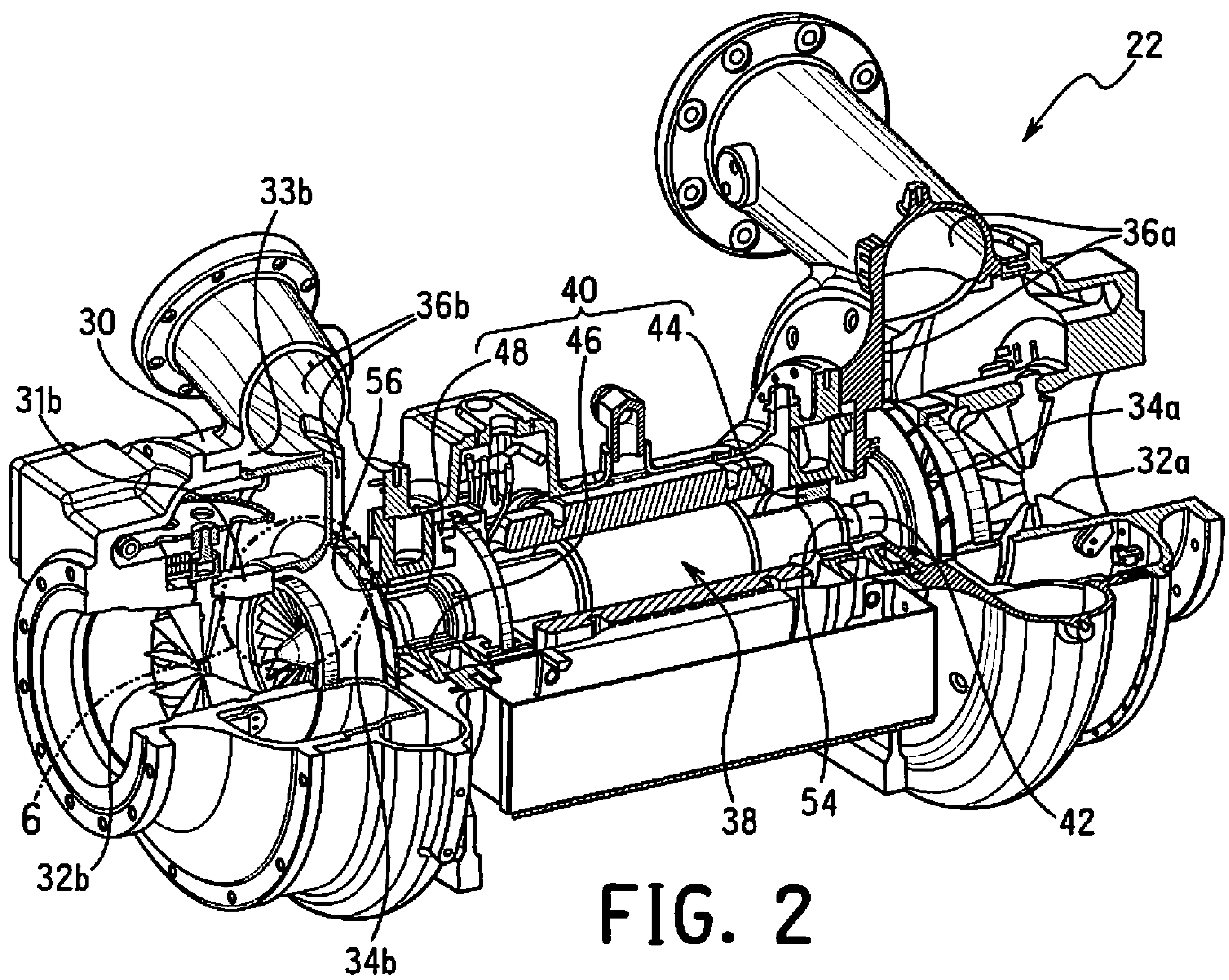

22
33b
36a
40
36b
30
48
46
44
31b
56
34a
32a
6
38
54
42
32b
34b

FIG. 2

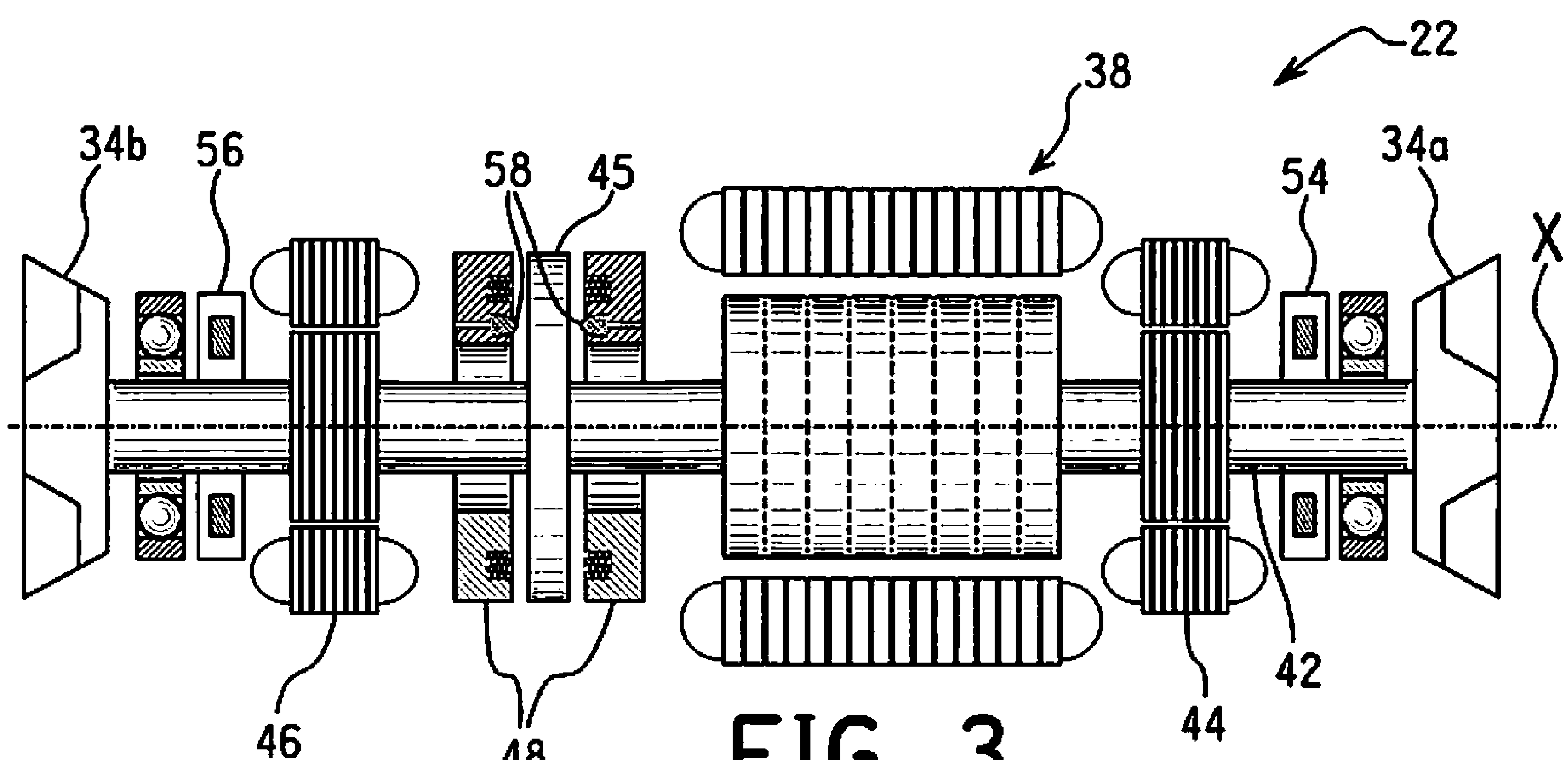

22
38
34b
56
58
45
54
34a
X
46
48
44
42

FIG. 3

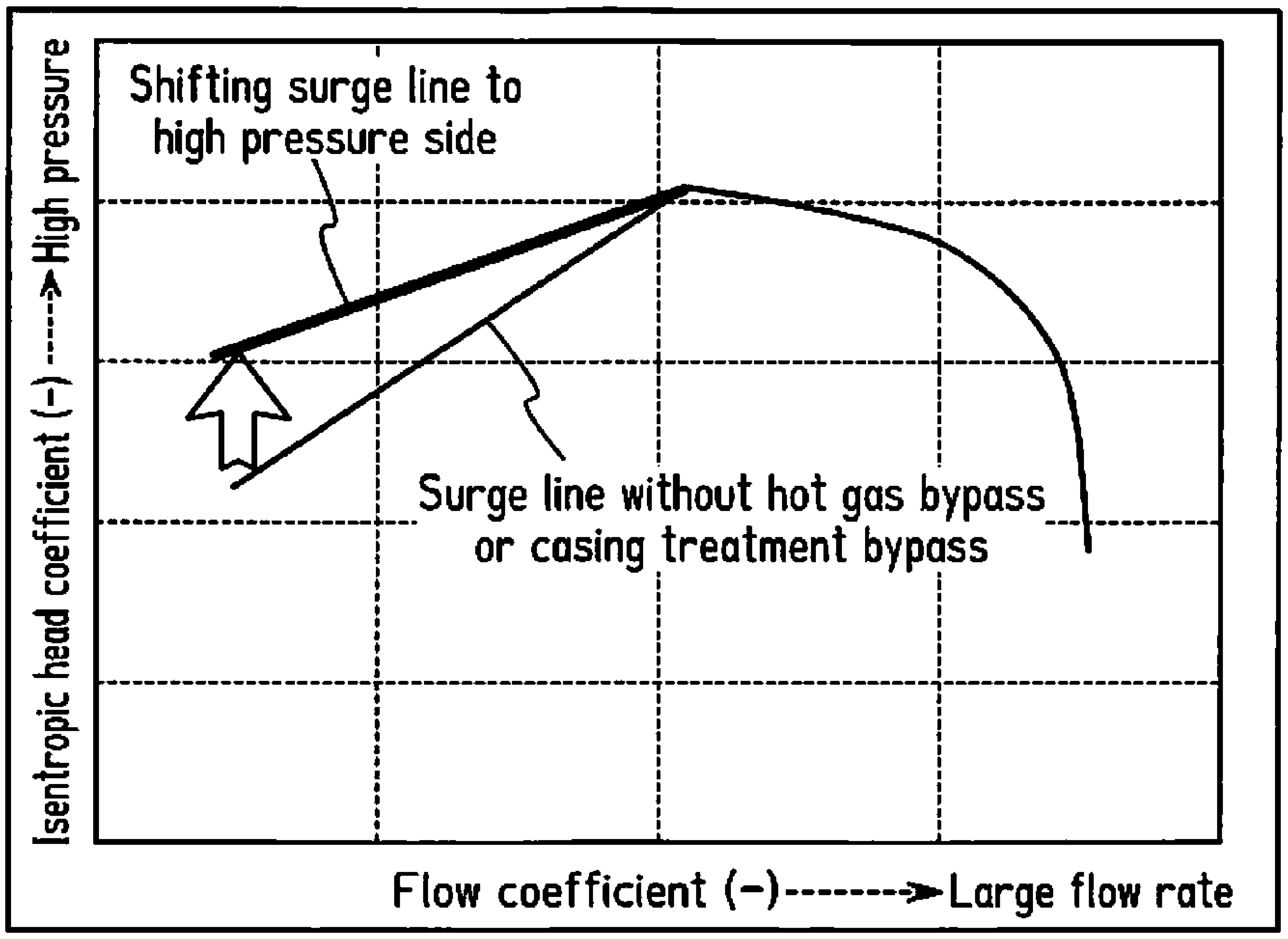


FIG. 4A

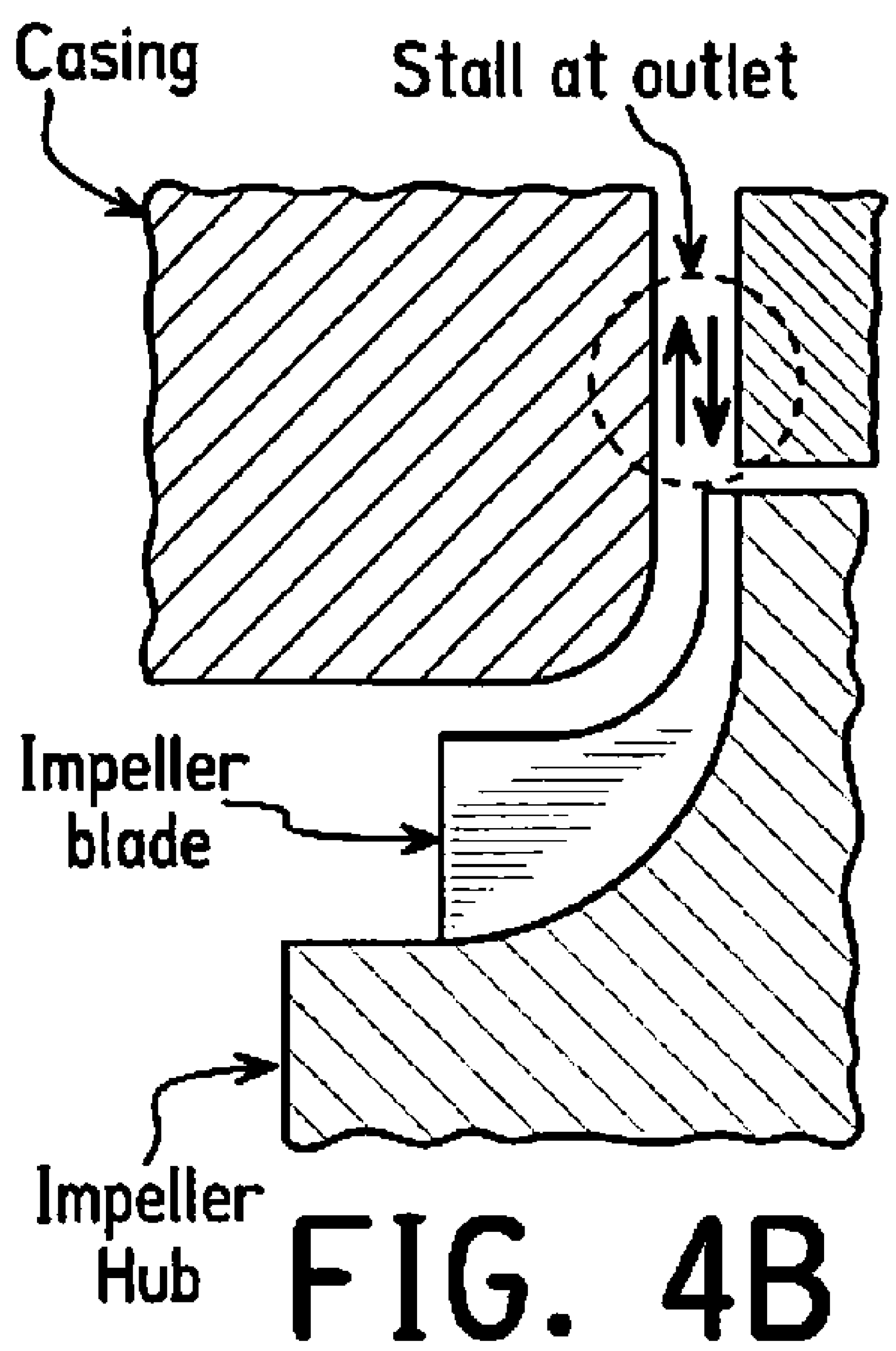


FIG. 4B

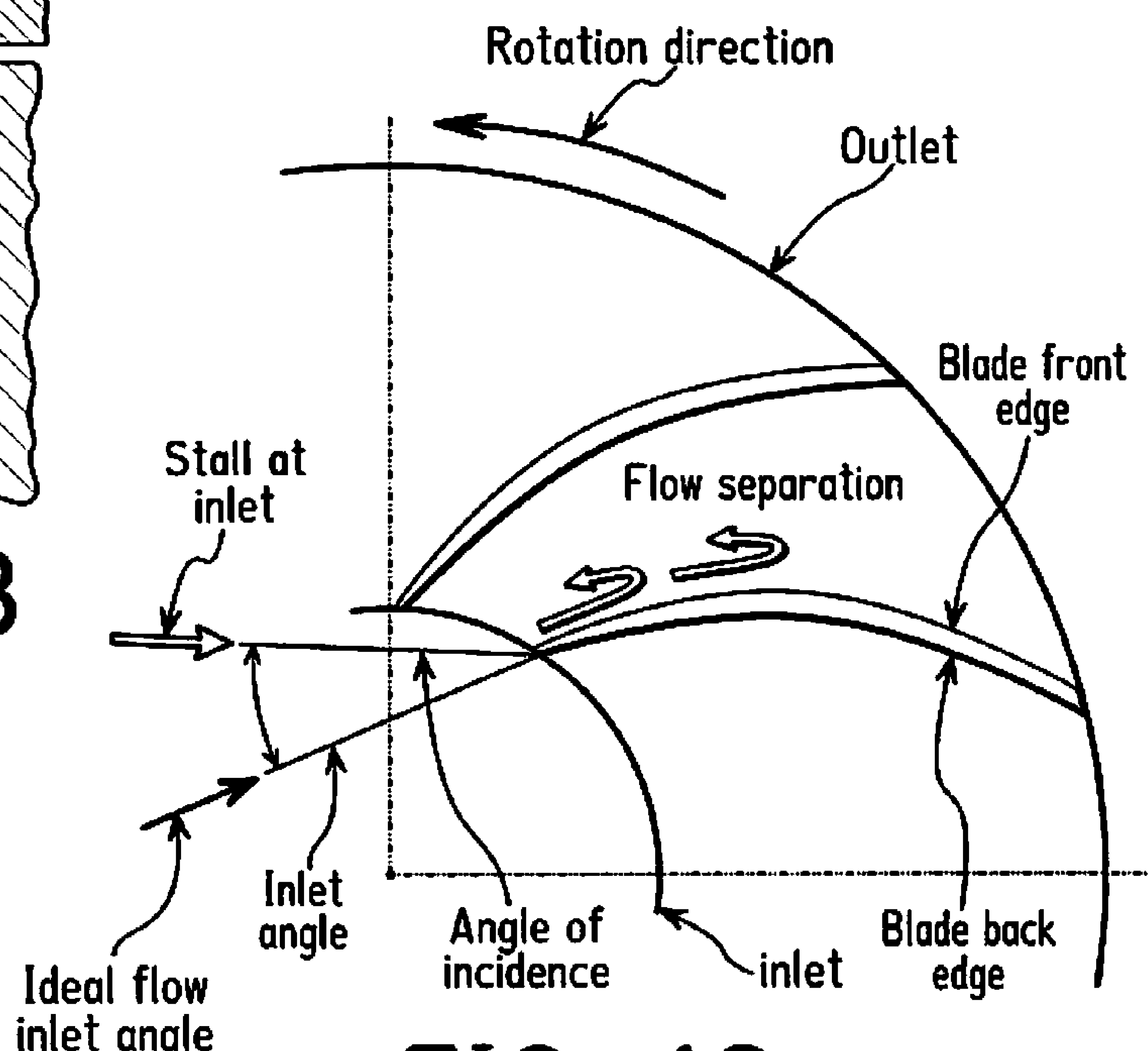
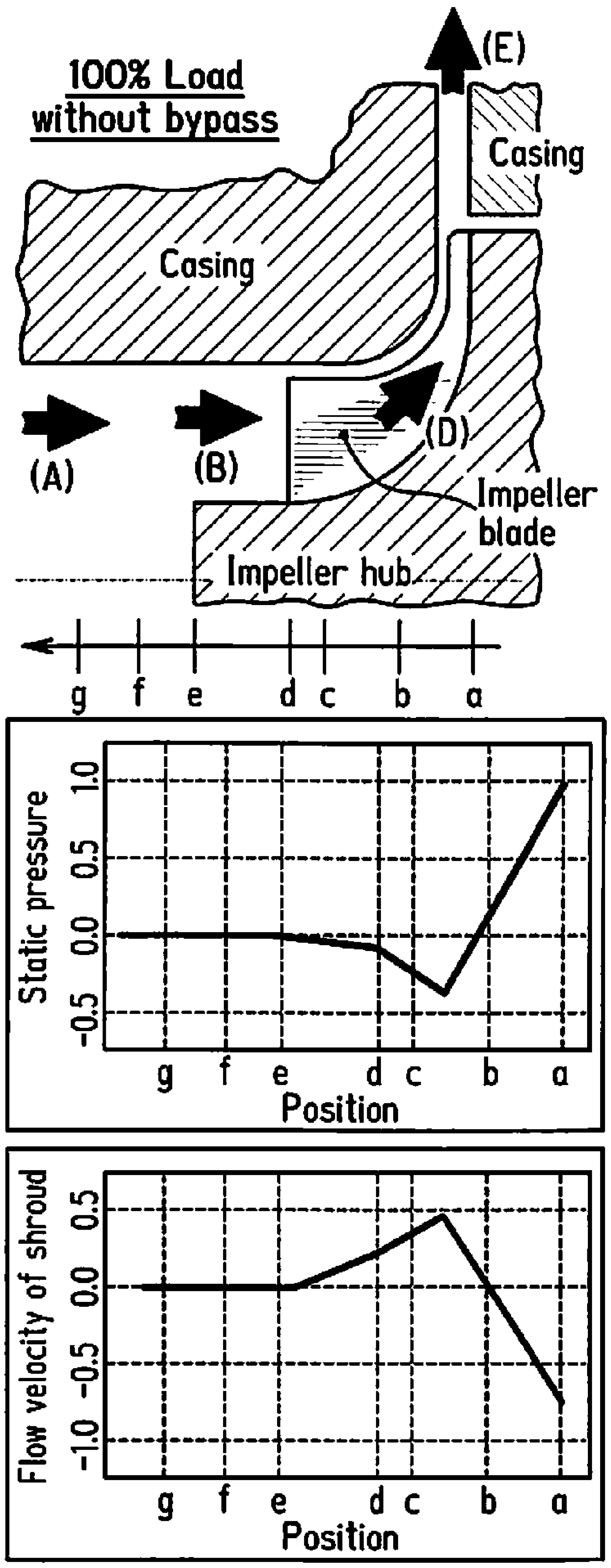
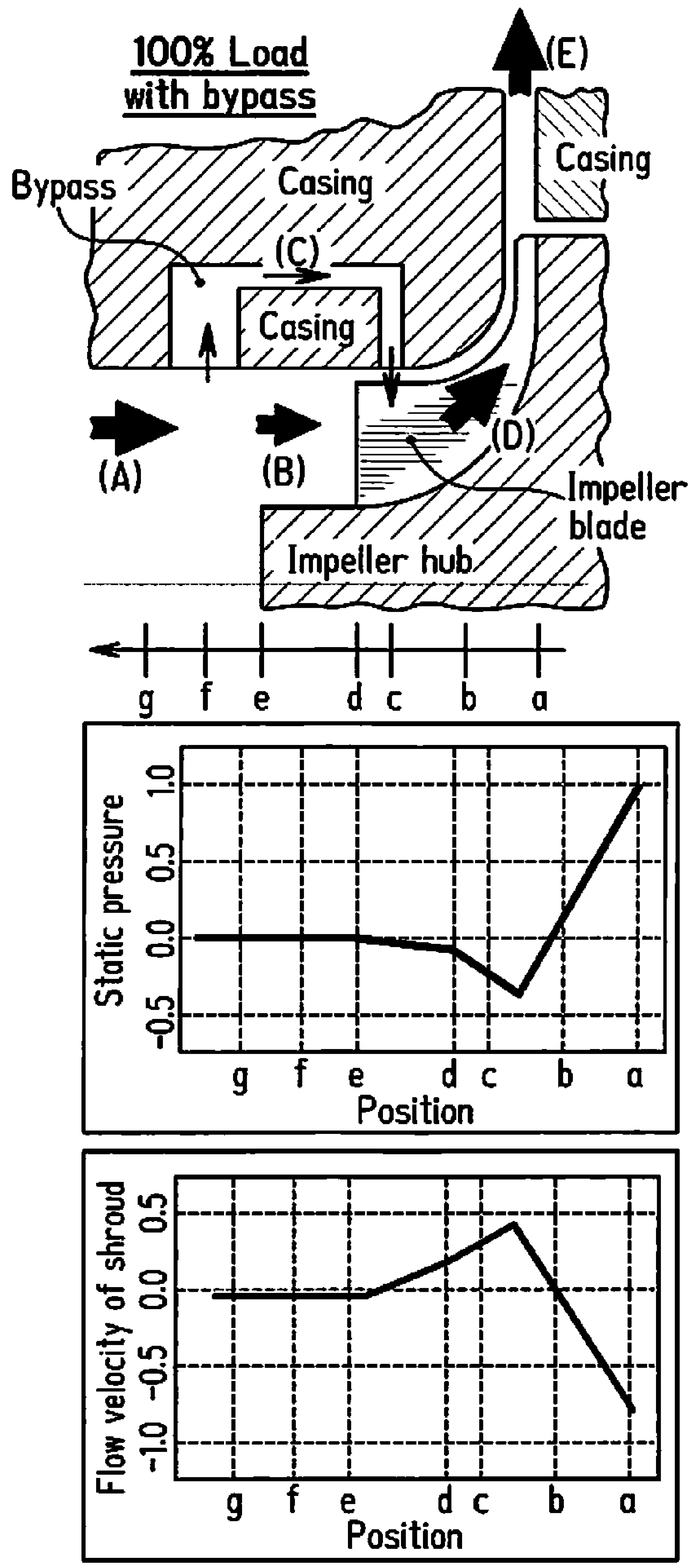


FIG. 4C



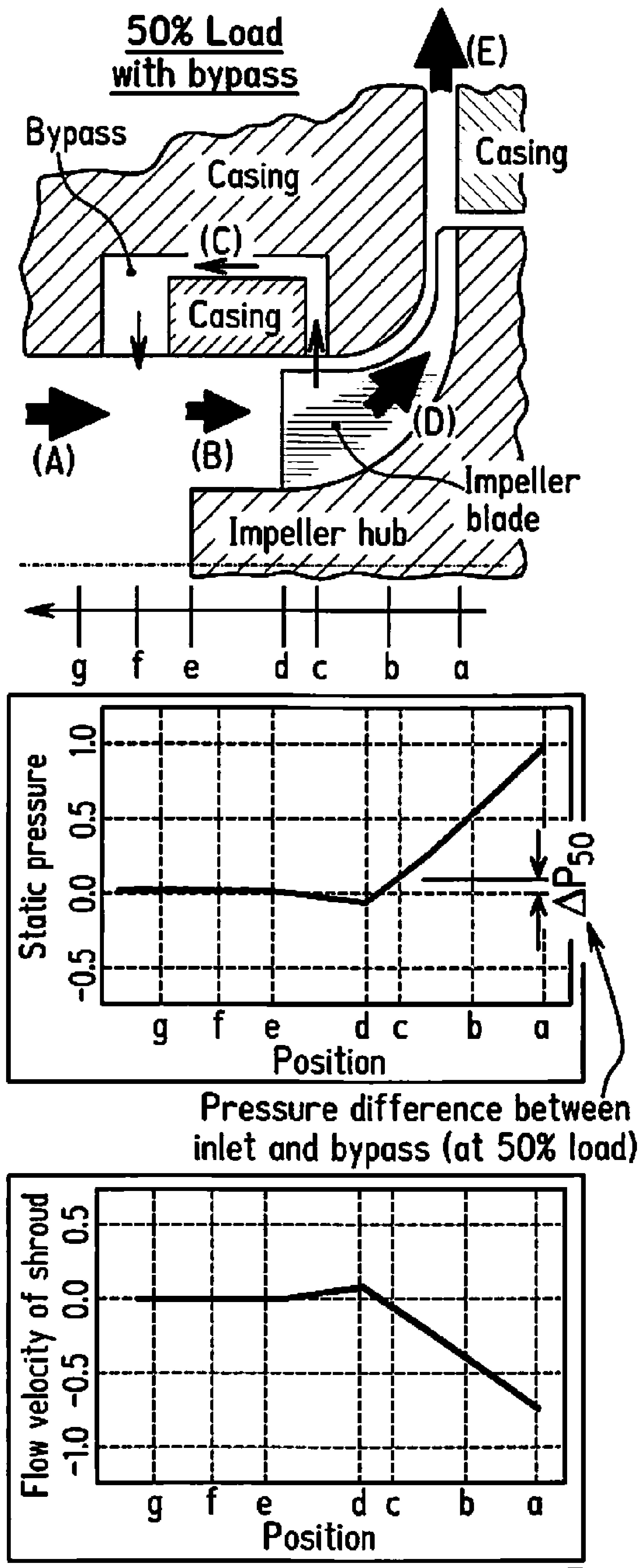
Symbol	Description	Flow (%)
(A)	Inlet	100
(B)	—	—
(C)	—	—
(D)	Impeller blade	100
(E)	Outlet	100

FIG. 5A



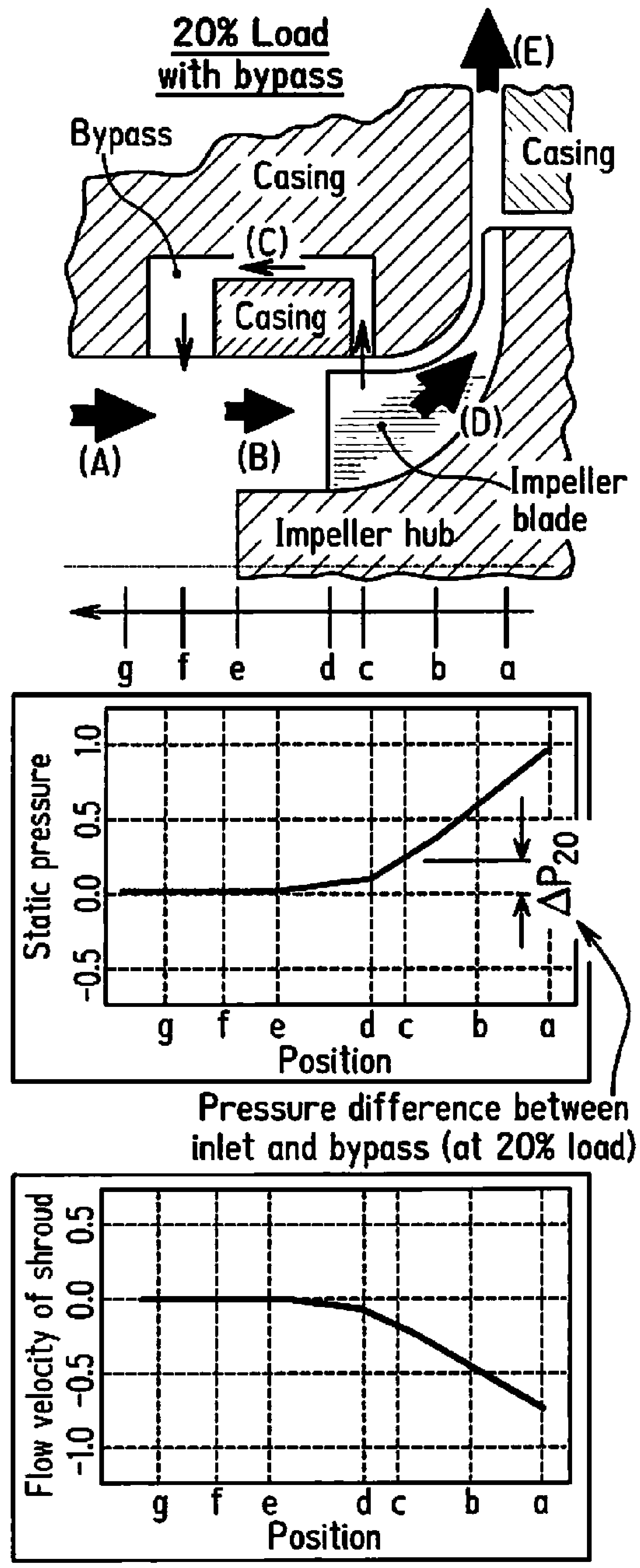
Symbol	Description	Flow(%)
(A)	Inlet	100
<u>(B)</u>	<u>Inlet after bypass port</u>	<u>95</u>
(C)	Bypass	5
(D)	Impeller blade	100
(E)	Outlet	100

FIG. 5B



Symbol	Description	Flow(%)
(A)	Inlet	50
(B)	Inlet after bypass port	55
(C)	Bypass	5
(D)	Impeller blade	50
(E)	Outlet	50

FIG. 5C



Symbol	Description	Flow(%)
(A)	Inlet	20
(B)	Inlet after bypass port	30
(C)	Bypass	10
(D)	Impeller blade	20
(E)	Outlet	20

FIG. 5D

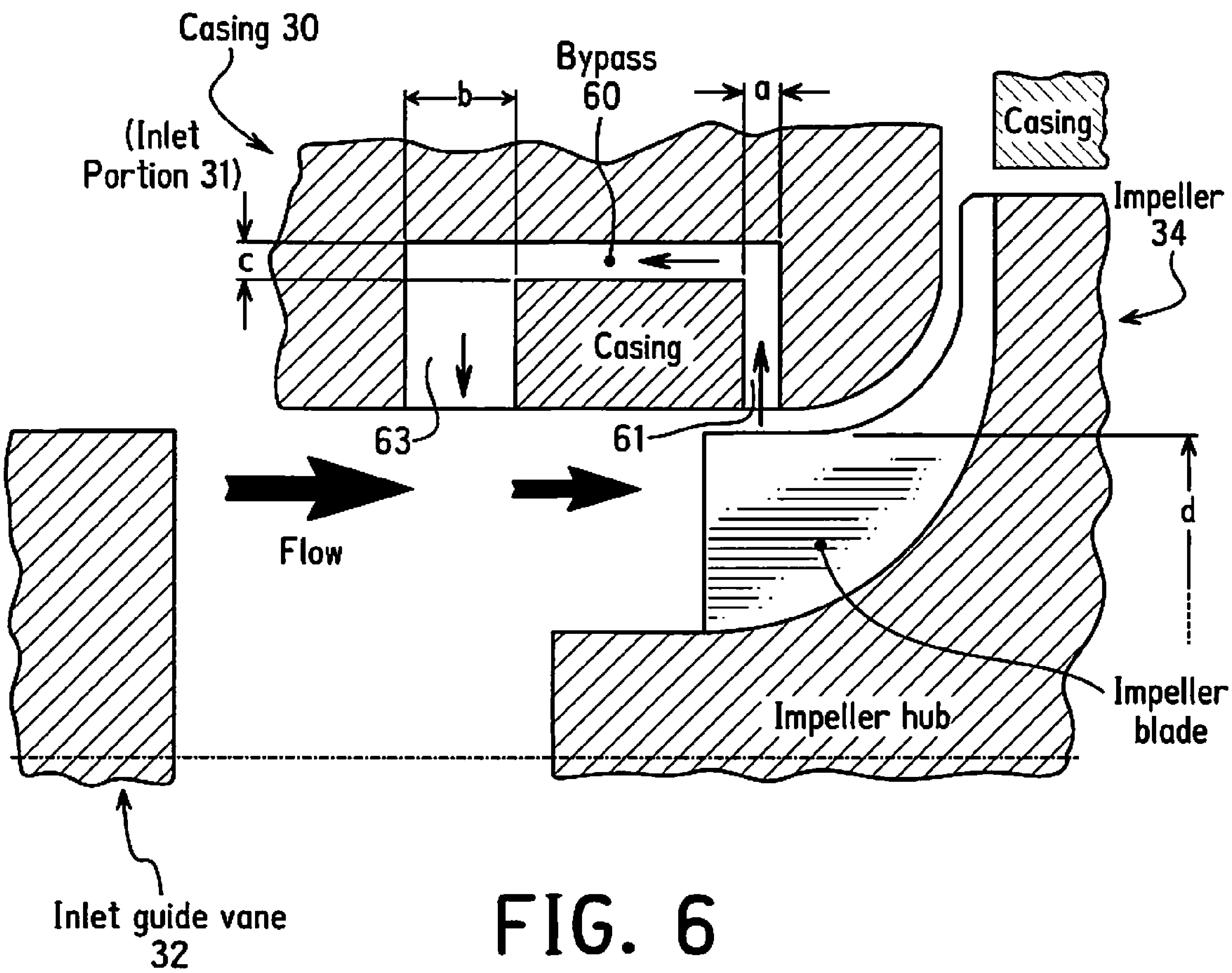
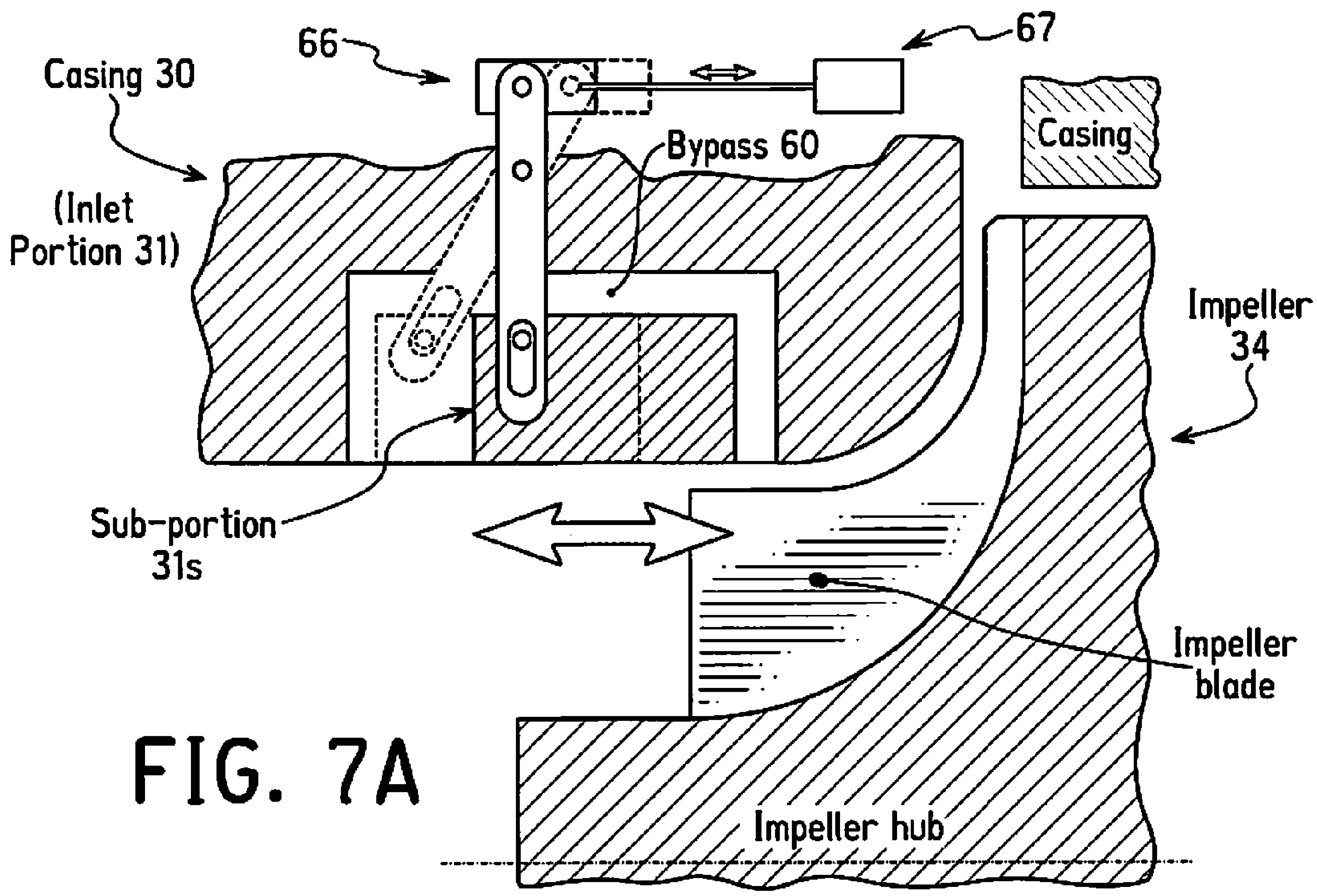
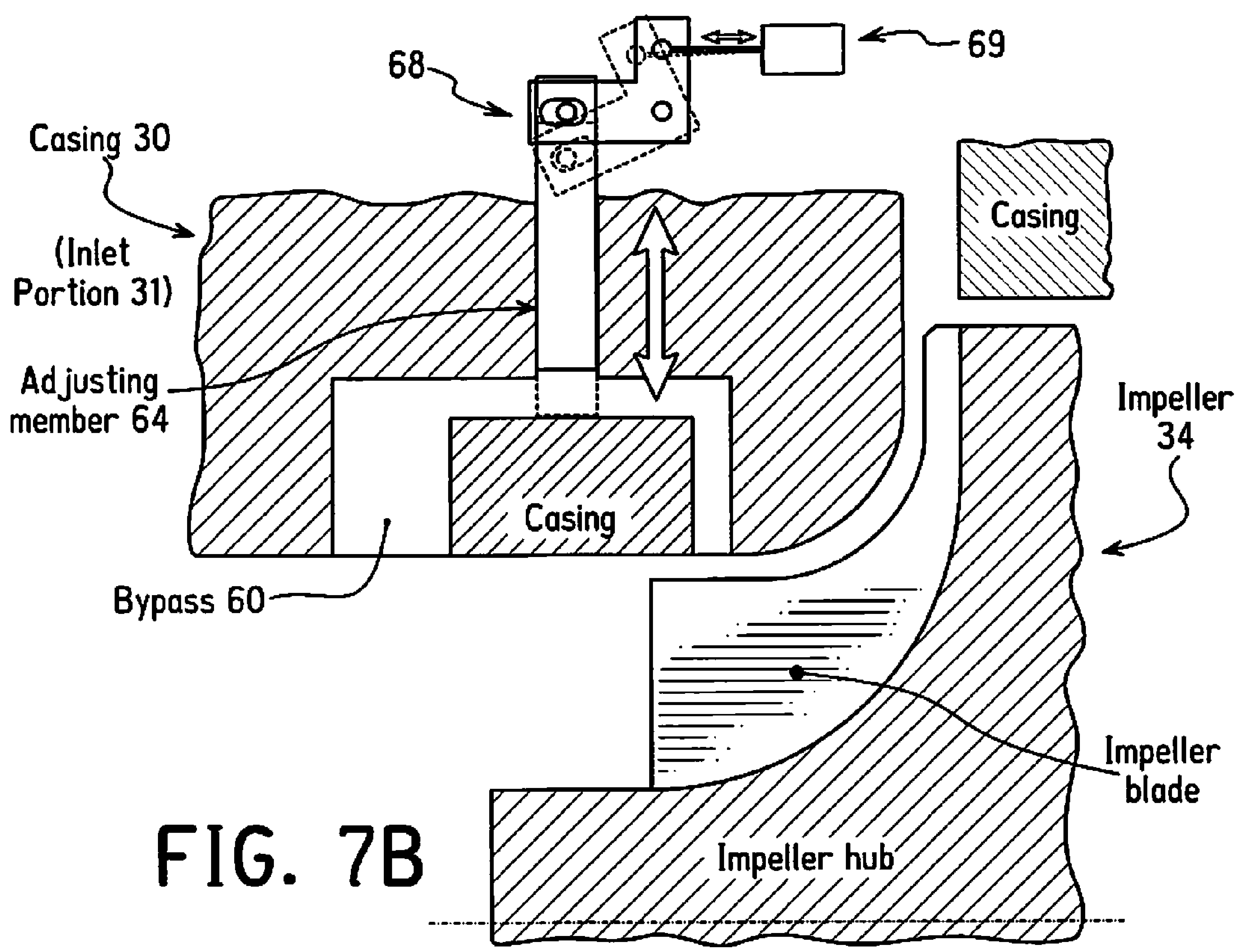

Casing 30
(Inlet
Portion 31)
b
Bypass
60
a
Casing
Impeller
34
c
Casing
63
61
Flow
d
Impeller
blade
Impeller hub
Inlet guide vane
32

FIG. 6



66
67
Casing 30
(Inlet Portion 31)
Bypass 60
Casing
Impeller 34
Sub-portion 31s
Impeller blade
Impeller hub

FIG. 7A



68
69
Casing 30
(Inlet Portion 31)
Casing
Adjusting member 64
Impeller 34
Casing
Bypass 60
Impeller blade
Impeller hub

FIG. 7B

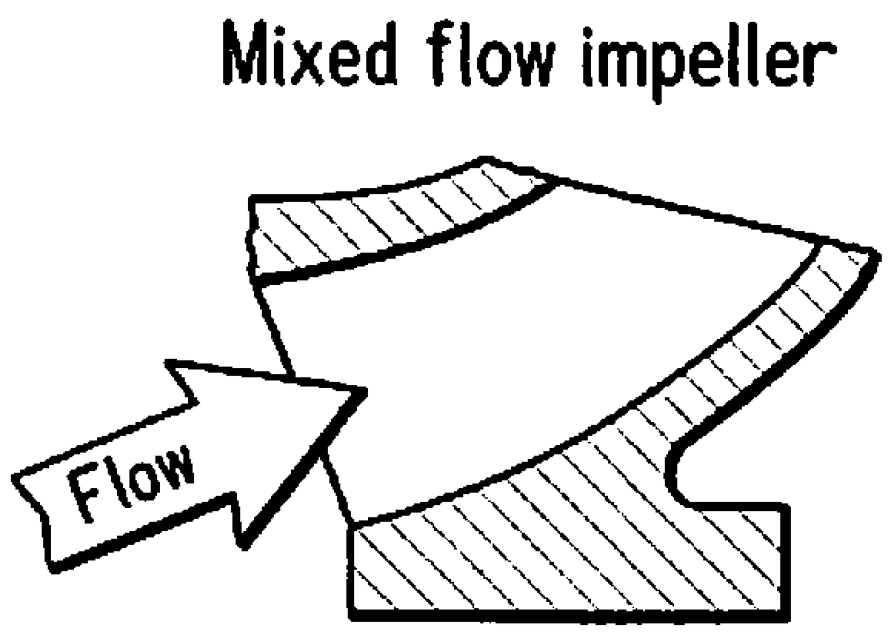


FIG. 8A

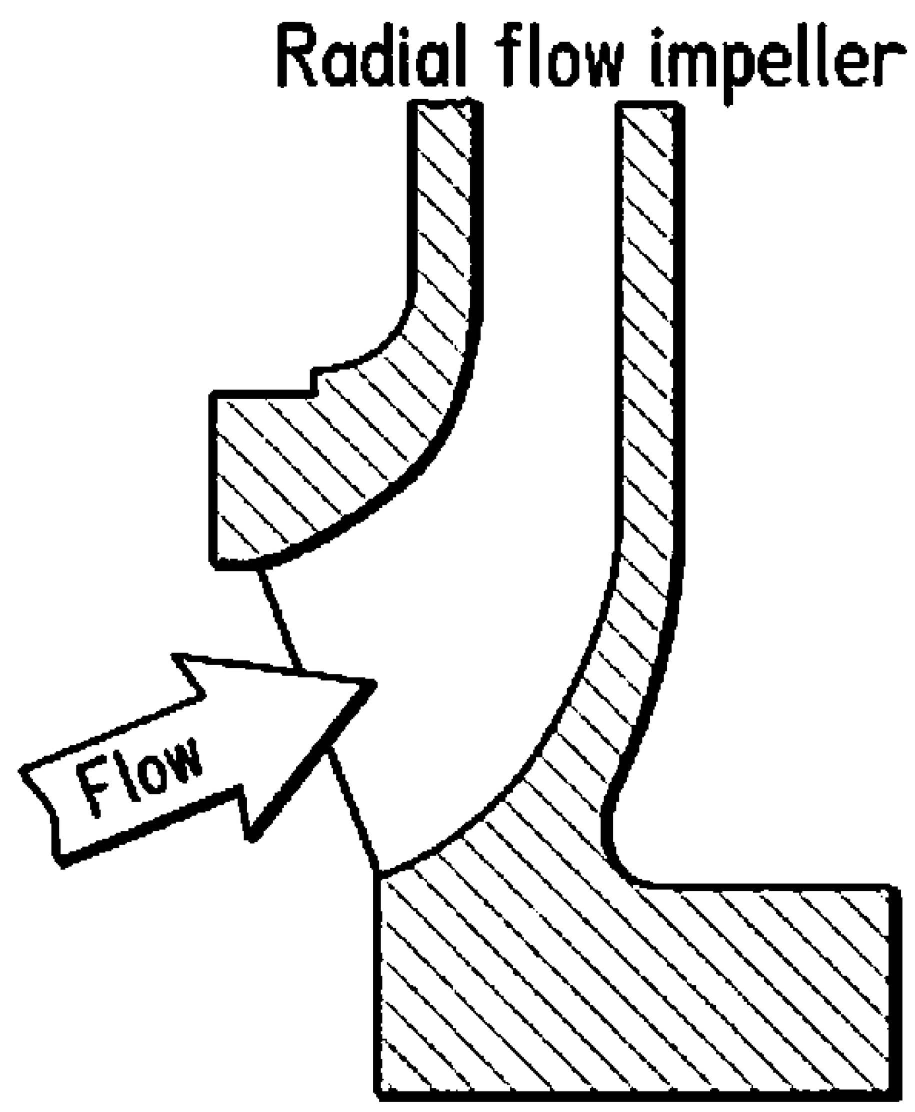


FIG. 8B

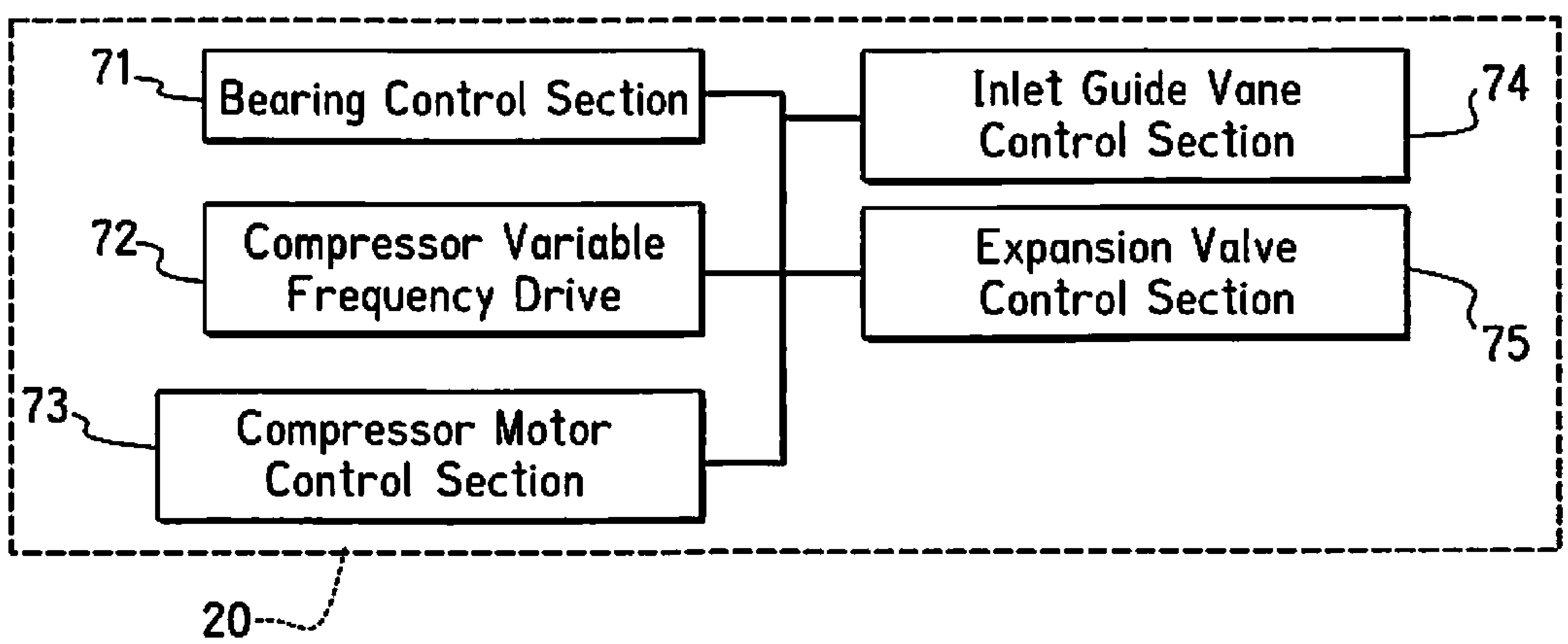


FIG. 9

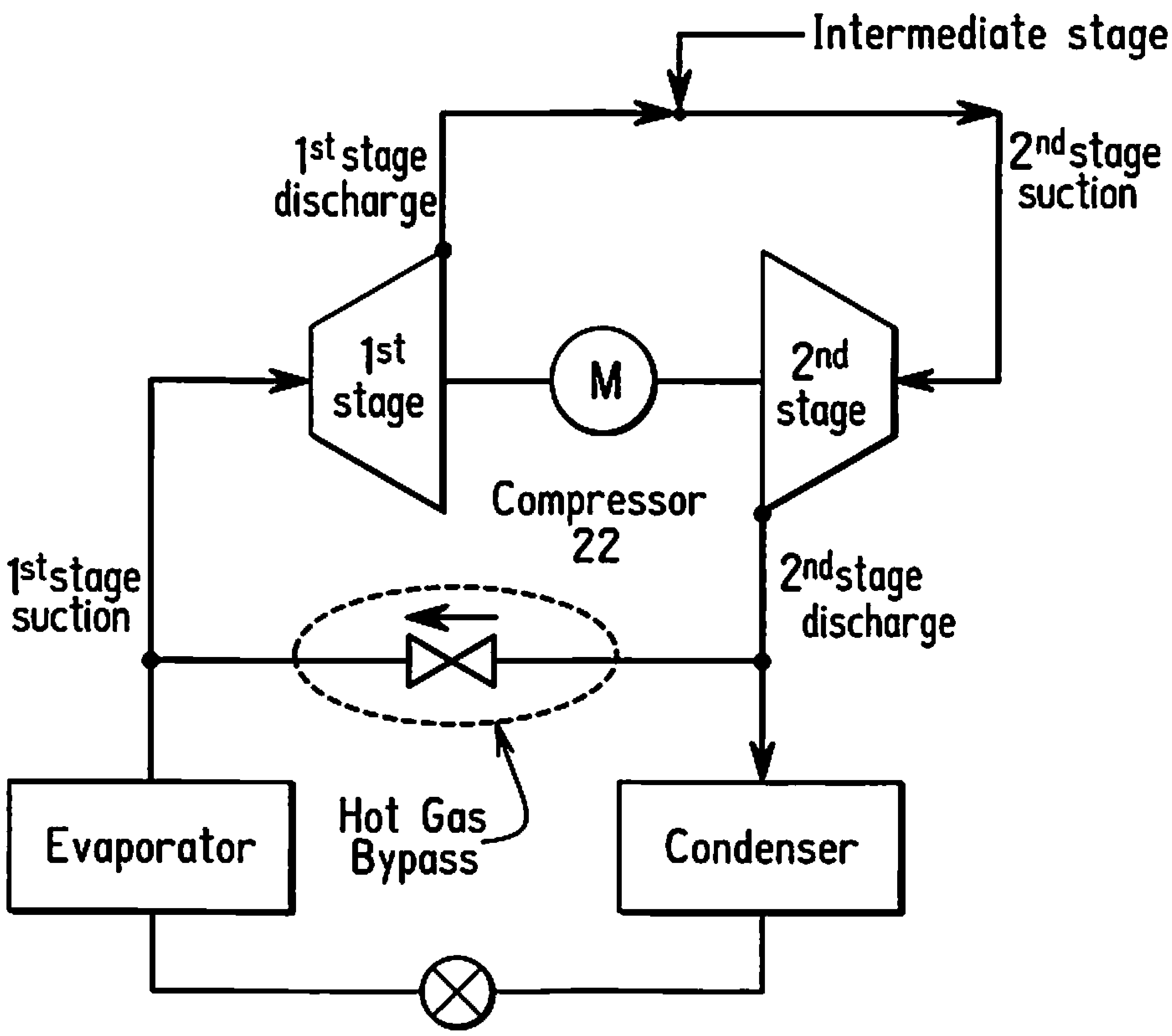


FIG. 10
(PRIOR ART)

CENTRIFUGAL COMPRESSOR WITH CASING TREATMENT BYPASS

BACKGROUND

[0001] Field of the Invention

[0002] The present invention generally relates to a centrifugal compressor used in a chiller system. More specifically, the present invention relates to a centrifugal compressor with a casing treatment bypass.

[0003] Background Information

[0004] A chiller system is a refrigerating machine or apparatus that removes heat from a medium. Commonly a liquid such as water is used as the medium and the chiller system operates in a vapor-compression refrigeration cycle. This liquid can then be circulated through a heat exchanger to cool air or equipment as required. As a necessary byproduct, refrigeration creates waste heat that must be exhausted to ambient or, for greater efficiency, recovered for heating purposes. A conventional chiller system often utilizes a centrifugal compressor, which is often referred to as a turbo compressor. Thus, such chiller systems can be referred to as turbo chillers. Alternatively, other types of compressors, e.g. a screw compressor, can be utilized.

[0005] In a conventional (turbo) chiller, refrigerant is compressed in the centrifugal compressor and sent to a heat exchanger in which heat exchange occurs between the refrigerant and a heat exchange medium (liquid). This heat exchanger is referred to as a condenser because the refrigerant condenses in this heat exchanger. As a result, heat is transferred to the medium (liquid) so that the medium is heated. Refrigerant exiting the condenser is expanded by an expansion valve and sent to another heat exchanger in which heat exchange occurs between the refrigerant and a heat exchange medium (liquid). This heat exchanger is referred to as an evaporator because refrigerant is heated (evaporated) in this heat exchanger. As a result, heat is transferred from the medium (liquid) to the refrigerant, and the liquid is chilled. The refrigerant from the evaporator is then returned to the centrifugal compressor and the cycle is repeated. The liquid utilized is often water.

[0006] A conventional centrifugal compressor basically includes a casing, an inlet guide vane, an impeller, a diffuser, a motor, various sensors and a controller. Refrigerant flows in order through the inlet guide vane, the impeller and the diffuser. Thus, the inlet guide vane is coupled to a gas intake port of the centrifugal compressor while the diffuser is coupled to a gas outlet port of the impeller. The inlet guide vane controls the flow rate of refrigerant gas into the impeller. The impeller increases the velocity of refrigerant gas. The diffuser works to transform the velocity of refrigerant gas (dynamic pressure), given by the impeller, into (static) pressure. The motor rotates the impeller. The controller controls the motor, the inlet guide vane and the expansion valve. In this manner, the refrigerant is compressed in a conventional centrifugal compressor.

[0007] When the pressure next to the compressor discharge is higher than the compressor discharge pressure, the fluid tends to reverse or even flow back in the compressor. This happens when the lift pressure (condenser pressure-evaporator pressure) exceeds the compressor lift capability. This phenomenon, called surge, repeats and occurs in cycles. The compressor loses the ability to maintain its lift when surge occurs and the entire system becomes unstable. A collection of surge points during varying compressor speed or varying inlet gas angle is called a surge surface. In normal conditions, the compressor operates in the right side of the surge surface. However, during startup/operation in part load, the operating point will move towards the surge line because flow is reduced. If conditions are such that the operating point approaches the surge line, flow recirculation occurs in the impeller and diffuser. The flow separation will eventually cause a decrease in the discharge pressure, and flow from suction to discharge will resume. Surging can cause damage to the mechanical impeller/shaft system and/or to the thrust bearing due to the rotor shifting back and forth from the active to the inactive side. This is defined as the surge cycle of the compressor.

[0008] Therefore, techniques have been developed to control surge. See for example U.S. Patent Application Publication No. 2014/0260385 and U.S. Patent Application Publication No. 2014/0260388.

SUMMARY

[0009] In a conventional centrifugal compressor as shown in FIG. **10**, a hot gas bypass may be provided to connect the discharge side of the compressor and the suction side of the compressor to expand the operation range of the compressor. While this technique works relatively well, this system requires a pipe of a large diameter for the hot gas bypass, which results in increased costs. Especially in a case where a centrifugal compressor uses low pressure refrigerant such like R1233zd, the specific volume of the refrigerant is large compared to a case of conventional refrigerant such like R134a. This requires a large-diameter pipe for the hot gas bypass, which results in increased costs.

[0010] Also, a conventional centrifugal compressor with a hot gas bypass requires sensitive control using a variable frequency drive (VFD) to prevent surge.

[0011] Therefore, one object of the present invention is to provide a centrifugal compressor that expands the operation range of the compressor to prevent surge without increased costs.

[0012] Another object of the present invention is to provide a centrifugal compressor that prevents surge from occurring without performing sensitive control.

[0013] One or more of the above objects can basically be attained by providing a centrifugal compressor adapted to be used in a chiller system, the centrifugal compressor including a casing having an inlet portion and an outlet portion, an inlet guide vane disposed in the inlet portion, an impeller disposed downstream of the inlet guide vane, the impeller being attached to a shaft rotatable about a rotation axis, a motor arranged and configured to rotate the shaft in order to rotate the impeller, a diffuser disposed in the outlet portion downstream of the impeller, and a casing treatment bypass having an entrance port and an exit port, the casing treatment bypass being arranged and configured to inject refrigerant from a gap between the impeller and the inlet portion of the casing toward an area between the impeller and the inlet guide vane, and the exit port of the casing treatment bypass being positioned upstream in a direction of a refrigerant flow with respect to the entrance port of the casing treatment bypass.

[0014] These and other objects, features, aspects and advantages of the present invention will become apparent to those skilled in the art from the following detailed description, which, taken in conjunction with the annexed drawings, discloses preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] Referring now to the attached drawings which form a part of this original disclosure:

[0016] FIG. **1** is a schematic diagram illustrating a chiller system in accordance with an embodiment of the present invention which includes a casing treatment bypass;

[0017] FIG. **2** is a perspective view of the centrifugal compressor of the chiller system illustrated in FIG. **1**, with portions broken away and shown in cross-section for the purpose of illustration;

[0018] FIG. **3** is a schematic longitudinal cross-sectional view of the impeller, motor and magnetic bearing of the centrifugal compressor illustrated in FIG. **2**;

[0019] FIG. **4**A is a graph illustrating expanding the operation range of a compressor by shilling a surge line, FIG. **4**B is a schematic diagram illustrating surge and a stall at the outlet, and FIG. **4**C is a schematic diagram illustrating a stall at the inlet;

[0020] FIG. **5**A illustrates the static pressure, the flow velocity, and the flow rate of refrigerant without a casing treatment bypass, and FIGS. **5**B-**5**D illustrate the static pressure, the flow velocity, and the flow rate of refrigerant with a casing treatment bypass of various load;

[0021] FIG. **6** is an enlarged schematic diagram inside circle **6** in FIG. **2**, illustrating the inlet guide vane, the impeller and the casing of the centrifugal compressor of FIGS. **1**-**3** with a casing treatment bypass;

[0022] FIGS. **7**A and **7**B are schematic diagrams illustrating other embodiments of the casing treatment bypass;

[0023] FIG. **8**A is a schematic diagram illustrating a mixed flow impeller and FIG. **8**B is a schematic diagram illustrating a radial flow impeller;

[0024] FIG. **9** is a schematic diagram of the chiller controller of the chiller system of FIG. **1**; and

[0025] FIG. **10** illustrates a conventional chiller system which includes a hot gas bypass.

DETAILED DESCRIPTION OF EMBODIMENT(S)

[0026] Selected embodiments will now be explained with reference to the drawings. It will be apparent to those skilled in the art from this disclosure that the following descriptions of the embodiments are provided for illustration only and not for the purpose of limiting the invention as defined by the appended claims and their equivalents.

[0027] Referring initially to FIG. **1**, a chiller system **10**, which includes a casing treatment bypass **60** (**60***a*, **60***b*), is illustrated in accordance with an embodiment of the present invention. The chiller system **10** is preferably a water chiller that utilizes cooling water and chiller water in a conventional manner. The chiller system **10** illustrated herein is a two-stage chiller system. However, it will be apparent to those skilled in the art from this disclosure that the chiller system **10** could be a single stage chiller system or a multiple stage chiller system including three or more stages.

[0028] The chiller system **10** basically includes a chiller controller **20**, a compressor **22**, a condenser **24**, an expansion valve **26**, and an evaporator **28** connected together in series to form a loop refrigeration cycle. In addition, various sensors (not shown) are disposed throughout the circuit of the chiller system **10**. The chiller system **10** is conventional except that the chiller system has the casing treatment bypass **60** (**60***a*, **60***b*) in accordance with the present invention.

[0029] Referring to FIGS. **1**-**3**, the compressor **22** is a two-stage centrifugal compressor in the illustrated embodiment. The compressor **22** illustrated herein is a two-stage centrifugal compressor which includes two impellers. However, the compressor **22** can be a multiple stage centrifugal compressor including three or more impellers. The two-stage centrifugal compressor **22** of the illustrated embodiment includes a first stage impeller **34***a* and a second stage impeller **34***b*. The centrifugal compressor **22** further includes a first stage inlet guide vane **32***a*, a first diffuser/volute **36***a*, a second stage inlet guide vane **32***b*, a second diffuser/volute **36***b*, a compressor motor **38**, and a magnetic bearing assembly **40** as well as various conventional sensors (only some shown). A casing **30** covers the centrifugal compressor **22**. The casing **30** includes an inlet portion **31***a* and an outlet portion **33***a* for the first stage of the compressor **22**. The casing **30** also includes an inlet portion **31***b* and an outlet portion **33***b* for the second stage of the compressor **22**.

[0030] The chiller controller **20** receives signals from the various sensors and controls the inlet guide vanes **32***a* and **32***b*, the compressor motor **38**, and the magnetic bearing assembly **40** in a conventional manner, as explained in more detail below. Refrigerant flows in order through the first stage inlet guide vane **32***a*, the first stage impeller **34***a*, the second stage inlet guide vane **32***b*, and the second stage impeller **34***b*. The inlet guide vanes **32***a* and **32***b* control the flow rate of refrigerant gas into the impellers **34***a* and **34***b*, respectively, in a conventional manner. The impellers **34***a* and **34***b* increase the velocity of refrigerant gas, generally without changing pressure. The motor speed determines the amount of increase of the velocity of refrigerant gas. The diffusers/volutes **36***a* and **36***b* increase the refrigerant pressure. The diffusers/volutes **36***a* and **36***b* are non-movably fixed relative to the casing **30**. The compressor motor **38** rotates the impellers **34***a* and **34***b* via a shaft **42**. The magnetic bearing assembly **40** magnetically supports the shaft **42**. Alternatively, the bearing system may include a roller element, a hydrodynamic bearing, a hydrostatic bearing, and/or a magnetic bearing, or any combination of these. In this manner, the refrigerant is compressed in the centrifugal compressor **22**.

[0031] In operation of the chiller system **10**, the first stage impeller **34***a* and the second stage impeller **34***b* of the compressor **22** are rotated, and the refrigerant of low pressure in the chiller system **10** is sucked by the first stage impeller **34***a*. The flow rate of the refrigerant is adjusted by the inlet guide vane **32***a*. The refrigerant sucked by the first stage impeller **34***a* is compressed to intermediate pressure, the refrigerant pressure is increased by the first diffuser/volute **36***a*, and the refrigerant is then introduced to the second stage impeller **34***b*. The flow rate of the refrigerant is adjusted by the inlet guide vane **32***b*. The second stage impeller **34***b* compresses the refrigerant of intermediate pressure to high pressure, and the refrigerant pressure is increased by the second diffuser/volute **36***b*. The high pressure gas refrigerant is then discharged to the chiller system **10**.

[0032] Referring to FIGS. **2** and **3**, the magnetic bearing assembly **40** is conventional, and thus, will not be discussed and/or illustrated in detail herein, except as related to the present invention. Rather, it will be apparent to those skilled in the art that any suitable magnetic bearing can be used without departing from the present invention. The magnetic bearing assembly **40** preferably includes a first radial magnetic bearing **44**, a second radial magnetic bearing **46** and an axial (thrust) magnetic bearing **48**. In any case, at least one radial magnetic bearing **44** or **46** rotatably supports the shaft **42**. The thrust magnetic bearing **48** supports the shaft **42** along a rotational axis X by acting on a thrust disk **45**. The thrust magnetic bearing **48** includes the thrust disk **45** which is attached to the shaft **42**.

[0033] The thrust disk **45** extends radially from the shaft **42** in a direction perpendicular to the rotational axis X, and is fixed relative to the shaft **42**. A position of the shaft **42** along rotational axis X (an axial position) is controlled by an axial position of the thrust disk **45**. The first and second radial magnetic bearings **44** and **46** are disposed on opposite axial ends of the compressor motor **38**. Various sensors detect radial and axial positions of the shaft **42** relative to the magnetic bearings **44**, **46** and **48**, and send signals to the chiller controller **20** in a conventional manner. The chiller controller **20** then controls the electrical current sent to the magnetic bearings **44**, **46** and **48** in a conventional manner to maintain the shaft **42** in the correct position.

[0034] The magnetic bearing assembly **40** is preferably a combination of active magnetic bearings **44**, **46**, and **48**, which utilizes gap sensors **54**, **56** and **58** to monitor shaft position and send signals indicative of shaft position to the chiller controller **20**. Thus, each of the magnetic bearings **44**, **46** and **48** are preferably active magnetic bearings. A magnetic bearing control section **71** uses this information to adjust the required current to a magnetic actuator to maintain proper rotor position both radially and axially.

[0035] Referring to FIGS. **1** and **9**, the chiller controller **20** includes a magnetic bearing control section **71**, a compressor variable frequency drive **72**, a compressor motor control section **73**, an inlet guide vane control section **74**, and an expansion valve control section **75**. The compressor variable frequency drive **72** and the compressor motor control section **73** can be a single section.

[0036] In the illustrated embodiment, the control sections are sections of the chiller controller **20** programmed to execute the control of the parts described herein. The magnetic bearing control section **71**, the compressor variable frequency drive **72**, the compressor motor control section **73**, and the inlet guide vane control section **74**, and the expansion valve control section **75** are coupled to each other, and form parts of a centrifugal compressor control portion that is electrically coupled to an I/O interface of the compressor **22**. However, it will be apparent to those skilled in the art from this disclosure that the precise number, location and/or structure of the control sections, portions and/or chiller controller **20** can be changed without departing from the present invention so long as the one or more controllers are programed to execute control of the parts of the chiller system **10** as explained herein.

[0037] The chiller controller **20** is conventional, and thus, includes at least one microprocessor or CPU, an Input/output (I/O) interface, Random Access Memory (RAM), Read Only Memory (ROM), a storage device (either temporary or permanent) forming a computer readable medium programmed to execute one or more control programs to control the chiller system **10**. The chiller controller **20** may optionally include an input interface such as a keypad to receive inputs from a user and a display device used to display various parameters to a user. The parts and programming are conventional, and thus, will not be discussed in detail herein, except as needed to understand the embodiment(s).

[0038] As mentioned above, the chiller system **10** has the casing treatment bypass **60** (**60***a*, **60***b*) in accordance with the present invention. In the illustrated embodiment, the compressor **22** is a two-stage centrifugal compressor. A first stage casing treatment bypass **60***a* and a second stage casing treatment bypass **60***b* are provided in the first stage and the second stage of the compressor **22**, respectively, as shown in FIG. **1**. It will be apparent to those skilled in the art from this disclosure that the structures of the first stage casing treatment bypass **60***a* and the second stage casing treatment bypass **60***b* are identical, except that they are mirror images of each other. Therefore, the first stage casing treatment bypass **60***a* and the second stage casing treatment bypass **60***b* are collectively referred to as the casing treatment bypass **60** hereinafter.

[0039] In the same manner, the elements of the first stage and the second stage of the compressor **22** are collectively referred to hereinafter without being distinguished. For example, the inlet portion **31***a* of the casing **30** for the first stage and the inlet portion **31***b* of the casing **30** for the second stage are collectively referred to as the inlet portion **31** of the casing **30**. The first stage inlet guide vane **32***a* and the second stage inlet guide vane **32***a* are collectively referred to as the inlet guide vane **32**. The first stage impeller **34***a* and the second stage impeller **34***b* are collectively referred to as the impeller **34**.

[0040] In accordance with the present invention, the casing treatment bypass **60** is provided in the chiller system **10** to inject refrigerant from a gap between the impeller **34** and the inlet portion **31** of the casing **30** toward an area between the impeller **34** and the inlet guide vane **32**, as explained in more detail below.

[0041] Referring to FIG. **4**A, the operation range of a compressor is expanded at low load (i.e., at a small flow rate) by shifting a surge line to the high pressure side. The surge line is a line connecting pressure limit values in which the compressor cannot be operated at a predetermined flow rate. As shown in FIG. **4**B, when surge occurs, the flow moves forward or backward repeatedly at the outlet, which results in severe vibration of the pressure and the flow rate. The severe vibration causes a stall of the flow at the outlet. As shown in FIG. **4**C, a stall of the flow occurs also at the inlet in a case where the flow rate is reduced. More specifically, when the flow rate is reduced, the flow goes into the blade of the impeller with a larger angle of incidence compared to the ideal flow inlet angle, which causes the flow separation from the front edge of the blade. The flow separation causes the stall of the flow at the inlet. The casing treatment bypass **60** in accordance with the present invention is provided to prevent the flow separation and the stall of the flow at the inlet so as to expand the operation range of the compressor **22**, as explained in more detail below.

[0042] FIG. **5**A illustrates the static pressure, the flow velocity, and the flow rate of refrigerant without a casing treatment bypass, and FIGS. **5**B-**5**D illustrate the static pressure, the flow velocity, and the flow rate of refrigerant with a casing treatment bypass of various load. In each of FIGS. **5**A-**5**D, the upper graph shows the static pressure of the refrigerant at positions "a" to "g" illustrated in the diagram at the top. Here, the static pressure at the inlet is 0.0, and the static pressure at the outlet is 1.0. The negative value means that the static pressure is lower than that at the inlet. In each of FIGS. **5A-5D**, the lower graph shows the flow velocity of the refrigerant at positions "a" to "g" illustrated in the diagram at the top. Here, the flow velocity at the inlet is **0.0**. The negative value means that the flow velocity is lower than that at the inlet. In each of FIGS. **5A-5D**, the table at the bottom shows the flow rate of the refrigerant at positions (A) to (E) illustrated in the diagram at the top.

[0043] Referring to FIG. **5A**, when the compressor is operated at 100% load without a casing treatment bypass, the static pressure of the refrigerant decreases, and then increases as the flow approaches the outlet. Referring to FIG. **5B**, when the compressor is operated at 100% load with a casing treatment bypass, the static pressure of the refrigerant decreases, and then increases as the flow approaches the outlet, similarly to the case shown in FIG. **5A**. In the case shown in FIG. **5B**, the exit port of the casing treatment bypass is arranged at the edge of the impeller blade, and thus, the ability of increasing the pressure does not significantly change even with the casing treatment bypass. In this manner, when the compressor is operated at 100% load, the static pressure of the refrigerant changes similarly regardless of whether a casing treatment bypass is provided or not.

[0044] As mentioned above, the stall of the flow at the inlet will occur when the flow rate of the refrigerant is reduced. In other words, the stall of the flow at the inlet will not occur when the flow rate of the refrigerant is sufficiently large as in the cases shown in FIGS. **5A** and **5B**. The casing treatment bypass **60** in accordance with the present invention is provided to prevent the stall of the flow at the inlet when the flow rate of the refrigerant is reduced as in the cases shown in FIGS. **5C** and **5D**.

[0045] Referring to FIG. **5C**, when the compressor is operated at 50% load with a casing treatment bypass, the static pressure of the refrigerant at position "c" is larger than the static pressure of the refrigerant at the inlet. The pressure difference between the static pressure at position "c" and the static pressure at the inlet at 50% load refers to ΔP_{50}. Here, 50% is an estimated value. In this instance, it is assumed that surge partially occurs at the inlet because the flow rate of the refrigerant is small. As a result of the pressure difference ΔP_{50}, the flow toward the inlet (toward position "f" in the diagram) is created in the casing treatment bypass. Referring to FIG. **5D**, when the compressor is operated at 20% load with a casing treatment bypass, the static pressure of the refrigerant at position "c" is much larger than the static pressure of the refrigerant at the inlet. The pressure difference between the static pressure at position "c" and the static pressure at the inlet at 20% load refers to ΔP_{20}. Here, 20% is an estimated value. As seen from FIGS. **5C** and **5D**, the pressure difference ΔP_{20} is larger than the pressure difference ΔP_{50}.

[0046] When the compressor is operated at low load such as 50% or 20% with the casing treatment bypass, the flow rate of the refrigerant increases at the inlet due to the flow introduced by the casing treatment bypass, which prevents the stall at the inlet from being caused by the flow separation at the front edge of the impeller blade. In this manner, the operation range of the compressor **22** is expanded when the flow rate of the refrigerant is small.

[0047] Referring to FIGS. **6**, FIGS. **7A** and **7B**, the casing treatment bypass **60** in accordance with the present invention will be explained in more detail.

[0048] FIG. **6** is an enlarged schematic diagram inside circle **6** in FIG. **2**, illustrating the inlet guide vane **32**, the impeller **34** and the casing **30** of the centrifugal compressor **22** of FIGS. **1-3** with the casing treatment bypass **60**.

[0049] In the illustrated embodiment, the casing treatment bypass **60** is a hole formed in the inlet portion **31** of the casing **30** of the compressor **22**. The casing treatment bypass **60** may include a plurality of holes, with each hole as illustrated in FIG. **6** being circumferentially disposed of the inlet portion **31** of the casing **30**. For example, the number of the holes may be eight, and the diameter "a" of each hole may be 46.1 mm.

[0050] The casing treatment bypass **60** includes an entrance port **61** and an exit port **63**. The entrance port **61** of the casing treatment bypass **60** is connected to a gap between the impeller **34** and the inlet portion **31** of the casing **30**. The exit port **63** of the casing treatment bypass **60** is connected to an area between the impeller **34** and the inlet guide vane **32**. As shown in FIG. **6**, the exit port **63** of the casing treatment bypass **60** is positioned upstream in a direction of the refrigerant flow with respect to the entrance port **61** of the casing treatment bypass **60**. In this manner, the casing treatment bypass **60** injects the refrigerant from the gap between the impeller **34** and the inlet portion **31** of the casing **30** back to the area between the impeller **34** and the inlet guide vane **32**. In the illustrated embodiment, the exit port **63** of the casing treatment bypass **60** is located in the area between the impeller **34** and the inlet guide vane **32**. In other words, the exit port **63** of the casing treatment bypass **60** is located downstream of the inlet guide vane **32** in the refrigerant flow direction. Alternatively, the exit port **63** of the casing treatment bypass **60** may be located upstream of the inlet guide vane **32** in the refrigerant flow direction.

[0051] As shown in FIG. **6**, the impeller **34** includes an impeller hub **35** and impeller blades **37**. The impeller blades **37** are disposed to surround the impeller hub **35**. The entrance port **61** of the casing treatment bypass **60** faces the impeller blade **37**. The exit port **63** of the casing treatment bypass **60** opens to the area between the inlet guide vane **32** and the impeller **34**. The diameter "a" of the entrance port **61** of the casing treatment bypass **60** is determined based on the diameter "d" of the impeller blade **37**. It is preferable, however, that the diameter "a" of the entrance port **61** of the casing treatment bypass **60** does not exceed 25% of the inlet area of the impeller **34**.

[0052] It is also preferable that the cross-sectional area of the exit port **63** of the casing treatment bypass **60** is equal to or greater than the cross-sectional area of the entrance port **61** of the casing treatment bypass **60**. For example, the diameter "b" of the exit port **63** of the casing treatment bypass **60** can be arranged to be greater than the diameter "a" of the entrance port **61** of the casing treatment bypass **60** as illustrated in FIG. **6**. With this arrangement, the refrigerant can stably flow in the casing treatment bypass **60** from the entrance port **61** toward the exit port **63**.

[0053] Referring to FIGS. **7A** and **7B**, the casing treatment bypass **60** in accordance with another embodiment will be explained.

[0054] The casing treatment bypass **60** illustrated in FIG. **7A** has an annular ring shape extending the whole circumference of the inlet portion **31** of the casing **30**. In this embodiment, the inlet portion **31** of the casing **30** includes a sub-portion **31***s* which is separated from the inlet portion **31** of the casing **30** by the ring-shaped casing treatment bypass **60**. For example, the sub-portion **31***s* is connected to the inlet portion **31** with a linkage mechanism **66** which is attached to the outside of the inlet portion **31**. The linkage mechanism **66** may include a connecting ring, and a connecting rod which is rotatably attached to the connecting ring. The linkage mechanism **66** is driven by a driving mechanism **67** such as a stepper motor or a hydraulic cylinder. In operation, the connecting ring of the linkage mechanism **66** is driven by the driving mechanism **67** to move in the axial direction corresponding to the rotation axis of the impeller **34**, and rotate the connecting rod of the linkage mechanism **66**. The connecting rod of the linkage mechanism **66** then moves the sub-portion **31***s* in the axial direction corresponding to the rotation axis of the impeller **34** as shown with the dotted line in FIG. **7**A. In this manner, the sub-portion **31***s* is arranged to be movable relative to the non-movable inlet portion **31** in the axial direction corresponding to the rotation axis of the impeller **34**. In this embodiment, the flow path area of the casing treatment bypass **60** can be adjusted by moving the sub-portion **31***s* in the axial direction corresponding to the rotation axis of the impeller **34**. Alternatively, the flow path area of the casing treatment bypass **60** may be fixed. For example, the width in the radial direction of the ring-shaped casing treatment bypass **60** may be 15.75 mm in a case where the diameter at the inlet of the impeller **34** is 270 mm.

[0055] The casing treatment bypass **60** illustrated in FIG. **7**B includes an adjusting member **64**. The adjusting member **64** is a movable ring disposed in the inlet portion **31** of the casing **30** so as to at least partly block the flow path area of the casing treatment bypass **60**. For example, the adjusting member **64** is connected to the inlet portion **31** with a linkage mechanism **68** which is attached to the outside of the inlet portion **31**. The linkage mechanism **68** may include a connecting ring which is rotatably attached to the adjusting member **64**. The linkage mechanism **68** is driven by a driving mechanism **69** such as a stepper motor or a hydraulic cylinder. In operation, the connecting ring of the linkage mechanism **68** is driven by the driving mechanism **69** to move the adjusting member **64** in the radial direction perpendicular to the axial direction corresponding to the rotation axis of the impeller **34** as shown with the dotted line in FIG. **7**B. In this manner, the adjusting member **64** is arranged to be movable relative to the non-movable inlet portion **31** in the radial direction perpendicular to the axial direction, and the flow path area of the casing treatment bypass **60** can be adjusted by moving the adjusting member **64** in the radial direction perpendicular to the axial direction. The adjusting member **64** can be applied to both of the case in which the casing treatment bypass **60** has a single hole and the case in which the casing treatment bypass **60** has a plurality of holes.

[0056] As mentioned above, the flow path area of the casing treatment bypass **60** can be optimized by moving the sub-portion **31***s* in the axial direction corresponding to the rotation axis of the impeller **34** (see FIG. **7**A) or by moving the adjusting member **64** in the radial direction perpendicular to the axial direction (see FIG. **7**B). The casing treatment bypass **60** in accordance with the present invention can use either one of the movable sub-portion **31***s* and the movable adjusting member **64** to optimize the flow path area of the casing treatment bypass **60**.

[0057] Referring to FIGS. **8**A and **8**B, various types of impellers can be used as the impeller **34** of the compressor **22** in accordance with the present invention. FIG. **8**A is a schematic diagram illustrating a mixed flow impeller and FIG. **8**B is a schematic diagram illustrating a radial flow impeller. However, the present invention is not limited to the type of the impeller **34**. The case treatment bypass **60** in accordance with the present invention can be applied to various types of impellers including the mixed flow impeller as shown in FIG. **8**A or the radial flow impeller as shown in FIG. **8**B.

[0058] In terms of global environment protection, use of new low GWP (Global Warming Potential) refrigerants such like R1233zd, R1234ze are considered for chiller systems. One example of the low global warming potential refrigerant is low pressure refrigerant in which the evaporation pressure is equal to or less than the atmospheric pressure. For example, low pressure refrigerant R1233zd is a candidate for centrifugal chiller applications because it is non-flammable, non-toxic, low cost, and has a high COP compared to other candidates such like R1234ze, which are current major refrigerant R134a alternatives. Especially in a case of using low pressure refrigerant, the compressor **22** including the casing treatment bypass **60** in accordance with the present invention has advantages because the operation range of the compressor **22** can be expanded to prevent surge without requiring a large-diameter pipe for a conventional hot gas bypass.

General Interpretation of Terms

[0059] In understanding the scope of the present invention, the term "comprising" and its derivatives, as used herein, are intended to be open ended terms that specify the presence of the stated features, elements, components, groups, integers, and/or steps, but do not exclude the presence of other unstated features, elements, components, groups, integers and/or steps. The foregoing also applies to words having similar meanings such as the terms, "including", "having" and their derivatives. Also, the terms "part," "section," "portion," "member" or "element" when used in the singular can have the dual meaning of a single part or a plurality of parts.

[0060] The term "detect" as used herein to describe an operation or function carried out by a component, a section, a device or the like includes a component, a section, a device or the like that does not require physical detection, but rather includes determining, measuring, modeling, predicting or computing or the like to carry out the operation or function.

[0061] The term "configured" as used herein to describe a component, section or part of a device includes hardware and/or software that is constructed and/or programmed to carry out the desired function.

[0062] The terms of degree such as "substantially", "about" and "approximately" as used herein mean a reasonable amount of deviation of the modified term such that the end result is not significantly changed.

[0063] While only selected embodiments have been chosen to illustrate the present invention, it will be apparent to those skilled in the art from this disclosure that various changes and modifications can be made herein without departing from the scope of the invention as defined in the appended claims. For example, the size, shape, location or orientation of the various components can be changed as needed and/or desired. Components that are shown directly connected or contacting each other can have intermediate structures disposed between them. The functions of one element can be performed by two, and vice versa. The structures and functions of one embodiment can be adopted in another embodiment. It is not necessary for all advantages to be present in a particular embodiment at the same time. Every feature which is unique from the prior art, alone or in combination with other features, also should be considered a separate description of further inventions by the applicant, including the structural and/or functional concepts embodied by such feature(s). Thus, the foregoing descriptions of the embodiments according to the present invention are provided for illustration only, and not for the purpose of limiting the invention as defined by the appended claims and their equivalents.

What is claimed is:

1. A centrifugal compressor adapted to be used in a chiller system, the centrifugal compressor comprising:
- a casing having an inlet portion and an outlet portion;
- an inlet guide vane disposed in the inlet portion;
- an impeller disposed downstream of the inlet guide vane, the impeller being attached to a shaft rotatable about a rotation axis;
- a motor arranged and configured to rotate the shaft in order to rotate the impeller;
- a diffuser disposed in the outlet portion downstream of the impeller; and
- a casing treatment bypass having an entrance port and an exit port,
- the casing treatment bypass being arranged and configured to inject refrigerant from a gap between the impeller and the inlet portion of the casing toward an area between the impeller and the inlet guide vane, and
- the exit port of the casing treatment bypass being positioned upstream in a direction of a refrigerant flow with respect to the entrance port of the casing treatment bypass.

2. The centrifugal compressor according to claim **1**, wherein
- the impeller includes an impeller hub and an impeller blade surrounding the impeller hub,
- the entrance port of the casing treatment bypass faces the impeller blade, and
- the exit port of the casing treatment bypass opens to the area between the inlet guide vane and the impeller.

3. The centrifugal compressor according to claim **2**, wherein
- a diameter of the entrance port of the casing treatment bypass is determined based on a diameter of the impeller blade.

4. The centrifugal compressor according to claim **1**, wherein
- a cross-sectional area of the exit port of the casing treatment bypass is equal to or greater than a cross-sectional area of the entrance port of the casing treatment bypass.

5. The centrifugal compressor according to claim **1**, wherein
- the casing treatment bypass includes a hole formed in the inlet portion of the casing.

6. The centrifugal compressor according to claim I, wherein
- the casing treatment bypass includes a plurality of holes formed in the inlet portion of the casing.

7. The centrifugal compressor according to claim **1**, wherein
- the casing treatment bypass has a ring shape.

8. The centrifugal compressor according to claim I, wherein
- a flow path area of the casing treatment bypass is fixed.

9. The centrifugal compressor according to claim **1**, wherein
- a flow path area of the casing treatment bypass is adjustable.

10. The centrifugal compressor according to claim **9**, wherein
- a movable adjusting member is disposed in the inlet portion of the casing so as to at least partly block the flow path area of the casing treatment bypass, and
- the flow path area of the casing treatment bypass is adjusted by moving the movable adjusting member in a radial direction perpendicular to an axial direction corresponding to the rotation axis of the impeller.

11. The centrifugal compressor according to claim **7**, wherein
- an flow path area of the casing treatment bypass is adjustable.

12. The centrifugal compressor according to claim **11**, wherein
- the inlet portion of the casing includes a movable sub-portion which is separated from the inlet portion of the casing by the casing treatment bypass, and
- the flow path area of the casing treatment bypass is adjusted by moving the sub-portion in an axial direction corresponding to the rotation axis of the impeller.

13. The centrifugal compressor according to claim **1**, wherein
- the refrigerant is low global warming potential refrigerant.

14. The centrifugal compressor according to claim **13**, wherein
- the low global warming potential refrigerant is low pressure refrigerant.

15. The centrifugal compressor according to claim **14**, wherein
- the low pressure refrigerant includes R1233zd.

16. The centrifugal compressor according to claim **1**, wherein
- the impeller is a mixed flow type impeller.

17. The centrifugal compressor according to claim **1**, wherein
- the impeller is a radial flow type impeller.

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