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(54) ACTIVE DISPLACEMENT CONTROL AGAINST TEMPERATURE TARGET FOR A VARIABLE DISPLACEMENT PUMP

(57) A system includes a variable displacement pump (VDP) (102) in fluid communication with an inlet line and with an outlet line. The VDP (102) includes a variable displacement mechanism. A bypass valve (BPV) includes a BPV inlet in fluid communication with the outlet line, and a BPV outlet in fluid communication with a bypass line that feeds into the inlet line upstream of the VDP (102). An actuator is operatively connected to control the BPV to vary flow from the BPV inlet to the bypass line. An electromechanical actuator (EMA) is operatively connected to actuate the variable displacement mechanism. A temperature sensor is operatively connected to the outlet line to generate sensor output indicative of fluid temperature in the outlet line, wherein the temperature sensor is operatively connected to a controller for active control of the EMA and/or of the actuator based on temperature in the outlet line.

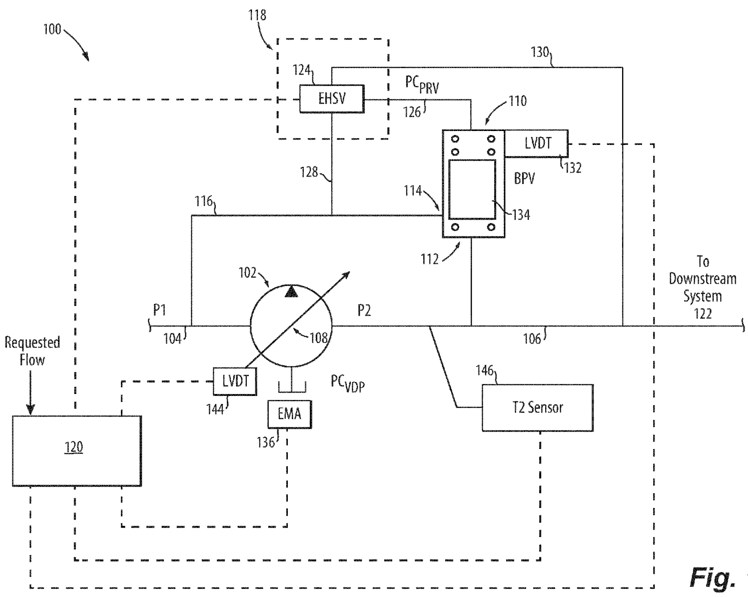

Fig. 1

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Description

BACKGROUND

1. Field

[0001] The present disclosure relates to pump control, and more particularly to control for variable displacement pumps (VDPs).

2. Description of Related Art

[0002] Variable displacement pumps have non-linear mechanical efficiencies as a function of percentage of displacement. Temperature rise in the fluid across the pump is inversely proportional to the mechanical efficiency. As a result, as a variable displacement pump decreases output flow, temperature rise in the fluid across the pump goes up.

[0003] The conventional techniques have been considered satisfactory for their intended purpose. However, there is an ever present need for improved systems and methods for control of VDPs. This disclosure provides a solution for this need.

SUMMARY

[0004] A system includes a variable displacement pump (VDP) in fluid communication with an inlet line and with an outlet line. The VDP includes a variable displacement mechanism configured to vary pressure to the outlet line. A bypass valve (BPV) includes a BPV inlet in fluid communication with the outlet line, and a BPV outlet in fluid communication with a bypass line that feeds into the inlet line upstream of the VDP. An actuator is operatively connected to control the BPV to vary flow from the BPV inlet to the bypass line. An electromechanical actuator (EMA) is operatively connected to actuate the variable displacement mechanism. A controller is operatively connected: to the EMA to control the variable displacement mechanism; and to the actuator to control recirculation flow passed through the BPV based on requested flow from a downstream system supplied by the outlet line and based on a predetermined low threshold of flow through the VDP. The BPV outlet can be the only outlet of the BPV so all flow through the BPV is supplied to the BPV outlet. A temperature sensor is operatively connected to the outlet line to generate sensor output indicative of fluid temperature in the outlet line, wherein the temperature sensor is operatively connected to the controller for active control of the EMA and/or of the actuator based on temperature in the outlet line.

[0005] The controller can be configured to control the BPV to maintain a baseline flow through the BPV under a first condition wherein requested flow from the downstream system is above than the predetermined low threshold. The controller can be configured to control the BPV to increase the flow through the BPV above the baseline flow for a second flow condition wherein requested flow from the downstream system is at or below the predetermined low threshold.

[0006] An electrohydraulic servo valve (EHSV) can be connected in fluid communication with the BPV by a first control line. The EHSV can be connected in fluid communication with both the inlet line and with the outlet line through respective connection lines. The EHSV can be operatively connected to the controller for active control of the EHSV to actuate the BPV.

[0007] A first position sensor can be operatively connected to the BPV to provide sensor output indicative of position of a valve member of the BPV. The first position sensor can be operatively connect the controller to provide feedback for controlling the BPV. A second position sensor can be operatively connected to the variable displacement mechanism to provide sensor output indicative of position of the variable displacement mechanism, wherein the second position sensor is operatively connect the controller to provide feedback for controlling the variable displacement mechanism.

[0008] The controller can be operatively connected to receive input indicative of flow demanded by the downstream system supplied by the outlet line. The controller can be configured to control position of the valve member of the BPV to maintain bypass flow through the BPV in the second condition wherein the controller governs the bypass flow through the BPV according to

$$BF = PF - DSFD$$

wherein BF is flow through the BPV, PF is flow through the VDP, and DSFD is flow demanded by the downstream system supplied by the outlet line.

[0009] A method includes receiving input indicative of flow demanded by a downstream system supplied from an outlet line of a variable displacement pump (VDP). The method includes controlling a bypass valve (BPV) to recirculate flow from the outlet line to an input line of the VDP in the event of flow demanded by the downstream system dropping below a predetermined low threshold of flow through the VDP. The method includes controlling displacement of the VDP, wherein at least one of controlling the BPV and controlling displacement is based on fluid temperature in the output line.

[0010] The method can include controlling the BPV to recirculate flow from the outlet line to the inlet line at a constant base recirculation rate in the event of flow demanded by the downstream system being at or above the predetermined low threshold of flow through the VDP. The base recirculation rate can be zero recirculation flow. Controlling the BPV to recirculate flow can include governing the bypass flow through the BPV according to

$$BF = PF - DSFD$$

wherein BF is flow through the BPF, PF is flow through the VDP, and DSFD is flow demanded by the downstream system supplied by the outlet line. The method can include receiving data from a sensor indicative of position of a valve member of the BPV. Controlling the BPV can include controlling the BPV based on position of the valve member. The method can include receiving data from a sensor indicative of position of a variable displacement mechanism of the VDP. Controlling displacement can include controlling displacement of the VDP based on position of the variable displacement mechanism.

[0011] These and other features of the systems and methods of the subject disclosure will become more readily apparent to those skilled in the art from the following detailed description of the preferred embodiments taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] So that those skilled in the art to which the subject disclosure appertains will readily understand how to make and use the devices and methods of the subject disclosure without undue experimentation, preferred embodiments thereof will be described in detail herein below with reference to certain figures, wherein:

Fig. 1 is a schematic view of an embodiment of a system constructed in accordance with the present disclosure, showing the connections of the variable displacement pump (VDP) and a bypass valve (BPV), with temperature based control.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0013] Reference will now be made to the drawings wherein like reference numerals identify similar structural features or aspects of the subject disclosure. For purposes of explanation and illustration, and not limitation, a partial view of an embodiment of a system in accordance with the disclosure is shown in Fig. 1 and is designated generally by reference character 100. The systems and methods described herein can be used to provide for temperature based control of variable displacement pumps, such as for use in supplying fuel to gas generators in aircraft engines.

[0014] The system 100 includes a variable displacement pump (VDP) 102 in fluid communication with an inlet line 104 and with an outlet line 106. The VDP 102 includes a variable displacement mechanism 108 configured to vary pressure to the outlet line 106. A bypass valve (BPV) 110 includes a BPV inlet 112 in fluid communication with the outlet line 106, and a BPV outlet 114 in fluid communication with a bypass line 116 that feeds into the inlet line 104 upstream of the VDP 102. An actuator 118 is operatively connected to control the BPV 110 to vary flow from the BPV inlet 112 to the bypass line 116. An electromechanical actuator (EMA) 136 is operatively connected to actuate the variable displacement mechanism 108.

[0015] A controller 120 is operatively connected: to the EMA 136 to control the variable displacement mechanism 108; and to the actuator 118 to control recirculation flow passed through the BPV 110 based on requested flow from a downstream system 122 supplied by the outlet line 106 and based on a predetermined low threshold of flow through the VDP 102. A temperature sensor 146 is operatively connected to the outlet line 106 to generate sensor output indicative of fluid temperature in the outlet line 106. The temperature sensor 146 is operatively connected to the controller 120 for active control of the EMA 136 and/or of the actuator 118 based on fluid temperature in the outlet line 106. The downstream system 122 can be a combustor, augmenter, or other gas generator of a gas turbine engine, for example. The low threshold of flow of the VDP 102 can be the threshold below which the VDP 102 cannot self-lubricate, or other design requirements for low or minimum flow. The BPV outlet 114 can be the only outlet of the BPV 110 so all flow through the BPV 110 from the BPV inlet 112 is supplied to the BPV outlet 114.

[0016] The controller 120 is configured, e.g. including analog circuitry, digital logic, and/or machine readable instructions, to control the BPV 110 to maintain a baseline flow through the BPV 110 under a first condition wherein requested flow from the downstream system 122 is above than the predetermined low threshold. The controller 122 is configured to control the BPV 110 to increase the flow through the BPV 110 above the baseline flow for a second flow condition wherein requested flow from the downstream system 122 is at or below the predetermined low threshold.

[0017] The actuator 118 includes an electrohydraulic servo valve (EHSV) 124 that is connected in fluid communication with the BPV 110 by a first control line 126. The EHSV 124 is connected in fluid communication with both the inlet line 104, by way of the recirculation line 116, and with the outlet line 106 through respective connection lines 128, 130. The EHSV 124 is operatively connected to the controller 120 for active control of the EHSV 124 to actuate the BPV 110.

[0018] A first position sensor 132, such as a linear variable differential transformer (LVDT), is operatively connected to the BPV 110 to provide sensor output indicative of position of a valve member 134 of the BPV 110 within the BPV 110. The first position sensor 132 is operatively connect the controller 120 to provide feedback for controlling the BPV 110. A second position sensor 144, such as an LVDT, is operatively connected to the variable displacement mechanism 108 to provide sensor output indicative of position of the variable displacement mechanism 108, wherein the second position sensor 144 is operatively connect the controller 120 to provide feedback for controlling the variable displacement mechanism 108.

[0019] The controller 120 is operatively connected to receive input indicative of flow demanded by the downstream system 122, as indicated by the arrow and label in Fig. 1. The controller 122 is configured to control position of the valve member 134 of the BPV 110 to maintain bypass flow through the BPV in the second condition, i.e. when recirculation through the BPV 110 is needed because flow demanded by the downstream system 122 drops below the predetermined low threshold for flow through the VDP 102. In this second condition, the controller 120 governs the bypass flow through the BPV 110 according to

$$BF = PF - DSFD$$

wherein BF is flow through the BPV 110, PF is flow through the VDP 102 (e.g. as indicated by sensors 144 and/or a pressure sensor elsewhere in the system or incorporated in sensor 146), and DSFD is flow demanded by the downstream system 122.

[0020] In the first condition, e.g. when flow demanded by the downstream system 122 is at or above the predetermined low threshold for flow through the VDP 102, the controller 120 controls the BPV 110 to recirculate flow from the outlet line 106 to the inlet line 102 at a constant base recirculation rate. The base recirculation rate can be zero recirculation flow.

[0021] Systems and methods as disclosed herein provide potential benefits including the following. Utilizing a variable displacement pump with direct pump displacement control via an EMA and a temperature feedback loop in the controller, a maximum temperature threshold at any given set of operating conditions can be actively maintained. This will allow the minimum displacement of the pump to be actively varied as the operating conditions dictate. Allowing for the absolute tolerable minimum displacement as a function of temperature will allow the pump to have the minimum parasitic horsepower loss while being able to maintain non-detrimental temperature rise, therefor favorable fluid properties to ensure the mechanical health of the pump.

[0022] The methods and systems of the present disclosure, as described above and shown in the drawings, provide for temperature based control of variable displacement pumps, such as for use in supplying fuel to gas generators in aircraft engines. While the apparatus and methods of the subject disclosure have been shown and described with reference to preferred embodiments, those skilled in the art will readily appreciate that changes and/or modifications may be made thereto without departing from the scope of the subject disclosure.

Claims

1. A system comprising:

a variable displacement pump "VDP" (102) in fluid communication with an inlet line and with an outlet line, wherein the VDP (102) includes a variable displacement mechanism configured to vary pressure to the outlet line;

a bypass valve "BPV" including a BPV inlet in fluid communication with the outlet line, and a BPV outlet in fluid communication with a bypass line that feeds into the inlet line upstream of the VDP (102);

an actuator operatively connected to control the BPV (110) to vary flow from the BPV inlet to the bypass line;

an electromechanical actuator "EMA" operatively connected to actuate the variable displacement mechanism;

a controller operatively connected:

to the EMA to control the variable displacement mechanism; and

to the actuator to control recirculation flow passed through the BPV (110) based on requested flow from a downstream system supplied by the outlet line and based on a predetermined low threshold of flow through the VDP (102); and

a temperature sensor operatively connected to the outlet line to generate sensor output indicative of fluid temperature in the outlet line, wherein the temperature sensor is operatively connected to the controller for active control of the EMA and/or of the actuator based on temperature in the outlet line.

2. The system as recited in claim 1, wherein the BPV (110) includes no outlets other than the BPV (110) outlet so all flow through the BPV (110) is supplied to the BPV outlet.

3. The system as recited in claim 1 or 2, wherein the controller is configured to:

control the BPV (110) to maintain a baseline flow through the BPV (110) under a first condition wherein requested flow from the downstream system is above than the predetermined low threshold, and

control the BPV (110) to increase the flow through the BPV (110) above the baseline flow for a second flow condition wherein requested flow from the downstream system is at or below the predetermined low threshold.

4. The system as recited in claim 3, further comprising a electrohydraulic servo valve "EHSV" connected in fluid communication with the BPV (110) by a control line, wherein the EHSV is connected in fluid communication with both the inlet line and with the outlet line through respective connection lines, and wherein the EHSV is operatively connected to the controller for active control of the first EHSV to actuate the BPV (110).

5. The system as recited in claim 4, wherein a first position sensor is operatively connected to the BPV (110) to provide sensor output indicative of position of a valve member of the BPV (110), wherein the first position sensor is operatively connect the controller to provide feedback for controlling the BPV (110).

6. The system as recited in any preceding claim, wherein a second position sensor is operatively connected to the variable displacement mechanism to provide sensor output indicative of position of the variable displacement mechanism.

7. The system as recited in claim 6, wherein the second position sensor is operatively connect the controller to provide feedback for controlling the variable displacement mechanism.

8. The system as recited in claim 7, wherein the controller is operatively connected to receive input indicative of flow demanded by the downstream system supplied by the outlet line.

9. The system as recited in claim 8, wherein the controller is configured to control position of the valve member of the BPV (110) to maintain bypass flow through the BPV (110) in the second condition wherein the controller governs the bypass flow through the BPV (110) according to

$$BF = PF - DSFD$$

wherein BF is flow through the BPV (110), PF is flow through the VDP (102), and DSFD is flow demanded by the downstream system supplied by the outlet line.

10. A method comprising:

receiving input indicative of flow demanded by a downstream system supplied from an outlet line of a variable displacement pump "VDP" (102);
controlling a bypass valve "BPV" to recirculate flow from the outlet line to an input line of the VDP (102) in the event of flow demanded by the downstream system dropping below a predetermined low threshold of flow through the VDP (102); and
controlling displacement of the VDP (102), wherein at least one of controlling the BPV (110) and controlling displacement is based on fluid temperature in the output line.

11. The method as recited in claim 10, further comprising controlling the BPV (110) to recirculate flow from the outlet line to the inlet line at a constant base recirculation rate in the event of flow demanded by the downstream system being at or above the predetermined low threshold of flow through the VDP (102).

12. The method as recited in claim 11, wherein the base recirculation rate is zero recirculation flow.

13. The method as recited in any of claims 10 to 12, wherein controlling the BPV (110) to recirculate flow includes governing the bypass flow through the BPV (110) according to

$$BF = PF - DSFD$$

wherein BF is flow through the BPF, PF is flow through the VDP (102), and DSFD is flow demanded by the downstream system supplied by the outlet line.

14. The method as recited in any of claims 10 to 13 , further comprising receiving data from a sensor indicative of position of a valve member of the BPV (110), wherein controlling the BPV (110) includes controlling the BPV (110) based on position of the valve member.

15. The method as recited in any of claims 10 to 14, further comprising receiving data from a sensor indicative of position of a variable displacement mechanism of the VDP (102), wherein controlling displacement includes controlling displacement of the VDP (102) based on position of the variable displacement mechanism.

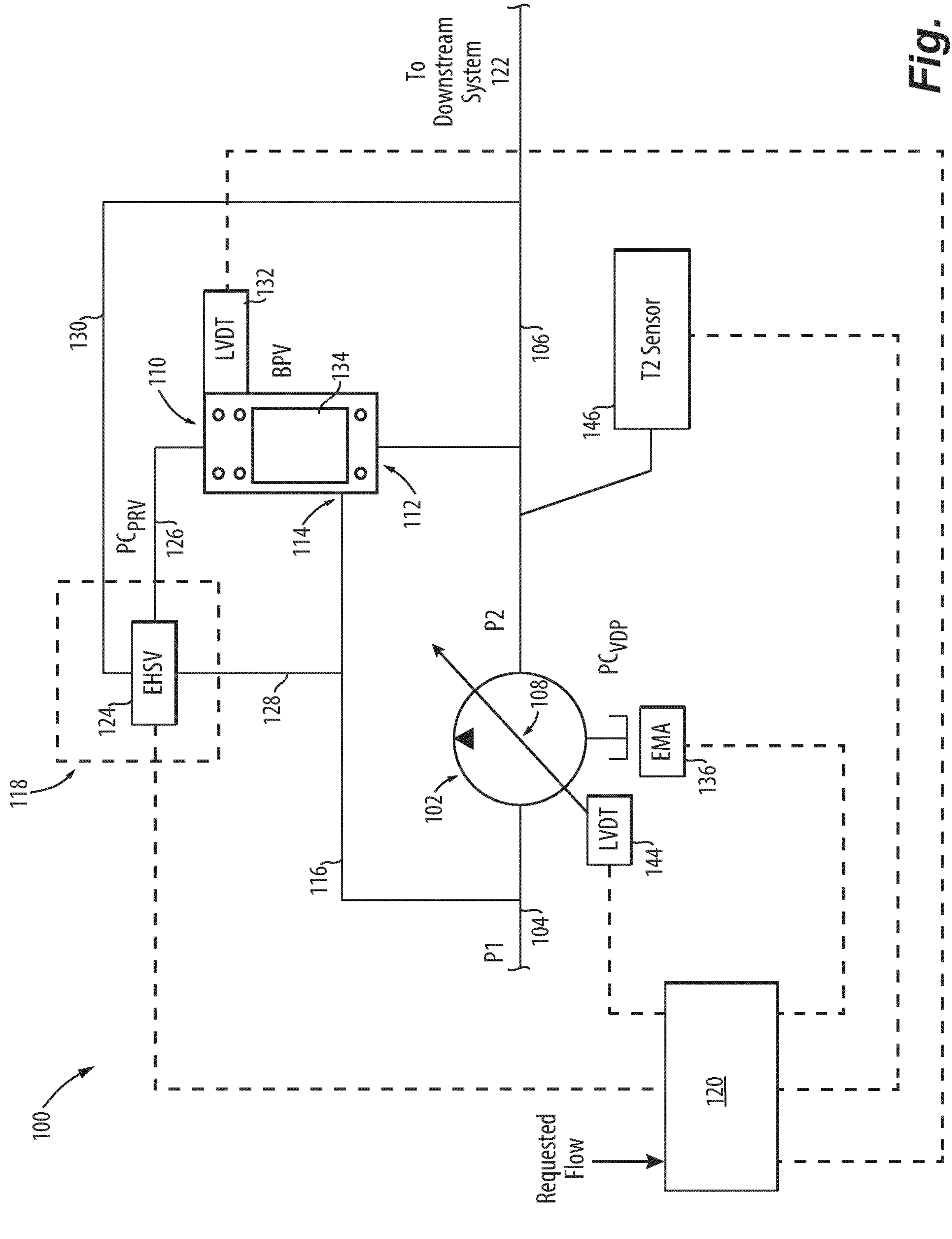
To
Downstream
System
122
130
110
LVDT
132
BPV
134
106
T2 Sensor
146
PC_PRV
126
114
112
118
EHSV
124
128
P2
PC_VDP
108
EMA
136
102
LVDT
144
116
P1
104
100
Requested
Flow
120

Fig. 1

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EUROPEAN SEARCH REPORT

Application Number
EP 24 17 6445

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A,P	EP 4 296 492 A1 (HAMILTON SUNDSTRAND CORP [US]) 27 December 2023 (2023-12-27) * paragraphs [0026] - [0032] * * figure 2 *	1-15	INV. F02C7/22 F02C9/30 F04B49/00 F04B49/06 F02C9/26
A	US 5 806 300 A (VEILLEUX JR LEO J [US] ET AL) 15 September 1998 (1998-09-15) * column 4, line 37 - column 6, line 55 * * figures 1-4 *	1-15	
A	US 2008/289338 A1 (DESAI MIHIR C [US]) 27 November 2008 (2008-11-27) * paragraphs [0022] - [0053] * * figures 1-3 *	1-15	
A	US 2018/372006 A1 (CHALAUD SÉBASTIEN CHRISTOPHE [FR] ET AL) 27 December 2018 (2018-12-27) * paragraphs [0040] - [0100] * * figures 1-5 *	1-15	TECHNICAL FIELDS SEARCHED (IPC)
A	US 2004/200459 A1 (BENNETT GEORGE L [US] ET AL) 14 October 2004 (2004-10-14) * paragraphs [0017] - [0023] * * figure 1 *	1-15	F04B F02K F02C

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	17 September 2024	Gnüchtel, Frank

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 24 17 6445

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17-09-2024

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 4296492 A1	27-12-2023	EP 4296492 A1	27-12-2023
		US 11713724 B1	01-08-2023
US 5806300 A	15-09-1998	CA 2206917 A1	04-12-1998
		DE 19722401 A1	03-12-1998
		GB 2325025 A	11-11-1998
		US 5806300 A	15-09-1998
US 2008289338 A1	27-11-2008	EP 1819914 A2	22-08-2007
		US 2008289338 A1	27-11-2008
		WO 2007044020 A2	19-04-2007
US 2018372006 A1	27-12-2018	FR 3068114 A1	28-12-2018
		US 2018372006 A1	27-12-2018
US 2004200459 A1	14-10-2004	EP 1636476 A2	22-03-2006
		JP 4689598 B2	25-05-2011
		JP 2006523897 A	19-10-2006
		US 2004200459 A1	14-10-2004
		WO 2004092568 A2	28-10-2004

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