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(11) **EP 1 069 312 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
17.01.2001 Bulletin 2001/03

(51) Int. Cl.⁷: **F04B 51/00**

(21) Application number: **00202417.2**

(22) Date of filing: **07.07.2000**

(84) Designated Contracting States:
**AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE**
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **15.07.1999 NL 1012606**

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(54) **Method and device for the evaluation of a hydraulic system**

(57) To evaluate the state of a hydraulic system, particularly a hydraulic aircraft system, one determines, with the system at rest and the pump (8) operating, at inlet (6), outlet (12) and leak outlet (18) of the pump temperature and pressure at those places with the pump operating as a pump with external leak outlet, while measuring the leak flow and operating the pump as a pump with internal leak return, and determines, using the known thermodynamic equations for these states, the pump efficiency and the system leak flow respectively.

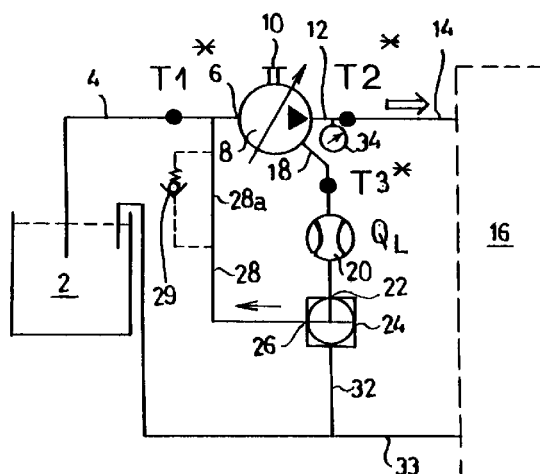


Fig. 1a.

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Description

[0001] The invention relates to a method for determining of a hydraulic system, comprising the combination of a hydraulic excitation pump with an external pump leak outlet and a hydraulic operating circuit connected thereto at least one of the following quantities: pump loss and leakage flow in the excited hydraulic circuit, as well as to a device for effecting such a method.

[0002] To obtain information about the state of a hydraulic system one determines in practice on the one hand the pump losses of the hydraulic excitation pump as used therein and on the other hand the loss in the system, which is excited by said pump. To evaluate the state of the pump it is necessary to remove the pump and to test it on a testing stand and to evaluate the system it is necessary to connect between the the pump outlet and the inlet of the system a volume flow meter for measuring the leak losses in the excited system. When one does not want to change meters this volume flow meter must not only be able to show the, important, volume flow which occurs during the operation of the system but this meter must also be able to show accurately the small system leak flow which is present at rest state, and which is between 2 and 10 of the maximum output flow. These two requirements are difficult to combine. The invention aims to provide a method and a device for executing the method as defined hereinabove by means of which the quantities which are of importance for judging the state of a hydraulic system can be determined without the necessity to remove the pump or to use a volume flow meter which must satisfy two, mutually contrary, requirements.

[0003] This aim is obtained by the invention in that one:

records temperature and pressure of the hydraulic medium at respectively pump inlet, pump outlet and pump leak outlet under each of the following conditions:

1) pump leak outlet connected to the system return conduit or the environment, combined with a determination of the leak flow under these circumstances, and

2) pump leak outlet directly connected to the pump inlet upwardly of the temperature recording position thereof, or pump leak outlet blocked, and:

assuming that in both cases (1) and (2) respectively the pump efficiency will be equal:

determining the pump efficiency and/or the leak flow of the operating circuit respectively from on the one hand the measured leak flow and on the other hand the thermodynamic relations between these quantities and the enthalpy and entropy values of the hydraulic medium as used on the other hand, as derived from the recorded values of temperature and pressure.

[0004] The method according to the invention is determined in more detail in claim 2.

[0005] The invention furthermore relates to a device for effecting the method as described hereinabove, such as defined in the claims 3-5.

[0006] The invention is thus based on the insight that the hydraulic fluid (of which the properties must be known) is used as information bearer using the thermodynamic processes such as occurring at the pump. By means of the known thermodynamic interrelations pump loss and system leakage are determined. This interrelations are described in the publications of the inventor (Dr. Ing. K. Witt) in "Ölhydraulik und Pneumatik", 1976-1977, combined in the publication "Thermodynamisches Messe" in der Ölhydraulik" (published by the "Instituut voor Aandrijftechniek", TU Eindhoven), particularly 21(1977) no. 3, page 162.

[0007] The method and device according to the invention have the important advantage that the implementation thereof requires only three temperature sensors (at the pump inlet, at the pump outlet and at the pump leakage outlet) and, starting from the presumption that both the pressure at the inlet respectively the pressure at the leakage outlet are equal to the pressure of the surrounding air, only one extra pressure sensor. The necessary volume flow meter connected to the pump leakage outlet must only be able to show only a small flow. Finally only a two-way valve with a connection to the pump inlet, or a simple shut-off valve connected to the pump leakage outlet are required.

[0008] Registration of temperature and pressure and measuring the pump leakage flow can be done before and after the starting up and shutting down respectively of a hydraulic installation. More particular this means that, when method and device are used in a system such as a hydraulic aircraft system, the state thereof can be monitored permanently and the result of this monitoring action can be stored. This results into a "case history" and at each moment one has an insight in the state of the installation as it is, without the necessity of any removal of any component.

[0009] The invention is elucidated on the hand of the drawing. Herein shows:

fig. 1a a first hydraulic diagram,
fig. 1b a second hydraulic diagram,
fig. 1c the entropy-enthalpy curves of the hydraulic medium,

fig. 2a a second hydraulic diagram,
fig. 2b the enthalpy-entropy curves thereof.

[0010] Fig. 1a shows a hydraulic system with a storage tank 2, filled with a hydraulic fluid of which the physical properties are exactly known. Via the conduit 4 this tank is connected to the inlet 6 of a hydraulic pump 8, of which the shaft 10 is driven by a driving motor, not shown. The outlet 12 of the pump 6 is via the conduit 14 connected to a hydraulic system which is schematically indicated by the broken lines 16, and which is for instance an aircraft system as known as in itself with, for instance, various actuators driving the flight controls. The pump 8 has, as known in itself, a pump leak outlet 18 which is connected via a volume flow meter 20 - which needs only be able to show a small flow - to the inlet 22 of the two-way valve 24. This two-way valve 24 has two outlets: the first, 26, is connected via the conduit 28 to the pump inlet 6 (and more particularly the position where the temperature (T1) of the inlet medium is measured) and the second, 30, leads via the conduit 32 to the system return conduit 33 which ends in the tank 2.

[0011] In the conduit 28, between the outlet 26 of the two-way valve and the pump inlet 6, a non-return valve 29 can be inserted which opens in the direction of the pump inlet. In that case the part 28a of the conduit is omitted.

[0012] Fig. 1b shows a diagram which closely resembles the one of fig. 1a, but here the volume flow meter 20 is not connected to a two-way valve, but to a simple shut-off valve 25. When the shut-off valve 25 is closed the pump 8 operates as a pump without external leak outlet - there are hydraulic pumps, particularly the ones used in hydraulic aircraft installations, which can be operated with a closed leak outlet for a short time.

[0013] However it is also possible that the pump leak outlet is connected to the pump inlet 6 via conduit 31 and the non-return valve 28', thus behind the volume flow meter 20.

[0014] Fig. 2a shows the situation in which the pump leak outlet 18 is connected, via the two-way valve 24, with the system return conduit 32.

[0015] Temperature and pressure of the hydraulic medium are recorded or measured respectively at three points:

- directly before the inlet 6 of pump 8 temperature (T1) and pressure (P1) of the medium passing this point are recorded. When the system is an "open system" the pressure P1 is known: it is the ambient pressure. The temperature is measured with the temperature sensor 9.
- Directly at the outlet 12 of said pump temperature (T2) and pressure (P2) of the medium which leaves the pump and enters the hydraulic system 16 are recorded. The temperature is measured with the temperature sensor 11; the pressure is measured by means of the pressure sensor 34.
- At the pump leak outlet 18 temperature (T3) of the medium which leaves this outlet is measured with the sensor 19. As the pump leak outlet 19 is connected, via the volume flow meter 20, with either the pump inlet 6 or the return conduit 32 the pressure P3 will be, in fact, equal to the ambient pressure.

[0016] The situations according to fig. 1a and 1b respectively thus, in fact, correspond with same of a pump without an external leak outlet, thus with only an inlet (6) and an outlet (12). It is known that for such a pump the pump efficiency η_T is given by the following relation:

$$\eta_T = \frac{h_2^* - h_2'^*}{h_2^* - h_2^*} \quad (1)$$

[0017] Herein is:

h_1^* = enthalpy of the hydraulic medium at the pump inlet with temperature T1 and pressure P1,
 h_2^* = enthalpy of the hydraulic medium at the pump outlet with temperature T2* and pressure P2*,
 $h_2'^*$: enthalpy of the hydraulic medium as obtained from the entropy-enthalpy diagram in the way as shown in fig. 1c:
the entropy-enthalpy diagram of a hydraulic medium is known from its physical properties. Fig. 1c and fig. 2b respectively give an example of the entropy-enthalpy diagram of a hydraulic medium used in the system according to the figs. 1a and 1b. Such an entropy-enthalpy diagram comprises lines of constant pressure - some of which are shown in fig. 1c and 2b respectively, indicated with Pa..Pd.-, as well as lines of constant temperature, some of which are shown in fig. 1c and 2b respectively and are indicated with Ta..Ti. For each combination of pressure and temperature of the hydraulic medium results from the entropy-enthalpy diagram a value of both the enthalpy and the entropy.

[0018] From the values of temperature (T1) and pressure (P1) as measured at the inlet 6 results in the entropy-enthalpy diagram the point 1* and therefrom the value of h_1^* which is to be used in equation (1); in a similar way results

from the value of T_2^* and P_2^* results the value of h_2^* . h_2^* is determined by drawing, starting from the point 2^* in the diagram of fig. 1a (which relates to T_2^* and P_2^*) a line perpendicular to the horizontal (entropy) axis, thus a line representing points of equal entropy, determining the intersection of this line with the line of constante pressure (P_a), corresponding with poin 1. This intersection, indicated with $2''$, is then the required value of the enthalpy h_2'' .

[0019] In the preceding discussion the quantities and values respectively, indicated with an asterisk, are those which are measured when het pump leak outlet is either returned to the pump inlet 6 (fig. 1a) or is blocked (fig. 1b). This situation is, in fact, the situation of a pump without external leak outlet and in both these cases the pump efficiency η_T is given by the preceding equation (1).

[0020] Thus η_T is known.

[0021] A second measurement is effected with the pump outlet 8 connected to the return conduit of the system; this is the situation during the normal use of a hydraulic system, be it with the addition that now in the connection between the pump leak outlet 18 and the return conduit 33 a volume flow meter is connected.

[0022] Fig. 2a and the entropy-enthalpy diagram according to fig. 2b relate to this situation: the leak outlet 18 of the pump 8 is connected directly via conduit 32 to the return conduit 33. It is known that in such a case the pump efficiency η_T is given by the following equation:

$$\eta_T = \frac{h_2 - h_2'}{h_2 - h_1 + \frac{M_L}{M_S} (h_3 - h_1)} \quad (2)$$

[0023] The values h_1 and h_2 in this equation (2) are again determined from T_1 , P_1 and T_2 , P_2 respectively; (in the way as described hereinabove) h_2' follows from the entropy-enthalpy diagram while h_3 represents the enthalpy of the hydraulic medium at the pump leak outlet, such as determined by T_3 and P_3 . Equation (2) further comprises the following quantities:

M_L = the mass hydraulic medium per time unit, discharged via the pump leak outlet, and
 M_S = the mass hydraulic medium per time unit, fed into the system.

[0024] The two equations (1) and (2) respectively are, in fact, two equations with two unknown factors: η_T on the one hand and M_S on the other hand.

[0025] Solved to M_S results into:

$$M_S = \frac{M_L \eta_T (h_3 - h_1)}{(h_2 - h_2') \eta_T (h_2 - h_1)} \quad (3)$$

[0026] η_T is known from (1) and can thus be introduced in equation (3). The volume flow meter 20 measures Q_L and from Q_L follows directly M_L , because: $M_L = Q_L \cdot p$, in which p represents the specific mass of the hydraulic medium. So M_L , too, can be introduced into (3). In this way the system leak, M_S , is determined.

[0027] This value of the system leak yields information about the state of the hydraulic system when excited by the pump.

[0028] The power loss P_v of the power pump results from the difference between the supplied power and the discharged power and is given by:

$$P_v = (P_2 - P_1) Q_s \left(\frac{1}{\eta_T} - 1 \right) \quad (4)$$

Claims

1. Method for determining of a hydraulic system, comprising the combination of a hydraulic excitation pump with an external pump leak outlet and a hydraulic operating circuit connected thereto at least one of the following quantities: pump loss and the one hand and leakage flow of the excited hydraulic circuit on the other hand, in which one:

records temperature and pressure of the hydraulic medium at respectively pump inlet, pump outlet and pump leak outlet under each of the following conditions:

1) pump leak outlet connected to the system return conduit or the environment, combined with a determination of the leak flow occurring under these circumstances, and

2) pump leak outlet directly connected to the pump inlet upstream of the temperature recording position thereof, or pump leak outlet blocked, and:

assuming that in both cases (1) and (2) respectively the pump efficiency will be equal: determining the pump efficiency and/or the leak flow of the operating circuit respectively from on the one hand the measured leak flow and on the other hand the thermodynamic relations between these quantities and the enthalpy and entropy of the hydraulic medium as used, as derived from the recorded values of temperature and pressure.

2. Method according to claim 1, **characterized** in that one assumes that the pump efficiency in the case in which the leak outlet is connected to the pump inlet is equal to the pump efficiency when the leak outlet is blocked and is in both cases defined by the following equation:

$$\eta_T = \frac{h_2^* - h_2'^*}{h_2^* - h_2^*} \quad (1)$$

said pump efficiency being equal to the pump efficiency with the pump leak outlet connected to the system return conduit or with the environment, and as defined by the following equation:

$$\eta_T = \frac{h_2 - h_2'}{h_2 - h_1 + \frac{M_L}{M_S} (h_3 - h_1)} \quad (2)$$

and derives from these equations the pump efficiency (η_T) on the one hand, and the system mass leak flow (M_S) on the other hand, determining the various quantities as follows:

h_1^* , h_1 resp. = enthalpy of the hydraulic medium at the pump inlet, resulting from temperature (T_1) and pressure (P_1) at that place;

h_2^* , h_2 resp. = enthalpy hydraulic medium at the pump outlet, resulting from temperature (T_2^* , T_2 resp.) and pressure (P_2^* , P_2 resp.) at that place;

h_3 = enthalpy hydraulic medium at the pump leak outlet, resulting from temperature (T_3) and pressure (P_3) at that place;

$h_2'^*$ and h_2 resp. = value of the enthalpy determined by constructing in the entropy-enthalpy diagram of the hydraulic medium, starting from h_2 , for a constant entropy value, the intersection with the curve of constant pressure which goes through both h_1 and h_3 ;

M_L = mass leak flow of the pump leak outlet

M_S = mass leak flow hydraulic system, excited and at rest.

3. A device for determining from a hydraulic system, which comprises the combination of an exciting pump with external pump leak outlet and a hydraulic operating system connected with the outlet thereof at least one of the quantities: pump loss power and leak flow of the excited operating circuit respectively, **characterized** by a volume- or mass flow meter of which the inlet is connected to the pump leak outlet and of which the outlet is connected to the inlet of a two-way valve, the one outlet of which is connected to the pump inlet and the other outlet is connected to

the system return conduit or the environment, and by means to record temperature and pressure of the hydraulic medium at pump inlet, pump outlet and pump leak outlet.

- 5 4. Device for determining from a hydraulic system, which comprises the combination of an exciting pump with external pump leak outlet and a hydraulic operating system connected with the outlet thereof at least one of the quantities: pump loss power and leak flow of the excited operating circuit respectively, **characterized** by a volume- or mass flow meter, connected into the pump leak outlet in series with a shut-off valve, and by means to record temperature and pressure of the hydraulic medium at the pump inlet, pump outlet and pump leak outlet.
- 10 5. Device according to claim 3-4, **characterized** by a non-return valve, connected into in the conduit between the outlet of the volume- or mass flow meter and the pump inlet, and opening in the direction of the pump inlet.

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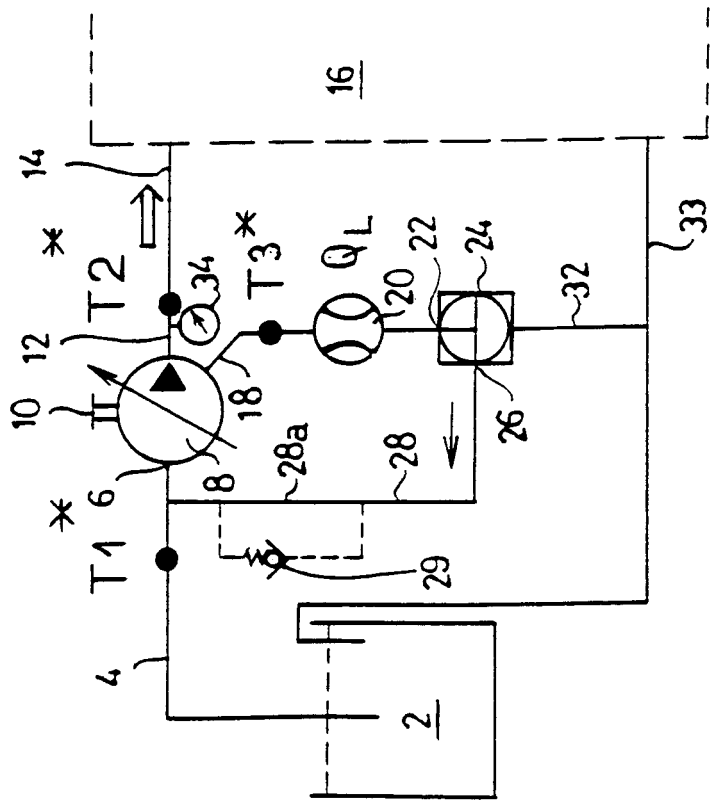


Fig. 1a.

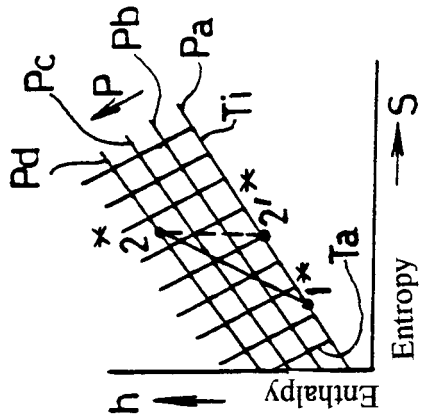


Fig. 1c.

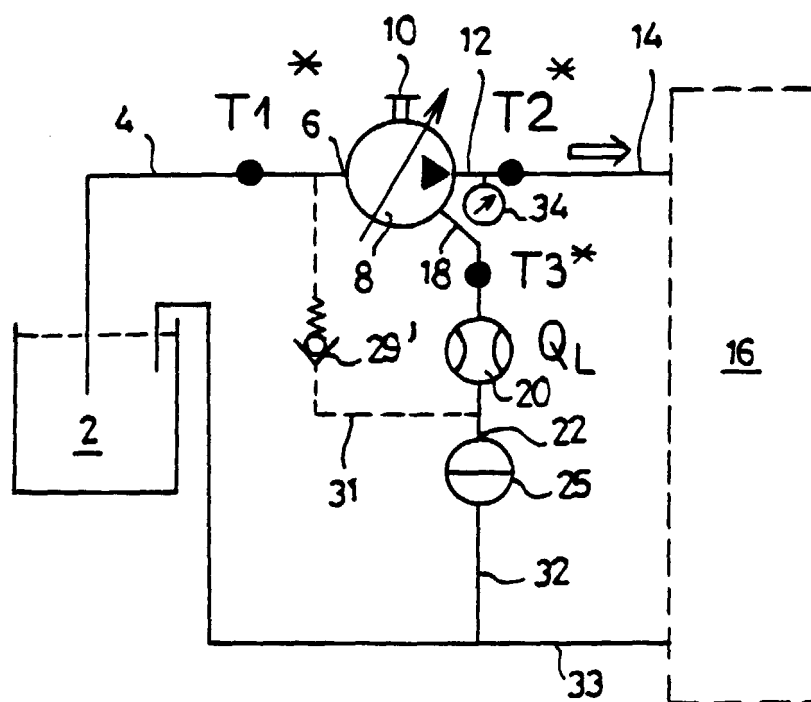


Fig. 16.

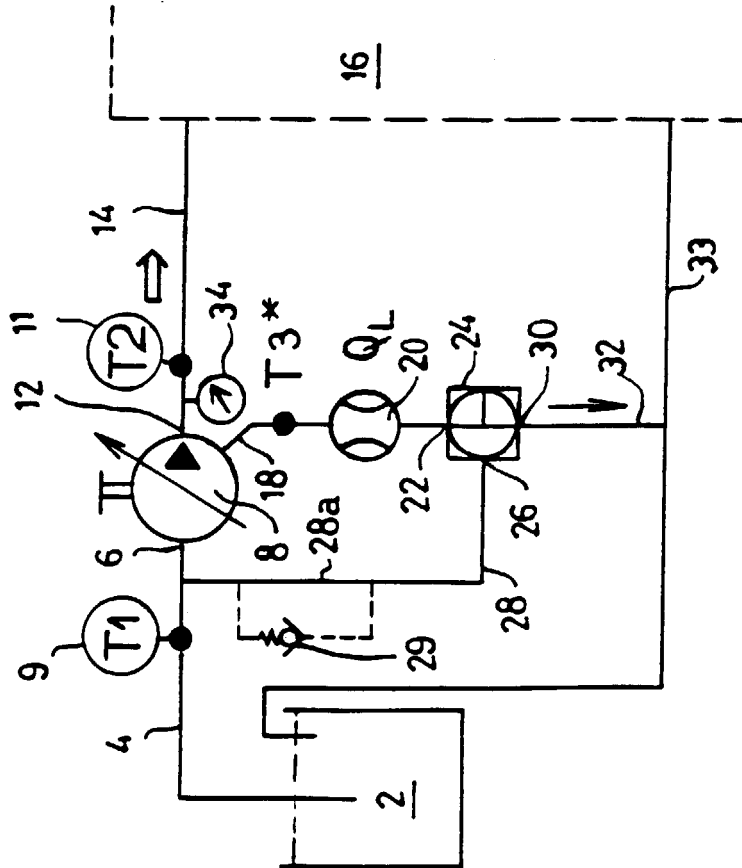


Fig. 2a.

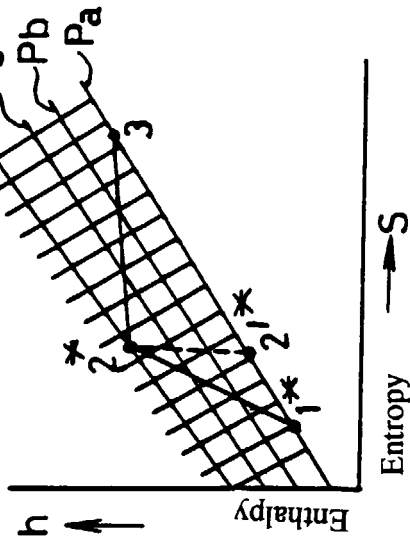


Fig. 2b.



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EUROPEAN SEARCH REPORT

Application Number
EP 00 20 2417

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
D,Y	WITT K.: "Thermodynamisches Messen in der Ölhdraulik" ÖLHYDRAULIK UND PNEUMATIK, vol. 20, no. 3 e.v., 1 September 1976 (1976-09-01) - 1 January 1978 (1978-01-01), pages 20.603-22.36, XP002131924 Mainz * the whole document * * page 21.95; figure 13; example 1; table 3 * * page 21.161; examples J,K; table 1 * * page 21.161, column 3, paragraph 2.2 - page 21.163, column 3, paragraph 3; figure 10 * * page 21.858, column 3, paragraph 2.1 - page 21.859, column 3, paragraph 1 *	1-5	F04B51/00
Y	US 5 628 229 A (MILLER DEAN E ET AL) 13 May 1997 (1997-05-13) * the whole document * * column 4, line 34 - column 5, line 28; claims 5-18; figure 5 *	1-5	TECHNICAL FIELDS SEARCHED (Int.Cl.7)
A	FR 2 372 422 A (HOFFLINGER WERNER) 23 June 1978 (1978-06-23) * the whole document *	1-5	F04B G01M G01L
A	DE 25 57 044 A (HOEFFLINGER WERNER DIPL ING) 23 June 1977 (1977-06-23) * the whole document *	1-5	
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 4 October 2000	Examiner Ingelbrecht, P
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 00 20 2417

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04-10-2000

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5628229 A	13-05-1997	DE 19512154 A	05-10-1995
		JP 7294365 A	10-11-1995
FR 2372422 A	23-06-1978	DE 2654307 A	01-06-1978
		CH 601782 A	14-07-1978
		DD 128773 A	07-12-1977
		GB 1519276 A	26-07-1978
		JP 53069901 A	21-06-1978
		SE 7703050 A	31-05-1978
DE 2557044 A	23-06-1977	NONE	

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