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(54) **A permanent magnet enhanced electromagnetic valve actuator**

(57) An electromagnetic valve actuator (10) for actuating movement of a valve (12) in a vehicle engine is disclosed.

The actuator (10) includes a valve assembly operatively connected to the valve for movement therewith. The valve assembly includes a shaft (14) connected to the valve (12), two armature plates (16,18) operatively associated with the shaft (14) each armature plate

(16,18) having a permanent magnet as an integral part. An electromagnetic coil (24) is positioned between the two armature plates (16,18) for electromagnetically pushing and pulling the armature plates (16,18) and two springs (26,28) are engaged with the two armature plates (16,18) for biasing them in opposing directions. The permanent magnets are used to assist the electromagnetic coil (24) in holding the valve (12) in a desired position to reduce power consumption.

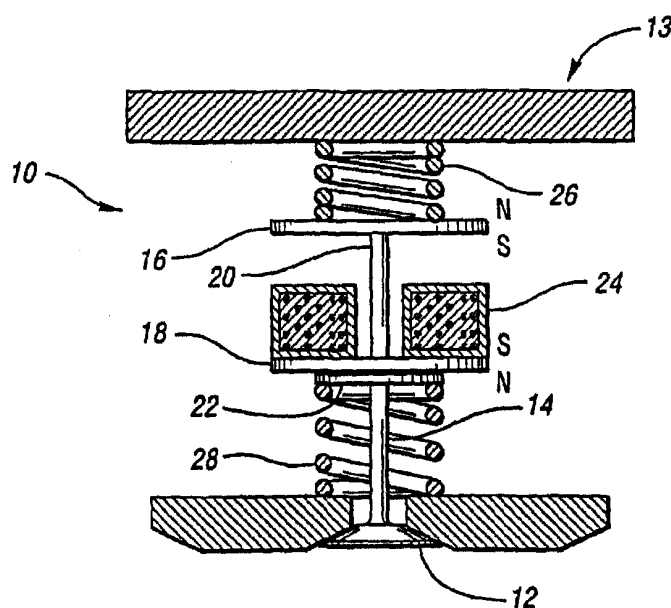


Fig. 1

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Description

[0001] The present invention relates to an electromagnetic valve actuator and in particular to an electromagnetic valve actuator for opening and closing a valve in a vehicle engine.

[0002] In a vehicle engine, a valve is controlled to open and close so that a cylinder may perform intake, compression, expansion, and exhaust operations.

[0003] In one example of a drive apparatus for opening and closing valves, a camshaft, which is configured by disposing cams for valve opening and closing on one shaft, is provided on the upper portion of the engine or on one side face thereof. A crankshaft, which translates the piston motion to rotational motion, and the camshaft which operates the valves are connected by means such as a belt or chain. The camshaft is driven in synchronism with the crankshaft of the engine. The valves are opened by the cam lobes on the camshaft via a link mechanism such as a rocker arm or push rod. The valve normally is held in the closed position by a spring.

[0004] In another example of a drive apparatus for opening and closing an intake exhaust valve, an intake camshaft having an intake valve opening profile, and an exhaust camshaft having an exhaust valve opening profile are disposed on the upper portion of an engine, the cam lobe of the intake camshaft pushes the axial end face of the intake valve directly, and the cam lobe of the exhaust camshaft pushes the axial end face of the exhaust valve directly, thereby opening the intake/exhaust valve.

[0005] This conventional drive apparatus for opening and closing the intake/exhaust valve results in an increase in engine size because the camshaft and link mechanism must be added onto the engine. Furthermore, since the camshaft and link mechanism are driven by the output shaft (crankshaft) of the engine, some of the engine output is consumed by frictional resistance when the camshaft and link mechanism are driven. This reduces the effective output of the engine.

[0006] Further, the actuation timing of the intake/exhaust valve is fixed and cannot be altered during engine operation. Hence, the valve actuation timing is a compromise between low and high engine rpm. As a consequence, the engine output torque is not optimum neither at low nor at high engine rpm.

[0007] In order to solve the foregoing problems, various systems for driving an intake/exhaust valve to open and close the same by electromagnetic force from an electromagnet, without relying upon a camshaft, have been proposed, such as in U.S. Patent Nos. 4,955,334 and 4,829,947. These patents teach the use of a single armature plate which is movable by a pair of electromagnetic coils positioned on opposing sides of the plate.

[0008] It is an object of this invention to provide an improved electromagnetic valve actuator.

[0009] According to a first aspect of the invention there is provided an electromagnetic valve actuator for

actuating movement of a valve in a vehicle engine characterised in that the actuator comprises a valve actuator assembly, an electromagnetic coil and two springs, the valve actuator assembly comprising a shaft connected to the valve and two armature plates operatively connected to the shaft for movement therewith wherein the electromagnetic coil is positioned between the two armature plates for electromagnetically pushing and pulling the armature plates and each of the two springs is engaged with a respective one of the two armature plates for biasing the armature plates in opposing directions and that each armature plate includes a permanent magnet operative to assist the electromagnetic coil in holding the valve in a desired position to reduce power consumption.

[0010] One of the armature plates may be operatively connected to the shaft via abutment with a plate fixed to the shaft, the armature plate being slidably engaged with the shaft.

[0011] One of the armature plates may be fixed directly to the shaft.

[0012] Advantageously, in order to control braking of the valve, the polarity of the electromagnetic coil may be selectively reversed near to open and closed positions of the valve so as to reduce valve landing speed.

[0013] Each of the permanent magnets may be a permanent magnet sheet connected to a ferromagnetic plate.

[0014] The permanent magnets may be arranged such that like poles face the electromagnetic coil.

[0015] According to a second aspect of the invention there is provided a method of controlling an electromagnetic valve actuator as claimed in any of claims 1 to 4 characterised in that the method comprises selectively energising the electromagnetic coil positioned between the two armature plates to push and pull the armature plates to affect opening and closing movement of the valve.

[0016] Said energising step may comprise providing a negative current to bias the armature plates in one direction, and a positive current to bias the armature plates in an opposite direction.

[0017] Said energising step may further comprise reducing the current to the electromagnetic coil as the valve approaches a closed position to minimise the closing force and to soften landing.

[0018] The method may further comprise reversing the current to the electromagnetic coil for a short period of time as the valve approaches a closed position to reduce landing velocity.

[0019] The method may further comprise reducing the current used to hold the valve in the open and closed positions by utilising the permanent magnets to assist in holding the valve in the open and closed positions.

[0020] According to a third aspect of the invention there is provided an internal combustion engine having two or more reciprocating valves wherein at least one of the reciprocating valves is actuated by an electromag-

netic valve actuator in accordance with the first aspect of the invention.

[0021] The invention will now be described by way of example with reference to the accompanying drawing of which:-

Figure 1 shows a schematic longitudinal cross-sectional view of an electromagnetic valve actuator in accordance with the present invention, with a valve in a closed position;

Figure 2 shows a schematic longitudinal cross-sectional view of the electromagnetic valve actuator assembly of Figure 1, with the valve in an open position;

Figure 3 shows a schematic longitudinal cross-sectional view of the electromagnetic valve actuator of Figure 1, with the valve in a fully open position;

Figure 4 shows a schematic longitudinal cross-sectional view of the electromagnetic valve actuator of Figure 1, with the valve in a nearly closed position; and

Figure 5 shows a graphical illustration of an electromagnetic coil current control scheme to actuate opening and closing of the valve assembly of Figures 1-4 in accordance with the present invention.

[0022] Referring to Figures 1-5, an electromagnetic valve actuator 10 and electromagnetic coil current control scheme are shown for opening and closing a valve 12 for the vehicle engine 13.

[0023] The electromagnetic valve actuator 10 includes a valve actuator assembly connected to the valve 12 for movement therewith.

[0024] The valve actuator assembly includes a shaft 14 and first and second armature plates 16, 18 operatively associated with the shaft 14 for moving the shaft 14 and the valve 12.

[0025] As shown in Figure 1 a shaft 20 connects the first and second armature plates 16,18 together, such that the second armature plate 18 is engageable with a plate 22 connected to the shaft 14, for driving the shaft 14 and the first armature plate 16 is directly fixed to the shaft 14.

[0026] More specifically the armature plate 18 is operatively connected to the shaft 14 via abutment with the plate 22 which is fixed to the shaft 14.

[0027] The armature plate 18 is slidably engaged with the shaft 14 and the system must have "lash" or clearance between valve shaft 14 and the armature plate 18 to ensure that the poppet valve 12 can fully seat or close.

[0028] Each armature plate 16, 18 includes a permanent magnet in the form of a permanent magnet sheet connected to a ferromagnetic plate.

[0029] An electromagnetic coil 24 is positioned be-

tween the two armature plates 16,18 for electromagnetically pushing and pulling the armature plates 16,18.

[0030] First and second springs 26,28 are engaged with the two armature plates 16,18 for biasing the armature plates 16,18 in opposing directions.

[0031] The actuation of the actuator 10 is described below.

[0032] In Figure 1, the fixed electromagnetic coil 24 is holding the lower armature plate 18 to compress the upper spring 26. The lower spring 28 then expands to close the valve 12.

[0033] The plates 16,18 use permanent magnets with a North-South (N-S, top-to-bottom) configuration in the upper plate 16 and a South-North (top-to-bottom) configuration in the lower plate 18 so that like poles face the electromagnetic coil 24.

[0034] In this position, a negative holding current is applied to the coil 24, as shown in Figure 5 (see "A" in Figure 5), giving the electromagnetic coil 24 a North pole on its lower surface (as viewed in Figure 1), thereby enhancing the closing force by pulling on the South pole of the lower armature plate 18. This ultimately reduces the electrical power required to hold the valve 12 in the closed position, and therefore reduces fuel consumption.

[0035] Referring to Figure 2, when the valve opens, the current in the electromagnetic coil 24 is reversed (see "B" in Figure 5) so that the electromagnet 24 has South pole on its lower surface. This creates an opposing force between the electromagnet and the lower armature plate 18 which supplements the opening force normally provided by the upper spring 26.

[0036] Additionally, the positive coil current creates an attractive force between the North pole of the upper surface of the electromagnet 24 and the South pole of the upper armature plate 16. This increases the opening speed of the valve 12, and therefore improves the volumetric efficiency of the engine at higher speeds. As the valve approaches the full open position, the current is reduced (see "C" in Figure 5) to minimize the closing force and soften the abutment or landing of the upper armature plate 16 on the coil 24.

[0037] If the armature speed and inertia are high, a negative current (see "D" in Figure 5) may be applied to the coil 24 for a short time to further reduce the abutment or landing velocity to a level below that possible for an armature without permanent magnets.

[0038] Referring to Figure 3, when the valve reaches the fully open position, the current is held at a positive level (see "E" in Figure 5) where the magnetic forces balance the spring forces. Again, the permanent magnet enhances the force and therefore reduces the electrical power required to hold the valve 12 open.

[0039] Referring to Figure 4, the valve closing process is similar to the opening process. The coil current is reversed (see "F" in Figure 5) to create a South pole on the upper surface of the electromagnet 24 (as viewed in the Figures). This repels the South pole of the upper

armature plate 16. The North pole on the lower surface of the coil 24 attracts the South pole on the lower armature plate 18. The additional attractive and repulsive forces created by the permanent magnets supplement the closing force provided by the lower spring 28.

[0040] As the valve approaches the full closed position, the current magnitude is reduced (see "G" in Figure 5) to minimize the closing force and soften the landing of the upper armature plate 16 on the coil 24. If the armature speed and inertia are high, a positive current (see "H" in Figure 5) may be applied for a short time to further reduce the landing velocity.

[0041] The control scheme is shown in Figure 5 in which the dashed line indicates valve position, and the solid line indicates the current through the electromagnetic coil 24.

[0042] Those familiar with the art to which this invention relates will recognise that the embodiment disclosed herein is only one way of exploiting the invention and that various alternative designs and embodiments for practicing the invention can be envisaged without departing from the scope of the invention.

Claims

1. An electromagnetic valve actuator (10) for actuating movement of a valve (12) in a vehicle engine **characterised in that** the actuator (10) comprises a valve actuator assembly, an electromagnetic coil (24) and two springs (26,28), the valve actuator assembly comprising a shaft (14) connected to the valve (12) and two armature plates (16,18) operatively connected to the shaft (14) for movement therewith wherein the electromagnetic coil (24) is positioned between the two armature plates (16,18) for electromagnetically pushing and pulling the armature plates (16,18) and each of the two springs (26,28) is engaged with a respective one of the two armature plates (16,18) for biasing the armature plates (16,18) in opposing directions and that each armature plate (16,18) includes a permanent magnet operative to assist the electromagnetic coil (24) in holding the valve (12) in a desired position to reduce power consumption.

2. An actuator as claimed in claim 1 wherein, in order to control braking of the valve (12), the polarity of the electromagnetic coil (24) is selectively reversed near to open and closed positions of the valve (12) so as to reduce valve landing speed.

3. An actuator as claimed in claim 1 or in claim 2, wherein each of the permanent magnets is a permanent magnet sheet connected to a ferromagnetic plate.

4. An actuator as claimed in any of claims 1 to 3 where-

in the permanent magnets are arranged such that like poles face the electromagnetic coil (24).

5. A method of controlling and electromagnetic valve actuator as claimed in any of claims 1 to 4 **characterised in that** the method comprises selectively energising the electromagnetic coil (24) positioned between the two armature plates (16,18) to push and pull the armature plates (16,18) to affect opening and closing movement of the valve (12).

6. A method as claimed in claim 5 wherein said energising step comprises providing a negative current to bias the armature plates (16,18) in one direction, and a positive current to bias the armature plates (16,18) in an opposite direction.

7. A method as claimed in claim 5 or in claim 6 wherein said energising step further comprises reducing the current to the electromagnetic coil (24) as the valve (12) approaches a closed position to minimise the closing force and to soften landing.

8. A method as claimed in any of claims 5 to 7 wherein the method further comprises reversing the current to the electromagnetic coil (24) for a short period of time as the valve approaches a closed position to reduce landing velocity.

9. A method as claimed in any of claims 5 to 8 wherein the method further comprises reducing the current used to hold the valve (12) in the open and closed positions by utilising the permanent magnets to assist in holding the valve (12) in the open and closed positions.

10. An internal combustion engine having two or more reciprocating valves (12) **characterised in that** at least one of the reciprocating valves (12) is actuated by an electromagnetic valve actuator (10) as claimed in any of claims 1 to 4.

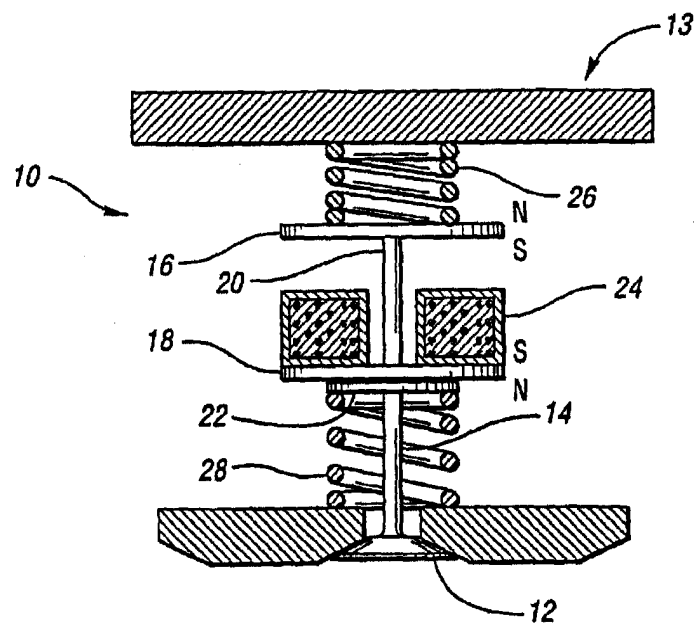


Fig. 1

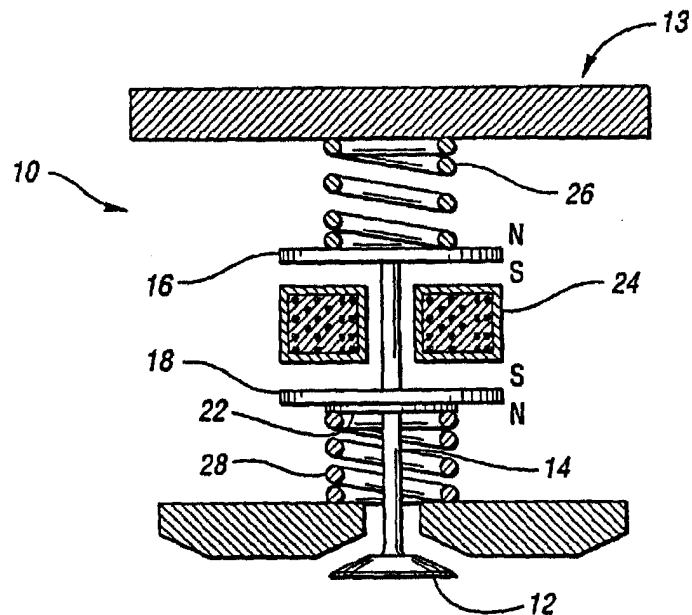


Fig. 2

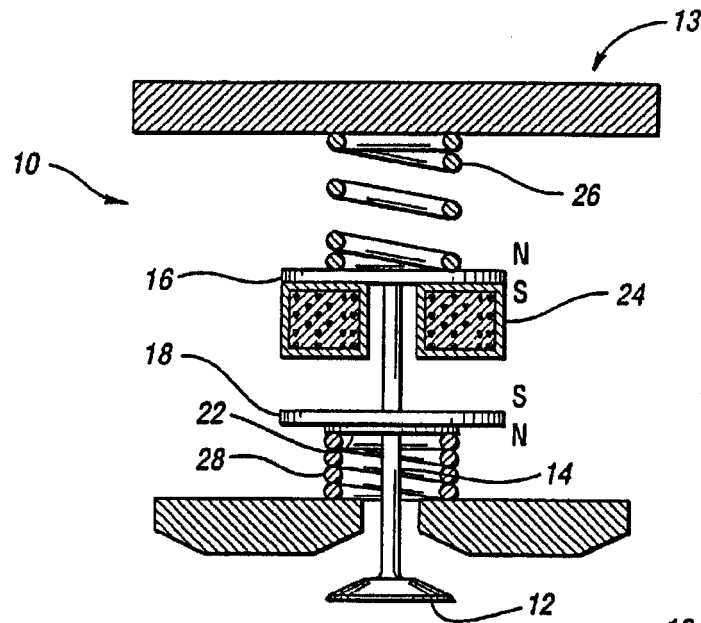


Fig. 3

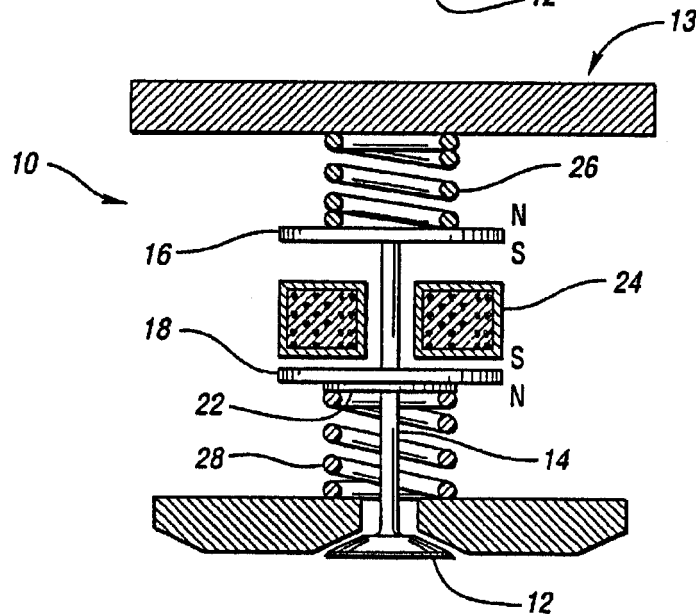


Fig. 4

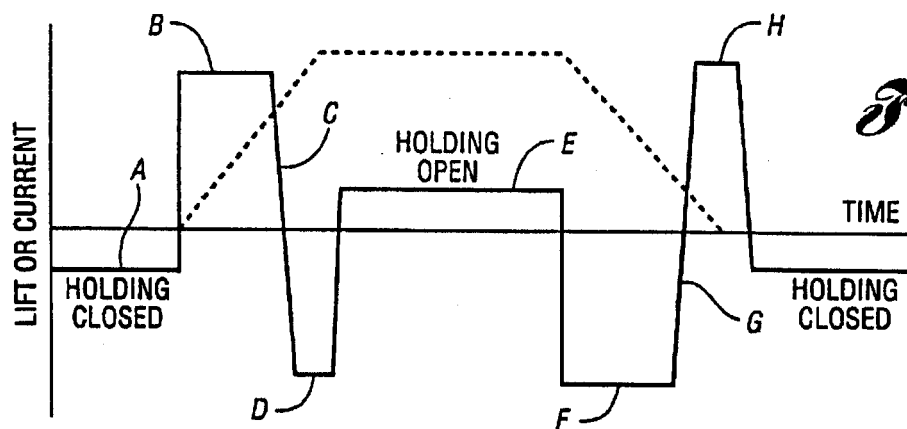


Fig. 5



European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 01 00 0702

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)
Y	US 6 318 312 B1 (BAUER ERWIN ET AL) 20 November 2001 (2001-11-20) * column 3, line 13 - column 3, line 28; figure 1 *	1-3,5-10	F01L9/04
Y	US 3 882 833 A (LONGSTAFF KENNETH ET AL) 13 May 1975 (1975-05-13) * column 1, line 40 - column 1, line 56 * * column 2, line 1 - column 2, line 34; figure 1 *	1-3,5-10	
Y	PATENT ABSTRACTS OF JAPAN vol. 1999, no. 09, 30 July 1999 (1999-07-30) & JP 11 101110 A (NISSAN MOTOR CO LTD), 13 April 1999 (1999-04-13) * abstract *	1,5	
Y	DE 197 12 669 A (DAIMLER BENZ AG) 8 October 1998 (1998-10-08) * claims 1,4; figure 1 *	1,5	
Y	EP 0 376 716 A (ISUZU MOTORS LTD) 4 July 1990 (1990-07-04) * column 4, line 34 - column 4, line 49; claims 1,2 *	1,2,5,6, 8,10	F01L
Y	US 4 533 890 A (PATEL BALKRISHNA R) 6 August 1985 (1985-08-06) * column 3, line 1 - column 3, line 19 * * column 3, line 49 - column 3, line 58; figures 1,2 *	1,5,6,9	
Y	US 5 095 856 A (KAWAMURA HIDEO) 17 March 1992 (1992-03-17) * column 3, line 45 - column 3, line 65 * * column 4, line 3 - column 4, line 12; figure 2 *	1,2,5,8	
		-/--	
The present search report has been drawn up for all claims			
Place of search MUNICH		Date of completion of the search 15 March 2002	Examiner Clot, 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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Application Number
EP 01 00 0702

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)
Y	EP 0 384 663 A (ISUZU CERAMICS RES INST) 29 August 1990 (1990-08-29) * column 5, line 5 - column 5, line 22 *	2,8,10	
Y	US 4 779 314 A (AOKI YOSHIHIRO) 25 October 1988 (1988-10-25) * column 2, line 42 - column 2, line 56; figure 1 *	3	
Y	DE 100 19 739 A (FEV MOTORENTECH GMBH) 30 November 2000 (2000-11-30) * claim 1; figure 4 *	7	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
The present search report has been drawn up for all claims			
Place of search MUNICH		Date of completion of the search 15 March 2002	Examiner Clot, 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			

EPO FORM 1503 03/82 (P04C01)

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

EP 01 00 0702

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15-03-2002

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 6318312	B1	20-11-2001	DE 19926412 A1 EP 1059424 A2	21-12-2000 13-12-2000
US 3882833	A	13-05-1975	GB 1391955 A DE 2335150 A1 FR 2192242 A1 JP 1147028 C JP 50047018 A JP 57038763 B	23-04-1975 24-01-1974 08-02-1974 12-05-1983 26-04-1975 17-08-1982
JP 11101110	A	13-04-1999	NONE	
DE 19712669	A	08-10-1998	DE 19712669 A1	08-10-1998
EP 0376716	A	04-07-1990	JP 1893945 C JP 2181011 A JP 6021531 B DE 68908142 D1 DE 68908142 T2 EP 0376716 A1 US 4955334 A	26-12-1994 13-07-1990 23-03-1994 09-09-1993 25-11-1993 04-07-1990 11-09-1990
US 4533890	A	06-08-1985	NONE	
US 5095856	A	17-03-1992	JP 2181007 A JP 2652802 B2 DE 68913196 D1 DE 68913196 T2 EP 0409996 A1 WO 9007637 A1	13-07-1990 10-09-1997 24-03-1994 19-05-1994 30-01-1991 12-07-1990
EP 0384663	A	29-08-1990	JP 2218808 A JP 2772534 B2 DE 69016223 D1 DE 69016223 T2 EP 0384663 A1 US 5009389 A	31-08-1990 02-07-1998 09-03-1995 24-05-1995 29-08-1990 23-04-1991
US 4779314	A	25-10-1988	JP 1875098 C JP 5082961 B JP 63031103 A AU 598834 B2 AU 7556287 A CA 1299159 A1 CN 87105323 A ,B DE 3723541 A1	26-09-1994 24-11-1993 09-02-1988 05-07-1990 28-01-1988 21-04-1992 03-02-1988 28-01-1988

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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15-03-2002

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4779314 A		ES 2008141 A6	16-07-1989
		GB 2192930 A ,B	27-01-1988
		HK 20192 A	27-03-1992
		KR 9308221 B1	27-08-1993
		NL 8701595 A ,B,	16-02-1988
		SG 6192 G	20-03-1992

DE 10019739 A	30-11-2000	DE 10019739 A1	30-11-2000
		WO 0073635 A1	07-12-2000
		EP 1101016 A1	23-05-2001
		DE 10019745 A1	30-11-2000
		WO 0073634 A1	07-12-2000
		EP 1101015 A1	23-05-2001
		US 6340008 B1	22-01-2002
