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(71) Applicant : **CUMMINS ENGINE COMPANY, INC.**
500 Jackson Street
Columbus Indiana 47201 (US)

(71) Applicant : **TOSHIBA CORPORATION**
1-1, Shibaura 1-chome,
Minato-ku
Tokyo, 105-01 (JP)

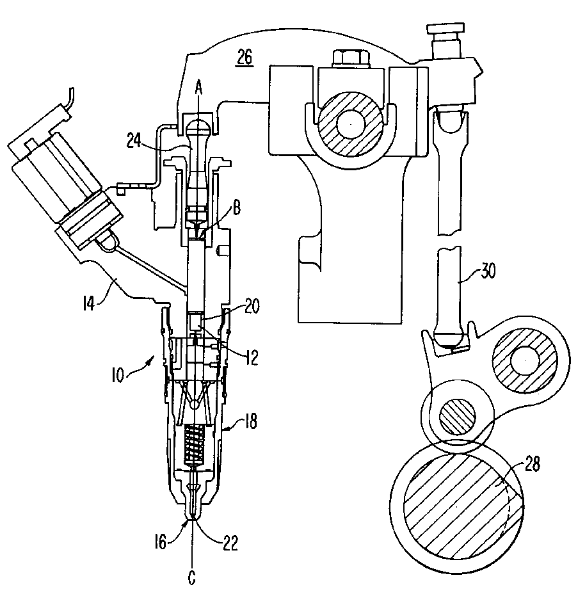
(72) Inventor : **Hickey, Dan K.**
947 Silver Creek Way
Greenwood, Indiana 46142 (US)
Inventor : **Perr, J. Victor**
487 North Graham Road
Greenwood, Indiana 46143 (US)
Inventor : **Rix, David M.**
1492 Lawton Avenue
Columbus, Indiana 47201 (US)
Inventor : **Bentz, Joseph C.**
3530 Oriole Drive
Columbus, Indiana 47203 (US)
Inventor : **Yonushonis, Thomas M.**
4412 Mallard Point
Columbus, Indiana 47201 (US)
Inventor : **Naylor, Malcolm G.**
P.O. Box 93
Jonesville, Indiana 47247 (US)
Inventor : **Shinosawa, Katsuhiro**
1-1 Shibaura, 1-Chome,
Minato-ku
Tokyo 105-01 (JP)
Inventor : **Carroll III, John C.**
730 Carya Square
Columbus, Indiana (US)

(74) Representative : **Patentanwälte Gesthuysen, von Rohr & Weidener**
Postfach 10 13 54
D-45013 Essen (DE)

(54) Ceramic fuel injector timing plunger.

(57) A wear and scuff-resistant timing plunger (12) for a timing assembly in a unit fuel injector (10) for an internal combustion engine is provided. The timing plunger (12) is formed of a high thermal expansion ceramic with a thermal expansion coefficient greater than $6x10^{-6}/°C$ and a hardness greater than 800 Kg/mm^2, which maintains a desired diametral clearance and efficient plunger function without scuffing or sticking under the axial, tangential and pressure loads encountered in the fuel injector operating environment. Preferred high thermal expansion ceramics are zirconia, alumina-zirconia and alumina.

FIG. 1



EP 0 683 314 A1

Technical Field

The present invention is directed generally toward timing plungers for fuel injectors and particularly to a scuff-resistant high performance fuel injector timing plunger made of a ceramic material.

Background of the Invention

Fuel injector timing plungers are required to operate under extremely adverse environmental conditions in a fuel injector assembly. Heavy mechanical loads are applied to the timing plunger in both axial and tangential directions. The plunger must reciprocate within a bore in the injector body that is often distorted so the original diametral clearance is not maintained, and the timing plunger is forced against the bore wall during injector operation, resulting in scuffing. Additionally, low quality and contaminated fuels contribute to the creation of an adverse timing plunger operating environment.

The timing plunger material has been modified throughout the years in an effort to make a timing plunger that is both scuff-resistant and wear-resistant and capable of functioning as required under the adverse conditions of the fuel injector environment. However, third body debris interferes with efficient injector function. Third body debris includes particles harder than the plunger or injector body bore which are not intended to be present within the injector. These particles become embedded into the timing plunger surface and ultimately cause the plunger and body to be wedged together so that the plunger cannot reciprocate in the injector body bore and becomes friction welded. The reduction of fuel lubricity, which could be caused by water contamination of the fuel, and may be a characteristic of some alternative fuels, is also a factor contributing to the friction welding of the timing plunger and injector body together. Injector operation is, of course, prevented if this occurs.

The prior art has proposed the use of wear-resistant materials and corrosion-resistant materials to form various structures and components of internal combustion engines. For example, U.S. Patent Nos. 4,794,894 to Gill and 4,848,040 to Bentz are directed to ceramic tipped pivot rods, and U.S. Patent No. 4,806,040 to Gill et al. is directed to a ceramic ball and socket joint. U.S. Patent No. 4,266,729 to Kulke et al. discloses forming an injector valve needle tip and/or disc from a corrosion-resistant material, such as high quality steel, ceramic, or industrial glass. However, neither this are nor any of the prior art of which the inventors are aware addresses the specific problems of fuel injector timing plunger scuffing and sticking which are encountered with available fuel injectors, particularly those used in diesel engines.

The types of fuels increasingly used in diesel engines, particularly fuels with low lubricity, alternative fuels and fuels which may be contaminated with water, require a scuff-resistant fuel injector timing plunger to maintain efficient engine operation. The prior art has failed to provide a fuel injector timing assembly including a timing plunger that is sufficiently scuff-resistant and wear-resistant, particularly when exposed to third body debris and such adverse operating conditions as low lubricity and contaminated fuels to operate efficiently. A need exists for such a fuel injector timing plunger.

Summary of the Invention

It is a primary object of the present invention, therefore, to overcome the disadvantages of the prior art and to provide a fuel injector timing assembly including a scuff-resistant timing plunger for a unit fuel injector for an internal combustion engine powered by diesel fuel.

It is another object of the present invention to provide a fuel injector timing assembly including a timing plunger for a diesel engine capable of operating efficiently in the presence of high axial and tangential loads on the timing plunger.

It is a further object of the present invention to provide a diesel engine fuel injector timing plunger that is wear- and scuff-resistant and maintains an optimum diametral clearance so that it does not stick during fuel injector operation.

It is yet another object of the present invention to provide a reliable fuel injector timing assembly for an internal combustion engine that includes a wear- and scuff-resistant timing plunger reciprocally positioned within an injector body.

The foregoing objects are achieved by providing a fuel injector timing assembly including a timing plunger for a unit fuel injector for a diesel engine operably positioned within an injector body that is wear- and scuff-resistant and maintains a sufficient diametral clearance with the injector body so that the timing plunger reciprocates freely within the unit fuel injector body without sticking even under adverse engine operating conditions. The injector timing plunger is formed from a ceramic material having a thermal expansion coefficient sufficiently correlated to the thermal expansion coefficient of the fuel injector body to provide optimum operating clearance between the plunger and injector body during engine operation while preventing fuel leakage around the timing plunger.

Other objects and advantages will be apparent from the following description, claims and drawings.

Brief Description of the Drawings

Figure 1 is a schematic cross-sectional view of a fuel injector assembly in a diesel engine incorporating the scuff-resistant anti-stick timing plunger of the present invention; and

Figure 2 presents graphically the dimensions of the injector body bore and timing plunger of the present invention for different materials at different temperatures.

Description of the Preferred Embodiments

Fuel injector timing plunger scuffing and sticking is one cause of high injector RPH (repairs per hundred). High warranty costs may result from the replacement of failed and inoperable timing plungers. The fuel injector body/timing plunger assembly of the present invention provides a reliable wear-resistant timing plunger that is free from sticking and scuffing, even when exposed to extremely abusive engine operating conditions. Consequently, the present invention effectively lowers both the injector RPH and warranty costs occasioned by failed and inoperable timing plungers.

Referring to the drawings, Figure 1 illustrates, in cross section, an open nozzle unit fuel injector 10 with a timing assembly of the type that includes a timing plunger 12. This type of fuel injector includes a body 14 and an injector nozzle 16. The injector nozzle 16 and the body 14 are axially aligned and held together by a retainer 18. An axial bore 20 extends throughout the length of the body 14. A plurality of spaced injection orifices 22 in the nozzle 16 is provided at the injector cup terminus to optimize fuel injection.

The injector 10 includes a timing plunger 12 that reciprocates axially within the injector along with a link 24 that is engaged by one end of a rocker lever 26. The other end of the rocker lever 26 is drivingly connected to the camshaft 28 via a pushtube 30. The rocker lever 26 typically applies both axial and tangential loads to the timing plunger 12 during engine operation. Arrow (A) represents the axial load applied to the timing plunger 12 by the rocker lever 26. Arrow (B) represents the tangential or side load applied to the timing plunger 12 by the rocker lever 26. The axial load applied by the rocker level 26 to the timing plunger 12 as it reciprocates in the injector body 14 can be elevated to as high as 2400 pounds. In addition to these axial and tangential loads, pressures as high as 24,500 psi are generated by the timing plunger's downward stroke as it travels toward the injector nozzle 16. This results in a load of 24,500 psi acting on the timing plunger 12 in an upward axial direction, away from the nozzle 16 and toward the rocker lever 26, as shown by arrow (C).

The ceramic timing plunger 12 is sized relative to the injector body bore 20 to provide a diametral clearance of 76-128 millionths (.000076 - .000128) of an inch. The diametral clearance can be less than that of known plunger designs due to differences in thermal expansion between the currently available stainless steel plunger and the ceramic timing plunger 12. The aforementioned loads on the timing plunger and the clamp load on the injector body 14 often distort the axial bore, which decreases the diametral clearance. The rocker lever generated side load (arrow B) then forces the timing plunger 2 against the wall of the body bore 20. Plunger scuffing and wear occur under such circumstances. The presence of third body debris in the injector body bore compounds the plunger problems under these loads.

The severity of the timing plunger operating environment is further increased by low sulfur and low lubricity fuels and fuels contaminated by water. Until the present invention, a fuel injector timing plunger that is scuff and wear-resistant and capable of functioning without sticking or failure under the adverse conditions encountered in a fuel injector operating environment has not been available.

The present invention provides a fuel injector timing plunger assembly for an internal combustion engine unit fuel injector that includes a timing plunger with a substantially higher resistance to scuffing and sticking than the timing plungers currently in use. It has been discovered that forming the injector timing plunger of a hard, wear-resistant ceramic material avoids the scuffing and sticking problems that have plagued steel and other metal plungers and, additionally, resists the axially and tangential loads applied during engine operation more successfully than available timing plungers. A ceramic timing plunger presents many advantages. The kinds of ceramic materials evaluated for use as timing plungers are much harder than the materials currently used for either the timing plunger or the injector body. Moreover, the ceramic material has a low reactivity and a low affinity to weld with petroleum lubricated metal counterfaces. However, the optimum surface finish must be created for the best sliding wear performance.

Timing plungers made from high thermal expansion ceramics, including zirconia, alumina-zirconia and alumina have been demonstrated to show significantly better scuffing resistance than plungers made from metal. Although other ceramics, most notably silicon nitride, also display superior scuff resistance, only high thermal expansion ceramics have been found to be suitable for use in forming unit fuel injector timing plungers. Achieving the optimum fuel leakage around the plunger during engine operation is critical. Since ceramics with low thermal expansion allow excessive leakage, only high thermal expansion ceramics are capable of maintaining fuel leakage within acceptable parameters. The preferred ceramic materials for use in forming fuel injector timing plungers are those with a thermal expansion coefficient greater than $6x10^{-6}/°C$ and a hardness greater than 800 Kg/mm^2. The thermal expansion coefficient of the ceramic selected for the timing plunger should match as closely as possible that of the metal forming the injector body.

Figure 2 compares the diameters of the injector body bore 30 (Figure 1) with the diameters of a timing plunger currently in use and two ceramic plungers with differing diametral clearances. Curve A represents the diameter of the injector body bore over the range of temperatures studied. Curve B shows the changes in plunger diameter when the timing plunger 12 is formed from stainless steel, which is the material presently used. The diametral clearance between the stainless steel timing plunger and the injector bore in the assembly tested was 5.0 microns. Curves C and D demonstrate diametral changes in timing plunger diameter for two ceramic timing plungers at different clearances. The diametral clearance between the timing plunger and the bore for the assembly represented by curve C was 2.5 microns, while the clearance between the curve D timing plunger assembly was 5.0 microns. Figure 2 clearly demonstrates that a ceramic timing plunger in accordance with the present invention can have a smaller diametral clearance in the injector bore than the presently used stainless steel plunger and still function effectively in the presence of the loads applied to the timing plunger during engine operation.

Unit fuel injector timing plungers with thermal expansion coefficients and hardness characteristics in the aforementioned range have survived extremely abusive bench and engine tests which have destroyed standard steel timing plungers. Injector RPH and warranty costs have been reduced by the use of ceramic timing plungers in timing assemblies for unit fuel injectors.

Industrial Applicability

The timing plunger of the present invention will find its primary application as an integral component of an injector timing plunger assembly for a unit fuel injector in an internal combustion engine, particularly a heavy duty diesel-type engine.

Claims

1. A timing plunger assembly for an internal combustion engine unit fuel injector operably connected to a drive train to inject a supply of fuel into an engine cylinder, wherein said timing plunger assembly includes an axial bore located within a body portion of said fuel injector and an axially movable timing plunger means for causing a controlled volume of fuel to be injected from said fuel injector at desired intervals during engine operation disposed within said fuel injector body axial bore, wherein said timing plunger means is made of wear-resistant ceramic material having a thermal expansion coefficient greater than $6x10^{-6}/°C$ and a hardness greater than 800 Kg/mm^2.

2. The timing plunger assembly described in claim 1, wherein said timing plunger means is made of a homogenous, chemically inert, hard ceramic material.

3. The timing plunger assembly described in claim 1 or 2, wherein said ceramic material is selected from the group consisting of zirconia, alumina-zirconia, and alumina ceramics.

4. The timing plunger assembly described in claim 1, 2 or 3, wherein the diametral clearance between said timing plunger means and said fuel injector body axial bore is 76 to 128 millionths of an inch.

5. The timing plunger assembly described in any preceding claim, wherein the timing plunger means and the fuel injector body are formed of materials having substantially the same thermal expansion coefficient.

6. A timing plunger for an internal combustion engine unit fuel injector plunger assembly, wherein said timing plunger is capable of reciprocal axial movement with an axial bore of an injector body and maintains a diametral clearance within said axial bore of 76 to 128 millionths of an inch during operation of the unit fuel injector without scuffing or sticking.

7. The timing plunger described in claim 6, wherein the timing plunger is formed of a material having a thermal expansion coefficient substantially the same as the thermal expansion coefficient of the material forming the injector body.

8. The timing plunger described in claim 6 or 7, wherein the timing plunger is made of a homogenous, chemically inert ceramic material having a thermal expansion coefficient greater than $6x10^{-6}/°C$ and a hardness greater than 800 Kg/mm^2.

9. The timing plunger described in claim 6, 7 or 8, wherein said ceramic material is selected from the group consisting of zirconia, alumina-zirconia and alumina ceramics.

FIG. 1

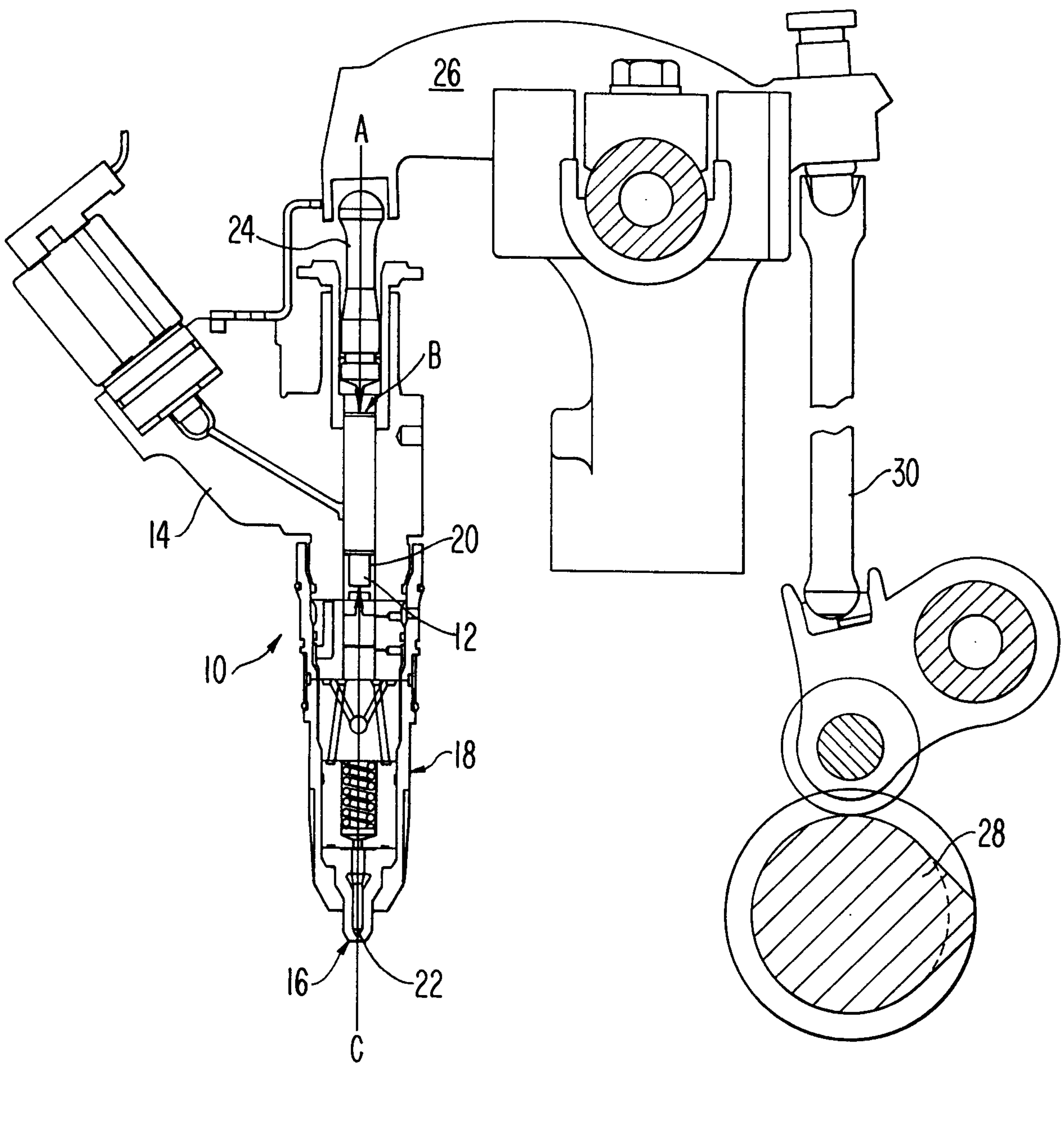
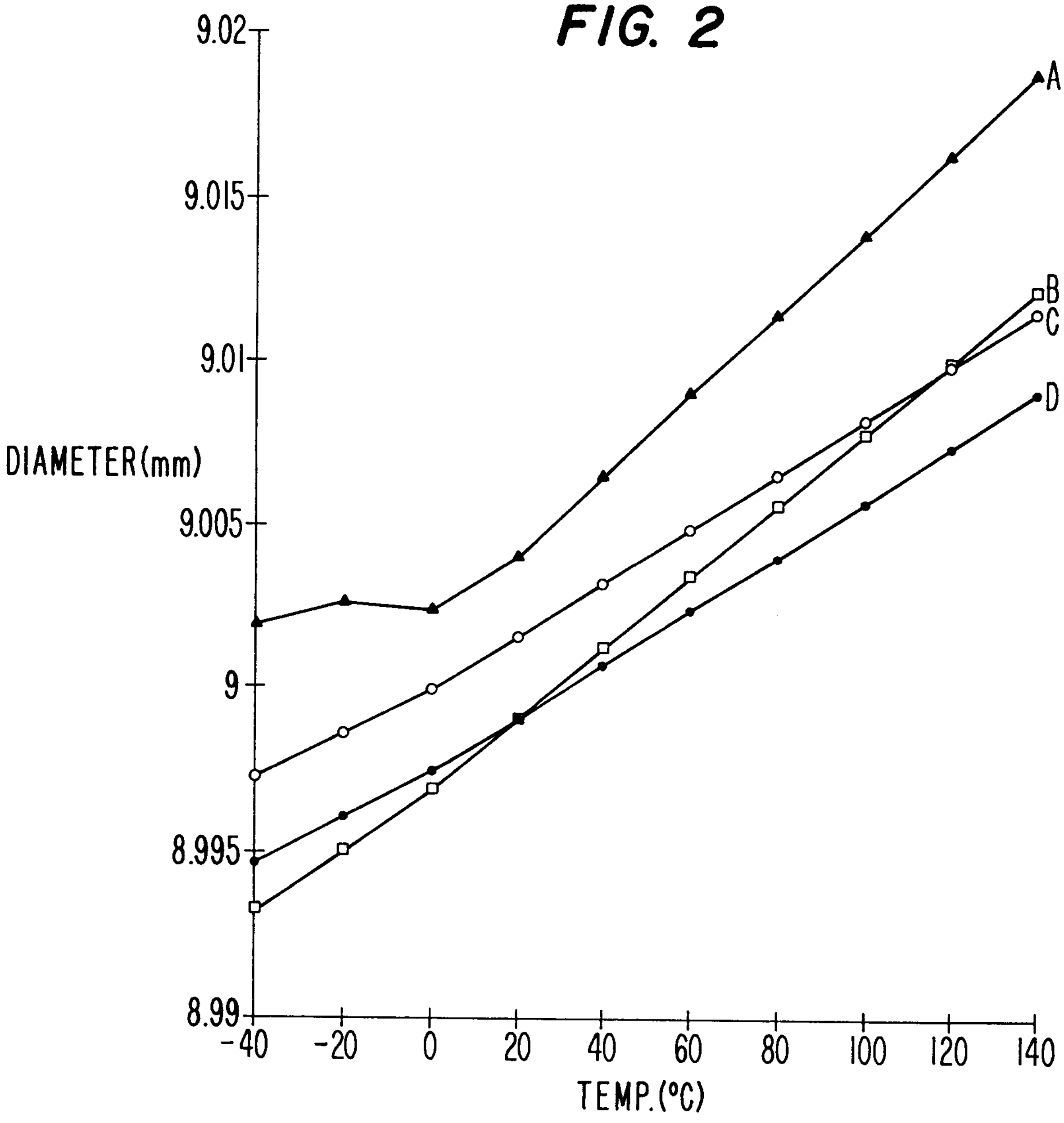


FIG. 2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EUROPEAN SEARCH REPORT

Application Number
EP 95 10 7461

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.6)
A	PATENT ABSTRACTS OF JAPAN vol. 9 no. 256 (M-421) ,15 October 1985 & JP-A-60 104765 (YANMAR) 10 June 1985, * abstract *	1,2,6,8	F02M59/44 F02M57/02
A	EP-A-0 450 891 (CUMMINS ENGINE COMPANY) * column 4, line 8 - column 9, line 4; figures 1,2 *	1,6	
A	US-A-4 848 286 (J.C. BENTZ) * column 4, line 10 - column 6, line 27; figures 1-4 *	1	
A	PATENT ABSTRACTS OF JAPAN vol. 10 no. 187 (M-493) ,2 July 1986 & JP-A-61 031659 (YANMAR) 14 February 1986, * abstract *	1,2	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			F02M F01L

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	29 August 1995	Hakhverdi, M

CATEGORY OF CITED DOCUMENTS

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