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[54] PISTONS AND CYLINDERS MADE OF CARBON-CARBON COMPOSITE MATERIALS

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[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration**, Washington, D.C.

[*] Notice: This patent is subject to a terminal disclaimer.

[21] Appl. No.: **09/480,421**

[22] Filed: **Jan. 11, 2000**

Related U.S. Application Data

[62] Division of application No. 08/808,290, Feb. 28, 1997.

[51] **Int. Cl.**[7] **F02F 75/06**

[52] **U.S. Cl.** **123/193.1**; 123/193.6; 123/193.4; 123/193.2

[58] **Field of Search** .... 123/193.1, 193.2, 123/193.3, 193.4, 193.5, 193.6, 195 R; 92/138, 208, 212

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,890,950	6/1975	Haldeman	123/193.6
4,539,894	9/1985	Harris	92/138
4,683,809	8/1987	Taylor	92/208
4,909,133	3/1990	Taylor et al.	92/212
5,687,634	11/1997	Ransone	123/195 R
5,769,046	6/1998	Ransone	123/193.2
6,044,819	4/2000	Rivers et al.	123/193.1

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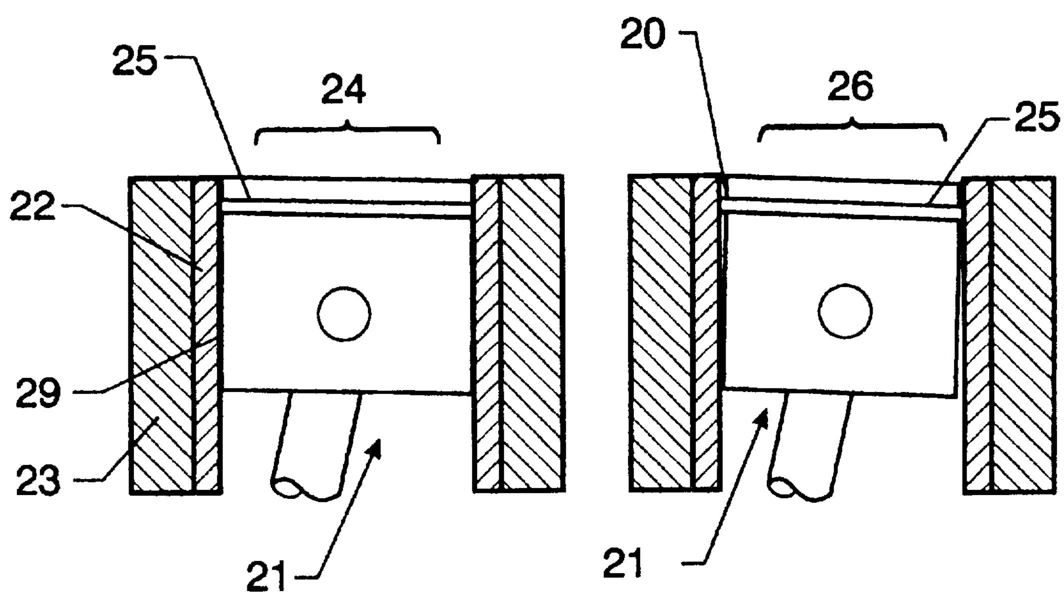
Attorney, Agent, or Firm—Kurt G. Hammerle

[57] **ABSTRACT**

An improved reciprocating internal combustion engine has a plurality of engine pistons, which are fabricated from carbon—carbon composite materials, in operative association with an engine cylinder block, or an engine cylinder tube, or an engine cylinder jug, all of which are also fabricated from carbon—carbon composite materials.

11 Claims, 6 Drawing Sheets



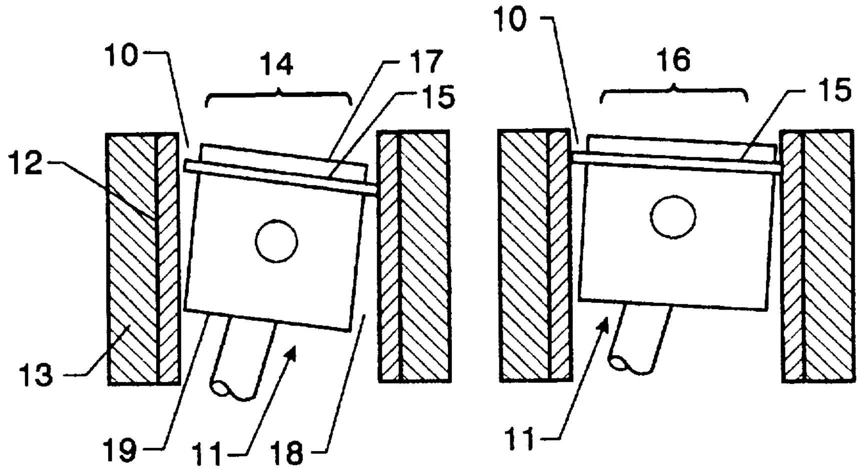


FIG. 1 PRIOR ART

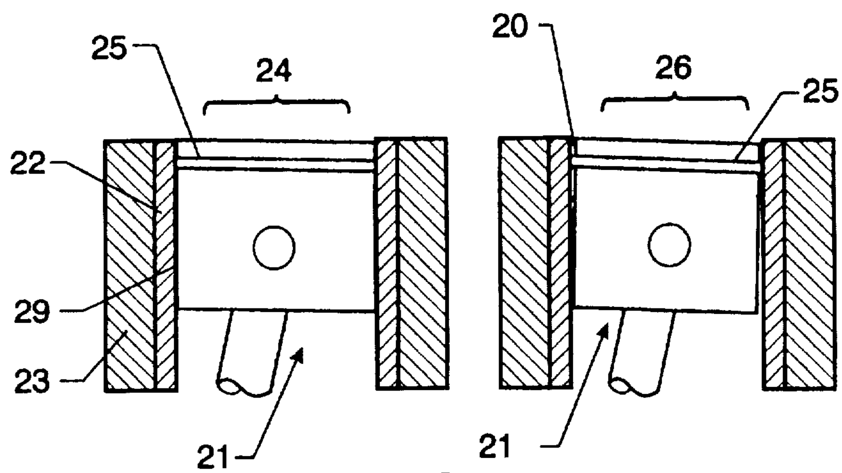


FIG. 2

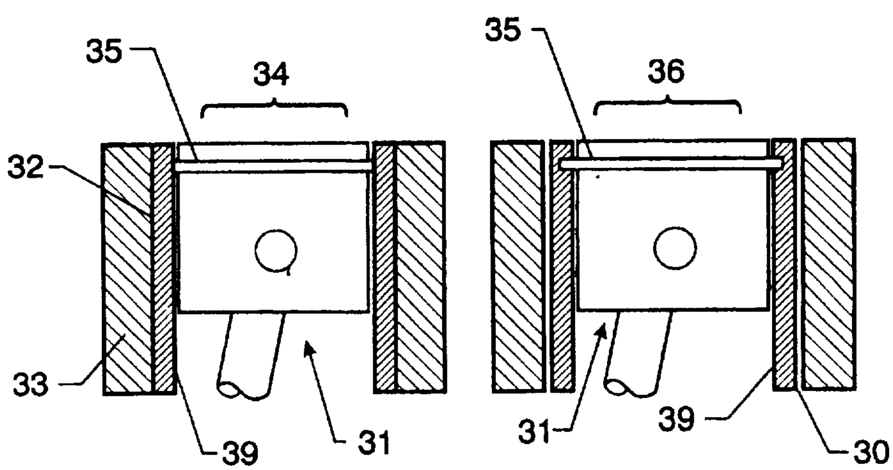


FIG. 3

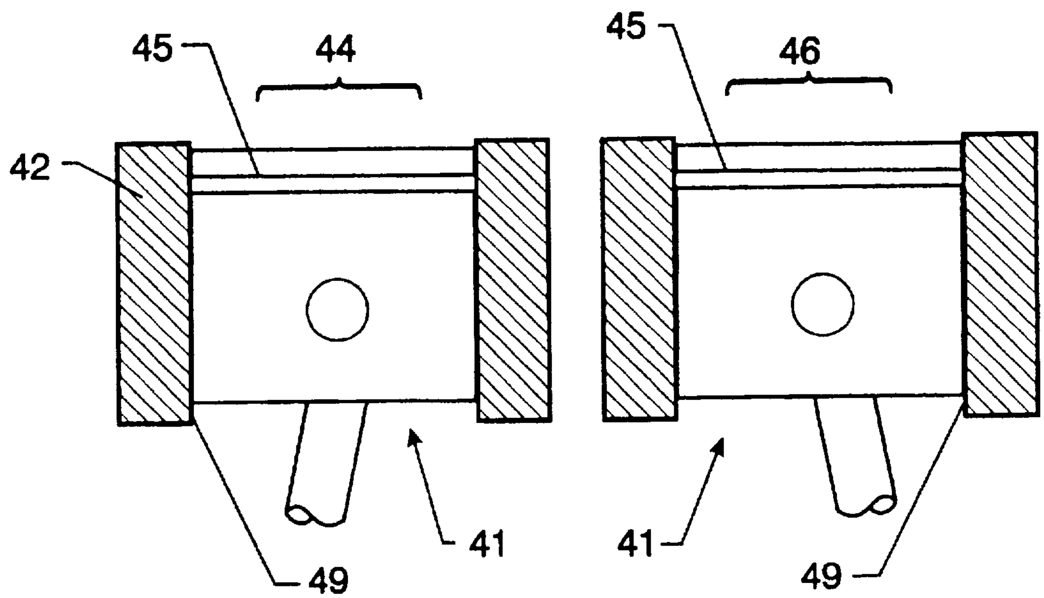


FIG. 4

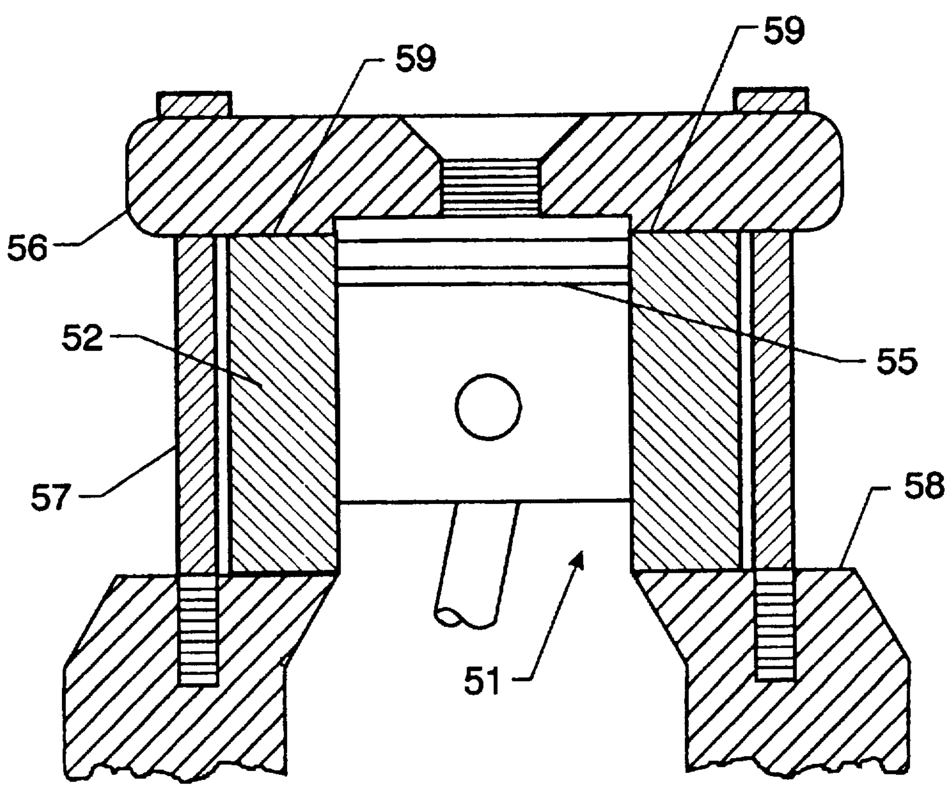


FIG. 5

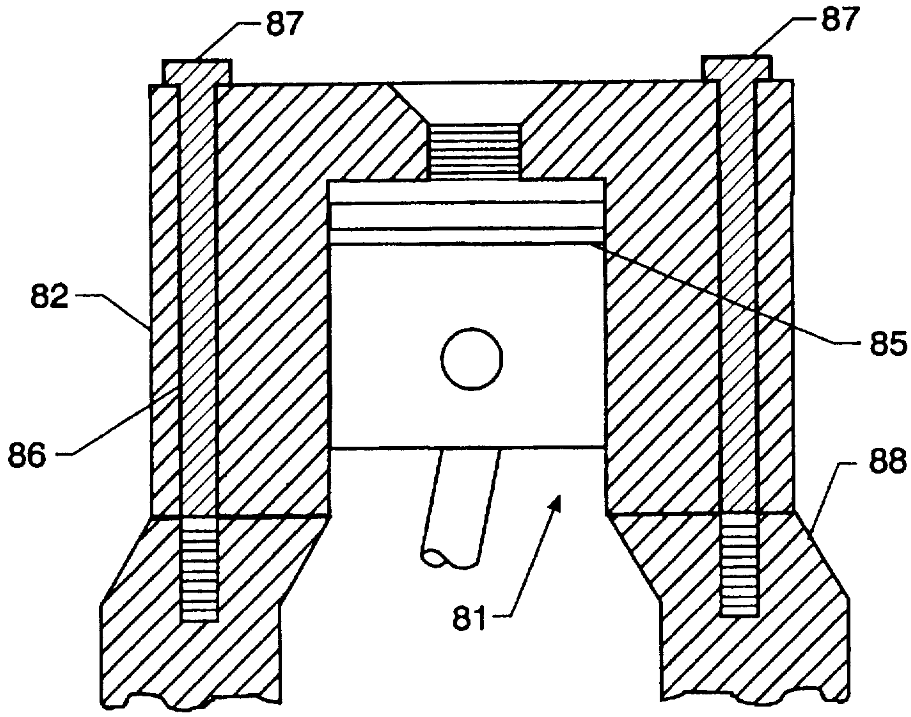


FIG. 8

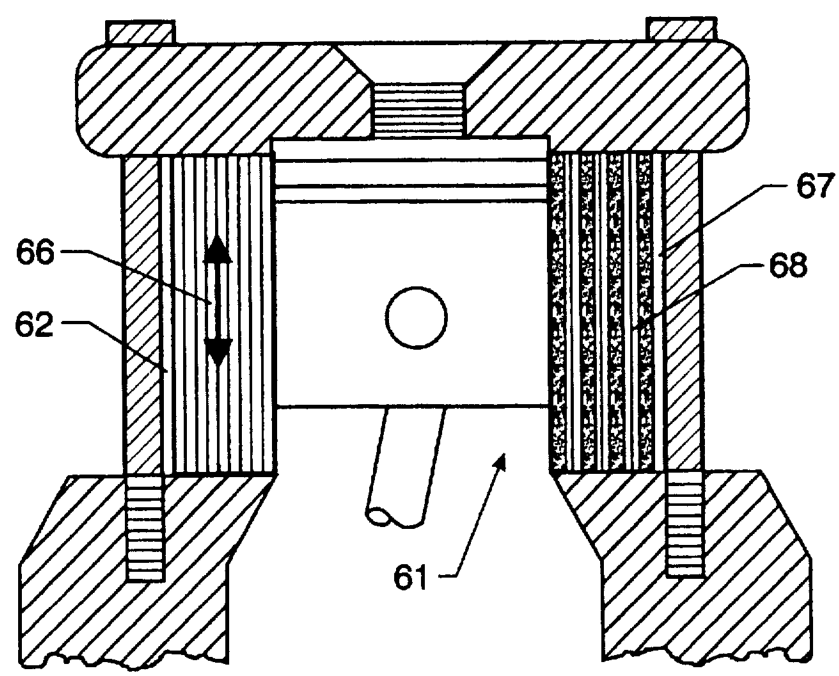


FIG. 6

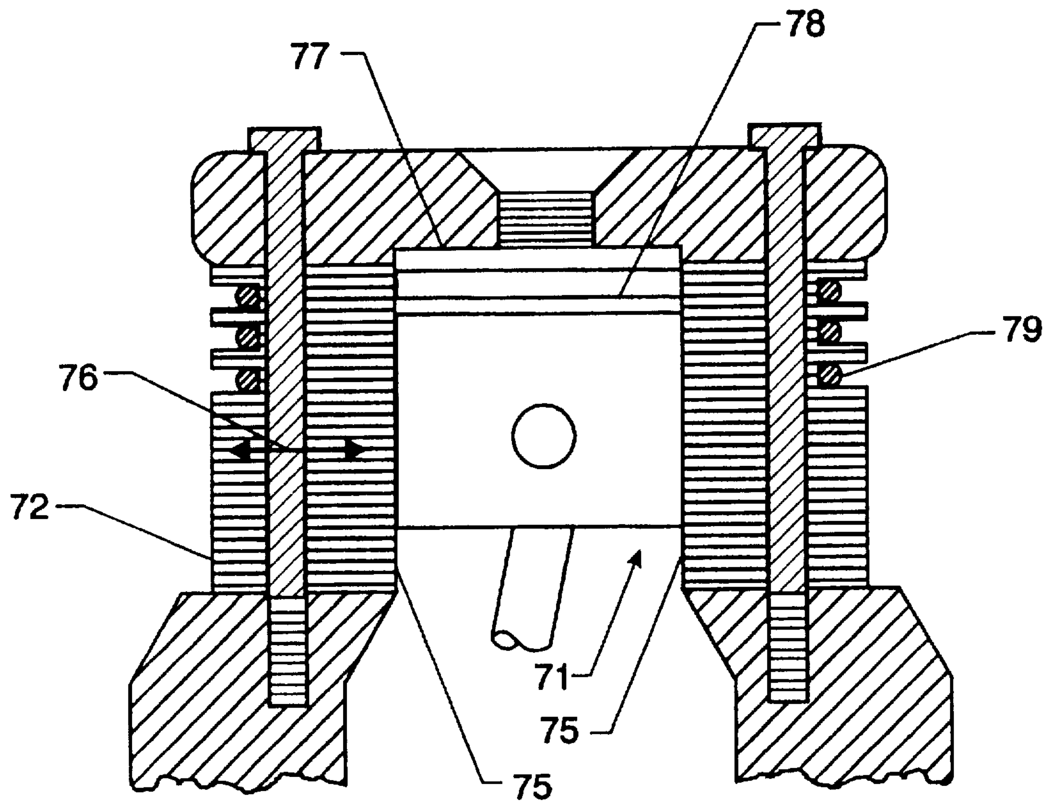


FIG. 7

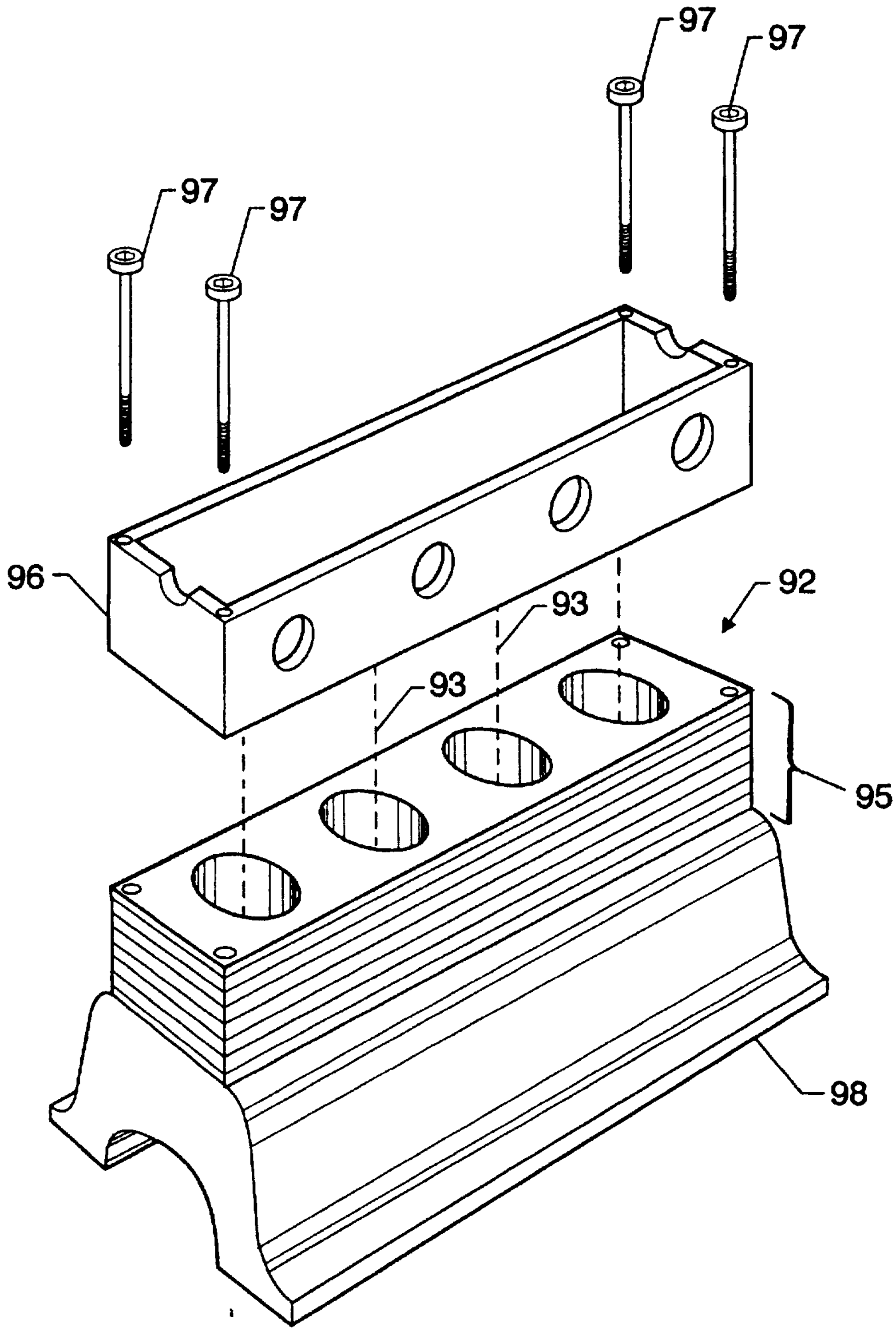


FIG. 9

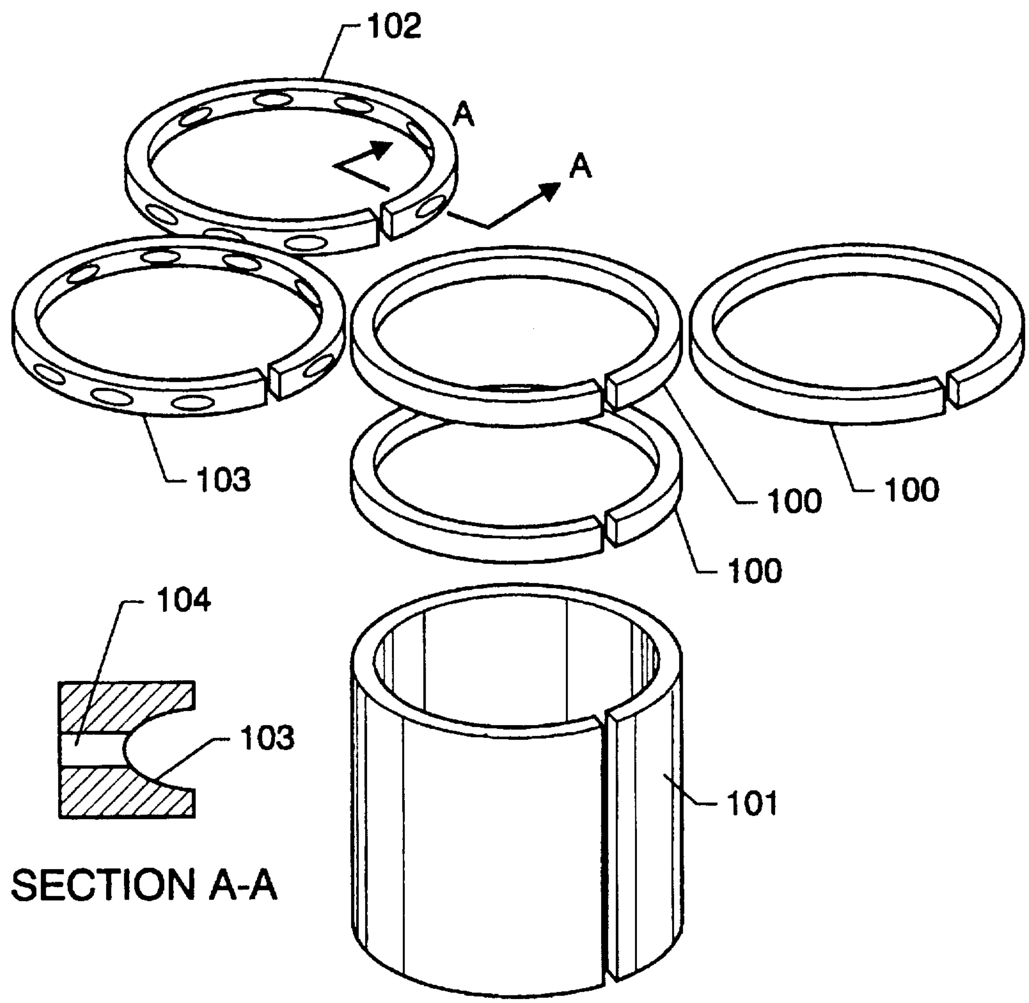


FIG. 10

PISTONS AND CYLINDERS MADE OF CARBON-CARBON COMPOSITE MATERIALS

CROSS-REFERENCE TO RELATED APPLICATION

This application is a divisional patent application of commonly owned, co-pending patent application Ser. No. 08/808,290, filed Feb. 28, 1997.

CLAIM OF BENEFIT OF PROVISIONAL APPLICATION

Pursuant to 35 U.S.C. §119, the benefit of priority from provisional application Ser. No. 60/012,933, with a filing date of Mar. 6, 1996, is claimed for this non-provisional application.

ORIGIN OF THE INVENTION

This invention was jointly made by NASA employees and an employee of Carbon—Carbon Advanced Technology, Inc. and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a machine comprising lightweight, high strength pistons with or without piston rings, operating in a reciprocating internal combustion engine cylinder block or liner, and more specifically to a machine using pistons and cylinder blocks or liners fabricated from carbon—carbon composite materials.

2. Description of the Related Art

Internal combustion reciprocating engines used for aerospace, military, and transportation applications must be lightweight and capable of operating at elevated temperatures and pressures. Under the current state-of-the-art, the relatively high temperatures and pressures associated with operation of a reciprocating internal combustion engine necessitates pistons made of either aluminum alloys, cast-iron, and/or steel. However, engine pistons manufactured of steel and/or aluminum alloys are heavy which adds weight to the reciprocating mass of diesel and gasoline engines. Steel and aluminum alloy pistons are also highly thermally conductive; hence, a significant heat transfer, i.e. heat loss, through the cylinder wall results. In diesel engines this "through-the-wall" heat loss reduces engine efficiency.

Cylinder blocks for reciprocating internal combustion engines in automobiles typically have been made of cast iron because of the need for high mechanical strength. Use of cast iron, however, adds weight to the engine and results in lower fuel economy. In an effort to reduce engine weight, various light-weight alloys such as aluminum alloy have been used to fabricate the cylinder block. Typically, the engine block mass is made of aluminum alloy and a thin-walled cast iron sleeve is inserted to line the cylinder bore(s). Alloys of aluminum are lighter than cast iron, however, they have a lower mechanical strength which creates undesirable vibration. In addition, aluminum alloys inherently possess lower temperature resistance and a higher coefficient of thermal expansion (CTE) than cast iron which means that differential thermal expansion between aluminum alloys and cast iron must be taken into account in design.

The inherently high coefficient of thermal expansion of aluminum alloys necessitates larger clearances between an aluminum alloy piston and a cast iron cylinder wall, to avoid piston scuffing and/or sizing which could occur as an aluminum alloy piston expands during high temperature engine operation. In order to seal the clearance, or gap, between an aluminum alloy piston and a cast iron cylinder wall, piston rings are required. Metallic and ceramic piston rings commonly are used in conjunction with steel and/or aluminum alloy pistons. Typically, ceramic rings replace metal rings when extreme operating temperatures so dictate. Ceramic rings, however, become brittle during extensive operation at extreme temperatures and are unreliable.

At operating temperatures above 300 degrees Celsius (C), the mechanical strength of aluminum alloy pistons decreases dramatically. The uppermost compression ring cannot be located too close to the crown because the reduced mechanical strength will result in deformation of the piston above the top ring due to forces exerted by ring friction. The need for positioning the top ring further from the crown increases the crevice volume between the piston and cylinder wall which, by necessity, must exist to accommodate thermal expansion of the piston. A further disadvantage of larger gaps between aluminum alloy pistons and the cylinder wall includes "piston rocking" in the cylinder bore which increases engine noise and necessitates additional piston mass as longer skirts are needed. Large amounts of lubricants are also required to control the wear rates of the piston and cylinder wall.

SUMMARY OF THE INVENTION

Accordingly an object of this invention is to reduce the weight of an internal combustion reciprocating engine with the use of carbon—carbon composite pistons in conjunction with carbon—carbon composite cylinder blocks or liners.

It is another object of the present invention to minimize or eliminate the thermal distortion in the piston-to-cylinder system, to minimize the clearance between the piston and cylinder wall, so as to promote quieter operation.

It is yet another object of the present invention to minimize or eliminate the thermal distortion in the piston-to-cylinder system, to minimize the clearance between the piston and cylinder wall, so as to provide for potential ringless operation.

It is still another object of the present invention to minimize or eliminate the thermal distortion in the piston-cylinder system, to minimize the clearance between the piston and cylinder wall, so as to reduce hydrocarbon emissions into the atmosphere.

It is a further object of the present invention to minimize or eliminate the thermal distortion in the piston-cylinder system, to minimize the clearance between the piston and cylinder wall, to improve engine efficiency.

Another object of the present invention is to provide an internal combustion reciprocating engine which operates with self-lubricating pistons.

A further object of the present invention is to provide an internal combustion reciprocating engine with piston rings which provide better sealing thus reducing "blow by" and oil consumption.

According to the present invention, the foregoing and additional objects are attained by combining a carbon—carbon composite piston with a carbon—carbon cylinder block or liner, and, if desired, carbon—carbon composite or graphite piston rings.

Carbon-carbon composite cylinder blocks and liners used in conjunction with carbon—carbon composite pistons according to the present invention represents a significant improvement over the prior art. While performing the same function as a cast iron or aluminum alloy cylinder block, a carbon—carbon composite cylinder block or liner weighs less and has negligible CTE which creates higher dimensional stability at normal operating temperatures, i.e. minimal expansion of the carbon—carbon composite material.

The use of carbon—carbon composite materials for pistons in internal combustion engines reduces engine weight, improves engine efficiency, reduces hydrocarbon emissions, potentially eliminates the need for piston rings, and produces a less noisy engine. Because the inherent porosity in carbon—carbon composite materials allows them tosoak up oil, good lubrication qualities are imparted to carbon—carbon composite pistons. Additionally, self-lubricating characteristics can be imparted by controlling the graphite content of the composite. Even in the absence of lubrication, carbon—carbon composite materials have no galling tendencies. Therefore, loss of lubricants and/or overheating does not result in catastrophic seizing of the pistons, but only the temporary loss of power due to increased friction.

While performing the same function as a cast iron or aluminum alloy cylinder block, a carbon—carbon composite cylinder block has lower weight and negligible coefficient of thermal expansion (CTE), thereby resulting in higher dimensional stability at extreme operating temperatures.

Thus, combining a low CTE carbon—carbon composite cylinder block or liner, and a carbon—carbon composite- or other material of very low CTE- piston greatly increases the potential for a ringless, reciprocating internal combustion engine which is a significant improvement over the current state-of-the-art, e.g. improved fuel economy, reduced oil consumption, and reduced blow-by.

Even though carbon—carbon composite materials oxidize at operating temperatures above 600 degrees Fahrenheit (F), coating technology for oxidation protection is sufficiently developed to satisfy requirements for most engine applications. Ceramic coatings, e.g. silicon carbide and silicon nitride, may be used in conjunction with diesel engines. Metallic coatings, e.g. nickel and/or copper, provide very good oxidation protection when applied directly to carbon—carbon composite piston crowns. Nickel also provides catalyticity and copper improves thermal conductivity.

When piston rings are required, carbon—carbon composite or graphite piston rings are capable of operating at higher operating temperatures without becoming as brittle as ceramic rings. In some applications, carbon—carbon composite or graphite rings may be coated with a ceramic coating, e.g. silicon carbide and silicon nitride, to prevent oxidation.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an illustration of a prior art engine employing aluminum alloy pistons and an engine block with a cast iron liner;

FIG. 2 is an illustration of an engine employing a carbon—carbon composite piston in cast iron liner;

FIG. 3 is an illustration of an engine employing carbon—carbon composite pistons in a carbon—carbon composite liners, according to the present invention;

FIG. 4 is an illustration of an engine employing carbon—carbon composite pistons in a carbon—carbon composite engine block, according to the present invention;

FIG. 5 is an illustration of an engine employing a carbon—carbon composite piston in a carbon—carbon composite tube, or liner, according to the present invention.

FIG. 6 is an illustration of an engine employing a carbon—carbon composite piston in a carbon—carbon composite tube, or liner, designed to limit radial heat flow, according to the present invention;

FIG. 7 is an illustration of an engine employing a carbon—carbon composite piston in a carbon—carbon composite tube, or liner, designed to enhance heat flow away from the pistons, according to the present invention;

FIG. 8 is an illustration of an engine employing a carbon—carbon composite piston in a carbon—carbon composite jug, according to the present invention;

FIG. 9 is an illustration of a carbon—carbon composite cylinder block, according to the present invention; and

FIG. 10 is an illustration of carbon—carbon composite piston rings, according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The inherent disadvantages of current internal combustion engines is depicted in FIG. 1 which depicts the combination of an aluminum alloy piston **11**, a cast iron liner **12**, and an aluminum alloy cylinder block **13**. During cold operation **14**, the gap **10** between the cast iron liner **12** and the piston **11** from the piston ring **15** to the crown of the piston **17**, called the "crevice volume," becomes a major source of hydrocarbon emission. In addition, the gap **18** formed between the piston ring **15** and the bottom of the piston **19** allows the piston **11** to rock in the cast iron liner **12** which results in noisy operation. During hot operation **16**, once the piston **11** has expanded, the gap **10** is less pronounced, but still allows hydrocarbons to escape into the environment. Piston rocking is also less dramatic, i.e, noisy, during hot operation **16**.

Carbon-carbon composite materials, as used herein, are well known in the art, and refer to a predominantly carbon matrix material reinforced with predominantly carbon fibers. These materials may be tailored to produce desired mechanical and physical properties by preferred orientation of the continuous or staple fibers in the composite; and/or by the selection of additives; and/or by thermal treatment of the fibers and matrix before, during, or after fabrication. Carbon-carbon composite materials may be cast or molded, and are machineable. The surface or near-surface material can also be treated and/or coated with oxidation protection or sealing materials, or with catalytic materials such as nickel.

FIG. 2 illustrates the effect of substituting a carbon—carbon composite piston **21** in an aluminum alloy cylinder block **23** with a cast iron liner **22**. Notice that in a very cold environment **24**, e.g. minus (−)30 degrees F, a cast iron liner **22** will contract and is likely to clamp down on the piston skirt **29** which could prevent turning over the engine and/or damage the pistons **21**. During hot operation **26**, the carbon—carbon piston **21** and the cast iron liner **22** work effectively to eliminate any gap **20** above the topmost compression ring **25**.

Two versions of the claimed invention with piston rings **35**, **45** are illustrated in FIGS. **3** and **4** which show a carbon—carbon composite piston **31**,**41**, respectively, in a carbon—carbon composite cylinder liner **32** and a carbon—carbon composite cylinder block **42**. During cold **34**,**44** and hot operation **36**,**46**, there are no gaps between the piston **31**,**41** and the cylinder wall **39**,**49**. It should be noted, however, that a gap **30** between the carbon—carbon cylinder liner **32** and the aluminum alloy cylinder block **33** may develop due to the differential expansion between the carbon—carbon composite material and the aluminum alloy material.

FIG. 5 depicts one preferred embodiment of the claimed invention which employs a carbon—carbon composite piston **51** within a carbon—carbon composite tube **52**. The tube **52** is captured between the cylinder head **56** and the crankcase **58** and secured using a plurality of head bolts **57**. The piston **51** may be either ringless (not shown) or grooved to include a cast iron, carbon—carbon composite, or graphite piston ring **55**.

FIG. **6** illustrates how the carbon—carbon fibers may be oriented to limit radial heat flow from the cylinder tube **62**. The carbon fabric or tape laminate **66** comprising the tube **62** should be oriented radially with respect to the tube **62**, i.e. the carbon filament axials **68** should be oriented along the same axis as the tube **62** and the carbon filament windings **67** should be wrapped around the circumference of the tube **62**. Two-dimensional wrappings may be orthogonal, i.e. at zero and 90 degrees; 30 degrees; ±45 degrees; 60 degrees; or any desired orientation of bias. To facilitate heat flow perpendicular to the cylinder tube **72** axis, FIG. **7** illustrates the preferred orientation of carbon fabric or tape laminate **76** which is perpendicular to the cylinder tube **72** axis.

To enhance heat flow from the piston **71** towards the cylinder wall **75**, several plies of carbon fabric or tape **78** may be placed on and parallel to the piston crown **77**. To provide hoop stress reinforcement to the cylinder tube **72**, a plurality of carbon filament windings **79** may be added.

FIG. **8** depicts another preferred embodiment of the claimed invention wherein a carbon—carbon composite piston **81** reciprocates in a carbon—carbon composite jug **82**, which is nothing more than the tube **52** and head **56** from FIG. **5** fabricated as a single unit. The advantage of this version over that of FIG. **5** is that sealing gaskets **59** between the tube **52** and head **56** are not required. The jug **82** is secured to the crankcase **88** by a plurality of head bolts **87**. Here again, the piston **81** may be either ringless (not shown) or grooved to include a cast iron, carbon—carbon composite, or graphite piston ring **85**. The principles which govern the orientation of carbon fabric and tape laminates shown in FIGS. **6** and **7** for the cylinder tube **52** of FIG. **5** also apply to the jug **82** of FIG. **8**.

FIG. **9** depicts the preferred embodiment of a carbon—carbon composite cylinder block **92** to promote heat flow perpendicular to the cylinder bore axis **93**. The stacked plies of carbon fabric **95** which make up the cylinder block **92** are captured between the head **96** and the crankcase **98** using a plurality of head bolts **97** to secure the cylinder block **92**.

FIG. **10** depicts the claimed carbon—carbon composite or graphite piston rings **100**. These rings **100** may be fabricated simply by cutting the rings **100** from a cylindrical tube **101** of carbon—carbon composite. Oil control rings **102** which have been machined to include face grooves **103** and oil return holes **104** may also be fabricated from cylindrical tubes **101** of carbon—carbon material; however, the face grooves **103** and oil return holes **104** should be machined into the cylindrical tubes **101** before the oil control rings **102** are cut from the cylindrical tube **101**.

The inside diameter of the rings **100**, **102**, made from carbon—carbon composite materials and/or graphite should be very close to the outside diameter of the piston (not shown) on which they are to be fitted because they cannot be spread open like cast iron or other conventional metals rings.

The invention can be practiced in other manners than are described herein without departing from the spirit and the scope of the appended claims.

What is claimed is:

1. In a reciprocating internal combustion engine wherein a mixture of fuel and air is burned in at least one cylinder containing a piston to form combustion products, and wherein heat produced by burning of the mixture of fuel and air causes the combustion products to expand and force the piston to move within the cylinder, which movement turns a crankshaft, the reciprocating internal combustion engine further comprising at least one piston ring, each piston ring operatively associated with the piston, the improvement comprising at least one piston, fabricated from carbon—carbon composite materials, being in operative association with a cylinder block fabricated from carbon—carbon composite materials and with at least one piston ring made of carbon—carbon composite materials.

2. The reciprocating internal combustion engine of clam 1, wherein the cylinder block is a cylinder tube.

3. The reciprocating internal combustion engine of claim 1, wherein the cylinder block is a cylinder jug.

4. The reciprocating internal combustion engine of claim 1, wherein each piston ring is sealed with a ceramic coating for oxidation protection.

5. The reciprocating internal combustion engine of claim 4, wherein the ceramic coating is silicon carbide.

6. The reciprocating internal combustion engine of claim 4, wherein the ceramic coating is silicon nitride.

7. The reciprocating internal combustion engine of claim 1, wherein each said piston ring is sealed with a metal coating for oxidation protection.

8. The reciprocating internal combustion engine of claim 7, wherein the metal coating is a catalyst.

9. The reciprocating internal combustion engine of claim 8, wherein the catalyst is nickel.

10. The reciprocating internal combustion engine of claim 7, wherein the metal coating is copper.

11. The reciprocating internal combustion engine of claim 1, wherein each piston ring has a face groove and oil return holes are machined into it to control oil flow.

* * * * *