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A HYDRAULICALLY CONTROLLED DIAPHRAGM-TYPE HYDROGEN GAS INJECTOR

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Abstract—The use of hydrogen as an alternative internal-combustion engine fuel is best achieved by direct cylinder injection late in the compression stroke. For this purpose, a hydraulically actuated injector using a diaphragm was designed as an alternative to conventional plunger-type devices. Preliminary tests and observations were conducted using nitrogen and then methane. The successful construction and preliminary testing has proved the feasibility of a diaphragm-type hydrogen gas injector. © 1997 International Association for Hydrogen Energy

INTRODUCTION

Due to air pollution and the depletion of fossil fuel reserves, the need to find an alternative to conventional hydrocarbon fuels is becoming increasingly urgent. The use of hydrogen as an internal-combustion (IC) engine fuel has shown promise as an alternative, particularly when injected directly into the cylinder late in the compression stroke. The design of an injector to achieve this is critical to the overall performance of the hydrogen engine. Injector designs can generally be classified as mechanically, hydraulically, or electrically actuated. Mechanically actuated injectors, using cams, have slow response times and lack flexibility. Electrically actuated injectors give fast response times and flexible injection timing, using solenoids with custom-built control circuits. However, they lack the simplicity of hydraulic injection systems, which can be actuated using an existing diesel fuel injection pump.

Such a system was chosen for initial research into hydrogen fuelled IC engines in the School of Mechanical Engineering, University of the Witwatersrand. The use of a diaphragm was proposed by the senior author as an alternative to the plunger mechanisms of conventional hydraulically actuated injectors. Previous injector designs by Furuhama [1, 2], Wallace [3, 4], Green, Glasson [5, 6] and others were studied, but none that made use of a diaphragm were found.

REQUIREMENTS OF DESIGN

An ASTM-CFR engine with an Otto Head was chosen, as used by Homan [7]. The principle requirements of the injector were as follows:

- the injector was to use compressed gas bottles as a source of hydrogen;
- the injector was to be actuated by the existing diesel injection pump;
- the injector needle assembly was to be as light as possible to minimise the response time;
- the stresses in the diaphragm were to be kept as low as possible;
- the emphasis of the design was on simplicity.

OPERATION OF DEVICE

The injector is shown in Fig. 1. The principle specifications of the injector are given below:

- needle travel, 0.5 mm;
- hydrogen supply pressure, 10 MPa;
- diaphragm material, spring steel;
- diaphragm thickness, 0.127 mm;
- diaphragm diameter, 50 mm to edge of clamped region;
- diaphragm designed for infinite life.

The injector is closed when the diaphragm is in its uppermost position and the diaphragm and needle assembly are supported individually in both the open and closed positions by the diaphragm backing plates, as shown in Fig. 2. The holes drilled in these plates are large enough to allow the flow of diesel oil and hydrogen onto the diaphragm, but small enough to ensure that the diaphragm is not unduly stressed. The surfaces of the backing pieces were roughened to prevent the diaphragm sealing against them and restricting the flow of the hydrogen, or diesel oil. When closed by the force of the hydrogen, the needle assembly elongates slightly under tension.

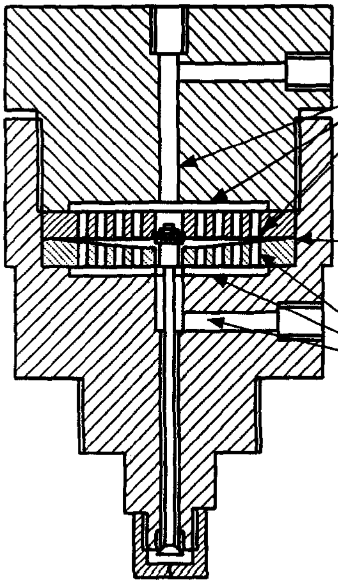

Fig. 1. Hydrogen injector.

sealing the poppet valve against its seat; a copper insert was used as a seat for the poppet valve, and the relative clearance adjusted accordingly. In the design shown, the flow is choked at the nozzle hole, not at the poppet valve. The second diesel inlet from the side was provided to allow a displacement transducer to be inserted through the top inlet, to record the needle movement.

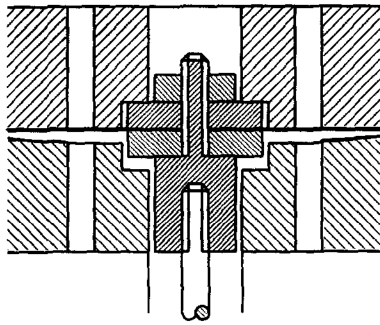

Fig. 2. Detail of injector assembly.

TESTS

The injector was first tested with nitrogen and then with methane. Methane was chosen instead of hydrogen for initial tests because it has a more visible flame, a lower flame velocity and a narrower flammability range in air. It also does not diffuse as rapidly through air and solid materials, and it has a distinctive odour, making it safer to work with than hydrogen. To observe its operation, the injector was mounted outside the engine for these proof of concept tests.

The injector operated as intended, although small amounts of leakage past the poppet valve between injection pulses were a recurring problem. Past researchers have also experienced this problem, and a possible solution is to use an elastomeric seat as used by Green and Glasson [6]. The methane was ignited with a spark plug and a repetitive spark as shown in Fig. 3. A 30 s exposure

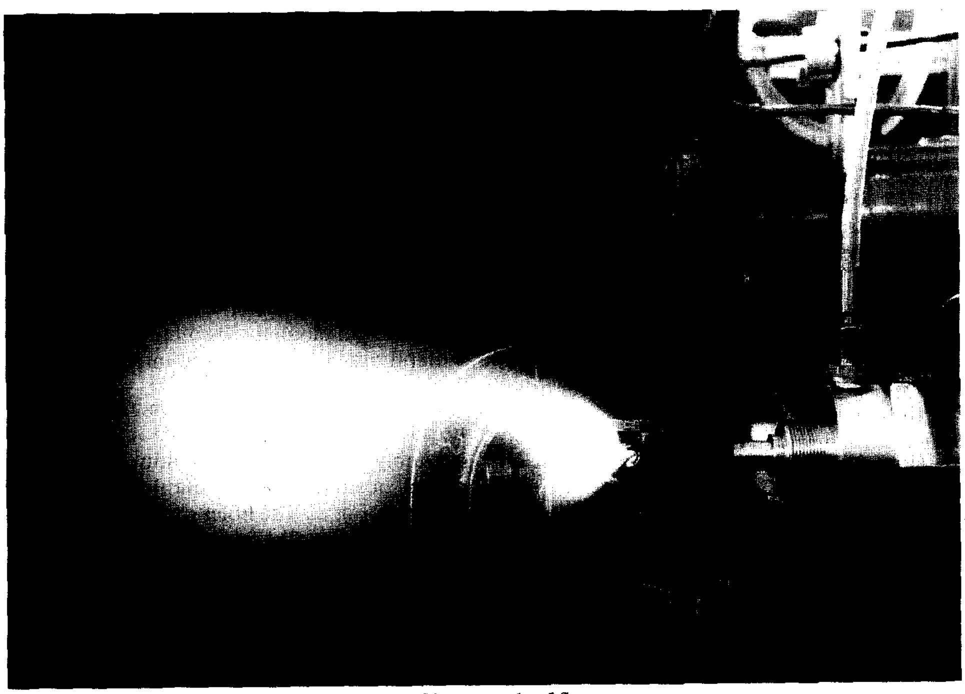

Fig. 3. Photograph of flame.

time was used in this photograph, equivalent to 150 injection pulses at the engine speed of 10 Hz (600 rev/min).

FURTHER WORK

The feasibility of the design has been proven, the next step will be to install the injector in the engine and record the cylinder pressure variation with the engine fuelled by hydrogen and methane. It is intended to measure the movement of the needle with a displacement transducer to determine the exact response time and behaviour of the injector. The design should be refined and the diaphragm reduced in size: this could be achieved by using a corrugated diaphragm. The possibility of inserting a choked orifice upstream of the poppet valve has been considered and would allow complete freedom in the design of the nozzle geometry. The effect that varying the nozzle geometry has on the spray penetration and distribution could then be more easily studied.

CONCLUSION

The use of a diaphragm has been shown to be a feasible alternative to conventional plunger mechanisms in hydraulically actuated injectors. The principle advantage of using a diaphragm is that it avoids the lapped surfaces of a plunger-type design. These surfaces move relative to one another and, therefore, require precision maching and special seals to prevent leakage. This is avoided with the use of a diaphragm, which is an effective and unexplored alternative to conventional designs.

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