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# Development of a Piezo-actuator for a Fuel Injector

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Abstract:

The development of stacked piezoelectric actuator was reported in this paper, where a number of disks of piezoelectric materials were piled up, as a means for solving the problem of displacement in the piezoelectric actuator to be used for driving the fuel injection valve in the engine of stratified combustion type. An actuator giving high displacement was successfully produced by stacking piezoelectric disks.

Key words: Piezoelectric Ceramics, Fuel Injector, Actuator, PZT, Response Time

## 1. INTRODUCTION

As understanding of the mechanism for affecting some engine performance, such as mileage, output and exhaust advances, a number of R&D works on the direct-injection engine have been reported. Currently, Toyota Motor Corp. [1], Mitsubishi Motors Corp. [2], and Nissan Motor Co., Ltd.[3] have put their direct-injection gasoline engines, particularly, those based on stratified combustion system, into the market. The direct-gasoline injection engine is characterized by the injection of atomized fuel in the compression stroke, and has the geometry of the piston crown designed in compliance with the combustion, based on the proposal of Barber et al.[4] The implementation of this design owes to the development of the electronic control for the fuel supply system and of the pressurized fuel injection.

There are two types of spark-ignited combustion of fuel directly injected into the cylinder, (1) homogeneous combustion and (2)stratified combustion. In the former, fuel is injected during the intake stroke, while in the latter, air taken in the intake manifold and fuel is injected in the compression stroke. In the fuel injection device for the current high pressure fuel injection system, the fuel is injected through a solenoid-controlled injection valve at an injection pressure of 7 MPa, which is higher than the pressure in the course of compression stroke. However, the operating time of a solenoid-controlled valve is in the order of a millisecond, which is rather long for the compression stroke. In case of stratified combustion system, it will be necessary to reduce the operation time. While the possible alternative of valve control device based on the available materials may include piezoelectric and magnetostrictive actuators, both actuators have not yet been put to the practical application. The former involves problems in displacement, and the latter those of drive coil.

The present report concerns the development of a stacked type piezoelectric actuators to be used for driving the fuel injection device for the stratified combustion system, where the problem of displacement has been solved by adopting the structure of stacking piezoelectric plates (Fig. 1 )

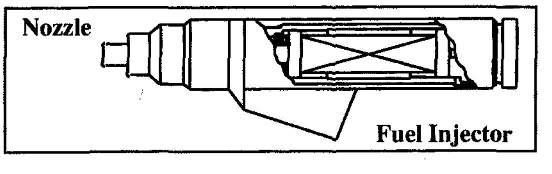



Figure 1 Schematic view of a piezoelectric actuator and a fuel Injector.

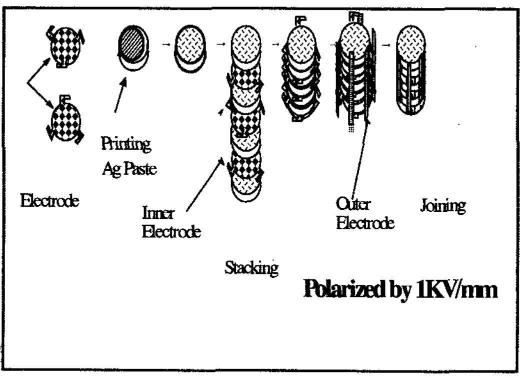
## 2. CONSTRUCTION AND OPERATIONAL CHARACTERISTICS OF PIEZOELECTRIC ACTUATOR

### 2.1 Piezoelectric materials

In the present study, lead zirconate titanate (PZT:Table1) commercially available, were used. Sintered material was shaped into a cylinder of 13 mm outer diameter by grinding and sliced into 0.3 to 0.4 mm thick disks. Electrodes were bonded to the disk surface with silver paste (containing glass ingredients). After being baked, an electrical field of 1 kV/mm was applied in the axial direction within silicone oil at 80 ° C to polarize. The manufacturing process is illustrated in Fig. 2. The piezoelectric material parameter($d_{33}$) of this experiment are : 570 pC/N.

Table1 Materials properties

| | PZT |
|---|---|
| $d_{33}$(pC/N) | 570 |
| Kt(%) | 51 |
| Kr(%) | 70 |
| $\varepsilon$ | 2500 |
| E(GPa) | 69 |
| t(mm) | 0.34 |
| Tc(K) | 503 |

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### 2.2 Construction of piezoelectric actuator

The actuator used in the present study consisted of 70 to 100 pieces of PZT disks stacked with silver electrode film sandwiched between adjacent disks, as illustrated in Fig. 2. The silver electrodes serve as anodes and cathodes alternately, and when a voltage is applied to each pair of electrodes, the device extends or contracts axially. At both ends of the device, metallic end plates (of stainless steel;SUS) are installed to receive the load directly. In practice, the metallic end plates undergo the load directly.

## 3. EXPERIMENTAL RESULTS

### 3.1 Static displacement

A piezoelectric actuator consisting of 100 pieces of piezoelectric disks stacked together is set in an evaluating setup (L=45mm) shown in Fig. 3. The actuator is subjected to a load of 0.09 to 0.17 MPa. When a test voltage of 0.05 Hz, 500 V and triangular waveform is applied to the actuator and the response is monitored by using a laser-based displacement sensor, the voltage-displacement characteristics as shown in Fig. 4 is obtained. The actuator gave 37 μm displacement at 500 V, and the ratio of maximum differential displacement to maximum displacement in the displacement loop was 21.0 % in terms of hysterisis. While the actuator is often used in combination with a displacement expander, the expansion factor is to be held lower for ensuring faster response and greater force output.

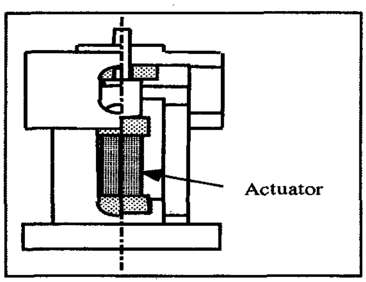


Figure 3 Displacement evaluation apparatus for an actuator

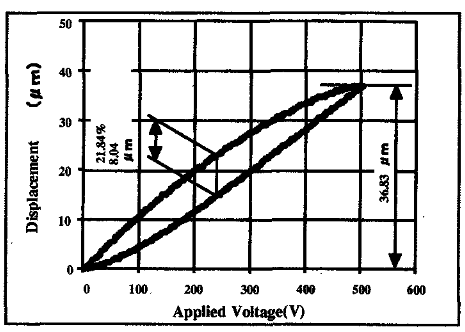


Figure 4 Displacement vs applied voltage

### 3.2 Effects of pre-loading to voltage-displacement

characteristics

A specified load is applied to the actuator mounted in an evaluating device (Fig. 5), and the voltage-displacement characteristics was measured. The relationship between load applied to and maximum displacement of the actuator is shown in Fig. 6. In this test, the voltage-displacement characteristics was measured at maximum voltage of 500 V and 800 V, while in loading the system every time the actuator was pre-loaded with 0-34.6MPa.

For the PZT devices shown in Fig. 6, the higher the preload value was, the greater the displacement became. At 34.6MPa pre-load, the displacement was 35-50 μm at 500 V, and 50-70 μm at 800 V, indicating that the higher the voltage applied to the actuator was, the more the response became susceptible to the pre-load.

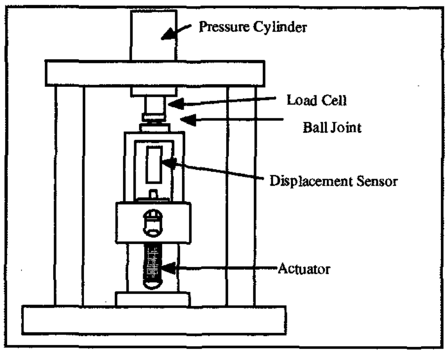


Figure 5 Equipment for measuring displacement

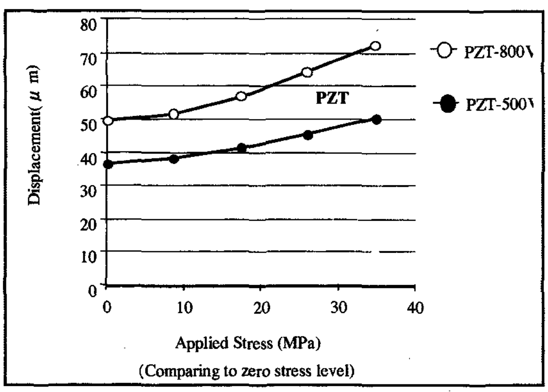


Figure 6 Pre-load dependence of displacement

then, the compression of displacement was measured while changing the load from 0 to 52MPa . As the load is increased, the actuator is compressed non-linearly, as a rule, with a segment of linear decrease between 17.4MPa and 43.3MPa. Beyond 52MPa, the change augments yielding a constriction of 70-100 μm.

The effect of pre-loading to the voltage-displacement response of this actuator is discussed. When the applied load exceeds 52MPa, the actuator fails to provide a displacement. This result is in compliance with the load-distortion relation at higher value of load, shown in Fig. 7. This indicates that overloading to the actuator may spoil its mechanical properties. It is recommended, therefore, to operate the actuator while applying voltage in an area relatively insensitive to the load.

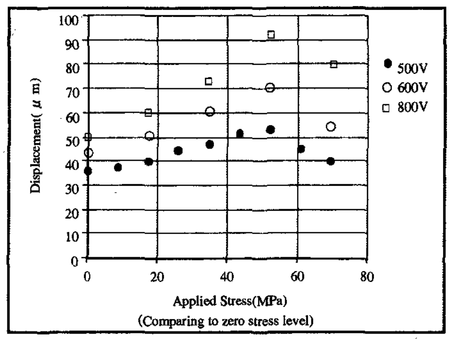


Figure 7 Pre-load dependence of PZT actuator

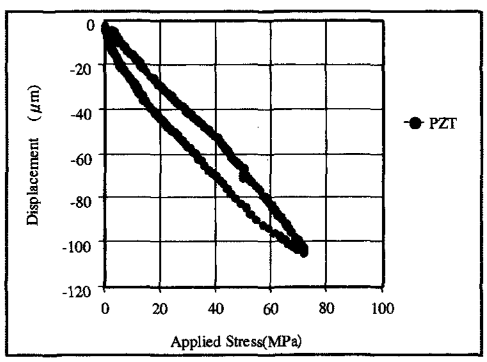


Figure 8 Load displacement(500V applied)

3.3 Load-Displacement characteristics for PZT device

The construction of the newly designed load-displacement evaluation gauge is illustrated in Fig. 5. For the evaluation, the gauge reading was set to zero by applying 500 V, without preload (0.09-0.17MPa), and

3.4 Response time for PZT device

A PZT actuator is mounted on the displacement gauge (Fig. 5) and preloaded. A square wave voltage is applied from an actuator driver to cause quick changes in displacement. The response of the actuator is evaluated by reading the behavior of voltage applied and the delay in displacement, while monitoring the reference signal to set off the actuator driver, the output voltage of the actuator driver and the displacement of the actuator (Fig. 9).

The response time depends upon matching between the actuator and the driver, and upon a time constant specified by electrostatic capacitance C and resistance R. The response time was 0.07 msec at the conditions given in Fig. 9 (preload 1.7MPa and driver output voltage 0, 500 V). In order to increase the response time, the time constant is to be set larger.

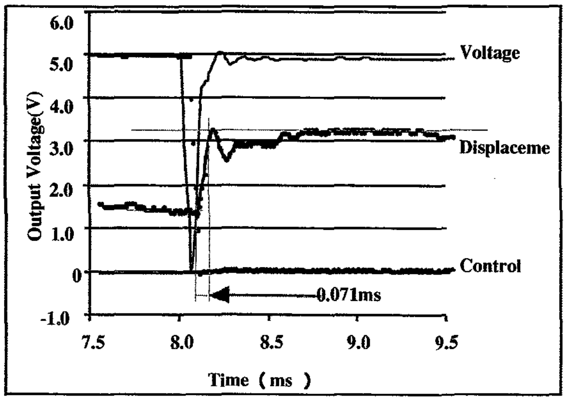


Figure 9 Response period as an actuator

4. CONCLUSION

The development of stacked piezoelectric actuator was reported in this paper, where a number of disks of piezoelectric materials were piled up, as a means for solving the problem of displacement in the piezoelectric actuator to be used for driving the fuel injection valve in the engine of stratified combustion type. An actuator giving high displacement was successfully produced by stacking piezoelectric disks.

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