

Technology for Reducing Engine Rubbing Resistance by Means of Surface Improvement

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ABSTRACT

A surface modification method has been developed that uses shot peening to reduce the rubbing resistance on piston wear surfaces. This technique shoots roughly spherical ceramic bead having a central particle diameter of 40 μm with compressed air at a speed of 100 m/sec or more against the surface of the object to be processed. This peening treatment produces countless microscopic dimples that improve the oil retention capability of the treated surface and results in a 2–2.6% reduction of the lost output from an engine unit due to friction. Engine units with this treatment were subjected to an extended operation test to verify the sustainability of the effects from this treatment. The results showed that dimples remained on the parts even after an extended period of operation. The treatment was also proven to be effective in increasing the anti-seizure characteristics of the pistons.

1. Introduction

Amid the ever-growing concern for the global environment and for the conservation of the planet's resources, there is an increasing demand for automobiles that consume less fuel. In order to improve heat efficiency and reduce mechanical loss to thereby improve the efficiency of automobile engines, research ⁽¹⁾⁽²⁾ has been undertaken from various approaches. Particularly worthy of note in terms of mechanical loss are the improvements that focus on even minute aspects of engine parts such as the improvements in the roller follower valve motion systems and the reduction of the weight and tensile strength of piston rings. The authors focused their current studies on reducing rubbing resistance by improving the properties of the rubbing area surfaces. As a result of their efforts, they managed to reduce piston drive loss, which accounts for 40% of mechanical loss, by 30% by improving the surface properties. This paper reports on the friction loss reduction results, anti-seizure characteristics, and sustainability of the effects accomplished by the authors. Further, it provides mass production application examples.

2. Technology for reducing mechanical loss

As shown in Fig. 1, 60% of the total loss sustained during partial load operation is accounted for by mechanical loss. A breakdown of the mechanical loss shows that piston driven loss (rubbing resistance of the pistons) is responsible for 40% of this loss, a figure that clearly shows that a reduction

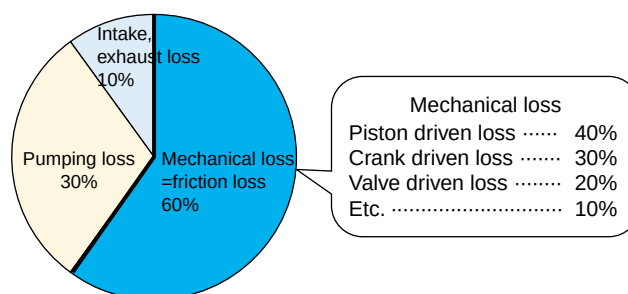


Fig.1 Engine component loss division at Ne =1500rpm, P intake =-53kPa

of the rubbing resistance of the pistons will be an effective way of improving fuel economy. In the past, a number of techniques have been used to reduce this rubbing resistance. They include coating solid lubricants typified by molybdenum and applying coatings or plating tin onto the walls of the pistons. However, these techniques were only marginally effective in reducing rubbing resistance, and the sustainability of their effects was called into question by peeling and wear. Marking a departure from these techniques, the authors tackled the issue by improving the surface properties of the rubbing areas to achieve sustainable rubbing resistance reductions.

2.1. Lubrication condition of piston skirts

In order for the rubbing resistance to be reduced by engineering improvements in surface properties, it is necessary to effectively increase the retention of the

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lubricating oil that comes between the mechanical parts and rubbing areas. By doing this, it then becomes possible to continuously maintain the fluid lubrication status under any engine operating conditions, facilitate smooth rubbing actions, and reduce rubbing resistance.

First, the rubbing surface characteristics of the currently available pistons and cylinders were examined (see Fig. 2). Spirally shaped tool marks around the piston skirt sides known as skirt streaks whose main purpose is to improve the anti-seizure characteristics were made by machining in the circumferential direction.

Furthermore, when the piston sides were observed under a microscope, it was found that countless microscopic tool marks had been made during the machining also in the circumferential direction.

These surface machining characteristics affect the surface lubrication characteristics during operation. When a piston is subjected by the combustion gases to an explosive load so that it moves in the thrust direction and is pushed forcefully against the cylinder, the capillary phenomenon occurs. According to this phenomenon, the lubricating oil between the cylinder and piston flows along these microscopic machine tool marks in the circumferential direction. For this reason, it is difficult for the oil film to be maintained between the rubbing sections of the cylinder and piston, which leads to an increase in the rubbing resistance and, in some cases, promotes galling and seizure.

3. Reduction in rubbing resistance achieved by micro dimple processing

The machine tool marks must be removed if the capillary phenomenon corresponding with these tool marks is to be prevented.

The authors used micro dimple (or “MD” for short) processing as the means to achieve this.

MD processing is a type of shot peening in which roughly spherical ceramic beads with a central particle diameter of 40 μm are shot with compressed air at high speeds of 100 m/sec or more against the surface of the object to be processed. It adds countless microscopic dimples (MD) to this surface and eliminates the machine tool marks without changing the dimensions of the object to be processed, and it forms oil pits which are effective in reducing rubbing resistance.

3.1. Verification of rubbing resistance reduction by a reciprocating friction test using test pieces

In order to verify the effectiveness of the MD processing in reducing rubbing resistance, the authors measured the coefficient of friction and seizure load by conducting a reciprocating friction test using test pieces (or “TPs”). An overview of this test is shown in Fig. 3.

While allowing lubricating oil to drip onto the rubbing surface of a plate that simulates a cylinder, the TP was rubbed back and forth at a stroke of 50 mm over the plate surface,

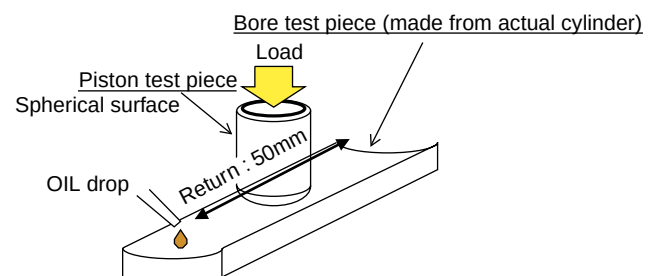


Fig.3 Two way friction test machine (simple drawing)

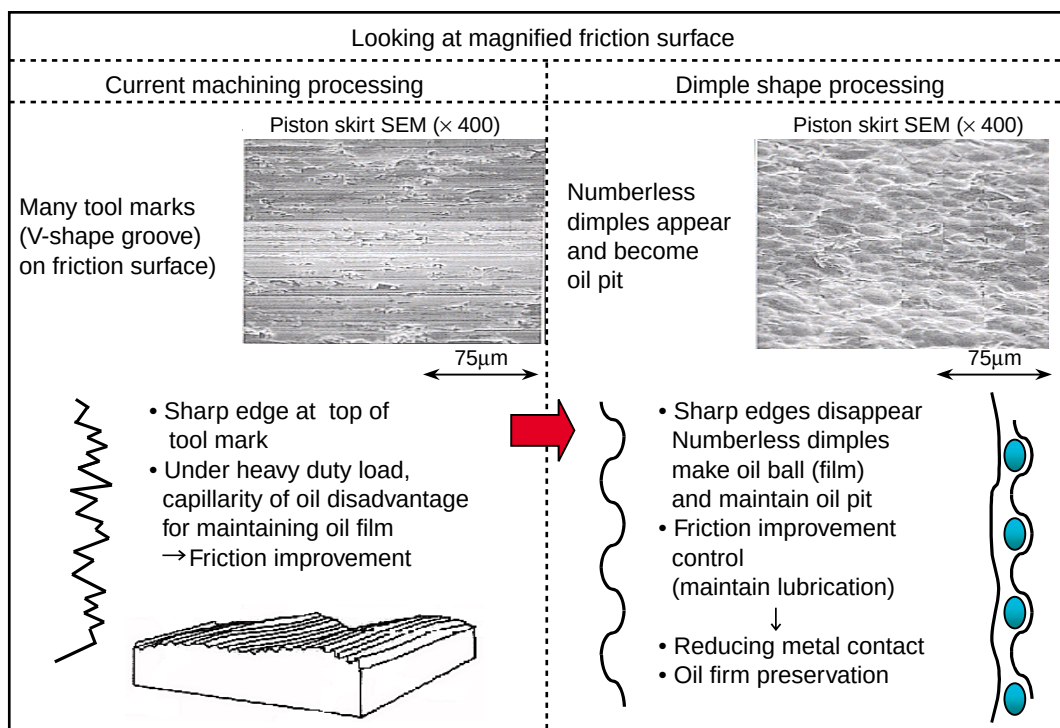


Fig.2 Dimple effect (expectation)

the pressing load was incrementally increased, the coefficient of friction (μ) was measured in real time and integrated with the time to calculate the average friction resistance per unit time. The results of this are shown in Fig. 4.

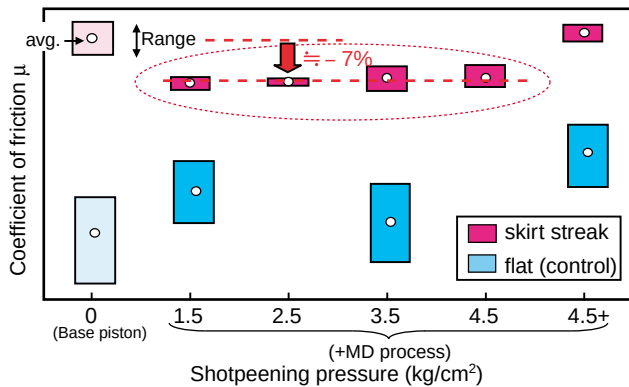


Fig. 4 Two way friction test result

The TP which was subjected to MD processing on its skirt streaked rubbing surface showed a reduction in the coefficient of friction (μ) of about 7% across the shot peening pressure range of 1.5 to 4.5 atmospheres (gauge pressure; hereafter all pressures will be given as gauge pressures) compared with a surface which had merely been skirt streaked.

For the purposes of comparison, the results for a TP which had been MD processed on a flat surface devoid of skirt streaking are also given. The TP with a flat surface which had not been MD processed yielded the lowest coefficient of friction (μ). Nevertheless, as shown in Fig. 5, the seizure load is higher for the skirt-streaked surface than for the flat surface, and it was clearly established that this load is further improved by conducting MD processing for the skirt streaking.

The authors were able to verify from the results of this test that performing MD processing on the skirt streaking is an effective way of improving both the coefficient of friction and seizure load.

3.2. Reduction in rubbing resistance by MD processing conditions

Based on the results obtained from the above TP friction test, the authors fabricated pistons whereon the entire rubbing

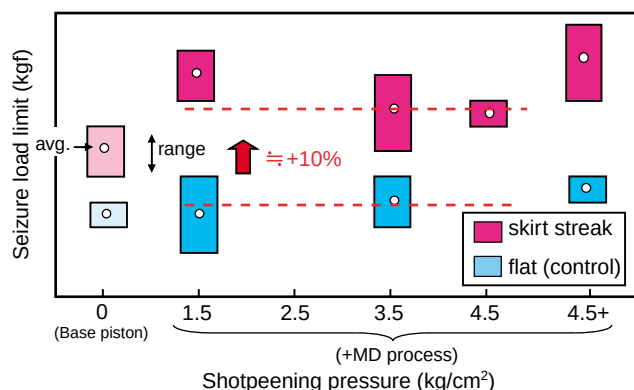


Fig. 5 Two way friction test result

surface of the skirt was streaked and MD processing was implemented at a shot peening pressure of 1.5 to 4.5 atmospheres as shown in Fig. 6. The mechanical loss for engine units was measured using the motoring method.

Fig. 7 shows the characteristics of the mechanical loss decrease versus shot peening pressure. Three engines with a displacement of 1.0, 1.5 and 2.2 liters were tested. A mechanical loss decrease rate of more than 1% was obtained with a shot peening pressure ranging from 1.7 to 4.5 atmospheres. This rate was at its highest at a shot peening pressure of 3.5 atmospheres for all the engines and a friction reduction rate of 2% to 2.6% was achieved.

On the basis of the above results, a shot peening pressure of 3.5 atmospheres was set as the MD processing condition, and a central particle diameter of 40 μ for the ceramic beads shot material was selected. The average MD depth obtained under these conditions turned out to be 0.6 to 1.8 μ . To determine this depth, surface roughness Ra was measured, and the resulting value was used.

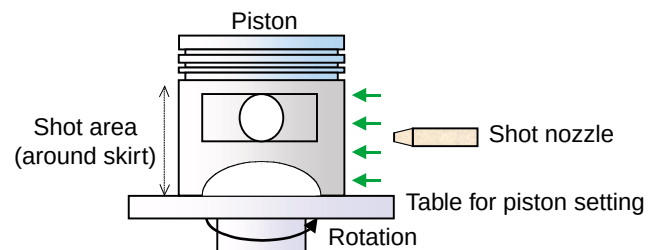


Fig. 6 MD process piston setting layout for machine

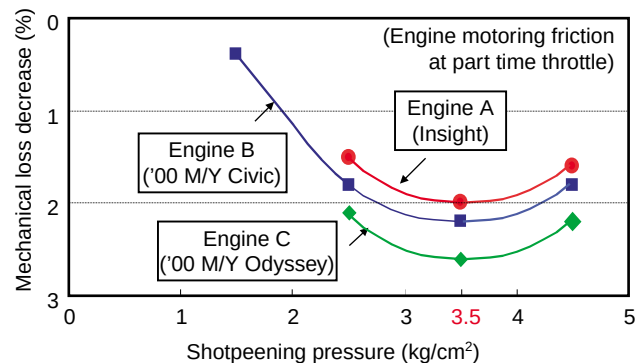


Fig. 7 Shotpeening pressure and mechanical friction loss

3.3. Verification of the sustainability of the MD processing effect

In order to understand the sustainability of the MD effect, the engine units were run on a dynamometer under a high load for a prolonged period. After a prescribed period of time had elapsed, the motoring method was used to measure the mechanical loss.

Fig. 8 shows that, compared with the unprocessed piston, the MD processed piston had a lower mechanical loss starting from the initial state. Even after 120 hours, it showed a mechanical loss reduction effect of at least 2%. The changes in the wear level of the skirt streaks occurring during this period are shown in Fig. 9.

The initial skirt streak height was approximately 10 μ

and, after a prolonged period of engine operation, it dropped to about 8 or 9 μ , signifying a wear level of 1 to 2 μ .

This wear is not progressive in nature but remains steady after approximately 100 hours of engine operation. As mentioned above, a mechanical loss reduction effect of at

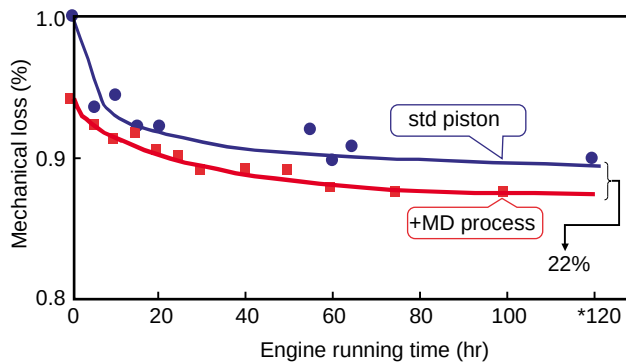


Fig.8 Mechanical loss decrease & eng running time

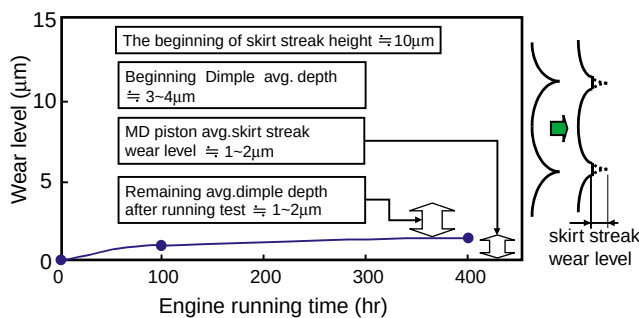


Fig.9 Wear level of MD process piston skirt streak

least 2% compared with the unprocessed piston was achieved in this state.

Fig. 10 shows the status of the rubbing surfaces before and after the prolonged period of engine operation.

It is possible to verify skirt streaking on the unprocessed piston prior to rubbing (see Fig. 10-1). In contrast, on the unprocessed piston after rubbing, the edges of the skirt streaks have been worn away to result in a roughly trapezoidal shape (see Fig. 10-2).

The edges are formed at the borders of the roughly trapezoidal areas by the wearing away of the skirt streak edges accompanying the rubbing of the piston. These edges then act as wipers for the lubricating oil with the reciprocating movement of the piston, and under heavy-duty loads, it is believed that this action, together with the capillary phenomenon, makes it difficult for the oil to be supplied to the actual rubbing parts.

In contrast, countless MDs with no gaps between them are visible on the MD processed piston prior to rubbing (see Fig. 10-3).

Furthermore, even after rubbing, the MDs still remain although the skirt streak edges which constitute the actual rubbing surface have been worn away (see Figs. 10-4 and 11).

The shape of the border areas on the actual rubbing surface is changed from a roughly trapezoidal one to that with many inlets formed by the subsequent MD processing. For this reason, it is believed that the lubricating oil present in the large valleys between the skirt streaks is supplied to the actual rubbing areas from these inlets while the piston reciprocates as well as being supplied to the MDs still remaining on the actual rubbing surface. This process results

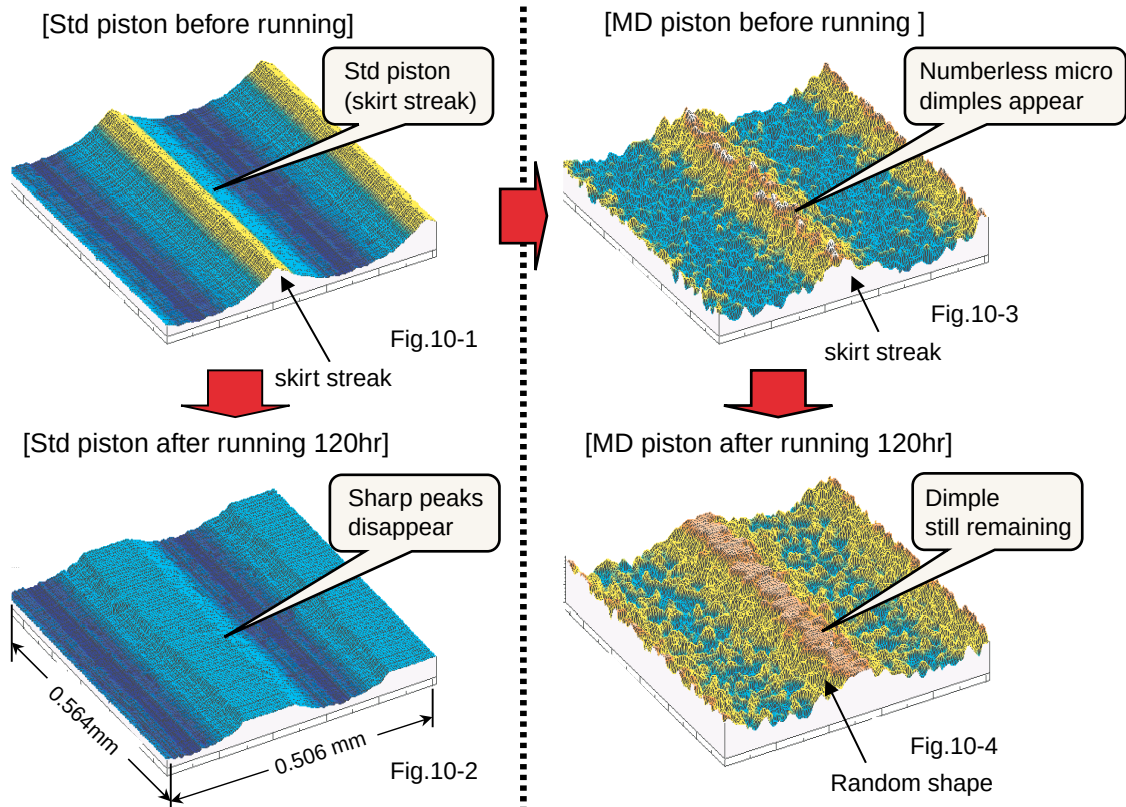


Fig.10 Characteristic of piston wear

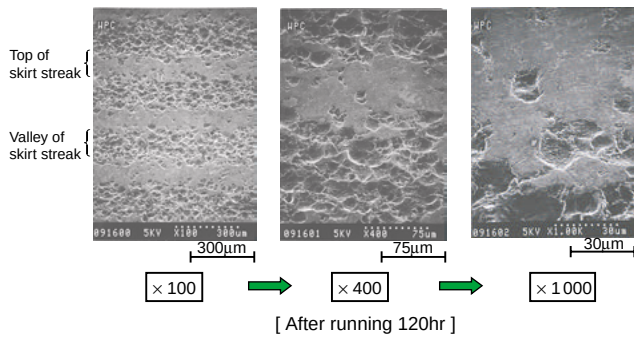


Fig.11 Looking at magnified MD piston skirt surface

in improved rubbing characteristics.

Figs. 12 and 13 show the results obtained by measuring the 2-dimensional surface shapes of piston skirt cross-sections with and without MD processing before and after prolonged engine operation. Countless microscopic dimples are formed by the MD processing, and the existence of these dimples can be verified even after the prolonged engine operation.

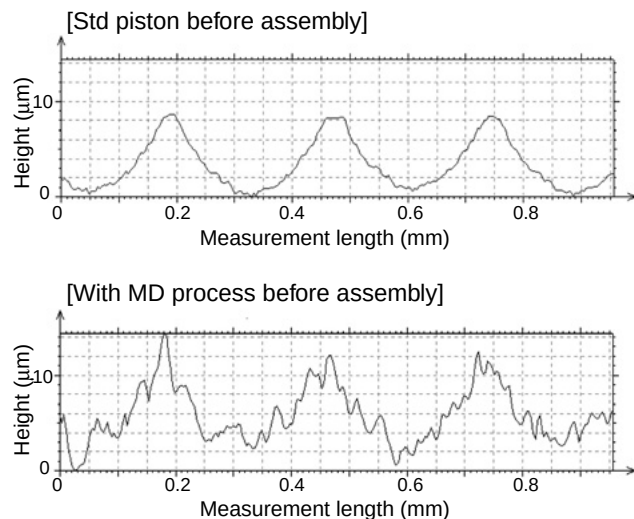


Fig.12 Surface curve of piston skirt-1

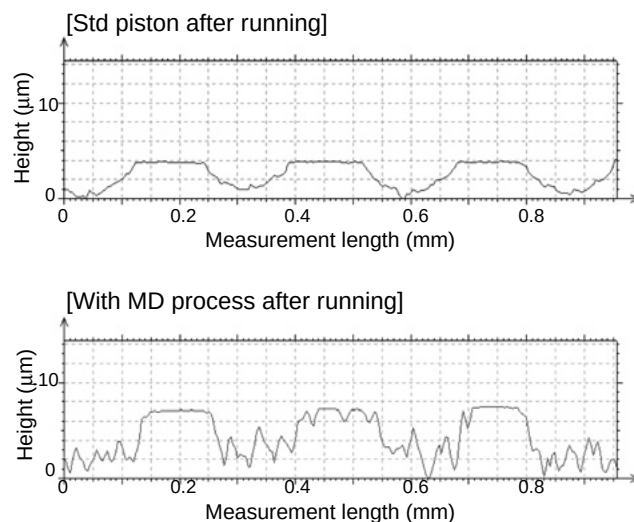


Fig.13 Surface curve of piston skirt-2

4. Summary

The following results were obtained by refining (MD processing) the surfaces of piston skirts with a shot peening process:

- (1) MD processing reduced the piston drive loss and cut the mechanical loss of the engine by 2% to 2.6%.
- (2) In terms of the MD processing conditions conducive to producing the most significant effect in reducing rubbing resistance, roughly spherical ceramic beads with a central particle diameter of 40 μ are shot at a shot peening pressure of 3.5 atmospheres with compressed air at speeds of 100 m/sec or more around the entire circumference of the piston skirts.

5. Conclusions

Application of the technology achieved through the authors' research has expanded since its initial application to Honda's first hybrid car, the Insight.

The authors believe that research to identify, improve and refine the kinds of local lubrication conditions which were explored in their own research will become more and more important with time.

Even in terms of surface properties, there is still a great deal of potential for improvement, development and application in terms of adoption with other parts, welding of different kinds of materials and improvements in surface roughness.

The authors intend to continue their efforts to develop the technology that will enable the creation at will of surface properties that correspond to the application.

Last but not least, the authors wish to acknowledge all the support they received in conducting their research and also express their sincere gratitude for all the valuable technological guidance and advice they received from Mr. Mase, Mr. Sugawara, Mr. Kumagaya and Mr. Ishiwata of Fuji Seisakusho and from Mr. Miyasaka of Fuji Kihan.

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