

Development of Lightweight and Compact 6-speed Manual Transmission

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ABSTRACT

A high capacity 6-speed manual transmission has been developed based on the existing compact, well-established 5-speed manual transmission for 1.5-liter engines without increasing the overall length of the transmission. In order to ensure both high capacity and compactness, the synchronizer sleeve stroke of each gear has been reduced, and the specification and width for each gear was optimized. Gear noise was reduced by using a rigid, yet lightweight case shape designed using CAE analysis. The resulting 6-speed transmission has an overall length of 352 mm and total weight of 47 kg, making it light weight and compact.

In addition, a new structure was employed for the change link mechanism in order to enhance the gear-shift feel.

1. Introduction

Though 6-speed manual transmissions (hereafter 6MTs) were formerly installed mainly in large-displacement and sporty vehicles, market trends in recent years suggest that they are increasingly being installed into ordinary, small-displacement vehicles. Currently, this trend is centered in Europe.

Honda has already installed 6MTs into engines of 2.0 L or larger displacement as well. Now, however, a new 6MT has been developed for installation in compact vehicles with small-displacement engines. For that purpose, the new 6MT has been made more compact with lower friction. This article will give an introductory overview of this 6MT and the main elements of the techniques involved.

2. Development Goals

The development concepts for the new 6MT included “achieving a balance of high capacity and lightweight compactness,” “enhanced gear shift feeling” and “enhanced transmission efficiency.” The four items described below were identified as objectives for the purpose of realizing the concepts for development.

- (1) Achieve a 6MT having, at most, the same total length as the conventional 5MT used with 1.5-L engines to ensure that there is an adequate degree of freedom for it to be installed into small-displacement vehicles.
- (2) Achieve a balance between enhanced noise and vibration (NV) performance and lighter weight.
- (3) Provide a crisper, smoother gear shift feeling.
- (4) Achieve a friction level equal to or lower than the conventional 5MT.

3. Basic Construction and Specifications

The external appearance and major sectional views are shown in Fig. 1 and Fig. 2, respectively. The main specifications are shown in Table 1.

The 6MT gear train is a parallel dual-shaft configuration. Gears 1 through 6 are synchromesh gears that are always in contact. The reverse gear has a selectable sliding configuration. A high-capacity single cone synchronizer was adopted, and the arrangement of the bearings was optimized as a way of reducing friction in the gear train.

As shown in Fig. 1, a new structure was set up for the change link mechanism and situated in the upper part of the gear train.

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Table 1 Specifications of transmission

Transmission type		6-speed Manual
Torque capacity (Nm)		Over 175
Gear ratio	1st	3.142
	2nd	1.869
	3rd	1.303
	4th	1.054
	5th	0.853
	6th	0.727
	Reverse	3.307
Weight (wet)	(kg)	47

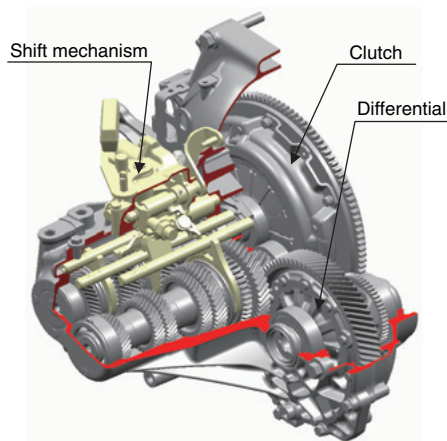


Fig. 1 View of transmission

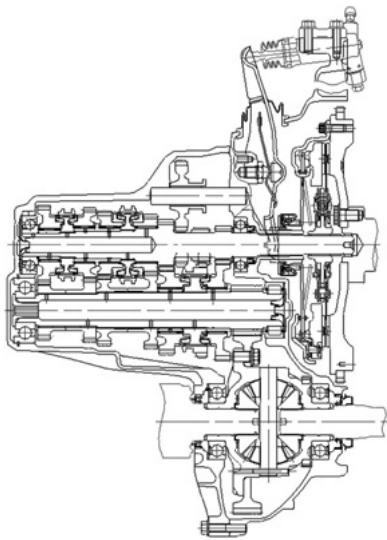


Fig. 2 Cross-sectional view of transmission

4. Techniques for Achieving Compactness

4.1. Gear Train Construction

Development proceeded with the objective of building a 6MT based on the existing 5MT for 1.5-L use and having the same length as the 5MT. This objective was achieved through the development of techniques for shortening the overall length so that in creating the 6MT, the expected overall lengthening would not occur (Fig. 3).

4.2. Shortening the Synchronizer Sleeve Stroke

The factors that determine the total length of a manual transmission include the dimensions of the gear and bearing components and the stroke space of the synchronizer sleeve (hereafter sleeve), which moves when the gears are changed.

The sleeve functions to actuate and synchronize the synchronizer ring. When the gear shifting is complete, the sleeve also meshes with the clutch gear and functions to transmit the power. The sleeve stroke is determined by the sum total of the dimensions necessary to fulfill those functions. Figure 4 shows the component elements of the sleeve stroke. In this development, the sleeve stroke was reduced by shortening the distance from completion of synchronizing to gear contact, as shown in Fig. 4.

That portion of the stroke was made shorter by changing the shape of the sleeve in first and second gears, and by revising the synchronizer ring shape for the remaining gears. The following describes the change of the sleeve shape for those remaining gears.

Conventional sleeves would use all their teeth for both their synchronizing and clutch gear meshing functions. In this development, however, the teeth used for synchronizing and the teeth used for meshing were separated and a relative difference in level was placed between them. This resulted in a shorter distance between synchronizing and contact with the clutch gear, achieving an approximate 5 mm shortening of the total length of the six gears. This was also effective in reducing the double-bump feeling, which will be discussed later. A structural comparison of the conventional sleeve and the newly developed one is shown in Fig. 5.

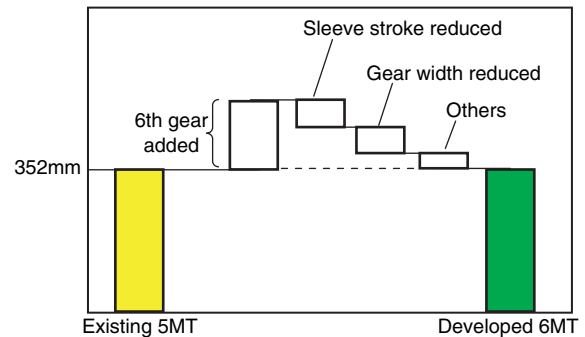


Fig. 3 Effect of reducing length of each part

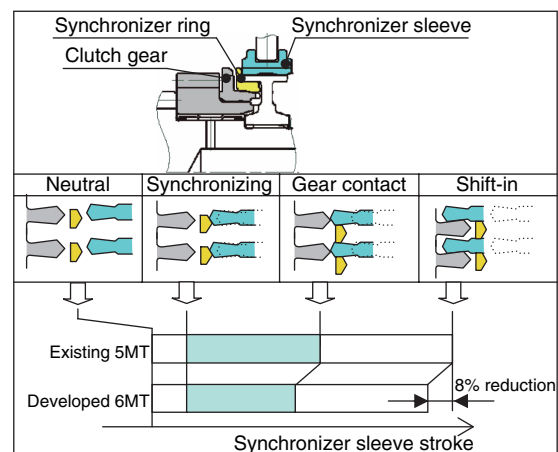


Fig. 4 Comparison of synchronizer sleeve stroke

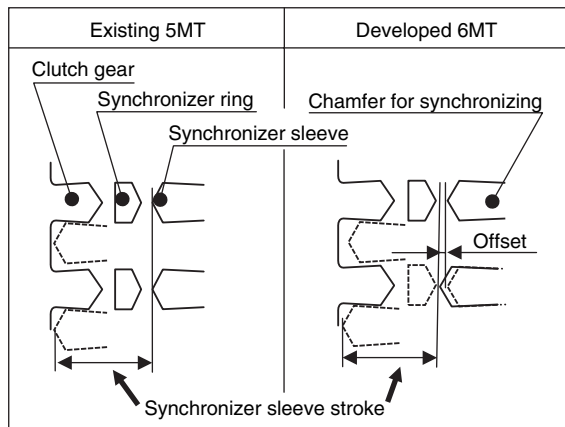


Fig. 5 Comparison of synchronizer sleeve shape

4.3. Reducing the Gear Width

There were concerns that reduction of the gear width would affect the durability of the gear itself and increase gear noise. In this development, some of the gears were made into small modules and the specifications were optimized in order to assure durability. This also increased the contact ratio, which affects gear noise. As a result, the gear width reduction yielded a 4 mm shortening of the total length.

5. Techniques for Achieving Lighter Weight

The use of techniques to achieve more compact dimensions and efforts to achieve lighter weight made it possible to develop a 6MT with a weight of 47 kg (wet), which is the same as that of a 5MT. A comparison of the total transmission weight is shown in Fig. 6. The main aspect of this weight-optimization effort to be described here is the design of the transmission case, which has the greatest impact on weight reduction.

Advances in CAE analysis technology have made it possible to use FEM models for analysis at the design stage. This means that stress, rigidity and behavior can be predicted accurately before fabricating a prototype. Using this technology not only enhances development efficiency, but also enhances accuracy in predicting the effects of means used to achieve objectives. In this development, the above-mentioned technology made it possible to create an effective design to achieve the dual objectives of rigidity and lighter weight, demands that are mutually contradictory⁽¹⁾.

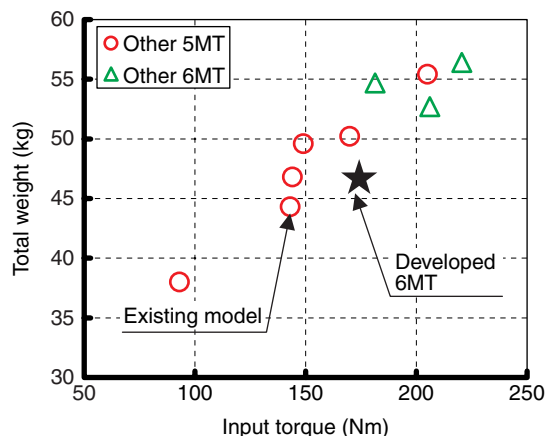


Fig. 6 Comparison of transmission weight

Making use of these analytical techniques, a new case structure was designed with the objective of raising rigidity to enhance NV performance with a minimum amount of weight increase. Analysis by FEM modeling of the case at the initial stages of design made it possible to predict vibration characteristics and stress. An effective rib layout was made and the case shape reevaluated accordingly to minimize surface vibration and thus mitigate the radiant noise⁽²⁾. As a result, the performance objective was achieved with a minimal weight increase relative to the base 5MT (Fig. 7).

The case example of analysis of vibration characteristics conducted for this development is illustrated in Fig. 8. The vibration characteristics obtained by the analysis are shown in Fig. 9.

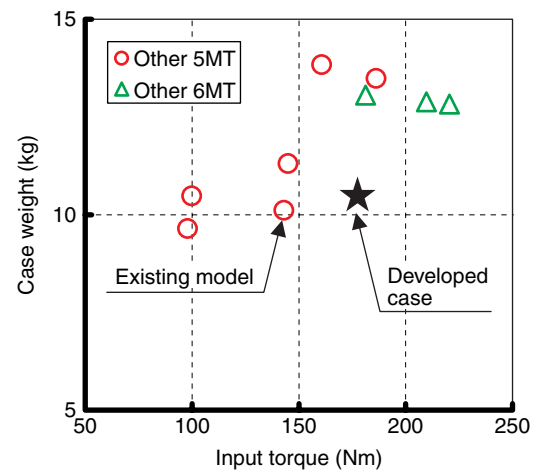


Fig. 7 Comparison of case weight

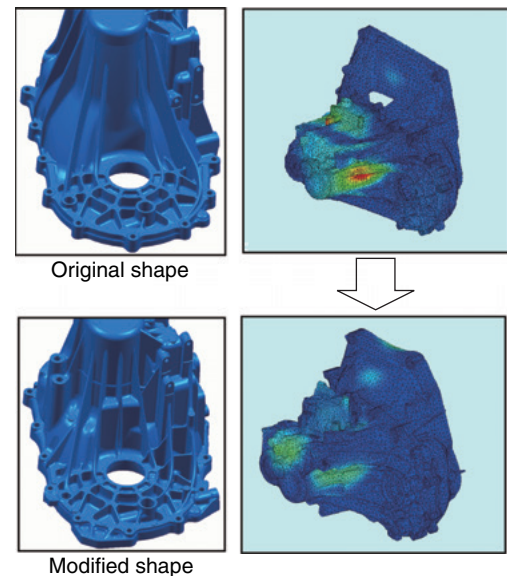


Fig. 8 Comparison of model shape

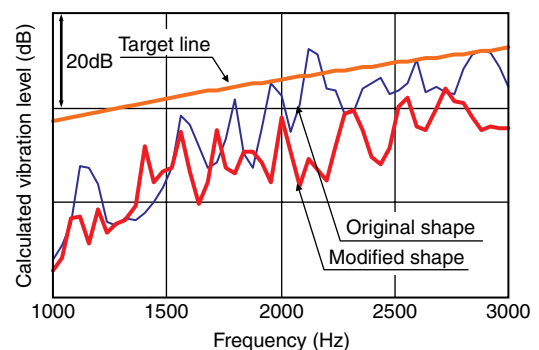


Fig. 9 Comparison of sound pressure level

6. Enhancing the Gear Shift Feeling

In order to realize the development objective of providing a crisper, smoother gear shift feeling, development focused on the following items:

- (1) Reducing the friction sensed when selecting a gear (lateral movement)
- (2) Reducing the effort involved in shifting gears (longitudinal movement)
- (3) Reducing the double-bump feeling

The change link mechanism was made compact by placing the shift selector and the reverse gear lockout as a unit in a single location (Fig. 10).

6.1. Reducing Friction during Gear Selection

Figure 11 shows the selector mechanism. The change link parts turn and slide during gear selection. This causes friction, a negative factor with regard to the shift feeling.

In order to reduce that friction, the development eliminated the link, which was the largest cause of friction during gear selection. Instead, the unit was designed so that the select cable would directly cause the select lever shaft to turn to select a gear position. The mount for that shaft was also equipped with a needle bearing to reduce the rotational friction. As shown in Fig. 12, these measures reduced the overall friction in the selector mechanism by 80% as compared to the conventional mechanism, thereby achieving smoother gear shifts with less sense of hysteresis.

Figure 13 shows the resulting selection effort characteristics.

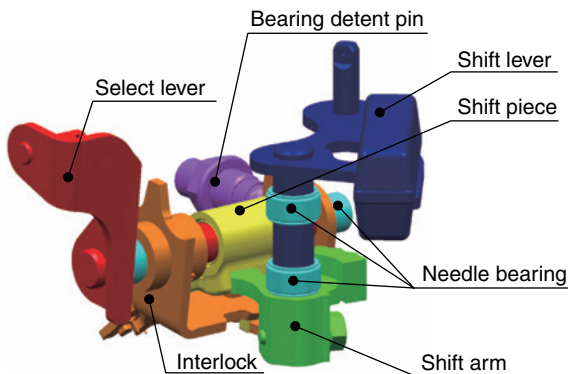


Fig. 10 View of gear change linkage

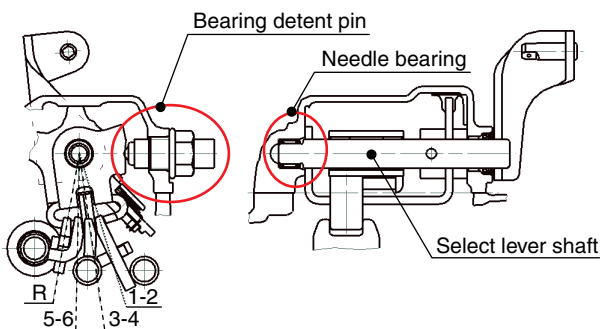


Fig. 11 Gear selector mechanism

6.2. Reducing the Effort of Shifting Gears

Conceivable means of reducing the effort needed to shift gears include not only raising the capacity of the synchronizer, but also increasing the lever ratio from the shift knob to the sleeve inside the transmission. Generally, however, increasing the lever ratio also requires lengthening the shift stroke, which tends to interfere with the light, sporty gear shift feeling.

To increase the lever ratio without lengthening the shift stroke, the shape of the operating part of the shift arm inside the change unit was altered. As shown in Fig. 14, two circles of different radii were combined to form a compound circle shape. This structure enables the lever ratio to be further extended, only when needed, for synchronizing that requires greater effort. Combined with the above shortening of the sleeve stroke, which served to increase the lever ratio, this structural modification enabled an approximate 14%

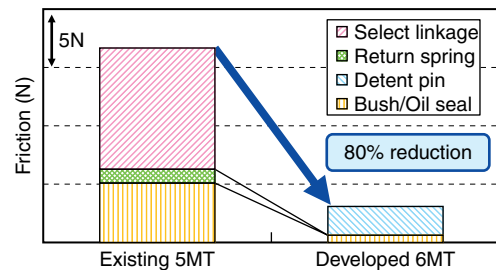


Fig. 12 Comparison of select lever friction

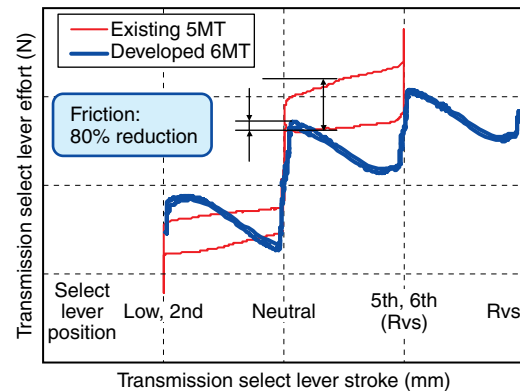


Fig. 13 Characteristics of select lever operation

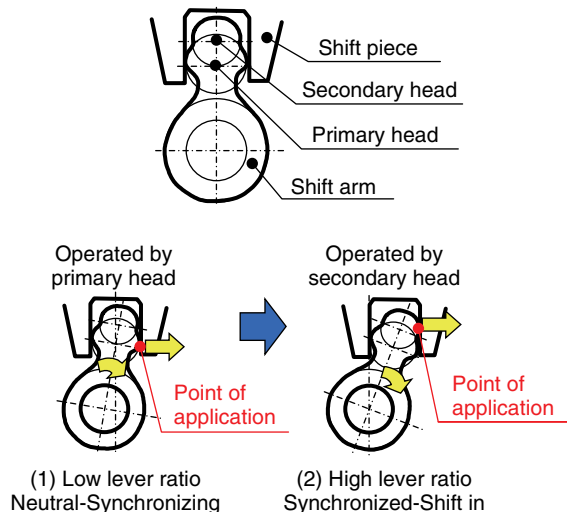


Fig. 14 Operation of variable lever ratio shift arm

reduction in the effort needed to shift gear. Figure 15 shows the effect on reducing the effort required to shift gears.

6.3. Reducing the Double-Bump Feeling

When using the gear shift, the load that occurs like a secondary kick-back after synchronizing ends is called the “double-bump” feeling. This double-bump degrades the shift feeling and occurs when the torsion deformation in the shaft being synchronized is released after synchronizing. This results in another differential rotation, which strongly resists the resultant sleeve-clutch gear contact. The resulting vibration is transmitted to the shift knob as the double-bump⁽³⁾. Figure 16 shows the principle of the double-bump effect.

The shortening of the synchronizer sleeve stroke, as described above, causes a shortening of the stroke and the time from when synchronizing ends to when the sleeve and clutch gear engage. This suppresses occurrence of the differential rotation, and has reduced the occurrence of the double-bump effect by approximately 30%.

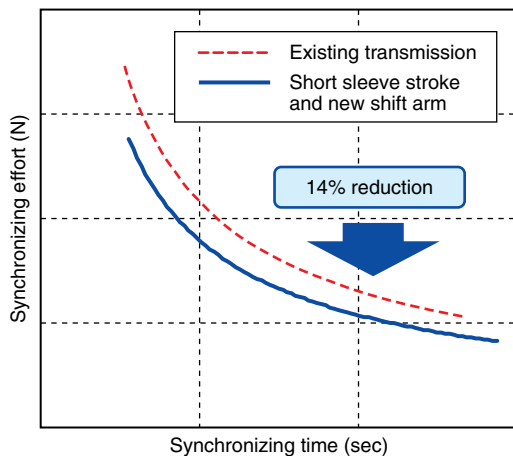


Fig. 15 Reduction of synchronizing effort

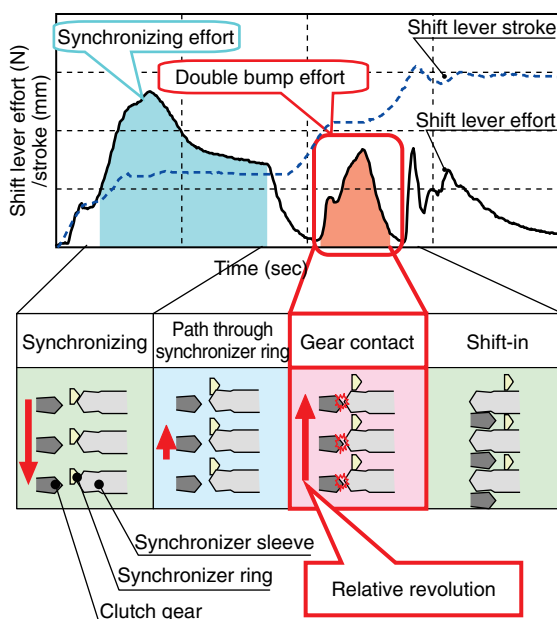


Fig. 16 Principle of double bump effort

7. Enhancing Transmission Efficiency

The factors that reduce transmission efficiency of a manual transmission include, for example, oil agitation resistance and friction in the synchronizer, bearings and other parts of the gear train.

The shift effort-reducing techniques used for this development were combined with the adoption of a high-capacity, single-cone synchronizer for 2nd gear. This made it possible to eliminate the double-cone synchronizer that was formerly used and reduced the rotational resistance occurring in the synchronizer. Conversion to a 6MT also involved reevaluation of the arrangement of bearings, and the roller bearings were consequently eliminated. The ribs located on the interior walls of the case were also made smoother, thus reducing the resistance caused by oil agitation.

The results are shown in Fig. 17. Although conversion to a 6MT caused some increase in friction, it was possible to reduce the friction felt when cruising at 60 km/h by approximately 13% as compared to the conventional 5MT.

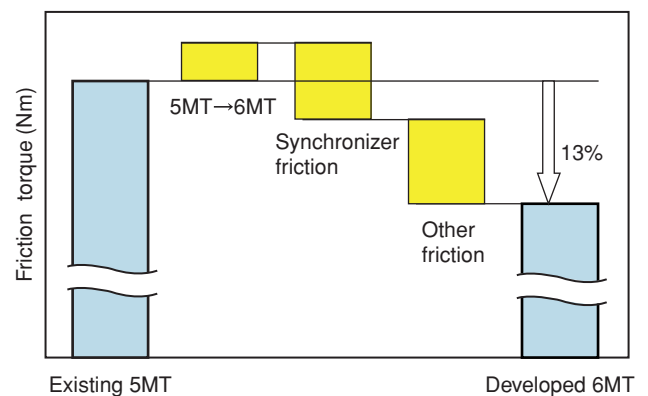


Fig. 17 Transmission friction torque at 60km/h

8. Conclusion

- (1) The total length of the transmission was made shorter by shortening the synchronizer sleeve stroke, and techniques for new gear specifications were established. The result of these methods was the development of a 6MT that has a total length equivalent to that of a conventional 5MT.
- (2) FEM modeling analysis was used to seek higher torque response and reduced vibration. At the same time, a case was developed with a shape that makes it the lightest in its class.
- (3) The friction in the selecting direction when shifting gears was reduced by approximately 80% by means of the structure of the change link mechanism and component technologies for friction reduction.
- (4) The synchronizer sleeve stroke was shortened and the change mechanism was enhanced to reduce the effort needed to shift gears. This also mitigated the double-bump feeling.
- (5) By means including optimization of the synchronizer and bearing specifications, the resulting transmission design, despite being a 6MT, achieved a reduction in friction of approximately 13% as compared to a conventional 5MT.

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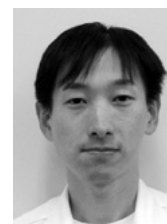
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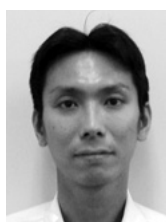
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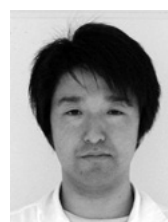
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