

6-Speed Manual Transmission for Honda S660

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ABSTRACT

A six-speed manual transmission has been newly developed for use in the new model S660 two-seater open-top sports car. The new transmission was developed as a compact six-speed manual that nevertheless can support up to 104 Nm of maximum input torque.

In order to take advantage of the engine characteristics, the gear ratios for the first five speeds were configured with close ratios. The sixth gear was configured with a cruise ratio to enhance the quietness of the cabin when cruising at high speeds.

The shift was configured with a short stroke to enable the quick handling of a sports car, and the load displacement characteristics during gear shift operation were optimized. This produced a smooth, moderate gear change feeling when shifting gears.

The noise caused by rotational speed fluctuation of the crankshaft, which is characteristic of three-cylinder engines, was reduced through the adoption of a no-backlash gear and friction washer.

1. Introduction

Manual transmissions for Honda's K-cars (mini-vehicles) include a five-speed manual transmission (K-car 5MT) that is teamed with a 0.66-L naturally aspirated engine (maximum torque of 59 Nm).

The S660, by contrast, is equipped with a 0.66-L boost engine, requiring a new manual transmission with the strength and endurance to support a maximum torque of 104 Nm.

In developing this new transmission, it was decided to make it a six-speed manual transmission (new model 6MT), the first such for a K-car, in order to make advantageous use of the engine's power and torque. Development of this new model 6MT also sought to realize a light, sporty gear change feeling. This paper will introduce technological features of the new model 6MT.

2. Development Goals

The S660 development concepts include the joy of driving and the joy of handling. In order for the transmission to realize these concepts, the following goals were specified in development of the new model 6MT.

- (1) Compact 6MT that can support an engine with maximum torque of 104 Nm
- (2) Gear ratios for six speeds configured to achieve a balance between performance on winding roads and quiet in the cabin when cruising at high speed

- (3) A smooth gear change feeling with a sense of agility and moderation when changing gears
- (4) Limit the noise and vibration (NV) of a three-cylinder engine

3. Basic Construction and Gear Ratio Settings

Table 1 shows the main specifications. Figure 1 shows a cross-section view of the transmission, and Fig. 2 shows a perspective view.

The gear train is a parallel dual-shaft configuration with one counter shaft for the input shaft. Reverse gear was made a selectable sliding configuration. In order to enhance transmission efficiency, splashing-type lubrication was adopted. In order to limit the influence of rotational speed fluctuation in the three-cylinder engine, a no-backlash gear (NB gear) was adopted for the first- and second-gear counter gears.

The input shaft and output shaft were positioned vertically one above the other in order to fit the new model 6MT into the limited space of the engine compartment.

Use of this vertical arrangement introduced the possibility that splashing-type lubrication might prove inadequate for both input and counter shafts since they are farther from the oil surface at the bottom of the transmission. Addressing this by increasing the volume of oil would not only increase the weight, it would also increase oil stirring resistance and therefore reduce

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Table 1 Specifications of developed 6MT

Transmission type		6-speed Manual	5-speed Manual
Torque capacity [Nm]		104	59
Dimension overall length [mm]		340	319
Shaft axis distance [mm]	Input-Counter	65	60
	Counter-Final	112	110
Oil amount [L]		1.4	1.3

transmission efficiency. The issue was resolved by placing an oil separator plate between the transmission case and the clutch case to make a two-level oil surface structure by which the transmission case wall forms an oil reservoir below the counter shaft (Fig. 2).

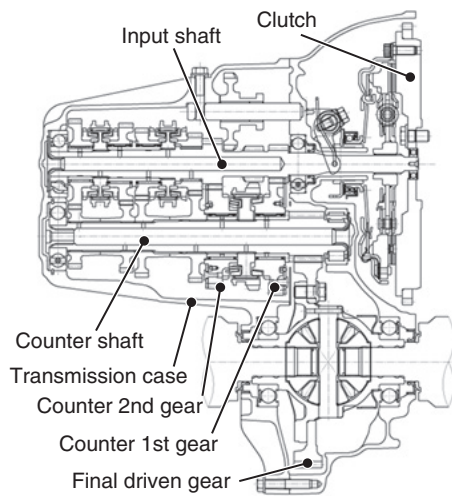


Fig. 1 Cross-section view of developed 6MT

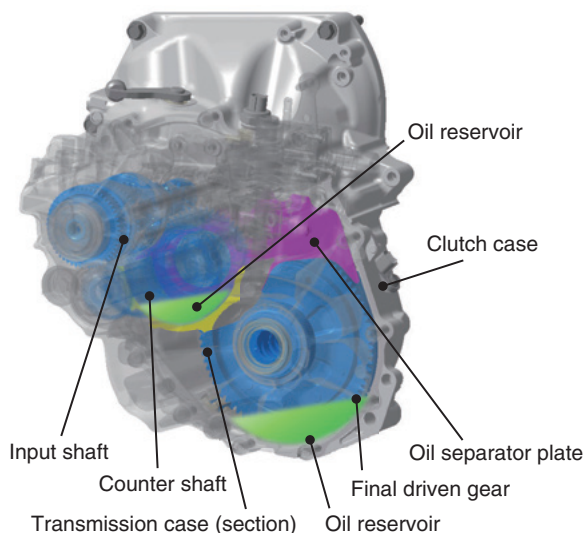


Fig. 2 Perspective view of developed 6MT

The structure was arranged so that oil splashed up by the final driven gear would also collect under the counter shaft. The reservoir of oil there would be splashed up by the counter shaft gear to lubricate the gear stages. With this arrangement, the increase in oil relative to the K-car 5MT was held down to just 0.1 L, and the required overall lubrication was secured without degrading the transmission efficiency.

The gear ratios were configured so that first through fifth are close-ratio gears that enable effective use of the engine's high torque range. Second gear, in particular, was configured to reach 75 km/h in the 7,700 rpm red zone. This allows it to cover the range from 30 to 60 km/h, which is the normal operating range for driving on winding roads. The sixth gear is set so that the engine speed when driving at 100 km/h will be the same 3,200 rpm as found with Honda's FIT RS 6MT. This enhances cabin quietness when cruising at high speeds. Figure 3 shows the driving force curve.

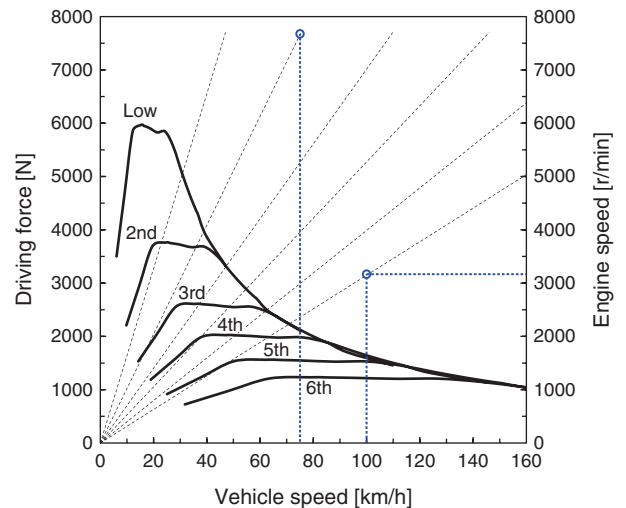


Fig. 3 Driving force curve

4. Increasing Capacity and Compactness

4.1. Increasing Capacity

In order to assure the strength and endurance to support high torque of 104 Nm while also achieving lighter weight and compactness, distances between the shafts were optimized. Higher torque can be supported by increasing the size of bearings or gears, or by switching to a stronger material. Dealing with this without changing the material requires increasing the distance between the input and counter shafts. Steps were taken to limit the increase in weight due to the increased distance between shafts. Bearing size was chosen according to strength and endurance requirements, and synchronizer size

was selected to achieve an appropriate shift load with a short shift stroke. The distance between shafts was set accordingly.

4.2. Increasing Compactness

In order to increase the transmission to six speeds while assuring its mountability in the vehicle, the total length of the transmission needs to be limited. A design for strength⁽¹⁾ was implemented, taking misalignment into account, in order to optimize the gear tooth width, and the synchronizer sleeve stroke was shortened⁽²⁾. Third through sixth gears were also combined into a compact module to assure the contact ratio while reducing the gear width by 5 mm. Optimization of the NB gear configuration also achieved a combined reduction of 0.8 mm in the first and second gears. These measures achieved support for high torque and the increase to six speeds while limiting the increase in total transmission length to just 21 mm relative to the K-car 5MT.

5. Gear Change Feeling

The joy of handling was realized in the S660 by development of a gear change feeling centered on three sensations: agility, moderation and smoothness.

5.1. Agile Feeling

A short stroke configuration was adopted in order to enable the agile sports car handling that would realize a light, agile feeling when changing gears. The shift stroke, shorter than in the previously marketed BEAT, was made 37 mm, which is on a par with the S2000 and NSX. The select stroke was made 22 mm to balance with the shift stroke and to allow for the compact packaging (Fig. 4).

Gear shift operation with a short shift stroke involves an increased synchronization load. Measures were taken to reduce this load by employing a double-cone synchronizer for the second gear and carbon synchronizer for the third gear.

Synchronizer selection was made according to

synchronization load when shifting down, which is a criterion for judging the light, agile feeling⁽³⁾. This will be explained using the selection of synchronizer for second gear as an example. Figure 5 is a chart showing the relationship between the shift stroke when shifting down from third to second and the synchronization load during gear shift operation.

5.2. Moderate Feeling

The load characteristic during gear shift operation is determined by the resultant of forces generated in three parts inside the transmission, namely the shift arm detent, the shift fork detent and the synchronizer spring (Fig. 6).

Figure 7 shows the load displacement characteristics of each part together with their total load displacement characteristics. The moderate feeling cannot be obtained when the load peak during gear shift operation (part A in Fig. 7) has a double peak or when the load rise and fall slopes are too gradual. With the new model 6MT, the load peaks of the three load generating elements (part B in Fig. 7) are combined to result in a single peak where the load rapidly rises and then falls. This realizes a naturally moderate gear change feeling.

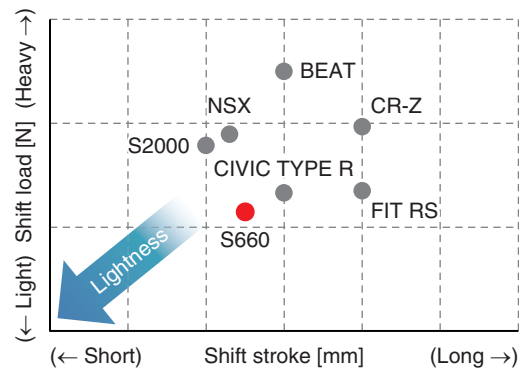


Fig. 5 Shift performance chart (Shift down from 3rd to 2nd)

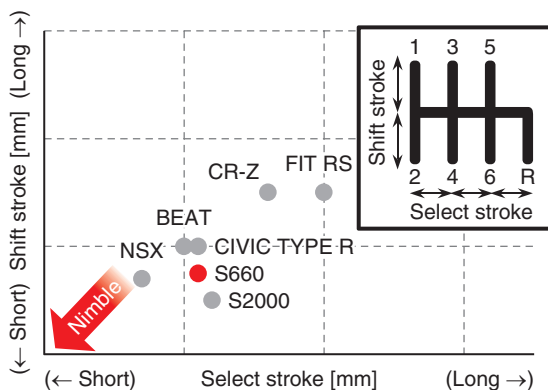


Fig. 4 Shift and select stroke

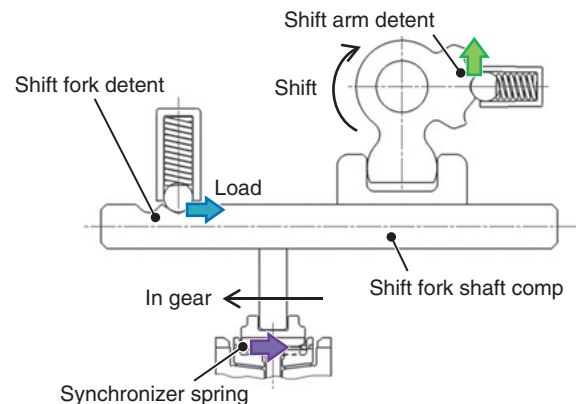


Fig. 6 Gear shift mechanism

5.3. Smooth Feeling

In order to obtain a smooth gear change feeling, the load characteristic that satisfies the moderate feeling in the previous section is modulated while at the same time performing modulation to increase the swallow feel⁽¹⁾, which refers to the feeling during gear shift operation that the shift is being sucked into position in the latter part of the operation. This swallow feel was also realized to an appropriate extent by aligning the load peaks (part C in Fig. 7).

Achieving a smooth gear change feeling also requires limiting the occurrence of a double-bump. A double-bump is a phenomenon felt as bumpiness during synchronization when the gear dog and sleeve are repelled by the drivetrain torsional reaction force^{(1), (2), (4)} (Fig. 8). In the new model 6MT, the double-bump load generation was reduced by the shape⁽³⁾ of the smaller-diameter part of the synchronizer sleeve and by adoption of a preceding sleeve tooth⁽¹⁾.

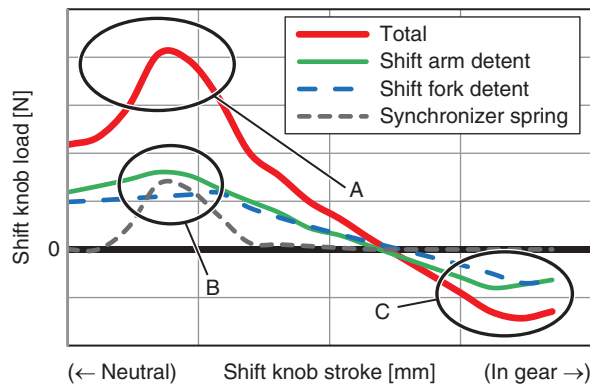


Fig. 7 Characteristics of shift load

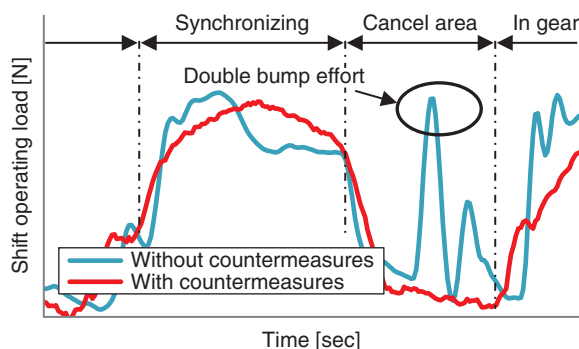


Fig. 8 Gear shifting time chart

6. Limiting Three-Cylinder Engine NV

In-line three-cylinder engines generally have higher cylinder pressure in a single cylinder than in-line four-cylinder engines with the same displacement, and therefore

experience greater combustion torque fluctuations. In addition, the S660 has a boost engine with increased power at lower engine speeds. This means that combustion torque fluctuations are greater in the low-speed range, and engine rotational speed fluctuations rise to a greater level than in naturally aspirated engines with the same displacement. As a result, the rotational speed fluctuations transmitted to the transmission are also greater. The new model 6MT adopts an NB gear and friction washer to limit NV when idling and when driving.

6.1. NB Gear

As a measure to counter the rattling noise caused by rotational speed fluctuations when idling, an NB gear structure like that in the K-car 5MT was adopted for the first and second gear counter gears, which are idle gears located above the counter shaft.

An NB gear eliminates backlash in order to limit noise caused by gear teeth rattling due to rotational speed fluctuations. Just as in the K-car 5MT, a spring is used to press the NB gear against the deceleration tooth surface of the corresponding gear in a structure that eliminates backlash. This measure limits rattling noise without causing any unnecessary increase in clutch inertia.

6.2. Friction Washer

The rotational speed fluctuations that are transmitted to the transmission because of combustion torque fluctuations are transmitted to the synchronizer hub, the synchronizer mechanism that follows the input shaft. The hub and the synchronizer ring collide inside the hub slots to produce a continuous metallic jangling noise. The rotational speed fluctuation increases in particular when the vehicle starts moving from a stop and when accelerating from low speeds, and this is transmitted to the cabin interior together with power plant vibrations. In the K-car 5MT, the synchronizer mechanism located on the input shaft has increased noise sources at three locations, for gears three to five, and the new model 6MT has an additional synchronizer mechanism due to the increased number of gear stages. This has increased the noise level.

In order to limit this jangling noise, a friction washer was placed between the synchronizer ring and the hub. This functions as a buffer that directly suppresses the source of noise, thereby achieving a reduction in cabin noise.

As shown in Fig. 9, the friction washer is a circular plate structure. It has 12 inside projections that slide circumferentially, functioning as a spring against the bosses inside the hub, and also has six outside projections that control the degree of freedom of the slots in the synchronizer ring.

The operation of the friction washer is shown in Fig. 10. In operating regions where combustion torque fluctuations are smaller, the friction washer, together with the synchronizer ring, is caused by centrifugal force to be positioned up against the edge of the slot in the hub. When

the combustion torque fluctuations increase, the rotational speed fluctuations of the input shaft also increase, causing the hub and synchronizer ring to collide inside the slots. When this happens, the inside projections that have a spring effect will generate torque from friction with the hub while the outside projections impede collision between the synchronizer ring and the slots, reducing the noise produced.

The friction torque value was set with upper and lower limit values according to the range of the interference fit. The upper torque limit value comes into play when, after synchronization by the synchronizer ring, the ring locks to a gear, so the inside projections of the friction washer need to move forcibly outward to that extent in a circumferential direction. The value is therefore set after determining the threshold at which it will not interfere with the synchronization function or the gear change feeling.

The lower limit takes into account the fact that wear of the areas that contact the inside projections due to deterioration of durability can lead to diminished torque. The deterioration of durability was therefore considered in

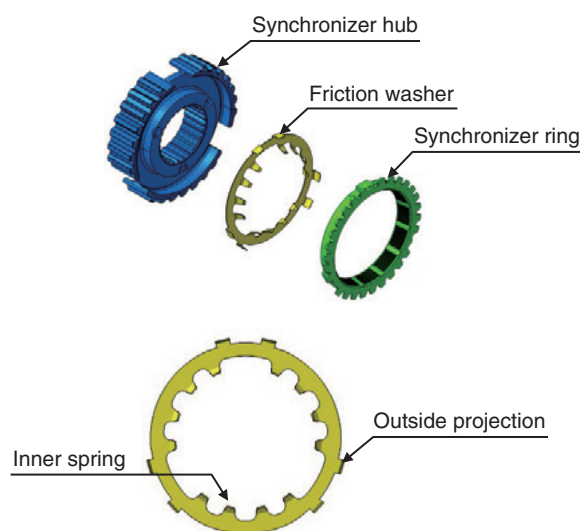


Fig. 9 Structure and function of washer

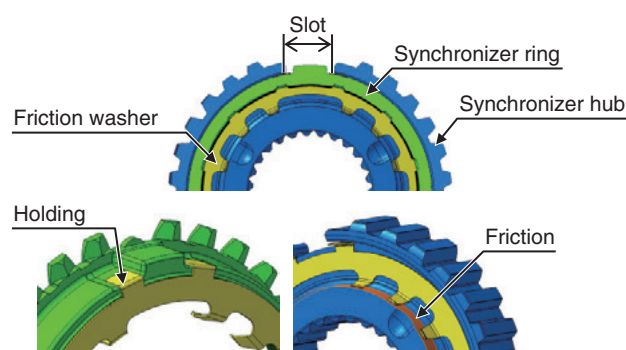


Fig. 10 Operating principle of friction washer

setting the threshold value.

Figure 11 shows the effect of the friction washer. The graph shows transmission case vibration levels when the engine is accelerated from idling speed in second gear to 5,000 rpm at wide-open throttle. The difference between the level with friction washers in all the synchronizer mechanisms above the input shaft (third through sixth gears) and that without having washers in any clearly shows that effects were obtained across a wide frequency range. The new model 6MT adopted friction washers for third through sixth gears, yielding satisfactory performance in NV, which had been an issue.

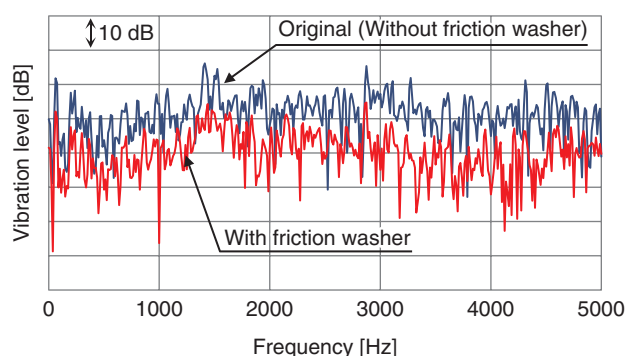


Fig. 11 Vibration level of transmission case

7. Conclusion

The new model 6MT has the following features:

- (1) A 6MT was achieved that supports a maximum torque capacity of 104 Nm while remaining compact enough to enable mounting in the vehicle.
- (2) The gear ratios set with the increase to six speeds achieve a balance between winding road driving and cabin quietness when cruising at high speeds.
- (3) Adoption of a short stroke and optimization of the load characteristics during gear shift operation achieved a smooth gear change feeling that provides a sense of agility and moderation.
- (4) Adoption of NB gears and friction washers reduced the noise and vibration of the three-cylinder engine.

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