Next-generation Fuel-efficient Automated Manual Transmission

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OVERVIEW: Fuel efficiency standards on vehicles are becoming increasingly strict to curb global warming, and Japan and Europe plan to reduce current standard values by about 25% in the timeframe from 2008 to 2010[1]. Transmission manufacturers have responded with a range of proposals for enhancing fuel efficiency. A number of alternative schemes have been developed as a more fuel-efficient next-generation transmission to succeed the existing ATs (automatic transmissions) and CVTs (continuously variable transmissions). One approach that is attracting considerable interest is an AMT (automated manual transmission), essentially an MT (manual transmission) with an automated control system. Hitachi Group is now developing a unique torque-assist AMT that is compactly implemented by adding a friction clutch mechanism to a conventional AT. Combining the fuel efficiency of an MT with the seamless shifting of an MT, this approach shows excellent promise as a compact and cost-effective next-generation transmission.

INTRODUCTION

MT (manual transmission) uses simple spur gears providing excellent transmission efficiency and thus typically get 10% or better fuel mileage than current ATs (automatic transmissions). The object of the AMT (automated manual transmission) is to automate the starting and gearshifting while retaining this excellent fuel efficiency. A round of fierce competition was triggered among European manufactures to see who would be the first to develop what is generally known as a conventional AMT that attempts to automate the shifting of MT. The problem with this design is that the drive torque is momentarily interrupted during shifting. This results in a very different shift feeling from an AT, and thus never saw widespread acceptance as a replacement for the conventional AT in mainstream vehicles. This was followed more recently by a twin-clutch AMT that is receiving a great deal of attention. Supporting smooth and responsive shifting much like an AT, the twin-clutch AMT has been installed by European vehicle manufacturer on some high-engine-capacity sports cars beginning last fall. Hitachi Group

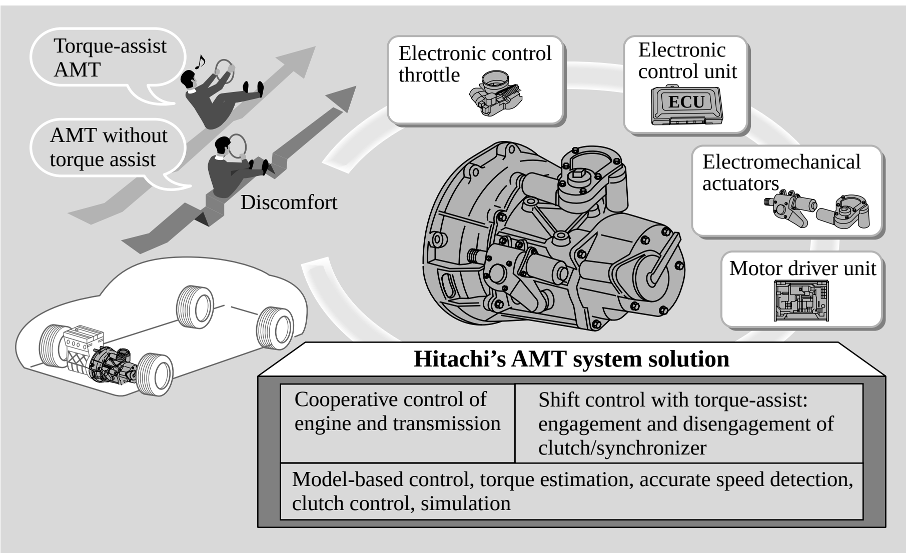

Fig. 1—Hitachi's Solution Technology for AMT Systems.
Hitachi Group contributes to the manufacture of environmentally-friendly vehicles through the development and deployment of innovative next-generation torque-assist AMT systems and integrated control technology enabling AMT systems to interwork smoothly with engine systems.

is now developing an original torque-assist AMT that is fundamentally different from these other two approaches. In this paper we will highlight the objectives, the concept, and the primary features of the torque-assist AMT.

OBJECTIVES AND FEATURES OF TORQUE-ASSIST AMT

In order to achieve widespread acceptance as a replacement for conventional transmissions, the next-generation transmission must provide the good fuel economy of an MT, the effortless shifting of an AT, and must also be compact and affordable. Unfortunately, the conventional AMT fails to achieve the seamless shifting of an AT and the twin-clutch AMT is difficult to implement compactly and cost-effectively.

Hitachi Group has proposed a third way that does meet all the above requirements — a torque-assist AMT — and is now in the process of developing this system. A key advantage of this approach is that it can be implemented with relatively little modification to existing AMTs by simply adding a friction clutch called an assist clutch to the transmission. Action of the assist clutch effectively solves the torque interruption problem of the conventional AMT while providing the smooth gear shifting of an AT. A compact and economical torque-assist AMT could thus be implemented fairly easily for application on mainstream FF (front-engine front-drive) compact vehicles with engine displacement under 2 liters.

OPERATING PRINCIPLE AND IMPLEMENTATION OF TORQUE-ASSIST AMT

Shifting Operation

Fig. 2 shows the shift timing of a 5-speed manual gearbox with added assist clutch. The first half of a shift operation when up-shifting from 1st to 2nd gear is illustrated in Fig. 2 (a). Transmitted torque from the assist clutch gradually increases until torque transmitted by 1st gear approaches zero. At this point, 1st gear is disengaged by the gear select-shift mechanism putting the transmission into neutral. In the next phase shown in Fig. 2 (b), torque is transmitted by 5th gear with assist clutch and controlled so that when the correct engine speed is reached to allow 2nd gear to mesh, the gear select-shift mechanism engages 2nd gear. Finally, the shift is complete in Fig. 2 (c) when transmitted torque from the assist clutch disappears and the torque transfer path only passes through 2nd gear.

During this shifting sequence, there is no torque interruption, and the torque waveform closely approximates that of an AT. All up- and down-shift transitions are similarly smooth with this torque-assist AMT.

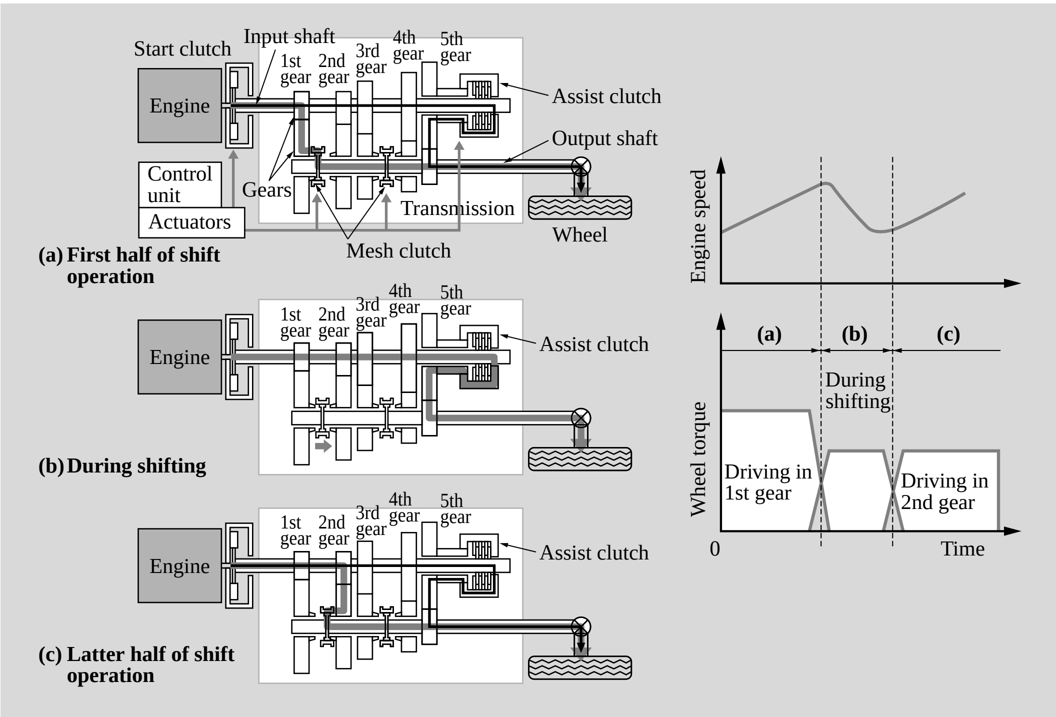

Fig. 2—Outline and Principle of Operation for Torque-assist AMT.
This new AMT transmits the engine torque to the wheels using the torque-assist mechanism during shifting, so an interruption of torque does not occur.

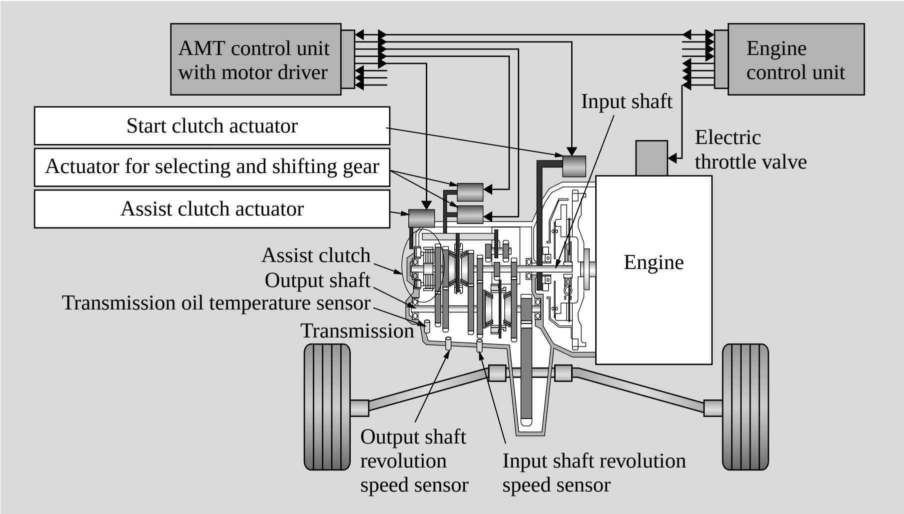

Fig. 3—System Configuration of Torque Assist AMT.
AMT control unit optimally controls three motor actuators.

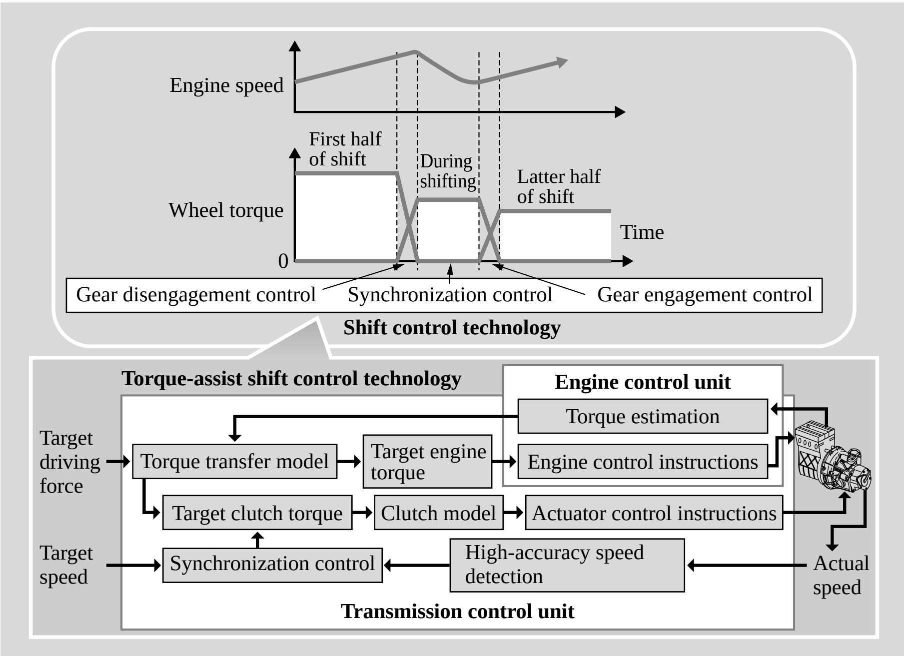

Fig. 4—Schematic of Primary Shift Control Elements.
Precise cooperative torque control between the engine and AMT is critically important for the system.

System Configuration

Fig. 3 shows a compact torque-assist AMT that is implemented simply by adding an assist clutch to the designated gear on the high-speed stage side of an existing MT.

Three types of actuators are used to automate the transmission: one for the start clutch, a second for the shift select, and a third for the assist clutch. Actuators can be driven hydraulically or directly by an electric motor, but we adopted the motor-driven approach for its simpler installation and better control accuracy. Six sensors help the transmission decide when to shift: an input shaft speed sensor, output shaft speed sensor, transmission oil temperature sensor, shift position sensor, select position sensor, and start clutch position sensor.

Sensor output goes to the AMT electronic control unit and the control unit drives the actuator motors by a built-in motor driver based on information from the engine electronic control unit to control the transmission so shifts are always performed perfectly matched to the transmission's decision.

Primary Shift Control Elements

Fig. 4 shows a core block diagram of the torque-assist AMT control module.

Shifting control can be divided into three phases: gear disengagement control in the first half of the shift operation, speed synchronization control during shifting, and gear engagement control in the latter half

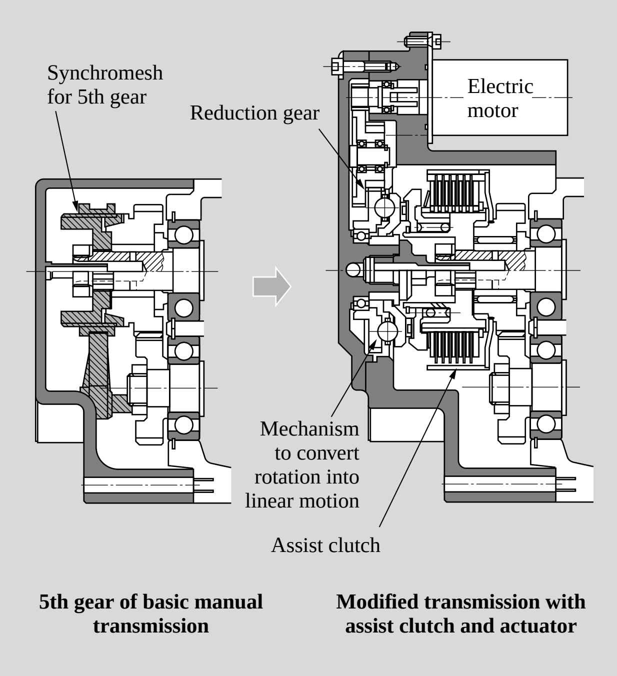

Fig. 5—Implementation of Assist Clutch Drive Module.
Length in the axial direction was significantly reduced by replacing a synchromesh with an assist clutch.

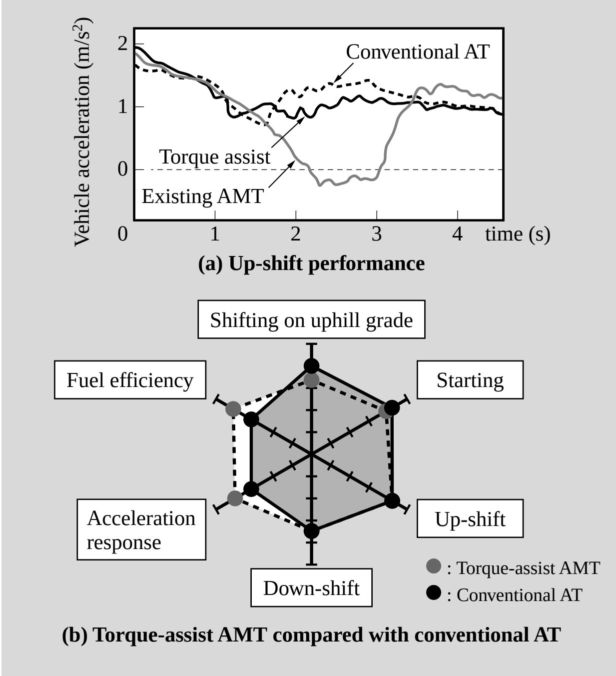

Fig. 6—Performance of Torque-assist AMT.
The torque-assist AMT combines the seamless shifting of an automatic with the superior fuel efficiency of an MT.

of the shift operation. The objective of the control is to complete the shift in minimal time without causing shift shock. This requires precise and highly responsive coordinated control between the engine electronic control unit and the AMT electronic control unit, and torque information is especially critical.

During shifting, the target driving torque (wheel torque) is optimally set in accordance with the driving state of the vehicle and the target engine torque and target clutch torque of the AMT are determined from calculations made by the powertrain torque transfer model. The target engine torque is controlled by the engine electronic control unit, while the target clutch torque is controlled by the assist clutch after it is converted to control commands of the assist clutch actuator are converted.

Implementation of Assist Clutch Drive

Fig. 5 shows implementations of key components of the system: the assist clutch module and the motor actuator that drives the assist clutch.

Note that we replaced the synchromesh on a basic 5-speed manual transmission with the assist clutch, which is driven by a motor combined with a device to convert rotation into linear motion. This enabled us to reduce the size of the transmission in the axial direction as much as possible, so the transmission can be mounted on mainstream FF vehicles where engine space is severely limited.

SYSTEM PERFORMANCE

In this section we will summarize our assessment of how well the torque-assist AMT achieves the seamless shifting of an AT and the fuel economy of an MT.

Fig. 6 (a) compares the up-shifting performance during acceleration of the torque-assist AMT with an existing AMT and conventional AT, and it is apparent that the torque-assist AMT provides nearly the same smooth shifting performance as the conventional AT. Fig. 6 (b) compares the torque-assist AMT with a conventional AT across six different performance measures. One can see from the figure that the up- and down-shifting performance of the torque-assist AMT is almost the same as the AT, but because there is no slippage from the torque converter that is required by an AT, the fuel efficiency and acceleration response of the torque-assist AMT are significantly better.

On the other hand, the torque converter on the AT gives somewhat smoother starts and more power when accelerating.

We believe based on this overall assessment that the torque-assist AMT has excellent potential as a compact and fuel-efficient next-generation transmission that is also affordable.

CONCLUSIONS

This report detailed our recent work on a torque-assist AMT that combines the seamless shifting of an AT with the fuel economy of an MT. As a basic part of Hitachi Group's business in developing transmission systems for the auto industry, we believe that the torque-assist AMT has enormous potential as a compact and affordable fuel-efficient transmission.

Exploiting the compact size and cost advantages of the torque-assist AMT, we are moving quickly to develop a practical next-generation AMT for implementation on mainstream FF compact vehicles with engine displacement under 2 liters.

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