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Development of a New Hybrid System - Dual System

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ABSTRACT

A new hybrid vehicle system has been developed, the Dual System, which combines the series and parallel hybrid systems.

Combination with a motor has reduced the engine size, only using the most efficient range of the engine. A transaxle employing a generator motor and a traction motor in one compact package is applicable to currently produced vehicles with little modification. Use of the generator as a motor realizes multiple control functions.

A prototype vehicle with this new Dual System was built and tested. Its driving performance and the fuel economy were measured, and the fuel economy results were analyzed.

INTRODUCTION

Toward the 21st century, energy conservation has keen global interest due to an expected sharp increase in energy demands according to ever increasing population and global warming caused by an increasing volume of generated CO_2. To decrease the energy used for vehicles, there are activities in various countries to find ways to greatly reduce the fuel consumption of vehicles, such as the "80 mpg Super Car Concept" in the U.S. It is required to adapt a completely new system, not just make a simple modification to the current system, to realize a dramatic improvement in fuel economy. It is recognized that one promising field is hybrid systems.

Both series and parallel hybrid systems are well known. This paper discusses a new hybrid system based on the "split" system which splits energy from the engine using a planetary gear [1] [2] [3], the new system being called the Dual System.

COMPARISON OF VARIOUS HYBRID SYSTEMS

Not only used as a range extender of electric vehicles, the hybrid system, employing both an engine and an electric motor, can improve fuel economy using the engine through its combination with the motor [4]. The hybrid system can improve fuel economy in light of the following:

1. Operation of the engine in optimum efficiency range
2. Transmission efficiency between the engine and the driving wheels is improved
3. Regeneration of deceleration energy

Figure 1 shows the four different hybrid systems.

(A) SERIES SYSTEM - This system supplements electricity generated by the engine. It is most commonly used as a range extender for electric vehicles. Since the engine is not mechanically connected to the drive wheels, this system has an advantage of controlling the engine independently of the driving conditions. Accordingly, the engine is used in its optimum efficiency and low emission range. This system is particularly suited to engines which are hard to mechanically connect to the drive wheels such as gas turbine engines.

Disadvantages, however, include large energy conversion losses because of the necessity of full electricity conversion of the engine output. Further, a generator large enough to convert the maximum engine output is required.

(B) PARALLEL SYSTEM - With the parallel system, an electric motor which supplements the engine torque, is added to the conventional driveline system of the engine and transmission. Accordingly, operations of the engine are quite similar to those of an engine in a normal vehicle. This system requires no generator, and there is a direct mechanical connection between the engine and the drive wheels, providing an advantage of less energy being lost through conversion to electricity.

On the other hand, this system requires a transmission because no speed adjustment mechanism is installed, though the motor supplements the torque. When an automatic transmission is used, a torque converter, oil pump, and other auxiliary components can reduce the transmission efficiency. Although the engine torque can be controlled by the motor, the engine speed is determined by gear ratios like a

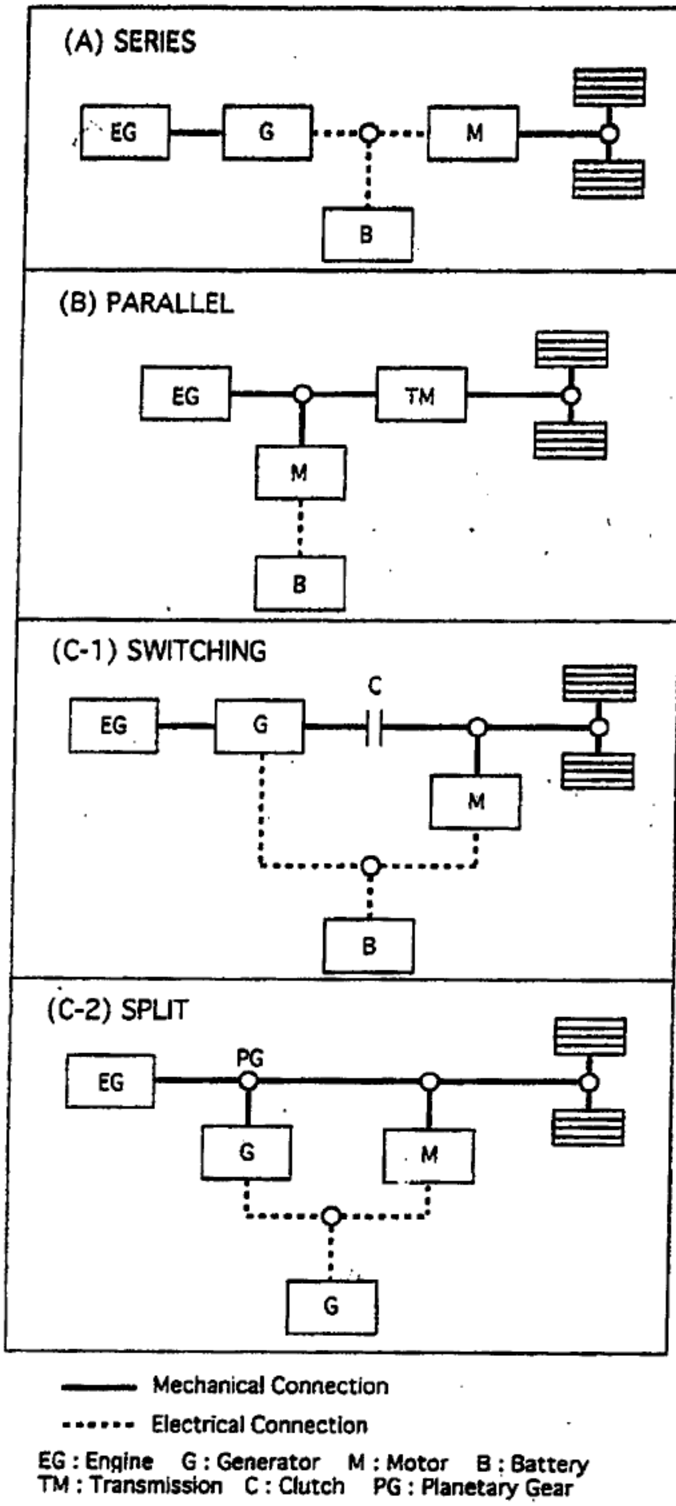

Figure 1: Four Different Hybrid Systems

conventional vehicle. Accordingly, the engine operation is linked to the driving conditions.

(C) SERIES-PARALLEL COMBINED SYSTEM - This combined type, having a generator and a motor, features characteristics of both the series and parallel systems, and the following two systems are possible:

(C-1) SWITCHING SYSTEM - Application and release of the clutch switches between the series and parallel systems. For driving as by the series system, the clutch is released, separating the engine and the generator from the driving wheels. For driving with the parallel system, the clutch is engaged, connecting the engine with the driving wheels.

For example, since city driving requires low loads for driving and low emissions, the series system is selected with the clutch released. For high speed driving where the series system would not work efficiently due to higher drive loads and consequently higher engine output is required, the parallel system is selected with the clutch applied.

(C-2) SPLIT SYSTEM - This system acts as the series and parallel systems at all times. The engine output energy is split by the planetary gear into the series path (from the engine to the generator) and the parallel path (from the engine to the driving wheels). It can control the engine speed under variable control of the series path by the generator while maintaining the mechanical connection of the engine and the driving wheels through the parallel path.

Correlation between the vehicle speed V and the engine speed NE is shown in Figure 2. When the engine is operating at a relatively constant torque in an optimum efficiency range, the energy from the engine is almost proportional to the engine speed NE. Accordingly, Figure 2 also indicates correlation between the vehicle speed and the engine output energy. In Figure 2, the engine speed NE is

$$NE = NEP + NES$$

where NEP is the engine speed by the parallel path and NES the engine speed by the series path. As the parallel path engine speed NEP increases in proportion to the vehicle speed, the output energy from the engine increases as the vehicle speed becomes higher. The higher the speed, the more energy is required for driving, it being appropriate that the parallel path energy becomes larger for higher speeds. For high speed

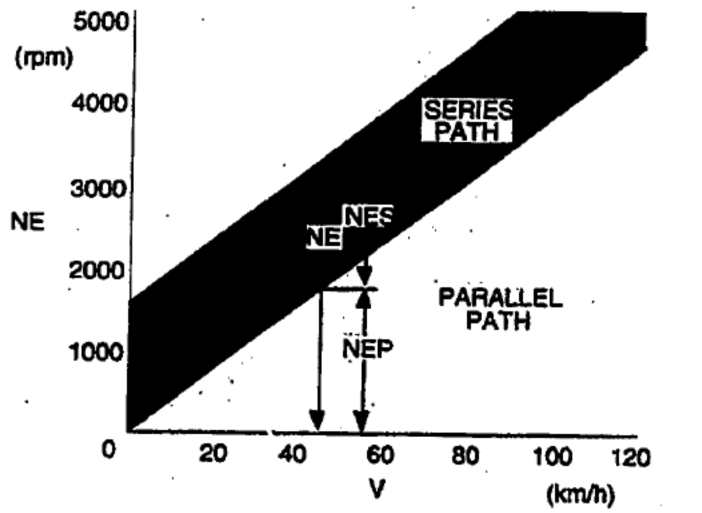

Figure 2: Engine Speeds in Split Hybrid System

driving, most of the output from the engine is supplied by the parallel path; consequently the energy conversion is small and not such a large generator as for the series system, is required.

Since the engine speed NES with the seri.s path is variable within the generator capacity, it is possible to control the engine conditions into ranges favorable for engine efficiency and lower emissions. It is also possible to control the amount of electricity charging the batteries.

OBJECTIVES OF THE DUAL SYSTEM

The maximum efficiency of the conventional reciprocating engine reaches 35% [5] and this could be increased to 40% through combination with a hybrid system. Other engines, for example, a gas turbine engine, may not easily exceed such an efficiency. We therefore consider it more realistic to take advantage of very developed reciprocating engine technologies so that the system can maximize the advantages of such engines.

Based on the comparison of various hybrid systems, recognizing that the split type has the largest potential among the hybrid systems, we developed the Dual System which maximizes the advantages of the split hybrid system. Features of this system are:

1. Compact Transaxle package design requires minimal modification of vehicles currently available.
2. Combination with a motor enables the engine to be small and lightweight. The engine can be operated in an optimum efficiency range.
3. The motor can operate as a generator, realizing a variety of control functions.

CONSTRUCTION

The complete schematic of the Dual System is shown in Figure 3. Figure 4 depicts the positions of major components within the vehicle. The vehicle is a modified "Corolla" production model, the vehicle weight being increased by 305 kg from the production weight of 1,040 kg, to 1,345 kg.

ENGINE - Since a small engine can meet requirements as the drive motor adds the torque, a 660cc engine for a commuter vehicle was used. Although a normal vehicle can rarely operate in the optimum efficiency range of the engine, engine downsizing should make it possible at all times. The engine throttle was disconnected from the accelerator pedal and computer-controlled by a throttle actuator motor.

An average maximum cruising speed which does not drain electricity from the batteries is determined according to the

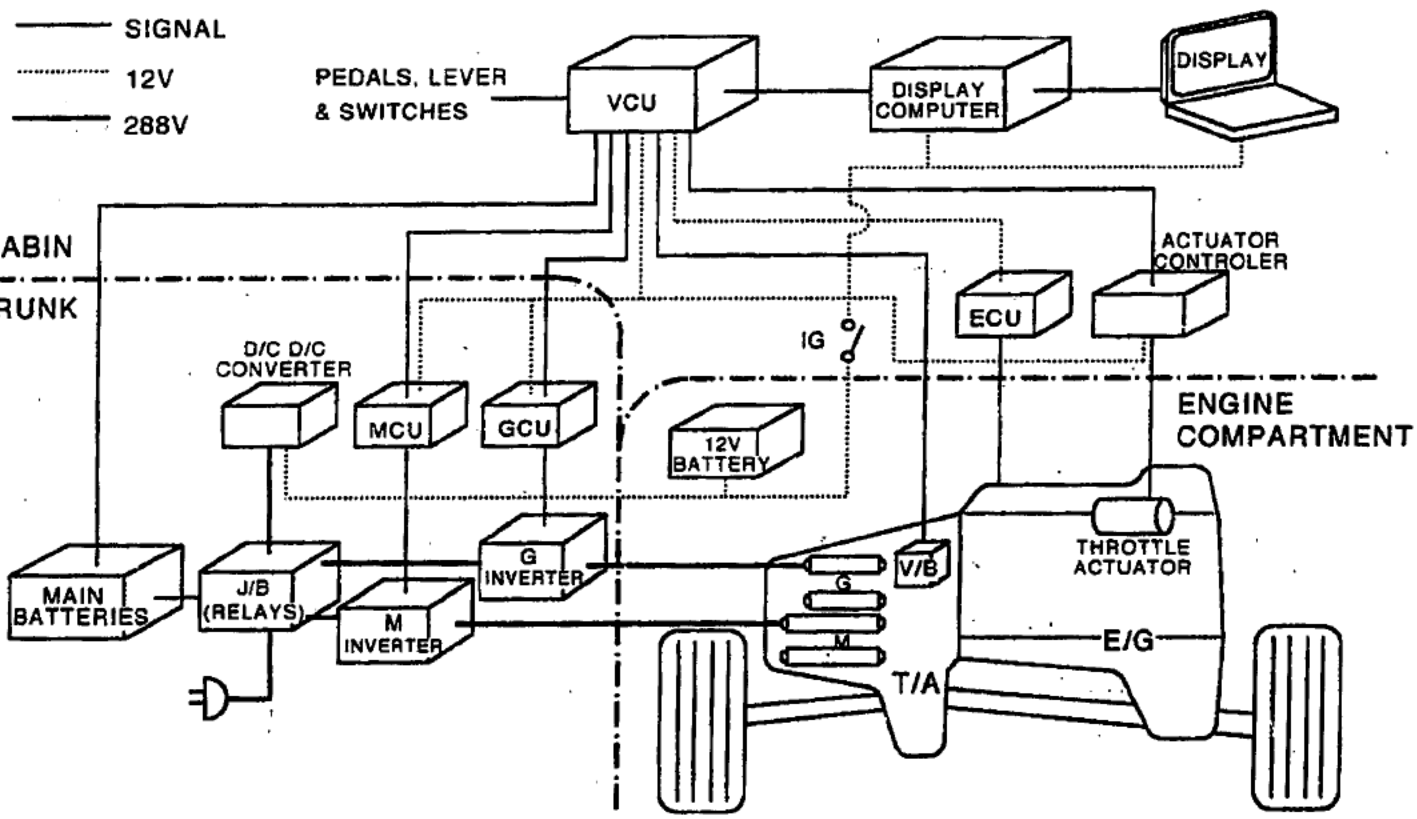

Figure 3: Complete Dual System Schematic

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