

Improvement of Fuel Consumption for the Strong Hybrid Motorcycle

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ABSTRACT

Any improvements of the fuel economy with engines are always required for all petroleum fuel vehicles. Such improvements often accompany some changes of the engine characteristics. It may cause slight disharmony with driving performances of the acceleration and/or top speed. The riding feelings on the motorcycles are so sensitive that means of changes for engine characteristics are limited to maintain good response in transition. We have developed the strong hybrid motorcycle "HV-X". It consists of a 4-stroke 250cm³ a cylinder engine and two 300V AC motors with a planetary gear set. Though the engine comes from a conventional scooter, utilizing the electric power, the HV-X attains better fuel economy without severe influence onto the drive performance even the engine character changes.

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INTRODUCTION

Generally speaking, the motorcycles have better fuel economy than the automobiles. It does not mean that the motorcycles have better engines, but it derives from being themselves smaller and lighter simply. Marking on the specific efficiency such as BSFC, the engines may perform less efficient than the automobiles. In case of the motorcycles, the engine adaptation has been well balanced between the fuel economy and drive performance so that when we weigh higher concern on to less fuel consumption than the driving performance, it may cause hesitation on the acceleration in transition. Then, it can bring worse fuel economy. Upon those potential risks, the improvements shall be so limited that the gain of the fuel economy may be modest.

When the strong hybrid system is taken, we can sweep those anxieties. Even the engine changes the character by lean setting for the efficiency, the electrically propelled motors can maintain their balance immediately.

This paper describes possibility of application of hybrid system to motorcycle, such as how large the range of operation with condition of stoichiometry can be extended and how much fuel economy can be improved without degradation of the drive performance.

CONSTRUCTION OF THE HV-X

The HV-X consists of a hybrid power unit, a battery pack including the battery management controllers, inverters and a fuel tank. The construction is shown in [figure 1](#). The prospects are shown in [figure 2](#).

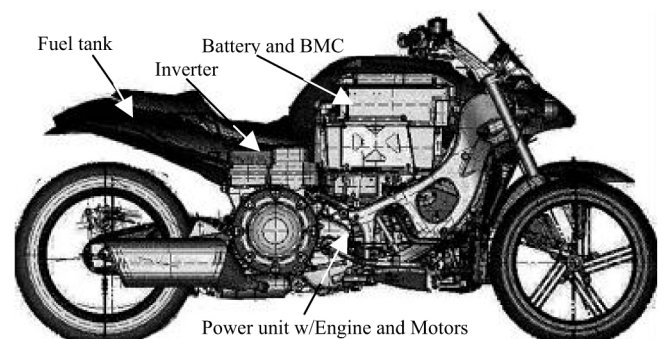


Figure.1. The construction of the HV-X



Figure 2. The prospect of the HV-X

The power unit is placed onto the center of the vehicle as the same as the typical big scooter like the Yamaha Tmax.

The battery pack including BMC is located just like a tank of the conventional motorcycle in which being placed in front of the rider who can make own knee grip.

The inverter is installed onto the power unit directly under the seat. The positioning has been chosen for shortening the power and cooling line.

The fuel tank is put onto the rear fender modestly.

A brief specification of the HV-X is shown in [Tab.1](#).

Table 1. The specification of the HV-X

Name of the vehicle	HV-X
Type of hybrid system	Strong (series-parallel)
Length	2200mm
Width	750mm
Height	1100mm
Wheel base	1600mm
Seat height	740mm
Tire size	Front/Rear 17 "
Vehicle weight (incl. Batteries)	258kg

CONSTRUCTION OF THE POWER UNIT

The power unit consists of a 4-stroke 250cm³ single cylinder engine, two 300V 3-phase alternating current synchronous motors, and gear trains including the planetary gear system. The construction is shown in [figure 3](#). The prospects are shown in [figure 4](#).

The ICE is connected to the carrier shaft of the planetary gear system through the sprockets and chain at the left side of the power unit. While the engine activates through these sprockets as primary speed reduction, the torque can be transmitted between the carrier and the crankshaft of ICE.

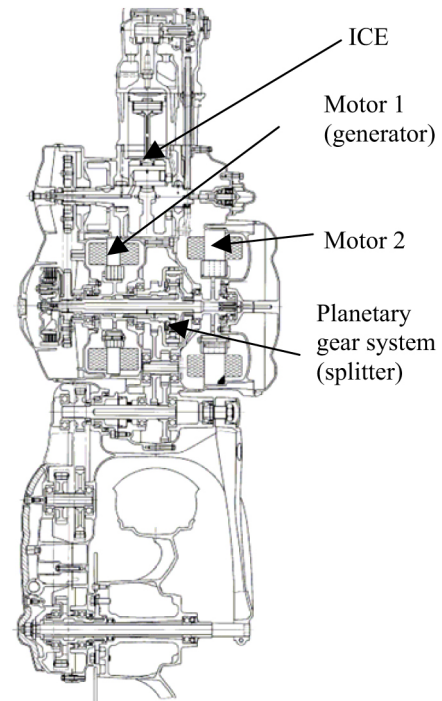


Figure 3. The construction of the power unit

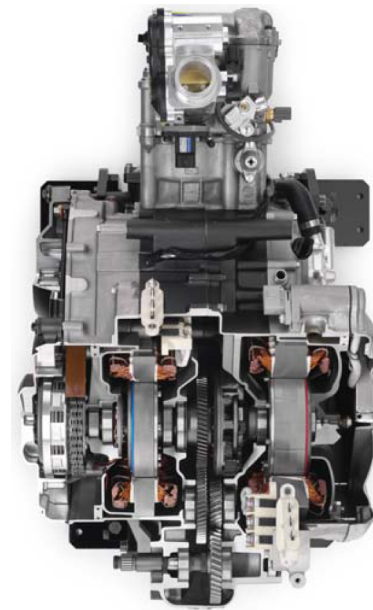


Figure 4. The top view of the power unit

The Motor 1, mainly acts as a generator, connects to the sun gear of the planetary gear system. When the ICE starts to activate, it acts as the engine starter. Besides that, it acts as a generator.

The Motor 2 takes both roles of a motor and/or a generator flexibly depending on the balance of power consumption and preservation. It connects to the ring gear of the planetary gear system. The ring gear is connected to the single track with gears and chains that transmits driving power to the rear wheel.

A brief specification of the power unit in this work is shown in Tab.2 respectively.

Table 2. The specification of the power unit

Type of hybrid system	Strong series-parallel
Combined output power	23kW at 120km/h
Combined output torque	67Nm at 50km/h
Engine displacement / B X S	249cm ³ / 66 X 73mm
Engine maximum power	15kW at 7000rot/m
Engine maximum torque	24nm at 5000rot/m
Type of motor 1	IPM 3-phase AC synchronous
Motor 1 maximum power	10kW at 10000rot/m
Motor 1 maximum torque	21Nm at 6000rot/m
Motor 1 maximum speed	12000rot/m
Motor 1 cooling system	water & oil
Type of motor 2	IPM 3-phase AC synchronous
Motor 2 maximum power	15kW at 7000rot/m
Motor 2 maximum torque	69Nm at 2000rot/m
Motor 2 maximum speed	7500rot/m
Motor 2 cooling system	water & oil

HYBRID MECHANISM

The fundamental function of the power unit is the same as any well-known strong hybrid systems of passenger cars [1] [2]. What is so distinctive is the mechanism of the power unit including timing, prioritizing and/or balancing on combined output power and internal energy storage [3].

The hybrid mechanism is described with the energy flow in figure 5. The rate of engine torque splitting is shown in Tab.3.

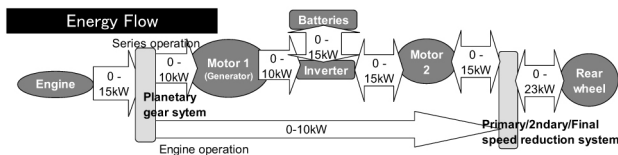


Figure 5. The configuration of power flows as the hybrid mechanism

Table 3. The specification of planetary gear system

Item of the planetary gear system	
Ring gear engaged pitch diameter	109.2 mm
Planetary gear carried diameter	76 mm
Sun gear engaged pitch diameter	42.8 mm
Rate of the engine operation	0.712
Rate of the electric transmitted operation	0.288

For the HV-X to starts from the standstill, the Motor 2 starts to rotate. As it is connected to the rear wheel directly, the HV-X moves immediately and quietly.

In case of the engine activation required, the Motor 1 shall be controlled to rotate for the crankshaft of the engine obtaining enough torque and speed to start the engine. This part of the mechanism is shown in figure 6. To show how split or gather each power easily, the loss of each part is ignored. The practical sytem has loss with each mechanism which alters upon the throttle angle, SOC and so on.

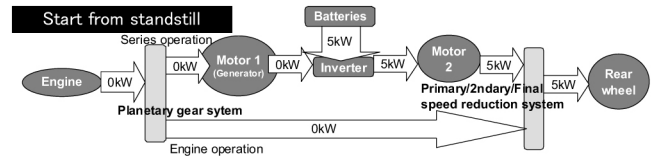


Figure 6. The mechanism of the strong hybrid system at the start

Vehicle keeps running continuously as long as the petroleum fuel remains, is called "cruising". While cruising, no power goes in and out the battery. While cruising, to perform best fuel efficiency, the ratio of the power flow via series operation versus engine direct operation shall be kept by controlling the engine throttle, the speed and torque of the Motor 1. For example, energy flow diagram under cruising condition is shown in figure 7.

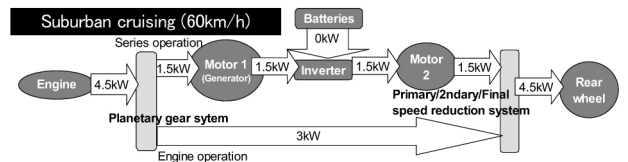


Figure 7. The mechanism of the strong hybrid system at the cruising

In case of the wide open throttle required, the engine highly activates with the available best efficiency, and the Motor 1 shall act as a generator to transform the mechanical power to the electric power as the ECVT. The mechanism at the wide open throttle is shown in figure 8.

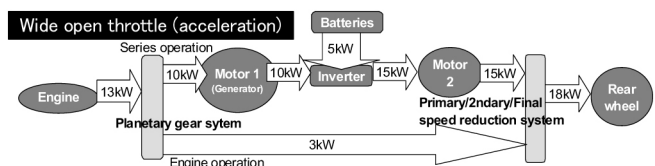


Figure 8. The mechanism of the strong hybrid system at the WOT

TEST ENGINE AND TEST BENCH

In this study, a conventional engine for Yamaha Grand Majesty250 in Japan (5VG) was diverted as the internal combustion engine. The engine specification is shown in Tab. 4 beside figured in Tab.2.



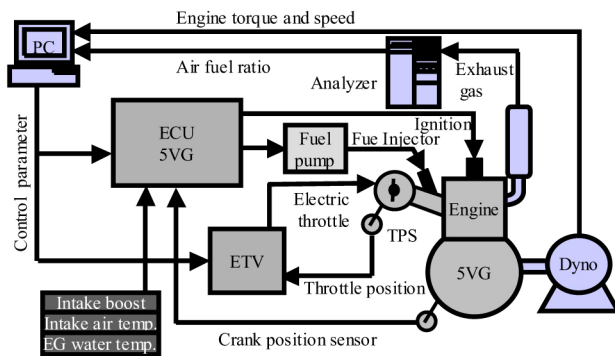
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Table 4. Engine specifications besides figured in Tab.2.

Number of Cylinder	1
Compression ratio	10.8
Fuel Injection System	SPI
Number of Valves	4
Intake Valve Open	23deg. BTDC
Intake Valve Close	229deg. ABDC
Exhaust Valve Open	51deg. BBDC
Exhaust Valve Close	21deg. ATDC

The ETV is equipped to control engine load. The ECU controls the ignition and fuel injection. The engine torque is measured by the engine-dynamometer. The air fuel ratio is calculated from the exhaust gas sampling rate monitored by the emission analyzer. The test configuration is shown in figure 9.

**Figure 9. The engine test configuration**

BENCH MARK ENGINE ADAPTATION

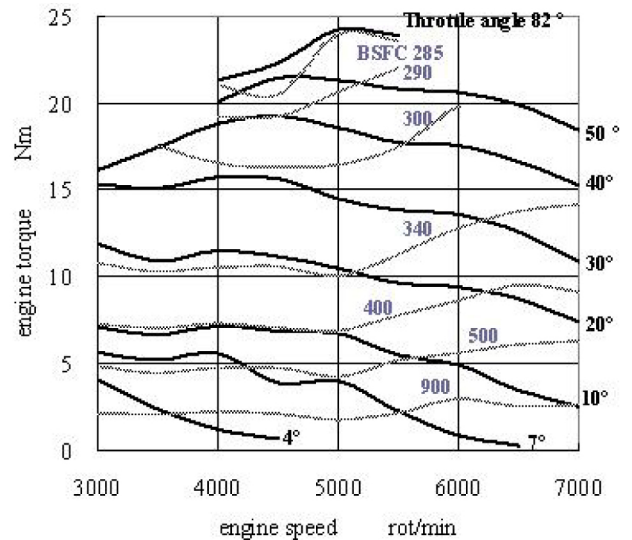
As the benchmark, all specification, such as the air cleaner, throttles body, intake manifold, exhaust pipe, and muffler, has been accordant on the vehicle "HV-X". The engine has been adapted with the best torque by the fuel injection adjustment under MBT condition.

The result of the benchmark engine adaptation is shown in Tab.5.

Table 5. The best performance of the bench mark engine

Power	Engine power kW	14.4
	Engine speed rot/min	6500
	BSFC g/kWh	306
	Ignition timing deg. BTDC	25
	Air fuel ratio	12.7
Torque	Engine torque Nm	24.2
	Engine speed rot/min	5000
	BSFC g/kWh	284
	Ignition timing deg. BTDC	19
	Air fuel ratio	12.8

The engine torque at various engine speed and various throttle opening ratio are shown in figure 10. These results show the engine characteristics.

**Figure 10. The benchmark engine characteristics configuration**

STOICHIOMETRIC MIXTURE ADAPTAION

Upon the same specification, such as the air cleaner, throttle body, intake manifold, exhaust pipe, and muffler with the benchmark adaptation engine, the engine has been adapted toward the stoichiometric air fuel mixture condition by the adjustment of fuel injection and ignition timing in avoidance from the knocking.

The result of the stoichiometric mixture adaptation is as follows:

1. The stoichiometric mixture is available with less than 2 or 3 % torque down.
2. The stoichiometric attains Fuel efficiency as the BSFC is improved more than 10%.

The influence of the stoichiometric mixture adaptation onto the output torque at the throttle angle 10° is shown in figure 11.

The influence of the stoichiometric mixture adaptation onto the output torque at the throttle angle 20° is shown in figure 12.

The influence of the stoichiometric mixture adaptation onto the output torque at the throttle angle 30° is shown in figure 13