

Prediction Technology of Output Power and Intake-Exhaust Noise Using 1D-Simulation for Small-Displacement Motorcycles

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ABSTRACT

Using a 1D simulation that transforms the 3D shape of intake-exhaust systems into one dimension and calculates the thermodynamics and fluid gas dynamics of internal combustion engines, a prediction technology of the output power and intake-exhaust noise for small-displacement single-cylinder motorcycles was established. Output power can be calculated accurately for various engines with different displacements and cooling systems by adjusting the boundary conditions in the calculation model. The intake-exhaust noise can be calculated accurately by clarifying some important points for accuracy when transforming the 3D shapes of the intake-exhaust system into the 1D model and by reflecting them in the calculation model. As for mufflers that have complicated internal structures, the calculation of exhaust-noise cannot be made with sufficient accuracy because 1D simulation does not calculate spatial flow behavior. But, improvement of accuracy is expected using a 1D-3D coupled simulation.

INTRODUCTION

Nowadays, In the Southeast Asian countries that are major markets for small-displacement motorcycles, the importance of noise reduction for such motorcycles has been growing. It takes a lot of time to decide the specifications of their engines and intake-exhaust systems in mass production development because they have complicated intake-exhaust system shapes due to limited space in the layout.

Usually, in the development of a new model, the specifications of the engine and intake-exhaust system are designed using various methods [1-2]. These methods specialize in either output power calculation or intake-exhaust noise calculation, and it is difficult to evaluate the influence on output power and noise coincidentally when specifications are changed.

As a result, specifications are often decided by repeating experiments using a prototype vehicle. Therefore, there has been a demand for the development of a prediction technology that can calculate both output power and intake-exhaust noise coincidentally in initial stages of development.

1D simulation is one solution to this problem. A high level modeling approach is required for 1D simulation to calculate the output power and intake-exhaust noise accurately at the same time. While studies of 1D simulation for automobiles and large-displacement multi-cylinder motorcycles have been reported in the past [3, 4, 5], there are no systematic studies found on the intake-exhaust system and single-cylinder engines for small-displacement motorcycles. A prediction technology that allows the calculation of both output power and intake-exhaust noise coincidentally for motorcycles with small-displacement single-cylinder engines using 1D simulation has been developed.

CALCULATION METHOD

1D-SIMULATION

In this study, WAVE®, a 1D simulation software from Ricardo Plc [6] was used. This 1D simulation calculates the dynamic behaviors of a working fluid by discretizing and solving basic equations such as the mass conservation law, Navier-Stokes equation, energy conservation law, and gas state equation after transforming the 3D shapes of the intake-exhaust system into a 1D shape. 1D simulation enables the calculation of output power and pressures in the intake-exhaust system. Moreover, sound waves that propagate to the surrounding space (i.e., intake-exhaust noise) can be calculated using flow velocity at the open end of intake-exhaust system.

SIMULATION MODEL

Some factors that affect the calculation accuracy in 1D simulation are as follows.

1. The accuracy of numerical values given as input conditions, such as port discharge coefficient, and mechanical friction loss.
2. The accuracy of boundary conditions related to heat transfer such as the inner surface temperatures of pipes and cylinders.
3. Modeling techniques that transform three-dimensional shapes such as duct length, duct diameter, and volume into the 1D shape.

Since the influence of these factors changes depending on engine type and load conditions, sufficient consideration is needed to consistently obtain high calculation accuracy under various conditions.

[Figure 1](#) shows an example of the calculation model. The range of the calculation model is all pipes and volumes from the opening of the intake duct in the air cleaner to the tail pipe end in the muffler, and the engine cylinder. The main input conditions and boundary conditions used for calculation are shown to be the following.

- The discharge coefficient of the intake-exhaust port is based on data that were measured with the test rig on steady flow.
- As a mechanical friction loss, the data that subtract pumping losses calculated by a 1D simulation from the total friction loss measured by the motoring friction method are used.
- As heat release by combustion, the Wiebe function with adjusted parameters to correspond to the measured heat release rate is used.
- The inner wall temperature of the intake pipe is based on measured data, and the wall temperatures of the cylinder and exhaust pipe are based on appropriate values referring to past measured values.

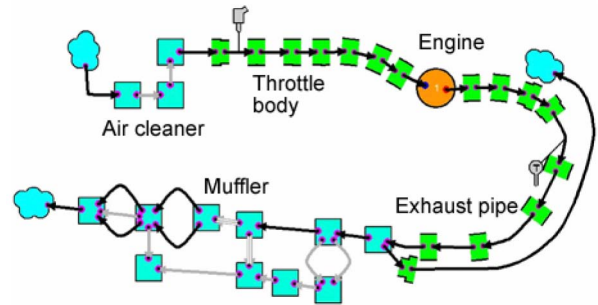


Fig. 1. Calculation model

VERIFICATION OF CALCULATION ACCURACY

TEST MOTORCYCLE

[Table 1](#) shows the major specifications of the engines and intake-exhaust systems of the test motorcycles used for verification. Each engine has a two-valve layout, and electronically controlled fuel injection system. The only major differences of engine specifications are the engine displacement and cooling system. On the other hand, the intake-exhaust systems are different in each test motorcycle. For example, Test Motorcycle C has a complex curved intake duct as shown in [Figure 2](#), and Test Motorcycle B has a U-shaped, curved pipe in the muffler as show in [Figure 3](#). These are typical examples of arranging components efficiently in the limited space in small-displacement motorcycles.

OUTPUT POWER

The output power of the test motorcycles was measured using a dynamometer under full load conditions. [Figure 4](#) shows a comparison of the measured and calculated output power. The calculated result of Test Motorcycle A, which has an air-cooled engine, corresponds most closely to the measured result. The calculation error of Test Motorcycle A is only 2%, and the characteristics of the output power curve also correspond closely to the measured result. For Test Motorcycle B, which

Table 1. Specification of motorcycles used for verification

Test Motorcycles	A	B	C
Engien type	4-stroke single cylinder	4-stroke single cylinder	4-stroke single cylinder
Cooling system	Air-cooled	Water-cooled	Air-cooled
Displacement (cm ³)	150	125	110
Valve layout	IN:1 / EX:1	IN:1 / EX:1	IN:1 / EX:1
Ignition type	Spark ignition	Spark ignition	Spark ignition
Air cleaner volume (L)	2.6	3.7	2.3
Muffler volume (L)	4.7	3.6	2.2
Muffler structure	3-pass	3-pass	3-pass

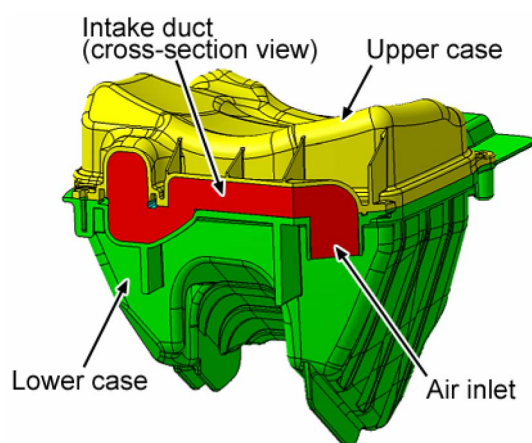


Fig. 2. Structure of intake duct of Test Motorcycle C

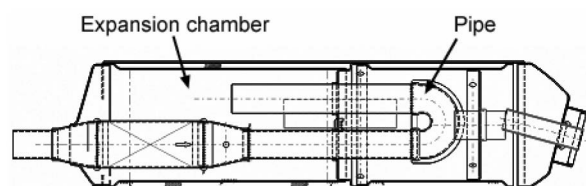


Fig. 3. Structure of muffler of Test Motorcycle B

has a water-cooled engine, the calculated result was lower than the measured result when using the same boundary conditions as Test Motorcycle A. The calculated volumetric efficiency was lower than the measured result, and the calculated pressures of the compression and expansion strokes were also lower than the measured results. These observations mean that the calculated results of the heat received by the mixture gas

from the walls of the intake system in the charging stroke and the heat released from the combustion gas to the engine cylinder are larger than the measured results of those factors if the boundary conditions for the air-cooled engine were applied. Therefore, the boundary conditions concerning heat transfer in the intake system and engine cylinder were adjusted for Test Motorcycle B with the water-cooled engine. As a result, sufficient accuracy of calculation was obtained. Thus, it was found that it is necessary to set different boundary conditions depending on the cooling system. For Test Motorcycle C, there is a slight error between the measured and calculated results at lower engine speeds. However, the characteristics of the output power curve do correspond, so it can be said that there is sufficient accuracy for practical use.

To confirm the validity of the input and boundary conditions, accuracy validation was carried out adding another four test motorcycles with different engine displacements and cooling systems.

Figure 5 shows the correlation of measured and calculated maximum output power between all the test motorcycles. Like the results of Test Motorcycles A, B, and C, there are very few calculation errors. From these results, it was found that 1D simulation can calculate the output power with sufficient accuracy for most small-displacement single-cylinder motorcycles.

Next, the calculation accuracy of the indicated work was verified. Test Motorcycles A and B were verified, with a measurement engine speed of 6000 r/min which generated maximum torque. Figure 6 shows a comparison of the measured and calculated P-V diagrams. Pumping losses in the

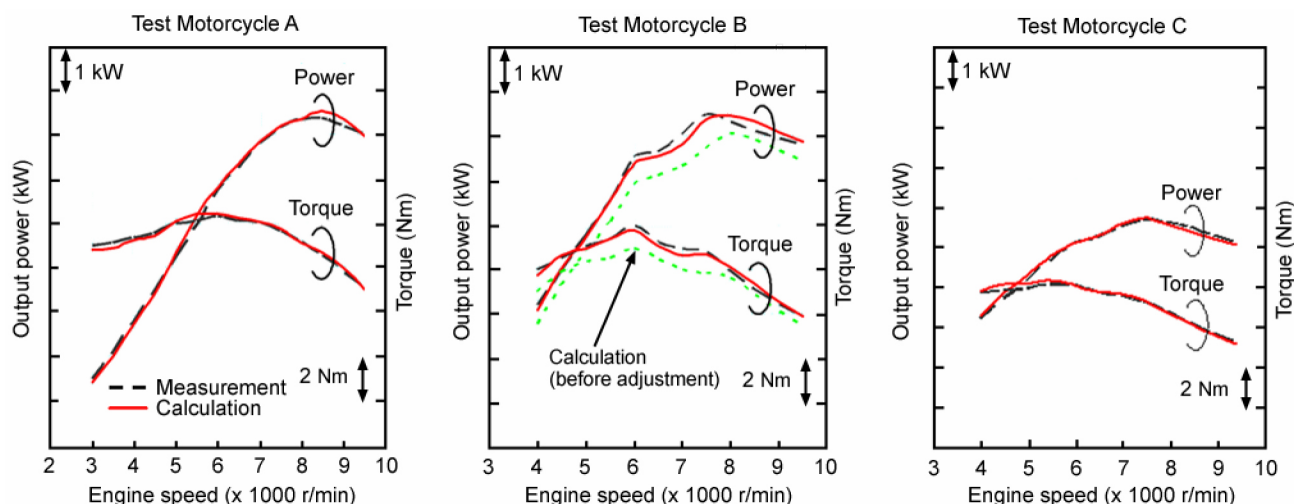


Fig. 4. Comparison of measured and calculated output power and torque