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Research on the Optimization Design of Motorcycle Engine Based on DOE Methodology

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Abstract

The optimization design of engine is always one of the top concerns in motorcycle industry. In this paper, effective torque and fuel consumption ratio are defined as the performance evaluation indexes of engine, while air-fuel ratio, intake valve timing angle, exhaust valve timing angel, pressure, and temperature are defined as input variables. With the application of DOE methodology, a full factorial DOE is conducted to estimate the regression model and identify the statistical significant factors. And then, with the selection of additional experimental points, RSM is introduced to construct the precise regression model between input variables and performance indexes. Based on that, an optimum solution that can satisfy both performance requirements are brought forward and testified.

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Keywords: Optimization Design, DOE, RSM, Motorcycle Engine

1. Introdution

Just as heart is to human body, engine is the most important part of motorcycle. As an example, a four-stroke engine can provide continuous power for motorcycle with the circulation of four strokes: intake stroke, compression stroke, power stroke and exhaust stroke. With the application of Variable Valve Timing (VVT) technology [1] and Variable Intake Manifold (VIM) System [2], engineers can enhance the engine power by controlling the switching time of valves, and then improve the dynamic performance. Generally, the dynamic performance can be described

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as effective torque, effective power, average effective pressure, and rotational speed, in which effective torque is preferred as the key index to reflect the engine's working ability. Besides that, fuel economy, compactness, reliability and durability should be considered synthetically when evaluating an engine's performance. Considering the complicated interaction among different evaluation indexes, engineers usually rely on simulation software (such as CAE, GT series, Converge, and etc.) to imitate the operation process of engine [3], and then optimize the design.

However, because most of variables that influence the performance of engine are of numerical data, there will be infinite variable portfolios. Though the application of simulation software can significantly reduce the experiment cost and enhance the experiment efficiency when each variable has a specific value, it can hardly deal with the situation of infinite potential variable combinations. So, we must consider carefully how to design the experiment plan properly, by which we can identify the key variables and their optimum value intervals with as few number of experiments as possible.

To solve this problem, in this paper, we introduce DOE (Design of Experiment) methodology into the R&D process of motorcycle engine, to arrange and conduct the experiments rationally [4]. With the statistical analysis of simulational experiment data, we set up the functional relationship model, discuss about the influences of different variables on the performance of engine, then search out and test the optimum variables combination.

2. Functional Model Definition and Description

2.1. The Definition of Outputs (Response) "Y"

Generally, the evaluation indexes of motorcycle engine include power, fuel economy, strength, compactness, reliability, durability, and etc. Considering the function design requirement, we mainly focus on the dynamic and economic performance of engine. We define Effective Torque (ET) as Y_1 to represent the dynamic performance (measurement unit is "N•m"), while Fuel Consumption Rate (FCR) as Y_2 to represent the economic performance (measurement unit is "g/(kw•h)"). Basically, greater torque of engine means higher acceleration performance and stronger off-road ability, so Y_1 is a the-larger-the-better (LTB) type of characteristic; the smaller the fuel consumption rate is, the more cost can be saved, so Y_2 is a the-smaller-the-better (STB) type of characteristic.

2.2. The Definition of Input Variables (Factor) "X"

Considering the feasibility of modeling and function analysis, we choose Air-Fuel Ratio (A/F), Intake Valve Timing Angle (IVTA), Exhaust Valve Timing Angel (EVTA), Pressure (P), and Temperature (T) as the main input variables after many discussions with R&D staffs of motorcycle companies, and define them as X_1, X_2, X_3, X_4, X_5 separately. More descriptions about the X are as follows.

Air-Fuel Ratio (A/F). It means the ratio between air quality and fuel quality in engine. A/F can indicate the status of air-fuel mixture. It is a very important variable for the operation of engine. The measurement unit of A/F is "%".

Intake Valve Timing Angle (IVTA). VVT technology can adjust the angle of intake valve dynamically to improve the combustion of fuel. The measurement unit of IVTA is "Degree".

Exhaust Valve Timing Angel (EVTA). VVT technology can also adjust the angle of exhaust valve dynamically to improve the combustion of fuel. The measurement unit of EVTA is also "Degree".

Pressure (P). Pressure can promote the combination of air and atomized fuel when engine is working. However, too much pressure can also cause the deflagration of mixture, and then raise the fuel consumption. The measurement unit of P is "Bar".

Temperature (T). The temperature in cylinder can reflect the combustion state of mixture, and its measurement unit is "°C".

2.3. Functional Model

Assuming that there are linear relationships between X and Y, we can set up the functional models as follows: