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Forming on Primary Control MAP Based on Fitting Surface with Scattered Data Point in Common Rail Diesel Engine

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Abstract. Performance of electronic controlled diesel engine is depended on quality of controlled MAP, the forming of primary electronic-control MAP in common rail diesel engine is made, the character of operational profile in diesel engine and rule of typical profile data obtained from experiment is analyzed, a method of fitting surface with scattered data point is applied, theory of Shepard rational interpolation surface is briefly provided, curved surface is converted to Lagrange interpolation formula to simplify the extent of this algorithm. Variable step of experimental dot is presented in order to test quantity according to operational profile demand. Root Mean Squared Error（RMSE）is introduced to evaluate control MAP precision by different experimental data. The process of forming of primary electronic control MAP based on fitting surface with scattered data point is given by real example, control effect's experiment of primary electronic control MAP is made in 493 type electronic controlled diesel engine, test data showed that this method can meet the demand of primary electronic-control MAP in electronic controlled diesel engine.

Keywords: fitting surface, electronic control, diesel engine

1. Introduction

Emission regulation in diesel engine is becoming increasingly stringent, electronic-control Diesel Engine is becoming main trend. High pressure common rail fuel injection can flexibly control injection parameter, and effectively decrease diesel engine emission and become main means for electronic control technology in diesel engine. Its control parameter, such as injection timing, injection quantity and injection pressure is looked in table obtained from experimental parameter MAP, in fact, so-called MAP is a chart of three dimension, one dimension axis is rotation speed, other axis is diesel engine load (position accumulator), another axis is control parameter. Electronic control unit (ECU) fulfilled looking-up table calculation and send to control signal to injection actuator according to real profile based on well calibration control MAP. MAP quality is directly affected operation performance of diesel engine.

Control parameter MAP includes injection pressure, injection quantity, injection timing and injection regularity (pre-injection and after-injection), with increasing dimension and number, experiment quantity and difficulty for match calibration is increased dramatically, Primary Electronic-control MAP is basic data to ensure control system formal work for mechanic engine to electronic control engine, generally, its MAP is obtained by experiment and simulation, there were some researching reports published in technological journals, [1] was provided a forming method of control MAP by means of Lagrange SUMT method, and it is verified to be effective by experimental data in real engine. [2] presented mathematical simulation method to fulfill primary control MAP forming, simulation calculation is based on math model for work process in diesel engine, by means of simulation calculation Primary control MAP is acquired, some errors calculated by this method are existed due to model simplification and error accumulation, and is verified by experiment.

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Control MAP obtained by experiment is depended on its requirement, Experiment quantity is much more, some profile is difficult to attach. In order to solve this problem, combination with character profile and operation frequency, appropriate experiment profile is selected, Primary control MAP is formed by fitting surface to scattered data point, and an effective method in decreasing Experiment quantity and improving accuracy.

2. Method Of Fitting Surface To Scattered Data Point

Geometry meaning of fitting surface to scattered data point is in fact formed smooth curved surface in the rectangle area, the definition is made: for given rectangle area, T=(a, b)x(c, d), observed value f k, k=1,2,…n, is freely measured in the N space point Vk=(xk, yk), dual function defined in area T is sought.

$$F(x,y) = F_k, \qquad k=1,2,...,n \tag{1}$$

$$\sum_{k=1}^{N}[F(x,y) - f_k]^2 = \min \tag{2}$$

In order to construct smooth curved surface in the condition of scattered data, rational function interpolation curved surface presented by Shepard is introduced, so for curved function f (x, y) is expressed,

$$f(x,y) = \sum_{k=1}^{n} w(r_k) f_k / \sum_{k=1}^{n} w(r_k) \quad when \quad r_k \neq 0, \quad or \quad f_k \quad when \quad r_k = 0 \tag{3}$$

Among (3), $w(r_k) = 1/r_k^{\alpha} \quad (\alpha \geq 1)$ coefficient of curved function f (x, y) is written.

$$W_k(x,y) = \sum_{k=1}^{N}[F(x,y) - f_k]^2 = \min \tag{4}$$

To meet $W_x(x,y) = \delta_{k,i}$, shepard curved surface is written in the forms Lagrange interpolation.

$$F(x,y) = \sum_{k=1}^{N} W_k(x,y) f_k \tag{5}$$

When curved surface is expressed by the forms Lagrange interpolation, some advantage of this change are not only ensured curved surface smooth, but flexible interpolation. On the contrary, disadvantage is existed data affecting stronger in overall situation, lower precision of algebraic expression, for example, when one data is changed, this resulted in variety of whole curved surface. To avoid this shortage, partial scheme is used, suitable constant R>0 is introduced into weighty factor.

$$w(r) = 1/R \quad when: 0 < r \leq R/3, \quad 27(r/R-1)^2/4R \quad when: R/3 < r \leq R, \quad 0 \quad when: r > R \tag{6}$$

Then weighty factor is becoming continuous differential, when observation value of observation point and its gradient are given.

Shepard curved surface is written as follow.

$$F(x,y) = \sum_{k=1}^{N} W_k(x,y)[f_k + (x-x_k) f_{xk} + (y-y_k) f_{yk}] \tag{7}$$

General forms is popularized

$$F(x,y) = \sum_{k=1}^{N} W_k(x,y) T_k(x,y) \tag{8}$$

Among, interpolation condition $T(x_k, y_k) = f_k$ is met $T_k(x_k, y_k)$, thus, $T_k(x,y)$ is written as follow formula

$$T_k(x,y) = f_k + (x-x_k) f_{xk} + (y-y_k) f_{yk} \tag{9}$$

3. Primary map forming

Structure of injection pump and fuel injector is complex in high pressure common rail system. These are most precise and complex parts in diesel engine, fuel is flowed in injection pump and injector, and passed different diameter line and effective section, and finally compressed and injected. Considered relative factors of fuel supply and injection process and character of pressure and injection fuel independent, some supposition is made. Firstly, fuel flow is treated as one dimension fixed coefficient. Secondly, regardless of fuel temperature varied with time, high pressure common rail system is simplified to boundary of high pressure pump, common rail, high pressure fuel line, boundary of high pressure pump, common rail is volume flow, flow rate is input to high pressure pump and flow rate is output to injector, common rail line is simulated based on multiple branch line, so flow boundary mode of high pressure pump and injector is built, it is really reflected input and output of common rail line, and formed simulation system of pressure control in common rail system.

3.1. Profile Sacttered Point

For diesel engine, crankshaft speed and pedal position is used as a profile point, many this points consisted on surface profile that diesel engine operated with, in the electronic controlled diesel engine, primary basic MAP included injection quantity, fuel advanced angle and injection pressure MAP, so limited representative point is selected to form basic point in order to consist basic MAP, so that diesel engine is operated.

In the speed and load of diesel engine, when experimental point is much more, it is improved control precision of MAP, on the contrary, it made experiment quantity increase, and point number is increased more, so there is existed a reasonable arrange between idle speed and max speed, according to follow rule.

1) Considering control parameter varying, profile point of large trend change is made closely for control parameter to improve control precision.

2) Considering operation frequency, profile point of max torque closely for control parameter to improve control precision.

3) Considering character profile, idle speed and max torque and max speed is included, and A, B, C speed in the ESC emission test is covered too.

Based on above rules, arrange of 55-70 percent of idle speed and max torque and max speed is belonged to high frequency operation. Diesel engine is often operated in Medium and high level load, so small step is used for this profile, and other profile is used by large step, it covered type profile, such as idle speed and max torque and max speed profile. Variable step is used to select profile point, distribution point is shown in Figure 1.

3.2. MAP Forming Process

Scattered sample Point consisted of experimental data, 95 percent of experimental data is used as basic sample, the other 5 percent of experimental data is used verification sample. In the basic sample data of different step is selected as input group, Fitting Surface method is used to form MAP surface, its forming process is followed

1) Different experimental data is used as a input group and a output control parameter.

2) Forming basic MAP based on experimental data.

3) According to volume quantity, interpolation point number is made to form primary control parameter MAP.

4) Test sample point is given to verify error of control MAP.

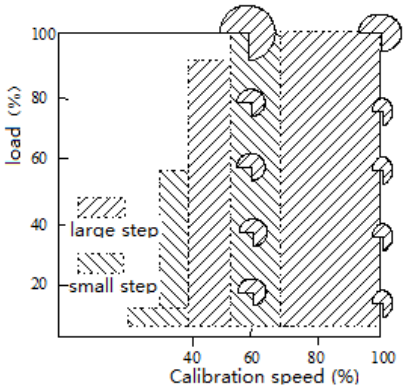

Fig. 1. Profile point distribution

3.3. Application Example

A 493 type diesel engine is used as experimental engine, its technology specification is shown in table 1, high pressure common rail injection system replaced mechanic fuel injection system, it covered low pressure supply part, high pressure injection fuel part and electronic control unit, high pressure bump, common rail and electronic controlled injector of Bosch company is selected as high pressure injection fuel part parts parameter of Bosch company is shown in table 2.

Table 1. Basic parameter of sample diesel engine

Engine brand	4JB493
Type	water cool, four strokes
Cylinder diameter and stroke (mm)	93×102
Fuel consume ratio (g/kw h)	210
Compress ratio	17.5：1
Rated power /rotation speed kW/r/min）	80/3200

Table 2. Parts parameter of Bosch common rail system

High pressure pump	0.1cm^3, 135MPa
Common rail volume	23ml
Orifice diameter	6x0.16

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In order to make basic injection fuel quantity and injection pressure MAP to meet operation requirement as soon as possible, considering usage error of different diesel engine and 2200, 2400, 2700r/min in Emission test speed of Vehicle engine, different step used is shown in table 3.

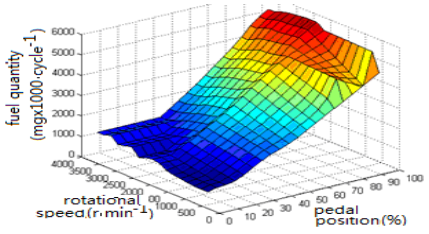
Based on variable step experimental data original data sample, according to sample even and balance principle, different rotational speed and pedal position is used to gain different input sample, shown in table 4. Due to limited page number, injection fuel and injection pressure MAP is shown in figure 2, 3 based on a group data. From fig 2, 3, smooth extent of these two MAP surface is more worse, because recommended MAP volume is 17x16, the other point is made by SHEAPRD Fitting Surface interpolation, injection fuel and injection pressure MAP is shown in figure 4, 5 based on a group data. Compared with figure 2, 3, smooth extent of the later is much better than that of the fore, it is improved precision of control MAP.

Table 3. Profile point arranged by different step

Speed arrange (r/min)	700-1200	1200-1800	1800-2800	2800-3600
Speed step (r/min)	100	200	100	50
Pedal step (%)	10	10	5	10

Table4. Different input sample

Group	Point number	Column A (*t*)	Column B (*T*)
A	190	100	10
B	120	200	10
C	95	100	20
D	60	200	20



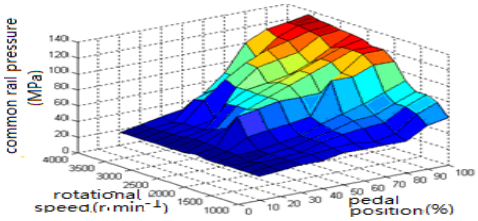


Fig. 2. Fuel quantity MAP of A group experimental data Fig. 3. Common rail pressure MAP of A group experimental data

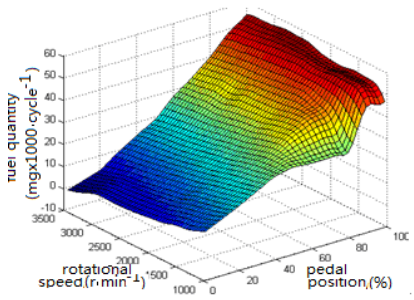


Fig. 4. Fuel quantity MAP of A group fitting data

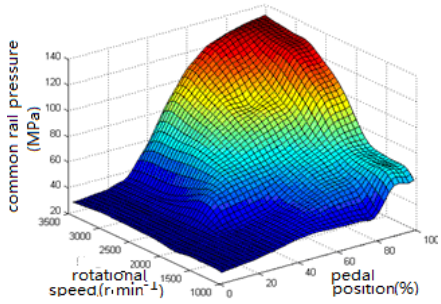


Fig. 5 Common rail pressure MAP of A group fitting data

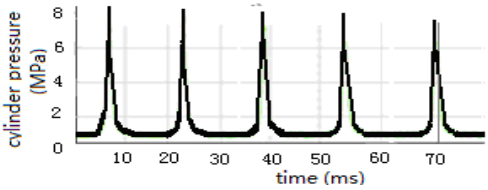


Fig. 6. Cylinder pressure change

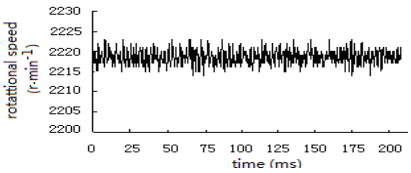


Fig. 7. Transent speed change of diesel engine

3.3.2. Variable Step

For primary MAP obtained by different data interpolation, error between MAP and verification data is used to evaluate reasonability, due to multi-data verification, Root Mean Squared Error (RMSE) is introduced to evaluate control MAP precision, error between primary MAP and verification point is defined as follow

Where, f(n) is value of primary MAP, f('n) is control parameter of verification point.

primary fuel quantity is selected as example, profile point:1200r/min 20%load, 2100 r/min 50%load, 2400 r/min 80%load, 3500r/min 100%load are selected as verification point, error of primary fuel quantity MAP is calculated, calculated result is shown in table 5. From data of table 5, with increase of speed and pedal step, error between B, C, D group and verification point is on enlarge trend, it showed that experiment point number formed by small step of speed and pedal position is reasonable and precision of primary MAP is relative higher.

Table5. Error of primary MAP under different step input sample

Group	Point number	RMSE
A	190	0.4885
B	120	0.5423
C	95	0.5843
D	60	0.6423

4. Experimental test

In order to verify the effect of primary MAP formed by this method, experiment is made in 493 type diesel engine bench, basic injection pressure MAP and fuel injection MAP is downloaded in electronic control unit, electronic controlled injector received injection pulse and fuel injection advance angle to fulfill injection fuel. Meanwhile, it is ensured cylinder burst pressure not to exceed max limit and emission temperature within 700℃, emission gas of diesel engine is black smoke.

Cylinder pressure sensor is arranged in first cylinder of 4JB1engine, continuous change of cylinder pressure is measured, in the decrease speed process of engine, cylinder pressure of different fuel quantity derived from primary fuel basic MAP is shown in figure 6. From figure 6, max cylinder burst pressure is gradually decreased, in the course of speed decrease, cylinder pressure is not all these showed primary fuel MAP is smoother and can make diesel engine operate steadily.

In the interpolation profile, rotational speed of diesel engine is measured in the stead state, rotational speed corresponding to a profile of primary fuel MAP is shown in figure 7. From figure 7, max change of

transient speed is within 5 r/min, this showed that fuel quantity interpolation calculated by primary fuel MAP can make diesel engine average speed to stationary basically.

5. Conclusion

1) Operation profile character of diesel engine and rule of selecting profile data is analyzed, according to vehicle engine character, variable step experimental point is provided.

2）Fitting surface scattering point method is introduced, curved surface is converted to Lagrange interpolation formula. Root Mean Squared Error (RMSE) is introduced to evaluate control MAP precision.

3）Conbined with real example, primary MAP surface fitted by high scattering point is present, control effect experiment of primary MAP is made in 493 common rail diesel engine bench. Experimental Data showed that this method can meet primary MAP requirement of electronic control diesel engine.

6. Acknowledgements

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