RedFame

Studies in Engineering and Technology
Vol. 1, No. 1; February 2014
ISSN 2330-2038 E-ISSN 2330-2046
Published by Redfame Publishing
URL: http://set.redfame.com

The Valve Timing Optimization of the Diesel Engine Based on Response Surface Methodology

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Received: October 30, 2013 Accepted: November 11, 2013 Available online: December 5, 2013

doi:10.11114/set.v1i1.262 URL: http://dx.doi.org/10.11114/set.v1i1.262

Abstract

To study the effect of valve timing on the diesel engine performance, the simulation model of diesel engine was established with AVL BOOST and its accuracy was proved. The volumetric efficiency is one of the important indicators to evaluate engine performance. The volumetric efficiency as optimization objective and valve timing were optimized and discussed by using Box-Behnken test method and the response surface methodology. Optimization result shows that volumetric efficiency of the diesel engine can been increased by 6.42% under rated speed.

Keywords: response surface methodology, valve timing, volumetric Efficiency

1. Introduction

The simulation of the engine's working process has become an important method to the research and development (Lei et al., 2011; Rakopoulos et al., 2004; Razmjooei et al., 2010). It is established the one-dimensional simulation model of the working process of diesel engine by AVL BOOST. And the simulation model is validated by speed characteristic. Then the influence of valve timing on the volumetric efficiency of diesel engine is analyzed and optimized in using the response surface methodology to obtain the optimal valve timing and the volumetric efficiency of engine. The volumetric efficiency can be increased 6.42% under the rated speed.

2. Model Establishment

2.1 The Model Establishment

The 4-cylinder, 4-stroke and turbocharged diesel engine was used in bench test. The basic parameter of the diesel engine is shown in Tab.1. The simulation model was established, shown in Fig.1. The Vibe 2 Zone heat release model and Woschni1978 heat transfer model was used (Liu, 2011).

Table 1. The main parameters of diesel engine

Basic parameters	Parameter values
Compression Ratio	18
Bore×Stoke (mm)	75×80
Rated Power(kW)	65
Rated Speed(r / min)	4500
Intake Valve Close(IVO)(℃A)	63
Intake Valve Open(IVC)(℃A)	101
Exhaust Valve Open(EVO)(℃A)	105
Exhaust Valve Close(EVC)(℃A)	63

2.2 Validation of the Simulation Model

The simulation model of diesel engine was verified from calculated results and experimental results, shown in Fig.2.

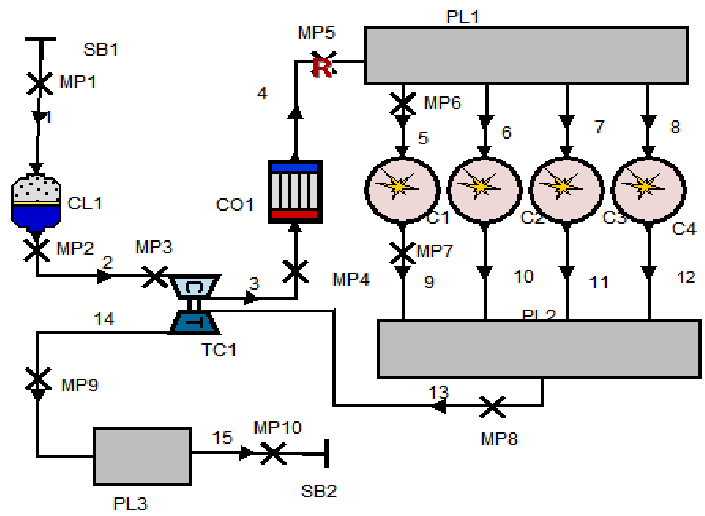

Figure 1. Simulation model of diesel engine

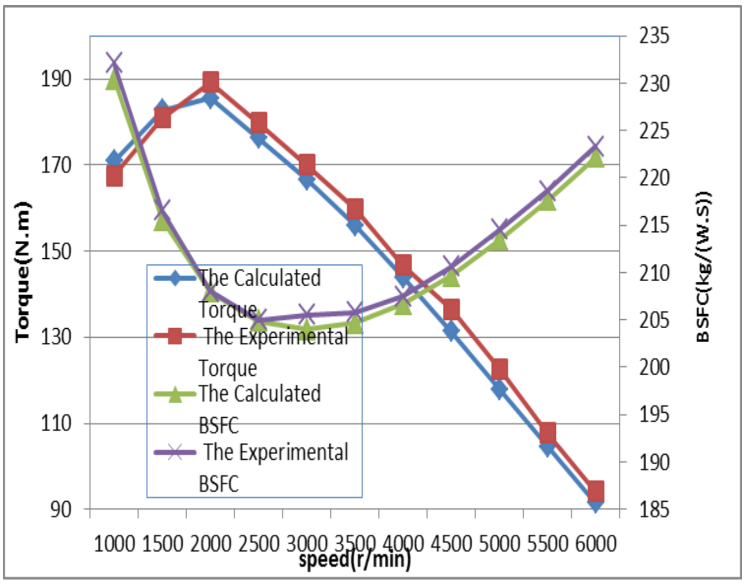

Figure 2. The calculated results compared with the experimental results

The comparative result shows that the relative deviation between simulation and experiment are both below 5%.Therefor the simulation model of diesel engine established in this paper is accurate and reliable.

3. Valve Timing Optimization Based on Response Surface Methodology

3.1 Response Surface Methodology

Response Surface Methodology is a product with the development of statistics, mathematics and computer science. Experimenting, modeling, analyzing data, using graphics technology are used in order to show up the relationship of response system and we can know and select the optimized response of experiment design directly (Montgomery, 2007; Chen et al, 2009; Simate et al., 2009; Li et al., 2007; Liu, S. S. et al., 2012; Liu, C. et al., 2012). Response surface analysis of experiment includes Central Composite Design, Box-Behnken Design, Quadratic saturation D-optimal Design, Uniform Design, etc. Box-Behnken Design which can be called the efficiency design method, can be estimated in the Linear and Quadratic polynomial with the Linear interaction of polynomial model by fewer tests (Chen et al, 2009). The influence of valve timing on the volumetric efficiency of diesel engine under the rated speed is discussed and the response surface experiment is designed by using Box-Behnken Design. The test points and test data are showed in Tab.2.

Table 2. Testing and test data of Box-Behnken design

Std	IVO	IVC	EVO	EVC	volumetric efficiency
1	73	101	105	73	0.8231
2	63	91	105	73	0.8066
3	63	111	105	53	0.8466
4	63	101	105	63	0.8400
5	63	91	105	53	0.7903
6	63	91	105	63	0.8400
7	53	101	105	73	0.8496
8	73	91	105	63	0.7896
9	73	101	115	63	0.8264
10	53	101	105	53	0.8268
11	63	101	105	63	0.8400
12	63	91	95	63	0.8034
13	63	111	105	73	0.8606
14	63	101	115	53	0.8216
15	63	101	105	63	0.8400
16	53	101	115	63	0.8481
17	73	101	95	63	0.8252
18	63	101	115	73	0.8441
19	63	101	105	63	0.8400
20	63	91	115	63	0.8090
21	63	101	95	73	0.8432
22	73	111	105	63	0.8469
23	53	101	95	63	0.8444
24	63	101	95	53	0.8258
25	63	111	95	63	0.8576
26	63	111	115	63	0.8628
27	53	91	105	63	0.8120
28	53	111	105	63	0.8632
29	73	101	105	53	0.8115

3.2 The Analysis of Response Surface

Design-Expert is a software which is used in optimized experiment by response surface widely. The equation of test response surface is some supposed. The hypothesis is: $H_0:\beta_1=\beta_2=\beta_3=\ldots=\beta_i=0$， $H_1:\beta_1, \beta_2, \beta_3, \ldots, \beta_i$

Where: at least, one parameter is not equal to zero, and the significance level is $\alpha=0.05$.The "P value" is a concept which is the judgment instead of rejection region in statistics. The Box-Behnken Design of optimized analysis is used in this paper. The Tab.3 shows that the P values of AC, BC, BD, CD and C2 are more than 0.05, which indicates the terms in model are not notable, and need to be re-optimized.

Table 3. ANOVA for response surface quadratic model

Source	Sun of Squares	df	Mean Square	F value	P-value Prob>F
Model	0.012	14	0.00083	344.14	<0.0001
A-IVO	0.00122	1	0.00122	504.82	<0.0001
B-IVC	0.00878	1	0.00878	3609.10	<0.0001
C-EVO	0.000012	1	0.000012	5.10	0.0038
D-EVC	0.000945	1	0.000945	389.24	<0.0001
AB	0.000009	1	0.000009	3.82	0.0453
AC	0.000001	1	0.000001	0.64	0.4363
AD	0.000036	1	0.000036	2.44	0.00140
BC	0.000001	1	0.000001	0.037	0.8502
BD	0.000001	1	0.000001	0.0092	0.9247
CD	0.000009	1	0.000009	2.67	0.1244
A^2	0.000151	1	0.000151	62.07	<0.0001
B^2	0.000352	1	0.000352	145.02	<0.0001
C^2	0.000002	1	0.000002	1.50	0.2409
D^2	0.000336	1	0.000336	138.22	<0.0001
Residual	0.000034	14	0.000002		
Lack of Fit	0.000034	10	0.000002		
Pure Error	0.000	4	0.000003		
Cor Total	0.012	28		R^2=0.9971	

The Tab.4 shows that the P values of all are less than 0.05, which indicates the terms in model are significant; then the response surface equation can be used. The response surface model equation is:

$$\begin{aligned} volumetricefficiency &= 0.814 - 0.010*A + 0.027*B + 0.001017*C \\ &+ 0.008883*D + 0.001525*A*B - 0.0028*A*D - 0.004967A^2 \\ &- 0.007517*B^2 - 0.007342D^2 \end{aligned} \quad (1)$$

Table 4. ANOVA for the optimized response surface quadratic model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob>F
Model	0.012	9	0.00130	538.74	<0.0001
A-IVO	0.00122	1	0.00122	508.82	<0.0001
B-IVC	0.00878	1	0.00878	3635.70	<0.0001
C-EVO	0.000012	1	0.000012	5.14	0.0038
D-EVC	0.000945	1	0.000945	392.11	<0.0001
AB	0.000009	1	0.000009	3.85	0.0453
AD	0.000031	1	0.000031	12.99	0.0019
A^2	0.000166	1	0.000166	68.72	<0.0001
B^2	0.000380	1	0.000380	157.39	<0.0001
D^2	0.000362	1	0.000362	150.15	<0.0001
Residual	0.000034	19	0.000002		
Lack of Fit	0.000034	15	0.000002		
Pure Error	0.000	4	0.000		
Cor Total	0.012	28		R^2=0.9971	

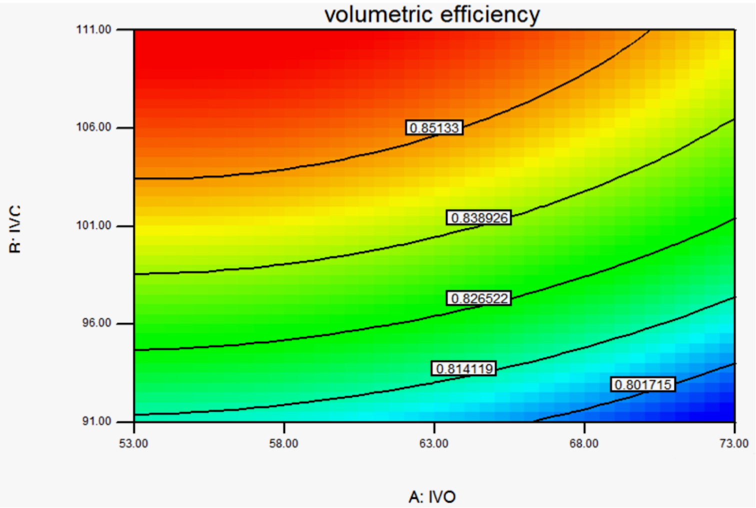

Figure 5(a). Contour plot of response surface methodology

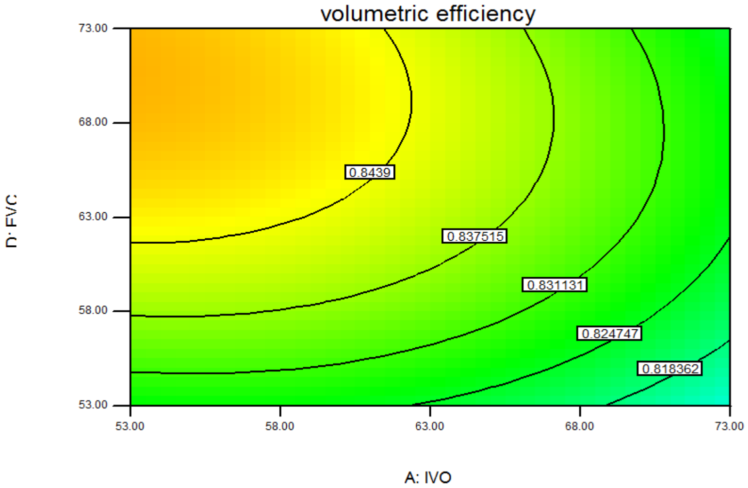

Figure 5(b). Contour plot of response surface methodology

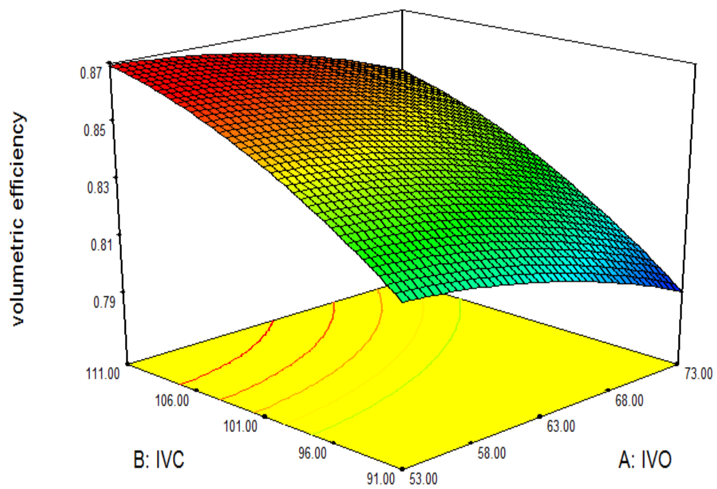

Figure 6(a). 3D surface of response surface methodology

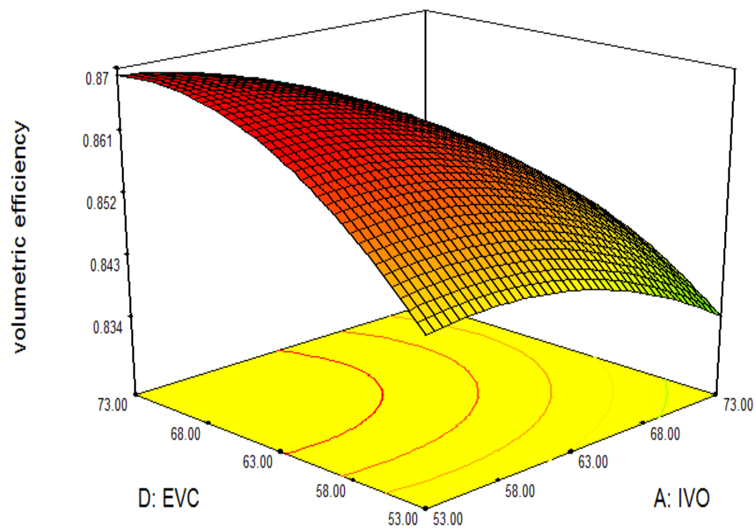

Figure 6(b). 3D surface of response surface methodology

The Fig.5 and Fig.6 shows that: IVO is 53 ℃A, IVC is 111 ℃A, EVO is 115 ℃A, EVC is 71 ℃A.

3.3 Verifying the Optimized Results of the Response Surface

The optimal valve timing which is got from the response surface methodology is used to verify the simulation model. The Tab.5 shows that the volumetric efficiency is increased by 6.42% after optimized.

Table 5. Volumetric efficiency contrast of before and after optimization

Type	IVO ℃A	IVC ℃A	EVO ℃A	EVC ℃A	volumetric efficiency
Original	63	101	105	63	0.841
Optimization	53	111	115	71	0.895

4. Conclusions

1) Based on the response surface methodology, we can optimize the volumetric efficiency and valve timing of diesel engine, establish the response surface quadratic model, draw the 3D surface of response surface methodology and then can carry out the optimization and interaction between volumetric efficiency and valve timing.

2) Getting the valve timing of the diesel engine from the response surface methodology, analyzed the simulation model of the diesel engine. The results show that the volumetric efficiency can be optimal value under the rated speed.

Acknowledgements

This project is supported by National Natural Science Foundation of China (No. 51305472) and Education and Teaching Reform Project of Chongqing CSTC, China (KJ090408; No.0903070)

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