Journal of Software Engineering

ISSN 1819-4311

Academic Journals Inc.

www.academicjournals.com

OPEN ACCESS Journal of Software Engineering

ISSN 1819-4311
DOI: 10.3923/jse.2016.392.399

Research Article
Research on Service Life Prediction of Diesel Engine

Da-shuai Wei, Xin-peng Xie, Feng-zhong Wang, Zhi-qiang Cai and DA-peng Zhang

Department of Military Vehicle, Military Transportation College, 300161 Tianjin, China

Abstract

Background and Objective: Perfect and reasonable research on service life prediction of diesel engine can be convenient for users to timely repair and replacement parts, which can avoid the user of the human and material resources of the waste. **Materials and Methods:** Based on the comprehensive analysis of various factors that influence the service life prediction of diesel engine, this study establishes a mathematical model of the life of military-use vehicle engine, which is based on the cylinder pressure as the main state parameter, the fuel injection pressure and oil pressure as the auxiliary parameters and the other conditions as the correction parameters. **Results:** Taking a vertical 195 military-use vehicle engine for example, based on the experimental results, it is indicated that the life prediction of the diesel engine by this method is more prolonged than that of the traditional statistical methods. **Conclusion:** The experimental results show that this method not only has the advantages of convenient operation, saving time and labor but also achieves a personalized treatment for life prediction of diesel engine. It can be known that the service life prediction of diesel engine has great economic value and social benefit. According to the gas clapyron equation established cylinder pressure and diesel engine life mathematical model and consider the fuel injection pressure, the oil pressure and all conditions of use to modify the theoretical model, for the prediction of the service life of diesel engine proposed a more practical method.

Key words: Diesel engine, life prediction, cylinder pressure, life of diesel engine, air leakage

Received: April 21, 2016 Accepted: May 13, 2016 Published: September 15, 2016

Citation: Da-shuai Wei, Xin-peng Xie, Feng-zhong Wang, Zhi-qiang Cai and DA-peng Zhang, 2016. Research on service life prediction of diesel engine. J. Software Eng., 10: 392-399.

Corresponding Author: Xin-peng Xie, Dongjuzi No. 1, Chenglinzhuang Road, 300161 Tianjin, China Tel: 13502114288

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The research on the life of diesel engine is to predict the residual (reserve) life of military-use vehicle engine and to predict the timing of failure. Perfect and reasonable diesel engine life prediction research can be convenient for users to timely repair and replacement parts, which can avoid the user of the human and material resources of the waste. The life prediction method of diesel engine, the current international mainly include: Dynamic prediction, statistical prediction and empirical prediction of three methods methods, each has its own advantages and disadvantages, especially the experience prediction method, a large number of manual operation is not adapted to the information transmission[1]. Through the study on the relationship of cylinder wear, cylinder leakage and diesel engine life, which leads to the relationship between cylinder pressure and diesel engine life, according to the gas clapyron equation established cylinder pressure and diesel engine life mathematical model and consider the fuel injection pressure, the oil pressure and all conditions of use to modify the theoretical model, for the prediction of the service life of diesel engine proposed a more practical method.

Some studies put forward a demand forecast model of aircraft engine by analyzing the demand caused by the engine to life and random faults, through both ways of fault rate and frequency and unreliability to compute the demand caused by engine to life by engine's specified life, remaining life, single flight task and so on and the demand caused by random faults[2], other studies consider engine control aims to provide desired performance based on stability margins while Life Extending Control (LEC) means to change the original control schedule to maintain the performance of engine and extend engine life[3], but this study mainly does research on service life prediction of diesel engine from the three aspects of air cylinder pressure, fuel injection pressure and oil pressure, which is different from demand forecast model of vehicle engine based on the demand of random failure of the previous literatures and the data needed to be collected by the established model is more practical and accurate.

MATERIALS AND METHODS

Main factors affecting the life of diesel engine: In addition to the cylinder pressure, fuel injection pressure, oil pressure, external conditions of use and other factors are closely related to the life of diesel engine.

Influence of cylinder pressure on the life of diesel engine: At present, the wear condition of diesel engine cylinder liner is both home and abroad to evaluate the diesel engine life[4]. Uneven wear of diesel engine cylinder liner will lead to the gap between the piston ring and the cylinder wall becomes larger[5] and over time will make a large amount of air air leakage in the cylinder body, so the wear of the cylinder liner is the main factor leading to the end of diesel engine life[6]. However, the direct consequence of the leakage in the cylinder body is the reduction of the pressure in the cylinder, so the cylinder pressure can directly reflect the wear of the cylinder liner, as the main parameters of the diesel engine life prediction[7]. At the same time, it is unnecessary to remove the diesel engine cylinder head for measuring the state parameters of cylinder pressure, only need to remove the injector is directly connected with the corresponding sensor can measure.

Effects of fuel injection pressure and oil pressure on the life of diesel engine: In addition to the cylinder pressure as the main factors of diesel engine life prediction, the researchers will consider the impact of fuel injection pressure and oil pressure on diesel engine life, fuel injection pressure is reduced, fuel injection atomization quality becomes poor, the fuel can not be good with the air mixture, diesel engine performance is reduced, long time work will affect the diesel engine life, in contrast to the high injection pressure is not normal injection, long time working diesel engine life will be reduced. Therefore, the height of the injection pressure will become an important reason for the diesel engine service life[8], the value of the oil pressure should be high enough to ensure the reliable transmission of oil to the lubrication surface. If the engine oil pressure is too low, will not be able to carry a large amount of lubricating oil supply to the friction between, causing the piston ring and cylinder wall and crankshaft bearing wear serious, greatly reducing the dynamic performance of the diesel engine, work for a long time will reduce the service life of the diesel engine[9]. Therefore, fuel injection pressure and oil pressure are the the auxiliary parameters influencing the life prediction of diesel engine.

Influence of the external environment on the life of diesel engine: In addition to the above three state parameters, the researchers will consider the influence of various environmental factors and various conditions on the life of diesel engine. Than as models of diesel engine is used in different conditions, even strictly follow the diesel engine specification requirements, parts of the wear and tear strength may also vary several times[10], the impact wear and tear parts outside factors can be divided into three categories: The first is the factors unrelated to vehicle users:

The road, climatic conditions and types of goods, quantity, distance etc., the second is a part of relationship with the factors of vehicle users: The use of quality system and operation material etc., the third category is depends entirely on a vehicle user factors, such as driving driver technology level, maintenance repair level and so on. These state parameters will vary greatly with different environmental areas, so it is difficult to measure, so the other environmental factors and conditions of use will be used as the correction state parameters.

Diesel engine life prediction model

Relationship between cylinder air leakage and diesel engine life: Due to the cylinder leakage and diesel engine running time is closely related. The cylinder leakage rule is increased with the increase of the diesel engine working time. This fact has a very close relationship with the cylinder wear and diesel engine life.

Basic rated wear life: The basic rating wear life of the cylinder liner is defined as the amount of gas leakage of the cylinder to the diesel engine intake Q_e (%) (the general provisions of 20%), diesel engine work time (h) or the distance of the vehicle (km).

Basic rating of the air leakage of the cylinder: In order to predict the service life of diesel engine, the maximum value of air leakage is often required to be the standard of the diesel engine life. The researchers take the diesel engine life as the basis of the end of the cylinder air leakage, known as "The basic rating of the amount of air leakage".

The service life of diesel engine corresponding to the basic rated air leakage is L_b (km), the Lb is called the basic rating life of diesel engine, the value of which is determined by the manufacturing industry and the use of the Department to develop.

The relationship between the cylinder leakage of diesel engine Q and the service life of diesel engine L can be seen in Fig. 1.

Relationship between the air leakage of the cylinder and the service life of diesel engine: From the life curve shown in Fig. 1, it can be seen that there is a relationship between the service life of diesel engine L and the cylinder wear leakage Q[11]:

$$Q_1^{\beta} \cdot L_1 = Q_2^{\beta} \cdot L_2 = \cdots\cdots = Q_i^{\beta} \cdot L_i = Q_b^{\beta} \cdot L_b = C \quad (1)$$

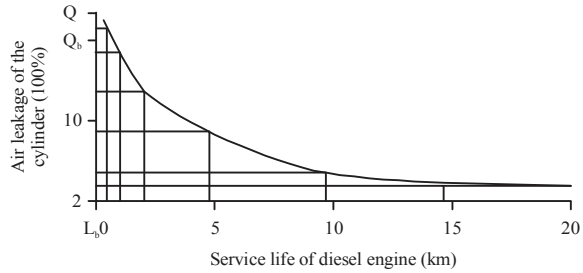

Fig. 1: Life curve of diesel engine

Where:

Q = The cylinder leakage (%)

β = The life index related to the compression ratio of the diesel engine

$\beta = \varepsilon/n$ = The ε for the compression ratio of the diesel engine and the n for the life index reduction factor, the value of which is determined by the experiment

L = The remaining life of diesel engine (1×10^4 km)

In our country, the cylinder leakage Q_b of the end of the service life of diesel engine and corresponding to the life of L_b (1×10^4 km). Then:

$$Q_i^{\beta} L_i = Q_b^{\beta} L_b \quad (2)$$

By the Eq. 2, the Eq. 3 for life can get:

$$L_i = L_b \cdot \left(\frac{Q_b}{Q_i}\right)^{\beta} \left(1 \times 10^3 \text{ km}\right) \quad (3)$$

Therefore, when the Q_i is measured, the remaining life L_i of the diesel engine can be predicted based on the Eq. 3.

Relationship between cylinder pressure and the life of diesel engine: Obviously, the application of the Eq. 3 to predict life is not easy, because in the practical application, the cylinder leakage is very unpredictable and cylinder pressure is easily measured, so the application of on-line measurement of cylinder pressure to predict diesel engine life is relatively easy to achieve. As the cylinder pressure can more directly reflect the wear of the cylinder liner, so it can be said that the cylinder pressure as the diesel engine life prediction of the state parameters, reflected by the cylinder liner wear, the application of cylinder pressure to predict the life of diesel engine is customary at home and abroad.

From the above analysis, it can be known that the cylinder wear leads to the leakage of the cylinder and the direct reflection of the leakage of the cylinder is the reduction of the cylinder pressure. So if it can be found that the function relationship between the cylinder gas leakage and cylinder pressure and then according to the relationship between the cylinder leakage and diesel engine life, the researchers can deduce the function relationship between the cylinder pressure and the diesel engine life.

Relationship between the cylinder pressure P and the cylinder air leakage Q in equal volume and isothermal condition[12]: According to the ideal gas state equation, that is the clapeyron equation:

$$pV = \frac{Q}{\mu} RT \tag{4}$$

So:

$$V = \frac{QRT}{\mu \cdot P} \tag{5}$$

Where:

P = Cylinder pressure
V = The volume of a gas in an instant cylinder
Q = Gas quality
R = Universal gas constant
T = Gas temperature
M = Mol g mol^{-1} gas moore

As the cylinder before and after the gas leak after the volume of V constant (piston in spite of the movement but because it is the same time of comparison, it can be considered that the volume of gas has not changed, that is, in the state of equal volume). The gas quality before the cylinder is Q_e, the cylinder pressure is P_e, the air leakage quality is Q_i, the gas quality becomes Q_e-Q_i after the leak is changed, the cylinder pressure at this time is P_i. Then there:

$$V = \frac{Q_e}{P_e \mu} RT;\ V = \frac{(Q_e - Q_i)}{P_i \mu} RT$$

Due to the volume V is equal before and after the leak, so it is:

$$\frac{Q_e}{P_e \cdot \mu} RT = \frac{(Q_e - Q_i)}{P_i \cdot \mu} RT$$

So:

$$\frac{Q_e}{P_e} = \frac{(Q_e - Q_i)}{P_i}$$

So:

$$P_e = (Q_e\text{-}Q_i) = Q_e P_i$$

So:

$$P_e Q_e\text{-}P_e Q_i = Q_e P_i$$

Then it is:

$$Q_i = \frac{P_e Q_e - P_i Q_e}{P_e} = \frac{(P_e - P_i) \cdot Q_e}{P_i} \tag{6}$$

Equation for the service life of a diesel engine by cylinder pressure: Taking the results above into the equation:

$$L_i = L_b \left(\frac{Q_b}{Q_i} \right)^{\beta}$$

Then the life equation r the diesel engine is:

$$L_i = L_b \left(\frac{Q_b}{\frac{(P_e - P_i) \cdot Q_e}{P_i}} \right)^{\beta} = L_b \left(\frac{Q_b \cdot P_i}{(P_e - P_i) \cdot Q_e} \right)^{\beta} \tag{7}$$

where, Q_e is a suction stroke piston at the lower end and the air quality of the air when the cylinder is not leaking. Obviously for the cylinder diameter of d, stroke of l, combustion chamber volume of V_c, the air density of μ for the diesel engine, the air quality is:

$$Q_e = (\frac{\pi d^2 \cdot l}{4} + V_c) \cdot \mu \tag{8}$$

For a certain type of diesel engine this value is a fixed value.

Rated air leakage and rated pressure: The Pe is the end of the compression cylinder pressure, cylinder pressure for gas cylinder when the mass is Qe, generally considered:

- When the piston is located at the lower end of the cylinder pressure is a atmospheric pressure
- When the piston is located at the top end of the cylinder pressure application experience equation $P_e = 0.15\varepsilon\text{-}0.22$ (Mpa) to calculate

In our country, the end of the diesel engine compression stroke, the air quality of the cylinder should not be less than 80% of the intake, that is, the amount of gas leakage should not be higher than 20%. The researchers set $Q_b = 0.8\ Q_e$.

So the prediction equation of the life of diesel engine becomes:

$$L_i = L_b\left(\frac{0.8Q_e \cdot P_i}{(0.1-P_i)\cdot Q_e}\right)^{\beta} = L_b\left(\frac{0.8P_e}{(P_e-P_i)}\right)^{\beta} \quad (9)$$

So as long as the cylinder pressure Pi can be measured can predict the life of diesel engine L_i.

For a certain type of diesel engine, the compression ratio is a fixed value. Therefore, the compression ratio can be used to express the life equation:

$$L_i = L_b\left[\frac{0.8P_e}{(0.15\varepsilon-0.22-P_i)}\right]^{\varepsilon/n} \quad (10)$$

Where:

L_b = The basic rating life of diesel engine
P_i = Online actual measurement of cylinder pressure
ε = Compression ratio (the compression ratio of diesel engine is generally 17~23)

This Eq. 10 is for predicting the service life of diesel engine, which is expressed by cylinder pressure.

The Eq. 10 shows that, as long as the measured cylinder pressure P_i can predict the remaining life of diesel engine L_i. Equation 10 is usually referred to as the equation for predicting the remaining life of diesel engine with cylinder pressure.

Functional relationship between fuel injection pressure, engine oil pressure and service life of diesel engine: Diesel engine life prediction Eq. 10 is only the main state parameters of diesel engine life prediction and it is a theoretical prediction equation. The analysis of the second section shows that the fuel injection pressure and engine oil pressure are the two main parameters of diesel engine life prediction. The work of the injection system is to rely on the fuel injection pressure curve for real-time monitoring but has not yet seen such a set of measurement system, it is necessary to develop the system, in order to clarify the relationship between the technical state of the injection system and diesel engine life. The exact relationship between injection pressure and the life of diesel engine is not known but it is clear that, with the extension of working time of diesel engine, each friction pair will have a certain wear and the wear of injection pump plunger will gradually reduce the injection pressure. The injection pressure decreased, resulting in a decline in the quality of fuel atomization, coke formation, acceleration of cylinder liner wear, reduce the service life of the diesel engine. The relationship between the fuel injection pressure data and the life of diesel engine can be seen in Fig. 2.

According to Fig. 2, it can be concluded that in the allowable range of injection pressure, fuel injection pressure and the life of diesel engine are as follows:

$$L_p = k_p L_j \left(\frac{P_p}{P_{bp}}\right)^m \quad (11)$$

Where:

L_p = The service life of considering the reduction of the fuel injection pressure
L_j = The life of diesel engine calculated by Eq. 10
P_p = Actual measurement of fuel injection pressure
P_{bp} = Standard injection pressure
M = The life reduction index, which is generally related to the structure and wear degree of the injector
k_p = Correction factor

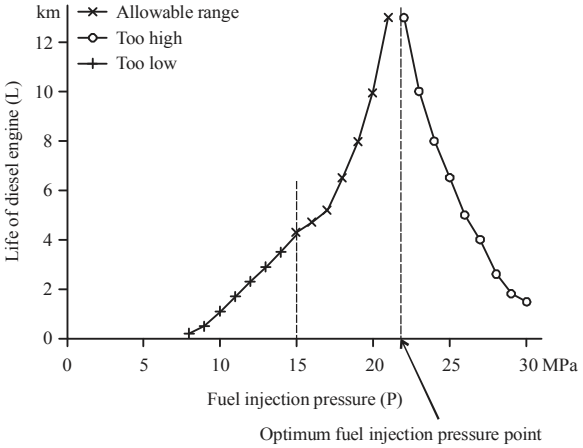

Fig. 2: Relationship between fuel injection pressure and the life of diesel engine

In the same way, the oil pressure of the main oil channel should be high enough to ensure the reliable transmission of the oil to the surface of the lubricating oil. If the engine oil pressure is too low, will not be able to carry a large amount of lubricating oil supply to the friction between, which causes include piston ring and the inner wall of the cylinder, crankshaft bearing shells of serious wear, greatly reducing the dynamic performance of the diesel engine, work for a long time will be reduced and the service life of the diesel engine. The relationship between the engine oil pressure data and the remaining mileage of the engine can be seen in Fig. 3.

According to Fig. 3, in the normal operation of the diesel engine, can be drawn in the normal range of oil pressure, oil pressure and the life of diesel engine expectancy is roughly the following relationship:

$$\begin{cases} L_j = k_j L_i \left(\frac{P_j}{P_{bj}}\right)^n & p_j < p_{bj} \\ L_j = k_j L_i \left(\frac{P_j}{P_{bj}} - 1\right)^n & p_j > p_{bj} \end{cases} \quad (12)$$

Where:

L_j = Service life of diesel engine after changing the engine oil pressure

L_i = Diesel engine life calculated by Eq. 10

P_j = The actual measurement of oil pressure

P_{bj} = Standard oil pressure

n = Life change index, which is generally related to the structure of the oil pump and the wear degree of the friction pair

k_j = Correction coefficient

Correction of the mathematical model through the comprehensive correction coefficient: The conditions and operating conditions of diesel engine are varied, such as different roads, temperature, humidity and wind blown sand and the quality and technical level, fuel oil, lubricating oil quality and load speed, etc., all of which will have a certain impact on diesel engine life. The method considered is to introduce the comprehensive correction coefficient to correct the theoretical mathematical model. The comprehensive correction factor is the sum of the actual conditions of use and the post correction factor of the environmental factors, which mainly are shown in Table 1.

Considering all the above parameters, the comprehensive correction coefficient K is:

$$K = K_a \cdot K_j \cdot K_w \cdot K_k \cdot K_c \cdot K_o \cdot K_r \cdot K_s \cdot K_q$$

where, K is the comprehensive correction coefficient. However, due to the limited time, the precise value of the correction factor and the specific functional relationship between them need to be further studied.

Considering the fuel injection pressure, oil pressure and the influence of using and environmental factors, the researcher get the equation of the life prediction of diesel engine:

$$L_i = L_b \left(\frac{Q_b}{K \cdot Q_i}\right)^{\beta} \left(1 \times 10^3 \text{ km}\right) \quad (13)$$

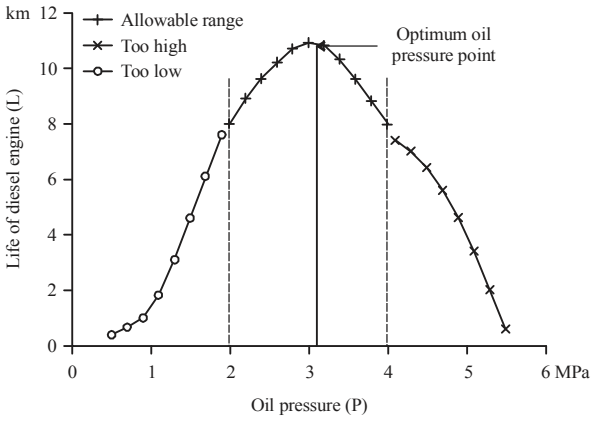

Fig. 3: Relationship between oil pressure and the life of diesel engine

Table 1: Types of modified state parameters for the life prediction of diesel engine

Factors unrelated to the vehicle users	Influence coefficient of road	K_a
	Influence coefficient of seasonal temperature	K_j
	Influence coefficient of humidity	K_w
	Influence coefficient of air cleanliness	K_k
Factors of completely depending on the vehicle users	Influence coefficient of operator	K_c
A part of factors related to the vehicle users	Fuel coefficient	K_o
	Coefficient of lubricating oil	K_r
	Influence coefficient of Load and velocity	K_s
	Other non predictive influence coefficient	K_q

Or:

$$L_i = L_b\left[\frac{0.8P_i}{K\cdot(0.15\varepsilon-0.22-P_i)}\right]^{\varepsilon/n}\cdot k_j\cdot(\frac{P_j}{P_{bj}})^n\cdot k_p\cdot(\frac{P_p}{P_{bp}})^m \quad P_j < P_{bj}$$

$$L_i = L_b\left[\frac{0.8P_i}{K\cdot(0.15\varepsilon-0.22-P_i)}\right]^{\varepsilon/n}\cdot k_j\cdot(\frac{P_j}{P_{bj}}-1)^n\cdot k_p\cdot(\frac{P_p}{P_{bp}})^m \quad P_j > P_{bj} \tag{14}$$

The K is the comprehensive correction coefficient:

$$K = K_a \,.\, K_j \,.\, K_w \,.\, K_k \,.\, K_c \,.\, K_o \,.\, K_r \,.\, K_s \,.\, K_q$$

where, the unit of the life of diesel engine L_i changes with the basic rating life of units L_b.

RESULTS

Experimental verification: With a vertical 195 diesel engine for bench test, the compression ratio of the diesel engine is 17 and the crankshaft speed is controlled by the motor and the gear box. The test bench is carried out by means of a cold drag and the diesel engine consists of a three-phase AC motor through the transmission belt is connected with the gear box and the diesel engine crankshaft is driven by the transmission on the transmission shaft. Three successive measurements are calculated, as shown in Table 2.

Error analysis

Calculation of the average error of the cylinder pressure: As it can be seen from the Table 2, the error of the three measurement is:

$$\Delta\overline{P} = \frac{\sum_{j=1}^{n}\overline{P}-P_i}{\overline{P}\cdot n} = \frac{(2.270-2.276)+(2.270-2.265)+(2.270-2.269)}{2.270\times 3} = 0.002$$

That is: 0.2%.

Average error calculation of the remaining life of diesel engine: Life equation:

$$L_i = L_b\left(\frac{0.12\varepsilon-0.176}{K\cdot(0.15\varepsilon-0.22-P_i)}\right)^{\beta}$$

Into the equation:

- $L_1 = 12.33\times10^4$ km
- $L_2 = 9.69\times10^4$ km
- $L_1 = 10.52\times10^4$ km

Average error:

$$\Delta\overline{L}_i = \frac{\sum_{i=1}^{3}\overline{L}_i - L_i}{\overline{L}_i\cdot n} = \frac{(10.85-12.33)+(10.85-9.69)+(10.85-10.52)}{10.85\times 3} = 0.091$$

That is: 9.1%.

Analysis of measurement results: From the measurement results of Table 2, the average error of cylinder pressure is about 0.4%, which is the key parameter of diesel engine life prediction, which directly affects the accuracy of the prediction of diesel engine life and the other two pressure errors can also meet the requirements of the measurement.

The repeatability error of fuel injection pressure looks slightly higher which reached 1.3%. This is because of the large measurement range of injection pressure sensor, the resolution is relatively low.

The minimum error of oil pressure is only 0.1%, which is necessary, because the oil pressure is generally only 0.2~0.4 MPa, if the resolution of the sensor is low, it will appear the phenomenon of miscarriage of justice, so it can be seen that the choice of sensors is very important.

Measured data can be calculated: Diesel engine life prediction of the average repeatability error is about 9%, the average life of 100,000 km of diesel engine, its prediction error is about 0.99 m, about 10,000 km.

Table 2: Experimental results of the diesel engine bench test

No. of experiments	Cylinder pressure (Mpa)		Fuel cylinder pressure (Mpa)		Oil pressure (Mpa)		Remaining life (10^4 km)	
	Measurement	Error	Measurement	Error	Measurement	Error	Prediction	Error
1	2.276	0.006	18.088	0.02	0.302	0.00	12.33	1.48
2	2.265	0.005	18.061	0.007	0.302	0.00	9.69	1.16
3	2.269	0.001	18.054	0.014	0.301	0.001	10.52	0.33
Average	2.270	0.004	18.068	0.013	0.302	0.001	10.85	0.99

DISCUSSION

Traditional life prediction of diesel engine is often used in the static analysis of oil analysis or radioactive isotopes. Through the static test of the content of iron in lubricating oil of diesel engine, to judge the wear of diesel engine cylinder and then predict the life of diesel engine[13]. The static analysis methods need a certain amount of time for instrument control and data analysis and the current information on the working state of engine can not be provided in a timely manner. Practice has proved that the traditional method to determine the life of diesel engine is very discrete, relatively low accuracy, about 80% earlier. At present, Wenhua *et al.*[14] proposed statistical distribution model for evaluating lifetime of automotive engine, Through identitying the distribution function of the cylinder wear lifetime of automotive engine, a lifetime evaluation model for engines based on cylinder wear rate was set up[14]. By analyzing the wear rate of air cylinder with time series method, this paper gained a relatively precision predicting result of the life of automotive engine with BP neural network by Chunhua and Lei[15]. Qiao *et al.*[7] proposed the method of predicting life time of cylinder based on measuring the air pressure in engine cylinder. The above methods are mainly based on the cylinder wear rate, considering the single factor and need to be built on the basis of a large number of statistical data, the life prediction of engine is not accurate enough. This study considering the impact of the diesel engine life for a variety of factors on the basis of previous studies, through the on-line dynamic measurement, real-time assessment, the life prediction of diesel engine is more accurate and it can provide timely the reliable basis for vehicle maintenance and repair.

CONCLUSION

The experimental results show that this method not only has the advantages of convenient operation, saving time and labor but also achieves a personalized treatment for life prediction of diesel engine. In addition, from the experimental results, the life prediction of the diesel engine by this method is more prolonged than that of the traditional statistical methods. Therefore, it can be known that the service life prediction of diesel engine has great economic value and social benefit.

REFERENCES

1. Liu, C., L. Zhang and C. Wang, 2003. Research on life prediction method for vehicle engine. Vehicle Engine, 1: 19-22.
2. Guo, F., S. Bai, B. Zhou, Y. Wang and Y.T. Li, 2015. Demand forecast of aircraft engine. Comput. Modernization, 42: 113-116.
3. Wang, J. and J. Lu, 2014. Aircraft engine optimal-acceleration schedule design combined with life factor. Comput. Simul., 39: 116-120.
4. Xiaonan, Z., L. Anxin, L. Bin, Z. Hongmei and L. Yong, 2011. A study on the wear prediction of engine cylinder liner based on optimized gray neural network model. Adv. Intell. Soft Comput., 33: 814-817.
5. Deng, Z., H. Zhu, G. Ouyang and W. Xu, 2011. Wear analysis and life prediction of cylinder liner-piston ring. Lubrication Eng., 36: 53-57.
6. Liu, X. and M. Chen, 2009. The grey forecasting for cylinder line wear of internal combustion engine. Lubrication Eng., 34: 78-80.
7. Qiao, X.Y., Y.B. Huang, X.M. Zhang and Y.B. Liu, 2008. Method of predicting lifetime of cylinder based on measuring the air pressure in engine cylinder J. Acad. Armored Force Eng., 22: 42-45.
8. Zhaoye, W., 2005. Research and analysis of the seal and lubrication of the plunger couple. J. Chin. Agric. Mech., 11: 85-90.
9. Lianbo, Z., 2013. Engine block fatigue life prediction method research. Master's Thesis, North Central University, Shanxi, China.
10. Wen, S. and P. Huang, 2012. Principles of Tribology. John Wiley and Sons, New York, ISBN: 9781118062890, Pages: 455.
11. Longbao, Z., 2011. Internal Combustion Engine. Mechanical Industry Press, Beijing, China.
12. Zhaocheng, Y., 2012. Internal Combustion Engine Design. Mechanical Industry Press, Beijing, China.
13. Shoudao, L., 2001. Research on intelligent fault diagnosis technology and life prediction method for large scale vehicle diesel engine. Petroleum University, Beijing, China.
14. Wenhua, X., L. Xiangkai and J. Zhang, 2010. Evaluating lifetime of automotive engine based on statistical distribution model. J. Acad. Military Trans., 4: 64-67.
15. Chunhua, S. and L. Lei, 2009. The prediction of vehicle's service life with BP neural network. J. Acad. Military Trans., 4: 49-51.