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Measurement system of fuel consumption for diesel engine based on function link neural network

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1. Introduction

Fuel consumption is one of the important technical performance indexes, and it directly reflects the fuel economy. The traditional measuring method of effective power is carried out on test-table in the laboratory, However, it needs a high investment and complex operations, so it is unsuitable to monitor the technique conditions of diesel engine, Above all, measuring the consumption is an urgent problem in the field of diesel engine monitoring. There are many researches based on internal combustion engine been done to improve precision of fuel consumption measurement [1-3]. In order to solve the measurement problems effectively, this paper has combined a function chain neural network and chaos optimization theory which corrected the measurement model for diesel fuel consumption based on mathematical relationship. At last we realize a continuous output of diesel fuel consumption information and give a powerful guarantee in the process of online monitoring and intelligent control. The research is of important theoretical significance and wide engineering application prospects.

2. Fuel consumption measurement model for diesel engine

Elliptical gear flow-meter is an unique kind of volumetric meters which has a simple structure without mechanical transmission parts. And two elliptical gears are the only function components in the metering system which have the characteristics of low price, corrosion resistant, easy installation, and insensitive for fluid viscosity measured, etc.. [4-6]. When the instrument coefficient is modified it can achieve higher measurement precision. Firstly we can only get the volume flux of the diesel fuel consumption with it, secondly make a further compensation on temperature and pressure to get mass flux, which we can get volume flux as well as temperature and pressure thirdly upon the relationship of density, temperature and pressure, we get the density under the condition, finally get the mass flux by multiplying the density of volume with flow density. Above is called as compensating quality flow measurement methods.

2.1. Diesel fuel consumption volume flux measurement model

2.1.1. Principle of elliptical gear flow-meter

The computation formula of elliptical gear volume flow-meter is described as follows

$$F=KQ \tag{1}$$

where F is the output pulse frequency, pulse/s; Q is the volume flux, m^3/s; K is the instrument coefficient, pulse/m^3; K is described by the testing chamber structure and magnet number n as follows

$$K=nk/q \tag{2}$$

where k is the number of pulses for each magnet; Q is the discharged fluid volume for each turn cycle of the elliptical gear; N is the magnet number.

To make test results stable and reliable, generally take $k = 1$, when flow-meter structure is confirmed, q is constant; F is proportional to n, then n is greater, the F is higher, the resolution is higher.

2.1.2. Accuracy revise

In order to eliminate accuracy deviation caused by differences of calibrations and working conditions, measurement precision of elliptical gear volume flow-meter is revised according to the actual conditions.

For elliptical gear flow-meter, in the case of low pressure (pressure value is less than 6.4 MPa), pressure is not need to be revised because of the minor effects on accuracy [4]. We focus on two points, first is the influence of flow meter accuracy caused by viscosity and temperature .second is the revise method of them.

The correction of measurement precision is actually a modification of meter coefficient K. Instrument coefficient, mainly used for unit conversion, converts output pulses of elliptical gear flow-meter into engineering units. Its physical meaning is emanatory the pulses number of unit volume fluid through the flow-meter. Revised instrument coefficient K is described as follows

$$K^{/} = K(1 + A) \tag{3}$$

$$A = E + C_T \tag{4}$$

$$E = E_2 - E_1 \tag{5}$$

$$C_T = -\alpha_T(t_2 - t_1) \tag{6}$$

where E is the viscosity modified value, %; E_2 is deviated medium value of user medium, %; E_1 calibration medium deviation median, %; C_T temperature modified value, %,; t_2 is temperature of the medium for conditions, °C; t_1 is calibration medium temperature, °C; α_T is shell expansion coefficient of flow-meter, %/°C.

With the measured pulse frequency F, the volume flux of tested medium can be gotten when the revised instruments coefficient $K^{/}$ joined formula (1)

$$Q_v = \frac{F}{K\left[1+\left(E_2-E_1\right)-\alpha_T\left(t_2-t_1\right)\right]} \tag{7}$$

2.2. Density compensation of volume flux

Usually, density compensation is carried out on volume flux of diesel fuel consumption, because of the small compression coefficient of diesel fuel, if the working pressure is low, we can ignore the variety of density, caused by pressure. And we only consider the influence of the temperature. With the temperature variation in small scope (less than in 40°C), diesel fuel density and temperature can be expressed a linear relationship

$$\rho = \frac{\rho_0}{1+\beta\left(t_2 - t_0\right)} \tag{8}$$

where ρ_0 is diesel fuel density under temperature t_0, kg/m^3; β is diesel volume expansion coefficient, 1/°C, ρ is diesel fuel density under temperature t_2, kg/m^3.

2.3. Diesel fuel consumption measurement model under the working conditions

Above all, when diesel fuel consumption volume flux and density are given, the mass flux of the diesel fuel consumption can be calculated as follows

$$Q_m = Q_v \rho \tag{9}$$

where Q_m is diesel fuel consumption mass flux, kg/s; Q_v is the volume flux of diesel fuel consumption, m^3/s; ρ is diesel fuel density, kg/m^3.

Joined the formula (7), (8) to the (9) formula, it can be obtained

$$Q_m = \frac{F\rho_0}{K\left[1+\left(E_2 - E_1\right) - \alpha_T\left(t_2 - t_1\right)\right]\left[1+\beta\left(t_2 - t_0\right)\right]} . \tag{10}$$

2.4. Function chain neural network correction

We should pay attentions to two points, one is to enhance the fuel consumption measurement precision of the model. and the other is to prevent the "floating" phenomenon of model parameters, which caused by property variety of fuel consumption measurement model, when environmental condition changes. We make online correction of fuel consumption measurement model based on function chain neural network [5-7] technology and its principle is prescribed as follows.

Assumed the corrected intelligent measuring output of consumption quantity can be described with a power series a polynomial (generally, take n = 3, it has a higher precision)

$$X(x_i) = c_0 + c_1 x_i + c_2 x_i^2 + c_3 x_i^3 \tag{11}$$

where x_i is the i measurement output value of fuel consumption quantity.

We can clearly indicate that, in the mathematical and the parallel distributed processing network conceptualization model, once a node (node k) is inspired, there will be many additional functions urged, that is, we can get not only x_i but also $g_0(x_k)$, $g_1(x_k)$, … , $g_n(x_k)$, … (Fig. 1). In principle, we can use single-layer network to realize supervision learning just with the function chain method.

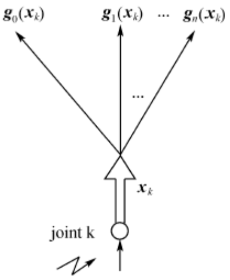

Fig. 1 Schematic diagram of function joint

In Fig. 2 $W_j (j = 0, 1, \ldots, n, n = 3)$ is network connection weights. The number of connection weights is the same as the order number against nonlinear polynomial ($j = n$). Assumed neural network of neurons is linear, the function chain neural network's input value is $1, x_i, x_i^2, x_i^3$.

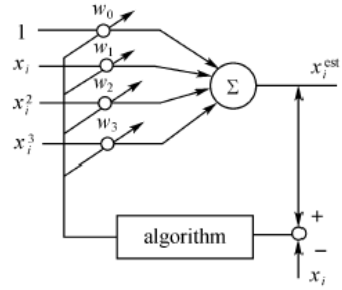

Fig. 2 Schematic diagram of FLANN

The output value $X_i^{est}(k)$ of neural network of function chain is

$$X_i^{est}(k) = \sum_{j=0}^{3} x_i^j W_j(k) \tag{12}$$

where $W_j(k)$ is the jth connection weights as the step k.

We compared the neural network output values $X_i^{est}(k)$ of function chain with actual measured value X_i with the ith output value of fuel consumption quantity. and after learn the function neural network; the minimum of the average-square errand between the output estimate value of neural network function chain and actual measurement value X_i corresponding to the i output value of fuel consumption quantity within the full scope is obtained

$$min\sum_{i=1}^{N}[x_i^{est}(k) - x_i]^2 =$$
$$= min\sum_{i=1}^{N}\left[\left(W_0(k) + W_1(k)x_i + W_2(k)x_i^2 + W_3(k)x_i^3\right) - x_i\right]^2 \tag{13}$$

s.t. $a_0 \leq W_0 \leq b_0$; $a_1 \leq W_1 \leq b_1$; $a_2 \leq W_2 \leq b_2$; $a_3 \leq W_3 \leq b_3$.

Namely, the minimum value is function of the weight W_0, W_1, W_2, W_3.

2.5. Adaptive chaotic optimization algorithm

Given the scope of the weight W_0, W_1, W_2, W_3 adaptive mutative scale chaos optimization algorithm is used to solve the global optimization problem of Eq. (13).

Choose one dimension self-mapping of infinite folding times as the chaos model in order to produce the chaotic variables of search iteration K_1 and K_2 denotes coarse and fine iteration times respectively.

$$\begin{cases} x_{n+1} = sin(2/x_n) & 0, \ 1, \ 2, \ \cdots, \ n \\ -1 \le x_n \le 1 & x_n \ne 0 \end{cases} \tag{14}$$

The basic steps chaos optimization algorithm as follows.

Step 1. Algorithm initialization.

Firstly we set $K_1 = 1$, $K_2 = 1$, and chose two larger positive integer N_1, N_2. Then x_0 is produced by random and put into the chaotic model shown in Eq. (14). At last the ith chaotic variables $x_{i,\,n+1}(i = 1, \ldots, n)$ as the chaotic variables with search iteration was produced.

Step 2. Coarse transformation of chaotic variables in the design of the variable interval.

Transform the ith chaotic variable in the range [-1, 1] into the value interval $[a_i, b_i]$ of variables η and n that is optimal designed in with formula (15)

$$x'_{i,n+1} = a_i + (b_i - a_i)x_{i,n+1} \tag{15}$$

Step 3. Using chaotic variables to coarse iterative search.

Make the optimization solution $f_i(K_1)$ from $x_i(K_1)=x'_{I,\,n+1}$, first set $x^*_i = x_i(0), f^*_i = f_i(0)$, then

1) if $f_i(K_1) \le f^*_I$, $f^*_i = f_i(K_1)$, $x^*_i = x_i(K_1)$;

2) if $f_i(K_1) > f^*_i$, give up $x_i(K_1)$. When $K_1 \le N_1$, enter the next iteration, $K_1 := K_1+1$, when $K_1 > N_1$, end coarse iteration.

Step 4. Reduction of chaotic variables search interval.

$$\begin{cases} a'_i = x^*_i - \varphi(b_i - a_i) \\ b'_i = x^*_i + \varphi(b_i - a_i) \end{cases} \tag{16}$$

where φ is the contraction factor, $\varphi \in (0, 0.5)$.

In order to prevent new range beyond the border, the following treatments are done: if $a/i < a_i$, then $a/i = a_i$, if $b/i > b_i$, then $b/i = b_i$.

Therefore, the vector y^*_1 which results from x^*_i in the new interval $[a/i, b/i]$ by reduction treatment is determined by following type

$$y^*_i = \frac{x^*_i - a'_i}{b'_i - a'_i} \tag{17}$$

Step 5. Fine transformation of chaotic variables in the design variables interval.

If f^*_i keeps constant after steps (3), use a new chaotic variable which is gotten by using formula (18) that combined y^*_i and $x_{i,\,n+1}$

$$x^*_{i,n+1} = (1-\beta_i)y^*_i + \beta_i x_{i,n+1} \tag{18}$$

where β_i is adaptive adjustment coefficient, $0 < \beta_i < 1$.

β_i is determined by following

$$\beta_i = 1 - \left(\frac{K_2 - 1}{K_2}\right)^m \tag{19}$$

where m is a integer decided by the optimal objective function, in this paper taken $m = 2$.

Next comes to the early terms of iterative search, because of the great change of $(x_1, x_2, \ldots, x_n)$, we need larger β_i. Along with the search, the most advantage is approaching, then we need to choose smaller β_i in order to search in smaller range of $(x^*_1, x^*_2, \ldots, x^*_n)$.

Step 6. Fine iterative search with chaotic variables.

Make the optimization solution $f_i(K_2)$ from $x_i(K_2) = x^*_{i,\,n+1}$:

1) if $f_i(K_2) \le f^*_i, f^*_i = f_i(K_2)$, $x^*_i = x_i(K_2)$.

2) if $f_i(K_2) > f^*_i$, give up $x_i\,(K_2)$. When $K_2 \le N_2$, enter the next iteration, $K_2 := K_2 + 1$, when $K_2 > N_2$, end fine iteration.

Generally, the weight W_0 and W_1 is the same order of magnitude, W_2 is at least one order of magnitude lower than W_1, and W_3 is more orders of magnitude lower than W_2. The low magnitude is determined by the nonlinear degree of nonlinear characteristics of the sensors. When we obtain the optimal solutions W_0, W_2, W_3, W_1 we can know that $c_0=W_0$, $c_1=W_1$, $c_2=W_2$, $c_3=W_3$, finally we put the undetermined coefficients c_0, c_1, c_2, c_3 into the memory.

3. Measurement system of diesel fuel consumption

The diesel fuel consumption measurement system is shown in Fig. 3.

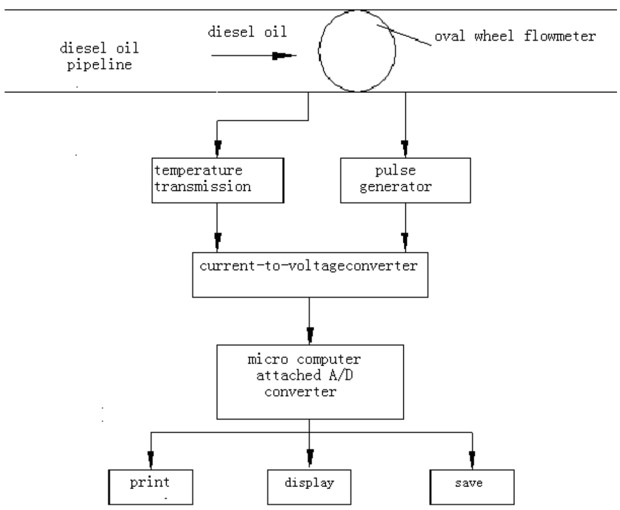

Fig. 3 Diesel fuel consumption measurement system schemes

3.1. System hardware

3.1.1. Measurement components

The number of pulse per turn cycle of Elliptical gear fuel consumption sensor is 4, and the gear precision 5, the instrument coefficient K is 1.553 pulse/m^3, other basic parameters is shown in Table1.

Table 1

Parameter of fuel consumption transducer with oval-shaped gear

Tooth number Z	Module m	Tooth thickness B	Eccentricity e	Semimajor axis l1	Semiminor axis l2	Center distance S
38	0.5	6.0	0.2774	11.708	6.623	18.33

3.1.2. Microcomputer

Taken DELL DIMENSION 4500 as the microcomputer, the external device includes keyboard, printer, display and disk drive.

3.1.3. Peripherals

He matched insert board of 12 A/D transformer is the standard pinboard which can directly insert into Host.

3.1.4. Automation instrumentation

1) YKE 202 type pulse generator;

2) The DDZ-II type temperature transmitter with the range of 0 ~ 200°C switches the temperature signal, and its output current is 4 ~ 20mADC and 1 ~ 5VDC by the current - voltage transformer.

3.2. System software

The application software of Diesel fuel consumption measurement system is adopted the VISUAL BASIC, it includes several parts.

3.2.1. Data acquisition and processing system

According to the instruction requirement, the various parameters (elliptical gear speed and diesel temperature) are transformed into electrical signals by the automatic instruments through the microcomputer interface with its data interface, further processed by the current - voltage converter, then sent to A/D transformer for A/D conversion, finally the digital quantity corresponding to the measuring parameter is obtained, thus the above two different types data collection is finished.

3.2.2. Volume flux measurement system

After measured the rotate speed of the elliptical gear, the volume flux Q_v of diesel fuel consumption may be calculated with formula (7).

3.2.3. Mass flux measurement system of diesel fuel consumption measurement

The volume flux Q_v can be compensated with formula (10), and get the mass flux Q_m of diesel fuel.

3.3. System operation

To install the diesel fuel consumption measurement system in the pipeline, the above parameters are collected and calculated every 15 s with the measuring system, and thus the instantaneous and cumulative value of diesel fuel consumption are obtained, and displayed on a monitor screen.

4. Application of diesel fuel consumption measurement system

Taken the diesel fuel mass flux as the benchmark with Corey ollie mass flow-meter under the different volume flux Q_V, the trend of the relative error η of fuel consumption measurement model is shown in Fig. 4 shown.

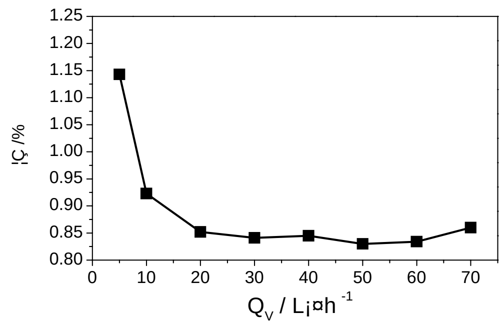

Fig. 4 relative error from the fuel consumption measurement

It shows that, when volume flux Q_V is in 20 ~ 70 L/h, the relative error of diesel fuel consumption measurement model is about 0.85%, but when Q_V less than volume flow 20 L/h, the relative error of elliptical gear oil consumption measurement model is sharpen, it may be due to the leakage when small flow caused by a large proportion.

Due to the small diesel oil temperature fluctuations, the viscosity has little change and E_2 can be regarded as fixed value. Therefore, the online measurement and real-time display and printing can be realized just with the online acquisition of working temperature t_2 of heavy oil and elliptical gear pulse frequency F conveniently.

5. Conclusion

1 Take the stainless steel elliptical gear flowmeter as metering component, based on volume flux model and the density compensation with the correction of instrument coefficient, and combined the function chain of neural network and chaos optimization theory to optimize and revise, the fuel consumption measurement model is established under the working conditions of diesel engine.

2 Revised by the function chain of neural network for elliptical gear fuel consumption measurement model, the relative error is reduced by 0.15% averagely, and it has a high precision, therefore, it can completely be realized online fuel consumption measurement with the elliptical gear flow meter for diesel engine.

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DYZELINIO VARIKLIO DEGALŲ SUVARTOJIMO MATAVIMO SISTEMA, PAGRĮSTA NEURONINIŲ TINKLŲ FUNKCINIAIS RYŠIAIS

R e z i u m ė

Sprendžiant dyzelinio variklio degalų suvartojimo matavimo problemą, buvo sukurtas degalų suvartojimo matavimo modelis. Dyzelinio variklio matavimo mechanizme naudojamas elipsinės pavaros degalų tekėjimo matuoklis, o parametrams derinti buvo panaudoti neuroninių tinklų funkciniai ryšiai ir chaoso optimizavimo algoritmas. Įdiegimo rezultatai parodė, kad dyzelinio variklio matavimo sistema yra labai tiksli ir variklis veikia ekonomiškiau.

YUAN Wen-hua, LIU Yu-mei

MEASUREMENT SYSTEM OF FUEL CONSUMPTION FOR DIESEL ENGINE BASED ON FUNCTION LINK NEURAL NETWORK

S u m m a r y

In order to solve measurement problem of fuel consumption measurement in the diesel engine, a fuel consumption measurement model using elliptical gear flowmeter for diesel engine was established based on its measurement mechanism, and its parameters adjustment by using function link neural network and chaos optimization algorithm were introduced. The application results revealed that the measurement system for diesel engine is of high precision and is useful for enhancing the economical quality of the diesel engine.

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