International Journal of Control and Automation
Vol. 9, No. 10 (2016), pp.209-218
http//dx.doi.org/10.14257/ijca.2016.9.10.20

Energy Saving Optimal and Numerical Simulation of New Car Engine Vane Pump

Chuanlai Yuan [1], Lingshuang Kong [1,*], Weilong Zhou [1] and Guangming Liu [2]

[1]College of Electrical and Information Engineering, Hunan University of Technology, ZhuzhAou, 412007, China
[2]Hunan Oil Pumb Co., Ltd.Hengdong, 421400, China
Lingshuangkong@126.com

Abstract

In this paper, optimization of new car engine lubrication system was discussed in our study. It boncluded key analysis of noise pump energy, optimal control strategy of the pump, optimal allocation of real-time detection and sensor pump working parameters. Fuel consumption and operating noise relationship model was built for energy saving and noise reduction as well as energy-saving pump optimization model, which was proposed for solving an effective energy-saving optimization model. Disscussion formed a more perfect pump optimization and energy saving noise control method for automotive engine energy saving. In our study, low-power car motor lubrication system consisted of energy noise vane pump was studied. Advanced optimization control theory was used in automotive motor lubrication system, the study of new energy-saving car pump noise optimal control strategy and oil pump working parameters achieved real-time detection and sensor optimized configuration. We built oil fuel with operating noise and working parameters of the relational model for energy-saving and noise reduction, it proposed an energy smart kinds of effective optimization model for forming a more perfect energy-optimized pump control system.

***Keywords**: Car engine; oil pump; flow-induced noise; numerical simulation*

1. Introduction

World energy problem catched continue demand of natural resources depleting [1]. Industrial companies, energy suppliers and consumers have faced a new challenge, so that the efficient and sustainable use of energy has become more seriously. With the rapid development of China's automobile industry, an urgent need for high performance, low energy, and environmental protection of new combustion engine systems achieve its requirements, which can improve the competitiveness of China's automobile industry. Therefore, countries have developed a number of policies to promote the automotive, internal combustion engine industry, energy conservation, the development of automotive products with energy-saving, low power consumption, light weight, low emission and environmentally friendly. By implementing technological progress and improve the level of product, China can meet with the world's advanced level of automobile product integration gradually [2].

The key method of optimization model for energy-efficient pump is take appropriate optimization algorithm to solve the optimal control problem, which is embodiment of pump energy-saving and noise reduction and was very worthy of study [3, 4]. The traditional optimization algorithm included the steepest descent method, conjugate gradient method, Newton's method, Marquart method and SQP algorithm. These traditional optimization algorithms were dependent on accurate mathematical model heavily, for the complex lubrication systems, optimization

ISSN: 2005-4297 IJCA

models tend to be very complex non-linear relationship. It is difficult to obtain analytical mathematical models, which limited the application of traditional optimization algorithms. The introduction of artificial intelligence can overcome this problem. Currently, the use of expert reasoning heuristic reasoning or three most optimization method is based on the idea of artificial intelligence rules in complex systems, optimization methods is similar to simulated annealing algorithm, random genetic algorithms, and particle swarm optimization search algorithm. Thus, the study of these intelligent optimization algorithms is an advanced optimizing control theory used in automotive lubrication system in a very critical issue successfully [5].

Currently, the oil pump optimization work most commited with gear pump and rotor pump-based structural optimization. Gear pumps because of its simple structure, high reliability, strong anti-pollution and good self-absorption properties, especially in the engine oil pump under high flow oil pump has been applied widely. A gear pump is the firstly studied by intelligent pump structure, company has developed a level of variable displacement and image pattern control system or multi-level control system and enter a mature application stage. The main research is how to improve the overall efficiency of the pump and development of high-volume commercial systems to adapt to the variable flow and variable pressure system, including the results of pilot study, the application of new materials and technologies. Passenger vehicle condition obtained more widely used, due to the eccentricity of the pump rotor cannot be adjusted, nor the length of the engagement like a gear pump as length of engagement change, the transformation of energy into sexual activity is more difficult [6].

In this paper, low-power car motor lubrication system was carried out for study, energy noise vane pump is controlled with core, advanced optimization control theory was used in automotive motor lubrication system. New energy-saving car pump noise optimal control strategy was built, the oil pump working parameters achieve real-time detection and optimized configuration. Oil fuel, operating noise and the working parameters of the relational model proposed a energy smart kinds of effective model for solving optimization algorithms, which forming a more perfect energy-optimized pump control methods. Application of research results in the actual system will improve the automation level of the automobile industry, energy-saving control of the whole optimal operation conditions, and provide an important way for low-power automotive engine lubrication system.

2. Research Status and Related Theory

2.1. Research Status of Oil Pump

In early 1950s, French scholar Hockly [7] began the study two-stage relationships of rotor millet oil temperature and extreme pressure. In 1990, Hablanian [8] put forward a new method of rapeseed, the study found the new design of oilseed rape have been improved greatly compared with previous oil properties in the spring. In 2001, Simon *et al* [9] studied oil millet valve blockage experimentally, the results showed that oil pump inner rotor friction is the main reason of oil spring valve blockage. In 2002, Tang [10] studied ion implantation and other major parts of the piston pump to improve the hardness and strength, thereby improved long life in harsh environments. In 2012, Jarnesf [11] put forward a method based on statistical process control, which can effectively pump performance of the car and the quality control method, and thus to optimize the performance of automobile oil millet. Marcus [12] use CFD software eccentric centrifugal oil millet flow field analysis conducted, the results showed numerical and experimental results are consistent basically, he also used parametric analysis methods to evaluate the geometry of oilseed rape oil from the volume flow.

In the 21st century, along with high-speed development of computer hardware and software, the application of computer simulation method has also been leaps and bounds. Sometimes, due to limitations and test cost of expensive experimental conditions, the numerical simulation method can compensate for these shortcomings, therefore CAE software and CFD software in the country used by many researchers. Zeng Fanping [13] used ANSYS vane pump to the valve plate and established a finite element model, the valve plate structure were static stress analysis. The results showed that the maximum strain occurs in the valve plate the hole weakest. Zeng [14] and Cai [15] engaged dynamic contact analysis, simulation results inside and outside the rotor contact stress contours, and large compressive stress site optimization. Yin Jun [16] used the CFD software internal flow field numerical simulation analysis which has been able to react the oil millet internal flow field characteristics of the pressure distribution and velocity profile.

2.2. Acoustic Theory of Pump Flow-Induced Noise

Sound is generated produced by vibration of the object, the vibration in medium have inertia and elasticity, as solids, liquids and gases, in the form of a pressure wave propagates, then acoustic waves are formed. In the medium, the acoustic energy of molecular motion is passed, the area involved collectively referred as sound field. Acoustic wave propagation velocity referred to the speed of sound c, unit is m/s, the number of medium particle vibration per second is called the frequency f (Hz), sound waves in a vibration cycle propagation distance is called wavelength λ; the unit is m. Relationship between the sound velocity, frequency and wavelength:

$$c = \lambda f \tag{1}$$

Silent air pressure wave propagation was called hydrostatic pressure. The acoustic wave propagation, where the air pressure generated additional Δp, called instantaneous sound pressure. Value of the secondary instantaneous sound pressure was called effective sound pressure p, the unit is Pascal (Pa).

$$p = \sqrt[2]{\frac{1}{t}\int_0^t (\Delta p)^2 dt} \tag{2}$$

Since the strength of sound is sound pressure expressed in absolute terms, the scope of its digital has changed so much, not easy to remember and use. Therefore reference sound pressure is set to P_0, size $2x10^5$ Pa, L_p commonly used to indicate the size of sound pressure level (dB).

$$L_p = 20\lg \frac{p}{p_0} \tag{3}$$

The actual calculation commonly used acoustic or power, W is an average expression as follows:

$$W = \frac{1}{T}\int_0^T pSudt = S\frac{1}{T}\int_0^T pudt \tag{4}$$

Wherein W is power; T is the period of the acoustic wave; u is the acoustic velocity; p is the effective sound pressure; S is the area.

I represented sound intensity, acoustic energy perpendicular to the direction of propagation of sound waves through unit area per unit time, the unit is w/m^2, expressed as follows:

$$I = \frac{Wt}{St} = \frac{W}{S} \tag{5}$$

2.3. Vane Pump Power Calculation

Mechanical power required to drive the pump shaft power is called shaft power N, the pump input power:

$$N_a = \omega T \times 10^{-3} = \frac{\pi n T}{30} \times 10^{-3} (kW) \tag{6}$$

Wherein, T is torque in the shaft, unit of N*m; ω is the angular speed, unit is rad/s; n is the rotational speed, unit is r/min.

Hydraulic power Nh: power through the suction action of the oil pressure applied to oil pump and hydraulic power, the effective output power of the pump is equal to the pump discharge port output power minus the pump suction flow of liquid stream power, namely:

$$N_h = \frac{\Delta p Q}{60} = \frac{(p_2 - p_1)Q}{60} (kW) \tag{7}$$

Wherein, Δp is the pressure difference between the pump inlet, p_2 is the outlet pressure, p_1 is the inlet pressure, unit is MPa; Q is the flow rate of the pump output, unit is L/min.

Theoretical power can be expressed as:

$$N_{th} = (N_a)_{th} = (N_h)_{th} \tag{8}$$

$$(N_a)_{th} = \omega T_{th} \times 10^{-3} = \frac{\pi n T_{th}}{30} \times 10^{-3} (kW) \tag{9}$$

$$(N_h)_{th} = \frac{\Delta p Q_{th}}{60} = \frac{\Delta p n q}{60} \times 10^{-3} (kW) \tag{10}$$

3. Optimal Control Strategy of Oil Pump Saving

3.1. Main Equipment of Noise and Vibration Testing

To imply the method for solving load in reverse vibration response, a number of vibration signal structure was needed completely, so as to ensure the accuracy of solving. The test conditions were shown in Table 1. Through multi-channel vibration signal acquisition device, a plurality of three acceleration sensors to repeat the test noise and vibration test, the main equipment was shown as follows:

(1) 40-channel data acquisition system;
(2) Three-way accelerometer, PCB microphone;
(3) Pump performance test;
(4) Test instruments and related consumables.

Table 1. Load Case of Testing

No.	Rotate speed (r/min)	Pressure (MPa)	Flow (L/min)
1	750	200	13.1
2	750	400	11.6
3	750	460	4.1
4	2000	200	35.1
5	2000	400	30.3
6	2000	500	15.9
7	3680	200	63.8

8	3680	400	50.6
9	3680	500	37.1
10	4500	200	74.1
11	4500	400	57.8
12	4500	500	46.0
13	5500	200	85.0
14	5500	400	64.7
15	5500	500	52.4

3.2. Optimized Sensor Configuration

Vibration acceleration testing arrangement consisted with eight measuring points, each measuring points are collected by three acceleration sensors in three directions X, Y and Z with vibration signal, sensor arrangement was shown in Figure 1; distance from the pump microphones arranged at 1m noise test in the center of the horizontal.

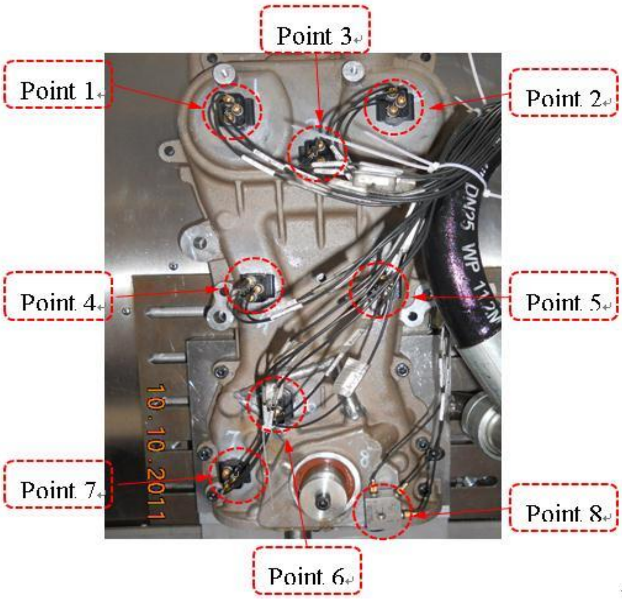


Figure 1. Sensor and Testing Point Layout Diagram of Sample

From structural modal analysis results and the entire specimen, vane pump housing in modal analysis modes larger portion of the first-order and second-order natural frequency. Vibration mode greater be arranged with acceleration sensor, and the work site (from the first vibration mode near) vibration is large, the first vibration mode is decisive, many measuring points reflect true vibration should be arranged. The direction of the acceleration sensor test option was the same.

Signal acquisition platform improved working conditions to form structure vibration, signals is stored as a text file for later solving calculations by FFT. Of course, other conditions may also be signal.

4. Experiment and Analysis

4.1. Signal Processing and Diagnosis

Internal meshing engine bench of rotor pump was tested analysis, the noise spectrum was changed with the speed of sweeping curves and waterfall diagrams was also observed. Results reflected the structure of overall radiation noise level exceeds the acceptable range, so the analysis and structural improvements was needed.

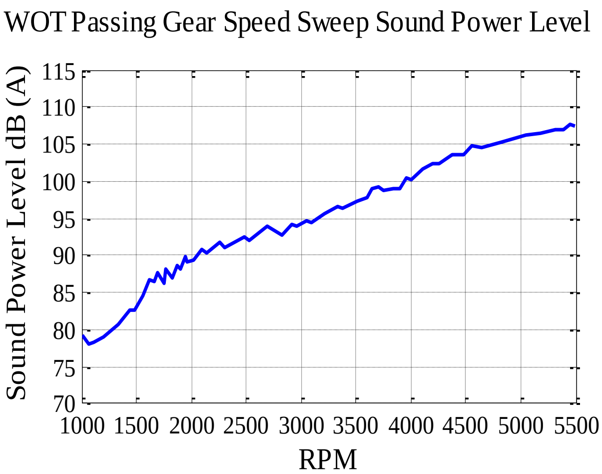


Figure 2. The Noise Increased With the Speed Rise

As it can be seen from Figure 2, the noise increases substantially as the speed rise, RPM was more than 2000 when noise was 90dB. From the trend curve,we can see the basic linear was changed.

The grid of discrete boundary constraints and other aspects of quality was taken into account due to the issues and differences of analysts understanding, leading to solve the different results, where the need for results modal analysis was verified. Modal analysis can be solved by numerical methods and results can be obtained by modal test under the natural frequency of distribution. Common modal test method constructed the actual connection by the force of the hammer hitting structure in order to excite the natural frequency of the structure. This method is simple and reliable, but it is difficult to arouse all the natural frequency, it is generally still modal solved by numerical calculation and verified by modal test.

Modal numerical calculation of external gear pumps installed in the pump comprehensive performance test bench, the structure of the surface is arranged a group of acceleration sensors, which connected to the signal acquisition device vibration signal acquisition. Here one-way acceleration sensor and signal acquisition system signal acquisition was processed through MATLAB software by FFT transform. Figure 3 was the spectrum of the signal.

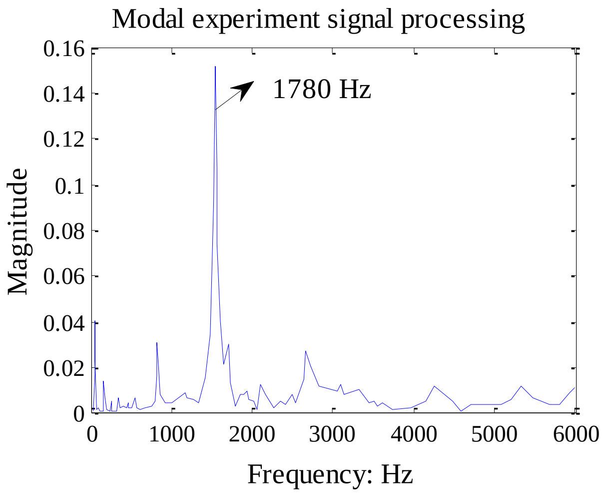


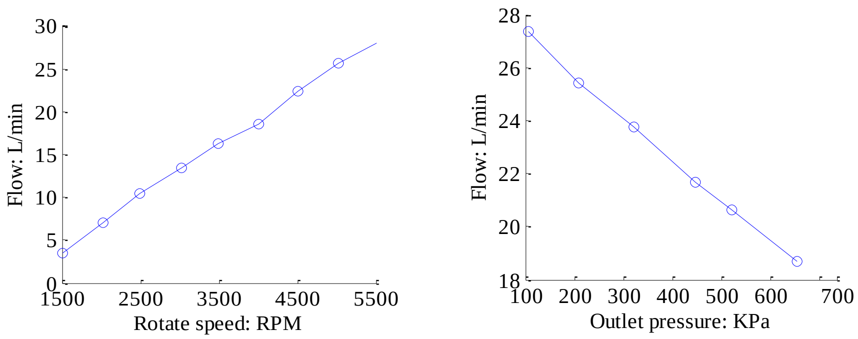
Figure 3. Spectrum Map of Modal Testing

As can be seen from Figure 3, during hammering modal test, the obvious frequency of 1780Hz closed with 1783.4Hz, which verify the accuracy of modal analysis to ensure that the boundary conditions and grid effectiveness.

4.2. Test Data Processing and Results Analysis

Oil pump design is the most important design specifications, other amounts was to meet the emission requirements on re-consideration. Factors affecting a lot of displacement, mainly pressure pulsation, volumetric efficiency, of course, an important prerequisite is to aviod oil trap. Vibration will produce different degrees of impact on emissions. Pump oil pressure pulsation instability, namely the displacement of instability, exert serious impact on the oil pump action, which restricts the performance of the engine.

The ratio of the theoretical displacement oil pump is volumetric efficiency, volumetric efficiency pump design is a very important design specifications. Figure 4 is the test of a pump flow with different speed and outlet pressure..



a: relationship between flow rate and rotate speed under the same outlet pressure

b: the change of flow with the outlet pressure under the same rotate speed

Figure 4. The Relationship between the Flow with the Outlet Pressure And Speed

As can be seen in Figure 4, flow rate will increase with the speed and near-linear increase under the same outlet pressure; at the same speed, traffic pressure along with exports increased and linear decrease.

4.3. Statistical Analysis of Pressure Pulsation at Different Speeds

Rotor inside the pressure pulsation can be divided into two categories. One is the internal fluid unstable oil springs flow, bad flow and trapped oil, gas candle caused by random factors such as random pressure pulsations, whose frequency is very close to the white noise. The other is the machine work process rapeseed, static, dynamic balance, the gap inside and outside the axis of the rotor shaft. The bearing inner rotor frequency and its harmonics caused by the pressure pulsation regularity.

There are statistical analysis, frequency domain analysis and other analytical methods of pressure pulsation. In this paper, the flow field obtained number of the pressure pulsation dig for analysis. Statistical analysis of trace amplitude domain analysis and correlation analysis, is a time-domain waveform performance analysis. Web domain analysis of the sample statistics foot flag was analyzed, including analysis of signal maximum, minimum, range value of the bit, the standard value and other parameters. Suppose a sample of n instantaneous values were x_1, x_2, ... ,x_n.

The range of values:

$z = \max(x_1, x_2, x_3, \ldots, x_n) - \min(x_1, x_2, x_3, \ldots, x_n)$ Standard deviation:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad (11)$$

Pump intake section and outlet section monitoring point range values at each speed was shown in Figure 5.

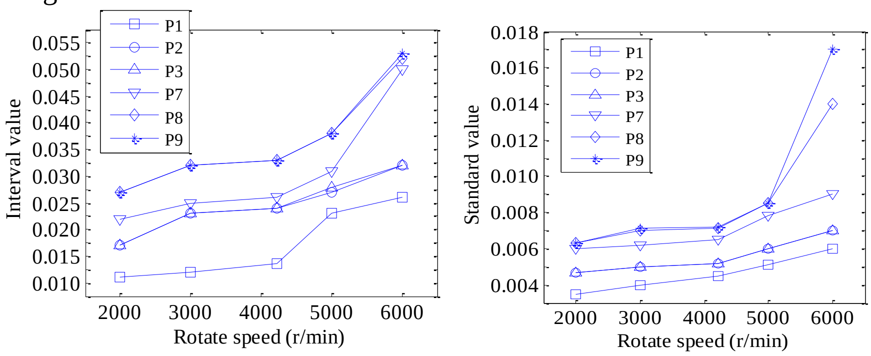


Figure 5. Pump Intake Section, Outlet Section Monitoring Point Range Values at Each Speed

5. Conclusions

The regulations state of vehicle noise become more stringent, the development of low-noise, low-pollution car is required. As one of the main sources of noise automobile engine, pump noise gradually attracted the attention of researchers. Rotor type oil pump work inside and outside of the rotor so that the mechanical noise compared to much lower gear oil pump, so fluid pump rotor noise was studied become increasingly critical. This article describes the overall pump performance indicators and corresponding evaluation methods, and focus on noise and vibration related indicators. Ordinary gear mechanical systems and pump structure is subjected to various forces of the engine torque, engine oil pressure and impact force, including structural forces and fluid forces. The result vibration behavior of the structure belonged to the complex fluid-structure, which can not be solved by conventional methods. Consider the fluid-structure interaction, analyze vibration test signal as the basis for new diesel pump failure due to failure caused by a successful diagnosis, and ultimately find the cause of the fault location for manufacturers to solve practical problems.

Acknowledgements

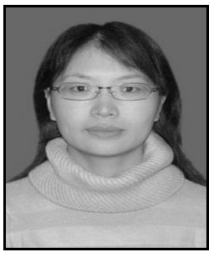
The authors are grateful for the financial support from the Hunan Provincial Natural Science Foundation of China (Grant No. 2015JJ5025) and the National Natural Science Foundation of China (Grant No.61203136).

References

[1] N. K. Roy, W. D. Potter and D. P. Landau, "Polymer property prediction and optimization using neural networks", IEEE Transactions on Neural Networks, vol. 17, no. 4, **(2006)**, pp. 1001-1014.
[2] L. Wang, J. C. Fang and Z. Y. Zhao, "Application of backward propagation network for forecasting hardness and porosity of coatings by plasma spraying", Surface & Coatings Technology, vol. 201, no. 9-11, **(2007)**, pp. 5085-5089.
[3] M. Wu, M. Nakano and J. H. She, "A distributed expert control system for a hydrometallurgical zinc process", Control Engineering Practice, vol. 6, no. 12, **(1998)**, pp. 1435-1446.
[4] L.C.-K. Liau, T. C.-K. Yang and M.-T. Tsai, "Expert system of a crude oil distillation unit for process optimization using neural networks", Expert System with Applications, vol. 26, no. 2, **(2004)**, pp. 247-255.
[5] R. Babuska, H. B. Verbruggon and H. J. L. Bancan, "Fuzzy modeling of enzymatic penicillin-G Anversion", Engineering Application of Artificial Intelligence, vol. 12, no. 1, **(1999)**, pp. 79-72.
[6] W. Xiao and B. Weidemann, "Fuzzy modeling and its application to magnetic bearing systems", Fuzzy Sets and Systems, vol. 73, no. 20, **(1995)**, pp. 20-217.
[7] L. C. Jun, P. Binay and L. J. Min, "Stochastic nonlinear optimization for robust design of catalysts", Industrial and Engineering Chemistry Research, vol. 50, no. 7, **(2011)**, pp. 3938-394.
[8] Y. Zhao, W. Wei, X.J. Tang and M.L. Zhao, "Choice of Optimized Scheme Parameters of Neural Networks Based on Error Handling", AISS. vol. 17, **(2012)**, pp. 76-82.
[9] P T Boggs and J W. Tolle, "Sequential quadratic programming for large-scale nonlinear optimization", Journal of Computational and Applied Mathematics, vol. 124, no. 1, **(2000)**, pp. 123-137.
[10] Y. Zhao, W. Wei, P.H. Mei, Y.S. Pei, M.L. Zhao and W. Wang, "An Effective Secure Routing Way to Reduce Energy Consumption in Wireless Sensor Networks", AISS., vol. 4, **(2012)**, pp. 277-283.
[11] W. Wustmann, S. Helduser and W. Wimmer, "CFD-simulation of the reversing process in external gear pump", 6thinternational fluid power conference, TU Dresden, no. 2, **(2008)**, pp. 455-468.
[12] Y. Zhao, W. Wei, B.S. Hou and L. Wei, "The hardware design of intelligent circuit breaker, Energy Education Science and Technology Part A: Energy Science and Research", vol. 1, **(2014)**, pp. 695-702.
[13] C. Kato, "Proceedings of the American Society of Mechanical Engineers Fluids Engineering Division Summer Conference", lPART B, **(2005)**, pp. 1273-1280.
[14] Y. Zhao, Y. Chen, G. Zhang and W. Wei, "Research on the VXI fault diagnosis for computer network based on immune genetic algorithm in process of data transfer Computer Modelling & New Technologies", vol. 5B, **(2013)**, pp. 71-75.
[15] J. Dhinakaran, C. Maharaja Ganapathy and T. Kodeswaran, "Quality Improvement of Lubricating Oil Pump Shaft through Statistical Process Control Used in Automobile Industry", Procedia Engineering, vol. 38, **(2012)**, pp. 2053-2062.
[16] M. Vinicius C. Alves, J.R. Barbosa Jr and A. T. Prata, "Analytical and CFD modeling of the fluid flow in an eccentric-tube centrifugal oil pump for hermetic compressors", International Journal of Refrigeration, 2012, Available online 11August.

Authors

Chuanlai Yuan, he received his bachelor degree in 1995 from Hunan Agricultural University, China. Currently, he works as associate professor at College of Electrical and Information Engineering, Hunan University of Technology. His current research interests include automatic detection, optimal control and design and control of industry robot.



Lingshuang Kong, she received her Ph.D. in 2010 from Central South University, China. Currently, she works as associate professor at College of Electrical and Information Engineering, Hunan University of Technology. Her current research interests include modeling and optimization control.

Weilong Zhou, he received his master's degree in 2011 from Hunan University, China. Currently, he works as a lecturer at College of Electrical and Information Engineering, Hunan University of Technology. His current research interests include embedded system design and application, wireless sensor networks technology and application.

Guangming Liu, he received his diploma in 1986 from School of hunan food packaging machinery, China. Currently, he works as a engineer at Hunan Oil pump Co., Ltd. His current research interests is design and development of oil pump.