Diesel Engine Misfire Fault Diagnosis Based on Instantaneous Speed

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Abstract—With the improvement of request in diesel engine dynamic performance, economical efficiency and emission behavior, test technology of diesel engine has gained extensive attention, which has become one of the hot points in the domestic and international relevant research fields. Among the performance parameters of diesel engine, the instantaneous speed signal contains relevant information about diesel engine combustion and working conditions. As researches show, the instantaneous speed can be used to detect the diesel engine cylinder compression pressure, working nonuniform, combustion difference and other working character. Therefore, the study of instantaneous speed has gradually become a significant technology of non-contact detection. In this paper, the algorithm of instantaneous speed signal is successfully realized under specific sampling frequency. Furthermore, the change law of instantaneous speed curve is compared under different rotate speed. At last, fuel supply of one cylinder is cut off to imitate the misfire fault of diesel engine, and then the fault is successfully diagnosed through the analysis of instantaneous speed. Thus, both the algorithm realization of instantaneous speed and the conclusion related to misfire fault diagnosis can be used to various kinds of diesel engines, which have important project application value.

Keywords-Fault Diagnosis; Diesel Engine; Instantaneous Speed; Data Sampling; Test

I. INTRODUCTION

Formerly, the diesel engine working condition diagnosis mostly based on various acting force in cylinder[1-2]. For example, the in-cylinder pressure is one of the most important performance parameters, it can be used to evaluate the combustion and gas exchange process of diesel engine, and it also can be used to calculate the indicated work, highest explosion pressure and compress pressure, to give an evaluation to diesel engine working condition further. However, the cost of the cylinder pressure sensor is high, and due to the severe working environment of high temperature and high pressure[3], the usage and life of sensor is limited. In addition, the installation of sensor needs special test pressure channel, if there is no installing hole on diesel engine, it must punching on cylinder head, it is hard to install. when it comes to small diesel engine, the test pressure channel is more hard to design and assign, therefore, to install cylinder pressure sensor on diesel engine directly and detect its working condition has some difficulty in practical application. To find a diesel engine signal which is easily measured and can characterize its working condition to replace the cylinder pressure to diagnosis diesel engine working condition has a practical value. It can be brought to a satisfactory settlement by measuring instantaneous speed. On account of diesel engine instantaneous speed signal contains a large number of diesel engine running information, on the other hand, the signal can all be measured easily and low cost can be its advantages, it is much fit for the non-contact detection, which has become a hot point of current research.

The working condition and fault can be judged expediently by using instantaneous speed of diesel engine. Such as dynamic property and combustion difference of each cylinder can be detected by analyzing and measuring the abnormal changes of instantaneous speed wave form, diagnosis the misfire fault of diesel engine, using it to processing inversion, torsional vibration, measuring motored engine flywheel instantaneous speed examine compressibility of cylinder , measuring acceleration of engine without load, torque measurement, and injection time of cylinder indicated pressure. Meanwhile, instantaneous speed has a wildly use in estimating explosion pressure in cylinder, judging work uniformity of each cylinder, testing injection timing, detecting fault of diesel engine and closed-loop faceback control and so on. It always is a hot point of using rotate speed measurement technology in engine performance test and diagnosis fault.

II. DIESEL ENGINE INSTANTANEOUS SPEED TEST

A. *Basic principles of test*

The test of instantaneous speed is indirectly, it contains both measurement of original signal and distilment of rotate speed signal[4]. The measurement of instantaneous speed is mainly tested with the help of electro-magnetic or photo-electronic sensor. The photo-electronic method is to install encoder on the crankshaft, whose output wave form is rectangular pulse signal. However, the electro-magnetic method depends on magnetoelectric sensor, whose division relies on gear ring (usually refers to the gear ring on the flywheel) that turn with the crankshaft, whose output similar to sinusoidal signal.

During measurement, use electro-magnetic or photo-electronic sensor to output crank angle signal, then record the time interval of crank angle signal by counter, using the average speed under each angular resolution to replace the instantaneous speed. Due to non-contact measurement, the measurement of instantaneous speed has advantage of without influence upon diesel engine work conditions, easy measuring equipment, reliable-operation. In this paper the electro-magnetic method is adopted.

gear- electro-magnetic sensor equipment is the most popular and easy equipment to measure the instantaneous speed. Face the electro-magnetic sensor to the gear while install, with the turn of the crankshaft, addendum and backlash of gear pass by the electro-magnetic sensor in turn, reluctance in magnetic path change alternately, cause the enhance or weaken of the magnetic line of force, that is the magnetic flux changed, then there will be a voltage signal similar to sine wave in the coil, every cycle of the signal is corresponding to each indexing of the gear. If the speed of an indexing is large, then the time when it pass the sensor is short, it means that the cycle is small when the signal at this indexing, and the frequency is high. On the contrary, the frequency is low. So the change of signal's frequency is corresponding to the fluctuation of the diesel engine rotate speed. When the indexing is small enough, the average rotational velocity of each indexing can be considered to instantaneous speed.

When measuring the instantaneous speed, the TDC(TDC: Top Dead Center) signal must be recorded too[5], so as to get the phase relationship between rotational velocity and crank angle. During experiment, the TDC signal is collected by installing a TDC sensor. Furthermore, in order to confirm the correspondence between serial number arranged with firing order and each cylinder, firstly the TDC signal of one cylinder should be confirmed.

B. *The constitution of instantaneous speed measurement system*

The measurement system includes diesel engine, electro-magnetic sensor, conditioning circuit, DAQ(DAQ: Data Acquisition) card, computer and so on, which is showed in Fig .1. When the diesel engine runs, the sine wave transmitted by the electro-magnetic sensor is magnified, quarantined and filtered by the signal conditioning circuit to eliminate distraction outside, which then will be input into the computer by the DAQ card, after that, the signal is disposed by the detection software system, at last, the value of rotational velocity outputs on the front panel[6-7].

The experimental subject is the 4135D-1 diesel engine, the experiment takes the Avantlite dynamical signal analysis system to collect and draw the signal received by the sensor. There is a gear with 125 teeth install in the free end of the crankshaft, the electro-magnetic sensor is installed directly on the support. The signal of electro-magnetic sensor is connected directly with the data collection card, the collected signal communicates with the USB interface.

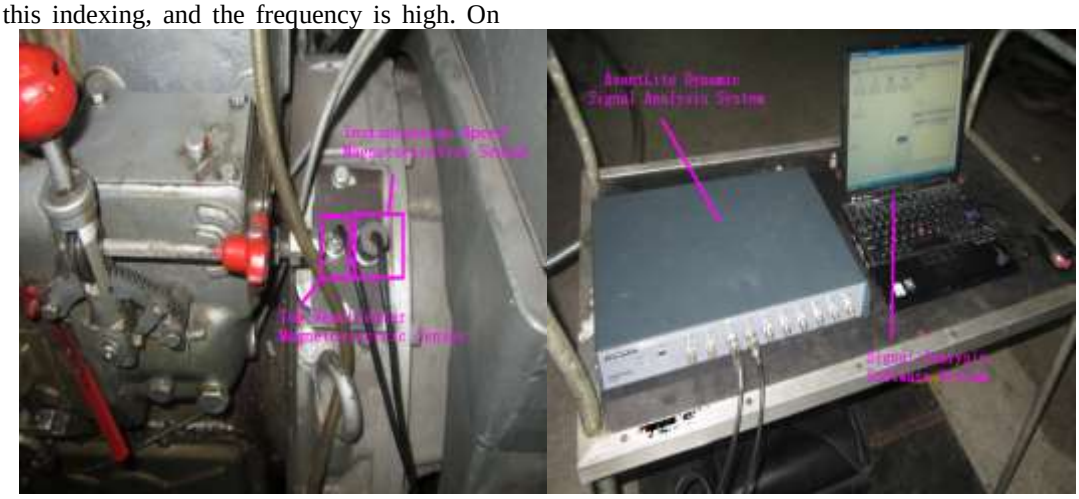

Figure 1. composition of instantaneous speed test system

During experiment, data collection system takes an equal time intervals sampling with the original signal of electro-magnetic sensor, calculating instantaneous speed at flywheel in accordance with sampling points of each tooth and sampling intervals; the data collection system is used to count the measured pulse signal, in

accordance with the count value between two pulse to calculate the time between two pulses, then the instantaneous speed can be got.

C. experimental data process

In order to eliminate the noise jamming in the result of the transient rotational velocity wave, so as to distinguish the fault model, essential procession to the instantaneous speed signal is needed[8], generally, digital filtering, whole cycle average and tooth average method are used to reject the noise jamming in transient rotational velocity signal.

1) Digital filtering

Filtering is a effective way to eliminate signal interference. As the instantaneous speed signal, it can be accomplished by digital filter. In this experiment during the process of data disposing, the fir digital filter is designed to eliminate the signal interference with the Hamming window.

2) Whole cycle averaging

Working conditions of diesel engine usually change with the speed, load and other external reasons often lead to the measured signal distortion, in order to avoid wrong diagnosis, that phenomenon should be distinguished and deleted. In this experiment, during the process of data disposing, truncate three experiment data in tdc signal by MATLAB programme to each couple of experiment data, that is the TDC and rotational velocity signal in one cycle. Measure the rotational velocity signal in three cycle apart and averaging them, the instantaneous speed after cycle averaging can be got.

3) *Tooth average*

The original signal of positive half cycle and negative half cycle is corresponding to the increase and decrease process of magnetic resistance in magnetic circuit separately, the calculated cycle is the time of crankshaft turn one indexing(one tooth crest and one teeth root), when the instantaneous speed is draw[9], the indexing is considered as absolute equal, but as the width of teeth crest and teeth root on gear can not be exactly same, the indexing can not be absolute equal, there must be random error, then if the interval used to calculate is too small(for example, take one or half cycle of the original signal), it can cause a great error. Then to increase the interval appropriately, the influence of the random error can be reduced, the precision of the transient rotational velocity can be enhanced, and this is the reason for averaging. During the process of experiment data disposing, compare the influence between different tooth number to instantaneous speed wave, the instantaneous speed results are as follows[10]: the average rotation speed of the diesel engine is at 700r/min, gear interval for instantaneous speed curve at 1 is showed in Fig .2:

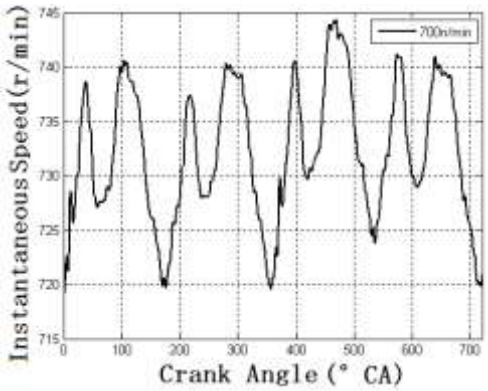

Figure 2. Instantaneous speed curve when gear interval is 1

By variation of the curve, we can get the following conclusions. when the number of teeth is too small, curve becomes sharp, peak increases, and high-frequency fluctuates significantly ;when the number of teeth is larger, curve becomes smooth, the peak becomes less, the high-frequency fluctuation becomes weak, errors caused by indexing gear reduced relatively.

Increasing the number of teeth gradually, we get the following speed curves that are showed in Fig .3 and Fig .4:

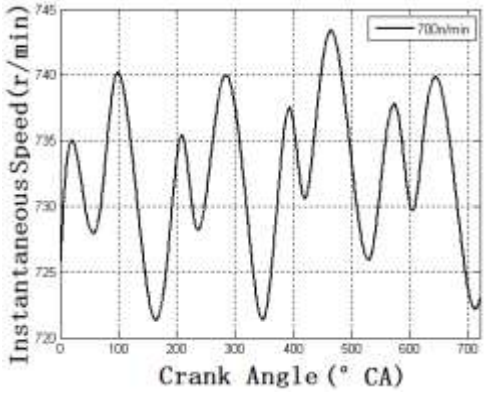

Figure 3. Instantaneous speed curve when gear interval is 8

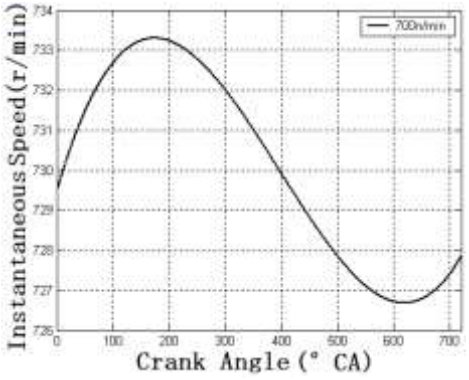

Figure 4. Instantaneous speed curve when gear interval is 80

By analyzing each curve, we can get the following conclusions: when the number of teeth becomes larger, the calculation interval increases, the instantaneous speed fluctuation significantly reduced, the speed curve

becomes smoother, the measured speed is closer to average speed .

To sum up, as the number of tooth average processing larger ,errors caused by gear will be smaller, but the tooth average treatment has certain limit. when the number of teeth is too large, the instantaneous speed will lose the meaning of “instantaneous”. In addition, determinning the average length of the teeth also need to consider the total tooth number of the gear ring. when determining the average length of tooth, tooth number calculation interval should not use the total number of teeth of the divisor, In order to avoiding the combination of tooth number used in computing is the same. By comparison, the gear interval is set at 8 in the calculation process of the instantaneous speed.

4) Comparison of experimental data of different conditions

In the same sampling frequency, contrast analysis is obtained when diesel engine speed increases successively, the results are showed in Fig .5、Fig .6 and Fig .7.

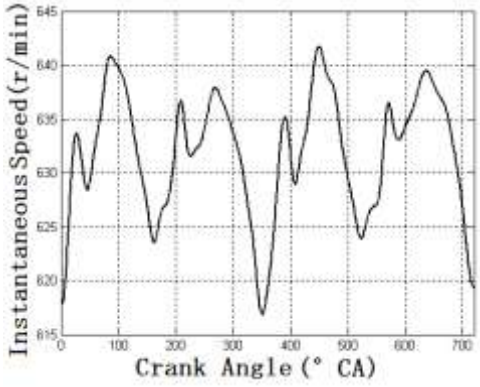

Figure 5. The rotation speed of the diesel engine at 600r/min

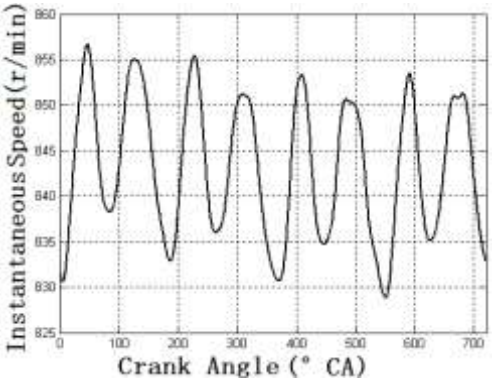

Figure 6. The rotation speed of the diesel engine at 800r/min

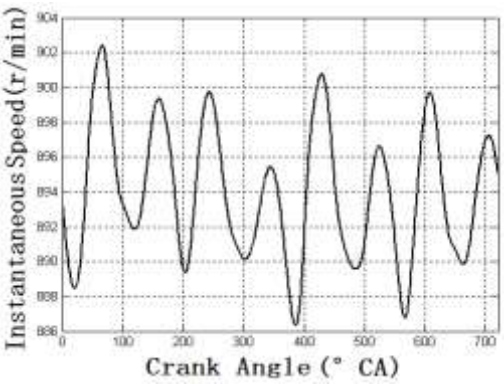

Figure 7. The rotation speed of the diesel engine at 850r/min

From the figures above, conclusions can be drown as follows:

(1) Effect of change of reciprocating inertia force to speed diagram line: speed at 600r/min~850r/min:As the speed increases, the impact of diesel reciprocating inertia force increased gradually, instantaneous speed fluctuates two times for one firing interval and There are two peak value. The torque generated by the gas pressure is larger than the torque generated by the reciprocating inertial force of cylinder. speed at 750r/min~850r/min: Speed increases further, continue to appear two peaks, the second peak becomes low, this is because the reciprocating inertia force increases with the increase of rotational speed.

(2) Fluctuations of transient speed fluctuation rate: The instantaneous change volatility with the increase of speed ,the figures of volatility are:4.36%、3.16%、3.08%。

From the data results, We can see that: With the increase of the speed, diesel engine instantaneous speed fluctuation rate show a downward trend in general, the transient speed fluctuation rate tends to be stable, the speed tended to be stable.

D. Misfire fault diagnosis of diesel engine

Start the engine, when diesel engine operation is stable, the speed is set to 700r/min. Start collecting data when the speed is stable. This is the normal working state of diesel engine. After saving the data, stop the diesel engine, blocking oil of one cylinder of diesel engine to imitate the misfire fault. Start the engine, when diesel engine operation is stable, the speed is set to 700r/min too. Starting to collect data when the speed is stable, and stop diesel engine after saving data. Results are showed in Fig .8 and Fig .9.

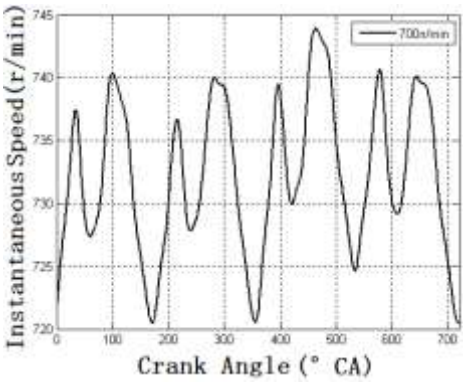

Figure 8. instantaneous speed curve under normal conditions

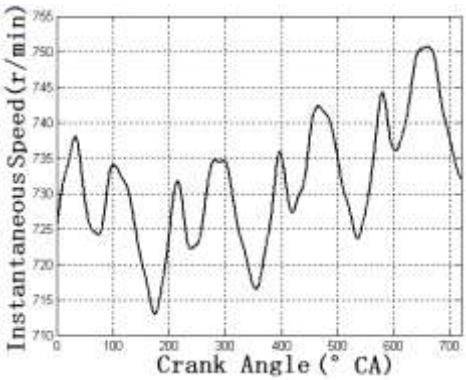

Figure 9. instantaneous speed curve under the state of one cylinder oil cutting off

Thus, we can draw the conclusion through the analysis of curves: Each cylinder of the diesel engine work uniformly in the normal state and there are four similar obvious peak.The peak of the speed fluctuation are roughly equal, the transient speed fluctuation rate is low. However when one cylinder misfires, each cylinder of the diesel engine work uniformly, speed curve appears obvious distortion. The transient speed fluctuation rate changed from 3.5% to 5.5%, speed fluctuation rate become lager, the running stability of diesel engine reduced.

III. CONCLUSIONS

1)The measurement precision of the instantaneous speed is affected by the installation accuracy, indexing precision, sampling frequency and other factors of gear obviously. In ensuring the accuracy of the gear and the sampling frequency of the condition, some methods are used, such as tooth average, filtering, full cycle average, which can obtain the instantaneous speed wave accurately.

2)We can get the result through the simulation of diesel engine misfire fault: When misfire fault appears, each cylinder of diesel engine work inconsistently, The fluctuation of speed becomes large, the stability of the diesel engine reduces. Through the successful diagnosis of misfire phenomenon, we can know the signal of instantaneous speed fluctuation of crankshaft can reflect the working state and quality of the machine. Through the analysis of instantaneous speed fluctuation signal, we can get lots of information about both the machine state and the related failure, which lay an important foundation for achieving the non-contact fault diagnosis technology of diesel engine.

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REFERENCES

[1] Y. L. Sun, G. S. Teng, W. Y. Guo. Exhaust Valve Leaking Fault Diagnosis of Diesel Engine Based on Transient Speed[J]. Internal Combustion Engines, Vol.3, Jun. 2011, pp. 60-62.

[2] B. Yang. Development of Fault Diagnosis System for the Diesel Engine Based on the Instantaneous Speed Signal. [D]. Dalian: Dalian Maritime University, 2013, pp.7-22.

[3] G. Y. Wang, H. L. Hu, Y. H. Bi, L. Z. Shen. Position Determination Strategy of CNG-diesel Dual-fuel Single-cylinder Engine Based on Crankshaft Instantaneous Speed[J]. Transactions of the Chinese Society for Agricultural Machinery, Vol.45, Oct. 2014, pp. 21, 34-38.

[4] X. Y. Qiao, C. H. Liu, J. Liu, Y. Jin. Detection of In-cylinder Compression Pressure for Diesel Engine Based on Instantaneous Speed Analysis[J]. Vehicle Engine, Vol.215, Dec. 2014, pp. 79-83,88.

[5] X. Y. Qiao, J. Liu, Y. Jin, C. R. Li. Approach to Detecting Misfire Fault of Tank Diesel Engine

Based on Instantaneous Speed Analysis[J]. Journal of Academy of Armored Force Engineering, Vol.28, Jun. 2014, pp. 36-41.

[6] Y. Cheng, J. X. Wang, R. J. Zhuang. Developing of Transient Rotational Speed Measurement of I.C.Engines[J]. Chinese Journal of Scientific Instrument, Vol.23, Oct. 2002, pp. 522-525.

[7] Y. L. Sun, B. S. He, X. W. Jiang. Experimental Research on Characteristics of Early Stages Rub-impact Rotor Transient Speed Fluctuation[J]. Journal of Naval University of Engineering, Vol.25, Feb. 2013, pp. 69-73.

[8] Y. P. Hu, B. Wu, L. M. Zhang. Analysis of Measured Errors of Transient Speed in Internal Combustion Engines[J]. Journal of Shandong University of Technology, Vol.31, Oct. 2001, pp. 408-415.

[9] S. X. Lin, G. Y. Wang, L. Z. Shen, S. B. Zhang. Measurement and Analysis of Instantaneous Speed Based on Virtual Instrument[J]. Vehicle Engine, Vol.191, Dec. 2010, pp. 86-89.

[10] Z. H. Xie, G. D. Li. From Introduction to Advancement upon MATLAB[M]. Beijing: Beihang University Press, 2012.