Use of the Wavelet Transform for the Analysis of Irregularity of Crankshaft Angular Velocity

B. Bodnar[1], O. B. Ochkasov[1], D V. Chernyaev[1], R. Skvireckas[2]

[1]*Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Lazaryan St., 2, 49010 Dnipro, Ukraine, E-mail: dmitropiper@gmail.com*
[2]*Kaunas University of Technology, Studentu st. 56, 51424, Kaunas, Lithuania, E-mail: ramunas.skvireckas@ktu.lt*

Abstract

The issue of quick and qualitative receiving of reliable and complete information concerning the technical state of a diesel engine in the locomotive is relevant one, although there are already many technical solutions in this direction. Indirect methods for diesel engine diagnostics are of gain ground. Among the existing methods, the diagnostics of the diesel engine technical state occupies a special place due to the analysis of irregularity of crankshaft angular velocity.
Within the working cycle of the diesel engine, the crankshaft angular velocity of rotation is constantly changed. The mechanical inertia system of the pistons, rods and shaft receives impulses of mechanical energy from fuel combustion, as well as pulsed losses of kinetic energy on pump pistons-stroke. Thus, the value and shape of the torque of each cylinder affects the angular velocity of the shaft.
The purpose of the research is to study the various types' application for basic functions of wavelet transform to emphasize the diagnostic information from the signal of angular velocity irregularity of the diesel engine shaft. This will automate the process of diagnosing the diesel engine.
The authors conducted simulation of the working process of a shunting diesel locomotive with hydrodynamic transmission. Type of the diesel engine: six-cylinder in-line engine with turbo-charger, power 750 hp. The nominal modes of the diesel engine operation at the crankshaft speed of 1400 rpm were considered. There are simulation of the fault-free condition and two types of faults: the change of fuel injection advance angle and change of the cycle fuel injection to greater and smaller sides from the passport date. For the resulting angular-velocity vectors and acceleration we applied continuous wavelet transform with different basic functions. The obtained results are estimated by energy criteria. The most promising basic functions are separated from the point of view of the most complete estimation of the energy for the portion of the signal carrying diagnostic information.
KEY WORDS: *angular velocity irregularity, non-separable diesel diagnosis, digital signal filtering, spectral analysis, phase shift*

1. Introduction

The issue of quick and qualitative receiving of reliable and complete information concerning the technical state of a diesel engine in the locomotive is relevant one, although there are already many technical solutions in this direction [3, 4]. Indirect methods for diesel engine diagnostics are of gain ground. Among the existing methods, the diagnostics of the diesel engine technical state occupies a special place using the analysis of irregularity of crankshaft angular velocity. The method is easy to measure, but requires a rather complex analysis for receiving the diagnostic information.

Within the working cycle of the diesel engine, the crankshaft angular velocity is constantly changed. The mechanical inertia system of the pistons, rods and shaft receives impulses of mechanical energy from fuel combustion, as well as pulsed losses of kinetic energy on pump pistons-stroke. Thus, the value and shape of the torque of each cylinder affects the angular velocity of the shaft [1]. The essence of the method is to measure the crankshaft angular velocity of the diesel engine with high resolution and to determine the characteristic indicators that give evidence of the working process quality in cylinders and the technical state of the diesel engine as a whole.

For the signal analysis of the irregularity of crankshaft angular velocity for a diesel engine, the Fourier series expansion is traditionally used. However, the analysis based on infinite basic functions (sin, cos) does not provide information about the local features of the signal and adequately reflects only the stationary processes. When considering the angular velocity signal of an ideally free-fault engine, it can be considered stationary one, at any time (extent to which) the signal frequency will be the same. But in a real engine, the working processes in adjacent cylinders differ significantly (according to the passport data of the diesel engine 211D2, the difference in Pz is allowed up to 0.2 MPa), in addition, the reason code in pressure may be various, so the signal of the real engine can hardly be called stationary. A more advanced analysis tool is a wavelet transform using finite basic functions of various forms. This provides wavelet transform with wide opportunities for separation and localization of signal features. A number of works are known in which wavelet transforms are used to diagnose the technical means [5-6, 11, 14] and internal combustion engines [7-10, 12, 15].

References

1. **Bodnar, B.Ye.; Ochkasov, O.B.; Chernyayev, D.V.; Detsyura O.Ya.** 2012. Methods of nonseparable diagnostics of diesel engines in operation of rolling stock, Bulletin of Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan 41: 63 -67.

2. **Bodnar, B.Ye.; Ochkasov, O.B.; Chernyayev D.V.** 2013. Definition of methods signal filtering irregularity crankshaft speed of diesel, Science and Transport Progress 1(43): 113-118. doi: 10.15802/stp2013/9583

3. **Bodnar, B.; Ochkasov O.** 2017. System Choice of the Technical Maintenance of Locomotives Equipped with on-Board Diagnostic Systems, Transport Means: Proceedings of 21st International Scientific Conference, September 20–22, 2017. Kaunas University of Technology Klaipėda University [and others]. Juodkrante, Kaunas, Lithuania, Part I: 43-47

4. **Lingaitis, L.P.; Mjamlin, S.; Baranovsky, D.; Jastremskas, V.** 2012. Experimental investigations on operational reliability of diesel locomotives engines. Eksploatacja i Niezawodnosc 14(1): 6-11.

5. **Hocine Bendjama, Mohamad S. Boucherit** 2016. Wavelets and principal component analysis method for vibration monitoring of rotating machinery, Journal Of Theoretical And Applied Mechanics 54(2): 659-670, doi: 10.15632/jtam-pl.54.2.659

6. **Roztočil, J.; Novák,M.** 2010. Fault diagnosis of rotating machinery based on wavelet transforms and neural network. Applied Electronics (AE), International Conference on: 1-6.

7. **Xia Wang; Changwen Liu; Fengrong Bi; Xiaoyang Bi; Kang Shao** 2013. Fault diagnosis of diesel engine based on adaptive wavelet packets and EEMD-fractal dimension. Mechanical Systems and Signal Processing 41(1-2): 581-597. doi: 10.1016/j.ymssp.2013.07.009

8. **Czech, P.; Wojnar, G.; Burdzik, R.; Konieczny, Ł.; Warczek, J.** 2014. Application of the discrete wavelet transform and probabilistic neural networks in IC engine fault diagnostics. Journal of Vibroengineering 16(4): 1619-1639.

9. **Zhenyou Zhang; Yi Wang; Kesheng Wang**. 2013. Fault diagnosis and prognosis using wavelet packet decomposition, Fourier transform and artificial neural network. Journal of Intelligent Manufacturing 24(6): 1213-1227. doi: 10.1007/s10845-012-0657-2

10. **Figlus, T.; Liščák, S.; Wilk, A**. 2014. Condition monitoring of engine timing system by using wavelet packet decomposition of a acoustic signal, Journal of Mechanical Science and Technology 28(5): 1663–1671. doi: 10.1007/s12206-014-0311-3

11. **Wang, Y.S.; Ma, Q.H.; Zhu, Q.; Liu, X.T.; Zhao L.H**. 2013. An intelligent approach for engine fault diagnosis based on Hilbert–Huang transform and support vector machine. Applied Acoustics, 75: 1-9. doi: 10.1016/j.apacoust.2013.07.001

12. **Zhixiong Li, Xinping Yan, Chengqing Yuan, Zhongxiao Peng.** 2012. Intelligent fault diagnosis method for marine diesel engines using instantaneous angular speed, Journal of Mechanical Science and Technology, 26(8): 2413-2423. doi: 10.1007/s12206-012-0621-2

13. **Ashkan Moosavian, Meghdad Khazaee, Gholamhassan Najafi, Majid Khazaee, Babak Sakhaei, Seyed Moha mmad Jafari**. 2015. Wavelet denoising using different mother wavelets for fault diagnosis of engine spark plug. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering 231(3): 359-370. doi: 10.1177/0954408915595952

14. **Wu, Jian-Da; Liu, Chiu-Hong** 2008. Investigation of engine fault diagnosis using discrete wavelet transform and neural network, Expert Systems with Applications 35(3): 1200-1213. doi:10.1016/j.eswa.2007.08.021.

15. **Gaeid, Khalaf; Hew, Wooi** 2011. Wavelet Fault Diagnosis of Induction Motor. Book chapter INTECH publisher. doi: 10.5772/19584