ИНФОРМАТИКА, ВЫЧИСЛИТЕЛЬНАЯ ТЕХНИКА И УПРАВЛЕНИЕ

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SYSTEM OF VESSEL VIBRATIONAL DIAGNOSING

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The purpose of the article is to propose the system of vessel diagnosing. Review of the currently used approaches has been conducted. Especial for vessel diagnosing issues were discussed. Diagnosing and maintenance system satisfying according requirements has been proposed. Industry 4.0 approaches and modern digital signal processing techniques have been applied. Future work plan has been proposed.

Keywords: *vibrational diagnosing, Industry 4.0, vessel diagnosing.*

Introduction. Vessel propulsion set is a complex equipment and requires regular maintenance. Its unexpected failure fraught with high losses. Equipment state assessment relying on vibration signals and predictive maintenance have been shown to be effective in industry. Less works devoted to ship equipment vibrational diagnosing are available. The most commonly used methods for diagnosing of vessel propulsion are [1; 2]:

1. Vibration level monitoring.
2. Octave spectrum levels.
3. Vibration spectrum analysis.
4. Detection of pulses.

Vibration level characterizes general state of equipment and do not allow to identify defect or damaged unit. Octave spectrum analysis is more informative and can be used under conditions of variated or unknown shaft speed. Spectral analysis is widely used for faulty units identification. Pulse detection is usually used for bearing defects identification.

The commonly used in industry signal processing methods are successfully applied for vessel equipment diagnosing, but the equipment exploitation experience has revealed especial requirements for the diagnosing and maintenance system.

Problem formulation. Unlike the factory, vessels aggregate diagnosing is limited due to absence diagnostics specialist onboard, then operative data acquisition and processing is required [1; 2]. Then diagnosing system adjustment is possible for specialist and full amount of needed for maintenance information is available for sheep crew. At the same time, on shore diagnosing and maintenance services obtain this information simultaneously [2].

Exploitation conditions of vessel aggregates makes often convenient spectral analysis difficult. Propeller rotation speed vary due to water flow influence [1; 3; 4]. Speed variation has periodic component conditioned by blades manufacturing tolerances. But speed variation is rarely uniform due to cavitation in water flow. Another reason of non-steady vibration is rapidly changing of load and speed (due to bad weather, for example) [1]. The most dangerous effect is hunting of an alternator set governor. Then propulsion set diagnosing is the most complicated due to strong simultaneous amplitude and angle modulation. Monitoring of aggregates in transient modes (e.g. engine start and stop) is recommended [1]. Shaft frequency vary rapidly in this mode. The solution is application of frequency tracking and signal resampling methods that require installation of additional hardware or high computational resources. Synchronous resampling accuracy is reported to be not enough in many cases [1]. Exploitation of rotary equipment and vehicles experience has shown that speed and load variation affected statistical characteristics of vibration. This effect is also required to be compensated. Especially attention must be paid to preventing of system failures that are usually occur in transient operating modes [1].

Discussed problems require complex solution consisting of application of complicated algorithms of digital signal processing and thus deployment of powerful processing server and convenient off-line access to processing results. The solution must fulfill the requirements to resolve given problems:

– be fully automated from data acquisition to decision making (problem 1);
– update information about technical state of vessel equipment (problem 1);
– be able to conduct complicated DSP (problem 2, 3);
– update the simplest metrics of vibration fast (problem 1).

Development of automatic control systems require their unified integration with each other. The issues of uncompatibility of different systems and data cleanup might be overcame [5].

Purposed solution. To resolve the problems and satisfy the requirements, the comprehensive solution is proposed. The general objective of the proposed system is condition monitoring and prescriptive maintenance of the ship propulsion system in order to reduce the number of breakdowns, reduce downtime of ships, and increase the efficiency of their use. The architecture of the proposed system for condition monitoring and prescriptive maintenance will consist of 3 main parts:

1. *Data acquisition system* for the collection and transmission of the marine propulsion units telemetry data.
2. Cloud-based *analytical platform* for telemetry data processing and diagnostic report generation.
3. *User interface* for results representation.

Data acquisition system consists of the data transmitter and the number of sensors installed on marine propulsion units. It collects telemetry data on equipment condition (such as vibration, temperature, rotational speed, etc.) by predetermined schedule and transfers it to the cloud-based analytical platform for processing.

The analytical platform is accountable for detecting defects of the serviced equipment and generating reports with detailed maintenance prescriptions (instructions). The analytical platform consists of the number of algorithms for vibration and telemetry data processing. Conditions of equipment exploitation require application and adaptation of modern DSP algorithms. For example, it has been discussed above that conventional spectral analysis is not effective under conditions of significant speed variation. To overcome this issue, shaft frequency tracking and signal resampling is applied [6]. To reveal modulated and pulse signals produced by bearings and gearings, wavelet analysis [7] and its modifications, such as packet wavelet transform [8], sparse wavelet decomposition [9; 10] are applied. Additional arrangements are speed and load evaluation and their influence on informative features compensation. For example, it has been shown to be effective in statistical measures of vibration trending task [11]. As a consequence, the following data processing algorithms are applied:

– vibration statistics trending (RMS, peak factor, kurtosis, etc.);
– ISO-based analysis (ISO 10816, ISO 7919, ISO 15242, VDI 3834, ISO 1940);
– 1-, ⅓-, ⅙-octave spectrum analysis;
– frequency-domain analysis (spectrum and demodulated HF-spectrum);
– time-frequency domain analysis (wavelet analysis, correlogram analysis);
– time-domain analysis (vibration shock pulses recognition & classification);
– time synchronous averaging (TSA);
– order spectrum analysis;
– cepstral domain analysis;
– equipment load operating mode recognition & compensation;
– equipment speed operating mode recognition & compensation;
– shaft rotational speed tracking & signal resampling;
– shaft orbit analysis;
– history data processing (trend analysis, defects verification, prognosis);
– equipment remaining useful life (RUL) estimation & etc.

The algorithms are used to determine the speed operating mode of the marine, estimate and prognosis the technical condition of the propulsion unit, and form a prescription for its maintenance (if it is required).

The user interface in the form of a personal account. The developed system will be also integrated within ERP systems (i.e., MES, CMMS, etc.) to transfer the processing results (orders for maintenance) to them.

The diagnosing and maintenance system diagram is presented on Figure 1. The server-based software conducts processing of vibration, informative features extraction, long term prognosis and maintenance prescriptions. At the same time, vessel technical state and recommendations for ship crew are operatively updated. The system of enterprise equipment maintenance, integrated with context broker and enterprise automated control system has been proposed [12]. The context broker has been shown to be effective for integration unification between diagnosing and control systems. Modified system for marine diagnosis (Figure 2) includes integration with context broker that updates virtual entity of ship aggregates. Each unit state and according recommendations (replace in two month, emergency stop) are updated through broker and consumed by indication and maintenance systems.

Future work plan. The most of assigned tasks can be potentially solved relying on existing methods and frameworks being parts of proposed system. Tasks of system failures prevention and transient mode vibration analysis require new algorithms development.

1. Selection of a vessel and analysis of the kinematic diagram of its propulsion system.
2. Analysis of failures in the ship's propulsion system and justification of the business model of its maintenance.
3. Adaptation of the acquisition system to collect and transfer the data of vibration and rotational speed, justification of the number and characteristics of the sensors for reliable diagnosis.
4. Equipping propulsion units of the vessel with a telemetry data acquisition and transmission system. Deploy cloud storage.
5. Developing a digital twin of the marine propulsion system for vibration-based diagnostics.
6. Preconfiguration of the analytical platform for diagnosing the propulsion system based on the data being taken. Create a preliminary user account to display the processing results.
7. Adaptation of vibration analysis algorithms for fault detection of propulsion system. Research and development of the additional algorithms for the specific operation and maintenance of the propulsion system.

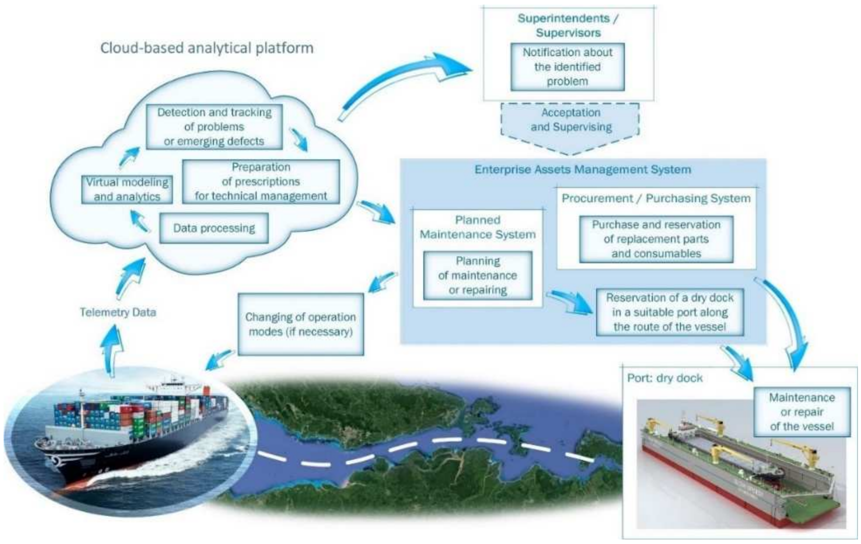

Figure 1. – Cloud-based system for vessel diagnosis

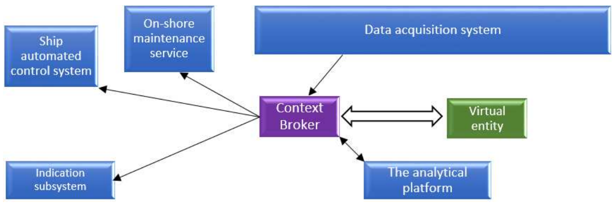

Figure 2. – Modified system for vessel diagnosis

8. Development of an indication system for detected faults (integration with ERP, push-notifications, etc.). Finalization of the user interface and the format of diagnostic reports.
9. Integration of diagnosing, telemetry and indication blocks and automated control systems with context broker.
10. Development of new algorithms of ship vessel diagnosing.

Conclusions. A review of vessel vibrational diagnosing problems and widely used solutions has been presented in this work. System of vessel diagnosing has been proposed. The system is fully automated, it operatively updates information about vessel technical state. Virtual entity metadata, consisting of informative features and diagnostic information, is updated. Automatic decision-making systems, onshore services and vessel state indication blocks receive the updates through context broker.

REFERENCES

1. Barkov, A. V., Barkova, N. A., & Grishchenko, D. V. (2012). Bortovaya sistema diagnostirovaniya sudovykh mashin [Onboard system of vessel equipment diagnosing]. *Sovremennye tekhnologii avtomatizatsii bor'by za zhivuchest' korablei i sudov [Modern technologies of vessel and ship damage control]*. Saint-Petersburg: Institut avtomatizatsii protsessov bor'by za zhivuchest' korablya, sudna. (In Russ.).
2. Barkova, N. A., Barkov, A. V., & Fedorishchev, V. V. (2017). Distantsionnaya diagnostika sudovykh mashin i oborudovaniya [Remote diagnostics of shipboard machinery and equipment]. *Sovremennye tekhnologii avtomatizatsii bor'by za zhivuchest' korablei i sudov [Modern technologies of vessel and ship damage control]* (254–259). Saint-Petersburg: Society of informatics, computational technic, connection and control systems. (in Russian).
3. Mangesh, V. L., Singh, Y. P., & Kumar, A. (2018). A Review of Marine Engine Vibration Performance Analysis and Counteract Measures. *IOSR J. of Mechanical and Civil Engineering, 15*(2) ver. II, 48–53. DOI: 10.9790/1684-1502024853.
4. Carlton, J. S., & Vlasic, D. (2005). Ship vibration and noise: Some topical aspects. *1st International Ship Noise and Vibration Conference*. London: Lloyd’s Register.
5. Kechik, D. A. Davydov, I. G., Gerasimuk, Ya. V., Tsurko, A. V., & Smolev, M. A. (2020). Integratsiya sistemy diagnostiki promyshlennogo oborudovaniya s ekosistemami trenda Industry 4.0, postroennymi na osnove freimvorka FIWARE [Integration of the system of diagnostics of industrial equipment and ecosystems of Industry 4.0 trend built on the basis of FIWARE framework]. In V. A. Bogush [et al.] (Eds.), *Informatsionnye radiosistemy i radiotekhnologii [Infromation radiosystems and radiotechnologies]* (206–210). Minsk: BSUIR. (In Russ., abstr. in Engl.).
6. Zhang, X., Wen, G., & Wu, T. (2012). A new time synchronous average method for variable speed operating condition gearbox. *J. Vibroengineering, 14*(4), 1766–1774.
7. El Morsy, M. (2019). Fault Diagnosis Approach for Roller Bearings Based on Optimal Morlet Wavelet De-Noising and Auto-Correlation Enhancement. *SAE Int. J. Passeng. Cars – Mech. Syst., 12*(2). DOI: 10.4271/06-12-02-0010.

8. Tian, J. Pecht, M., & Li, C. (2012). Diagnosis of rolling element bearing fault in bearing-gearbox union system using wavelet packet correlation analysis. *65th Meeting of the Machinery Failure Prevention Technology Soc. (MFPT2012)* (354–359). Dayton, OH, USA.
9. Aslamov, Y., Aslamov, A., Davydov, I., & Tsurko, A. (2019). Sparse Wavelet Decomposition with Redundant Dictionary for Vibration Waveform Analysis. *14th International Conference on Pattern Recognition and Information Processing* (6). Minsk: BSUIR.
10. Smith, E., & Lewicki, M. S. (2005). Efficient Coding of Time-Relative Structure Using Spikes. *Neural Computation*, (17), 19–45.
11. Kechik, D. A. (2020). Kompensatsiya izmeneniya moshchnosti vibroakusticheskogo signala pri izmenenii skorostnogo rezhima oborudovaniya. [Vibrational signal power variance compensation during equipment speed mode changing]. *Doklady BGUIR*, *18*(5), 26–34. (In Russ., abstr. in Engl.).
12. Kechik, D., Davydov, I., Hierasimuk, Ya., Tsurko, A., & Smolev, M. (2021). Integration of the system of diagnostics of industrial equipment and enterprise asset management systems using FIWARE framework. *Vestnik Polotskogo gosudarstvennogo universiteta. Seriya C, Fundamental'nye nauki [Herald of Polotsk State University. Series C. Fundamental sciences]*, (4), 20–28.

ЛИТЕРАТУРА

1. Барков, А. В. Бортовая система диагностирования судовых машин / А. В. Барков, Н. А. Баркова, Д. В. Грищенко // Современные технологии автоматизации борьбы за живучесть кораблей и судов : первая науч.-практ. конф., СПб., 6 дек. 2012 г. / ОАО «Концерн «НПО «Аврора». – СПб., 2012.
2. Баркова, Н. А. Дистанционная диагностика судовых машин и оборудования / Н. А. Баркова, А. В. Барков, В. В. Федорищев // Информационная безопасность регионов России (ИБРР-2017) : юбилейная X с.-петерб. межрегион. конф., СПб., 1–3 нояб. 2017 г. / СПОИСУ. – СПб., 2017. – С. 254–259.
3. Mangesh, V. L. A Review of Marine Engine Vibration Performance Analysis and Counteract Measures / V. L. Mangesh, Y. P. Singh, A. Kumar // IOSR J. of Mechanical and Civil Engineering. – 2018. – Vol. 15, iss. 2, ver. II. – P. 48–53. – DOI: 10.9790/1684-1502024853.
4. Carlton, J. S. Ship vibration and noise: Some topical aspects / J. S. Carlton, D. Vlasic // 1st International Ship Noise and Vibration Conference, London, June 20–21. – London, 2005. – 11 p.
5. Интеграция системы диагностики промышленного оборудования с экосистемами тренда Industry 4.0, построенными на основе фреймворка FIWARE / Д.А. Кечик [и др.] // Информационные радиосистемы и радиотехнологии : материалы Респ. науч.-практ. конф., Минск, 28–29 окт. 2020 г. / Белорус. гос. ун-т информатики и радиоэлектроники ; редкол. : В. А. Богуш [и др.]. – Минск, 2020. – С. 206–210.
6. Zhang, X. A new time synchronous average method for variable speed operating condition gearbox / X. Zhang, G. Wen, T. Wu // J. Vibroengineering. – 2012. – Vol. 14, № 4. – P. 1766–1774.
7. El Morsy, M. Fault Diagnosis Approach for Roller Bearings Based on Optimal Morlet Wavelet De-Noising and Auto-Correlation Enhancement / M. El Morsy // SAE Int. J. Passeng. Cars – Mech. Syst. – 2019. – Vol. 12, iss. 2. – DOI: 10.4271/06-12-02-0010.
8. Tian, J. Diagnosis of rolling element bearing fault in bearing-gearbox union system using wavelet packet correlation analysis / J. Tian, M. Pecht, C. Li // 65th Meeting of the Machinery Failure Prevention Technology Soc. (MFPT2012). – Dayton, OH, USA, 2012. – P. 11.
9. Sparse Wavelet Decomposition with Redundant Dictionary for Vibration Waveform Analysis / Y.P. Aslamov [et al.] // 14th International Conference on Pattern Recognition and Information Processing, Minsk, 21–23 May 2019 / BSUIR. – Minsk, 2019. – P. 354–359.
10. Smith, E. Efficient Coding of Time-Relative Structure Using Spikes / E. Smith, M.S. Lewicki // Neural Computation. – 2005. – № 17. – P. 19–45.
11. Кечик, Д. А. Компенсация изменения мощности виброакустического сигнала при изменении скоростного режима оборудования / Д. А. Кечик // Доклады БГУИР. – 2020. – Т. 18, № 5. – С. 26–34.
12. Integration of the system of diagnostics of industrial equipment and enterprise asset management systems using FIWARE framework / D. Kechik [et al.] // Вестн. Полоц. гос. ун-та. Сер. C, Фундам. науки. – 2021. – № 4. – С. 20–28.

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СИСТЕМА ВИБРАЦИОННОЙ ДИАГНОСТИКИ СУДОВ

Д. А. КЕЧИК, Н. В. КОСМАЧ, П. Г. РЯБЦЕВ, Р. В. ТОЛКАЧ, И. Г. ДАВЫДОВ

Цель настоящей работы – предложить систему диагностики морских судов. Проведен обзор используемых в настоящее время подходов. Рассмотрены специфические для диагностики судов проблемы. Предложена система диагностики и обслуживания судов, удовлетворяющая соответствующим требованиям, для чего использовались подходы тренда Индустрии 4.0 и современные методы цифровой обработки сигналов. Предложен план будущей работы.

Ключевые слова: *вибрационная диагностика, Индустрия 4.0, диагностика судов.*