CONDITION MONITORING OF MARINE POWER PLANTS

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Summary

Due to frequent failures of machine elements, international organizations dealing with the safety at sea and shipowners alike are interested in the introduction of available diagnostic methods as well as the development of new ones. In the case of a machine set such as the electric motor – working machine, vibroacoustic methods based on vibration and acoustic emission measurements on bearing casings give promising results. Most problems are encountered when such machine sets are to be diagnosed, where one of the machines features a piston-crank mechanism. We can identify the conditions of crosshead thrust bearing and the piston - piston rod connection. Wider possibilities exist when it comes to the condition identification of elements in methods using longitudinal and torsional vibrations of the crankshaft free end. In this case it is possible to monitor the condition of crank bearings, main bearings and the alignment of the crankshaft.

Keywords: marine power plants, machine failures, vibroacoustic signals, vibration signals.

DIAGNOSTYKA SIŁOWNI OKRĘTOWYCH

Streszczenie

Ze względu na częste uszkodzenia elementów urządzeń, organizacja międzynarodowa zajmująca się bezpieczeństwem na morzu oraz armatorzy zainteresowani są wprowadzaniem dostępnych i rozwojem nowych metod diagnozowania. W przypadku pary maszyn silnik elektryczny – maszyna robocza obiecujące wyniki daje stosowanie metod wibroakustycznych bazujących na pomiarach drgań i emisji akustycznej na obudowach łożysk. Najwięcej problemów stwarza diagnozowanie zespołów, gdzie jedna z maszyn jest maszyną z mechanizmem tłokowo-korbowym. Możliwa jest identyfikacja stanu łożyska wzdłużnego wodzika i stanu połączenia tłoka z trzonem tłokowym. Dużo większe możliwości identyfikacji stanu elementów kryją się w metodach wykorzystujących drgania wzdłużne i skrętne wolnego końca wału korbowego. Możliwa jest identyfikacja stanu łożysk korbowych, łożysk ramowych i ułożenia wału korbowego.

Słowa kluczowe: siłownie okrętowe, uszkodzenia urządzeń, sygnały wibroakustyczne, sygnały drganiowe.

1. INTRODUCTION

The marine power plant is an assembly of machines converting the energy contained in liquid and gas energy carriers first into heat and mechanical energy, then into hydraulic and electric energy. The transmission of mechanical power from the diesel engine to the propeller may take place by mechanical devices of power transmission (including gearing) or by electrical transmission.

The marine power plant has to satisfy certain requirements: high availability, safety and efficiency. These requirements are stipulated in legal regulations of the port and flag states and result from the aims and policy of the ship owner – a shipping company. If we use the terms strictly connected with quality systems, the requirements to be met by marine power plants may be brought down to specific requirements for desired effectiveness and efficiency both in operation and maintenance of the power plant. For appropriate quality of operation to be achieved we have to maintain a good technical condition of power converting machines and mechanical power transmission units; the assurance of good technical condition of these machines and devices is what power plant maintenance aims at. In both cases the identification of machinery technical condition is necessary.

The identification of technical condition of marine power plant machinery may go along two ways: the identification of specific features of a machine or of specific features of its components – condition parameters of machine components. Such identification is based on reliability characteristics of the same type machines based on overhauls and measurements of diagnostic symptoms determined while a machine is running. The identification based on overhauls has a priority due to obligatory safety regulations. Although the obligation to perform overhauls of machines in the power plant allows to maintain a certain standard of the safety of the ship and the environment, it actually results in an illusory sense that the machines are in good condition, high costs of such overhauls, risk of damage done during an overhaul, and finally, in hindering progress in the field of machine diagnostics (condition monitoring). In spite of overhauls, failures of machine components which lead to major breakdowns are relatively frequent. For this reason international organizations concerned with the safety at sea and shipowners are interested in implementing available diagnostic methods and appliances and developing new ones to enhance the quality of ships in operation.

2. METHODS AND MEANS OF POWER PLANT MACHINERY DIAGNOSTICS

Statistics show that:

– marine accidents happen almost daily, many of them involve body injuries or loss of life. As many as 60% of these accidents are related with propulsion system failures [1];
– on average two large ships sink weekly. Investigations to find the causes have never been as detailed as in the case of an airplane crash. 'Bad weather' is among causes of sinkings. Over the past 20 years bad weather has been blamed for going down to the bottom of 200 very large crude carriers and container ships of more than 200 m in length [2].

The 'sea state' is in direct relation with 'the weather'. In transatlantic shipping the sea state may feature maximum waves more than 30 meters high, as confirmed by satellite surveillance [2]. Their origin is not quite known.

As reliable analyses of ship sinkings are not available, we can assume that 'dangerous' sea state caused mainly by 'bad' weather leads to ship hull deformations and/or damage and thus has a destructive effect on the ship's propulsion system. One cannot exclude that many sinkings have been directly caused by a failure of the propulsion system.

At present diesel engines are primarily those machines that are subject to condition monitoring (damages paid due to failures of main engines account for 46% of all damages paid [3]) as well as stern bearings of the shafting. There are methods and means of diagnosing aimed at either component failure or disturbances in the operation of the mentioned machines elements. The element temperature in the vicinity of friction heat is a basic diagnostic symptom.

Where stern bearings are concerned, apart from their bush temperature, another symptom is the presence of foreign particles in a sample of oil lubricating the stern bearing. Besides, transducers controlling the tightness of sealings which protect the stern bearing from sea water are used. Condition monitoring of the gear transmission located between the propeller shaft and the diesel engine is limited to measurements of pressure, oil flow intensity and oil temperature as well as slide bearing temperature.

In diesel engines, condition monitoring consists in measuring temperatures of such components as cylinder liners, main bearings and crank bearings. The so called indicator diagrams provide information, among others, on the condition of combustion chamber. The diagrams show combustion pressure as a function of crankshaft rotation angle (if combustion pressure cannot be measured, it is replaced by other quantities such as tensile forces acting on cylinder head bolts, forces between the cylinder head and liner, or exhaust gas pressures in exhaust manifolds). Eddy current transducers placed in cylinder liners, particularly those of slow-speed engines) provide data allowing to some extent to infer on the condition of piston rings (first piston ring is sometimes of special design). In medium-speed engines transducers measure the content of lubricating oil in the air in the crankcase in order to detect the concentration that might result in a fire or explosion. A new development in condition monitoring is a possibility of examining inlet and outlet valves condition by acoustic emission measurements and analysis. The conception has returned of measuring the 'fall' of the piston-crosshead-connecting rod. This is aimed at the determination of the sum of backlashes in connecting rod, crank and main bearings.

There are a number of machines in the engineroom that belong to the so called auxiliary systems. These include the charge exchange (air / turbocharging), lubricating system, injection system, cooling etc. Diagnosing of charge exchange, lubrication and cooling systems is mainly based on measurement and analysis of thermodynamic quantities (primarily temperature and pressure, sometimes combined with flow intensity measurement) of working media: air, exhausts, oil and water. In the case of the injection system occasionally the pressures in the injection process are measured, as well as head vibrations, injector needle lift and acoustic emission on the head. It follows from [3] that main propulsion combustion engines, despite monitoring by above mentioned methods, are characterized by frequent failures and high repair costs; most failures occur in turbochargers, crankshaft and bearings of the piston-crank mechanism.

3. INTRODUCTION AND DEVELOPMENT OF METHODS AND TOOLS FOR POWER PLANT MACHINERY DIAGNOSTICS

Machines in the marine power plant are installed within a limited space of the engineroom. Combined in units such as engine – working machine, they are mounted on foundation beds rigidly connected with the ship's hull. As a result, vibrations generated by one machine are conveyed on other machines, while hull deformations may affect machine bodies. There is also a risk of thermal deformations of bearing supports. The above circumstances justify the implementation and development of machine unit diagnostic methods.

The most numerous group of marine machines are those working in pairs, in which quite common are units such as an electric motor – working rotor machine. Their characteristic feature (concerning both flow and displacement machines) is the fact that the direction of resultant working force acting on the rotor changes in a narrow range, and the average value of the resultant working force is always larger than zero and relatively low amplitude. While monitoring such machine pairs, we obtain promising results by the application of vibroacoustic methods based on measurements of vibration and acoustic emission on roller bearing casings. While working on the methodology of measurements, we found discrepancies between what we had expected according to the relevant publications and actual results. For instance, the measurement oriented vertically-horizontally-axially relative to the unit foundation in shipboard operating conditions did not yield expected results; vibrations from other working machines located near the examined one, sometimes relatively far from it, sum up and modulate with vibrations being measured. Therefore, it is necessary to specify optimal measurement conditions for each machine, in which the level of disturbances from other sources is the lowest [4].

One particular example of the said machine units are thrusters, composed of a propeller, intersecting axis gear and electric motor, with the first two components placed in water, thus unavailable from the inside of the ship. Successful diagnostics requires that actual loads are taken into consideration in drawing diagnostic conclusions. Research has shown that it is possible to identify the condition of the transmission gear by vibration measurement performed at the gear flange, while the propeller condition can be identified by measurement and analysis of acoustic emission measured at the shell of the thruster tunnel (in places accessible inside the ship) [5]. In order to facilitate diagnostics of thruster gearing, some thruster manufacturers have started installing fixed vibration transducers inside the gearing body.

Those machine units are most difficult to diagnose where one of the machines has a piston-crank mechanism. The application of vibroacoustic methods calls for the knowledge of dynamic characteristics and load of the machine unit as well as the course of forces generating vibrations. It is possible to identify the condition of the thrust bearing of the crosshead and the condition of piston-piston rod connection by measurements and analysis of the crosshead guide body vibrations. Much wider possibilities of identifying the machine component condition are offered by methods where longitudinal and torsional vibrations of the crankshaft free end are used. We can identify the condition of crank and main bearings and the position of the crankshaft [6].

4. CONCEPTION OF DIAGNOSTICS USING LONGITUDINAL AND TORSIONAL VIBRATIONS

Deformations of a machine body, uneven wear of support bearings and non-aligned position of shafts of the machine unit (e.g. combustion engine – propeller shaft and propeller) are due to such causes as creeping of shims. These deformations lead to the occurrence of substantial additional forces and moments – additional loads on bearings and shafts. In order to avoid damage caused by this type of load, one should exclude from operation those machines where deviations of bearing and shaft coaxiality exceed admissible values. One solution to this problem may be the identification of shaft deformation while it is rotating – diagnosing of the shaft positioning, i.e. alignment.

The grounds for such proposal are contained in author's publication [6], where it has been indicated that the same signal – the longitudinal vibrations signal of the shaft free end can be used for diagnosing the condition of crank bearings and the shaft position. The crankshaft free end may also be used for measurements of torsional vibrations and/or angular acceleration of the shaft. These quantities convey information on the technical condition of tribological nodes, such as piston-liner pairs and some main bearings.

It has been observed empirically that one of the measures of varied reactions in the bearing supporting the crankshaft – shaft deflection – has an influence on the path of longitudinal vibrations of the crankshaft free end. A model was developed which describes relationships between the crank deflections and axial displacements of the free end. The model has not been fully verified yet. Besides, it does not account for the effect of non-uniform loads of engine cylinders.

Periodical signals of longitudinal vibrations are overlapped with transitive signals generated by variable resultant forces from each cylinder. Experimental research has confirmed the influence of load and technical condition, particularly of the crank bearing, on longitudinal vibrations; quality dependence between bearing slackness and relevant measures of longitudinal vibrations has been determined. It has been confirmed that the desired signal would be that of longitudinal vibrations accelerations as a function of the crankshaft rotation angle.

The rotating movement of the crankshaft is not uniform due to periodical developing of the torque by each cylinder in turn. With a constant external load, the instantaneous angular acceleration is proportional to the instantaneously acting torque. Torsional vibrations of the whole machine unit rotor combine with the rotating movement of the shaft free end. It has been determined experimentally that the accelerations value of torsional vibrations of the shaft free end significantly depends on the condition of engine main bearings placed in the kinematic pairs of torsional vibrations.

It has been proved [7] that it is possible to determine from torsional vibrations the resultant forces that act on each crankpin. This better utilizes diagnostic information contained in vibration signals, e.g. for the creation of longitudinal vibration measures oriented on crank bearing failures (measures independent of load).

As the angular accelerations, distances and accelerations of longitudinal vibrations as a function of crankshaft rotation angle provide information useful in diagnostics, appropriate transducers are needed for measurements of these phenomena. Transducers commercially offered at present measure the distance of torsional and longitudinal vibrations relative to a constant reference point. We can calculate mathematically speed and acceleration if vibration distance is known. However, for diagnostic use the desired symptoms have to be measured directly. It matters whether the diagnostic signal has been directly measured or is a derivative signal. That is because during differentiation some information contained in constant values of the differentiated signal is lost while signal components generated by all errors are amplified. For this reason the elements of a track for position and angle measurements have to meet high requirements in terms of assembly and performance accuracy. Therefore, it is necessary to either find or make transducers of longitudinal and torsional vibration accelerations.

Apart from torsional and longitudinal vibrations, the crankshaft and its free end produce transverse vibration. Consequently, the measurements of vibrational symptoms by transducers with a constant reference point contain strong disturbing signals; besides a transducer may be damaged. Therefore, it becomes necessary to develop transducers without a constant reference point. As presented in [8] there are transducers that can be adapted and used in the construction of an integrated transducer of engine crankshaft free end vibrations.

Work is in progress on constructing an integrated transducer composed of ferrari, electrodynamic and eddy current transducers. Although a substantial effect of errors from the transducer rotating part relative to the machine body was identified, these errors can be corrected by applying two pairs of transducers shifted by 180 degrees and averaging the signal. However, a better solution for an angular acceleration transducer turned out to be a special mounting of the non-movable part of the transducer so that this non-movable part makes all the motions along with the shaft except rotary motion.

5. CONCLUSIONS

1) Identification of marine machinery condition based on overhauls and methods used so far is not satisfactory.
2) Diagnostics using vibroacoustic methods, especially when combined with load measurement methods is effective in the case of units composed of rotor machines.
3) In the case of machine units, where one machine has a piston-crank mechanism, the knowledge of dynamic characteristics and loads as well as the course of forces generating vibrations makes it possible to identify the conditions of such components as crosshead thrust bearing, piston-piston rod connection, crank and main bearings and the crankshaft position.

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