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MARINE DIESEL ENGINES DIAGNOSTICS

LAIVŲ DYZELINIŲ VARIKLIŲ DIAGNOSTIKA

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The new diagnostic and tuning method which could be used on marine high speed diesel engines is presented in the paper. Vibration signals generated by the fuel injection valves and in valve gear mechanisms together with special signal processing are also described in the paper. Diagnostic methods which based on vibration signals analysis are sensitive on engine load and speed changes. Conventional diagnostic methods for engine fuel injection system and valve gear mechanism depends on injection timing checks and injectors technical condition assessments, on valve clearances checks and valve timing diagram checks on crankshaft flying wheel. The new presented method based on vibration signal analyzing in crankshaft revolution angle domain. Using this method checking angle of fuel injection or timing in valve gear mechanism without stopping the engine and dismantling it is possible.

Marine diesel engine, diagnostics, tuning, fuel injector, valve gear.

Introduction

Checking and tuning of the fuel injection valve timing and exhaust or inlet valve clearance is a common practice in marine diesel engines. From small engines up to the largest 2-stroke units some regulations and tunings are necessary after repair works, and in normal use, after period of time given by the manufacturer. Such maintenance works are time consuming and sometimes extort partial engine dismantling. In a marine practice are known situations when technical state of maintained mechanism is worse than before overhaul. Cost lowering tendency in engine maintenance schedules and unmanned vessel's propulsion plants require new approach to these outdated and "reliable" procedures. One of the ways to solve these problems could be using vibro-acoustic diagnostic methods.

Subject of the research

Diesel engine vibrations are caused by several mechanical and thermal factors which affect sometimes simultaneously at different phases of the engine cycle. Vibration observed on marine engine parts could be caused by various sources, resulting from the combination of combustion and inertia forces which act on the moving parts of the engine. The main sources of diesel engine vibration are the: combustion process, inertia forces, pistons slaps, high pressure processes in fuel system, impacts in fuel valves, impacts in valve gear mechanism, gas flows in engine manifolds, oil flows in hydraulic and lubricating systems and others. Moving parts of the engine accelerate by combusting pressure (P_c –Fig. 1) or by cams running across their clearances what causes mechanical impacts. These impacts are found to be the main cause of the predominant high frequency noise and could be observed by vibro-acoustic methods [2].

Fuel injection valve as a source of vibration signal

Fuel goes through the high-pressure system is a source of noise and vibrations. Moving parts of the high-pressure pumps and fuel valves are source of impacts which may be observed as displacements, speeds of displacements and accelerations of the vibrations. Needle up and down movements' coincide with sharp impacts on the fuel valve main body and needle seat as it is shown in Fig. 1. To get such signals from working injectors the vibration sensor should be installed directly on the injector or very close to it.

If the whole fuel delivery system works properly two sharp and strong vibrations' signals – picks – created by the fuel valve needle are usually observed in crankshaft angle domain (deg OWK – Fig. 1), but when jamming or other malfunction occurs the signal pattern is changed. The first pick is usually a little bit stronger than the second one, what can be easy explained by pressure value (P_f) during the fuel delivery process.

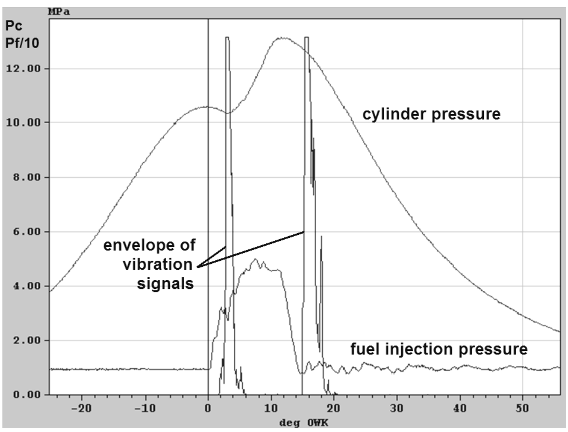

Fig. 1. Cylinder pressure diagram together with the fuel injection pressure and envelope of vibrations measured on the one of the fuel nozzles of examined cylinder

1 pav. Dujų slėgio cilindre diagrama kartu su degalų įpurškimo slėgiu ir tiriamajame cilindre išmatuotu vieno iš degalų purkštukų vibracijų kitimo paketu

Information about needle moving, period of fuel delivery which correlates with fuel quantity, are especially valuable on engines which have more then one nozzle in specific cylinder (SULZER RTA, MAN B&W LMC, MITSUBISHI UEC engines). In these types of engines harder to find damaged fuel valve in the suspected cylinder and engine room crew have to check injectors one by one.

Valve gear mechanism as a source of vibration signal

Valves strikes in valve seats during valves closing and rocker arms strikes in valve stems when they are being opened could be observed in time or angle domain. Observed signals give information about valve gear mechanism timing, technical condition of valve seats, valves' steams, and other elements. In big 2-stroke diesel engines which have one hydraulically open exhaust valve, vibration sensors might be connected to the cylinder heads. Mass of valves in such engines and cylinder head dimensions are big enough to effortless signal selection. It looks quite differently in small high-speed engines where more than one or two valves per cylinder are mounted. For example in SULZER type 6AL20/24 engine (0.42 MW at 750 rpm) one cycle (two crankshaft revolutions – 4-stroke engine) takes only 0.16 second. Vibration signal from sensor connected to the cylinder cover bolt is strongly disturbed by vibration processes in other cylinders and engine mechanisms. To find out which impact is caused by valve gear mechanism sometimes additional sensors (for example rocker arms lift sensors) are necessary. In the case presented on Fig. 2 only impact from inlet valve closes (AIVC) is strong enough to be observed.

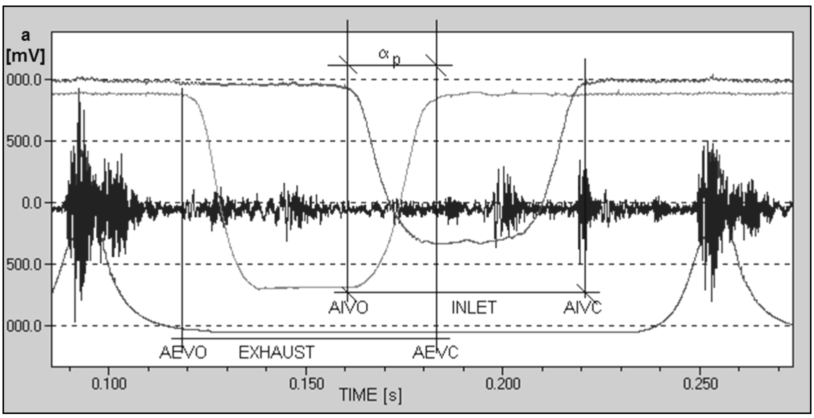

Fig. 2. Dynamic valve gear diagram for medium speed marine diesel engine AIVO – angle inlet valve opens, AIVC – angle inlet valve closes, AEVO – angle exhaust valve opens, AEVC – angle exhaust valve closes, α_p – valves overlap
2 pav. Dinaminė dujų skirstymo vožtuvų diagrama vidutinių sūkių laivo dyzelinio variklio AIVO – įleidimo vožtuvo atidarymo kampas, AIVC – įleidimo vožtuvo uždarymo kampas, AEVO – išmetimo vožtuvo atidarymo kampas, AEVC – išmetimo vožtuvo uždarymo kampas, α_p – vožtuvų persidengimas

Vibration signals from diesel engines could be analyzed in time/crank angle domain or in the frequency domain using the Fast Fourier Transformation. The frequency analysis is useful and the most frequently used for stationary signals. For the non stationary signals generated by the diesel engine the frequency content varies with a time and in this case time-frequency or angle-frequency analysis tools should be used.

Test results and discussion

The statistical analysis of the signal which is sometimes used to compute scalar parameters such as maximal value, the mean, the root mean square, the Kurtosis or other parameters is hardly useful for the non stationary signals [1,3]. The typical visual analysis in the time/angle domain gives usually limited information. The original method presented in this paper precisely is the angle analysis of the envelope of vibration acceleration. That method for low-, medium-, and high-speed marine diesel engines was worked out in Technical Institute of Ship Maintenance of the Polish Naval Academy in Gdynia and is still evaluated for the new and more complex marine diesel engines.

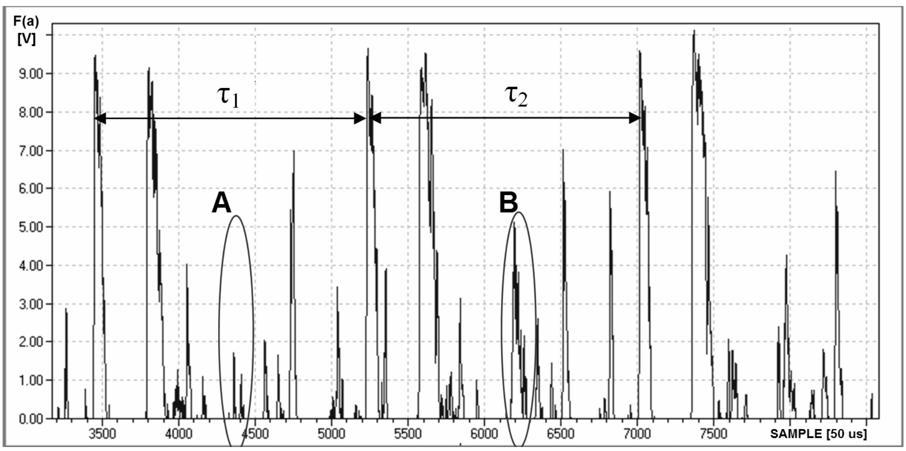

Fig. 3. Envelope of vibration signal measured on cylinder head of marine high-speed diesel engine type MB820 – τ_1 τ_2 – signal periods, A B – varied values of signal amplitude

3 pav. Greitaeigio MB820 tipo laivų dyzelinio variklio cilindrų galvutės išmatuoto vibracijos signalo kitimo paketas – τ_1 τ_2 – signalo periodai, A B – kintamos signalo amplitudės reikšmės

In the Fig. 3 envelope of vibration signals measured on a high-speed marine diesel engine cylinder head is presented. The strongest vibration signal on the diagram probably comes from the combustion process in the closest cylinder to the sensor location. This typical vibration signal has periodical character (τ_1 τ_2), which is strongly influenced by vibration source distance to the sensor. Other vibration signals come from the rest of cylinders. To find a proper signal and to assign to it the engine sequences order we have to use many different signal selection methods such as time selection, frequency and spatial selection. Sensor location and type of sensor fitting methods are important too. The closer to the signal sources the better for signal amplitude and quantity of information carried by the signal. If it is possible sensors should be mounted directly on the cylinder heads, injectors or valve housings. The engine body and cylinder covers are the places that should be avoided during the sensor montage as they are elastic or thin. Fitting sensors by screw-in bolts or clamp bolts secure high frequency signal components transmission. Magnetic or stick sensor fitting methods result in big losses in signal spectrum. Acquired signals might be passed across the frequency window analyzer function to cut out some of the disturbed parts of the signals. As it is presented in the Fig. 3 (two ellipsis marked places A and B) some of the repeated parts of the signal vary considerably according to the amplitude value. However, when the signal is analyzed only as an event in time/angle domain and when the frequency sampling is high enough as well as the time/angle axis is stable, having appropriate reference signals we could easily check the signal sequence order. The proper sequence order means that engine or other technical assets are in a good technical condition. A problem appears when we have to observe signals on multi-cylinder engines and without any access to the angel axis of the engine crankshaft. Vibration signals registered separately on cylinder heads of one of two banks of 12 cylinders MB820 diesel engine are shown on the Fig. 4.

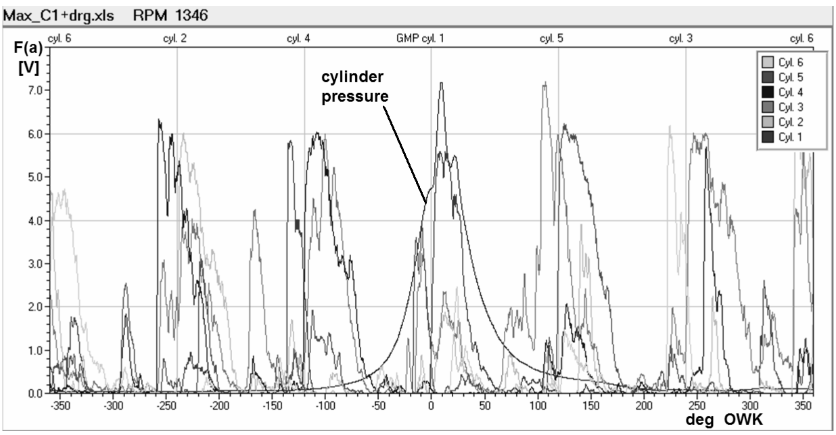

Fig. 4. Cylinder pressure signal from one cylinder is a reference signal for vibrations traces from six cylinders in the same bank of high speed marine diesel engine

4 pav. Greitaeigio laivų dyzelinio variklio vieno iš cilindrų dujų slėgio kitimo signalas, kurį galima panaudoti kaip informacinį signalą, kituose tos pačios eilės šešiuose cilindruose vykstančioms vibracijoms aptikti

In order to synchronize the vibration signals the cylinder pressure signal was used as a reference signal. It can be observed that it is still very difficult to recognize separate signals from different cylinders. The signal traces from six cylinders were shifted to the TDC (Fig. 5) of the first (in this bank) cylinder to assure higher accuracy of analysis. The places where signals from different cylinders could interfere (for 4-stroke 6 cylinder diesel engine it is usually ±120°, ±240° to TDC) are shown on Fig. 5.

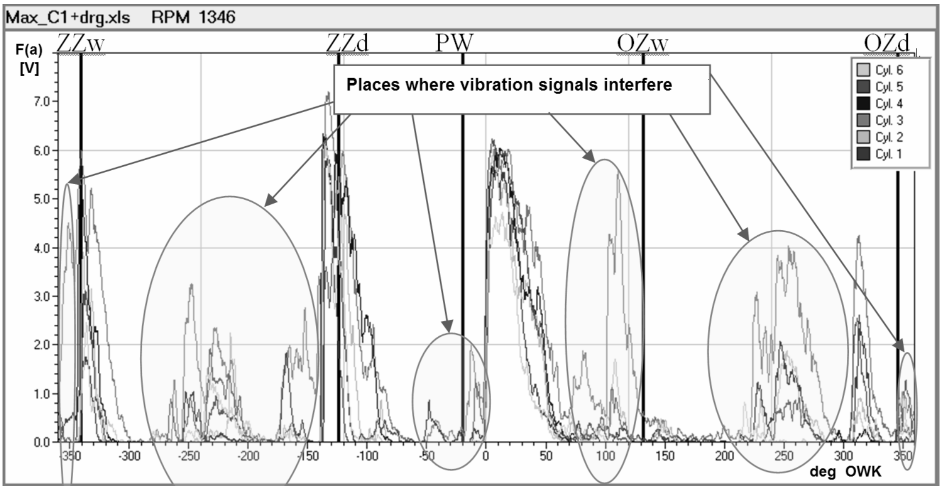

Fig. 5. Specific places where vibration signals from different cylinders interfere with one another

5 pav. Specifinės vietos, kuriose interferuoja skirtingų cilindrų generuojami vibracijos signalai

Additionally, on Fig. 5 the static engine timing points are shown: ZZw – means static exhaust valves closes, ZZd – means static inlet valves closes, PW – means static point of start of fuel feed-in when idling, OZw – means static exhaust valves opens and OZd – means static inlet valves opens. Using special analyzing system with “zoom” function (as it is shown on Fig. 6) each part of the diagram could be magnified to read-out the engine dynamic timing parameters. Using a cursor the analyzer operator can asses’ angles of fuel valve openings and valve gear timing for each cylinder in the bank with reasonable accuracy [4]. As it is shown in the Fig. 6 differences between the starting points of the needle valves lifts for separate injectors in tested bank are less than 2° of engine crankshaft revolution.

Conclusions

Diesel engines technical condition assessment is a very complex process. Most of the malfunctions and troubleshooting in the diesel engine installations are generated by the fuel injection system and valve gear mechanism. According to the engine manuals crews should inspect these systems in relatively short periods. Opening and closing of the fuel injection valves, inlet and exhaust valves generate vibration signals in engine structure. There are some tools available in signal analysis which gives the opportunity to trace changes in signal patterns in real time monitoring systems. Presented special vibration method gives opportunity to change the whole engine maintenance philosophy from scheduled to condition based maintenance without fear about real operating engine conditions.

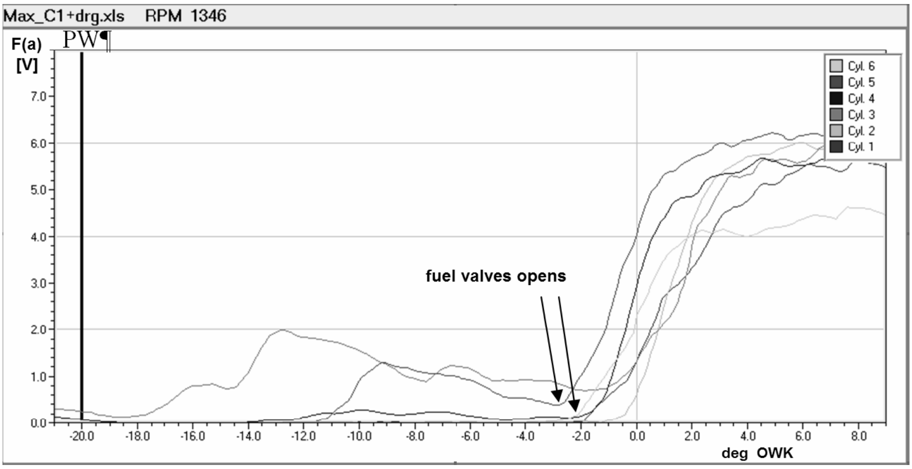

Fig. 6. Dynamic angles of fuel injection valves opens
6 pav. Dinaminiai degalų purkštuvų atsidarymo kampai

The "dynamic" valve gear mechanism timing diagram can be observed when using a proper method of signal processing. Dynamically estimated angles of valve closing and openings are different to that diagram given in the engine manual. These angles are usually determined in static conditions because of what a special database for prophylactic engine controls has to be created within preliminary tests. Dynamically measured the fuel injection valve opens and closing angles and exhaust and inlet valves opens and closing angles are determined by engine speed and rating. Taking into account that maintenance may be taken in different load conditions the database should contain the whole spectrum of measured parameters.

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ДИАГНОСТИКА СУДОВЫХ ДИЗЕЛЬНЫХ ДВИГАТЕЛЕЙ

Аннотация

В статье приводится новый метод диагностики и регулирования, который можно использовать в быстроходных судовых дизельных двигателях. Топливными форсунками и механизмом привода клапанов создаваемые вибрационные сигналы совместно с применением специальной обрабатывающей методики также описываются в этой статье. Методы диагностики, базирующиеся на анализе вибрационных сигналов, зависят от изменения нагрузки двигателя и частоты вращения коленчатого вала. Традиционные методы диагностики системы впрыскивания топлива и газораспределительного механизма двигателя зависят от проверок угла опережения впрыскивания топлива и оценки технического состояния форсунок, проверок тепловых зазоров клапанов и проверок диаграммы газораспределения клапанов по углу поворота маховика на коленчатом валу. Представлен новый базирующийся на анализе сигналов вибрации в зависимости от угла поворота коленчатого вала метод диагностики. Применение этого метода позволяет проводить проверку угла опережения впрыскивания топлива и/или оценить состояние газораспределительного механизма без остановки и разборки двигателя.

Судовой дизельный двигатель, диагностика, установка углов газораспределения, топливная форсунка, привод клапанов.

Tomasz Lus, Marek Łutowicz

LAIVŲ DYZELINIŲ VARIKLIŲ DIAGNOSTIKA

Reziumė

Straipsnyje nagrinėjamas naujas diagnostikos ir sureguliavimo metodas, kurį galima panaudoti laivų greitaeigiuose dyzeliniuose varikliuose. Degalų purkštuvų ir vožtuvų pavaros mechanizmo generuojami vibracijos signalai kartu su specialia signalų apdorojimo įranga taip pat aprašomi šiame straipsnyje. Diagnostikos metodai, kurie paremti vibracijos signalų analize, priklauso nuo variklio apkrovos ir sukimosi greičio pokyčių. Tradiciniai variklio degalų įpurškimo sistemos ir vožtuvų pavaros mechanizmo diagnostikos metodai yra paremti įpurškimo ankstinimo patikrinimais ir purkštuvų techninės būklės įvertinimais, vožtuvų šiluminių tarpelių patikrinimais ir dujų skirstymo diagramos patikrinimais pagal alkūninio veleno smagračio posūkio kampą. Naujai pristatomas laivų variklių diagnostikos metodas paremtas vibracijos signalų analize pagal alkūninio veleno posūkio kampo sritį. Panaudojant šį metodą, galima patikrinti faktinį degalų įpurškimo kampą ir/arba vožtuvų pavaros diagramos kampus, nestabdant ir neardant variklio.

Laivų dyzelinis variklis, diagnostika, dujų skirstymo mechanizmo sureguliavimas, degalų purkštuvas, vožtuvų pavara.