ACQUISITION OF DIAGNOSTIC INFORMATION FROM THE INDICATOR DIAGRAMS OF MARINE ENGINES USING THE ELECTRONIC INDICATORS

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Abstract

The paper analyzes the factors influencing the quantity and quality of diagnostic information obtained by engine indication with electronic indicators and pressures analyzers. Amount of information obtained virtually unchanged since the advent of the first construction pressure analyzers produced by Autronica and ABB Company. In many cases, the value of the maximum combustion and compression pressures, can be measured using these devices with sufficient accuracy and reliability, is if ignition occurs after piston TDC. Determination of the mean indicated pressure, compression ratio and heat release characteristics required to develop a method of TDC determination on the indicator diagrams, generate reliable angular axes in real time and pressure sensors of sufficient accuracy. It should be noted that in the latest solution of ABB system, a correction of thermodynamic loss angle and combustion pressure sensors of high accuracy were introduced. For marine diesel engines diagnosis, the pressure sensor measuring sustainability is important because of the ability to create trends of specific diagnostic parameters, which may constitute an additional, important source of diagnostic information.

The paper presents an overview of currently available pressure sensors that can be used during marine engines indication. Most important issues related to the pressure measurement on indicator valves were characterized. An assessment of the gas channels and the quality of the angular axis impact for the parameters of indicator graphs was done.

Keywords: *marine engines, engine indication, angular axis, pressure sensors, TDC, heat release characteristics*

1. Introduction

The late sixties and early seventies of the last century was the beginnings of the emergence and development of marine engines electronic monitoring systems based on the combustion pressure curves in the cylinders. This development was possible through the elaboration of pressure transducers construction able to withstand working conditions on the indicator valves, and with advances in analog-digital processing of measurement data and the possibilities of computer processing. A significant step was the use of Ethernet and the Internet to transmission of measurement data and the results of their analysis.

Autronica (Pressure analyzers NK-2 and NK-5) and ABB company (analyzer Cyldet 1800) ware precursors in the construction and implementation of indication measurement systems for marine diesel engines. Autronica NK-200 analyzer is currently offered by KRONGSBERG [9].

Consistenty, the quality of combustion pressure sensor in the aspect of sufficient stability conditions and long-term work on the indicator valves of marine engines, determines quality results of cylinder indication. So far there had not yet universal combustion pressure sensor capable of long-term reliable operation in these conditions on the engines of various types. Further problems remain to generate the angular axis and setting the TDC possition. Positive solution to these problems is the key to creating the trends of parameters designated indicator diagrams and to determine the characteristics of heat release. Analysis of these parameters enables to obtain complete diagnostic information contained in the indicator graphs.

2. Combustion pressure sensors used for marine diesel engines indication

For marine engines indication, it can be used, sensors that are suitable durability and retain sufficient accuracy in terms of measurements on the indicator valves, or before them.

The most important information which demonstrates the suitability of pressure sensors for measuring on the indicator valves of marine engines are: maximum working temperature, the maximum number of load cycles (durability), the ability to install sensors on the indicator valve, or before it (Tab. 1).

Tab. 1. Main determined parameters of cylinder pressure sensors can be used on marine engines

Manufacturer (sensor type)	Maximum working temperature, °C	Maximum number of load cycles	Place of measurement
Kistler [1] (6613C…)	Measuring element (front of sensor) - 350 °C	>16000 h can be achived for a service life in a gas engine running [1]	Before indicator valve or on
ABB [2], [3] (PFPL…) For low speed engines	Max. ambient temperature of transducer cable: 150 °C for PFPL 201, 200 °C for PFPL 202.	The transduer is designed for ontinius combustion measurement: 24 h per day, 365 days without recalibration [2]	Before indicator valve
Kongsberg [4] (Autronica) (GT-25/GE-3)	350 °C at transmitter body	Nie deklarowana (w ramach gwarancji).	On indicator valve
AVL [5] (GO41DA)	Front of sensor: 350 °C. Cable: 200 °C.	16 000 h [5] depending on application.	Not declared
Imes [6] (HTT – 04)	Max. temp. at measuring cell 300 °C.	Designet life expectancy of 16000 h @ 1500 rpm.	Not declared
Optrand [7] Natural Gas-Engine Sensors (3/8-24 Rotating Nut)	Front of sensor: 350 °C. Fiber Optic Cable: 200 °C.	200 Million Pressure Cycles or 2 Yers.	For instalalations in cylinder heads, or indicator ports/Kiene adapters wich are prone to indicator port detaonations
LEMAG [8] (Lemag sensors of kisteler senors)	No data	No data	On indicator valves

Measurements on the indicator valves or before in pose the greatest demands on the cylinder pressure sensors, because they are not cooled. Direct measurement would require the execution by the engine manufacturer of special sockets in the cylinder head for direct installation of sensors, which generally is not used. Direct mount of pressure sensor in the cold head can greatly improve the working conditions of the sensor (the lower the temperature of bodies), significantly increasing its working time. Therefore in relation to manufacturer’s information about achieved sensor stability (number of load cycles) it should be payed particular attention to where the sensor should be installed.

The existing measurement experience [7] show that the working conditions on the indicator valves in the first place it difficult to cope membrane sensors, both tensometric and optical fiber. It should be noted that the piezoelectric sensors are not common membrane sensors, but although they have a protective membrane. Among the sensors listed in Tab. 1, the membrane sensors are Imes [1], Optrand [10] and Lemag [14] (if not used sensors - Kistler inserts or AVL [8]). Tensometric sensors are used principally for the periodic measurements There are more procuders of tensometric sensors, the study omitted the presentation of these sensors because of their limited application to the measurement of periodic and frequent problems with the measurements on high load.

ABB current sensor design is characterized by the original working principles, based on the measurement of the magnetic field changes due to deformation of the sensor caused by changing pressure (Fig. 1) [3].

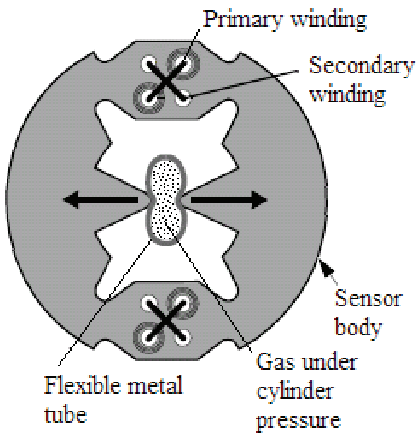

Fig. 1. The priniple of ABB's sensor construction and operating

Accoring to producer the measuring accuracy is 0.5% over the full measuring range. ABB states that sensor operation and the accuracy is not influenced by any clogging or heat flash from the combustion gases, which is a common problem of membrane based pressure transducers [5]. There is no known signal transmission frequency band. It should be noted that the weight of the sensor body is significant which can seriously limit the frequency bandwidth of the signal.

3. The main problems of pressure measuring on the indicator valves

It should be noted that almost all manufacturers of sensors trying to declare a maximum operating temperature not lower than 350°C in the measurement part, and up to 200°C at the output signal and power cables (Tab. 1). Today, as one of the causes of any sensors defective manufacturers provide knock combustion, not a lack of adequate heat resistance. Multiple times measurements of temperature on indicator valves of low speed marine diesel engines, medium speed and gas engines with spark ignition have not confirmed the presence of excessively high temperatures. Maximum temperatures measured on the indicator valves did not exceed 250° C. Miniature thermocouple mounted in a body of original sensors with the measuring point appearing in the forehead of the measuring diaphragm was used.

Because of the of frequent failures of sensors on gas engines GMVH sets in Krio enterprise, Optrand company recommended the use of special pulse dampers in the form of sintered pellets (particulate matter) metal (Fig. 2).

Application of pressure dampers, solved the problem of sensors defective. Silencers, however, were relatively fast pollutted and caused significant distortion of the pressure curvers. Damping inserts require frequent replacement, which further complicates the operation of the measuring system. It is easy to carry out automatic control of the degree of curves distortion, but the need for frequent replacement silencers complicates the functioning of the monitoring system. This problem does not occur in gas compressors GMVH sets, where the gas temperature reaches only 100°C.

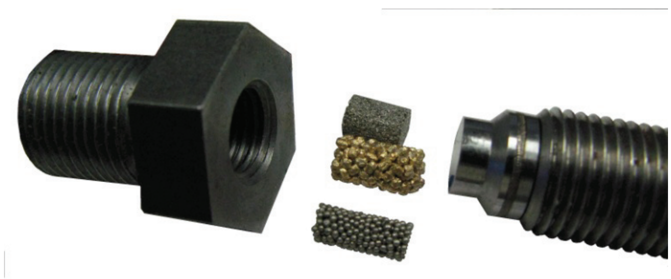

Fig. 2. Pressure pulses and flame dampers uses by Optrand company before front of sensor

Temperature measurements made on the indicator valves showed that even under conditions of simulated gas blowing temperature does not exceed 250°C. It has been suggested, that the main cause of these problems is the lack of adequate heat resistance, not knock combustion. Inserts are undoubtedly a thermal barrier. In this model, the sensor and the output cable is shielded, which can significantly contribute to an excessive increase the temperature inside the sensor and the output signal wires.

Pollution of the gas channels and sensors by the postponement of lakes and cokes can significantly distort the curves of pressure on marine engines until the complete disappearance of the signal. This problem essentially concerns the engines operating on heavy fuel oils. For portable use of pressure sensors, before connection to indicator valve it is recommended to blow up gas channels, which allows them to clean and give an orientation that there are no excessive contamination. In practice measurements of ship engines, in sporadic cases it was necessary to use the drill to restore patency of the gas channel.

The problem of gas channels contamination is particularly important for on-line measurement systems. Kistler [2] and ABB [3] solutions, in which sensors are mounted before the indicator valve allows purging of channels without removing the sensor (Fig. 3).

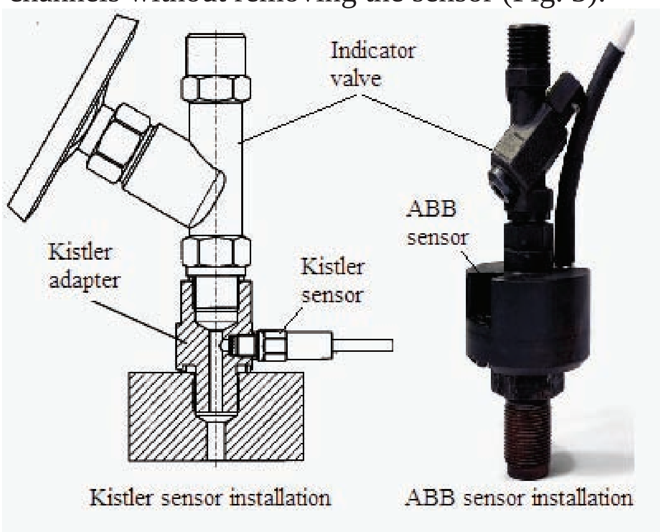

Fig. 3. Pressure sensors monted before indicator valves

It should be recalled previous construction of Kistler company, whose origin can be associated with a view to a radical solution to this problem by changing the measurement principle and sensor construction. It was a piezoelectric washer type 9149Q type mounted under the bolt head and a sensor type C (also piezoelectric) provided for mounting on the indicator valve - similarly to the to ABB sensor.

Installation of cylinder pressure sensors, before the indicator valves have the advantage of significantly decreasing distortion and delay of pressure curves compared with the measurement on the indicator valve. This is particularly important for indication of engines operating at speeds higher than 500 rpm, characterized by long (high volume) gas channels.

4. Sampling of pressure curves and the creating of the angular axis

Amplitude discretization of cylindre pressure is currently not a problem. They are widely available fast, cheap AC converters 12-bit, 16 bit and a greater number of bits. For marine engines indication use of 12-bit converter, and even 10 bit [6] is perfectly adequate but 16-bit sampling has now become standard.

One of the basic measurement problems faced by producers and users of the pressure analyzers is to provide a sampling in the crank angle domain. The portable analyzers are often used sampling in time domain and then transform to the crank angle domain which, unfortunately, brings a significant errors. In this case, an important informational value has only a maximum value of pressure, which can be measured using an ordinary indicator.

The earliest solution to this problem, Autronica analyzer NK-5, applied 30 angle markers (sector) and the reference marker position of the shaft. Markers were mounted on the circumference of the side surface of the flywheel with a reference marker on one circuit. Then producers started to use the passive teeth of turning gears on which inductive sensors are mounted. In Poland, there were developed and patented a universal angular axis generator, which generates pulses from the rotation angle of 0.1 ° CA on the basis of any number of teeth. This solution was used in both stationary and portable analyzers.

Impulses from the passive teeth of the turning gears wheels are used in the ABB system - Cylmate. There are two options of reference signal generation [3]. The Lemag Company introduced toothed wheel of the 360 cuts, which delivers pulses to generate the angular resolution of 1° CA. Previously, Lemag system was based on one marker of shaft position and in the time domain registration.

Presented solutions pose many practical problems caused by vibration, wear of teeth, beating of the wheels. As a result of these interactions are disturbances in the generation of angular axis (Fig. 4), the picking, etc.

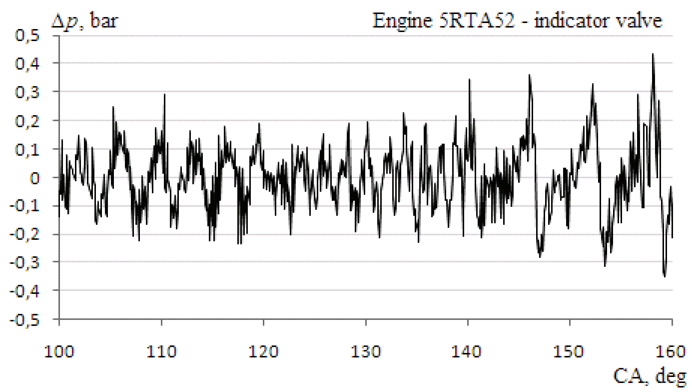

Fig. 4. High frequency disturbances on the curve of compression of low-speed engine 5RTA52 caused by interference in the generation of the angular axis

The problem that exists from the beginning of the analyzers is to generate pressure pulses with a given angular resolution, based on different, sometimes significantly lower angular resolution of signals from the markers of the shaft angle. The optimum solution is to predict linear pulse duration based on the measured instantaneous values of the time sector. The optimum solution is to linear predict of pulse duration based on the measured instantaneous values of the time sector.

From individual measuring experience outcome that, it is possible to generate sufficient quality axis angular with resolution of 0.1° CA for fixed operating conditions based on the number of markers (teeth) higher than 60th. Increase of the accuracy of measurement would require a change in strategy, that is, cancellation of registration in the shaft angle domain and proceed to register in time domain, both the curves of pressure and angle pulses. In this case, the axis angle and the indicator diagram will be generated with a delay. Otherwise, the forecasting error is inevitable.

Angular sampling rate of 1 ° CA is to be considered as the limit in terms of determining the accuracy of TDC, the mean indicated pressure and the heat release characteristics. Determining this values for smaller sampling resolution of 1 ° CA it very difficult. In this case, there is a penetration of higher frequency (interference) of to a band of pressure variation. The desired frequency of sampling to determine the heat release characteristics is 0.25 ° CA. There should be no larger than 0.5° CA.

5. Evaluation of the gas channels impact on the informational value of the indicator diagram of marine engines

Delays and pressure signal distortion caused by gas channels and indicator valves induced the TDC position error on indicator graphs. The value of these errors increases with engine speed. As we know the error position of TDC about 0.1° CA causes an error in the designation of the mean indicated pressure or heat release characteristics in the order of 0.8% at nominal load of marine engine. In addition, the chart is distorted following the suppression, heat exchange and gas oscillations in the gas channels.

From the viewpoint of diagnostic knowledge of marine engines absolute values of the mean indicated pressure, or parameters of heat release is of secondary importance. Important is that the impact of gas channels and indicator valves on determination of indicator parameters and pressure curves for each cylinder was the same, and the measurement results and analysis were reproducible.

Test results on low speed medium speed marine engines, indicate the diagnostic usefulness of the mean indicated pressure and heat release characteristics determined on the basis of indicator diagrams measured on indicator valves. In order to clarify the effect of the gas channels to the distortions of the indicator diagram, and especially the course of the heat release characteristics, tests were performed on the engine 6AL20/24 at nominal rotational speed of 750 rpm. During the test one pressure sensor was located near the combustion chamber (channel 10 mm), and a second sensor on the indicator valve (Fig. 5).

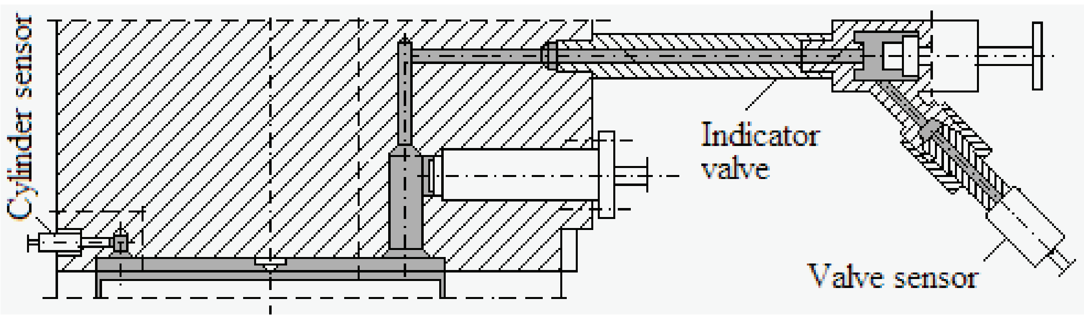

Fig. 5. Gas channels of Sulzer AL20/24 engine - pressure sensors location during the test

The Fig. 6 and 7 shows the net heat release characteristics for an ideal gas for the cylinder pressure curve and for the indicator valve [13].

Characteristic distortion (Fig. 6) caused by the gas channels are visible on the characteristics of the medium speed engine. They are not observed at low speed engine characteristics (Fig. 7). Fig. 5 is shown fully overlapping waves on the characteristics of q and Q, which shows an identical individual impact of passage of gas cylinders. These distortions are not observed in case of low speed engines and other types of medium speed engines with more favourable course of gas channels. Even if a disruption occurs, and is repeatable, it does not affect the value of diagnostic information. However, it is necessary to control the possible changes the characteristics of gas channels due to contaminants.

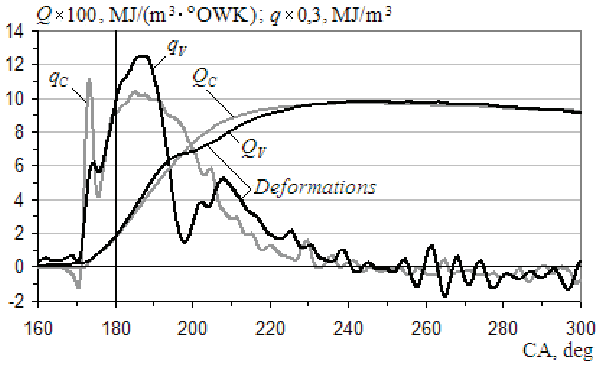

Fig. 6. Heat release characterictics based on the indicator graph of medium speed engine 6Al20/24: meassured in the cylinder – q_c ,Q_c, meassured on the indicator valve – q_v ,Q_v : q – intensity of heat release, Q – heat release

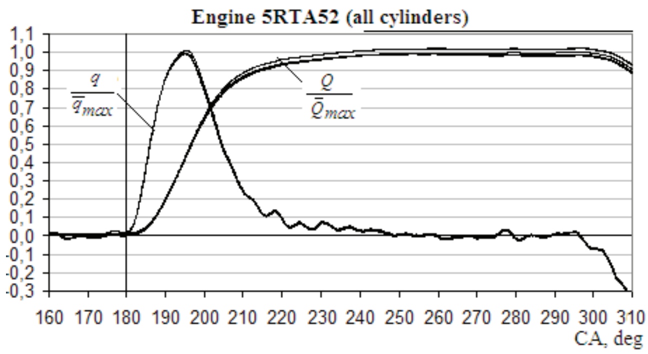

Fig. 7. Heat release characterictics referenced to maximum values q_{max} ,Q_{max} , designated from inditator graphs meassured on the indicator valves of low speed diesel engine (sea trials) Sulzer 5RTA 52

Major impact on the course of the heat release characteristics has TDC position error. In the example TDC was set with the thermodynamic correction [11]. The delay of graph measured on the indicator valve of engine 6AL20/24 was 2.7° CA in relation for the graph measured in the cylinder.

On-line TDC determination of the thermodynamic TDC was introduced in ABB Cylmate system (Fig. 8) [4].

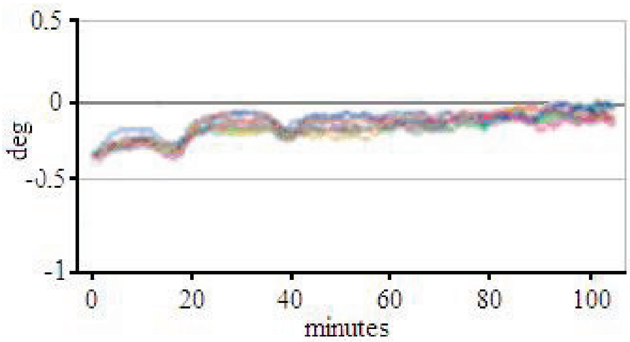

Fig. 8. ABB Example curves of thermodynamic TDC appointed in on-line Cylmate ABB system [4]

As shown in Fig. 8 TDC position is changed after changing the load or during the inquiryto a new thermodynamics equilibrium, and because of the volatility of gas blowing.

6. Conclusions

The quality of the indication results and obtained diagnostic information depends on: the quality of the combustion pressure sensor, the determination accuracy of the axis angle and TDC location accuracy on the indicator graphs.

Gas channels and indicator valves in the cylinder pressure can not deform significantly diagrams of low speed engines, and their influence on the error (distortion) of the indicator diagram medium speed engines is systematic and does not diminish the amount of diagnostic information.

In on-line systems, continuous monitoring of contamination of gas channes is necessary, which is possible if the angular axis is functioning properly.

Substantially reduce of the impact of gas channels on the measurement results are achieved by installing the combustion pressure sensor before indicator valves. This solution is offered by Kistler and ABB.

Measuring stability of pressure sensors, stable functioning of the angular axis, control of the purity gas channels and the dynamic determination of TDC allow to create trends and determination of diagnostic parameters and diagnostic use of heat release characteristics of marine engines.

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