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ASYMMETRY INCREASE IN THE COURSE OF COMPRESSION PRESSURE AS A MEASURE OF OBSTRUCTION IN INDICATING CHANNEL

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Abstract

Indicating process of large combustion engines for both marine and industrial applications is performed using the indicating channels with valves. The impact of these channels on the values of parameters obtained from engine's indication is significant. In previous studies, it had been shown that during exploitation accidental degradation of the indicating channels occurs. Carbon deposits, which appear in the channels, are limiting their patency. Leaks in channels connections are also appeared. Disregarded state of degradation of indicating channels will change the image of indicated pressure course, different for each cylinder of the engine. When cylinders are indicated using commercial instruments, the status of the channel is not in any way taken into account. At one gas compressing station in Poland, which has compressor diagnostic system, developed by the author, with stationary indicator, inverted IIR filter has been used. This filter is used to adjust the recorded waveforms of indicated pressure on motor-compressors GMVH type, and the filter coefficient is chosen to offset the associated throttling signal delay. Information about the delay of the signal is missing, however, in the case of popular portable indicators that do not use tags from crankshaft position. The paper presents a method for assessing the state of the indicating channel, based on the asymmetry measurement of compression course obtained after cut-off the fuel supply to the tested cylinder. The study model shows that leakage from the combustion chamber, interference in cooling and other defects cause only slight and predictable disruption of symmetry. The analysis of compression pressure course (without fuel delivery) immediately prior to each cylinder indication, in the case of positive verification, increases the reliability of diagnosis. In the case of negative verification, measure of the asymmetry could be the basis for the adjustment of acquired pressure waveforms and achieved from them parameters.

Keywords: *marine diesel engine, indicated, indicated channel, diagnostics*

1. Introduction

One of the basic methods of controlling the proper operation of the internal combustion engine is to assess the quality of compression and combustion processes. This evaluation is done, inter alia, based on a pressure in the engine cylinder. Diagnostic team from Polish Naval Academy regularly diagnoses all the engines on board of the Polish Navy ships by measuring pressures through the indicating channels with indicator valves. So far, five cases of total channel obstruction by carbon deposits had been found. Then, the measurement was impossible. However, there is a possibility that the channel has lost some patency earlier. Then, the measurement was possible, but it was cursed with an error. As part of the earlier published study [1] it was found that cleaned indicator channel under nominal engine load brings only a minimal measurement errors of compression pressure and maximum combustion pressure. In technical conditions, these errors can be omitted.

It was found that with the deposits overgrowth in the channel signal throttling increases. Simulated channel throttling, which did not result in audible and visual obstruction symptoms, depending on engine speed and load, caused 9.64-15.85% lower measured value of compression pressure and maximum pressure compared to the channel without throttling. The channel's pressure measurements are subject of systematic error equal for all of the engine cylinders. Even though the measurement errors in this diagnostic method it is suitable for comparative purposes while balancing the engine. However, as practice shows, the process of indicator channel deposits overgrowing in each cylinder is progressing unevenly. Then there is an additional random error, which is not covered by any existing commercial indicators. In the case of limited patency of the channel, deformation in obtained course always leads to a reduction in the measured pressure differently in each cylinder. Such measurements are not suitable even for comparative purposes. It is therefore recommended before engine indication to clean channels and valves. This recommendation is usually ignored or limited to blowing the channels. In the case of undetected loss in patency of the channel the indicator usually erroneously states, reduced compression pressure interpreted as a symptom of piston rings and cylinders wear which reduced the maximum pressure. Apparently, reduced maximum pressure is adjusted by earlier fuel injection angle before TDC and possibly by increasing the fuel dose. This result, in an ideal manner, in the false image of indicated pressure, leading to uncontrolled overload of the cylinder with the obstructed channel.

During the construction of stationary indicators prepared for continuous operation at gas compressor stations, it turned out that the process of deposits overgrowth in the channel is very common. Initiated process usually deepens very quickly, leading to misdiagnosis. At diagnosed GMVH type engines angle of ignition usually occurs shortly after TDC, so the distance between the reference mark on the crankshaft and a clearly visible TDC is easily measurable. Tests, which were made (described in [2]), showed that the symptom of the channel patency loss is increase in the signal delay seen as TDC delay. Based on this observation a methodology of throttling channel adjustment utilizing inverse IIR filter was developed, which admittedly is not corrected all deformation, but allowed the correct reading of the most important parameters as compression pressure and maximum pressure. The proposed algorithm is effective, but only if there is proper synchronization of the engine with measurement marks on the shaft. In the case of engine, unstable angular speed the number of markers should be as large as possible. In the prototype indicator, it was 360 marks.

Currently, the market is dominated by portable indicators without possibility of synchronizing measurement marks on the crankshaft. In this case, the developed method proved to be useless. The researches were made to detect loss of the channel patency based on pressure measurement.

2. Decrease of compression pressure as a symptom of change in channel patency

The first obvious symptoms of deposits overgrowing in the channel are measured decline in the value of compression pressure and maximum pressure. The value of maximum pressure is primarily a function of compression pressure, the angle of the start of fuel injection, fuel delivery volume, quality of fuel atomization. This parameter is so ambiguous that it is omitted in the following discussion. The assessment of technical conditions of the indicator channel can be performed on the base of compression pressure measurement when cutting off fuel supply to the tested cylinder. The compression pressure is also a function of many other parameters. It can be assumed that some of the parameters, for example the engine speed, boost pressure, intake air temperature, back pressure, exhaust gases and cooling water temperatures are identical for all cylinders of the engine. The influence of these parameters on the differences in compression pressure in each cylinder is negligible. Differences of compression pressure in engine each cylinder may be mainly due to loss of tightness, changes in timing, loss of patency of the intake ports, change in the volume of the combustion chamber. Typically wear processes lead to leakage and to deterioration of the cylinders filling process, causing an actual reduction in compression pressure and the increase throttling. The measured compression pressure lower than the average value in the remaining cylinders should lead to reflection, whether they are actually lower if only apparently as a result of choking in the channel. During engine operation, the combustion chamber volume may decrease due to formation of carbon deposits. This will increase the compression pressure. However, if the carbon deposits are on the walls of the combustion chamber they are also in the indicator channel. It may then be the case that these changes will compensate for each other, or even throttling effect in the channel exceeds the actual increase in pressure leading to misdiagnosis. It is therefore clear that a single measurement does not resolve anything.

The decisive criterion in the interpretation of ambiguous indication results conducted by diagnostic team of Polish Naval Academy is the dependence of the measured compression pressure and engine speed. As part of the laboratory tests on, the idling SULZER engine type 6AL20/24 the maximum pressures in the subsequent cylinders were measured. During these tests, fuel supply to measured cylinder was cut off. Then maximum pressure has the same value as the compression pressure. Increase in engine speed on all cylinders always result in an increase in the measured pressure, regardless of engine technical condition. This pressure increase was forced by increase of mechanical losses, increased energy of exhaust gases and consequently a higher-pressure boost. In case of the not supercharged engine with increasing rotational speed, minimal loss of compression pressure can be expected induced by increase throttling in air filter, in the inlet channels and valves. These changes should be comparable (across all the time of measurement) on all engine's cylinders. During the tests in indicator channel of the 6-th cylinder, an adjustable plate with orifice was introduced simulating loss of patency in the indicator channel. This orifice had reduced the measured compression pressure. Increase in engine speed deepened this pressure drop. Tests results are presented in Fig. 1.

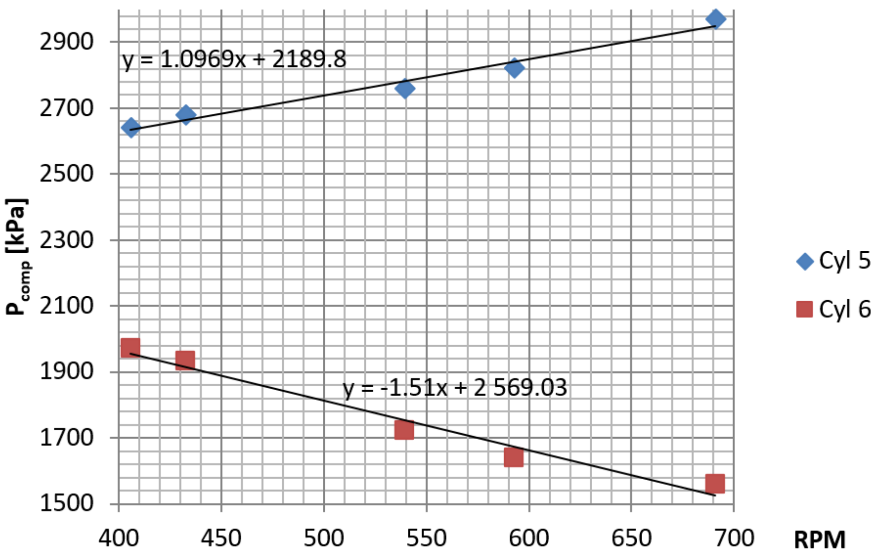

Fig. 1. Cylinder compression pressure as a function of engine speed for patent channel (cyl. 5) and channel choked by plate with orifice (cyl. 6)

The decrease of compression pressure together with increasing engine rotational speed greater than in other cylinders is a sufficient condition to determine loss patency of the channel, and to recognize the results as unreliable. This method can be ambiguous in the case of simultaneous occurrence of several different failures. For example, leak in the combustion chamber lowers compression pressure in particular at low engine speeds. Throttling effect in the indicator channel increases with increasing engine rotational speed and carbon deposits in combustion chamber increases compression pressure, regardless of the engine speed. It is possible that in the event of these three failures, almost an ideal measurements result can be achieved, which does not confirm the absence of choking in the channel. Despite the imperfections of this method, it can be applied using any type of indicator, both mechanical and electronic. Calculations needed are very simple. All you need is at least measurement of compression pressure twice throughout the period in which engine has cut-off the fuel supply. Due to the complexity of this measurement, it is performed only when the results of both indication, measuring envelope of vibration signals and exhaust gas temperatures are ambiguous or even contradictory. At the only indicating tests, the method is less useful. It may exclude erroneous measurements, but cannot confirm correct ones.

3. A measure of the asymmetry of the curve of pure compression

Currently, the Polish Naval Academy is working on development of the test method, which can detect obstruction in the indicator channel based on a single measurement. The course of the pressure inside the sealed cylinder, measured directly without the indicator channel and without the fuel supply should be symmetrical with respect to TDC, regardless of the engine speed and compression ratio. The source of small asymmetry may be only heat exchange between the working fluid and walls of combustion chamber. Far greater asymmetry introduces the escape of air through any leaks in working chamber of the engine [4] and throttling indicator channel. The most visible are oscillations after compression pressure curve passing in the expansion curve shown in Fig. 2.

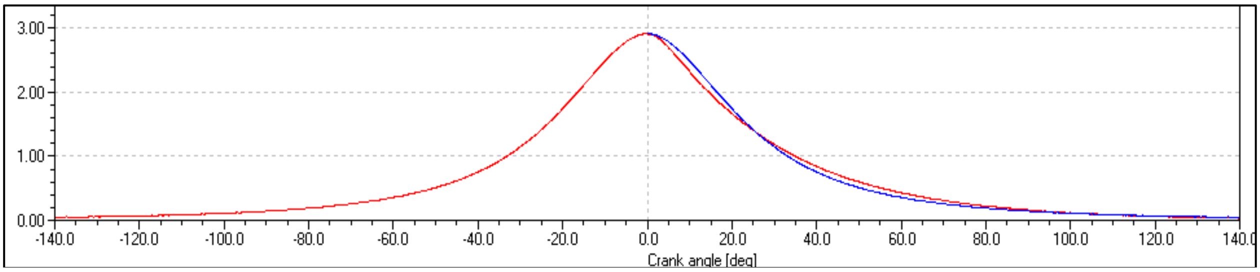

Fig. 2. Comparison of the expansion curve with the mirror image of compression curve

These oscillations depend on the engine speed, boost pressure and are unique for subsequent series of measurements. They cease around 90˚ of crank angle (CA) after TDC so it is why the area of TDC ± 90º is treated as ambiguous and omitted in the research. As a simple measure of asymmetry the difference of mean arithmetic value of samples located in the area from -100º to -120º of CA and the mean arithmetic value of the samples in area from 100º to 120º of CA are taken. Symmetry axis is drawn through the highest point of pressure curve $\alpha(p_{max})$. Investigations have been done to assess model of sensitivity of this parameter to gasses escape. Gasses escape was modelled as an outflow by artificial uniform annular gap between piston and cylinder [3]. The dependence of this measure according to the gap width and engine speed was tested. The test results are shown in Fig. 3.

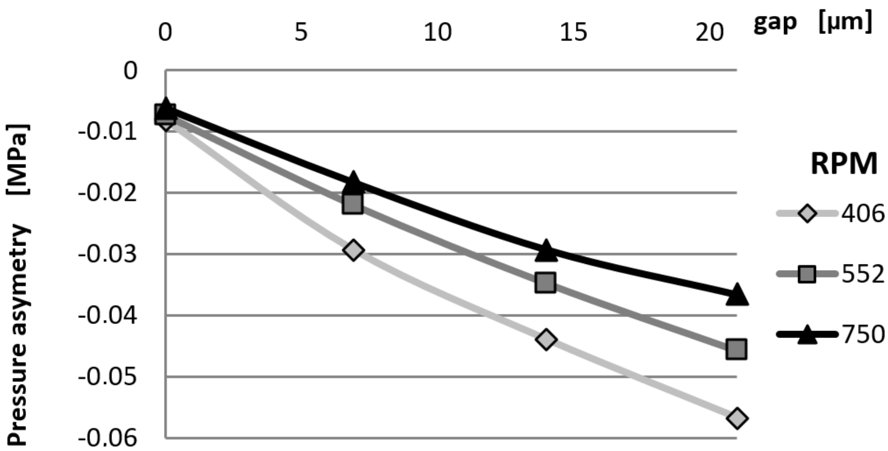

Fig. 3. Effect of gasses leaks and engine speed on compression curve asymmetry

The outflow (gasses escape) always led to values reduction in the expansion pressure curve versus compression pressure curve for the value proportional to the gap width and proportional to the time of one crankshaft revolution. With a maximum engine speed, the impact of gasses leaks is the smallest. 21 μm gap at a speed of 750 resulting in a 20% decrease in compression pressure is generating asymmetry, which does not exceed 0.04 MPa.

The actual study of the impact of channel un-patency on pressure curve asymmetry was carried out on the engine where channel was throttling with orifice. The results of one measurement without throttling and with throttling at engine speed 700 RPM are shown in Fig. 4.

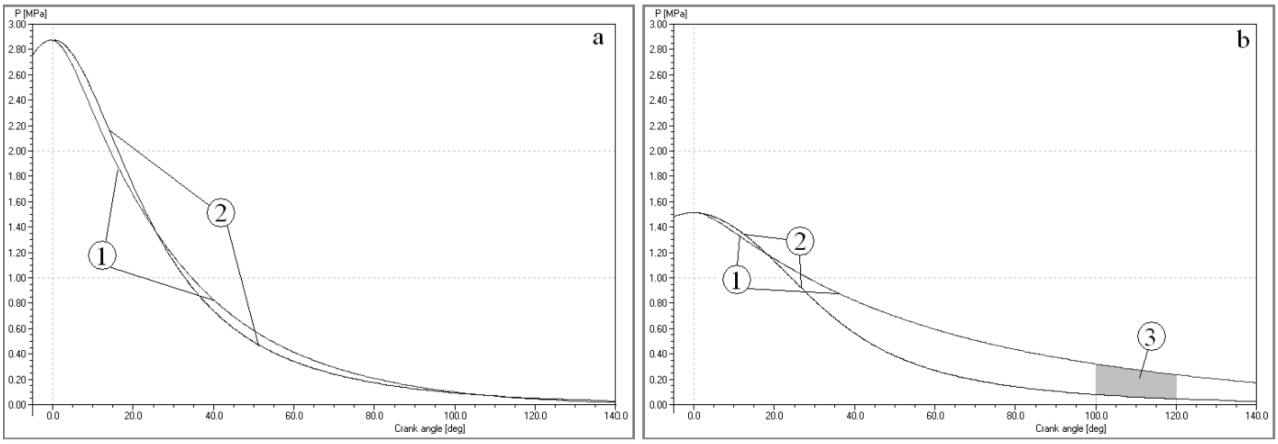

Fig. 4. The measurement of the asymmetry of compression curve with no load at engine speed 700 RPM: a) for the clean channel b) for channel partly chocked: 1) the expansion curve, 2) the mirror image of the compression curve 3) measure of the asymmetry

Researches were carried out for eight different engine speeds without throttling and with throttling with the same orifice. The dependence of the asymmetry factor as a function of the engine rotational speed is shown in Fig. 5.

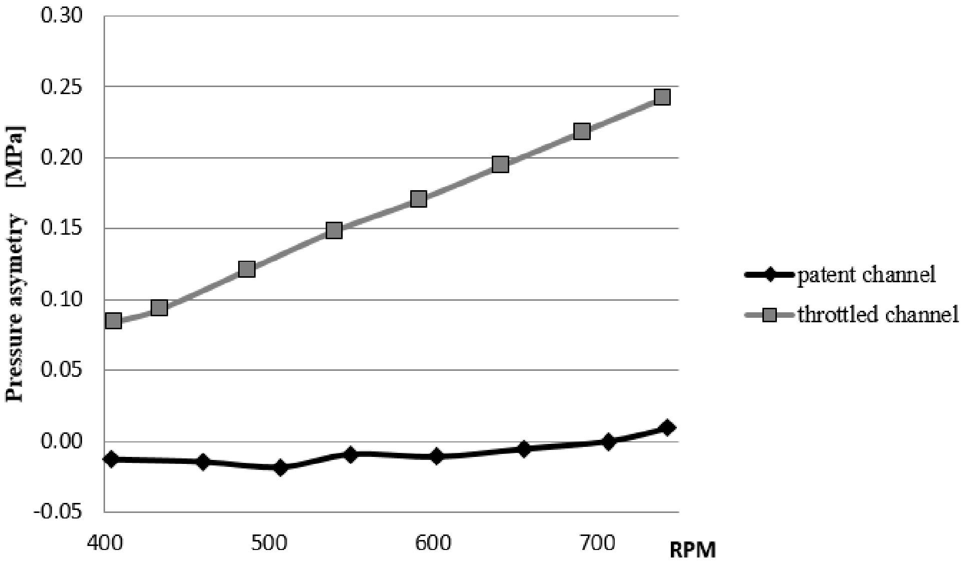

Fig. 5. Effect of channel throttling on compression curve asymmetry

Throttling in the indicator channel which gives a seemingly similar effect as gasses leaks causes that the expansion pressure in cylinder reaches higher values than the compression pressure. Designated asymmetry at engine maximum speed exceeded 0.24 MPa; this is 6 times the value of the asymmetry caused by a leak in cylinder causing a 20% drop in compression pressure.

This situation has not any real reasons resulting from the thermodynamic processes taking place in the cylinder. It means simply that there is throttling in the indicator channel, and the measurement results after the discovery of such fact must be rejected as unreliable.

4. Conclusions

Compression pressure measured on the indicator valve lower than in the other cylinders is usually a symptom of leaks between piston and cylinder, throttling in the charge air supply channel, increasing volume of the combustion chamber, but it can be also the result of increased throttling in the indicator channel.

If the indicator channel of Sulzer engine type 6AL20/24 is clean, the mean difference between expansion and compression pressure is in the area of ± 100-120° of CA toward to α (p_{max}) is close to zero and is growing rapidly with the advent of throttling. Therefore, it may be a symptom of obstruction in the channel.

In case of detection of low compression pressure during engine indication, fuel supply to the cylinder should be cut-off and measured the asymmetry of the pressure course. If it does not differ from the asymmetry in remaining cylinders, the measurement result can be considered as verified. Such verification should be done without engine load and at maximum speed, then the sensitivity of the method is the greatest, and sensibility to charge escapes the smallest.

The study was performed on only one engine type, so before making general conclusions research on other types of engines with other channels and valves should be repeated. Perhaps the resonance phenomenon in channels may cause that the results would not be so clear.

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