MARINE DIESEL ENGINE VALVE GEAR MECHANISM DIAGNOSTICS PROBLEMS

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Abstract

Marine diesel engines have changed their construction last years because of electronic control implementation in fuelling process. Electronic control implementation could be also important in valve gear mechanism which is main part of the engine gases exchange system. In this paper problems connected with of valve gear mechanisms operation and diagnostics have been presented. The diagnostic methods and processes which could impact diagnostic process will be shown together with examples from test bed and real vessels. Diagnostic methods which based on vibration signals analysis are sensitive on engine load and speed change. Separate engine cylinder's loads generate differences in so called "dynamic valve gear diagrams" which will be shown for some marine engine types.

Opening and closing of inlet and exhaust valves generate vibration signals in entire engine structure. There are some tools available in signal analysis which gives opportunity to trace changes in signal patterns in real time monitoring systems. Special diagnostic method based on vibration signal analysis worked out in the Polish Naval Academy, gives opportunity to change engine maintenance philosophy from scheduled planed maintenance system to condition based maintenance system without fear about real operating engine conditions.

Keywords*: marine diesel engine, diagnostics, valve gear*

1. Introduction

Conventional diagnostic methods for engine valve gear mechanism depend on valve clearances checks and valve timing diagram checks on crankshaft flying wheel. After determined period of working hours or in calendar schedule crew members are obligated to check clearances in valve mechanisms. This is very important to avoid situation when valves are opened during compression and working stroke because of lack of clearance between valve stem and rocker arm. Such malfunction easy could lead to valve thermal or even mechanical damage. During clearance checks condition of valve springs are also checked. Valve timing is checked only in situations when engine crew have some doubts about engine performance and obligatory after connection between crankshaft and camshaft dismantling. From the moment when electronic devices start to be implemented in engine control, monitoring and diagnostics there is a tendency to use these methods also to control, monitor and diagnose the valve gear mechanism. But there some problems with it which could be divided into several groups: how to check clearance with out stopping the engine and dismantling it, how observe valve timing diagram on working engine and which is difference between static and dynamic valve timing diagram and in the end how engine load and speed changes disturb observed parameters. Answers for these questions will be given in next parts of the paper.

2. Valve clearance checking method

Vibration methods are used to estimate value of valve clearance on operating engine. Among many different vibration signals analyzing methods described in a literature as proper in this case we could find vibration signal amplitude analysis and vibration signal pattern time analysis. Because signal amplitude value is highly dominant by engine speed and load, for the author, much better method is vibration signal pattern time analysis. This method used in Polish Naval Academy for more then 20 years enables to estimate value of valve clearance according to angle of vibration signal presence on crankshaft rotation axis. Accuracy of this method depends on many factors among which the most important is TDC or other reference point determination. Mistakes in TDC determination lead to false value of vibration signal presence and in the end to false value of the valve clearance. Each type of engine could be characterized by the correlation between valve clearance and angle of vibration impulse presence. For SULZER engine 6AL20/24 type such correlation has been determined during laboratory test. Chosen results of these tests for impulses which appear when inlet valve is closed are shown in Tab. 1.

Tab. 1. Valve clearance versus angle of vibration signal presence for SULZER A type engine

Clearance value	0.40 mm	0.50 mm	0.60 mm
Angle of vibration signal position before TDC	-144.5 ^{o}	-146.0	-150.0

As it is presented in the table change in valve clearance from nominal equal 0.40 mm to 0.60 mm generate change in vibration impulse position on crankshaft angle rotation axis for 5.5°. This value is specific for tested engine and may varying for other engine types. In any case separate dedicated tests should be held to establish this correlation.

3. Dynamic valve gear diagrams

To observe dynamic valve timing diagram the same vibration method is used which was presented in point 2 of this paper. Typical valve timing diagram is known from engine manual and could be given as a graphic or in table form. Angle values in such diagram or in the table are taken from static measurements in defined engine condition – engine temperature is usually equal ambient temperature and clearances during the measurement are nominal or special because of cam profile. Nowadays more and more engines are delivered with systems which enable to change valve timing during engine operation. Expect full flexibility in fuel system – CR or Fig. 1 example from firm MAN[5], leading firms such as MAN Diesel and Wärtsilä offer engines with valve timing variable systems – Fig. 2.

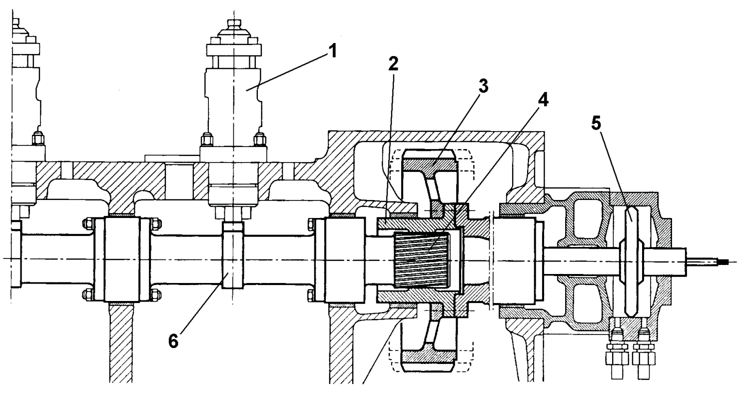

Fig. 1. MAN Diesel fuel injection timing control system [5]: 1 - fuel pump, 2 - moving cylinder with internal slanting connection with camshaft end, 3 - gear, 4 - end of camshaft, 5 - hydraulic servomotor

These solutions for medium and high speed engines make them more flexible and less smoke generate. Also firm Wärtsilä has in her offer medium-speed engine with variable inlet valve closing which main purpose is to improved engine smoke behaviour especially at low load – Fig. 3.

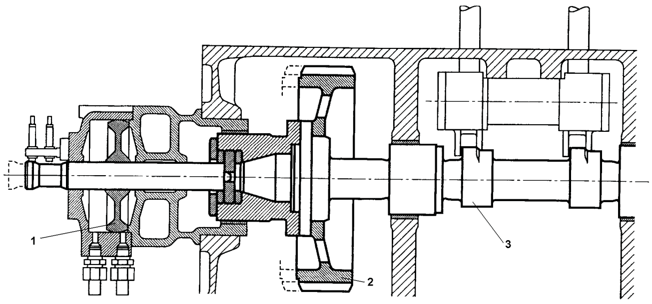

Fig. 2. MAN Diesel valve gear timing control system[5]: 1 - hydraulic servomotor, 2 - gear, 3 - camshaft with two sets of different cams

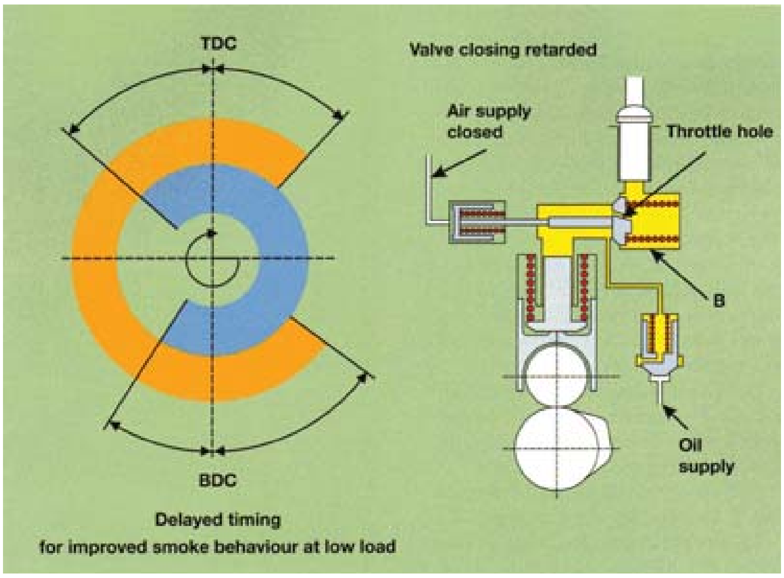

Fig. 3. Wärtsilä ZA40S engine with variable inlet valve closing system [1]

Dynamic valve timing diagram registered with using vibration method is shown in the Fig. 4. To research dynamic valves gear timing diagram on working engine except vibration sensor special non-contact sensors were mounted in cylinder cover above the rocker arms to measure rocker arms movement. As it is seen in the Fig. 4 vibration diagram is strongly involved by vibration generated by compression and combustion process. Signals from valve gear mechanisms are weaker than these generated by combustion process.

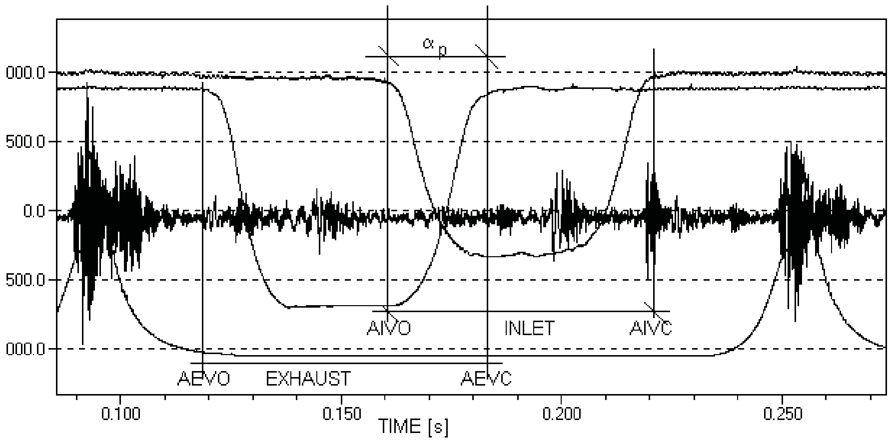

Fig. 4. Dynamic valves gear timing of SULZER engine type 6AL20/24, AIVO - angle inlet valves opening, AIVC - angle inlet valves closing, AEVO - angle exhaust valves opening, AEVC - angle exhaust valves closing; $\alpha_{p.}$ - valves overlap period

In big 2-stroke diesel engines, which have one hydraulically opened exhaust valve, vibration sensors might be connected to the cylinder heads. Mass of valves in such engine and cylinder head dimensions are big enough to signal selection easily. It looks quite different in small high-speed engines, where are more than one or two valves per cylinder. 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. The biggest vibration signal on the diagram comes from the combustion process in cylinder on each vibration sensor is mounted. This typical vibration signal has periodical character, which is strongly influenced by vibration source distance to the sensor. Other vibration signals come from the rest of cylinders. To find proper signal 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 carrying by the signal. If it is possible sensors should be mounted directly on cylinder covers or valve housings. Elastic, thin engine and cylinder covers are the places that should be avoided during the sensor montage. Fitting sensors by screw-in bolts or clamp bolts secure high frequency signal components transmission. Magnetic or stick sensor fitting methods give big losses in signal spectrum. Acquired signals might be pass across the frequency window analyzer function to cut out some of the disturbed parts of the signals. For better understanding the process in tested engine, additionally cylinder pressure and valves lift were observed.

As we can see time (for 750 rpm on tested engine) when exhaust valves are opened take 0.03 s, valves are 0.09 second in closed position. For opening and closing processes it is 0.02 second. Such short time for these processes generates sharp impulses in cylinder heads of the engine. It is not easy to select these signals because they are very short and not as strong as signals generated by combustion processes. Impulses from the other cylinders could be coincident and easy cover weak signals making them almost invisible.

Another characteristic symptom of such diagrams is that impulses which accompany the valve closing are a little bit stronger than valve opening process. When vibration sensors are correctly chosen, when places of their location are proper and if they are sensitive enough we may observe, register and estimate valve gear mechanism timing diagrams. Using proper method of signal filtration we can observe dynamic valve gear mechanism timing diagram. Dynamically estimated angles of valve closing and openings are different to that given in engine manual. These angles are usually determined in static conditions. Because of that special database to prophylactic engine controls has to be created within preliminary tests. Dynamically measured exhaust and inlet valves opening and closing angles are determined by engine speed and rating. Taking into account that maintenance may be taken in different load conditions; date base should contain whole spectrum of the measured parameters. Values of Angles when Inlet Valve is Closed (AIVC) for different types of marine diesel engines are shown in Tab. 2.

Tab. 2 Dynamic angle value of inlet valve closing (AIVC) for marine diesel engines

No	Engine type	Rpm	Load	AIVC
1	6AL25/30	762	7.3	- 155.3
2	6ATL25/30	915	7.2	- 157.8
3	8ASL25/30	838	7.2	- 155.9
4	8AL25/30	746	7.5	- 158.0
5	6AL20D	889	8.0	- 159.0
6	6NVD36-1U	396	5.0	- 150.7
7	6NVD48A2	346	5.0	- 140.0

3. Engine load change influence on signals generated by valve gear mechanism

It is well known fact that some types of diesel engines have bigger valve clearances for exhausts valves than for intake valves. It is caused by non-equal thermal lengthen of these valves during engine operation. By the analogy we could say that in an engine which has not proportional loaded cylinders valve stem dimensions caused by temperature should be also different. These changes in valves stem length impact on valve clearance value, which should be smaller in most loaded and bigger in less loaded engine cylinders. This claim should be thru for working engine but is not. Traditional engine testing methods do not give possibility to find out such malfunctions. Method of clearances measuring on working engine gives possibility to point out among engine cylinder these which are more or less loaded on base that their valves opened and closed earlier or later. On the basis of valve angle opening and closing clearance in separate cylinder units could be estimate and this way not-directly cylinder's load.

Tab. 3. Engine load versus angle of vibration signal presence for SULZER A type engine

Engine load in % of nominal	25%	50%	75%	100%
Angle of vibration signal before TDC	-138.9	-143.8	-144.8	-145.3

Such information could be used for static and dynamic engine tuning but only in this case that we know formula between load and valve clearance on working engine. For SULZER engine type A20/24 this correlation was tested on laboratory test bed and results are shown in Tab. 3. When engine load is change form 25% to 100% angle of inlet valve closing varying about 5 ° degrees on crankshaft revolution scale. Angle change in case of this type of engine is such as the valve clearance became bigger at higher engine loads. It is probably cause by the relatively bigger valve mushroom-shape closing element thermal extension than valve stem extension. Similar test were performed for other types of engines and for example for engine type WOLA57H6Aa angle change is smaller and has only 1° degree.

4. Engine speed change influence on signals generated by valve gear mechanism

Engine speed is constant in marine diesel generators but varies in case of engine which is connected to ship shaft with propeller screw. It is obvious that speed change strongly involved vibration processes in such mechanism as diesel engine is and in valve gear mechanism as follows. Amplitude of vibration signal risen together with engine speed increase but also time/angle pattern of the signal has changed. To check this influence on high-speed SULZER marine diesel engine type 6A20/24 laboratory tests have been made. Results of these tests how change in engine speed from 450 rpm to 750 rpm impact the angle of inlet valve closing (before TDC) are shown in Tab. 4.

Tab. 4. Engine speed versus angle of vibration signal presence for SULZER A type engine

Engine speed in rpm	450	550	650	750
Angle of vibration signal position before TDC	-132.8	-133.5	-145.0	-145.8

In case of such big differences in engine speed change in angle of signal presence is equal 13°. In typical maintenance engine tests differences in rpm are not such big. They differ about several revolutions from one measurement to another.

How important is to know this correlation shows Tab. 5 where results of chosen engine tests for period of four years are presented. As we see the differences in speed and load on the same engine during making tests are quite big although tests team tried to persuade crew to chose the same engine load condition every time. Some times it is impossible because of engine technical condition, some times crew or shipyard insists to make tests on nominal or even maximum load. As we see in the Tab. 5 much more significant in Angle of Inlet Valve Closing (AIVC) are changing in engine load (Load index and Mean Indicated Pressure – MIP) than differences in engine speed (rpm). Maximum difference in AIVC achieve about 10° when engine speed varies from 719 to 750 rpm and engine load understand as MIP varies from 13.1 to 25.0 bar.

Tab. 5. Measurements condition on chosen main engine type 6ATL25/30

Year of test	rpm	Load index	MIP	PMAX	AIGN	AFVO	AIVC
	[min^{-1}]	[-]	[bar]	[bar]	degree before TDC	degree before TDC	degree before TDC
2004	750	6.8	13.1	99.3	- 8,5	- 14.7	- 152.6
2006	728	6.5	14.4	101.2	- 7.6	- 13.8	- 152.1
2007_07	719	7.3	17.7	100.9	- 5.0	- 10.0	- 148.4
2007_12	730	7.7	19.5	109.1	- 4.9	- 9.6	- 147.9
2008	735	8.3	23.1	119.3	- 4.0	- 8.7	- 142.2
2008	733	8.7	25.0	123.7	- 3.7	- 8.1	- 141.9

5. Conclusions.

Marine diesel engines technical condition assessment is a very complex process. Opening and closing of inlet and exhaust valves generate vibration signals in entire engine structure. There are some tools available in signal analysis which gives opportunity to trace changes in signal patterns in real time monitoring systems. But to achieve proper results of analysis there is important to know correlations between vibration pattern and engine operation condition parameters. As it was shown in the paper engine load and speed have to be taken in to account during engine tests. Although only about ten per cent of engine malfunctions can be caused by the valve gear mechanism monitoring and diagnosing of this system is necessary as according to engine manuals crews have to inspect these systems relatively often. Special diagnostic method based on vibration signal analysis worked out in the Polish Naval Academy, gives opportunity to change engine maintenance philosophy from scheduled planed maintenance system to condition based maintenance system without fear about real operating engine conditions.

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