12th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2008, Istanbul, Turkey, 26-30 August, 2008

EXPERIMENTAL INVESTIGATION OF MARINE DIESEL ENGINE PERFORMANCE ON TEST BED

Ivan Komar
Radovan Antonić
Goran Belamarić
Faculty of Maritime Studies in Split, Univ. Split
Zrinsko-Frankopanska 38, 21000 Split, Croatia
e-mail: antonic@pfst.hr

ABSTRACT
Marine diesel engine in ship's propulsion is very complex, high risk process that mainly determines the ship's mission. Therefore, its operational reliability and availability within severe sea environments, even in the case of failures or faults, should be provided. The main prerequisite for safe and reliable engine operation is good engine parameters adjustment based on proper investigation of engine dynamics in all working conditions. The most effective way for that investigation is, for sure, experimental using engine testbed with conditions very close to real ones.
In the paper some experimental results of working cycles investigation of large marine diesel engine with different load conditions on testbed will be presented.
Keywords: marine diesel engine, test bed, experimental identification, performance analysis

1. INTRODUCTION

The topic of this work is experimental testing of large marine 2-stroke diesel propulsion engine on testbed using hydraulic brake as engine shaft load. The testing was done in the Factory of Diesel Engines in Shipyard Split (TDM – Split) with slow-speed, turbocharged, 2-stroke marine propulsion diesel engine of type MAN B&W 6S60 MC-C. Such engines include very large number of moving components, mutually interconnected and related with a very complex dynamics.
From the exploitation practice experience the majority of large marine diesel engine failures are caused by engine component faults (cylinders, pistons, valves, crankshaft, bearings, etc.). Therefore it is very important to investigate the working conditions of most essential engine components like engine cylinders within different engine loads and environments. The measurements of engine cylinders combustion pressure during working cycles in accordance with engine crankshaft angle is very important for engine dynamics investigation as well as for engine parameters adjustment. Cylinders combustion pressure is, for sure, the parameter with a crucial impact to the output engine shaft torque and power, so the main focus in the work is engine cylinder pressure tracking, recording and analysis.

2. CYLINDER DYNAMICS TRACKING

During the tests on the engine testbed, the engine is to be operated at the load points i.e. working regimes which are selected according to the *Rules* of the *Register*. The load points are 25%, 50%, 75%, 100% and 110% of the maximum rated power; along the nominal i.e. theoretical propeller curve and at constant speed for propulsion engines.
Since base, during engine testing, is presented analyze of the thermodynamic process in combustion space, particular attention is to be paid to analyse the combustion process in the engine cylinder.

Therefore at each load points of the engine, during the tests on the testbed, cylinder pressure and working diagrams should be recorded. The indicator diagrams are used to analyse and possible for optimization of the engine
working cycle.

In this paper, the method of the engine cylinder pressure measuring and indicating diagrams recording during experimental investigation of MAN B&W 6S60 MC-C marine diesel engine performance on testbed is illustrated.

Recordings of the working diagrams are performed using Pressure Measurement Indicating System – PMI (see Fig. 1.).

The PMI System is a user-friendly computerized tool for reliable and precise performance evaluation on two and four stroke diesel engines. The system replaces the traditional mechanical indicator, and hence no planimetry or manual calculation is required.

The PMI System uses a high performance piezo-electric pressure transducer of well proven design. The pressure transducer is mounted on the cylinder head indicator cock for measurements and then moved from one cylinder to another in order to complete the measurements on all cylinders.

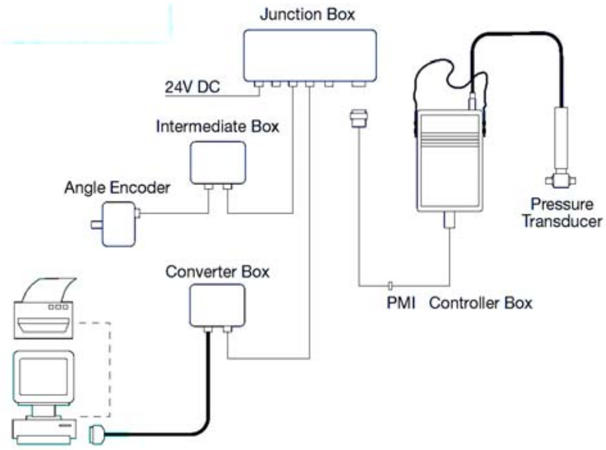

Figure 1. The PMI System

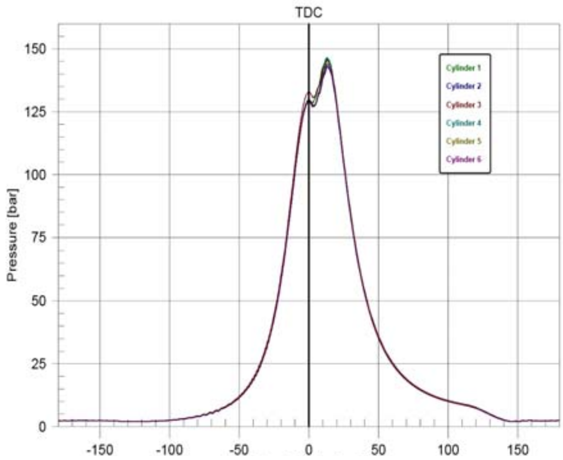

Figure 2. P-α diagram taken at engine load of 90% MCR

Measuring and acquisition of cylinder pressure during engine working cycles were strictly in correspondence with crankshaft angle α_{KV} relative to top dead centre (TDC).

It is therefore only exposed to the harsh environment of the combustion chamber for a very short time. For detecting the crankshaft angular position incremental optoelectronic encoder is used. Crankshaft angular position encoder with 2048 marks respectively position per one crankshaft full revolution, providing resolution of 360/2048 $\cong$ 0,18 degrees of crankshaft angle.

These generate a continuous train of electrical pulses which are used to trigger the PMI System in accordance with the rotation of the crankshaft. The trigger pulses and pressure transducer/PMI controller signal are transmitted via cable to a junction box which is permanently mounted on the engine. Both the controller and junction box include the communication interfaces necessary to on-line collect the measurement data and automatically transfer it to a PC where it is stored in the database of the system for subsequent calculation, analysis and display.

Once measurements data have been stored in the PMI database they can be instantly viewed on the PC monitor and printed. Cylinder pressure and work diagrams (i.e. P-α and P-V diagrams) can be displayed for one or a selected number of cylinders at the same time. The P-α diagram in fig. 2. shows the pressure curves for all six engine cylinders during one working cycle i.e. one crankshaft revolution during engine test with power of 90% of Maximum Continuous Rating - MCR. The P-V diagram in fig. 3. shows the closed indicating diagram for all six engine cylinders during one working cycle with the same engine working regime.

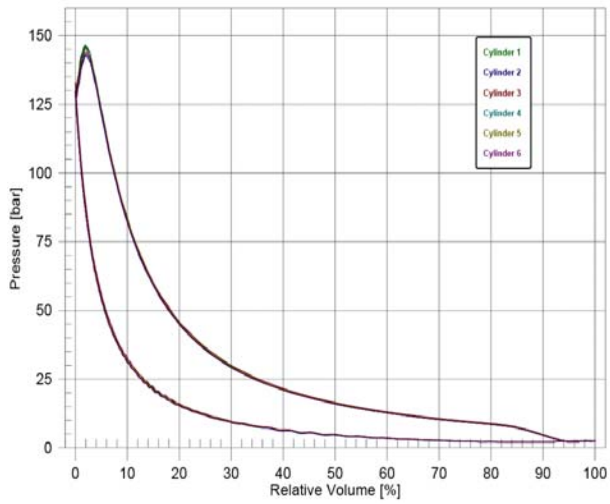

Figure 3. P-V diagram taken at engine load (90% of MCR).

The PMI System can generate proposals for adjusting the mean indicated and maximum combustion pressure of each cylinder of two stroke diesel engines.

These are based on comparing the current measurements with the nominal ones i.e. the pressure deviation limits defined by the engine maker or engine user.

The PMI System can directly export measurement data to the CoCoS-EDS Computer Controlled System - Engine Diagnostics System which is also available from MAN B&W Diesel engines, and thus expand the engine measurements, analysis and diagnostic capabilities of CoCoS-EDS.

The diagrams are used for assessing engine performance.

From the diagrams given here (fig. 2. and 3.) it can be seen that all six engine cylinders are well balanced in their dynamics during working cycles. The largest deviations are for maximum compression pressures close to the TDC and maximum combustion pressures. These deviations are within limits of 4% for maximum compression pressures and 3% for maximum combustion pressures.

3. TEST RESULTS AND ANALYSIS

The results are presented in tabular form and show how much the fuel pump ‘index’ of the cylinders must be adjusted to achieve a properly, and may be optimally, balanced engine without further readjustment.

In addition, values are given for the compression pressure, maximum pressure, mean indicated pressure and scavenge air pressure, as well as the engine speed and engine output for each cylinder and the engine as a whole (see tables 1).

On the basis of cylinder pressure measured and recorded data, the analysis of the engine working condition can be made. Cylinder pressure difference generating useful shaft torque, pressure impulse generated by each engine cylinder during one engine working cycle and its mean value in k cycles was calculated so making comparison of each cylinder contribution to total engine torque possible.

Table 1. Values table at engine load of 90 % MCR

Cylinder Number	p(i) [bar]	p(comp) [bar]	p(max) [bar]	Engine Speed [rpm]	Effective Power [ekW]	Effective Power [bhp]	p(i) Deviation [bar]	Index Adjust [-]	Rotation of Link [-]	p(max) Deviation [bar]	VIT Adjust [-]	Rotation of Link [-]
1	18,18	128,7	146,1	104,9	2039	2772	0,04			1,5		
2	17,98	129,3	142,5	104,7	2011	2734	-0,16			-2,1		
3	18,19	132,3	145,3	104,7	2036	2768	0,05			0,7		
4	18,28	128,8	145,6	104,9	2049	2786	0,13			1,0		
5	18,24	129,0	144,7	104,7	2041	2775	0,09			0,2		
6	18,01	128,9	143,4	104,9	2018	2744	-0,14			-1,2		
Mean	18,15	129,5	144,6	104,8	2032	2763						
New Mean	18,15		144,6									
Total					12195	16580						

p(scav) = 2,39 bar

The following mathematical expressions are used in calculation:

$$p_{c,IM}(\alpha_{KV})_j = p_c^g(\alpha_{KV})_j - p_c^{ng}(\alpha_{KV})_j \qquad \dots (1)$$

where: $p_c^g(\alpha_{KV})_j$ - cylinder pressure in *j*-th cycle with fuel combustion; $p_c^{ng}(\alpha_{KV})_j$ - cylinder pressure in *j*-th cycle without fuel. Cylinder pressure impulse in *j*-th cycle is:

$$IMp_{c,j} = \int_{\alpha_1}^{\alpha_2} \left[p_c^g(\alpha_{KV})_j \; - \; p_c^{ng}(\alpha_{KV})_j \right] \; d\alpha \qquad \ldots (2)$$

For engine condition evaluation using k working cycles, very important thing is to determine each cylinder deviation from mean values of all cylinders. Therefore, mean values and standard deviations were calculated using PMI system.

- mean values in k engine working cycles:

$$p_{c,\max}^{sr} = \frac{1}{k}\sum_{j=1}^{k}\left(p_{c,\max}\right)_j \qquad IM_{p_c}^{sr} = \frac{1}{k}\sum_{j=1}^{k}(IM_{p_c})_j \qquad \ldots (3)$$

where: $p_{c,\max}^{sr}$ - maximum cylinder pressure mean value during k cycles.

$IM_{p_c}^{sr}$ - pressure impulse mean value during k cycles.

- standard deviations during k working cycles:

$$\sigma_{p_{c,\max}} = \sqrt{\left(\frac{1}{k}[\sum_{j=1}^{k}\left(p_{c,\max}\right)_j - p_{c,\max}^{sr}]^2\right)} \qquad \sigma_{IM_{pc}} = \sqrt{\left(\frac{1}{k}[\sum_{j=1}^{k}(IM_{p_c})_j - IM_{pc}^{sr}]^2\right)} \qquad \ldots (4)$$

Mean indicated cylinder pressure and total engine shaft torque and power have been also calculated during k engine cycles.

From experimental data analysis obtained during diesel engine testing on test bed it was shown that cylinder pressure impulse IMp_c and generated power is correlated, not only with maximum cylinder pressure $p_{c_{\max}}$, but also with fuel injection pressure, injection starting time and period, fuel quality, scavenge air pressure, engine speed, engine compression factor and others.

4. CONCLUSION

Experimental investigation of engine dynamics is very effective, not only in the case of normal working conditions, but specifically in faulty conditions. It's the most effective method to study engine components dependences and relations.

With continuous measuring and on-line tracking of most relevant engine parameters like cylinder pressure, fuel injection pressure, injection starting time and period with strong correspondence to engine crankshaft angle and other important parameters like combustion gas temperature, NOx emissions, scavenge air pressure and so on, one can take good and respective conclusion about engine working optimization and necessary corrective actions.

5. REFERENCES

[1] Antonić R.: Fault Tolerant Control System for large Marine Diesel engine in Ship Propulsion, doctoral thesis, Faculty of Electrical Engineering and Computing, Univ. Zagreb, Croatia, 2002.,

[2] Komar I.: Marine diesel engine speed digital control system, Master's thesis, Faculty of Maritime studies, Univesity Split, Croatia, 2006.

[3] Morton T.D., L.Jackson: Motor Engineering Knowledge for Marine Engineers, Thomas Reed Publications, UK, 2002.,

[4] P. Sunn, Sorensen: Computer Controlled System for two-stroke Machinery , 22nd Marine Propulsion Conference, Amsterdam 2000.,

[5] S60MC-C Project Guide Two-stroke Engines , MAN B&W, Copenhagen, 2005., Croatian Register of Shipping: Rules for the classification of sea-going ships, September, Split, 2005.