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MODEL TESTS OF PISTON RING-CYLINDER LINER COLLABORATION ON HIGH POWER ENGINES

Wojciech Serdecki

Institute of Combustion Engines and Transport
Poznań University of Technology
3, Piotrowo St., 60-965 Poznań
tel.+48 665 2243, fax: +48 6652204
e-mail: wojciech.serdecki@put.poznan.pl

Piotr Krzymień

Institute of Combustion Engines and Transport
Poznań University of Technology
3, Piotrowo St., 60-965 Poznań
tel.+48665 2239, fax: +48 6652204
e-mail: piotr.krzymien@put.poznan.pl

Abstract

Proper selection of materials for cylinder liner and piston rings, correct design of collaborating surfaces as well as the use of lubricating oils of better and better properties assure long and reliable operation of piston rings in small and medium size engines. In the case of high power engines, especially marine ones failures caused by incorrect collaboration of rings and liner still happen. Supply and correct distribution of lubricating oil over cylinder surface could be one of the causes of this phenomenon.

Regulations introduced by classification societies make impossible research on piston ring – cylinder liner set of running engines. Mathematical models or simulation test benches are the possible way of carrying out such tests.

This paper presents some test rigs and analytical models revealing their advantages and shortcomings.

Keywords*: combustion engine, friction losses, measuring methods*

1. Introduction

Full information on phenomena accompanying the collaboration of engine kinematic pairs is available from tests carried out on running engines but such tests very often are impossible. For example, tests on collaboration of marine engine kinematic pairs such as piston rings and cylinder liner require an installation of certain type of sensors (pressure, temperature or distance, for instance) that means a need for changes in construction of collaborating parts. Such modifications on marine engines are forbidden by the classification societies because they can considerably affect the ship's safety.

Tests on material models of piston–cylinder assembly parts could be a substitution for an investigation on phenomena accompanying the collaboration of these elements conducted on a real engine. Such models allow to reconstruct the operational conditions of frictional associations , geometry of mating parts contact, kinematics and dynamics of their loading as well as phenomena occurring by the process of lubrication. An additional advantage of such tests is a relatively low cost, short time needed for carrying out the investigation and no chance for engine failure.

Another way to evaluate the phenomena present on engine subassemblies is a construction and running the mathematical models of these subassemblies. It is noteworthy that a mathematical model is merely an approximation and should be validated in a course of tests carried out on a real engine or at least on its material model. Successive chapters of this paper will present selected constructions of test benches where investigation on piston ring – cylinder liner collaboration could be performed and the most significant information about mathematical models will be provided.

2. Model test benches for tests on piston ring – cylinder liner collaboration

Tests benches where investigation on collaboration of piston cylinder group elements could be carried out can be classified into those entirely designed and constructed for this purpose and other ones constructed on the basis of a typical engine where certain parts and subassemblies have been modified.

The model test benches of the first type offer wider possibilities for investigation, because the constructional details such as the range of operational parameters adjustment, location of sensors, selection of measurement devices could be foreseen at the very beginning stage of design. On the other hand, they are much more expensive than those using parts of a typical combustion engine.

Taking into consideration methods employed for investigation one can distinguish test stands using optical and electrical methods.

Test stands presented in Figs 1 and 2 are the examples for the use of optical methods in tests on evaluation of ring-liner collaboration quality.

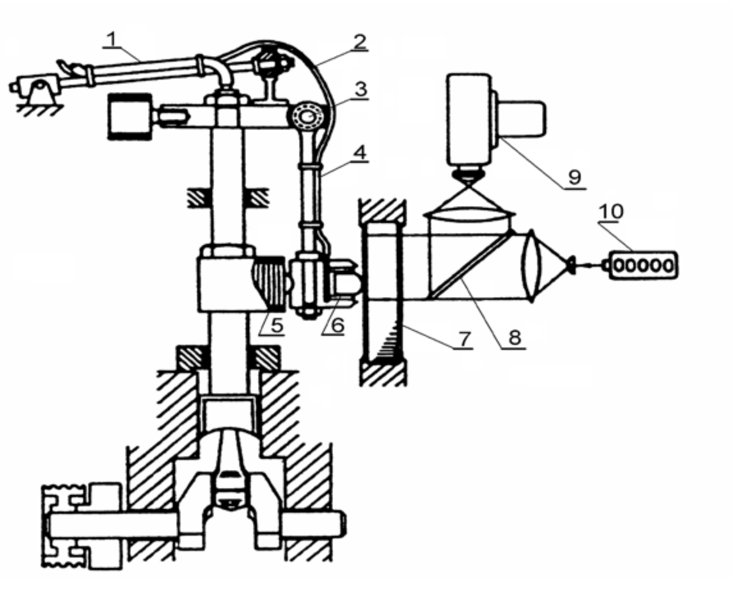


Fig. 1. Model tests stand for optical measurement of oil film parameters: 1 – high pressure pipe supplying air to the actuator, 2 – lubricating oil supply pipe, 3 – joint, 4 – slider leading beam, 5 – air actuator, 6 – slider, 7 – glass plate, 8 – semitransparent plate, 9 – camera, 10 – coherent light source (laser) [2]

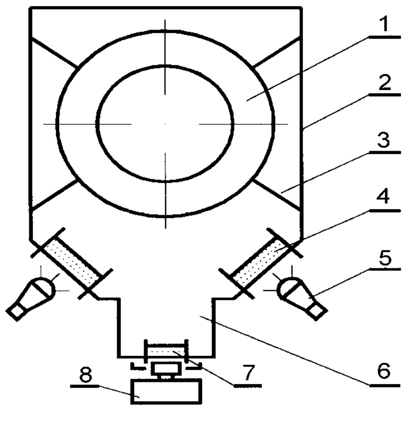


Fig. 2. Schematic of the piston-cylinder assembly model, projector and observer (camera) positions for reflection method: 1 – glass cylinder, 2 – dark chamber, 3 – diaphragm, 4 – primary filter, 5 – impulse xenon lamp, 6 – camera box, 7 – secondary filter, 8 – camera [2]

The test stand presented in Fig. 1 has been constructed on the basis of a typical IC engine equipped with systems for research on oil film formed between models of ring (6) and cylinder (7). The model of ring fixed to a piston moves reciprocally relative to a steady glass plate lubricated with oil and ring pressure against the plate is exerted by a pneumatic servomotor (5). Through a semitransparent plate(8) and transparent one (7) a laser beam (10) comes to the oil layer (oil film) which makes that as a result of interaction between reflected and falling waves an arrangement of interference strips characteristic for a momentary oil layer thickness is being recorded by the camera (9). There is a possibility to reproduce the changes in oil film thickness throughout the entire cycle of engine operation thanks to the further analysis of recorded images.

The test stand presented in Fig. 2 offers a quite different method of oil film evaluation. Cylinder liner made of cast iron has been substituted by a glass model (1). The cylinder surface is being lubricated with oil mist outflowing from slide bearings and additionally with oil sprayed to precisely specified regions of liner by a set of special jets (omitted in Fig. 2) which allows for a continuous adjustment of oil dose. Thanks to strong xenon lamps it is possible to observe and record (camera 8) the oil layer over the cylinder surface and to estimate certain oil parameters including oil layer thickness and oil film extent, in particular.

Design of the stand presented in Fig. 3 is quite different from a typical model of engine piston-cylinder assembly. A flat slat (5) representing a piston ring slides over a plate (1) covered with lubricating oil. Differently than in real engine the oil layer is not renewable, i.e. fresh oil does not come to the plate in consecutive strokes. The slat is fixed in a groove cut in a flat model of piston (clamp 7) hanged on transducer (8). It is pressed on against the moving plate with a flat spring or hydraulic actuator controlled by a special circuit. It is possible to fix in the clamp a series of slats of profiles corresponding to the face profile of a real piston ring.

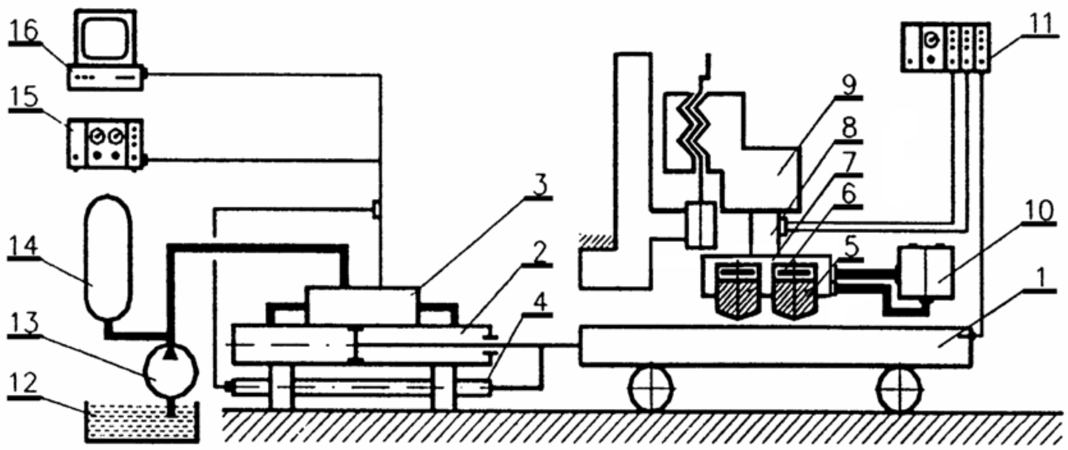


Fig. 3. Schematic of test stand: 1 – plate, 2 – actuator, 3 – control valve, 4 – position resistor, 5 – slat, 6 – flat spring, 7 – piston model, 8 – force transducer, 9 – support, 10 – slat pressure system, 11 – measuring&control system, 12 – hydraulic oil reservoir, 13 – oil pump, 14 – pressure accumulator, 15 – analogue control system, 16 – digital control system [5]

The hydraulic oil from oil reservoir (14) is being pumped to the control valve (3) by the oil pump (13). According to the position of control valve the oil is being pumped to the left or right side of the actuator plunger (2) which results in the movement of cart with the plate simulating cylinder liner surface.

Either an analogue (15) or digital (16) control system can be used. The first one allows for a reciprocating movement according to gradually selected parameters of speed and amplitude.

When applying the digital control system it is possible to use a computer program which allows to realize an arbitrary motion of the plate including a reciprocating movement, typical for combustion engines.

Due to a sophisticated measuring system (11) which is a part of the simulation stand it is possible to determine oil film essential parameters like thickness, pressure and friction forces connected with the motion of ring model. Also other sensors monitoring plate motion and recording its position, speed and acceleration are installed on the test stand.

Taking into consideration features of the stand including possibility of tests on rings of big size and different profile geometry it can be assumed provisionally that this test stand allow to conduct tests on oil film parameters of the engine of high power. Next chapter will validate this assumption.

3. Is it possible to test a ring-liner collaboration on a test stand?

Both marine and generator engines belong to the group of high power engines (power higher than 100 kW/cyl) as well as the bigger railway engines which have the power indices close to the border value [3]. Among those mentioned the biggest are two stroke low speed marine engines. Their popularity results from the highest efficiency (nowadays beyond 50%) and possibility of consumption so called heavy fuel of relatively low price.

The stroke to cylinder diameter ratio is the characteristic parameter for contemporary marine diesels of high power where it reaches the value of 4 (this secures continuity of oil film over cylinder surface thanks to the high value of the piston mean speed at low rotational speed). For engines of higher rotational speed the value of this parameter is far lower (see Table 1).

Tab.1. Vital technical data of exemplary engines of high power [1, 3, 4]

Engine / Technical data	locomotive		generator		marine	
	12LDA28	214D40	L23	L21	L35MC	K80MC-
D cylinder diameter [mm]	280	230	230	210	350	800
S piston stroke [mm]	360	300	300	310	1050	2592
k ratio (S/D)	1.28	1.30	1.30	1.47	3.0	4.00
Rotational speed [rpm]	750	750	720	900	210-178	93-70
Power per cylinder [kW/cyl]	94.7	77.2	130	190	650	3640
λ ratio	0.25	0.26	0.25	0.23	0.42	0.44
Piston mean speed [m/s]	9.0	7.5	7.2	9.3	7.35	8.10

Full reconstruction of engine kinematics on the model stand would mean the same piston displacement with similar speed. It means that it is impossible to fulfill conditions listed in Table 1 on the presented test stand [5,6]. Boundary value of speed that could be performed on test stand is about 12 rad/s which corresponds to the piston mean speed of about 3.8 m/s (when maximum is 4 m/s), i.e. the value several times lower than that on real marine engine (see Fig. 4).

Course of speed vs. crank angle presented in Fig. 4 show only the maximum value of speed and its position expressed as corresponding angle. Presentation of speed fluctuations at selected points of its displacement seems to be a better form of such illustration (see Fig. 5).

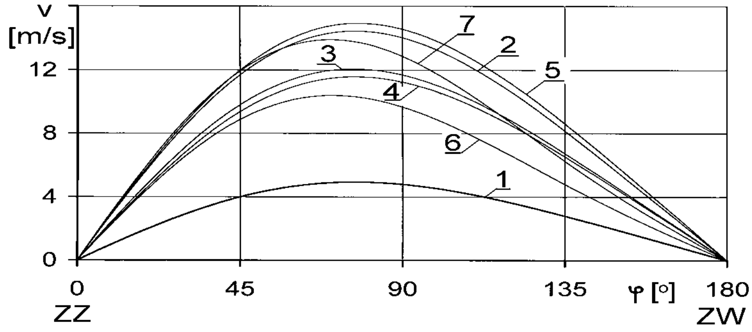


Fig. 4. Courses of speed vs. crank angle for: 1 – model test stand 2 – the LDA28 engine, 3 – the D40 engine, 4 – the L23 engine, 5 – the L21 engine, 6 – the L35MC engine 7 – the K80MC engine

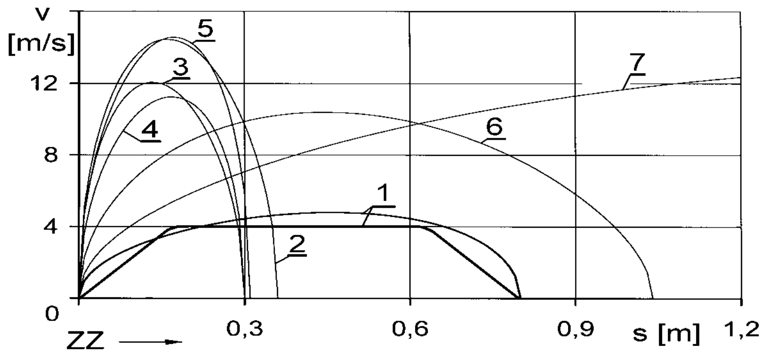


Fig. 5. Courses of speed vs. displacement for: 1 – model test stand 2 – the LDA28 engine, 3 – the D40 engine, 4 – the L23 engine, 5 – the L21 engine, 6 – the L35MC engine 7 – the K80MC engine

According to the test stand technical data the range of plate stroke is several centimeters to less than one meter (0.8 m) which allows for reproduction of ring displacement of most of locomotive and generator engines but could not represent the long stroke marine engine (of far longer stroke).

Digital control of plate movement makes possible any kind of displacement between both dead center with a constant speed of 4 m/s (horizontal line no 1 in Fig. 5). Though the ring movement with constant speed differs from that on a real engine it can be employed for tests because it facilitate the evaluation of the effect of ring selected design parameters on the formation of oil film.

As it comes from the above considerations full reproduction of piston and rings movement (taking into account speed and range) would not be possible on the presented test stand, which does not mean that it is completely aimless. For the engines of stroke longer than the plate range another kind of tests could be performed, namely over the sections shorter than the stroke. On the other hand, for engines of shorter stroke tests could concern speeds lower than the nominal one. Thanks to the fact that both the oil layer thickness and the friction force are approximately proportional to the speed of ring movement, the value of these parameters can be estimated this way for a real engine.

A large number of input values for which tests could be performed makes that investigation could be time consuming and expensive and the results obtained could be of low value. The reasonable solution could be development of stand mathematical model (as a computer program). Such creation and further application (after validation) could improve the effectiveness of research and carry them out within a range possible to be performed on the test stand.

4. Mathematical model of test stand

Description of the test stand presented in chapter 2 shows that this solution does not allow for a full reproduction of phenomena encountered on the engines of high power (listed in Table 1). Beside differences resulting form different kinematics of the stand following shortcomings should be noted: omitting the effect of ambient pressure, low operational temperature (ambient temperature), ring sliding over unreconstructed oil layer, constant value of ring pressure against the plate.

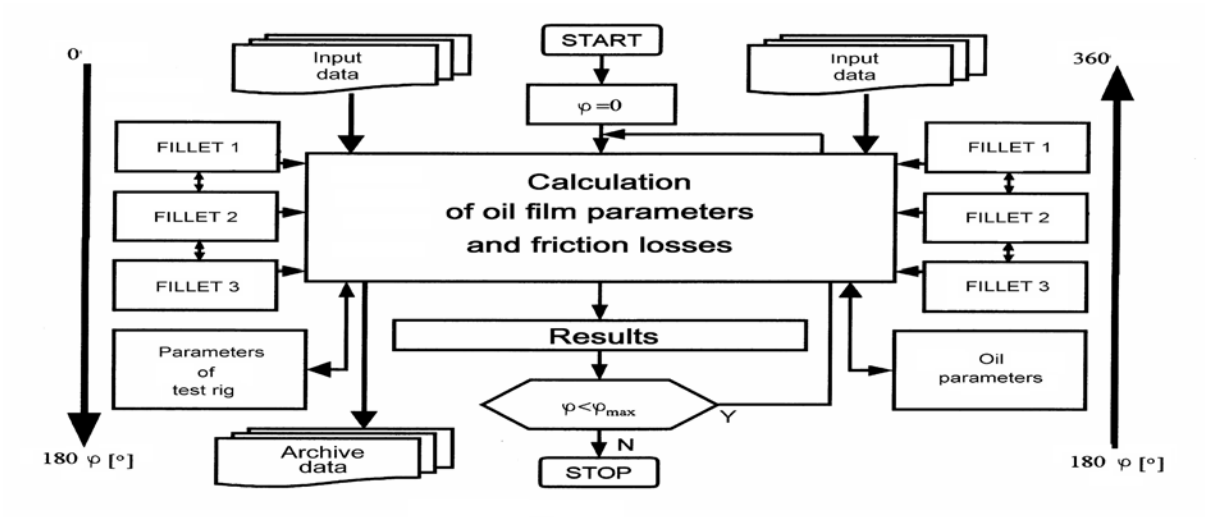


Fig. 6 Block schematic diagram of test stand mathematical model [5]

Fig. 6 shows the most important modules and mutual connections of the model. Within initial 180 grades of crank angle the slat encounters the fresh layer of oil on the plate which secures fully flooded contact with plate (at the inlet). Along with the increase in plate speed the pressure in oil film increases which eventually causes the rise in oil layer thickness. After the maximum oil layer thickness came along in the region of maximum speed, a slow decrease appears. Thanks to so called squeeze effect this pressure drop does not reach the value of zero at both dead centers. At consecutive strokes (180 to 360 degrees and beyond) the slat slides over the oil layer left after previous stroke. The layer thickness slowly decreases because the oil surplus is being swept towards the plate turning points. As a result the slat face area covered with oil also decreases.

Computations carried out according to the described model give courses of oil layer thickness (in front, behind and under the slat), pressure distribution in oil film as well as courses of friction force. Results can be presented in tables or graphs and can be further processed.

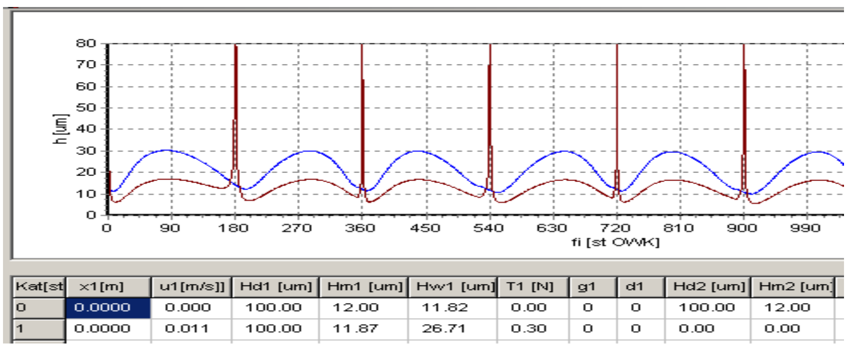
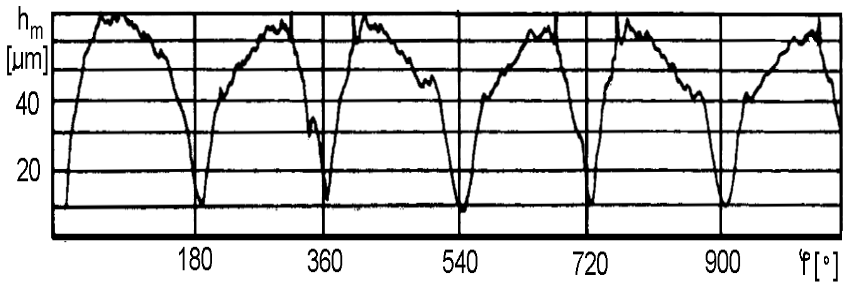


Fig. 7. A view of computer program chart – noticeable fragments of oil film parameter computations performed on the test stand

Exemplary picture of simulation program chart with courses of minimum oil film thickness and the thickness of oil layer left behind the slat is presented in Fig. 7.

Fig. 8 shows a comparison of minimal oil film thickness measurement results recorded on test stand (a) with results of model computations (b) carried out for input data corresponding to the stand operational parameters. As it can be seen maximum and minimum values of oil film thickness are the same, also the drop in thickness along the consecutive strokes is very similar. There are numerous discontinuities and waves on the course of recorded film thickness which result from plate shape imperfections not taken into consideration in the computational program.

a)



b)

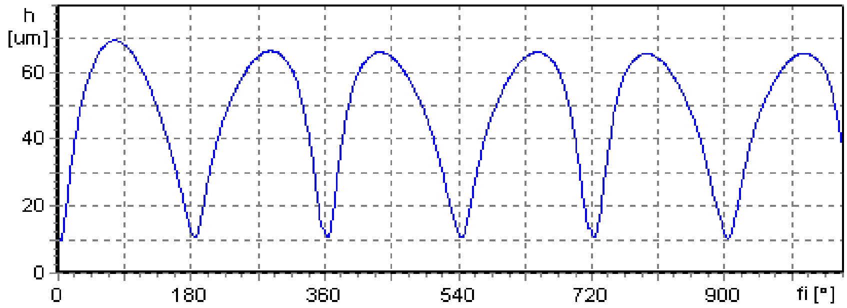


Fig. 8. Courses of oil film minimum thickness recorded on model stand (a) and for mathematical model (b)

5. Summary and conclusions

Summarizing analyses presented in the previous part of this paper one can note that the presented test stand allows:

- to evaluate phenomena accompanying the collaboration of piston ring and cylinder liner in a presence of lubricating oil, including oil film thickness and friction force, for a single ring (slat) or the complete set of rings,
- to reconstruct partially the piston movement for long stroke marine engines
- to reconstruct phenomena accompanying the piston movement for locomotive and generator engines, however at speeds lower than nominal ones.

On the other hand, use of computational program allows to execute tests within the range unreachable for the test stand.

At present efforts on development of the model stand are being carried out towards possibility of refreshing the oil layer over cylinder surface in a way similar to that applied on marine engines and perform the test at higher temperature of operation.

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