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УДК 629.12-8
DOI: 10.34046/aumsuomt93/23

ОСОБЕННОСТИ ИСПОЛЬЗОВАНИЯ ЭЛЕКТРОННОГО ИНДИКАТОРА ДЛЯ СУДОВЫХ ЧЕТЫРЁХТАКТНЫХ ДВИГАТЕЛЕЙ ВНУТРЕННЕГО СГОРАНИЯ И ДВС БЕРЕГОВЫХ ЭЛЕКТРОСТАНЦИЙ

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Данная статья освещает следующие задачи: Правильное использование электронного индикатора во время индицирования четырёхтактных двигателей внутреннего сгорания; правильный перенос результатов индицирования и диаграмм на ПК; корректировка ВМТ индикаторной диаграммы и правильный расчёт выходных параметров индицирования, таких как P_{MI}–средне–индикаторное давление, P_{ME}–средне–эффективное давление, N_{IND}–индикаторная мощность и N_{EFF}–эффективная мощность для каждого цилиндра и двигателя в целом.
Ключевые слова: Индицирование двигателя, параметры индицирования, электронный индикатор, средне–индикаторное и средне–эффективное давление, индикаторная и эффективная мощность.

The present publication illuminate the tasks as follows: Electronic indicator proper usage at four–stroke internal combustion engines (diesel engines) indication; Indication results & diagram proper transfer to PC; indicator diagram top dead center TDC correction and engine performance data output values such as P_{MI}–mean indicated pressure, P_{ME}–mean effective pressure, N_{IND}–indicated power and N_{EFF}–effective power proper calculations for each cylinder and engine total.
Keywords: Engine indication, performance data, electronic indicator, mean–indicated pressure, mean–effective pressure, indicated power, effective power.

Introduction

Currently on the worldwide fleet motor–vessels and shore diesel power plants for internal combustion engines–diesel engines indication and performance data measurement readings carrying–out the micro–processing gauging and systems, such as Doctor–Engine, Diesel–Doctor and Electronic indicators (different kind of brands and manufacturers) are used in most of cases. However, actually they are not carrying–out the functions of the engines technical condition (cylinder tightness, fuel injection equipment condition and turbocharger system condition) diagnostic and analysis, overload/download analysis and load distribution between the cylinders analysis, but they are electronic gauges for compression pressures P_{COM}, maximum combustion pressures P_{MAX} measurement by open indicator diagrams (Fig.1) and closed indicator diagrams (Fig.2) for each cylinder and for engine speed measurement at each cylinder indication. All others values are required for the engine technical condition diagnostic and analysis has determined by calculation from indicator diagrams or entered manually to the electronic equipment tables.

Examine the engine indication results from Electronic indicator type HLV–2005 MK (Praezisionsmesstechnik Beawert GMBH, Germany):

1) The values are calculated from the indicator diagrams:

- Cylinders indicator diagrams area A_D (mm^2);
- Cylinders mean–indicated pressure P_{MI}^{CYL} (bar) (Fif.3);
- Cylinders mean–effective pressure P_{ME}^{CYL} (bar);
- Cylinders indicated power N_{IND}^{CYL} (IKW) (Fif.3);
- Cylinders effective power N_{EFF}^{CYL} (EKW);
- Engine average mean–indicated pressure P_{MI}^{ENG} (bar) (Fig.3);
- Engine average mean–effective pressure P_{ME}^{ENG} (bar);
- Engine indicated power N_{IND}^{ENG} (IKW) (Fif.3);
- Engine effective power N_{EFF}^{ENG} (EKW);
- Engine mechanical efficiency η_{MEC} (%).

2) The values are entered manually to the electronic equipment tables (Fig.3):

- Scavenging air temperature after turbocharger or before scavenging air cooler T_{SC}^{BC} (^{O}C);
- Scavenging air temperature after scavenging air cooler T_{SC}^{AC} (^{O}C);
- Scavenging air pressure after scavenging air cooler P_{SC}^{AC} (bar);
- Exhaust gas temperature after turbocharger T_{EXH}^{ATC} (^{O}C);
- Turbocharger speed n_{TC} (rpm);
- Cylinders exhaust gas temperatures T_{EXH}^{CYL} (^{O}C);
- Cylinders fuel rack position FRP (fuel pump index FPI) (mm);

Note: However, the mentioned above values are not enough for the engine technical condition full diagnostic and analysis (cylinder tightness, fuel injection equipment condition and turbocharger system condition).

In completion of indication data entering to the PC without TDC correction the engine average mean–indicated pressure & indicated power calculation can give tolerance up to $\pm$10%, while the same values calculation from indicator diagrams are taken by mechanical indicator with usage of computerized technology gives tolerance up to $\pm$0.5% only.

The engine average mean–indicated pressure and indicated power calculation tolerance up to $\pm$10% is not satisfactory for the engine technical condition (cylinder tightness, fuel injection equipment condition and turbocharger system condition) diagnostic and analysis, overload/download analysis and load distribution between the cylinders analysis.

Thereby we suggest the engine (4–stroke engine) indicated power accurate calculation procedure, afterwards it is possible a TDC accurate correction for each cylinder, and then a cylinders mean–indicated pressure P_{MI}^{CYL}, cylinders indicated power N_{IND}^{CYL} & engine average mean–indicated pressure P_{MI}^{ENG} same accurate calculation within tolerance $\pm$0.5%.

Work object

The high accuracy obtaining in the indicator diagram treatment and as results high accuracy in the cylinder power calculation, determination of load distribution between cylinders and cylinders/engine condition diagnostic & analysis without engine dismantling.

Ways of investigation

Investigations has carried out on the vessel's and shore engines (with effective power from **300 EKW** up to **6600 EKW**) with different kind of micro–processing gauging and systems (Doctor–Engine, Diesel–Doctor and Electronic indicator) & with mechanical indicators.

Investigation results and discussion about

1. The indicator diagrams TDC correction and each cylinder/total engine output data calculation after the 4–stroke Generator Engine MAN–B&W type 6L23/30 indication by Electronic indicator type HLV–2005 MK.

1) The Generator Engine performance data some measurement readings are taken at each cylinder indication and its average values calculation (table 1):

Table 1

CYLINDER No.		1	2	3	4	5	6		
FW TEMPERATURE	C	72	73	73	73	74	74,5	AVERAG	73,3
TEMPERATURE	C	IN	70,5						
EG TEMPERATURE	C	320	353	342	350	380	337	AVERAG	347
FUEL PUMP INDEX	mm	20,5	21,5	19,5	19	20	20	AVERAG	20,1
COSINUS PHY	(-)	0,66	0,66	0,66	0,66	0,66	0,66	AVERAG	0,664
FREQUENCY	Hz	60	60,1	60	60	60	59,8	AVERAG	59,98
CURRENT	A	1040	1030	1030	1030	1025	1025	AVERAG	1030
VOLTAGE	V	440	443	442	440	438	438	AVERAG	440,17
ACTIVE POWER	kW	528	512	522	524	524	517	AVERAG	521,2

2) The generator calculated active load by the average values of voltage V, amperage A and power factor cosφ measurement readings at each cylinder indication from the table 1:

$$P = \frac{\sqrt{m} \cdot V \cdot A \cdot \cos\varphi}{1000} = \frac{\sqrt{3} \cdot 440.17 \cdot 1030 \cdot 0.664}{1000} = 521.17 \text{ KW}$$

where: m = 3 – NOs of phases.

3) The generator active load by the kilo–watt-meter measurement readings at each cylinder indication from the table 1:

$$P = 521.17 \text{ KW}$$

4) The generator calculated reactive load by the average values of active load P and power factor cosφ measurement readings at each cylinder indication:

$$Q = P \cdot tg(\arccos(\cos\varphi)) = 521.17 \cdot tg(\arccos(0.664)) = 587.39 \text{ KVAr}$$

5) The generator calculated total load by the average values of voltage V, amperage A and measurement readings at each cylinder indication:

$$S = \frac{\sqrt{m} \cdot V \cdot A}{1000} = \frac{\sqrt{3} \cdot 440.17 \cdot 1030}{1000} = 785.26 \text{ KVA}$$

or

$$S = \sqrt{P^2 + Q^2} = \sqrt{521.17^2 + 587.39^2} = 785.26 \text{ KVA}$$

6) The Generator Engine measurement readings data are taken from the shop trial test results (table 2):

Table 2

Alternator frequency	F	Hz	by observation	60	60	60	60	60
Alternator current	I	A	by observation	1323,26	1204,1	903,72	599,8	292,52
Alternator voltage	U	V	by observation	450	450	450	450	450
Alternator active load	P	KW	by observation	825,1	750,8	563,5	374	182,4
Alternator reactive load	Q	KVAr	$Q = P \cdot tg\varphi$	618,825	563,1	422,625	280,50	136,8
Alternator total load	S	KVA	$S = m^{0,5} \cdot U \cdot I / 10^3$	1031,38	938,503	704,38	467,50	228,0
Alternator total load	S	KVA	$S = (P^2 + Q^2)^{0,5}$	1031,38	938,5	704,375	467,50	228,0
Alternator power factor	cosφ	-	by observation	0,8	0,8	0,8	0,8	0,8
Engine indicated power	N_{IND}	IKW	by indication results	887,2	809,2	614,2	419,2	224,2
Alternator total load factor	F_{ATL}	IKW	$F_{ATL} = N_{IND} / S$	0,86021	0,86223	0,87198	0,89668	0,98333

7) Draw the diagram of alternator total load factor dependence of total load from shop trial test results table and found its dependence function by the trend line (Diagram 1).

8) The alternator calculated total load factor by the function is founded from the diagram 1.

$$F_{ATL} = 5.551340 \cdot 10^{-13} \cdot S^4 - 1.871722 \cdot 10^{-9} \cdot S^3 + 2.403963 \cdot 10^{-6} \cdot S^2 - 1.432312 \cdot 10^{-3} \cdot S + 1.205615 = 5.551340 \cdot 10^{-13} \cdot 785.26^4 - 1.871722 \cdot 10^{-9} \cdot 785.26^3 + 2.403963 \cdot 10^{-6} \cdot 785.26^2 - 1.432312 \cdot 10^{-3} \cdot 785.26 + 1.205615 = 0.868$$

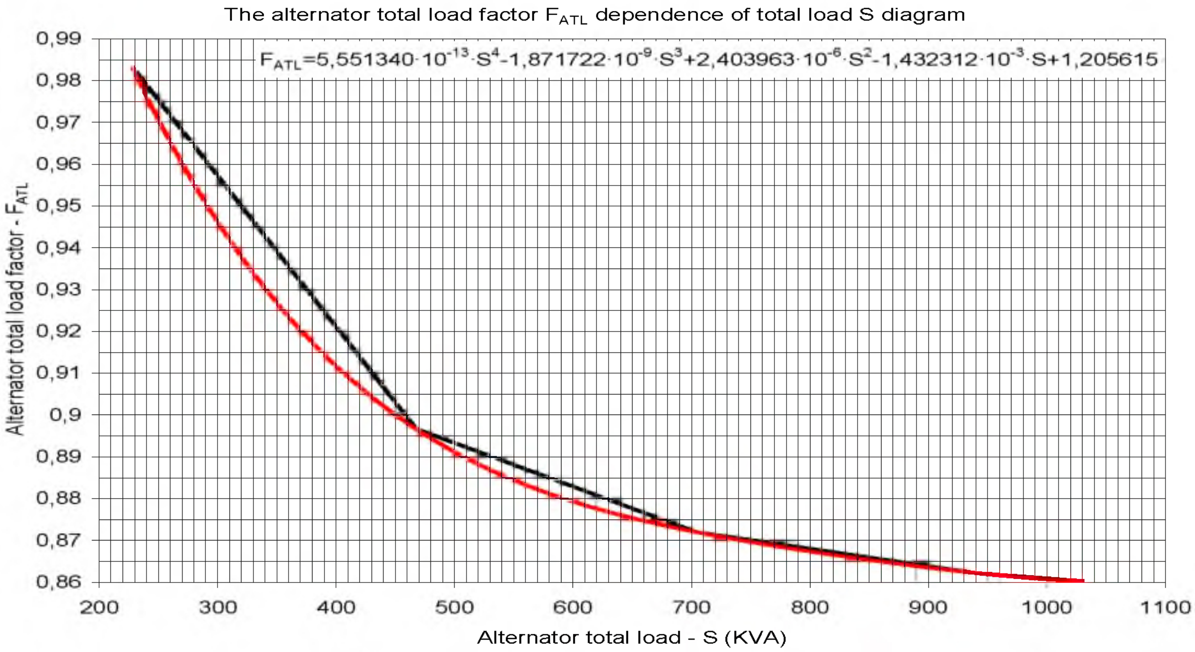
9) The engine calculated indicated power by the engine & alternator performance data results:

$$N_{IND} = S \cdot F_{ATL} = 785.26 \cdot 0.868 = 681.6 \text{ IKW}$$

10) Enter the engine indication and performance data to the PC (Fig.1, Fig.2, Fig3):

Conclusion: As we have seen from the Fig.1 and Fig.2 the engine all cylinders indicator diagrams compression lines are in different position (arrow 1), that is what can not be for the same designed cylinders. They are should be in one line, that is can be adjusted by cylinders TDC correction individually (arrow 2). As we have seen from the Fig.3 the engine indicated power is 719.02 IKW instead of calculated in item 9 – 681.6 IKW, that is become 5.5% tolerance, which is not acceptable for the engine technical condition diagnostic and analyses. We have to correct the engine cylinders TDC totally.

Diagram 1



11) The engine cylinders TDC angles (Fig.1) in degreases of crank angle CA:

Cylinder 1 TDC = 0 ° CA; Cylinder 2 TDC = 1 ° CA; Cylinder 3 TDC = 1 ° CA;

Cylinder 4 TDC = 0 ° CA; Cylinder 5 TDC = 0 ° CA; Cylinder 6 TDC = 2 ° CA;

12) Correct the engine cylinders TDC first of all individually for making the diagrams compression lines in one line (arrow 1), then totally for making the engine indicated power same as calculated in item 9 (arrow 2), (Fig.4, Fig.5, Fig6):

Cylinder 1 TDC = 2 ° CA; Cylinder 2 TDC = 2 ° CA; Cylinder 3 TDC = 1 ° CA;

Cylinder 4 TDC = 1 ° CA; Cylinder 5 TDC = 2 ° CA; Cylinder 6 TDC = 2 ° CA;

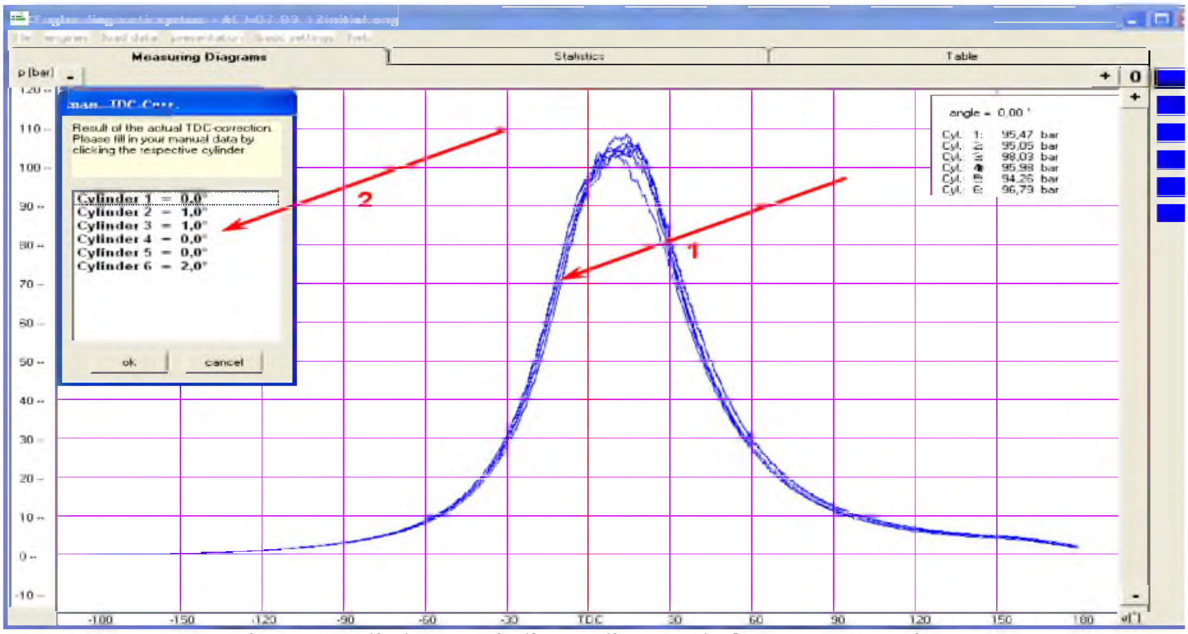


Figure 1. Cylinder open indicator diagrams before TDC correction

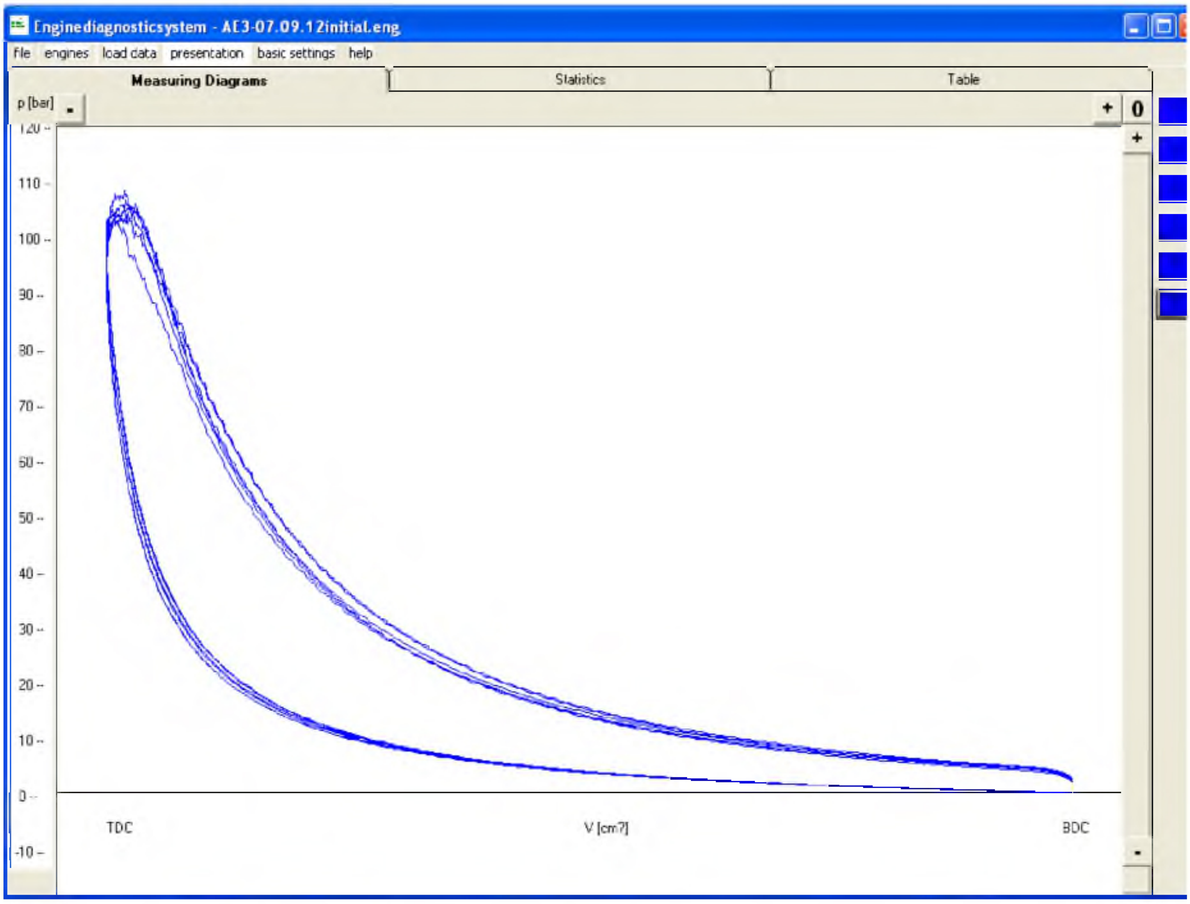
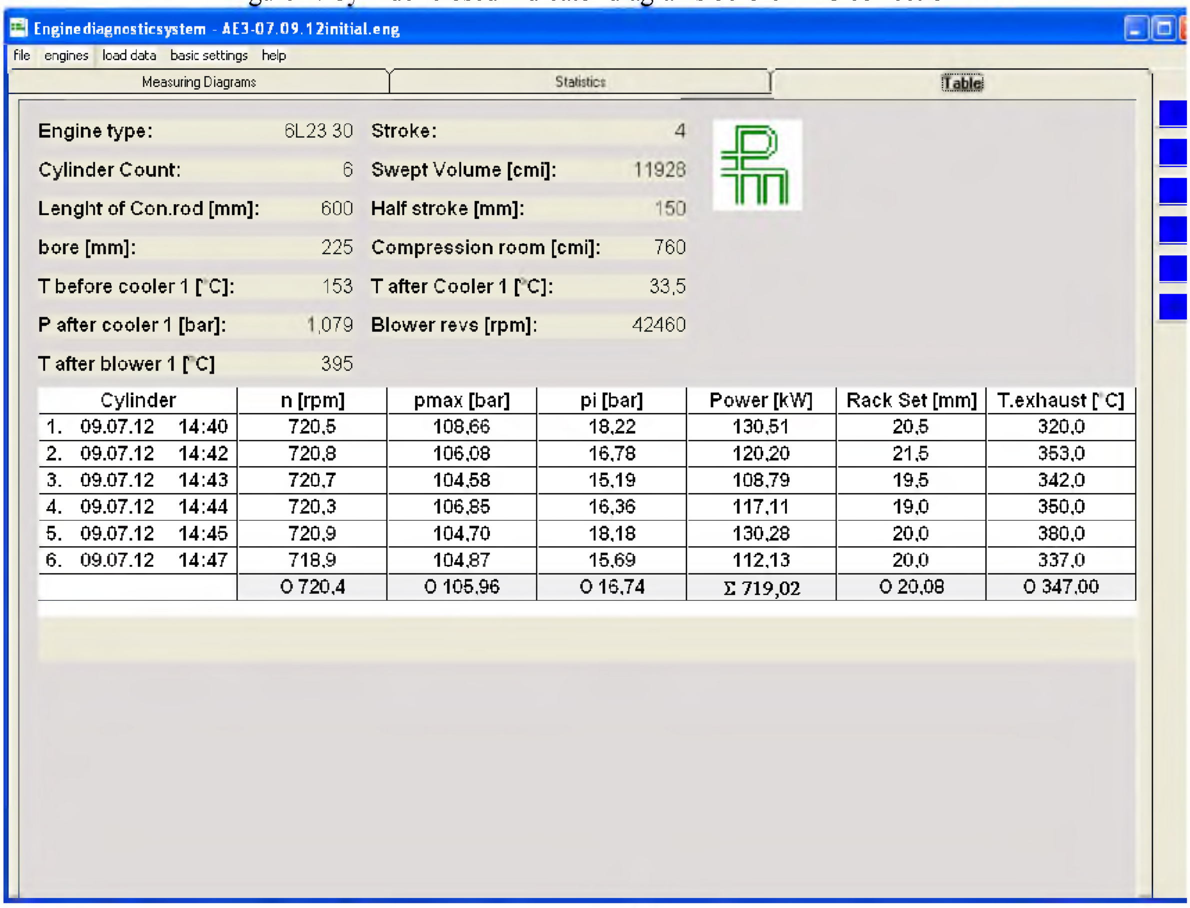


Figure 2. Cylinder closed indicator diagrams before TDC correction



Engine type:	6L23 30	Stroke:	4
Cylinder Count:	6	Swept Volume [cmi]:	11928
Lenght of Con.rod [mm]:	600	Half stroke [mm]:	150
bore [mm]:	225	Compression room [cmi]:	760
T before cooler 1 [°C]:	153	T after Cooler 1 [°C]:	33,5
P after cooler 1 [bar]:	1,079	Blower revs [rpm]:	42460
T after blower 1 [°C]	395		

Cylinder	n [rpm]	pmax [bar]	pi [bar]	Power [kW]	Rack Set [mm]	T.exhaust [°C]
1. 09.07.12 14:40	720,5	108,66	18,22	130,51	20,5	320,0
2. 09.07.12 14:42	720,8	106,08	16,78	120,20	21,5	353,0
3. 09.07.12 14:43	720,7	104,58	15,19	108,79	19,5	342,0
4. 09.07.12 14:44	720,3	106,85	16,36	117,11	19,0	350,0
5. 09.07.12 14:45	720,9	104,70	18,18	130,28	20,0	380,0
6. 09.07.12 14:47	718,9	104,87	15,69	112,13	20,0	337,0
	Ø 720,4	Ø 105,96	Ø 16,74	Σ 719,02	Ø 20,08	Ø 347,00

Figure 3. Cylinders indication & performance data results table before TDC correction

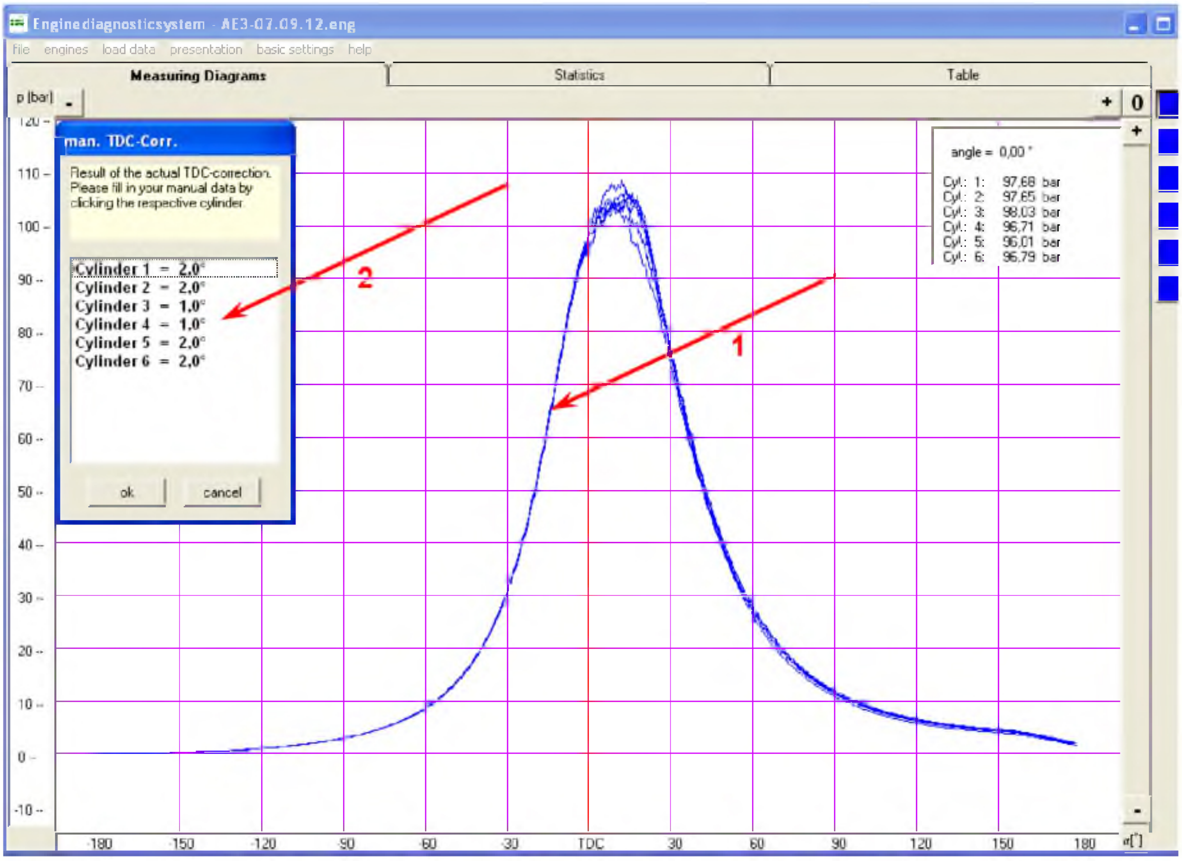


Figure 4. Cylinder open indicator diagrams after TDC correction

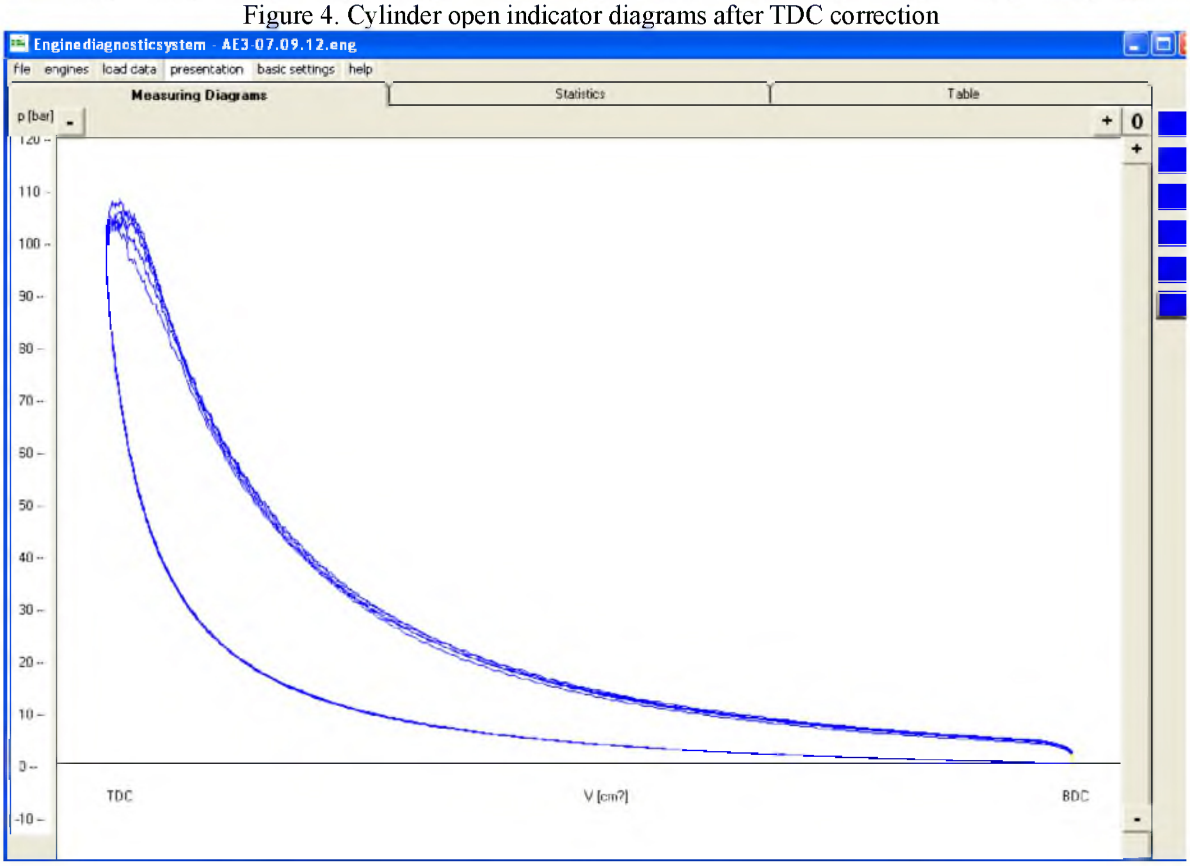
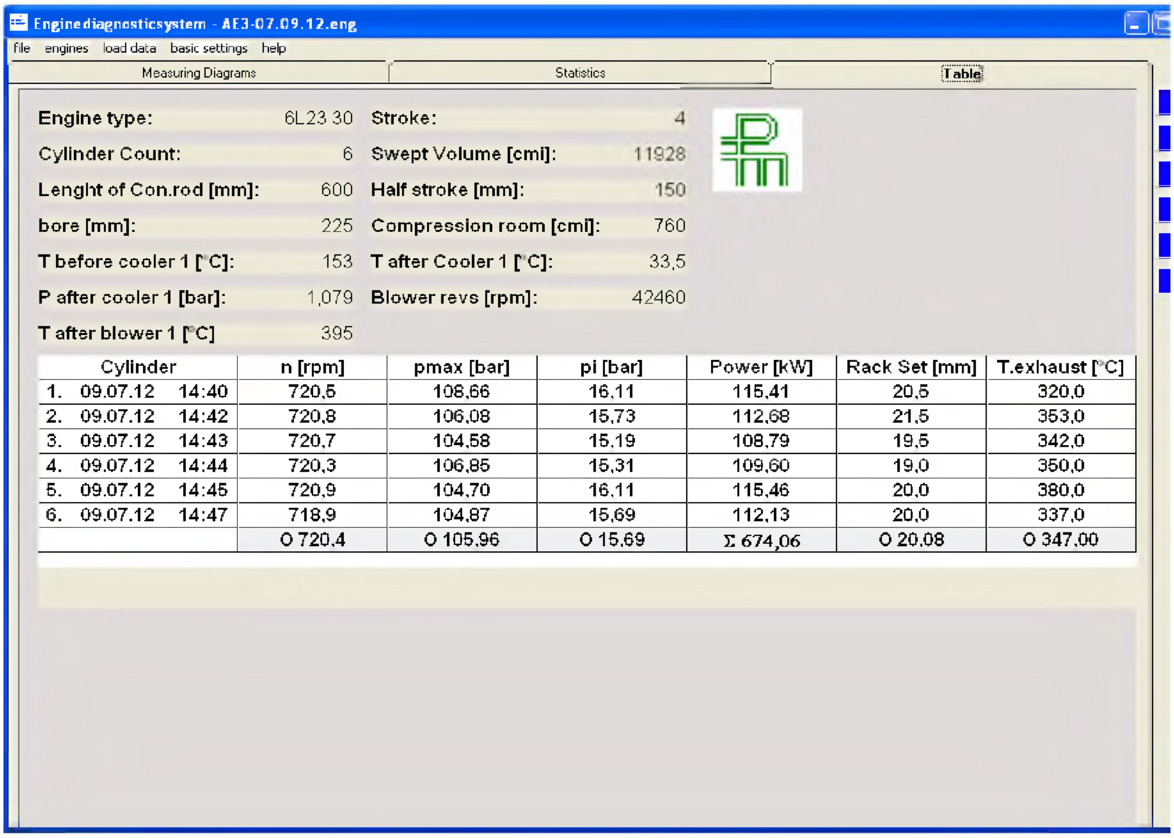


Figure 5. Cylinder closed indicator diagrams after TDC correction



Engine type:	6L23 30	Stroke:	4
Cylinder Count:	6	Swept Volume [cml]:	11928
Lenght of Con.rod [mm]:	600	Half stroke [mm]:	150
bore [mm]:	225	Compression room [cml]:	760
T before cooler 1 [°C]:	153	T after Cooler 1 [°C]:	33,5
P after cooler 1 [bar]:	1,079	Blower revs [rpm]:	42460
T after blower 1 [°C]	395		

Cylinder	n [rpm]	pmax [bar]	pi [bar]	Power [kW]	Rack Set [mm]	T.exhaust [°C]
1. 09.07.12 14:40	720,5	108,66	16,11	115,41	20,5	320,0
2. 09.07.12 14:42	720,8	106,08	15,73	112,68	21,5	353,0
3. 09.07.12 14:43	720,7	104,58	15,19	108,79	19,5	342,0
4. 09.07.12 14:44	720,3	106,85	15,31	109,60	19,0	350,0
5. 09.07.12 14:45	720,9	104,70	16,11	115,46	20,0	380,0
6. 09.07.12 14:47	718,9	104,87	15,69	112,13	20,0	337,0
	Ø 720,4	Ø 105,96	Ø 15,69	Σ 674,06	Ø 20,08	Ø 347,00

Figure 6. Cylinders indication & performance data results table after TDC correction

Conclusion: As we have seen from the Fig.4 and Fig.5 the engine all cylinders indicator diagrams compression lines are in one line (arrow 1) after TDC correction (arrow 2), that is what to be for the same designed cylinders. As we have seen from the Fig.6 the engine indicated power is 674.06 IKW and almost the same with calculated in item 9 – 681.6 IKW, that is become – 1.1% tolerance, which is perfect for the engine technical condition diagnostic and analyses.

13) The Generator Engine mechanical loss pressure from shop trial test results:

$$n_{ENG} = 720 \text{ rpm} \rightarrow P_{MEC} = 0.68 \text{ bar}$$

14) The Generator Engine mean–effective pressure calculation:

$$P_{ME} = P_{MI} - P_{MEC} = 15.69 - 0.68 = 15.01 \text{ bar}$$

where: P_{MI} = 15.69 bar – from the engine performance data results table (Fig.6);

P_{MEC} = 0.68 bar – from item 13).

15) The Generator Engine effective power calculation:

$$N_{EFF} = k \cdot P_{ME} \cdot n \cdot i = 0.0099357 \cdot 15.01 \cdot 719.8 \cdot 6 = 644.1 \text{ EKW}$$

where: $k = 1.3084 \cdot D^2 \cdot S \cdot m = 1.3084 \cdot 0.225^2 \cdot 0.3 \cdot 0.5 = 0.0099357$ – cylinder constant;

D = 0.225 mtr – cylinder diameter;

S = 0.3 mtr – piston stroke;

m = 1 – stroke factor (for 4–strike engine m = 0.5; for 2–stroke engine m = 1).

Conclusion

As we have seen from mentioned above information for Diesel Generators indicator diagrams TDC correction the generator unit (alternator) electric performance data measurement readings to be taken, recorded & output data are effected to the TDC correction to be calculated.

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УДК 629.735.33
DOI: 10.34046/aumsuomt93/19

ЧИСЛЕННОЕ МОДЕЛИРОВАНИЕ МНОГОРЕЖИМНОГО ГОРЕНИЯ В ТЕПЛОВЫХ МАШИНАХ

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Численное исследование горения углеводородных топлив требует решения системы дифференциальных уравнений,описывающих многоступенчатые цепные химические реакции, молекулярныйперенос, перенос импульса, тепла и массы путем конвекции, излучение, турбулентность, испарениежидких капель и т. д.В данной работе показан опыт численного моделирования горения на основе однородной модели, отображающей непрерывный спектр режимов горения - от диффузионных пламен и до детонации.Модель является составной частью аппаратачисленных исследований нестационарных пространственных течений вязкой среды в разнообразных тепловых машинах. Течение газа описывается законами сохранения массы, импульса и энергии. Для отображения движения частиц химически реагирующей смеси с различной предысторией используется смешанный эйлерово-лагранжев подход. Идентификация положительных энергетических скачков, адекватных определенным уровням активации химических превращений, реализуется на основе дифференциальных анализаторов активации процесса. В работе приведены примеры расчета рабочего процесса в пульсирующем воздушно-реактивном двигателе.

Ключевые слова: многорежимное горение, численные исследования, тепловые машины, эйлерово - лагранжев подход, дифференциальный анализатор

A numerical study of the combustion of hydrocarbon fuel requires solving a system of differential equations.This describes multistage chain chemical reactions, molecular transfer, momentum transfer, heat and mass due to convection, radiation, turbulence, evaporation of liquid droplets, etc. In this paper we have the experience of numerical simulation of combustion based on a homogeneous model. This model displays a continuous spectrum of combustion modes - from diffusion flame to detonation. Knitted environment in a variety of heat engines. The gas flow is described by the laws of conservation of mass, momentum and energy. To display the motion of particles of a chemically reacting mixture with a different background, a mixed arbitraryLagrangian - Eulerian method is used. The identification of positive energy surges is realized on the basis of differential process activation analyzers. In this case, energy jumps are adequate to certain levels of activation of chemical transformations. The paper gives examples of the calculation of the working process in a pulsejet engine.

Key words: multi regime combustion, numerical studies, heat mashines, arbitrary lagrangian - eulerian, differential process activation analyzers