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COMPUTER AIDED SIMULATION OF DIESEL ENGINES UNDER VARIABLE LOAD CONDITIONS

KOMPJUTORSKA SIMULACIJA RADA DIZELSKOG MOTORA POD PROMJENLJIVIM OPTEREĆENJEM

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Abstract

The paper reports the results of a theoretical investigation on the computer aided simulation of a diesel engine under variable load conditions.

The variable load conditions were simulated by altering the amount of fuel injection to engine cylinders. The computer simulation programme employs the well established ***Method of Characteristics*** *to simulate the unsteady gas flow in the intake and exhaust manifolds of the engine. A heat release scheme is employed for the in-cylinder calculations and a turbocharger simulation routine is also incorporated into the code. For the validation of the results, the MTU 16V 396 TB34 D stationary diesel generator engine data were used. The variable load conditions of 1/4th of the full load up to full load in 1/4th increments and 10 percent overload conditions were considered. The measured and calculated values for the effective power, mean effective pressure, specific fuel consumption and thermal efficiency were compared and found to be in good agreement.*

Sažetak

U radu se iznose rezultati teoretskog ispitivanja o kompjutorskoj simulaciji rada dizelskog motora pod promjenljivim opterećenjima.

Promjenljiva opterećenja su simulirana promjenom količine ubrizgavanja goriva u cilindre motora. Program kompjutorske simulacije koristi već iskušanu ***Metodu karakteristika*** *za simuliranje neravnomjernog protoka plina u usisnom i ispušnom kolektoru motora. Koristi se shema oslobađanja topline za proračune unutar cilindra, a u isti je kod uključen i simulacijski rad turbo-puhala. Za potvrdu rezultata korišteni su podaci MTV 16V 396 TB34 D stacioniranog dizelskog generatora. Razmatrani su promjenljivi uvjeti opterećenja od 1/4 punog opterećenja do punog opterećenja uz 1/4 povećanja i 10 posto preopterećenja. Usporedbom mjerenih i izračunatih vrijednosti efektivne snage, srednjeg efektivnog tlaka, specifične potrošnje goriva i toplinske iskoristivosti ustanovljeno je da se one dobro podudaraju.*

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INTRODUCTION
UVOD

Diesel engines have become the most widely preferred power sources of the industry and marine applications both as the prime mover and electrical generator driver. The search for competitiveness with alternate power sources have led diesel engine manufacturers to produce more power from smaller sized engines. The main targets have been identified as reducing the initial cost, reducing the maintenance and operation costs and producing high performance engines with lower specific fuel consumption.

Extensive research and development work on high speed, supercharged and modular diesel engines is still under progress. The main topics where this research and development work have been concentrated on are that the combustion chamber geometry in order to burn the fuel in the most effective manner, combustion modelling, reduction of NO_X emissions, the structure of inlet and exhaust systems and increasing the air charge.

When experimental methods for the design of diesel engines are used both the laboratory work and the design of the prototype become more time consuming and demand longer time. Present day design work largely relies on computer simulation suites which model the diesel engine in a realistic way. Those numerical methods, which include CAD/CAM and CAE enable the designer to investigate the subsystems of the diesel engine separately and the effects of the most minute changes in the design parameters on the engine performance are predicted realistically.

This research work employs the computer aided simulation of a pre-designed diesel engine running at constant speed under variable load conditions. The

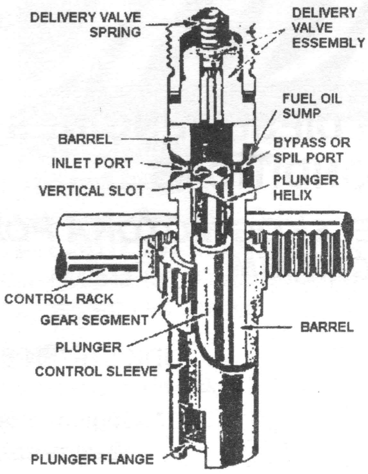

Figure 1. Injector pump and control rack
Slika 1. Pumpa ubrizgača i kontrolna letva

computer software used is the program developed by SAG [1] which simulates the unsteady gas flow during the intake and exhaust phases at the turbocharger and in the intake and exhaust manifolds based on the "Non-Homentropic Flow Model".

THEORETICAL MODELLING
TEORETSKO MODELIRANJE

The theory of modelling which forms the basis for the simulation program is based on the assumption that the gas flow in the inlet and exhaust manifolds of the diesel engines progress as time dependent, one dimensional flow with variable entropy among the gas particles [2,3,4,5]. The non-linear hyperbolic partial differential equations obtained from the continuity, momentum, and energy conservation equations are solved by the Method of Characteristics with employing the theories of boundary conditions [6].

INVESTIGATION OF DIESEL ENGINES UNDER VARIABLE LOAD CONDITIONS
ISPITIVANJA DIZEL MOTORA POD PROMJENLJIVIM OPTEREĆENJEM

A diesel engine can meet the demands of variable load situation by increasing or decreasing the fuel injected to the combustion chamber at each cycle. This variation can be achieved either by a speed control lever for the case of a variable speed engine or by a constant speed governor for the case of a constant speed diesel engine. In both cases, the command that is given either by the speed control lever or by the constant speed governor is fed into the fuel injection pump's control rack; whose axial motion is converted to the rotational motion by a control gear inside the pump and vary the effective stroke of the injector's plunger (Figure 1). The fuel camshaft of the pump moves the plunger axially whose effective stroke is thus varied and therefore different amounts of fuel are injected to cylinders for different load conditions.

In order to simulate the above mentioned process numerically, the amount of fuel injected should be altered at the input data file of the program. Since, the variation of the fuel will change the amount of heat released as a result of the combustion process, the pressure and temperature of the exhaust gases will also change. Consequently, the energy recovered at the turbine of the turbocharger unit will vary and the pressure and temperature of the air charged into the intake manifold of the engine will change.

As a result, the parameters to be changed for a diesel engine to be simulated for variable load conditions are specified as:

- Amount of fuel to be injected to the cylinder for a cycle,
- Mean pressure of the exhaust manifold,
- Mean temperature of the exhaust manifold,
- Mean pressure of the intake manifold,
- Mean temperature of the intake manifold.

Table 1. Engine Performance Values Under Variable Load Conditions
Tabela 1. Vrijednosti performansa motora pod promjenljivim opterećenjem

Load Conditions	%110	%100	%75	%50	%24
Engine Speed (rpm)	1500	1500	1500	1500	1500
Power (kW)	2068	1880	1410	940	470
Power per Cylinder (kW)	129.25	117.50	88.12	58.74	29.37
Total Fuel Consuption (kg/h)	488.9	429.5	315.1	213.9	122.9
Delivered Fuel per cylinder ($x10^{-3}$) (kg/cycle)	0.6791	0.5964	0.4377	0.2971	0.1707
Pressure in Exhaust Manifold (mm H_2O)	300	240			
Absolute Pressure in Exhaust Manifold (bar)	1.009	1.004	1.000	0.996	0.992
Temperature in Exhaust Manifold (°C)	565	535	460	411	340
Absolute Temperature in Exhaust Manifold (°K)	838	808	733	684	613
Pressure in Intake Manifold (bar)	2.360	2.180	1.570	0.970	0.480
Absolute Pressure in Intake Manifold (bar)	3.340	3.160	2.550	1.960	1.460
Temperature in Intake Manifold (°C)	56	55	53	52	51
Absolute Temperature in Intake Manifold (°K)	329	328	327	326	325

ANALYTICAL CALCULATIONS
ANALITIČKI PRORAČUNI

This research was carried out on the MTU 16V 396 TB 34D diesel engine, which is a stationary generator application of the MTU's 396 TB series. Five different data files for the variable load conditions of the engine are created based on the information [7] supplied by the manufacturing company's Istanbul branch office (Table 1).

The computer program was first run for the 100 % load condition. This study was aimed at the converging criteria research of the results by varying the number of cycles. When the results of effective power, mean effective pressure, specific fuel consumption and thermal efficiency are compared, the second group of results are seen to be nominally similar to the subsequent group of results. Therefore the number of cycles for the program was assumed to be 8 and the second group of results obtained were assumed to be the analytic solution [8]. The following graphs were plotted by using the data in the output files for the 100 % load condition:

- Variation of pressure during the gas exchange period (open cycle), Figure 2a;
- Variation of pressure during compression, combustion and expansion period (closed cycle), Figure 2b;
- Variation of pressure at the cylinder end of the intake manifold, Figure 2c;
- Variation of pressure at the cylinder end of the exhaust manifold, Figure 2d;
- Variation of mass flow rate while the exhaust valves are open, Figure 2e;
- Variation of mass flow rate while the intake valves are open, Figure 2f.

DISCUSSION AND RESULTS
RASPRAVA I ZAKLJUČCI

The program has been executed with the values given in Table 1 for the variable load conditions. The effective power, mean effective pressure, specific fuel consumption and thermal efficiency values were obtained for five different loading conditions [8]. The highlights of the results may be summarised as follows:

i. When the analytical results and the relevant engine test bed results included in the engine protocol [7] are compared (Table 2), the results are seem to be in a good agreement and the performance curves plotted in Figure 3 are in the same character.

ii. In the previous studies, this simulation program [1] has been used for the diesel engines running at different engine speed values This research has indicated that the above-mentioned simulation program can be effectively used for constant speed diesel engines, generator driver diesel engines and pitch-controlled marine power plants.

For further studies, the researchers interested in this topic may achieve more effective engine design by changing some design parameters on this simulation

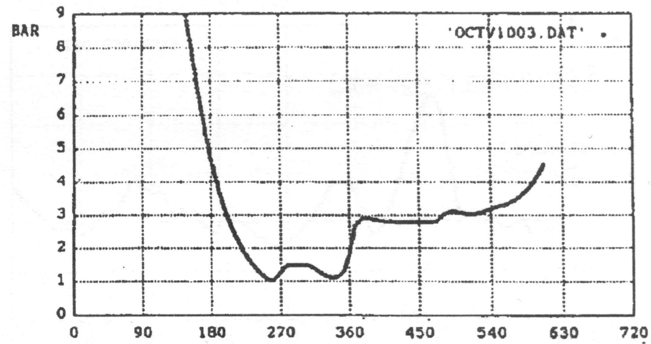

Figure 2a. Open cycle pressure change for B3 cylinder
Slika 2a. Promjena tlaka otvorenog ciklusa za cilindar B3

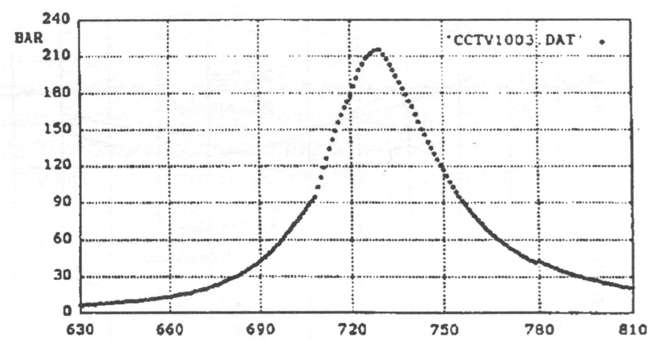

Figure 2b. Closed cycle pressure change for B3 cylinder
Slika 2b. Promjena tlaka zatvorenog ciklusa za cilindar B3

Table 2. Comparison of Analytical and Test Results
Tabela 2. Poredba analitičkih i pokusnih rezultata

Load Conditions		% 110	% 100	% 75	% 50	% 15
Test Results	Power per Cylinder (kW)	129.25	117.50	88.12	58.74	29.37
	Mean Effective Pressure	26.13	23.76	17.82	11.88	5.94
	Specific Fuel Cons. (g/kW.h)	236.50	228.40	223.50	227.60	261.60
Analytical Results	Power per Cylinder (kW)	138.41	123.07	90.92	59.65	27.19
	Mean Effective Pressure (bar)	27.99	24.89	18.39	12.06	5.50
	Specific Fuel Cons. (g/kW.h)	220.84	218.11	216.67	224.77	298.51
% Percent Change	Power per Cylinder (kW)	+7.09	+4.74	+3.18	+1.55	-7.42
	Mean Effective Pressure (bar)	+7.12	+4.76	+3.20	+1.51	-7.41
	Specific Fuel Cons. (g/kW.h)	-6.62	-4.51	-3.06	-1.24	+14.11

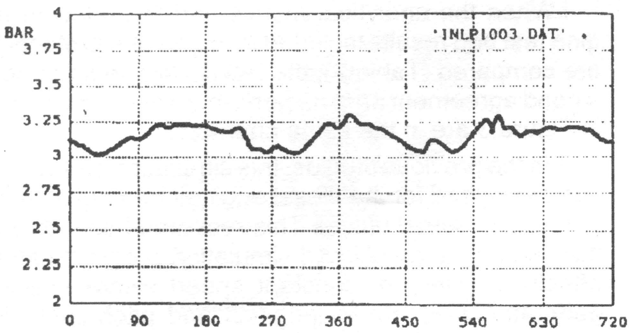

Figure 2c. Intake manifold pressure change for b3 cylinder
Slika 2c. Promjena tlaka usisnog kolektora za cilindar B3

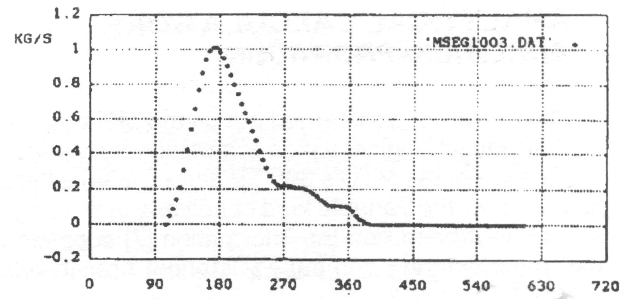

Figure 2e. Mass flow rate variation at exhaust period for B3 cylinder
Slika 2e. Promjena cjelokupne količine protoka u periodu ispuha za cilindar B3

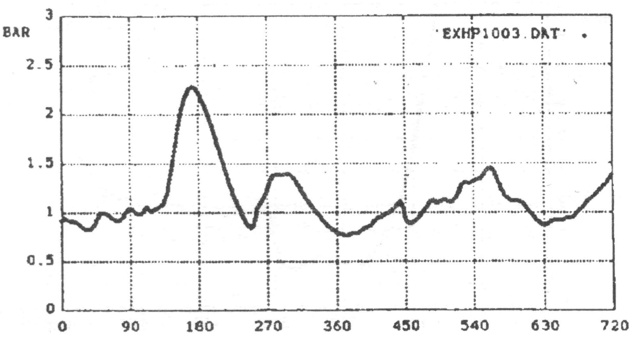

Figure 2d. Exhaust manifold pressure change for B3 cylinder
Slika 2d. Promjena tlaka ispušnog kolektora za cilindar B3

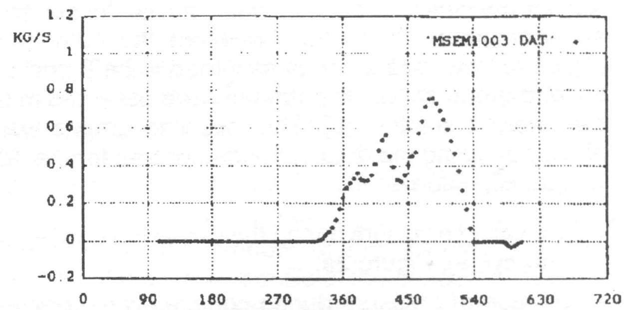

Figure 2f. Mass flow rate variation at intake period for B3 cylinder
Slika 2f. Promjena cijelokupne količine protoka u periodu usisa za cilindar B3

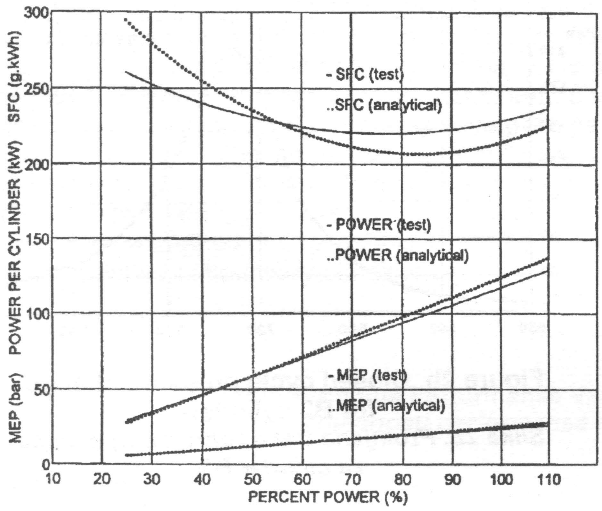

Figure 3. Comparison of analytical and test results
Slika 3. Poredba analitičkih i pokusnih rezultata

programme which simulates a diesel engine running at variable load conditions. For instance, at variable load conditions:

- different valve timings,
- different fuel injection timings,
- different ignition orders,
- different combustion models,

may be investigated and by comparing their effects on the engine performance, a series of parametric studies may be performed.

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