

UNIVERZITET U KRAGUJEVCU
(University of Kragujevac)

MAŠINSKI FAKULTET
(Faculty of Mechanical Engineering)

u K r a g u j e v c u (in Kragujevac)

Katedra za motorna vozila i motore
(Department for Motor Vehicles and IC Engines)



Saša Milojević, dipl.maš.inž. (Mr. B.Sc.)

ISTRAŽIVANJE UTICAJA STEPENA KOMPRESIJE NA RADNI PROCES DIZEL MOTORA

(Analyzing the Impact of Variable Compression Ratio on
Combustion Process in Diesel Engines)

– Magistarska teza – (M. Sc. Thesis)

Serbia, Kragujevac, IV 2005.

SADRŽAJ (The Content):

“ISTRAŽIVANJE UTICAJA STEPENA KOMPRESIJE NA RADNI PROCES DIZEL MOTORA” (Analyzing the Impact of Variable Compression Ratio on Combustion Process in Diesel Engines)

| | |
|--|----------|
| 0. REZIME (Abstract) | |
| I. UVOD (Introduction) | 1 |
| I.1. Dizel motor i zagađenje okoline (Diesel engine and environmental pollution) | 2 |
| I.1.1. Uticaj emisije iz vozila na okolinu (Impact of vehicle emissions on the environment) | 3 |
| I.1.1.1. Emisija produkata sagorevanja (Emission of combustion products) | 3 |
| I.1.1.2. Emisija isparenja iz vozila (Vapor emission from vehicles) | 6 |
| I.1.2. U.S.A. propisi za emisiju vozila sa dizel motorom (USA regulations for the emission of vehicles with diesel engines). | 7 |
| I.1.2.1. Propisi za putnička i laka teretna vozila (Regulations for passenger and light-duty vehicles) | 7 |
| I.1.2.2. Propisi za teška teretna vozila i autobuse (Regulations for heavy-duty vehicles and buses) | 8 |
| I.1.2.3. Propisi za vanputnu mehanizaciju (Regulations for off-road mechanization) | 10 |
| I.1.3. Evropski propisi za emisiju vozila sa dizel motorom (European regulations for the emission of diesel vehicles) | 11 |
| I.1.3.1. Propisi za putnička i laka teretna vozila (Regulations for passenger and light-duty vehicles) | 11 |
| I.1.3.2. Propisi za teška teretna vozila i autobuse (Regulations for heavy-duty vehicles and buses) | 12 |
| I.1.3.3. Propisi za vanputnu mehanizaciju (Regulations for off-road mechanization) | 13 |

| | |
|---|-----------|
| I.2. Dizel motor i angažovanje energije (Diesel engine and energy engagement) | 14 |
| I.2.1. Izvori energije (Energy sources) | 14 |
| I.2.2. Angažovanje energije (Energy engagement) | 15 |
| I.2.3. Propisi za emisiju CO ₂ (Emission regulations for CO ₂) | 16 |
| I.2.4. Propisi za potrošnju motornih vozila (Regulations for the consumption of motor vehicles) | 18 |
| I.3. Aktuelne teme u razvoju dizel motora (Current topics in diesel engine development) | 19 |
| I.3.1. Strategije razvoja dizel motora za putnička vozila (Diesel engine development strategies for passenger cars) | 19 |
| I.3.2. Strategije razvoja dizel motora veće snage (Higher power diesel engine development strategies) | 21 |
| I.3.3. Optimiranje procesa sagorevanja (Combustion process optimization) | 24 |
| I.3.3.1. Strategije za optimalno sagorevanje u dizel motoru (Strategies for optimal combustion in a diesel engine) | 27 |
| I.3.4. Primena alternativnih goriva (Application of alternative fuels) | 28 |
| I.3.5. Smanjenje ukupne mase i recikling vozila (Total weight reduction and vehicle recycling.) | 30 |
| II. DOSADAŠNJI RADOVI U OBLASTI DIZEL MOTORA SA PROMENLJIVIM STEPENOM KOMPRESIJE (PREVIOUS WORKS IN THE FIELD OF DIESEL ENGINES WITH VARIABLE COMPRESSION RATIO) | 31 |
| II.1. Konstrukcije motora sa promenljivim stepenom kompresije (Engine designs with variable compression ratio) | 32 |
| II.1.1. Motori sa relativnim pomeranjem klipova u cilindarskom paru (Engines with relative piston displacement in a cylinder pair) | 33 |
| II.1.1.1. Benzinski "A motor" sa samoregulacijom stepena kompresije (Gasoline "A engine" with self-regulation of the compression ratio) | 33 |

| | | |
|-----------|--|----|
| II.1.1.2. | Dizel motor sa promenom stepena kompresije pomoću među vratila (Diesel engine with a change in the compression ratio using between the shafts) | 34 |
| II.1.1.3. | "VAM" dizel motor sa promenljivim stepenom kompresije ("VAM" diesel engine with variable compression ratio.) | 36 |
| II.1.2. | Motori sa klipovima promenljive kompresione visine (Engines with variable compression piston height) | 37 |
| II.1.2.1. | Prototip klipa sa hidrauličkim mehanizmom za promenu kompresione visine (Piston prototype with hydraulic mechanism for changing the compression height.) | 37 |
| II.1.2.2. | Prototip klipa sa elastičnim mehanizmom za promenu kompresione visine (Piston prototype with elastic mechanism for changing the compression height.) | 38 |
| II.1.3. | Motori sa mehanizmom za promenu rastojanja između ose kolenastog vratila i glave cilindra (Engines with a mechanism for changing the distance between the crankshaft and the cylinder head) | 40 |
| II.1.3.1. | Benzinski motor "RICARDO" sa promenljivim stepenom kompresije ("RICARDO" petrol engine with variable compression ratio) | 40 |
| II.1.3.2. | Benzinski "FEV" motor sa ekscentričnom osom kolenastog vratila (Petrol "FEV" engine with eccentric crankshaft axis) | 42 |
| II.1.3.3. | Benzinski "SAAB" motor sa promenljivim stepenom kompresije (Gasoline "SAAB" engine with variable compression ratio) | 44 |
| II.1.4. | Motori sa klipnjačom promenljive dužine (Variable length piston engines) | 46 |
| II.1.4.1. | Motor sa tri klipnjače i automatskom promenom stepena kompresije (Engine with three connecting rods and automatic change of compression ratio) | 46 |
| II.1.4.2. | Dizel motor sa promenljivim stepenom kompresije preko složenog mehanizma sa klackalicom (Diesel engine with variable compression ratio via a complex mechanism with a seesaw) | 47 |
| II.1.4.3. | Klipnjača sa hidrauličkim mehanizmom za promenu dužine u cilju promene | |

| | |
|---|-----------|
| stepena kompresije (Connecting rod with hydraulic mechanism for changing the length in order to change the compression ratio) | 48 |
| II.1.4.4. Benzinski motor "Mayflower-e3" sa promenljivim stepenom kompresije (Gasoline engine "Mayflower-e3" with variable compression ratio) | 49 |
| II.1.5. Motori sa promenljivom geometrijom glave cilindra (Engines with variable cylinder head geometry) | 51 |
| II.1.5.1. "CFR" dizel motor sa promenljivim stepenom kompresije (<i>"CFR"</i> diesel engine with variable compression ratio) . . . | 51 |
| II.1.5.2. Dizel motor "Hispano – Suiza" sa promenljivim stepenom kompresije (Diesel engine "Hispano - Suiza" with variable compression ratio) | 52 |
| II.1.5.3. Benzinski motor sa promenljivim stepenom kompresije preko pomoćnog klipa u glavi cilindra (Gasoline engine with variable compression ratio via auxiliary piston in the cylinder head) | 53 |
| III. MATEMATIČKO MODELIRANJE RADNOG PROCESA DIZEL MOTORA (MATHEMATICAL MODELING OF DIESEL ENGINE WORKING PROCESS) | 55 |
| III.1. Matematički modeli termodinamičkih procesa u motoru (Mathematical models of thermodynamic processes in engine) | 55 |
| III.1.1. Jednačine koje opisuju stvarni radni ciklus u cilindru dizel motora sa direktnim ubrizgavanjem (Equations describing the actual duty cycle in a direct injection diesel engine cylinder.) | 56 |
| III.1.1.1. Količina toplote koja se oslobodi sagorevanjem goriva (The amount of heat released by fuel combustion.) | 59 |
| III.1.1.2. Razmena toplote u cilindru motora (Heat exchange in the engine cylinder) | 61 |
| III.1.1.3. Određivanje promene zapremine nadklipnog prostora (Determining the change in the volume of the piston space) | 62 |
| III.1.1.4. Protok gasa kroz prigušno mesto (Gas flow through the damping point) | 63 |
| III.1.1.5. Određivanje promene koeficijenta količine vazduha | |

| | | |
|---------------|---|-----------|
| | (Determining the change in the coefficient of the amount of air) | 64 |
| III.2. | Predviđanje emisije oksida azota i čestica kod dizel motora sa direktnim ubrizgavanjem (Prediction of nitrogen oxide and particulate matter emissions in direct injection diesel engines) | 66 |
| III.2.1. | Model formiranja emisije oksida azota i čestica (Nitrogen oxide and particulate matter emission formation model) | 66 |
| III.2.1.1. | Model formiranja azot – monoksida –NO (Nitrogen monoxide formation model - NO) | 66 |
| III.2.1.2. | Model formiranja čestica (Particle formation model) | 69 |
| IV. | ISTRAŽIVANJE UTICAJNIH PARAMETARA NA OPTIMALNE VREDNOSTI STEPENA KOMPRESIJE (INVESTIGATION OF INFLUENTIAL PARAMETERS ON OPTIMAL VALUES OF COMPRESSION RATIO) | 71 |
| IV.1. | Uticaj radnog režima dizel motora na optimalnu vrednost stepena kompresije pri radu sa dizel gorivom (Influence of diesel engine operating mode on the optimal value of compression ratio when working with diesel fuel) | 73 |
| IV.1.1. | Hladan start i rad dizel motora na praznom hodu (Cold start and diesel engine idling) | 73 |
| IV.1.2. | Rad dizel motora na različitim opterećenjima (Diesel engine operation at different loads) | 74 |
| IV.2. | Zavisnost parametara radnog procesa dizel motora od vrednosti stepena kompresije (Dependence of diesel engine working process parameters on compression ratio values) | 76 |
| IV.3. | Uticaj promene stepena kompresije na emisiju dizel motora pri radu sa dizel gorivom (Influence of changing the compression ratio on the emission of diesel engines when working with diesel fuel) | 79 |
| IV.4. | Analiza uticaja kvaliteta goriva na tok radnog procesa u dizel motoru (Analysis of the influence of fuel quality on the workflow in a diesel engine) | 82 |
| IV.4.1. | Izbor optimalne vrednosti stepena kompresije dizel motora iz uslova uspešnog starta na temperaturi okoline pri radu sa gorivom odgovarajućeg CB | |

| | | |
|-------------|--|-----------|
| | (Selection of the optimal value of the compression ratio of the diesel engine from the conditions of successful start at ambient temperature when working with the fuel of the appropriate CB) | 83 |
| IV.4.2. | Višegorivost dizel motora sa promenljivim stepenom kompresije (Multi-fuel diesel engine with variable compression ratio) . | 85 |
| V. | SOPSTVENE METODE EKSPERIMENTALNOG ISTRAŽIVANJA (PROPER METHODS OF EXPERIMENTAL RESEARCH) | 88 |
| V.1. | Eksperimentalni motor (Experimental engine) | 88 |
| V.1.1. | Pogonski materijali (Fuel and lubricants) | 90 |
| V.2. | Način promene stepena kompresije (Compression ratio change description) | 91 |
| V.3. | Probni sto za ispitivanje (Test bench) | 92 |
| V.4. | Kalibracija i ugradnja delova merne opreme pre ispitivanja (Calibration and installation of measuring equipment parts before testing) | 92 |
| V.4.1. | Davač pritiska u cilindru motora (Engine cylinder pressure transducer) | 92 |
| V.4.2. | Marker ugla kolenastog vratila (Crankshaft angle marker) | 95 |
| V.4.3. | Merenje temperatura (Temperature measurement) | 96 |
| V.4.4. | Način promene ugla predubrizgavanja (How to change the pre-injection angle) | 96 |
| V.4.5. | Uređaj za analizu sastava produkata sagorevanja (Device for analyzing the composition of combustion products) | 97 |
| V.5. | Indiciranje pritiska u motorima sa unutrašnjim sagorevanjem (Pressure indication in internal combustion engines) | 98 |
| V.5.1. | Sistem za piezoelektrično merenje pritiska (Piezoelectric pressure measurement system) | 99 |

| | | |
|------------|---|------------|
| V.6. | Radni režim eksperimentalnog motora (Experimental engine operating mode) | 100 |
| VI. | REZULTATI EKSPERIMENTALNOG ISTRAŽIVANJA (RESULTS OF EXPERIMENTAL RESEARCH) | 104 |
| VI.1. | Rezultati ispitivanja motora na režimu prvog starta (Results of engine tests on the first start conditions) | 104 |
| VI.2. | Rezultati ispitivanja motora na režimu praznog hoda (Engine idling test results) | 106 |
| VI.3. | Rezultati ispitivanja motora na konstantnom broju obrtaja i punom opterećenju (Results of engine tests at constant speed and full load) | 109 |
| VI.4. | Uticaj promene opterećenja i stepena kompresije na karakteristike motora (Influence of change of load and compression ratio on engine characteristics.) | 113 |
| VI.5. | Uticaj promene broja obrtaja i stepena kompresije na karakteristike motora (Influence of change of speed and compression ratio on engine characteristic) | 117 |
| VI.6. | Uticaj ugla predubrizgavanja i stepena kompresije na karakteristike motora (Influence of pre-injection angle and compression ratio on engine characteristics.) | 121 |
| VI.6.1. | Uticaj ugla početka sagorevanja i stepena kompresije na karakteristike motora na konstantom broju obrtaja (Influence of combustion start angle and compression ratio on engine characteristics at constant speed.) | 124 |
| VI.7. | Uticaj kvaliteta dizel goriva na karakteristike motora (Influence of diesel fuel quality on engine characteristics) | 126 |
| VI.8. | Optimalne vrednosti stepena kompresije za rad sa minimalnom potrošnjom i emisijom (Optimal values of compression ratio for operation with minimum consumption and emission) | 127 |
| VI.8.1. | Uticaj stepena kompresije na specifičnu potrošnju goriva (Influence of compression ratio on specific fuel consumption) | 127 |

| | | |
|---------------|--|------------|
| VI.8.2. | Uticaj stepena kompresije na specifičnu emisiju NO _x i čestica (Influence of compression ratio on specific exhaust emission of NO _x and particulate matter) | 129 |
| VI.9. | Ukupna emisija motora prema ESC ciklusu (Total engine emission according to ESC cycle) | 131 |
| VI.10. | Rezultati provere matematičkog modela (Mathematical model test results.) | 133 |
| VI.10.1. | Identifikacija parametara modela procesa sagorevanja (Identification of combustion process model parameters) . | 133 |
| VI.10.2. | Uticaj parametara modela procesa sagorevanja na modelirani tok pritiska (Influence of combustion process model parameters on modeled pressure flow) | 135 |
| VI.10.3. | Zavisnost parametara modela procesa sagorevanja od stepena kompresije (Dependence of combustion process model parameters of the compression ratio value) | 138 |
| VII. | IZGLEDI I POBUDE ZA DALJA ISTRAŽIVANJA (OUTLOOK AND INITIATIVES FOR FURTHER RESEARCH) | 140 |
| VIII. | ZAKLJUČCI (CONCLUSIONS) | 142 |
| IX. | SPISAK KORIŠĆENIH OZNAKA (LIST OF MARKINGS USED) | 146 |
| X. | LITERATURA (LITERATURE) | 151 |

REZIME

Dizel motori imaju dobru ekonomičnost i nisku emisiju ugljen–dioksida. Primenom savremenih tehničkih rešenja, ostvaren je rad dizel motora sa niskom emisijom oksida azota i čestica, tako da oni zadovoljavaju zakonske propise o dozvoljenoj emisiji štetnih produkata sagorevanja, bez pogoršanja njihove dobre ekonomičnosti.

Zbog toga se ekonomični dizel motori sve više koriste za pogon putničkih vozila, u kojima su do sada dominirali benzinski motori.

U klasičnim motorima, stepen kompresije je konstantan i njihove performanse su, zbog toga, posledica kompromisa između različitih zahteva.

Osnovni problemi svih pogonskih agregata u vozilima su da efikasno rade u promenljivim režimima i u različitim ambijentalnim uslovima. Ako dizel motor ima konstantan stepen kompresije, bira se najmanja vrednost koja obezbeđuje pouzdano samoupaljenje kada se startuje motor u uslovima hladnog starta.

U dizel motorima, promenljiv stepen kompresije obezbeđuje kontrolu i upravljanje nad maksimalnim pritiskom u cilindru, smanjenje potrošnje goriva i povećanje specifične izlazne snage kada se koristi natpunjenje. Dalje, promenljiv stepen kompresije poboljšava hladnu vozivost, rad na niskim opterećenjima, višegorivost, ekonomičnost goriva i dovodi do smanjenja emisije štetnih produkata sagorevanja. Naročito je moguće smanjenje emisije azotovih oksida na visokim opterećenjima, kada se automatski smanji vrednost stepena kompresije. Automatskom promenom stepena kompresije smanjuju se normalna opterećenja kliznih parova u motoru a time i mehanički gubici, što rezultira smanjenjem potrošnje goriva.

U radu su prikazani rezultati sopstvenih teorijskih i eksperimentalnih istraživanja promenljivog stepena kompresije na parametre radnog procesa dizel motora. Ilustrovane su i kritički razmatrane različite metode uvođenja promenljivog stepena kompresije, uz navođenje savremenih tehničkih rešenja u oblasti dizel motora, i zakonskih propisa koje oni moraju zadovoljiti.

ABSTRACT

Diesel engines have good economy and low carbon emissions. By applying modern technical solutions, the operation of diesel engines with low emission of nitrogen oxides and particles has been achieved, so that they meet the legal regulations on the permitted emission of harmful combustion products, without deteriorating their good economy.

As a result, fuel-efficient diesel engines are increasingly being used to power passenger vehicles, which have so far been dominated by petrol engines.

In classic engines, the compression ratio value is constant and their performance is, therefore, a consequence of a compromise between different requirements.

The basic problems of all propulsion units in vehicles are that they work efficiently in changing modes and in different ambient conditions. If the diesel engine has a constant compression ratio, the lowest value is selected that provides reliable self-ignition when starting the engine in cold start conditions.

In diesel engines, variable compression ratios provide control and management of maximum cylinder pressure, reduced fuel consumption and increased specific power output when refueling is used. Furthermore, the variable compression ratio improves cold driving, operation at low loads, multi-fuel, fuel economy and leads to a reduction in emissions of harmful combustion products. It is especially possible to reduce the emission of nitrogen oxides at high loads, when the value of the compression ratio is automatically reduced. Automatic change of compression ratio reduces normal loads of sliding pairs in the engine and thus mechanical losses, which results in reduced fuel consumption.

The paper presents the results of our own theoretical and experimental investigations of the variable compression ratio on the operating parameters of a diesel engine. Different methods of introducing variable compression ratio are illustrated and critically considered, with the indication of modern technical solutions in the field of diesel engines, and legal regulations that they must meet.

X.0. LITERATURA (LITERATURE)

- [1] Veinović S., Pešić R. i Petković S.: **“Pogonski materijali motornih vozila”**, knjiga od 375 strana, Banja Luka – Kragujevac, 2000.
- [2] Magnot – Cuvru P.: **“MOTEURS DIESEL”**, 3^e Édition, (E.T.A.I. Éditions techniques pour l'automobile et l'industrie), Paris, France, 1973.
- [3] Robert Bosch GmbH.: **“Diesel accumulator fuel-injection system Common Rail”**, Technical Instruction, Stuttgart, 1st Edition, March 1999.
- [4] Gruden D.: **“Ökologische entwicklung – zukunftsweisend für den fahrzeugverbrennungsmotor”**, XIII International Scientific Symposium “Motor Vehicles and Engines”, Plenary Lecture, Kragujevac, 04. – 06. October, 2004.
- [5] Schindler K. P.: **“The future of the Diesel engine in passenger cars”**, Volkswagen AG, Wolfsburg, Germany, presented on 7th Diesel Engine Emissions Reduction Workshop, Portsmouth, Virginia, August 5–9, 2001.
- [6] Schindler K. P.: **“Advances in Diesel Engine Technologies for European Passenger Vehicles”**, Volkswagen AG, Wolfsburg, Germany, presented on 8th Diesel Engine Emissions Reduction (DEER) Conference, San Diego, California, August 25–29, 2002.
- [7] www.politika.rs
- [8] Discussion Material on Climate Change prepared for the World Economic Forum: **“What is the Automotive Industry doing about Climate change”**, Governors Meeting for the Automotive Industry, New York, February 3, 2002.
- [9] Pešić R.: **“Automobilski oto motori sa minimalnom potrošnjom”**, specijalno izdanje internacionalnog časopisa Mobility & Vehicle Mechanics, Monografija, Kragujevac, 1994.
- [10] Robert Bosch GmbH.: **“Diesel fuel-injection: An overview”**, Technical Instruction, Stuttgart, 3rd Edition, September 1999.
- [11] [Milojević S.](#): **“Primena alkoholnih goriva u automobilskim motorima”**, (Application of alcohol fuel in automotive Otto engines). Diplomski rad, Mašinski fakultet, Kragujevac, 1999. Mentor rada prof. dr Stevan P. Veinović.
Rad nagrađen od strane SCG Asocijacije za naftu i gas – YUNG, kao najbolji diplomski rad koji obrađuje problematiku od posebnog značaja za asocijaciju. Međunarodno savetovanje o nafti i gasu – YUNG 4P 2000, Vrnjačka Banja, Septembar 2000.
- [12] www.dieselnet.com/standards
- [13] Stover T.: **“Off – Road Engine Emissions: Bridging the Gap”**, Cummins Inc. 2000.
- [14] EUCAR: **“Presentation to OICA”**, Feb. 20, 2002.
- [15] Pavlović R., [Milojević S.](#): **“Ekološke karakteristike klasičnih i savremenih dizel motora” (Ecological Characteristic of Classic and Moderne Diesel Engines)**, XII International Scientific Symposium “Motor Vehicles and Engines”, Proceedings, YU–02056, Kragujevac, 7. – 9. October, 2002.
- [16] Petrović S., Popović V. i Tomić M.: **“Aktuelno stanje i problemi kontrole izduvne emisije motora”**, Simpozijum AE `03, Ulcinj 2003.
- [17] Pešić R.: **“Motori za vozila 3 litra / 100 km”**, Monografija, “Istraživanja u oblasti motora sus”, Laboratorija za motore sus, Mašinski fakultet u Kragujevcu, 2000. str. 329–351.
- [18] A Government – Industry Research Partnership: **“Technology Roadmap for the 21st Century Truck Program”**, U.S.A., December 2000.
- [19] Gruden D.: **“Goriva i ekologija vozila”**, Monografija, “Istraživanja u oblasti motora sus”, Laboratorija za motore sus, Mašinski fakultet u Kragujevcu, 2000. god., str. 53–79. Monografiju priredio prof. dr Radivoje B. Pešić.
- [20] Ahmed A.: **“Perspective du moteur automobile avec la problématique de réduction de CO₂”**, Reunion des Ingénieurs Arts et Métiers du Petrole, Institut Français du Pétrole, Paris, 12 juin 2002.
- [21] Hofbaner P.: **“Advanced Diesel Engines for the EU and US Automotive Markets”**, FEV Engine Technology, Inc. Aachen, 2002.
- [22] Reyhofen G. P.: **“The Truck of the Future”**, Auto Technology, International Magazine for Engineering, Production and Management, Volume No. 2, October 2002., p. 46–49, EAEC.

- [23] Pischinger F. and Walzer P.: **“Future Engine Technologies for Passenger Cars”**, Auto Technology, International Magazine for Engineering, Production and Management, Volume No. 3, February 2003, p. 92–95, EAEC.
- [24] ACEA: **“Report on small particle emissions from passenger cars”**, 1999.
- [25] Volkswagen AG: **“Environmental Report 2001/2002”**, Wolfsburg, 1st Edition, 12/2001.
- [26] Hoerner v. R.: **“Technologies to meet future emission standards with heavy duty engines”**, MAN Nutzfahrzeuge Aktiengesellschaft, München, 2002.
- [27] Pešić R., [Milojević S.](#) i Veinović S.: **“Periodi zamene motornih ulja – poređenje mineralnih, polusintetskih i potpuno sintetskih”**, (**Drain Intervals for Engine Oil-Mineral, Semi and Full Synthetic Lubricants**). 8th International Tribology Conference, 8. – 10. October 2003., Belgrade, Serbia.
- [28] Frank W., Hüthwohl G. and Neumann P.: **“Sintered Metal Filter for Commercial Vehicle Exhaust Aftertreatment”**, Auto Technology, International Magazine for Engineering, Production and Management, Volume No. 2, October 2002, p. 54–56, EAEC.
- [29] Mahr B., Polach W. and Ripper W.: **“Dosing system for reducing agent of SCR catalysts”**, Technical Congress, VDA, Frankfurt, 28. – 29. September, 2000.
- [30] Robert Bosch GmbH: **“Diesel Fuel-Injection Systems Unit Injector System / Unit Pump System”**, Technical Instruction, Stuttgart, 1st Edition, March 2000.
- [31] Combe R., Amblard A. et Allio P.: **“Unit Injector UI2: La nouvelle génération d'injecteur-pompe pour moteurs 4 soupapes”**. Congrès Le diesel: aujourd'hui et demain – Page 1 sur 12; Ecole centrale Lyon – 12 et 13 mai 2004.
- [32] Knežević D., Petrović S. i Matejić M.: **“Uticaj sistema EGR na korelaciju NO_x-dim i NO_x-HC kod dizel motora sa direktnim ubrizgavanjem”**, XII International Scientific Symposium “Motor Vehicles and Engines”, Proceedings, YU-02053, Kragujevac, 7. – 9. October, 2002.
- [33] Pešić R., Veinović S. i Petković S.: **“Motorna vozila i motori – oprema”**, knjiga u pripremi, Kragujevac 2005. godine.
- [34] Decker G.: **“The Potential of Alternative Fuels and Adapted Concepts”**, Volkswagen AG, Wolfsburg, 1997.
- [35] Mortimer J.: **“Audi set to follow Ford in use of CGI for diesels”**, Auto Technology, International Magazine for Engineering, Production and Management, Volume No. 2, April 2002, p. 32–35, EAEC.
- [36] Metz N. and Cozzarini C.: **“Hydrogen – The BMW Strategy on Future Fuels”**, Auto Technology, International Magazine for Engineering, Production and Management, Volume No. 3, February 2003, p. 60–63, EAEC.
- [37] Volkswagen AG: **“Environmental Report 1997”**, Wolfsburg, 1st Edition, 10/1997.
- [38] Gruden D.: **“Future Ecological Requirements in Automobile Industry”**, Mobility & Vehicles Mechanics, International Journal for Vehicle Mechanics, Engines and Transportation Systems, Volume 28, Number 1 & 2, March – June 2002. p. 45–68. Faculty of Mechanical Engineering in Kragujevac, Serbian and Montenegro Society of Automotive Engineers.
- [39] Pešić R.: **“Prilog povećanju ekonomičnosti oto motora, promenljivim stepenom sabijanja”**, Magistarska teza, Mašinski fakultet, Kragujevac, 1985.
- [40] www.mce-5.fr
- [41] Schwaderlapp M., Habermann K. and Yapici I. K.: **“Variable Compression Ratio – A Design Solution for Fuel Economy Concepts”**, presented as SAE Technical Paper 2002-01-1103, FEV Motorentchnik GmbH, Aachen, Germany, 2002.
- [42] Махалдиани В. В., Эджибия И. Ф. и Леонидзе А. М.: **“Двигатели внутреннего сгорания с автоматическим регулированием степени сжатия”**, Мецниереба, Тбилиси, 1973.
- [43] Sobotowski R., Porter C. B. And Pilley D. A.: **“The Development of a Novel Variable Compression Ratio, Direct Injection Diesel Engine”**, SAE Technical Paper 910484, Detroit, Michigan, February, 1991.
- [44] [Milojević S.](#), Pavlović R.: **“Istraživanje primene automatski promenljivog stepena kompresije kod dizel motora”**, (Research of a Using Diesel Engine with Automatic

- Variable Compression Ratio**). XIII International Scientific Symposium "Motor Vehicles and Engines", Proceedings, MVM04–B20, Kragujevac, 04. – 06. October, 2004.
- [45] Min. L. A.: **"Four – Stroke Internal Combustion Engines with Variable Compression Ratios to Produce High Supercharging Pressures (Perspects and Advances) "**. Master Thesis, Promoter Prof. Dr. Marc Van Overmeire; Vrije Universiteit, Brussel, 1998.
- [46] Wirbeleit F. G., Binder K. and Gwinner D.: **"Development of Pistons with Variable Compression Height for Increasing Efficiency and Specific Power Output of Combustion Engines"**, SAE Technical Paper 900229, Daimler – Benz AG, Research Labs.
- [47] Brevick J. and Howden K.: **"Pressure Reactive Variable Compression Ratio Piston Development"**, Combustion and Emission Control for Advanced CIDI Engines, FY 2000 Progress Report, p. 45–49, U.S.A. DOE.
- [48] Brevick J. and Howden K.: **"Desing and Development of a Pressure Reactive Piston (PRP) to Achieve Variable Compression Ratio"**, Combustion and Emission Control for Advanced CIDI Engines, FY 2002 Progress Report, p. 154–159, U.S.A. DOE.
- [49] Mendler C. and Gravel R.: **"Variable Compression Ratio Engine"**, SAE Technical Paper 2002–01–1940, presented on 2002. Future Car Congress, Arlington, Virginia, June 3–5, 2002.
- [50] Cuenca R., Roehm C., Mendler C. and Gravel R.: **"Variable Compression Ratio Engine Technology"**, Vehicle Systems Programs, FY 2000 Progress Report, U.S.A. DOE.
- [51] EU Project (G3RD–CT–1999–00004): **"Variable compression ratio for CO₂ – reduction of gasoline engine"**, Projekat odobren 2002–09–10.
- [52] Pischinger S., Habermann K., Imren K., Baumgarten H. and Kemper H.: **"On the Road Consequent Downsizing Engine with Continuously Variable Compression Ratio in a Demonstration Vehicle"**, Motortechnische Zeitschrift MTZ, 5/2003, p. 398–405, Wiesbaden.
- [53] Bergsten L.: **"Saab Variable Compression SVC – Variabilität und Kontrolle"**, Motortechnische Zeitschrift MTZ, 6/2001, p. 424–431, Wiesbaden.
- [54] Saab Information: **"Saab Variable Compression"**, Geneva, 28 February, 2000.
- [55] Nilsson Z.: **"Cylinder volume function for SVC engines"**, Department of Electrical Engineering, Vehicular Systems, Linköping University, 2001.
- [56] Bergström A.: **"Torque Modeling and Control of a Variable Compression Engine"**; Master's thesis, performed in Vehicular Systems, Reg nr.: LITH–ISY–EX–3421–2003; Linköping, April 2003. Supervisor: P. Andersson; Examiner: Assistant professor L. Eriksson.
- [57] Unknown Autor: **"Fundamental Research in Russia on Development of Engines with Variable Compression Ratio"**.
- [58] Gheorghiu V.: **"Variable Compression Ratio (VCR) Crank Mechanism"**, University of Applied Sciences Fachhochschule, Hamburg, 2002.
- [59] www.mayflower-e3.com
- [60] Webb A.: **"A piston revolution"**, Engineering Management Journal, p. 25–30, February 2002.
- [61] National Standard ISO 5165: 1998 (E).
- [62] Демидов Б. П.: **"Двигатели с переменной степенью сжатия"**, Машиностроение, Москва, 1978.
- [63] www.alvar-engine.se
- [64] Erlandsson O.: **"Alvar – Engine A Engine with Variable Compression Ratio"**. Master Thesis, Lund Institute of Technology, Sweden, 1998.
- [65] Erlandsson O.: **"Thermodynamic Simulation of HCCI Engine Systems"**, Doctoral Thesis, Lund Institute of Technology, Department of Heat and Power Engineering, Sweden, 2002.
- [66] Erlandsson O., Lundholm G., Söderberg F., Johansson B. and Wong W. V.: **"Demonstrating the Performance and Emission Characteristic of a Variable Compression Ratio, Alvar – Cycle Engine"**, SAE Technical Paper 982682.
- [67] Erlandsson O., Einewall P., Johansson B., Amneus P. and Mauss F.: **"Simulation of HCCI – addressing compression ratio and turbo charging"**, SAE Technical Paper 2002 – 01 – 2862.

- [68] Walzer P. und Seiffert U.: **“Variable Verdichtung Motor”**, MTZ Nr. 4 (1986), p. 15–20.
- [69] Adamis P., Heinrich H. und Walzer P.: **“Ottomotor mit variablem Verdichtungsverhältnis”**, Automobil – Industrie 4/85, p. 439–444.
- [70] Petrović S., Jankov R., Tomić M., Filipi Z., Pušonja M. i Jovanović Z.: **“Modeliranje sagorevanja u oto – motoru”**, Mašinski fakultet, Beograd, 1995.
- [71] Radonjić D. i Pešić R.: **“Toplotni proračun motora sus”**, Mašinski fakultet, Kragujevac, 1996.
- [72] Jankov R.: **“Matematičko modeliranje strujno – termodinamičkih procesa i pogonskih karakteristika dizel – motora”**, Naučna knjiga, Beograd, Septembar 1984.
- [73] User’s Guide: **“AVL Boost, Version 4.0”**, AVL List, GmbH, Graz, May 2002.
- [74] Tomić M. and Petrović S.: **“Spark Ignition Engine Part Load Fuel Economy Improvement: Numerical Consideration”**, FME Transactions, Vol. 31, Number 1, Faculty of Mechanical Engineering, Belgrade, 2003, p. 21–25.
- [75] Tomić M.: **“Identifikacija parametara matematičkog modela motora”**, Monografija, “Istraživanja u oblasti motora sus”, Laboratorija za motore sus, Mašinski fakultet, Kragujevac, 2000. str. 191–213. Monografiju priredio prof. dr Radivoje B. Pešić.
- [76] Gastaldi P., Argueyrolles B., Passerel D. and Truant M.: **“3D Simulation for the Development of CR Diesel Combustion Chambers”**, Auto Technology, International Magazine for Engineering, Production and Management, Volume No. 3, June 2003, p. 40–43, EAEC.
- [77] Willems W., Heuvel van den B., Sommerhoff A., Krämer F. and Karvounis E.: **“Computational Methods for Diesel Combustion System Development”**, Auto Technology, International Magazine for Engineering, Production and Management, Volume No. 2, April 2002, p. 64–66, EAEC.
- [78] Pischinger S.: **“Verbrennungsmotoren”**, Lehrstuhl für Verbrennungskraftmaschinen, Rheinsch – Westfälische Technische Hochschule Aachen, 1998.
- [79] Cvetić M.: **“Predviđanje emisije NO i čađi kod dizel – motora sa direktnim ubrizgavanjem pomoću fenomenološkog modela sagorevanja”**, XI International Scientific Symposium “Motor Vehicles and Engines”, Proceedings, p. 353–356, Kragujevac, 5. – 7. October, 2000.
- [80] Hiroyasu H. and Kadota T.: **“Models for Combustion and Formation of Nitric Oxide and Soot Emission Engines by Using Phenomenological Simulation”**, SAE Technical Paper 760129, 1976.
- [81] Mattes P., Rimmels W. und Sudmanns H.: **“Untersuchungen zur Abgasrückführung am Hochleistungsdieselmotor”**, Automobiltechnische und Motortechnische Zeitschrift ATZ – MTZ, Nr. 4, April 1999. p. 424–431, Wiesbaden.
- [82] Stiesch G., Eiglmeier C., Merker G. P. und Wirbeleit F.: **“Möglichkeiten und Anwendung der Phänomenologischen Modellbildung im Dieselmotor”**, Automobiltechnische und Motortechnische Zeitschrift ATZ – MTZ, Nr. 4, April 1999. p. 274 – 284, Wiesbaden.
- [83] Barba C., Burkhardt C., Boulouchos K. und Bargende M.: **“Empirisches Modell zur Vorausberechnung des Brennverlaufes bei Common – Rail – Diesel – Motoren”**, Automobiltechnische und Motortechnische Zeitschrift ATZ – MTZ, Nr. 4, April 1999. p. 262–270, Wiesbaden.
- [84] Davinić A.: **“Analiza mogućnosti smanjenja emisije čestica dizel motora”**, Magistarska teza, Mašinski fakultet, Kragujevac, 1995.
- [85] Davinić A.: **“Emisija čestica dizel motora –Problematika i mogućnosti njenog snižavanja–”**, Monografija, “Istraživanja u oblasti motora sus”, Laboratorija za motore sus, Mašinski fakultet, Kragujevac, 2000. str. 419–442. Monografiju priredio prof. dr Radivoje B. Pešić.
- [86] Fraidl K. G. und Herzog P.: **“Otto & Dieselmotoren Perspektiven für die Zukunft”**, 16. Internationaler AVL Kongress "Motor & Umwelt", 9. – 10. September 2004, Graz, Österreich, p. 100 – 121.
- [87] Davinić A. i Tešić A.: **“Ispitivanje uticaja stepena kompresije na mehaničke gubitke motora”**, Elaborat br. 01/97, Mašinski fakultet, Kragujevac 1997 god.
- [88] Гершман И. И. и Лебединский А. П.: **“Многотопливные дизели”**, Машиностроение, Москва, 1971.

- [89] Pešić R., Golec K., Hnatko E., Kaleli H. and Veinović S.: **“Experimental Engine with flexible Otto or Diesel cycle (VCR – Variable Compression Ratio)”**, 6th Conference and Exhibition, Koper/Portorož, Slovenija 24. – 25. april 2003., page 281–289.
- [90] Davinić A., Pešić R. i Veinović S.: **“Novi koncept motora za realizaciju oto i dizel procesa u istom cilindru”**, XIII International Scientific Symposium “Motor Vehicles and Engines”, Proceedings, MVM04–B12, Kragujevac, 04. – 06. October, 2004.
- [91] Walter B. and Gatellier B.: **“Near Zero NO_x Emissions and High Fuel Efficiency Diesel Engine: the NADI™ Concept Using Dual Mode Combustion”**, Oil & Gas Science and Technology – Rev. Vol. 58, No. 1, Institut Français du Pétrole, Paris, 2003., p. 101 – 114.
- [92] Walter B., Monteiro L. Miche M. and Gatellier B.: **“Improvement of Exhaust and Noise Emissions of the NADI™ Concept Using Pre – Mixed Type Combustion with Multiple Stages Injections”**, Congrès Le diesel: aujourd'hui et demain – Page 1 sur 18; Ecole centrale Lyon – 12 et 13 mai 2004.
- [93] Pešić R., Veinović S., Hnatko E. and Golec K.: **“Environmental challenges to the passenger car powerplant of the future”**, “Mobility and Vehicle Mechanics”, International Journal for Vehicle Mechanics Engines and Transportation Systems, Volume 25, Number 1, YU ISSN 1450–5304, March 1999. Kragujevac.
- [94] Pešić R., Veinović S. i Davinić A.: **“Prirodni gas kao sirovina i gorivo za motorna vozila”**, XII International Scientific Symposium “Motor Vehicles and Engines”, Proceedings, YU– 00015, Kragujevac, 7. – 9. October, 2002.
- [95] Pešić R., Veinović S. i Davinić A.: **“Motorske karakteristike gasovitih goriva”**, Međunarodno savetovanje o nafti i gasu – YUNG 4P 2002, “U tranziciju znanjem”, Zbornik radova, strana 27–33, Septembar 2002, Novi Sad.
- [96] Veinović S., Pešić R., i Pavlović R.: **“Razvoj dizel motora u svetu i kod nas”**, X naučni skup JUMTO, Pravci razvoja traktora i mobilnih sistema, Decembar 2003., Novi Sad.
- [97] Weidmann K.: **“Anwendung von Rapsöl in Fahrzeug–Dieselmotoren”**, Volkswagen AG, Wolfsburg, 1997.
- [98] “21 maj”, Fabrika malolitražnih motora: **“Uputstvo za rukovanje i održavanje motora 3 LD 450”**, Beograd, 2003 godine.
- [99] **“Handbuch für hydraulische Leistungsbramse Größe U1–16h”**, Fert. –Nr. LLF0291; Carl Schenck Maschinenfabrik, GmbH Darmstadt, 1961.
- [100] Handling Instructions: **“Quartz Pressure Transducers QC32D, QH32D for high-precision thermodynamic indicating in IC engines”**, AVL List GmbH, Graz, 01/2004.
- [101] Engine Instrumentation – Operating Instructions: **“AVL IndiCom Indicating Software Version 1.2”**, AVL List GmbH, Graz, November 2002.
- [102] Engine Instrumentation – Operating Manual: **“AVL Angle Encoder 365CC”**, AVL List GmbH, Graz, January 2003.
- [103] Pischinger R.: **“Engine Indicating”**, University of Technology, Graz, January 2002.
- [104] Engine Diagnostics – Operating Manual: **“AVL DiGas 4000, AVL DiCom 4000 and AVL DiSmoke 4000 for software version 1.02”**, AVL Ditest GmbH, Graz, 03/2001.
- [105] Engine Instrumentation – Operating Instructions: **“AVL Indimeter 619 Hardware”**, AVL List GmbH, Graz, December 2002.
- [106] Engine Power Test Code – Spark Ignition and Compression Ignition: **“Gross Power Rating”**, SAE J1995 JUN90, SAE Standard.
- [107] Engine Power Test Code – Spark Ignition and Compression Ignition: **“Net Power Rating”**, SAE J1349 JUN90, SAE Standard.
- [108] Drumska vozila – ISPITIVANJE MOTORA – Neto snaga: **“J U S M.F.2.025”**, Savezni zavod za standardizaciju, Beograd 1982.
- [109] Council of the European Union: **“Proposal for a Directive of the European Parliament and of the Council on the approximation of the laws of the Member States relating to the measures to be taken against the emission of gaseous and particulate pollutants from compression–ignition engines for use in vehicles, and the emission of gaseous pollutants from positive–ignition engines fuelled with natural gas or liquefied petroleum gas for use in vehicles”**, Brussels, October 2003.

- [110] United Nations – Economic and Social Council – Economic Commission for Europe: **“Draft 03 Series of Amendments to Regulation No. 49 (Emissions of C.I., NG and P.I. (LPG) engines)”**, World Forum for Harmonization of Vehicle Regulations (WP.29), December 2002.
- [111] Paul J. C.: **“Emissions and Efficiency Targets: Advanced Technology Reciprocating Internal Combustion Engines”**, Ricardo Inc., England, 2001.
- [112] Engine Instrumentation – Application Notes: **“Measurement of Smoke Values With the Filter Paper Method”**, AVL List GmbH, Graz, December 2001.
- [113] Emissions Test Instruments: **“AVL 415S Smoke Meter The New Correlation Curve”**, AVL List GmbH, Graz, October 2002.
- [114] An American National Standard: **“Diesel Engine Smoke Measurement – SAE J255 Reaffirmed February 1995”**, SAE Standard.
- [115] Numata A., Nagae Y., Kumagai T. and Osafune S.: **“Increase of Thermal Efficiency and Reduction of NO_x Emissions DI Diesel Engines”**, Mitsubishi Heavy Industries, Ltd. Technical Review Vol. 38 No. 3, October 2001., Nagasaki, p. 136 – 140.
- [116] List H.: **“Emissionsverbesserung von direkteinspritzenden Dieselmotoren durch Formung des Einspritzverlaufs”**, Abschluß – ind Zwischenberichte der Forschungsstellen, gehalten auf der Informationstagung der FVV am 16. September 1988. in Karlsruhe, p. 148 – 168.
- [117] Gruden D., Hahn R. und Lörcher H.: **“Sekung des Kraftstoffverbrauches durch Thermodynamische Optimierung des Otto – Motors (Vergleichende Untersuchungen Otto – Dieselmotor)”**, Dr. –Ing.h.c.F. Porsche AG, Entwicklungszentrum Weissach Bundesrepublik Deutschland.