UDK 621.43.038

Zajemanje in obdelava podatkov na preizkuševališčih sistemov za vbrizgavanje goriva

Data Acquisition and Data Processing on the Fuel Injection System Test Stand

IGOR ŠAUPERL — ŽELIMIR DOBOVIŠEK — ANTON ČERNEJ

Sodobno preizkušanje sistemov za vbrizgavanje goriva (SVG) zahteva natančno vzorčenje in hitro obdelavo podatkov, s katerimi se odločamo o mogočih posegih, da bi SVG prilagodili motorju in bi ta izpolnjeval tržne zahteve, predvsem pa vse ostrejše predpise s področja emisije. Obe omenjeni zahtevi sta izpolnjeni le, če je postopek preizkušanja ustrezno računalniško podprt. V Laboratoriju za termoenergetske stroje, tehniške meritve in motorna vozila na Tehniški fakulteti Univerze v Mariboru smo zasnovali računalniško podprt postopek in v ta namen sestavili sistem za zajemanje in obdelavo podatkov. Zaradi posebnosti procesa vbrizgavanja, kamor sodijo časovno hitro spreminjajoče se veličine, ki jih moramo upoštevati, da lahko analiziramo glavne parametre vbrizgavanja, smo razvili lastno programsko opremo, ki omogoča nadzorovanje preizkušanja in vrednotenje preizkušanja SVG. Z omenjeno opremo lahko preizkušamo SVG na preizkuševališču in brez posebnih posegov v strojno ali programsko opremo, tudi prigrajenega motorju.

Accurate sampling and fast data processing are demands that have to be considered in up-to-date testing of fuel injection systems (FIS). With the support of fuel injection system testing data it is possible to improve the FIS, to satisfy market requirements and exhaust emission regulations, which are becoming more strict year by year. A computer aided testing procedure has been designed at the Engine Research Laboratory of the Faculty of Engineering of the University of Maribor and a concept of a PC-based data acquisition and processing system, including software, has been developed, concerning the specific characteristics of the fuel injection process, and hardware and software have been integrated into a powerful data acquisition and processing system (DAPS). The data acquisition procedure has been standardized, enabling the DAPS to be used for FIS testing on the test stand as well as on the engine, without any modifications.

0. UVOD

Vse strožjim ekološkim predpisom, ki so začeli veljati v letu 1992, posebej pa tistim, ki so pripravljeni za leto 1995 [1], lahko zadostimo na dva načina: s posegi v motor ali z dodatno opremo k motorju. Če se odločimo za posege v motorju, se je pri dieselskih motorjih pametno lotiti sistema za vbrizgavanje goriva, saj ta omogoča neposredni nadzor emisije.

Eden od načinov je prilagajanje SVG zahtevam motorja in veljavnim predpisom. Končni cilj je prikrojiti določeni SVG motorju tako, da bo slednji izpolnjeval tako ekonomska (cena, teža in izmere, poraba goriva, zanesljivost, doba trajanja, izhodne karakteristike) kakor tudi socialna (emisija izpušnih plinov, delci v izpuhu, hrup, nihanja, vzdrževanje) tržna merila. Pojem prilagajanje oziroma prikrojevanje je treba razumeti kot vrsto posegov v SVG, s katerimi izboljšujemo lastnosti sistema in s tem posredno motorja pa tudi zgolj odpravljanje pomanjkljivosti z enakim namenom. Sem

0. INTRODUCTION

ECE exhaust emission regulations for 1992 and 1995 [1] can be satisfied by engine optimisation or by adding external devices. Choosing the first option, the optimising interventions should be made on the fuel injection system in the first place, enabling direct exhaust emission control.

One of the approaches is FIS matching, considering engine demands and emission regulations. The aim of this approach is to tailor the FIS to the engine, to satisfy economic (price, weight and dimensions, fuel consumption, liability, life cycle, performances) and social (exhaust emission, particulates, noise, vibrations, maintenance) market criteria. The terms, matching and tailoring, have to be understood as a series of interventions on the FIS to improve its characteristics as well as indirectly to improve the engine performances. One of the first steps in this series is FIS testing, thus the judgement of correspondence and title of interventions is based on testing results seveda nujno sodi preizkušanje, saj analiza rezultatov omogoča presojo o ustreznosti in upravičenosti posegov [2]. Razviti sodoben računalniško podprt postopek za preizkušanje sistemov vbrizgavanja goriva, je bila naloga, ki smo si jo postavili v Laboratoriju za termoenergetske stroje in motorna vozila na TF v Mariboru [3].

1. RAČUNALNIŠKO PODPRT POSTOPEK PREIZKUŠANJA SISTEMOV ZA VBRIZGAVANJE GORIVA

Pri snovanju in izpeljavi celotnega postopka smo sledili načelom poteka sodobnega preizkušanja, ki je razdeljeno na *pripravljalno* in *izvedbeno fazo* (sl. 1). Po končani pripravljalni fazi, katere rezultat je bil ustrezno preizkušen sistem zajemanja in obdelave podatkov (strojna in programska oprema), lahko izvedbeno fazo — meritev, poljubno pogosto ponavljamo. Na tej stopnji se celotni postopek preizkušanja omeji zgolj na izvedbeno fazo in je odvisen le od uporabnika sistema. Preizkušanje poteka na standardnem preizkuševališču sistemov za vbrizgavanje goriva, opremljenim s sistemom za zajemanje in obdelavo podatkov (sl. 2).

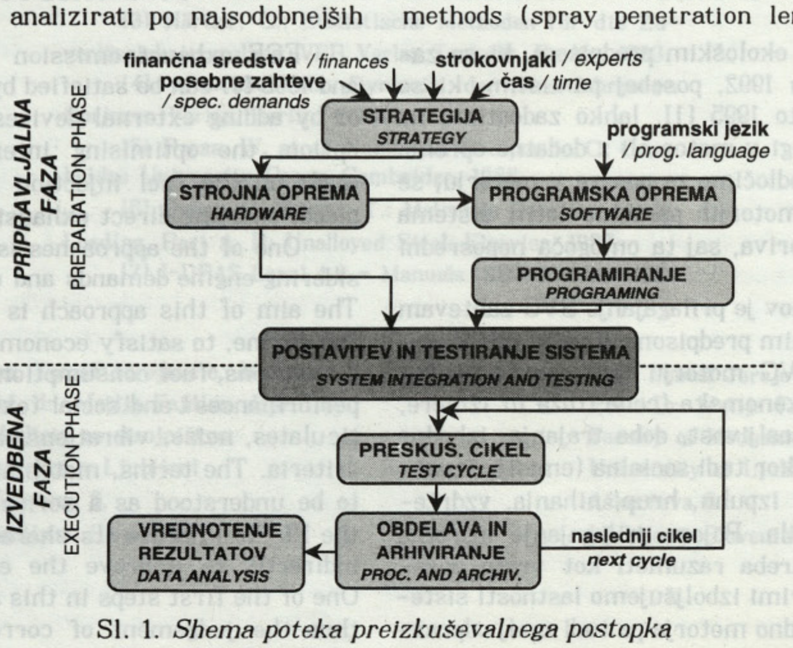
Na podlagi dolgoletnih izkušenj s preizkušanjem SVG smo se odločili opazovati tlak na začetku (p_I) in na koncu (p_{II}) visokotlačne cevi ter dvig igle (h_i) vbrizgalne šobe. Omenjeni trije parametri izpolnjujejo dve temeljni zahtevi: mogoče jih je preprosto vzorčiti in jih, neposredno ali obdelane, uporabiti za analiziranje preizkušanega SVG. Z izbiro teh treh veličin smo zadovoljili tudi dodatni zahtevi, postopek smo »standardizirali«, kar pomeni, da bomo vselej zajemali in obdelovali iste parametre in dobili rezultate, s katerimi je mogoče nastavljati SVG in ga analizirati po najsodobnejših

analysis [2]. So the main task at the Engine Research Laboratory at the Faculty of Engineering in Maribor has been to develop a Computer Aided FIS Testing Procedure [3].

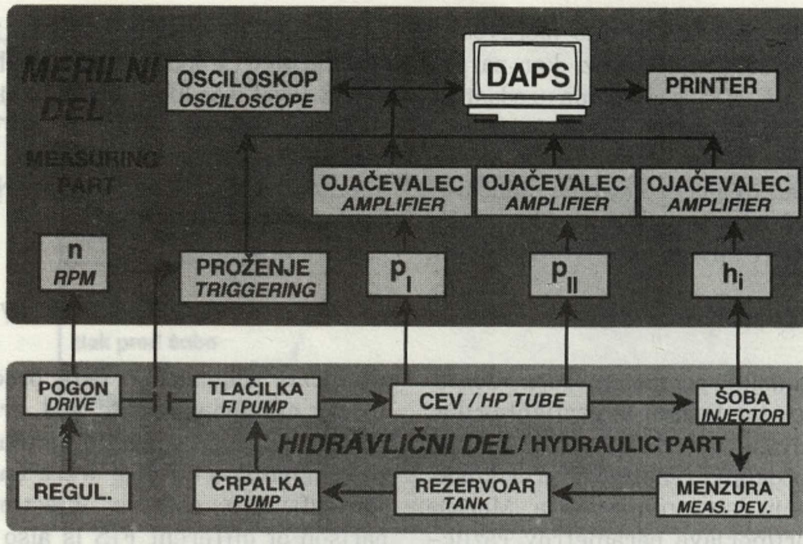
1. COMPUTER AIDED FUEL INJECTION SYSTEM TESTING PROCEDURE

Principles of up-to-date testing were followed in developing and realising the testing procedure. The whole procedure was divided into two major phases, *preparation* and *execution* (fig. 1). After the preparation phase had been finished by testing the DAPS (hardware and software), the FIS testing procedure was reduced to the execution phase. FIS testing is now depending on the system user only and can be repeated as required. FIS are tested on a standard FIS test stand, which is equipped with DAPS as shown on fig. 2.

The decision to acquire pressure at the beginning (p_I) and at the end (p_{II}) of the high pressure tube and the injector needle lift (h_i) was made on the basis of experience with FIS testing. Two major requirements are fulfilled by the mentioned three parameters, they can be acquired simply and they can be used, directly or processed, to analyse the tested FIS. An additional requirement has been satisfied by choosing those parameters: the procedure has been »standardised«. This means that the same parameters will be measured and processed, so that the FIS can be adjusted and analysed by the latest methods (spray penetration length, atomisation,



Sl. 1. *Shema poteka preizkuševalnega postopka*
Fig. 1. *Testing procedure flow chart*



Sl. 2. *Shema preizkuševališča sistemov za vbrizgavanje goriva*
Fig. 2. *Fuel injection system test stand*

zahtevah (domet curka, atomizacija, količina vbrizganega goriva v različnih fazah, razmerje srednji/največji tlak itn.), ne glede na to, ali bo preizkušanje potekalo v preizkuševališču ali na samem motorju.

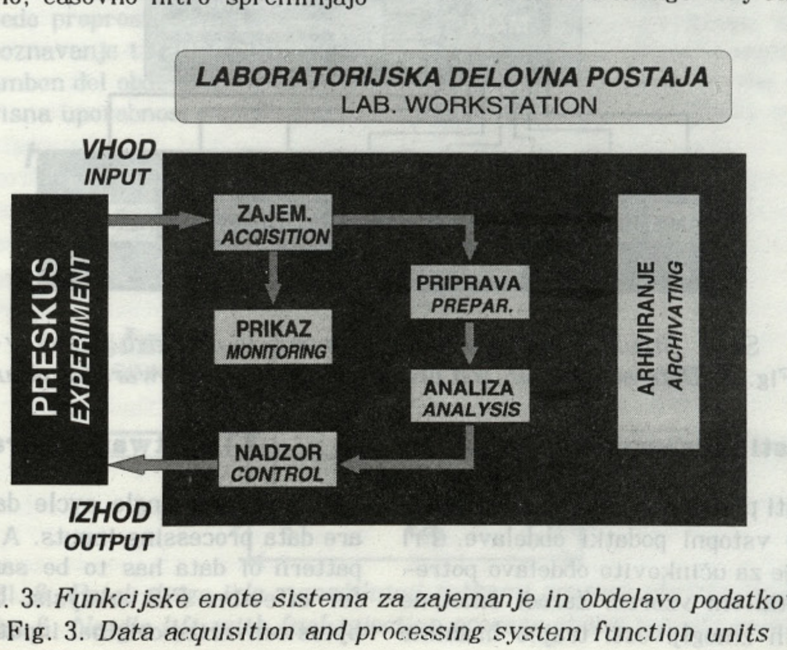
2. STROJNA OPREMA

Sistem za zajemanje in obdelavo podatkov sestavljajo različne delovne enote, prikazane na sliki 3. V laboratoriju smo se odločili za »vgrajeno« izvedbo. Za osnovo smo izbrali osebni računalnik, ki smo ga z vgradnjo vstopno-izstopnega vmesnika in analogno-digitalnega pretvornika razširili v zmogljiv sistem za zajemanje in obdelavo podatkov, ne da bi pri tem okrnili njegovo glavno funkcijo. Pri izbiri pretvornika smo upoštevali, da se veličine, ki jih zajemamo, časovno hitro spreminjajo

amount of fuel injected in different phases of injection, pressure rate etc.), no mater whether the FIS is tested on the test stand or on a running engine.

2. DAPS HARDWARE

The Data Acquisition and Processing System is composed according to fig. 3. The decision in favour of so called »on-board system« version was made at the Engine research Laboratory. A PC base was extended to efficient DAPS by adding I/O interface and A/D converter, without interfering with any of its primary functions. In choosing the A/D converter, the acquired data characteristics (variables change very fast with time) were



Sl. 3. *Funkcijske enote sistema za zajemanje in obdelavo podatkov*
Fig. 3. *Data acquisition and processing system function units*

in se odločili za pretvornik z 12-bitno ločljivostjo in skupno frekvenco vzorčenja 1 MHz, kar za potrebe preizkušanja na TF popolnoma zadostuje (vrtilna frekvenca < 4000 min^{-1}, korak zajemanja ≥ 0,1° motorne gredi, raven signala 0 do 10 V). Problemu izgube podatkov pri prenosu po standardnem vodilu (PC-Bus) smo se izognili z 1 MB dinamičnega spomina (DRAM) na razširitveni plošči.

considered, as well as the real testing demands at the Faculty (< 4000 RPM, sampling step 0,1 °CAM, signal level 0 to 10V) and a 12 bit A/D Board with 1 MHz sustained sampling rate was chosen. Data loss during direct transfer to the memory over a standard PC-Bus was prevented by a 1 MB on-board buffer (DRAM).

3. PROGRAMSKA OPREMA

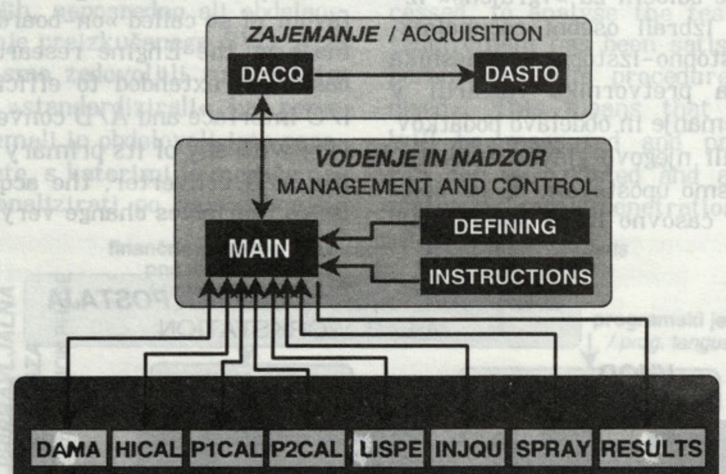
Vgrajena programska oprema omogoča vzorčenje, obdelavo podatkov ter izpisni in grafični prikaz rezultatov posameznega preizkuševalnega cikla, kakor tudi dodatno obdelavo rezultatov preizkušanja v celotnem območju delovanja motorja. Mogoča je tudi neposredna primerjava parametrov različnih SVG med seboj.

Programska oprema je bila izdelana s programskim orodjem ASYST in jo sestavljajo trije programski moduli: *zajemanje, obdelava* in *modul za vodenje in nadzor poteka* (sl. 4). Vsak modul je sestavljen iz več podprogramov in je zasnovan tako, da ga je mogoče po potrebi razširiti z dodatnimi in s tem povečati zmogljivost oziroma področje uporabe celotnega sistema. Omenjena je tudi poglavitna prednost predstavljene zasnove sistema, saj ta ostaja »odprt« in ga je moč dopolnjevati in prirejati potrebam eksperimentalnega dela.

3. DAPS SOFTWARE

Data acquisition, data processing and monitoring of alphanumeric and graphic single cycle results as well as additional data processing over the engine speed range were enabled by the built-in software. A direct injection parameter comparison of different FIS is also possible.

DAPS software was developed using the ASYST programming tool. It is composed of three program modules, acquisition, processing and procedure management and control (Fig. 4). Each of the mentioned modules is composed of subroutines and is designed to be extended by additional subroutines to increase the capacity or application range of the system if necessary. DAPS remains open for possible completion or adaptation to experiment demands, which is the main advantage of the presented system architecture.



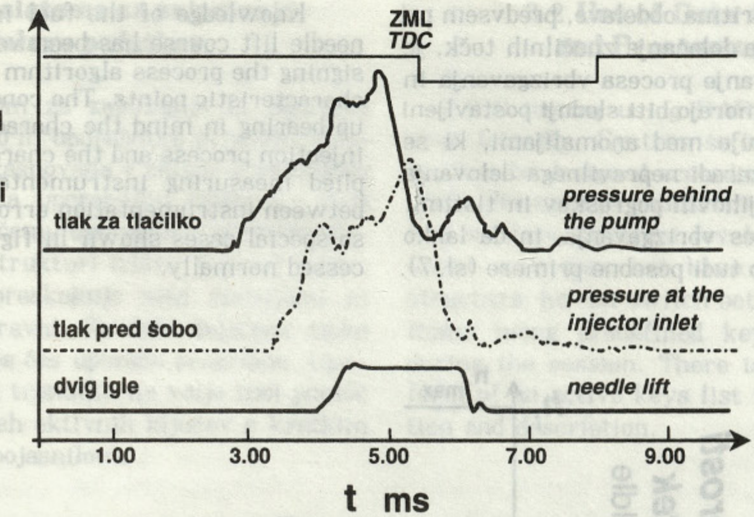
Sl. 4. *Struktura programa za zajemanje in obdelavo podatkov*
Fig. 4. *Data acquisition and processing system software structure*

3.1 Značilnosti programske opreme

Zajete vrednosti posameznega preizkuševalnega cikla (sl. 5) so vstopni podatki obdelave. Pri preizkušanju SVG je za učinkovito obdelavo potreben velik reprezentativni vzorec. Zaradi smotrne izrabe računalniških zmogljivosti trajno hranimo

3.1 Software Characteristics

Acquired single cycle data shown in Fig. 5 are data processing inputs. A large representative pattern of data has to be sampled and processed for effective FIS analysis. Using DAPS only in bytes converted original input data of type integer



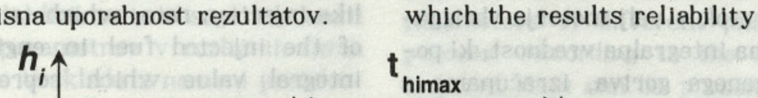
Sl. 5. *Potek zajetih vrednosti*
Fig. 5. *Acquired injection variables*

le vstopne podatke, torej v bajte pretvorjene zajete vrednosti, ki zaradi svoje narave (cela števila) zasedajo najmanj spominskega prostora. Vmesnih in končnih rezultatov ne hranimo, saj je čas obdelave zanemarljivo kratek, hkrati pa imamo vselej dostop do izvirnih izmerjenih vrednosti, ki jih lahko uporabimo tudi v druge namene, na primer za oceno uporabnosti različnih simuliranj vbrizgavanja.

Celotni proces vbrizgavanja je treba, zaradi različnega vpliva začetka, trajanja in konca vbrizgavanja na proces zgorevanja in s tem posredno na lastnosti motorja in njegovo ekološko sliko, premišljeno razdeliti na omenjene tri faze. Tak način omogoča boljšo analizo preizkušanega SVG in lažje odkrivanje pomanjkljivosti. Najpreprosteje je meje posameznih faz procesa vbrizgavanja določiti iz poteka zajetih vrednosti dviga igle (sl. 6), pri čemer pa je treba besedo preprosto pojmovati relativno. Pravilno prepoznavanje t.im. značilnih točk procesa je zelo pomemben del obdelave, od katerega je v veliki meri odvisna uporabnost rezultatov.

were stored permanently, so that the smallest area of the storage device would be occupied. Because of the very short running time, it was more rational to run the program again than fill the disk with results, when they were needed more than once. In addition, the same input (raw) data could be used further in injection modelling and by comparing the output with test results the models could be evaluated.

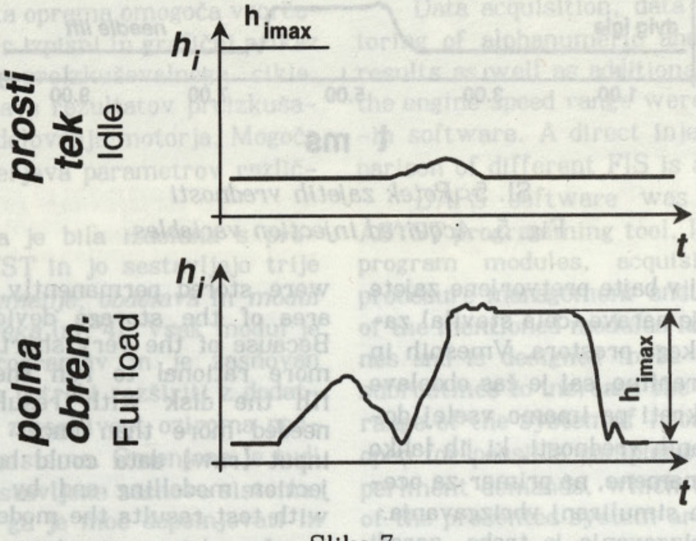
In order to get a better analysis of the tested FIS and better defects detection, and also because of the different influence of the beginning, duration and end of the injection process on the combustion and so on the engine performance and exhaust emission, the entire injection process was divided into the mentioned three main phases in the testing software. Single phase boundaries were set up using the acquired needle lift signal (Fig. 6). That was the simplest way, though simplicity in this concept is very relative. The correct recognition of these, so called characteristic points, was a very important step in the data processing, on which the results reliability very much depended.



Sl. 6. *Potek dviga igle z značilnimi točkami procesa vbrizgavanja*
Fig. 6. *Needle lift with fuel injection process characteristic points*

Pri snovanju algoritma obdelave, predvsem pri postavljanju pogojev za določanje značilnih točk, je koristno dobro poznavanje procesa vbrizgavanja in poteka dviga igle, saj morajo biti slednji postavljeni tako, da program ločuje med anomalijami, ki se pojavljajo na primer zaradi nepravilnega delovanja merilnih naprav ali njihovih pogreškov in tistimi, katerih vzrok je proces vbrizgavanja, in da lahko brez težav spremljamo tudi posebne primere (sl. 7).

Knowledge of the fuel injection process and needle lift course has been very important in designing the process algorithm and determining the characteristic points. The conditions have to be set up bearing in mind the characteristics of the fuel injection process and the characteristics of the applied measuring instrumentation, to distinguish between instrumentation error and FIS behaviour, so special cases shown in fig. 7 can also be processed normally.



Slika 7

a) spodnji prosti tek - igla vbrizgalne šobe ne doseže največjega dviga
b) polna obremenitev pri nizkih vrtilnih hitrostih (primer) - igla vbrizgalne šobe doseže največji dvig pri drugem dvigovanju

Figure 7

a) idle - no injector needle lift maximum
b) full load and low speed (example) - injector needle lift maximum in second lifting

Nekatere parametre vbrizgavanja (dejanski kot predvbrizga, trajanje vbrizgavanja in srednji tlak) je mogoče določiti neposredno iz zajetih vrednosti, druge, npr.: hitrost vbrizgavanja (karakteristika), ki je prostorninski pretok v valj motorja vbrizganega goriva ali pa njena integralna vrednost, ki pomeni količino vbrizganega goriva, izračunamo s poenostavljenim matematičnim modelom.

Poleg omenjenih glavnih parametrov vbrizgavanja omogoča programska oprema tudi določanje najpomembnejših parametrov curka, med katere spadajo srednji Sauterjev premer kapljic, domet curka, kot pri vrhu curka in razmerje mase zraka in goriva v curku. Vrednosti teh parametrov moramo obravnavati posebej kritično, saj algoritem obdelave temelji na različnih eksperimentalnih modelih, ki so bili postavljeni v določenih obratovalnih razmerah, ki pa pri preizkušanju navadno niso izpolnjene. Bolj kakor absolutne vrednosti nas zanimajo spreminjanja omenjenih parametrov, ki dopolnjujejo sliko o preizkušanem SVG.

Some of the main FIS parameters (injection delay, duration, mean pressure) could be determined directly from the acquired data. Others, like injection rate, which is the volumetric flow of the injected fuel in engine cylinder, or its integral value which represents injected fuel amount (fuelling), however, were calculated with a simple mathematic model.

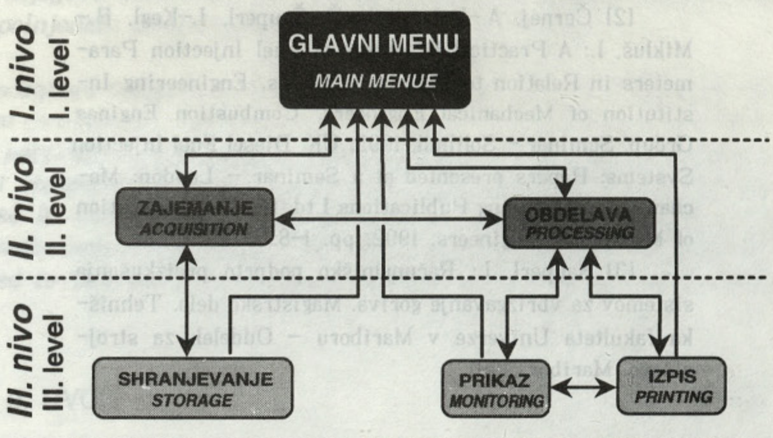
In addition, the mentioned fuel injection parameters, the most important parameters of the fuel spray structure, such as the Sauter diameter, spray penetration length, spray angle as well as air/fuel mass rate of the spray, were estimated while running the program. Those parameters were calculated according to different spray models based on experimental results under particular operating conditions, which is why they have to be treated critically. Not absolute values but trends were used to complete the picture of the tested FIS.

3.2 Uporaba sistema za zajemanje in obdelavo podatkov

Delo s sistemom za zajemanje in obdelavo podatkov je preprosto in uporabniku prijazno. Programska oprema je zasnovana v skladu s sodobnimi standardi in omogoča uporabniku izbiro na treh stopnjah (sl. 8). Veščemu uporabniku ni treba vselej slediti drevesni strukturi izbire, temveč lahko, seveda pomensko, preskakuje med stopnjami in funkcijami na isti ravni. Za delo določene tipke (ključ) so aktivne ves čas uporabe programa. Uporabniku je v vsakem trenutku na voljo tudi pomoč v obliki seznama vseh aktivnih ključev s kratkim navodilom oziroma pojasnilom.

3.2 Use of Data Acquisition and Processing System

FIS testing using DAPS is very simple and user friendly. System software is menu driven and has be designed according to up-to-date standards. Its user is enabled to choose between menus on three different levels (Fig. 8). An experienced user does not have to follow the menu structure; he can switch between levels and menu items using predefined keys which are active during the session. There is also on-line help in form of an active keys list with a short explanation and description.



Sl. 8. *Drevesna struktura izbire programske opreme*
Fig. 8. *Software menu tree structure*

Rezultate preizkušanja je mogoče prikazovati na zaslonu in/ali jih izpisati s tiskalnikom. To velja tako za številčne vrednosti kakor za grafični prikaz poteka izračunanih ali vzorčenih vrednosti. Na trenutni stopnji razvoja programske opreme je izpis rezultatov standardiziran in obsega vrednosti zajetih in obdelanih parametrov v različnih fazah procesa vbrizgavanja. V skladu z nameni preizkušanja je mogoč prikaz poteka vseh zajetih parametrov in vsakega posebej, poleg tega pa tudi poteka karakteristike vbrizgavanja, količine vbrizganega goriva ter srednjega Sauterjevega premera kapljic v curku vbrizganega goriva.

4. SKLEP

Predstavljeni računalniško podprt postopek preizkušanja sistemov za vbrizgavanje goriva, oziroma v ta namen razviti sistem za zajemanje in obdelavo podatkov, omogoča zanesljivo preizkušanje SVG za potrebe raziskav in razvoja. Zasnova sistema na temelju osebnega računalnika se odlikuje

The acquired data, as well as alphanumeric and graphic testing results, can be displayed on the screen or/and printed out. At the present stage of software development, the printouts were standardised and include acquired and processed parameters of different phases of the injection process. According to the aim of testing, each acquired item can be presented separately or all together, as well as the injection rate, fuelling and mean Sauter diameter of the droplets in the fuel spray.

4. CONCLUSION

Following the computer aided testing procedure and using the data acquisition and processing system presented in the paper, efficient and reliable fuel injection system testing can be carried out. Low costs, hardware and software compatibility and adaptability are the most significant advantages of the developed PC-based data acquisition and processing system. The same DAPS po razmeroma nizki nabavni ceni in visoki stopnji združljivosti, kar omogoča povečevanje zmogljivosti in prilagajanje različnim potrebam preizkušanja. Tak sistem je uporaben pri spremljanju različnih dinamičnih procesov na področju motorjev z notranjim zgorevanjem, pa tudi na drugih področjih energetike. Prikazani način ob dobri pripravi, močno skrajša trajanje preizkušanja in s tem znižuje stroške raziskav.

concept, adapted to current demands, can be used in different areas of mechanical engineering. By the described approach, along with good test planing, the FIS test duration is greatly shortened and the research costs are reduced.

5. LITERATURA
5. REFERENCES

[1] Ricardo Groups News — Future Concepts for Trucks, No. 38, 1989.

[2] Černej, A.–Dobovišek, Ž.–Šauperl, I.–Kegl, B.–Mikluš, I.: A Practical Diagnosis of Fuel Injection Parameters in Relation to Vehicular Diesels. Engineering Institution of Mechanical Engineers. Combustion Engines Group. Seminar — Solihull, 1992, UK. Diesel Fuel Injection Systems: Papers presented at a Seminar — London: Mechanical Engineering Publications Ltd. for The Institution of Mechanical Engineers, 1992, pp. 1–8.

[3] Šauperl, I.: Računalniško podprto preizkušanje sistemov za vbrizgavanje goriva. Magistrsko delo. Tehniška fakulteta Univerze v Mariboru — Oddelek za strojništvo, Maribor, 1991.

Naslovi avtorjev: mag. Igor Šauperl, dipl. inž.
prof. dr. Želimir Dobovišek, dipl. inž.
prof. dr. Anton Černej, dipl. inž.
prof. dr. Rudolf Pušenjak, dipl. inž
Tehniška fakulteta
Univerze v Mariboru
Smetanova 17
Maribor, Slovenija

Authors' Address: Mag. Igor Šauperl, Dipl. Ing.
Prof. Dr. Želimir Dobovišek, Dipl. Ing.
Prof. Dr. Anton Černej, Dipl. Ing.
Prof. Dr. Rudolf Pušenjak, Dipl. Ing.
Faculty of Engineering
University of Maribor
Smetanova 17
Maribor, Slovenia

Prejeto: 13.12.1993
Received:

Sprejeto: 27.1.1994
Accepted: