UDK 658.512.2

Razvoj motorjev - skupinski hkratni inženiring z metodami oblikovanja in simuliranja*

Engine Development Distributed Concurrent Engineering Including Design and Simulation Techniques

G.Ph. RAINER

Podjetje AVL ponuja vrhunsko razvite storitve motorskega inženiringa, umerjanja in testiranja motorjev podjetjem po vsem svetu. Slednje terja vrhunsko razvite lastne izdelke in sodelovanje s partnerji v programih hkratnega inženiringa (HI) postopkov in izdelkov.

Pogoji za uspešno partnerstvo so uporaba informacijske tehnologije znotraj podjetja in med podjetjema, standardizirani protokoli za prenos podatkov in zanesljivo vodstvo projektov. V prispevku je opisano, kako AVL deluje znotraj partnerjevih HI-ekip v procesu oblikovanja kot člen v razvojni ekipi. Opisani so splošni ukrepi za podporo hitrega razvoja izdelkov. Prispevek opisuje sodelovanje med strokovnjaki za oblikovanje in simuliranje kot prvi korak na poti k analitični izdelavi prototipov.

AVL is offering sophisticated engine engineering services, instrumentation and engine test systems to companies all over the world. This demands on the one hand to develop high quality products and on the other had to be a partner in the concurrent product and process engineering programmes of the customer.

The use of information technology within and between cooperating companies, standardised data transfer protocols and a strong project management are preconditions for successful partnerships. This paper describes how AVL applies its services within the customers concurrent engineering teams during the design phase as an actor in the »distributed development team«. General measures to support rapid product development are outlined. The interactions between design and simulation work as a first step to meet the target of »analytical prototyping« are explained.

0 UVOD

Ponudniki tako specifičnih storitev, kakršne ponuja AVL so na trgu uspešni le:

— če so njihove storitve boljše od tistih, ki jih ponuja konkurenca,

— če s svojim delovanjem pomagajo stranki zvišati kakovost lastnih izdelkov in storitev,

- če stranki pomagajo skrajšati razvojni čas izdelkov.

Za dosego omenjenih ciljev na vseh področjih razvojnih aktivnosti je potrebna uporaba sodobnih merilnih, računskih in proizvodnih metod. Slednje zahteva kakovostno aparaturno in programsko opremo ter visoko raven izvajalčevega znanja. To pa terja intenzivno raziskovalno in razvojno delo, ki pripelje do t.i. »razvojnih metod« [1], [2]. Opisan je le del današnjega razvojnega procesa.

Drugi del zajema organizacijo, pretok informacij in informacijsko tehnologijo ter vpliva na uspešno delo razvojnih ekip:

— standardni podatkovni formati (npr.: STEP, IGES),

— metodologijo vodenja projekta,

— informacijske tehnologije za modeliranje medsebojnega vpliva med podjetji,

— vmesnike med programskimi orodji za HI.

0 INTRODUCTION

Suppliers of high level services can only be successful if products and services are offered to the customers which:

— cannot be offered by many competitors (high tech),

— help the clients to encrease the quality of their own products and services, and

— help the clients to shorten development time.

To reach these targets in all segments of development activities, advanced calculation, measurement and production methods are required. These methods consist of hardware and software components and, to a high degree, on the expertise of the supplier. Intensive research and development work has therefore to be done to develop »development methods« [1], [2]. However, this is only one important component in today's development process.

The second part consists of organisation, data flow and information technologies to support development processes conducted by distributed teams including e.g.:

— standardised model data formats (e.g. STEP, IGES),

— project management methodologies,

— information technologies to model interactions between companies and

— interfaces to combine applications in concurrent engineering.

* Referat na drugi mednarodni konferenci »Od konstruiranja do proizvodnje v sodobni industriji — DMMI' 95«, Bled 29.-30.5. 1995. — This paper has been presented at 2nd international conference »Design to Manufacture in Modern Industry — DMMI'95«.

Vedno večja vlaganja v »neproizvodne dejavnosti« so potrebna, če hočemo obdržati kakovost storitev, neodvisno od izdelkov. To pomeni velik izziv za mala in srednje velika podjetja, ki bodo preživela le, če bodo močna na področju proizvodnih in neproizvodnih dejavnosti.

1 POTEK HKRATNEGA INŽENIRINGA

Uspešno razvojno delo je pogosto plod sodelovanja med podjetji. Obstaja več razlogov za takšen način dela:

- posebna znanja partnerja,
- povečanje inženirskih zmogljivosti,
- skupna uporaba posebne namenske opreme,
- dotok novih idej.

Iz zgoraj navedenih razlogov tudi večina strank AVL pri razvoju novih ali izpopolnjevanju sedanjih motorjev uporablja metode skupinskega razvojnega dela.

Običajno delujejo ekipe obeh partnerjev na sedežih matičnih podjetij s podobnimi nalogami kakor ekipe HI (sl. 1).

To have these »product independent« capabilities available, suppliers must devote rapidly increasing resources to »non productive« activities. This is a big challange for small and medium enterprises (SME) which have till now focused on »product oriented« knowledge, but SME's will only survive if they are strong in both areas.

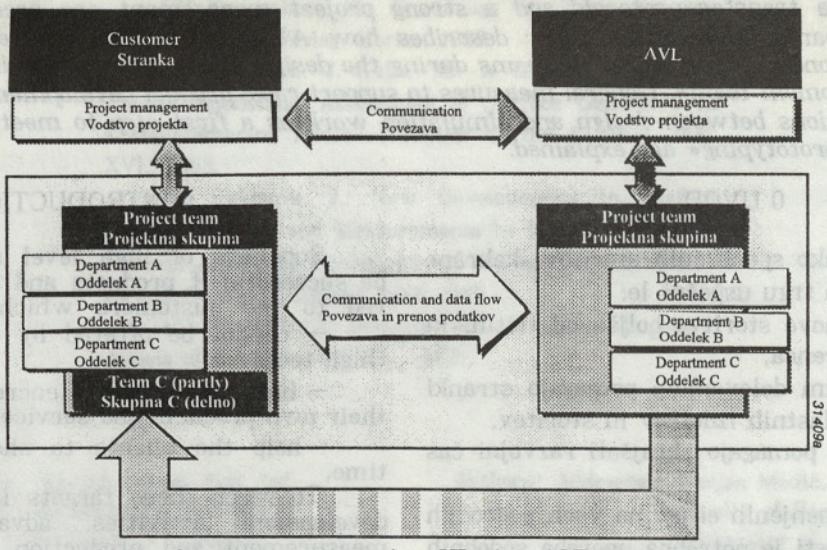
1 CONCURRENT ENGINEERING PROCESS

Successful development is done in many cases by collaborative projects between companies. Reasons to share development activities between companies can be:

- special knowledge of a partner,
- extension of engineering capacities,
- joint use of dedicated equipment,
- inclusion of new ideas.

For similar reasons, most of AVL's customers which are developing new engine families or enhancing existing engines want to do these tasks as distributed development work.

Very often, departments on the customer's and AVL site with similar responsibilities cooperate as »simultaneous engineering« teams, Fig. 1.



Sl. 1. *Organizacija projekta HI-ekip AVL in stranke*

Fig. 1. *Project organization for »simultaneous engineering« teams of AVL and customer*

1.1 Organizacija projekta

Pogoj za uspešno izvedbo skupnih projektov je pravilna organizacija:

Vodstvo projekta (VP)

Na obeh straneh (stranka in AVL) je treba imenovati vodjo projekta, ki bosta zadolžena za koordiniranje podprojektov (čas, stroški, itn.), ki se izvajajo v različnih oddelkih podjetja. Poleg tega morajo biti v tesnem stiku z vodjem v partnerskem podjetju. Sodelovanje naj bo še posebej tesno pri reševanju nalog, ki imajo medsebojen vpliv.

VP odloča tudi o tem, ali je treba najeti AVL-jeve strokovnjake v strankinem podjetju. V interesu AVL je, da postavi svoje zmogljivosti za področje oblikovanja in inženiringa.

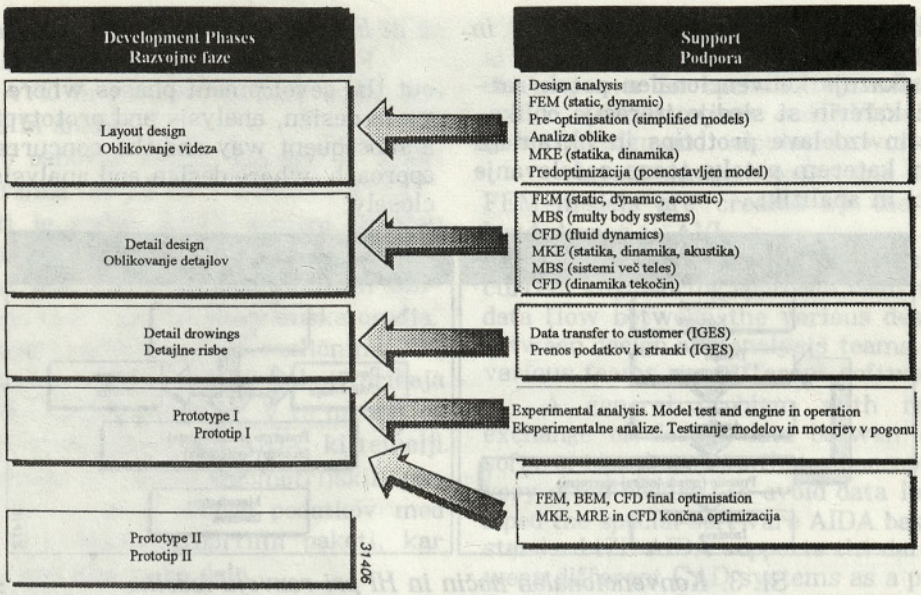
1.1 Project organisation

To perform joint development projects efficiently the project organisation has to be established in the following way:

Project management (PM)

On both sides (customer and AVL) a project managers must be installed. The project managers have to coordinate the subprojects (time, cost, etc.) which are performed in different departments of each company and have to be in close contact with the cooperating company to coordinate the complete project, especially the direct interacting parts.

On top of that, PMs have to decide whether it is necessary to install AVL's staff on the customer's site or not. It is an upcoming demand for AVL to install design and engineering capabilities on the customer site.



Sl. 2. *Faze razvoja motorja*

Fig. 2. *Engine development phases*

Natančno opredeljena odgovornost

Projekt je običajno sestavljen iz posameznih podnalog. Določiti je treba odgovorno osebo za vsako od njih. Sodelujoči morajo upoštevati vnaprej določena pravila, nujno se je treba izogniti neusklajenim spremembam.

Tesno sodelovanje med projektnimi skupinami

Skupine morajo poročati vodji projekta. Še pomembnejše je sodelovanje z ustrezno skupino v partnerskem podjetju, ki se ukvarja z isto nalogo.

Komuniciranje in pretok informacij

Vzpostaviti je treba zanesljiv pretok informacij, ki omogoča prenašanje večje količine podatkov in tesno sodelovanje med projektnimi skupinami.

Osebni stiki

- sestanki,
- telefon, telefaks,
- video.

Prenos podatkov brez izgub

- pošta, telefaks
- trak, diskete, mreža
- poročila, risbe, aparaturna oprema.

1.2 Primer HI

AVL ima dolgo tradicijo uporabe računskih metod za optimiranje motorjev [3], [4]. Včasih so razpoložljive motorje izboljševali z uporabo MKE, danes pa se uveljavlja način dela, da uporabimo računske metode že v fazi snovanja novih motorjev [5], [6].

Clear responsibilities

The projects may consists of various subtasks. The responsibility of each subtask has to be defined. All teams must obey standards which have to be defined before the project starts. It is necessary to avoid e.g. having to modify drawings with different design status.

Close interaction of the project teams

The project teams have to report to the responsible project manager. But even more important is the interaction with the corresponding team located in the cooperating company because, often, two teams are working on the same subtask.

Communication and data flow

A reliable data flow has to be established. Because of the very close interaction between various departments and necessity of extensive data exchange additional to personal communication, the project management has to arrange that.

Personal contact are enabled via

— meetings,
— telephone, telefax,
— video conferencing.

Data flow works without data loss via

— mailing, telefax,
— tape, floppy, network,
— reports, drawing, hardware.

1.2 Example for Concurrent Engineering

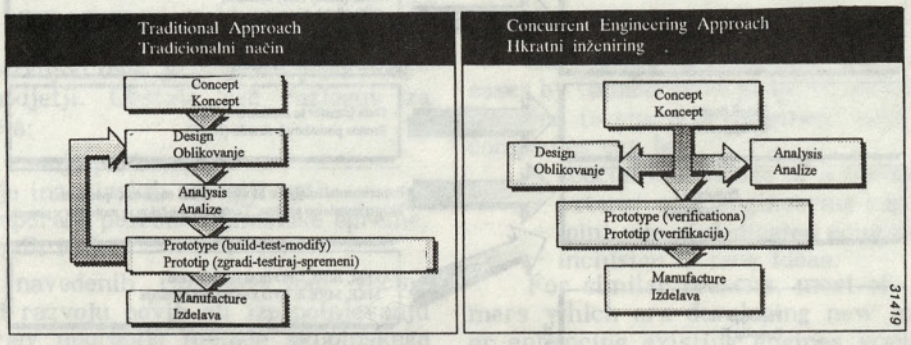
AVL has a long tradition in applying calculation methods to optimize engine structures [3], [4]. Originally, existing engines were improved by FEM calculations, but in recent years, a clear trend has been observable of the use of calculations more and more to support the design phase [5], [6].

Vzajemni vpliv med fazama oblikovanja in analize

Slika 3 prikazuje konvencionalen potek razvojnih faz, pri katerih si sledijo iteracije oblikovanja, analize in izdelave prototipa in hkratnega inženiringa, pri katerem poteka tesno sodelovanje med oblikovalci in analitiki.

Interaction between design and calculation

Fig. 3 shows the conventional steps throughout the development phases where iterations between design, analysis and prototyping are done in a subsequent way and the concurrent engineering approach, where design and analysis interact very closely.



Sl. 3. *Konvencionalen način in HI pri razvoju izdelka*

Fig. 3. *Conventional steps and concurrent engineering approach in product development*

Način dela po HI naj bi uporabljali v vseh razvojnih skupinah.

Konvencionalen način dela vodi v podaljšanje razvojnega časa in povečanje stroškov. Vzrok za to je, da je treba izvesti mnoge teste, preden ugotovimo vpliv posameznih parametrov in kakovost izdelka. Optimiranje poteka s testiranjem prototipov in učenja na napakah.

HI podaljša trajanje faze oblikovanja in analize, po drugi strani pa bistveno skrajša čas izdelave prototipa, zaradi česar se skrajša skupni razvojni čas in zmanjšajo stroški. Poleg navedenega takšen način dela omogoča poglobljeno razumevanje vpliva oblike na kakovost izdelka.

Mogočih je več načinov sodelovanja med AVL in stranko, (sl. 4):

– oblikovanje izvede stranka, analize pa AVL ali nasprotno,

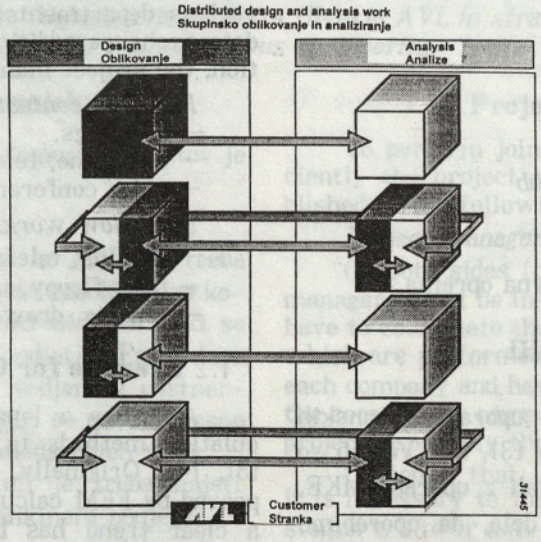
The concurrent engineering approach should be used in all distributed teams.

The conventional steps lead to an elongation of the development time and to an increase in development costs. This is caused by the fact that a lot of tests have to be performed to discover influence of various parameters on product quality. The main optimization work is done during the prototype testing phase by trial and error.

The concurrent engineering approach extends the design and analysis phase but shortens the prototype phase considerably. This leads to shorter total development time and to cost reduction. Additionally, the concurrent design and analysis work leads to a deeper understanding of the influence of design modifications on product quality.

The interaction between customer's and AVL's teams can work in different ways, Fig. 4,

– design work is done by the customer and calculation is done by AVL or vice versa,



Sl. 4. *Sodelovanje med AVL in stranko v času oblikovanja in analize*

Fig. 4. *Interactions between AVL and Customer during design and analysis phase*

— oblikovanje in analizo izvede AVL in jih da v optimiranje stranki,

— ekipe AVL in strankine ekipe sodelujejo pri oblikovanju in analizi,

— zasnovo osnovne oblike izdelka in model MKE izdela stranka ter jih da v obdelavo AVL.

Upoštevati je treba, da HI pomeni povečan pretok informacij med posameznimi skupinami oblikovalcev ter med oblikovalci in analitiki. Običajno uporabljajo tudi različna programska orodja.

Pri izmenjavi podatkov med različnimi računalniško podprtimi programskimi paketi prihaja do nesprejemljive izgube podatkov. V ta namen so pri AVL izdelali poseben program AIDA, ki temelji na IGES standardu za prenos geometrijskih podatkov [7]. AIDA omogoča prenos podatkov med posameznimi računalniško podprtimi paketi, kar je pogoj za uspešno skupinsko delo.

Sodelovanje med posameznimi računskimi programskimi moduli

Pri optimiranju komponent motorja v fazi oblikovanja mora inženir nujno razpolagati z rezultati obširnih preračunov. Slika 5 prikazuje primer prenosa računalniško podprtih podatkov z uporabo in brez uporabe programa AIDA med paketoma BRAVO in MEDUSA.

— basic design and calculation work is done at AVL, afterwards the data are handed over to the customer for optimisation work,

— the customer's and AVL's teams interact in both design and calculation work,

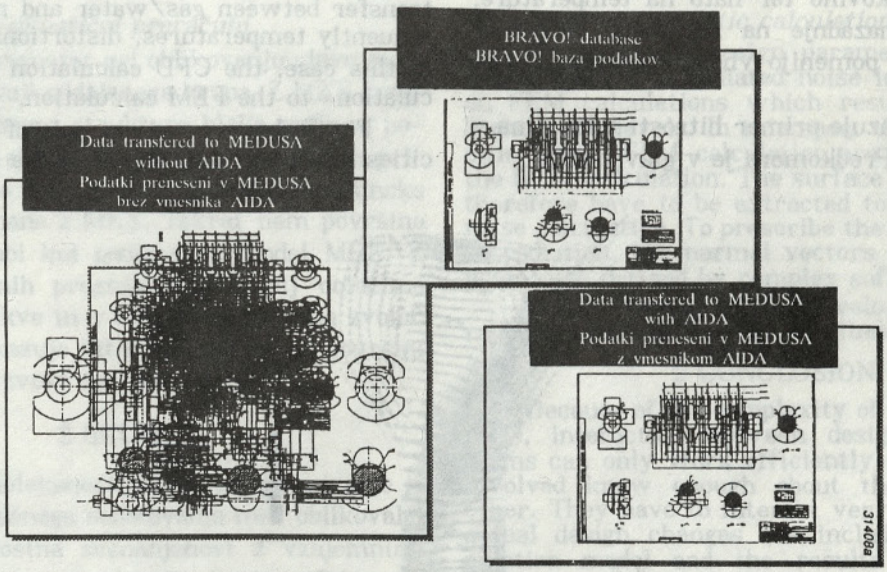
— layout design results and basic (parts of) FEM-models are created by the customer and handed over to AVL.

An important consideration is that the concurrent engineering approach leads to an increased data flow between the various design teams and between design and analysis teams. Normally, the various teams use different software packages.

A general problem with respect to the exchange of design data betwen different CAD software packages is that unacceptable data loss very often occurs. To avoid data loss, AVL developed the special software AIDA based on the IGES standard [7]. AIDA supports the data transfer between different CAD systems as a precondition for design teamwork.

Interaction between different calculation software modules

For engine components optimized during the design stage, it is necessary to support the design engineer by extended calculations. Fig. 5 shows and example of CAD-data transfer with/without-AIDA between the CAD systems BRAVO and MEDUSA.



Sl. 5. *Prenos podatkov RPN (računalniško podprtega načrtovanja) odmične gredi*
Fig. 5. *CAD-data transfer of crankshaft design*

Slika 6 prikazuje uporabo različnih programskih orodij za optimiranje glave in bloka valja.

Optimiranje glave in bloka valja zajema:

— statične preračuna in

— dinamično-akustične preračune.

Statični preračuni

Opravimo analizo treh obremenitvenih primerov:

— montažne obremenitve (montaža glave valja na blok valja),

Fig. 6 shows as an example of various numerical methods used to optimise cylinder head-cylinder block compounds [4], [8].

The optimisation procedure includes:

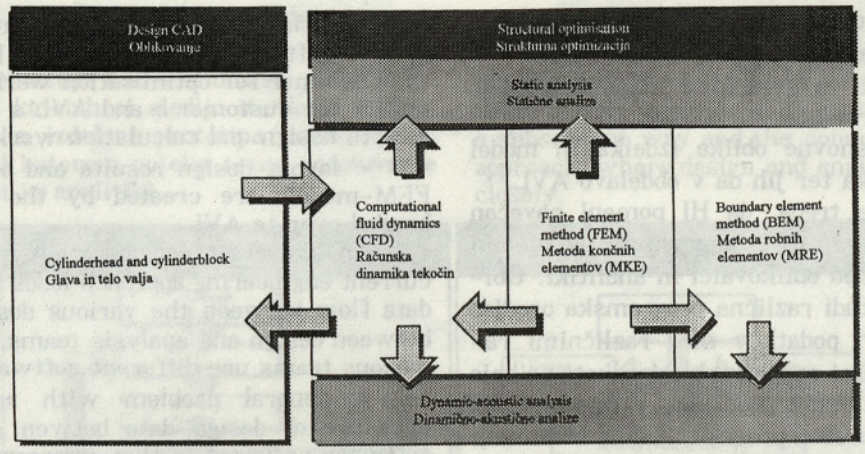
— static calculations and

— dynamic-accoustic calculations.

Static calculation

For static calculations, three load cases are applied:

— assembly load (mounting the cylinder head to the cylinder block),



Sl. 6. *Računske metode za optimiranje motorja*
Fig. 6. *Calculation methods used for engine optimisation*

– plinska obremenitev (največji tlak plina),
– toplotna obremenitev (zgorevanje plina in hladilni krog).

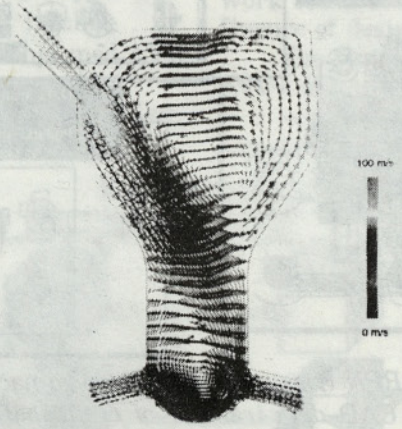
Najprej je treba izračunati temperaturno porazdelitev v valju, ki je odvisna od temperature plina v valju in temperature hladilne tekočine. Po metodah analitične dinamike tekočin (ADT) izračunamo, na podlagi hitrosti, koeficient prenosa toplote. Rezultat vpliva na prenos toplote med plinom/vodo in kovino ter nato na temperature, deformacije in nazadnje na napetosti. Rezultati preračunov ADT pomenijo vhodni podatek preračunom po MKE.

Slika 7 prikazuje primer hitrosti toka plina v predkomori [9]. Predkomora je v glavi valja.

– gas load (maximum gas pressure),
– thermal load (gas ignition and cooling circuit).

To apply the thermal load, the temperature distribution has first to be calculated. The temperature distribution is influenced by the gas temperature in the cylinder and by the cooling water temperature. Computational fluid dynamics (CFD) calculates heat transfer coefficients based on velocities. The results influence the heat transfer between gas/water and metal and subsequently temperatures, distortions and stresses. In this case, the CFD calculation in a »pre-calculation« to the FEM calculation.

Fig. 7 shows as an example of gas flow velocities in a pre-chamber [9] in the cylinderhead.



Sl. 7. *Hitrostna razporeditev v predkomori*
Fig. 7. *Velocity distribution in a pre-chamber*

Modela ADT in MKE uporabljata iste mejne površine. Tako površje modela MKE uporabimo kot temelj za izgradnjo modela ADT. Običajno je mreža ADT gostejša od mreže MKE. Da lahko predpišemo vozliščne temperature v modelu MKE, moramo interpolirati rezultate preračuna ADT. To naredimo z uporabo posebnega programskega vmesnika.

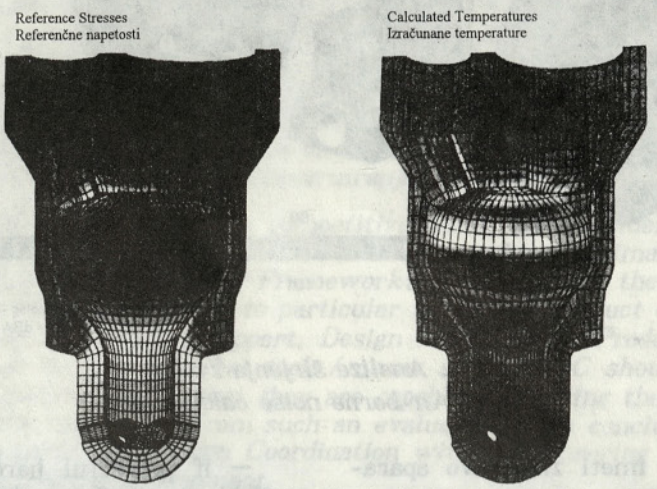
As an interface between the CFD and FEM calculation, the surfaces of the gas flow area are coincident with the surfaces of the FEM-structure. Therefore, the surfaces of the FEM-structure have to be extracted as a basis for the CFD-mesh. The CFD-mesh normally has to be finer that the FEM-mesh. To apply the CFD-results to the FEM-mesh the values have to be transformed and interpolated by special software modules.

Z MKE izračunamo temperature, deformacije, napetosti in vibracije. Geometrijske podatke dobimo iz poenostavljenega geometrijskega modela iz modelirnika prek predprocesorjev MKE. Mreža MKE je odvisna od namena analize. Npr. statična in dinamična analiza enake konstrukcije zahtevata mreži različnih gostot.

Slika 8 prikazuje rezultate temperaturne in napetostne analize predkomore.

The finite element method (FEM) is used to calculate temperatures, distortions, stresses, and vibrations. To prepare the FEM input data, design data are simplified and transfered to the FEM-processor. The FEM-mesh depends on the calculation target. As an example, different meshes are used for static and dynamic analyses to consider the dissimilar aims of the calculations.

Results of the temperature and stress analysis for a pre-chamber as a part of the cylinderhead are shown in Figure 8.



Sl. 8. *Temperaturna razporeditev in toplotne napetosti v predkomori*
Fig. 8. *Temperature distribution and thermal stresses in a pre-chamber*

Dinamično-akustični preračuni

Dodaten parameter pri oblikovanju glave valja predstavljajo nivoji oddajanega hrupa. Z MKE izračunamo nivoje hrupa strukture bloka valja, s postopkom robnih elementov pa za zrak. V tem primeru uporabimo kot vhodne podatke površinske hitrosti, izračunane z MKE. Tokrat nam površina MKE modela rabi kot podlaga za model MRE. Z uporabo zahtevnih programskih orodij določimo normale na ploskve in s tem smer širjenja zvoka.

Slika 9 prikazuje hitrostne nivoje na površini in moč širjenja zvoka na bloku valja.

2 SKLEP

Zaradi kompleksnosti orodij za optimiranje je glavni pogoj uspešnega sodelovanja med oblikovalci in analitiki zadostna seznanjenost z vzajemnimi področji dela. Samo v primeru, ko je sodelovanje med njimi dovolj tesno, se spremembe oblike pri analizah konstrukcije upoštevajo takoj, rezultati analiz pa pri oblikovanju izdelka. Zelo pomembno je, da izvedemo obsežne analize v čim krajšem času, da imajo oblikovalci na voljo obilo podatkov za oblikovanje izdelka. Slednje je mogoče le, če so izpolnjeni naslednji pogoji:

— učinkovit prenos podatkov med oblikovalci (RPK) ter ekipami za analize (RPA). Običajno uporabljamo posebej razvite programe za prenos podatkov RPK in dodatna orodja za povezave med MKE, ADT in MRE;

Dynamic-acoustic calculation

An additional design parameter e.g. for he cylinder block is radiated noise levels [8]. Based on FEM calculations which result in structure borne noise levels. In this case, the surface velocities of the FEM-calculation are input values for the BEM-calculation. The surface of the FE-mesh therefore have to be extracted to start air borne noise calculation. To prescribe the direction of noise radiation, the normal vectors on the surfaces have to be defined by complex software modules.

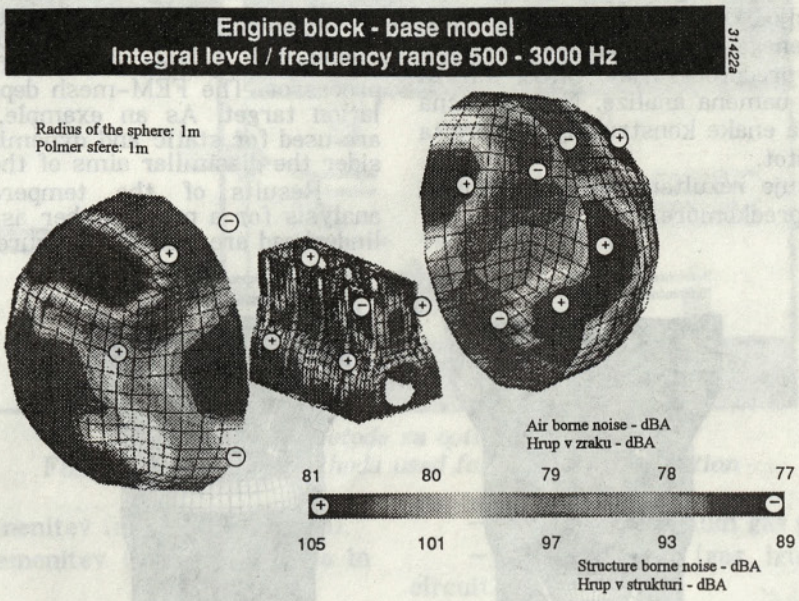
Fig. 8 shows surface velocity levels and radiated sound power for a cylinder block.

2 CONCLUSION

Because of the complexity of the optimisation tools, interaction between design and analysis teams can only work efficiently if the engineers involved know enough about the task of each other. They have to interact very closely so that actual design changes are included in the calculation model and the results of the calculation are considered for design changes.

The most critical point for effective interaction of design and analysis work is the performance of intensive calculations in an extremely short time, because otherwise the design engineer cannot include the results into the actual layout. This can only be handled:

— if data transfer from the design team (CAD) to the analysis team (CAE) and data transfer between different analysis software is working well. The transfer of design data to analysis software is supported by specially developed programs similar to the software supporting the CAD-data transfer. Additional software extracts data which are used for the different analysis packages for FEM/CFD and BEM.



Sl. 9. *Analiza širjenja zvoka*
Fig. 9. *Air borne noise calculation*

— na voljo moramo imeti zmogljivo aparaturno in programsko opremo;

— rezultati morajo biti predstavljeni v obliki nedvoumnih standardnih risb preprostih za interpretacijo.

Naraščajoča kompleksnost razvojnega dela in težnja po skrajšanju razvojnega časa zahtevajo uporabo metod HI. Pri tem morajo partnerska podjetja zelo tesno sodelovati.

Pogoji za uvedbo načina HI dela so:

— razvite programske povezave med orodji za oblikovanje in simuliranje,

— razvita uporabniško prijazna programska orodja za komuniciranje,

— razvit sistem skupinskega razvojnega dela.

— if powerful hardware and software is available to perform the calculations;

— if results are presented in standardised and clearly arranged pictures which are easy to interpret by the engineers.

Increasing complexity of product development work and the necessity to shorten the development time demands the concurrent engineering approach.

To make concurrent engineering »state of the art« tool, considerable progress in

— interfacing design and simulation software

— the development of user friendly communication tools

— organizing distributed teams has to be made.

4 LITERATURA
4 REFERENCES

[1] Rainer, G.Ph.: The Integration of the FEM into the Product Development by Means of a Calculation Method for the Prediction of the Dynamic Acoustic Behaviour of Engines. Congress Proceedings »8th Meeting in Reutlingen - FE in practice«, T-Programm Reutlingen, 1985.

[2] Kampelmühler, F.T.-Scheucher, P.: Simultaneous Engine Testing - Ein Beitrag zur Entwicklungszeitverkürzung. Proceedings, 14. Internationales Wiener Motorensymposium, 1993.

[3] Priebsch, H.H.-Affenzeller, J.-Kuipers, G.: Structure Borne Noise Prediction Techniques. SAE Technical Paper Eeries 900019, Internaional Congress and Exposition 12990, Detroit, 1990.

[4] Rainer, G.Ph.-Gschweitl, E.: Optimization of Cylinder Head-Gasket-Cylinder Block Compound Using FEM and Experimental Methods. Proceedings, CIMAC-20th International Congress on Combustion Engines, London, 93.

[5] Rainer, G.Ph.-Gschweitl, E.-Hübl, H.P.: Einfluß von Konstruktionsvarianten auf das akustische Verhalten von Motoren. Tagung Verbrennungsmotorenakustik, Haus der Technik, Essen, 1993.

[6] Brandl, F.K.-Wünsche, P., Gschweitl, E.: Design Strategies for Low Noise Engine Concepts. Proceedings, SAE Noise & Vibration Congress, Travers City, 1991.

[7] Rainer, G.Ph.: IGES - Hilfe oder Hemmnis für den Einsatz von CAD zur Durchführung firmenübergreifender Entwicklungsprojekte. VDI-Report 861.2, 1990.

[8] Rainer, G.Ph.-Gschweitl, E.-Herster, P.: Basic Investigations to Compare Calculational and Experimental Results of Air Borne Noise. European Simulation Multiconference, Lyon, 1993.

[9] Dexter, S.G.-Ennemoser, C.: FIRE not Misfire in Pre-Chamber Gas Engines. CIMAC-Congr., Interlaken, 95.

Avtorjev naslov: G.Ph. Rainer
AVLG-Gesellschaft für Verbrennungskraftmaschinen und Messtechnik Mbb
Graz, Austria

Prejeto:
Received: 12.10.1995

Sprejeto:
Accepted: 22.11.1995