© Strojniški vestnik 49(2003)12,566-574
ISSN 0039-2480
UDK 658.5:167.7
Izvirni znanstveni članek (1.01)

© Journal of Mechanical Engineering 49(2003)12,566-574
ISSN 0039-2480
UDC 658.5:167.7
Original scientific paper (1.01)

Sočasno inženirstvo v teoriji in praksi

Concurrent Engineering in Theory and Practice

Janez Kopač

Prispevek je osredotočen na glavne strategije, principe, procese, prakse, tehnologije in ljudi, ki se nanašajo na sočasno inženirstvo. S tem obsega osnovne organizacijske faktorje, orodja, metodologije, računalniško podprte analize in prototipiranje. Še vedno običajen, zaporeden pristop k razvoju izdelka v veliko proizvodnih podjetjih zamenjuje sodoben sočasen pristop. Za doseganje najboljših učinkov morajo biti vsi glavni prepletajoči elementi od trženja, proizvodnega menedžmenta, nabave, proizvodnje in kakovosti prav tako sočasni.

(Ključne besede: inženirstvo sočasno, načrtovanje izdelkov, konstruiranje izdelkov, oblikovanje virtualno)

This paper focuses on the main strategies, principles, processes, practices, technologies and people related to concurrent engineering (CE). In this way it describes the major CE organizing factors, tools, methodologies, computer-aided analysis and prototyping. The common approach to product development, still used by many manufacturing companies, is based on the sequential principle and is being replaced by the contemporary concurrent approach. To achieve the best results all key cross-functional elements from marketing, product management, purchasing, manufacturing engineering and quality must be concurrent as well.

(Keywords: concurrent engineering, product development, product design, virtual design)

0 UVOD

Popolni razvoj kakovosti pomeni nov postopek razvoja konkurenčnih izdelkov in vsebuje najboljše razvojne, vodstvene, strateške in skupinske elemente. Rezultati se kažejo v zmanjšanju razvojnega časa, zmanjšanju stroškov, povečani kakovosti in raznolikosti izdelkov ter v končni fazi v zadovoljstvu kupca. Z opisano filozofijo želimo doseči boljše načrtovanje izdelkov in tudi hitrejšo proizvodno spremembo. Hiter odziv na povpraševanje tržišča dosežemo s spremljanjem zahtev kupca, razvojem robustnih tehnologij in uvajanja osnovnih načel sočasnega inženirstva tako s tehničnega kakor tudi vodstvenega vidika. Tako je sočasno inženirstvo nova razvojna metodologija, ki vodi k boljšemu razvoju in izboljša produktivnost [2].

S skrajševanjem cikla obstojnosti izdelkov se intenzivnost uvajanja novih izdelkov neprestano povečuje. Pravočasnost dobave izdelka in njegovo zanesljivo delovanje pomenita poleg cene enega ključnih elementov za konkurenčnost na trgu.

Agresivni razvoj podpirajo računalniki, ki ob uporabi orodij sočasnega inženirstva omogočajo hitro obdelavo informacij s hkratno povezavo vseh sodelujočih v verigi načrtovanja in vodenja proizvodnje novega izdelka [3].

0 INTRODUCTION

Total-quality development is the modern way of developing competitive products, and combines the best development, management, strategy and teamwork. The resulting improvements are reflected in a reduced development time, a reduction in all costs, higher quality and increased product variety. Together, these improvements increase customer satisfaction. The described philosophy achieves many benefits, from better product planning to a faster transition to production. A rapid time-to-market is achieved by listening to the voice of the customer, developing robust technology and employing basic concurrent engineering (CE), from the technical and management points of view. Hence, CE refers to a new development methodology, which leads to better development and increases productivity [2].

The shortening of a product's life cycle increases the rate at which new products are introducted. The on-time delivery of products and their reliability are, together with price, the key factors affecting a product's competitiveness.

Aggressive product development is computer aided and employs various CE tools for fast information processing, which is simultaneously linked to all cooperating areas in a chain for product planning and shop-floor control [3].

Sodobno podjetje se srečuje s celo vrsto računalniških in podatkovnih sistemov. Različna programska oprema zagotavlja velik korak v smeri poenotenja in učinkovitega obvladovanja informacij. Pokrivajo pa tudi pretežno vsa področja razvoja, od zasnove do priprave za proizvodnjo, pa tudi od zamisli do reciklaže izdelka. Model hrani razvoj svojega nastanka, vsaka izmera je parameter, zato so spremembe preproste [1].

1 SOČASNO INŽENIRSTVO

V primerjavi z običajnim načinom razvoja izdelkov, pri katerem si posamezne razvojne dejavnosti projekta sledijo zaporedno, je temeljna zamisel sočasnega inženirstva hkratno izvajanje različnih razvojnih dejavnosti, kar vidno prispeva k skrajšanju razvojnega kroga (sl. 1). Sočasno inženirstvo se nanaša na načrtovanje dejavnosti s poudarkom na razvoju izdelka in proizvodnje, z namenom skrajšati čas prihoda izdelka na trg ter znižati njegove razvojne, proizvodne in druge stroške [3].

Pospešen razvoj izdelkov in njihovo dinamično uvajanje na trg je privedlo do novih spoznanj pri načrtovanju novih izdelkov. Eden od načinov, kako skrajšati razvojno fazo novega izdelka je torej poznan kot osnutek sočasnega inženirstva, ki ga razumemo kot vključevanje in časovno hkratno uvajanje tako razvoja izdelka kakor tudi postopka njegove izdelave. Pomembno vlogo v tem razvoju ima računalniško podprto konstruiranje izdelka ter načrtovanje izdelovalne tehnologije. S tem je načrtovalcem izdelka in tehnologije omogočeno vnaprejšnje preverjanje ustreznosti izbranih rešitev, še preden je izdelek fizično izdelan. Na podlagi odkritih razmerij je zato mogoče pravočasno izvesti ustrezne popravke na izdelku/postopku ter s tem neposredno vplivati na skrajševanje izdelovalnih časov in stroškov.

Temelj sočasnega inženirstva pomeni razvojna skupina strokovnjakov, ki je seznanjena s tem, kako njihove odločitve vplivajo na razvojno pot izdelka. Strokovnjaki, ki takšno skupino sestavljajo, morajo misliti splošno in se ves čas zavedati, kakšne posledice bodo imeli morebitni ukrepi na končni izdelek oz. na njegovo razvojno pot, s čimer se zmanjša tudi število predelav osnutka izdelka. Pri tem je eden od temeljev sočasnega inženirstva zagotavljanje zgodnjega prepletanja razvojnih funkcij, ki omogočajo manjše spremembe, ki se jih izvesti z majhnimi stroški v kratkem času.

Za izrabo temeljnih prednosti sočasnega inženirstva moramo:

- začeti z izvajanjem nalog takoj, ko je mogoče;
- uporabiti bistvene informacije takoj, ko je mogoče;
- omogočati sodelovanje posameznikov in skupine pri definiranju (za)danih nalog;
- enotno izvajati odločitve, ki se nanašajo na načrtovanje, proizvodnjo in podporne dejavnosti;
- določati trajne odločitve;
- vzpostaviti zaupanje med člani skupine;

Contemporary enterprises deal with numerous computer-data systems. Various software packages ensure uniformity and effective information control; they also cover all fields of development, from concept to production planning and from idea to product recycling. The model that contains its history specifies each dimension as a parameter, which means that modifications are simple to make [1].

1 CONCURRENT ENGINEERING

In comparison with traditional product design, with its successive project-design activities, concurrent engineering (CE) is based on the idea of the simultaneous execution of design activities, which leads to a significant shortening of the development cycle (Figure 1). CE refers to design activities that are focused on product development and production, which lead to a faster product transition to the market and a reduction in manufacturing and overall costs [3].

Rapid product design together with its dynamic introduction to the market leads to new cognition in product design. One of the ways of reducing the time of the product-development cycle is known as the concept of simultaneous engineering, which integrates the simultaneous implementation of the product and manufacturing development. Computer-aided design (CAD) and computer aided manufacturing (CAM) have an important role in the abovementioned development. CA methods enable the product and production planners to check the appropriateness of selected solution varieties in advance. On the basis of known relations we are able to carry out all the necessary corrections to a product/production process in time, which has a direct influence on the manufacturing time and on the reduction of costs.

The development team forms a CE basis and is aware of a decision's influence on the product development. Team experts should deliberate globally and be aware of the product outcome after the eventual arrangement. In this way the amount of concept remodelling can be reduced. CE ensures early development function crossings, which always enable minor modifications that can be implemented in a short time and at low cost.

The major benefits of CE stem from a few principles:

- Start all tasks as early as possible
- Utilize all relevant information as early as possible
- Empower individuals and teams to participate in defining the objectives of their work
- Make single decisions for design, production and field-support activities
- Make lasting decisions
- Develop trust among team members

- skušati doseči skupno soglasje;
- uporabljati jasen sočasni postopek.

Najboljši sočasni inženiring je uresničen z načrtovanjm proizvodnje in podpornih dejavnosti zgodaj, hkrati z načrtovanjem izdelka. Sočasni postopek ima pet glavnih prednosti:

- hiter začetek načrtovanja proizvodnje in podpornih dejavnosti;
- možnosti sočasnih kompromisov znotraj načrtovanja, proizvodnje in logistike;
- olajšana obdelovalnost zaradi dobrega načrtovanja;
- člani proizvodnih in podpornih oddelkov razumejo načrtovanje in pripomorejo k izboljšavam;
- število prototipnih ponavljanj je zaradi izboljšanega načrtovanja zmanjšano.

Nadaljnje izboljšave za večjo konkurenčnost se poleg sočasnega postopka, ki ga uvaja večfunkcijska skupina, nanašajo na:

- osredotočenje na kakovost, stroške in dobavo;
- poudarek k zadovoljnemu kupcu;
- poudarek konkurenčnosti.

Izboljšave skupinskega sodelovanja pa se nanašajo na:

- združevanje večfunkcijske skupine;
- vključitev zaposlenih in udeležb v vodenju;
- strateške povezave med dobavitelji.

Poglavitno načelo sočasnega inženirstva tako temelji na povezovanju metodologij, postopkov, ljudi, raznih uporabniških orodij in metod za podporo razvojne poti izdelka. Sočasno inženirstvo vključuje vse interakcijske povezave različnih individualnih skupin, ki so lahko porazdeljeni. S tem omogoča dejansko in popolno komunikacijo med njimi, ker lahko v istem trenutku obstaja npr. več različnih tehničnih zasnov, ki morajo biti organizirani in rešljivi hkrati. Prednosti sočasnega inženirstva so tako v delitvi in izmenjavi informacij ter vključevanju hkratnih pogledov na različne faze izdelka.

Učinkovitost sistema zagotavljajo močne informacijske povezave na vseh stopnjah med izdelovalcem in končnim uporabnikom. Za čim večjo učinkovitost in uspešnost sočasnega inženirstva morajo dejavnosti samega postopka potekati čim bolj vzporedno. Dejavnosti morajo biti merljive, s čimer lahko sprotno odkrivamo napake še preden zaidejo v končni izdelek, saj z njihovim pravočasnim odkrivanjem v končni fazi močno zmanjšamo nepotrebne stroške. Nezaželenim konstrukcijskim spremembam se izogibamo z ustreznimi metodologijami sočasnega inženirstva, ki se nanašajo na:

- kakovost (metode za zgodnje odkrivanje napak in posledic, razvitje funkcij kakovosti itn.);
- organizacijo (projektne skupine strokovnjakov);
- tehnologijo (RPN, RPI, hitra izdelava prototipov, navidezne simulacije itn.).

Stroški projekta se bistveno zmanjšajo zaradi:

- izmenjav koristnih informacij,
- zmanjšanja števila prototipov,

- Strive for team consensus
- Use a visible concurrent process

In the best form of CE, the design of the production and of the field support starts early, concurrently with the design of the product. This has five major benefits:

- The development of the production and field support has an early start
- Trade-offs occur among design, production and logistics at the same time
- Good design for manufacturability is facilitated
- The production and field-support teams gain a clear understanding of the design and are committed to its success
- Prototype iterations are reduced because of the mature design

Additional improvements beyond CE for quality enhancement carried out by a multifunctional product-development team are related to:

- Focus on quality, cost and delivery
- Emphasis on customer satisfaction
- Emphasis on competitive benchmarking

The improvements to cooperation are:

- The integration of a multifunctional product-development team
- Employee involvement and participative management
- Strategic relationships with suppliers

The fundamental CE principle is thus based on the integration of methodologies, processes, individuals, various software and product-development support. CE includes all the interactions between different teams, which can be distributed. Thus enables effective and total team communication, as there could be additional different technical concepts, which have to be organised simultaneously. CE precedence is related to information partition and exchange along with the inclusion of a simultaneous view of the different product phases.

System effectiveness is ensured by strong information connections at all levels between the manufacturer and the end user. The activities of effective and successful CE should run as parallel as possible. They have to be measurable in order to detect errors before they appear in the end product. Thus timely error detection drastically reduces unnecessary costs. Unwanted design modifications can be avoided with appropriate CE methodologies related to:

- Quality (failure mode and effects analysis FMEA, quality function development QFD, etc.)
- Organisation (project teams)
- Technology (CAD, CAM, rapid prototyping, virtual simulations, etc.)

Project costs are significantly reduced as a result of:

- Exchange of useful information
- Reduction of the number of prototypes

- sodelovanja in usposobljenosti vseh udeleženih pri projektu,
- uporabi modernih računalniških programskih tehnologij (izdelave modelov RPN, simulacij obdelav, reoloških analiz itn.),
- uporabi ustreznih obdelovalnih strojev.

Sočasno inženirstvo je torej postopek, ki vsebuje:
- močno izmenjavo informacijskih podatkov,
- ponavljalen postopek prenove in preoblikovanja,
- postopek stroškovnih analiz za optimizacijo,
- dokumentiranje vseh danosti postopka.

1.1 Organizacijski dejavniki sočasnega inženirstva

Usposobljeni člani projektnih skupin sestavljajo interdisciplinarno projektno skupino in so dobro seznanjeni s prednostmi projekta in izpostavljajo tveganja in kompromise glede na zastavljene cilje. Za združevanje različnih stopenj znanja brez pomembnega poseganja v organizacijsko strukturo podjetja se zamenjava rotacija delovnih mest, ki pripomore k uspešnosti podjetij (sl. 2). Projektno usmerjeno podjetje se je zmožno bolj dinamično odzivati na zahteve trga kakor podjetje z običajno organizacijsko strukturo [4].

Koordinacijo funkcij, prepoznavanje in reševanje funkcijsko-organizacijskih problemov opravlja organizacijsko osebje, ki mora zagotavljati učinkovit prenos informacij med funkcionalnimi enotami podjetja. Izvedba sočasnega inženiringa je

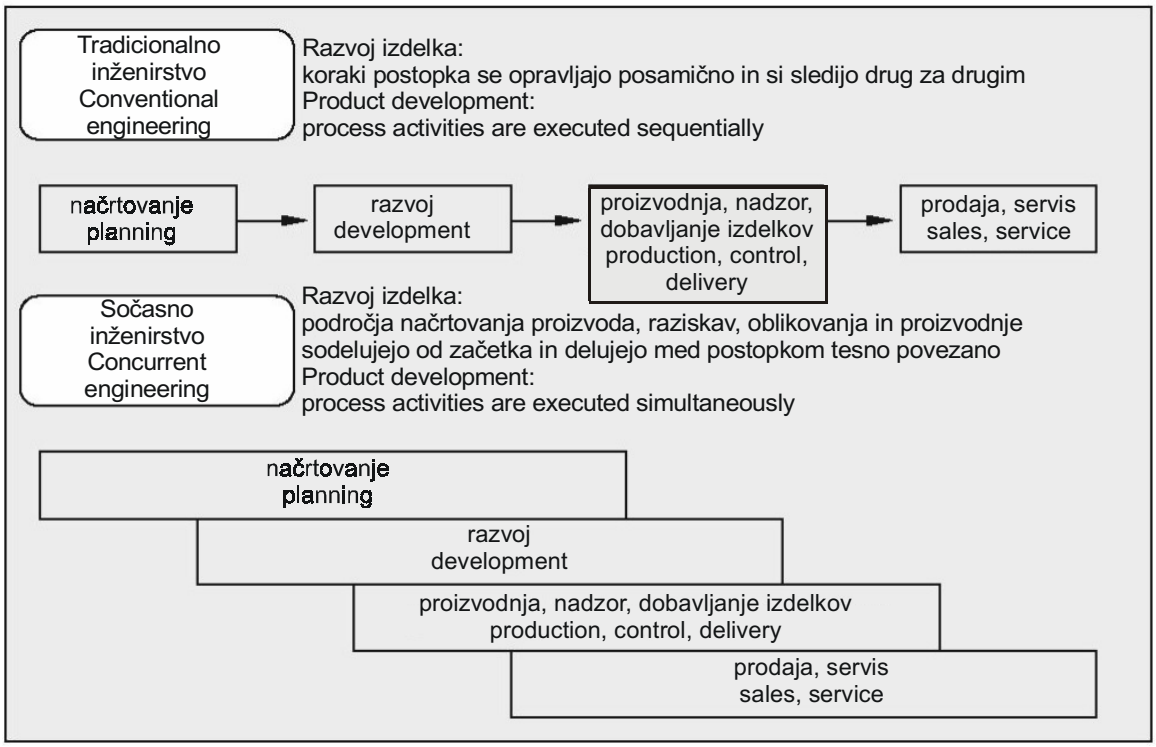
- Cooperation and competency of team members
- Employment of contemporary CAE tools (CAD modelling, process simulations, rheology analysis, etc.)
- Employment of suitable machine-tools

CE is, therefore, a process that contains:
- Strong information exchange
- Iterative process of re-design and modification
- Cost analysis and cost optimisation
- Documentation of all process entities

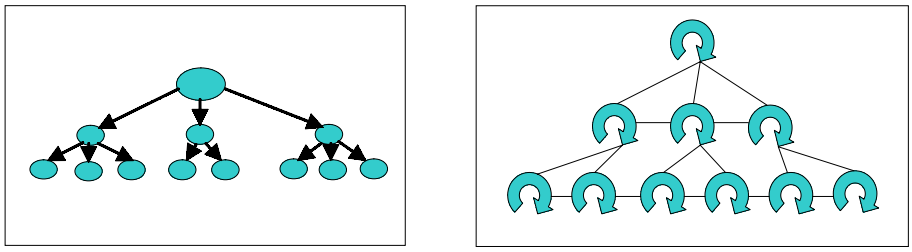
1.1 CE organisation factors

Competent team members form an interdisciplinary project group and are well acquainted with the project's priorities, which help them to set out risk and compromises relating to the planned objectives. The integration of different knowledge levels without any substantial interference in the organisational structure is achieved with workplace rotation, which consequently enhances the success of the enterprise (Figure 2). A project- oriented enterprise is capable of a dynamic response to market demands, which is not the case with enterprises that have a conventional organisational structure.

The organisation's personnel ensure effective data transfer between the enterprise's functional units and coordinates all the necessary functions, recognises and solves functional-organisation problems. CE execution is team-based. The CE project is a



Sl. 1. *Primerjava običajnega in sočasnega inženirstva*
Fig. 1. *A comparison of conventional engineering and concurrent engineering*



Sl. 2. *Običajna in projektno usmerjena organizacijska struktura*
Fig. 2. *Conventional and project-oriented organisational structure*

projektna. Projekt sočasnega inženiringa je sklenjen postopek izvajanja med seboj logično povezanih dejavnosti z namenom doseganja vnaprej postavljenega cilja. Za izvajanje dejavnosti so potrebni ljudje z ustreznim znanjem in drugi viri. Primerna organizacijska struktura za učinkovito projektno vodenje je matrična organizacija.

1.2 Orodja sočasnega inženirstva

Orodja sočasnega inženirstva so pravzaprav posamezni deli, s katerimi si lahko pomagamo pri vzpostavljanju in pospeševanju sočasnega inženirstva, ki pa je v samem bistvu pravzaprav organizacijski prijem.

Obstaja cela vrsta različnih orodij, postopkov in informacijskih podpor, ki so v pomoč uvedbi sočasnega inženirstva. Naloga skupine, ki uvaja ali pospešuje sočasno inženirstvo, pa je, da zna uporabiti prava orodja na pravi način, s čimer doseže organizacijske izboljšave dela ter s tem hitrejše postopke.

Naj naštejemo nekatera od orodij načrtovanja in organiziranja:
- Razvoj funkcij kakovosti (RFK - QFD);
- Metode projektnega vodenja in informacijska podpora projektnemu vodenju; multidisciplinarni timi,itn.;

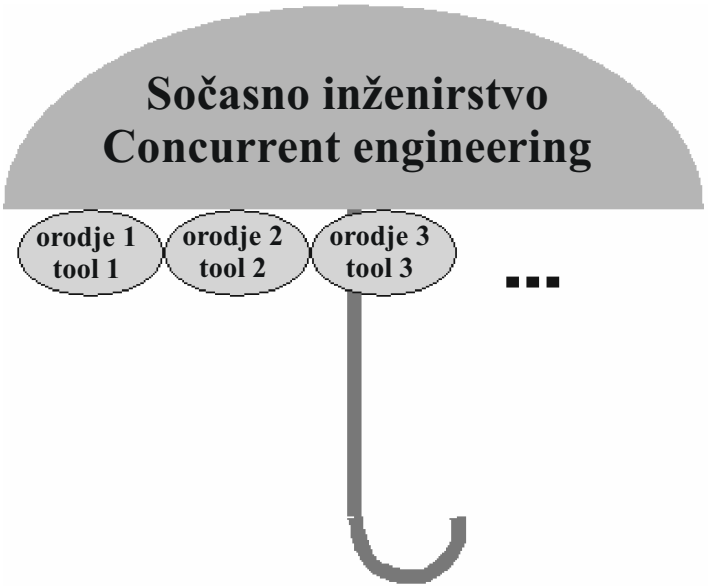
concluded process of the execution of logically connected activities with the intention of achieving previously planned objectives. Implementation of the activities requires personnel with appropriate knowledge and other resources. The appropriate organizational structure for effective project management is a matrix organisation [4].

1.2 Concurrent-engineering tools

Concurrent-engineering tools represent individual support for the reestablishment and acceleration of CE, which refer to the organisational method.

There are a large number of tools, methodologies and information support that help to implement CE. The team task for the introduction and acceleration of CE is to employ suitable tools in the right manner in order to achieve work-organisation improvement and faster processes.

Let us list some of the tools for the design and organisation:
- QFD (Quality Function Deployment)
- Team-management methods and information support; multidisciplinary teams, etc.



Sl. 3. *Orodja sočasnega inženirstva*
Fig. 3. *Concurrent-engineering tools*

- Načrtovanje za ciljne stroške (NCS - DTC);
- Koncept nadzorovanja konvergence (KNK - Con-Con);
- Sistem za podporo skupinskemu odločanju (SPSO - GDSS).

Metode za modeliranje in izdelavo izdelka, kakor so:
- Načrtovanje za montažo (NZM - DFA);
- RPx (RPN / RPNI / RPI itd.). Nove metode konstruiranja izdelka in simulacij (integrirane računalniške analize);
- Različni načini hitre izdelave prototipov.

Metode za modeliranje procesov (delno vključene že v zgornji točki), ki obsegajo:
- Proizvodne analize (PA - MA).

Metode za povečevanje kakovosti celotnega kroga:
- Analiza možnih napak in njihovih posledic (AMNINP - FMEA).

Informacijska podpora izmenjavi informacij:
- Računalniško podprto sodelovanje (RPS - CSCW); npr. Lotus Notes platforma;
- Podatkovni standardi, baze znanja, povezave.

V nadaljevanju bi izvzeli tri široko uporabna in preverjena orodja, ki jih podjetja običajno uporabijo, če želijo napredovati na področju sočasnega inženirstva:
- metode za konstruiranje izdelka,
- integrirane računalniške analize,
- izdelavo prototipov.

1.3 Metode za konstruiranje izdelka

Za podporo kakovostnega razvoja izdelka poznamo več metod konstruiranja:
- konstrukcija za proizvodnjo; optimizacija obsega z upoštevanjem vseh proizvodnih omejitev, s čimer zmanjšamo število sestavnih delov, uporabljamo standardizirane dele itn.,
- konstrukcija za kakovost; integrirana v sistem konstruiranja,
- konstrukcija za stroške; obvladovanje stroškovnih elementov in stroškovna analiza,
- konstrukcija za montažo; optimizacija stroškov montaže izdelka,
- konstrukcija za zanesljivost; zagotavlja zanesljivost v skladu s zahtevanimi specifikacijami.

1.4 Integrirane računalniške analize

Računalniško podprto načrtovanje izdelkov in postopkov postaja ključna integrirana tehnologija za racionalizacijo. S tem se izognemo časovno in stroškovno potratnemu izvajanju preskušanj. To t.i. navidezno inženirstvo sestoji iz treh glavnih področij:
- navidezno oblikovanje (konstrukcija, RPN),
- navidezna izdelava (simulacije postopkov),
- navidezno preizkušanje (analize z MKE).

1.4.1 Navidezno oblikovanje

V zadnjem času so se zelo razvile posebne tehnike, ki omogočajo navidezni razvoj izdelka.

- DTC (Design to Target Cost)
- Con-Con (Controlled Concept Convergence)
- GDSS (Group Decision Support System)

Methods for modelling and product manufacturing:
- DFA (Design for Assembly)
- CAx (CAD / CAPP / CAM, etc.). New methods of product design and simulation (integrated computer analysis)
- Various methods of rapid prototyping (RP)

Methods for process modelling (partly included in the above listing) include:
- MA (Manufacturing Analysis)

Methods for overall quality improvement:
- FMEA (Failure Mode and Effect Analysis)

Information support for information exchange:
- CSCW (Computer Supported Cooperative Work); e.g. Lotus Notes platform
- Data standards, knowledge bases, linkage.

In the following proceeding we would like to emphasise three widely employed and verified tools, which are commonly used by enterprises that strive to make progress in the field of concurrent engineering:
- Methods of product design
- Integrated computer analysis
- Prototyping

1.3 Methods of product design

Quality product development is supported with various design methods:
- Design for production; optimisation of the production range with a consideration of all manufacturing constraints, which reduces the number of product components and apply standardised components
- Design for quality; integrated in the design system
- Design for costs; control of cost elements and cost analysis
- Design for assembly; product-assembly cost optimisation
- Design for reliability; reliability assurance in terms of required specifications

1.4 Integrated computer analysis

The computer-aided design of products and processes is becoming a key process- integrated technology for overall rationalisation and helps to avoid the time and cost of wasteful tests. The so-called virtual engineering comprises three main areas:
– Virtual design (design, CAD)
– Virtual manufacturing (process simulation)
– Virtual testing (FEM analysis)

1.4.1 Virtual design

Recent developments in virtual software techniques enable virtual product development,

Prostorninski 3D model RPN pri tem igra glavno vlogo, saj rabi kot vhodni podatek za vsa nadaljnja vrednotenja. 3D model v digitalni obliki je mogoče prek različnih standardnih vmesnikov, ki omogočajo prikaz podatkov v različnih sistemih RPN, uporabiti kot vhodne podatke za nadaljnje analize in izdelavo orodij in priprav. Modelirati je mogoče tako posamezne dele kakor celotne, kompleksne sestave.

1.4.2 Navidezna izdelava

Pod navidezno izdelavo razumemo predvsem simulacije postopkov. Da pridobimo čas, že med samo izdelavo računalniškega 3D modela izdelamo analizo izdelave. S postopkovnimi simulacijami lahko že vnaprej analiziramo različne tehnološke parametre, ki pomembno vplivajo na kakovost izdelka. V primeru brizganih izdelkov iz termoplastov za analizo brizganja uporabimo programsko opremo, ki omogoča predhodno analizo polnjenja kalupa orodja. Nameni analize so naslednji:

- simulirati vpliv oblike konstrukcije na postopek brizganja (analizira se čas brizganja, temperature in tlaki v orodju, mesta nastajanja hladnih spojev, usmerjenost vlaken);
- ugotoviti optimalno lego in izmere dolivka;
- optimirati geometrijsko obliko izdelka glede doseganja ustreznih rezultatov pri brizganju;
- določiti krog za izdelavo in s tem neposredno stroške dela;
- optimirati izdelavo orodja (temperiranje, hladilni kanali);
- izogniti se slabi kakovosti izdelka (čez deformacije, zvijanje);
- nadzor parametrov izdelave (kakovost izdelka).

Analize so iterativnega značaja, zato močno vplivajo na oblikovanje in spremembe izdelka. Izdelava

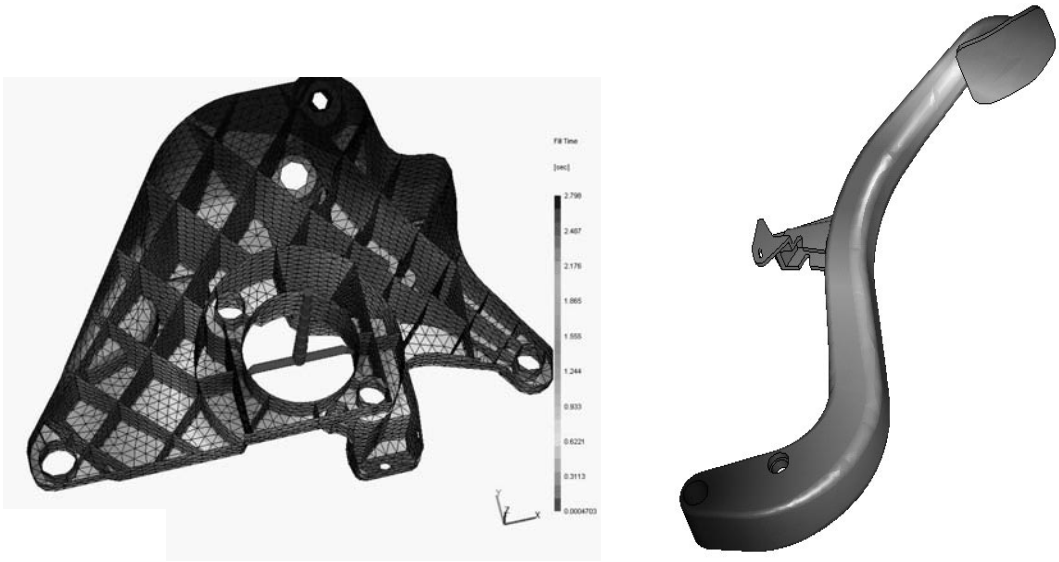
which is based on a 3D CAD model, used as the input data for further evaluations. By using different standardized interfaces, a digitalized 3D model can be represented in various CAD formats. Moreover, the model is used for subsequent analysis and tool manufacturing. Virtual modelling may be referred to a particular component and complex assembly modelling.

1.4.2 Virtual manufacturing

Virtual manufacturing means process simulation. Time saving can be achieved with simultaneous machining analysis, conducted as early as the 3D modelling. Process simulation enables the advanced analysis of technological parameters, which significantly affect product quality. In the case of thermoplastic injection-moulding the process analysis is conducted with software that enables a preliminary analysis of mould filling. The goals of such an analysis are:

- Simulation of the designed shape's influence on injection moulding (injection time, mould temperature and pressure, locations of cold junctions, fibre orientation)
- Assessment of the optimum location and the dimension of the influx
- Product-geometry optimisation for adequate injection moulding
- Injection-moulding cycle and costs determination
- Tool-making optimisation (tool temper, cooling channels)
- Avoidance of inadequate product quality (excessive deformations, folding)
- Control of process parameters (product quality)

The process analysis is iterative, hence it has a significant influence on product design and



Sl. 4. *Simulacija časa zapolnjevanja orodja pri brizganju in analiza izdelka z MKE*
Fig. 4. *Simulation of filling time in injection moulding and FEM analysis*

kakovostne analize zahteva usposobljenega strokovnjaka, ki je sposoben smiselno povezati množico medsebojno odvisnih podatkov v optimalen rezultat.

1.4.3 Navidezno preizkušanje

Polimerni materiali se zaradi svojega nelinearnega obnašanja zelo razlikujejo od običajnih gradiv. Za analize je mogoče uporabiti običajne metode, vendar je pri tem treba vedeti, da je postopek primeren za razmeroma preproste geometrijske oblike in le za linearno elastično področje. Prav zaradi teh omejitev se je v praksi dobro izkazala uporaba metode končnih elementov, katere prednosti so:
- možnost obravnave zapletene geometrijske oblike,
- možnost nelinearne analize.

1.5 Izdelava prototipov

Spremembe oz. iteracije modela RPN so končane z rezultati vseh navideznih analiz, ki se nanašajo na tehnologičnost izdelave in reološke analize. Naslednja faza je izdelava prototipov. Ti naj bi bili po možnosti izdelani iz istega materiala kakor serijski izdelki. V ta namen pogosto izdelamo prototipna orodja, ki po navadi ne izkazujejo vseh lastnosti serijskih orodij, vendar zadostujejo, da na njih simuliramo postopke. Ta zadnja preizkusna faza je zelo pomembna, saj tu pridobimo še zadnje podatke za morebitne poprave na serijskih orodjih. Hkrati pa lahko preskusimo tako pridobljene izdelke in se prepričamo, ali ustrezajo naročnikovim specifikacijam. Morebitne spremembe lahko uporabimo in preverimo na prototipnem orodju. Tako lahko zagotovimo, da bo pri uvajanju izdelka v proizvodnjo nastalo kar najmanj težav. V prototipni fazi so spremembe tudi stroškovno veliko manjše od morebitnih sprememb na serijskih orodjih [6].

2 SKLEPI

Pospešen razvoj izdelkov in njihovo dinamično uvajanje na trg je privedlo do novih spoznanj pri načrtovanju novih izdelkov in tehnologij. Zaradi nenehnega povečevanja zahtev po kakovosti izdelka, po znižanju cen ter vedno krajših dobavnih rokih postaja delo razvojnih inženirjev čedalje težje. Izpolnjevanje zahtev trga na ustaljen način je postalo nemogoče. S konstruiranjem, ki temelji na sodobnih metodah, pa so te zahteve obvladljive.

Za natančnejši vpogled v postopkovna dogajanja vse bolj pogosto uporabljamo računalniško podprt inženiring (RPI). Na tem novem področju smo v zadnjem desetletju priča izjemnemu napredku. Prednosti uporabe se s pridom izkoriščajo v namene skrajšanja izdelavnih časov, zmanjševanja stroškov, večanja produktivnosti, izboljševanja kakovosti in zanesljivosti postopkov. Na podlagi inženirskih

modifications. Quality analysis requires a competent expert who is capable of reasonable unifying of multiple correlating data into an optimum result.

1.4.3 Virtual testing

Because of their non-linear characteristics polymer materials are significantly different from conventional materials. Conventional analysis is limited, and only appropriate for, a simple product geometry and the domain of linear elasticy. Because of the mentioned constraints the FEM (Finite Element Method) is appropriate for practical applications. The FEM's advantages are related to:
- Ability to analyse complex product geometry
- Possibilities of non-linear analysis

1.5 Prototyping

CAD model iterations are concluded by the results of all virtual analyses that are related to manufacturing characteristics and rheology analyses. The next phase refers to prototyping. Prototypes should be made of the same material as the serial products. For this purpose we often make prototype tools, which usually do not demonstrate all the serial tools' characteristics. However, they are sufficient for the process simulation. This final phase of testing is very important because it supplies the final information for the eventual corrections to the serial tools. Simultaneously, we are able to test the properties of the products, which have to correspond to the buyer's specifications. Final modifications can be applied and tested on the prototype tool. In such a manner we are able to ensure a trouble-free product transition to production. Furthermore, all prototype modifications are significantly cheaper than the eventual modifications to the serial tools [6].

2 CONCLUSIONS

Accelerated product design and its dynamic introduction to the market have led to a new understanding of product and technology design. Due to the ever-increasing demand for product quality, cost reduction and a shortening of delivery times, the activities of design engineers are becoming more and more demanding. The fulfilment of market demands using conventional methods has become impossible. However, the use of contemporary design methods enables the fulfilment of these demands.

For a more accurate insight into a process, CAE tools are frequently used. In the last decade computer-aided engineering has made great advances. CAE's advantages are exploited in terms of production-time shortening, cost reduction, increasing manufacturing yield, quality improvements and increased process reliability. On the basis of engi-

projektov ugotavljamo, da se s postopnim uvajanjem sočasnega inženirstva kakovost izdelka močno izboljša.

Z izmenjavo koristnih in potrebnih informacij v sočasnem delovanju dejavnosti projekta se čas konstrukcije kot same izdelave končnega izdelka skrajša na najmanjšo mero. Pri tem je treba poudariti, da se brez ustreznega specifičnega znanja vseh sodelujočih pri projektu omenjenega skrajševanja projekta sploh ne da zamisliti. Usposobljenost vseh posameznikov je tu lahko bistvenega pomena. Ključni pomen imajo tudi stroški, ki morajo biti najmanjši. Pri tem so stroški od zamisli do izdelka značilno manjši, povpravki med postopkom pa eksponentno zmanjšajo celotne spreminjevalne stroške. To pa v veliki meri zagotavlja uporaba sočasnega inženirstva.

Obvladovanje proizvodnje zapletenih sodobnih izdelkov je označena s stopnjo organiziranosti razvojne skupine in proizvodnje. Strokovne skupine, ki skrbijo za uvedbo sočasnega inženirstva, so dandanes pod velikim pritiskom, kako razviti izdelek boljših zmogljivosti, večje zanesljivosti, s čim nižjo ceno, v čim krajšem dobavnem času. Z ustreznimi programskimi orodji in inženirskim znanjem, ki temelji na podlagi modela ter optimizacije, zagotovimo najmanjše število popravkov.

neering projects we are able to conclude that the gradual introduction of concurrent engineering can greatly improve product quality.

The useful and necessary exchange of information in concurrent project activities results in reducing the time of design and manufacturing of the product to a minimum. It should, however, be stressed that a prerequisite for project-time reducing is related to an adequate specific knowledge of all the team members. Their competence could be essential. Costs are very important, they must be minimized. Costs, from the idea to the product, are significantly smaller; and corrections during the process exponentially reduce the overall modification costs. Cost minimisation is ensured by concurrent-engineering employment.

Control of the production of complex contemporary products is characterised by the level of the development team and the manufacturing organisation. CE teams are nowadays under pressure, which refers to the demands for enhanced product efficiency and reliability, combined with the demands for reduced prices and a short delivery time. Minimal modifications can be ensured by the use of appropriate software and engineering knowledge based on models and optimisation.

3 LITERATURA
3 REFERENCES

[1] ProEngineer software for CAD/CAM/CAE/PMD(PLM); news://comp.cad.pro-engineer/

[2] Clausing, D. (1994) Total quality development: a step-by-step guide to world-class concurrent engineering; *ASME Press*.

[3] Ribbens, J. (2000) Simultaneous engineering for new product development: manufacturing applications, *John Wiley & Sons, Inc*.

[4] Milavec, D. (2003) Design and technology tool production process using concurrent engineering,graduate work No.802, *Faculty of Mechanical Eng.,* Ljubljana, Slovenia.

[5] Pogačnik , M., S. Stefancic (1998) Computer aided project management , *14th World Congress on Project Management*.

[6] Dolinšek, S., S. Ekinović, J. Kopač, M. Dolinšek (2003) Introduction of DMLS rapid tooling technology into Slovenian industry. 9th International Scientific conference on production engineering, *CIM 2003*, Lumbarda, Korčula, June 05/06, *Croatian association of production engineering,* I-029 - I-036.

Avtorjev naslov: prof.dr. Janez Kopač
Fakulteta za strojništvo
Univerza v Ljubljani
Aškerčeva 6
1000 Ljubljana
janez.kopac@fs.uni-lj.si

Authors Address: Prof.Dr. Janez Kopač
Faculty of Mechanical Eng.
University of Ljubljana
Aškerčeva 6
1000 Ljubljana, Slovenia
janez.kopac@fs.uni-lj.si

Prejeto: 29.9.2003
Received:

Sprejeto: 12.2.2004
Accepted:

Odprto za diskusijo: 1 leto
Open for discussion: 1 year