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INTEGRATED PRODUCT AND PROCESS DEVELOPMENT IN COLLABORATIVE VIRTUAL ENGINEERING ENVIRONMENT

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Original scientific paper

The paper presents integrative approach in the application of virtual engineering technologies in design of products and production processes for their manufacture. This has resulted in the integration of CAD/CAM/CAE and Virtual Reality technologies in product design and FE/FV numerical simulations and optimization of production processes as digital prototyping of products and processes on one side, and rapid prototyping techniques as physical prototyping, on the other side. Reverse engineering and coordinate metrology have been also applied in reengineering of sheet metal forming process of existing products, with the aim of generating initial digital information about product and final quality control on multi-sensor coordinate measurement machine.

Keywords: *coordinate metrology, rapid prototyping, reverse engineering, virtual manufacturing, virtual reality*

Integrirani razvoj proizvoda i procesa u kolaborativnom virtualnom inženjering okruženju

Izvorni znanstveni članak

Članak prikazaje integrativni pristup u primjeni virtualne inženjerske tehnologije u oblikovanju proizvoda i proizvodnih procesa za njihovu proizvodnju. To je rezultiralo integracijom CAD/CAM/CAE, tehnologija virtualne stvarnosti u oblikovanju proizvoda, FE/FV numeričke simulacije i optimizacije proizvodnih procesa, kao što je digitalna izrada prototipova proizvoda i procesa, s jedne strane, i tehnike brze izrade proizvoda kao izrada fizičkih prototipova, s druge strane. Reverzni inženjering i koordinatna metrologija također su primijenjeni u reinženjeringu procesa oblikovanja lima postojećih proizvoda, s ciljem generiranja inicijalnih digitalnih informacija o proizvodu i konačne kontrole kvalitete na višesenzorskom koordinatnom mjerenom stroju.

Ključne riječi*: brza izrada prototipova, koordinatna metrologija, reverzni inženjering, virtualna proizvodnja, virtualna stvarnost*

1 Introduction
Uvod

Virtual engineering (VE) is an advanced technology, which helps engineers in decision making and establishing control in process development and its manufacturing, using computer environment for precise simulation of geometrical and physical properties of real systems. VE includes simulation of various engineering activities, starting from design, manufacturing of tools and product components, assembling, control and servicing. Application of simulations can eliminate expensive physical prototypes and experiments [1]. The development time is radically reduced, several design alternatives can be tested, all resulting in increased quality. VE also provides for excellent user interface, which allows the user to see the three-dimensional product model in advance, to perform necessary changes and to monitor the material behavior during the manufacturing processes. Such capabilities of the VE system are very precious in automotive and aerospace industries, where the physical models are expensive, require long development time, while products are extremely complex.

A large number of papers in literature presents the most recent investigations and achievements in the area of virtual product and processes development, realized in the integrated VE system, which is using the set of the previously described technologies for modelling, simulation, optimization, control and verification of the real production systems and designed products. Stark et al. [2] were analyzing the key elements in the modern virtual product creation, which includes parametric design in the 3D-CAD modelling, CAE analyses, CNC production, validation by simulations and rapid prototypes, Digital Mock-ups, for creating the robust integrated system in the competitive engineering design. Also emphasized are advantages of the application of the VR techniques for the interactive assessment of virtual prototypes.

Intergated design and manufacturing approach applied in [3] is used for the shape optimization of the structural components, starting from the primitive conceptual design, based on the reverse engineering by the application of the CMM or laser scanning, setting the boundary conditions related to complex assembly and exploitation requirements, via application of the VM technologies in verification of the formability and estimates of costs for the proposed structural components. For validation are used, besides the virtual models of components and technological processes, also the used rapid prototypes. At the end is the application of the CAM technologies and the CNC manufacturing of the functional parts and tools.

Results of the integrated application of the 3D digitalization and RE techniques in the rapid tooling concept in foundry processing technology, together with finite element analysis (CAE) for providing the methodological accuracy of tooling geometry and optimization are presented in [4]. Advantages of this concept are demonstrated on four case studies. Authors emphasize that integration of the RE/CAE/RT technologies significantly improves the competitive position of the manufacturer at the market through decrease of the lead-time and associated design and production costs.

The similar RT integrated manufacturing system is developed and demonstarted through the case studies [5] based also on the RP techniques. Architecture of the system contains 4 blocks: digital prototype, virtual prototype, physical prototype and RT system. Digital prototype is generated by the CAD software or the RE technique. Virtual prototype is referred to the CAE (FE based) analysis for optimization of the mould design and manufacturing planning, while the RP techniques are used for producing the pattern for further RT system. Through the integration of virtual/rapid techniques this system leads to safe reducing of the cycle and costs in design of the tool for minimizing the errors. Lots of researches have been lately conducted by application of the RP and RT techniques, or known as the

RPM (Rapid Prototyping/Manufacturing) techniques [6, 7, 8].

Reverse engineering methodologies are successfully being used for optimization of design of components, subassemblies or subsystems, in the sense of substituting the material of already existing new technologies and generally for improvement and re-engineering of existing products and processes. Javidrad at al. [9] have proposed integrated re-engineering plan for substituting aerospace components/sub-systems, which consists of four steps: technical data gathering (RE-CMM), data analysis and simulations (FEA), processing and implementation. They demonstrated the proposed plan on re-engineering of the rupture disc, where the new materials and the new production processes were applied, thus verifying the proposed solution by functional test.

Besides the development, research and application of the integrated systems in engineering, in recent years that concept has been more applied in biomedicine, which represents the significant potential for future applications. The CT records of internal structure of the human body have limited application in diagnostics as the 2D figures, thus the 3D CAD modelling of the internal structures is very important for the diagnostics itself, presurgery preparations and RP of physical models and implants. A step forward is the representation of the CAD model in the VRML format by application of the VR system [10].

It is indubitable that the virtual engineering techniques are also present in the virtual quality control, thus it is hard to draw a boundary between the digital and physical world in the modern metrology. The processes of digital integration and physical verification and validation are presented in [11]. Authors analyzed methods and techniques for verification and validation of design, especially for complex products in their lifecycle, with considering the industrial requirements and needs and trends in research covered by international standards. Integration of metrology into the design processes, as an early verification of the conceptual versions and manufacturing itself are the key trends. Development of advanced PLM capabilities, according to the authors' opinion is vital for successful application and implementation of the new methods for the verification and validation (V&V) of design. Starting from the wide definitions of V&V in digital and physical domains, it is emphasized that digital/virtual verification through modelling and simulation has been increasingly applied in the early stages of the product development, considering that the costs are significantly lower than in the physical one.

This paper starts with description of the VE system components, i.e. technologies of virtual engineering, which are being applied in the virtual product and processes development, rapid prototyping, validation and verification of the design solutions and in the quality control. The first part of the paper also includes the review of references and state of the art in this area, primarily in the integrative approach in application of the VE technologies in the engineering design. In the second part the concept of integration of virtual engineering technologies is described. Through the case study is presented the complete VE integration in the re-engineering of product and technology for its manufacturing. The proposed integrated system represents a feasible and useful tool in engineering design, not only for researchers but for industrial engineers, too.

2 Components of virtual engineering system
Komponente sistema virtualnog inženjeringa

2.1 Virtual prototyping (VP)
Virtualni prototipovi (VP)

Virtual prototypes (VP) are the inevitable part of the new product development, which enable visualization of the product, investigation of its functionality and exploitation characteristics before the manufacturing itself, estimate of process parameters influence on the product characteristics in its conceptual design. Contemporary CAD/CAM/CAE systems are powerful tools that can simulate the complete life cycle of a product, from the conceptual to the parametric design, testing, assembling, maintenance and even sale. Possibilities of the automatic generating of the NC code and simulation of the tool motion, selection of strategies and tolerances checking, are especially important in the tool and parts manufacturing on the CNC machines. Also, in the modern CA tools, the modules are available for automatic design of the tools' engraving based on the product model, in processes of the injecting moulding of plastics, forging, sheet metal forming and others.

2.2 Physical prototyping – Rapid prototyping/manufacturing (RPM)
Fizički prototipovi – Brza izrada prototipova/proizvodnja (RPM)

The RP technologies, through the physical model of a product, enable an analysis of the product functionality within the assembly, checking of design, ergonomic analysis and other functional testings. The RP appeared as a key enabling technology, whose application exhibited reduction of the lead time for about 60 % with respect to the traditional way. For instance, for development of an automobile, 10 years ago about 60 months were necessary, while now the development time is reduced to 18 months, on average. RPs are being applied within the wide spectrum of industrial areas, for achieving the whole series of objectives that the modern market imposes on them, like the primary requirements for reducing the time until appearance of a new product on the market and decrease of the product price.

When the RP model contains also other functions, besides geometry and shape, like the special mechanical characteristics (RP based on plastics, composites, metals), or biological properties (biocompatible materials), then it can be used not only in manufacturing in the automobile and aerospace industries, but also in household appliances fields and biomedicine. Thus, the RP and the trend of reducing the product development time caused the appearance of the RT (Rapid Tooling) and BM (BioManufacturing) technologies. All together, they make the integrated rapid approach RPM (Rapid Prototyping/Manufacturing) technologies.

2.3 Reverse engineering (RE)
Reverzni inženjering (RE)

Reverse engineering is a process of digitalization of the existing part, assembly or the whole product, by precise measuring or scanning. Application of this technology is especially useful when the electronic models of technical documentation are not available. The two phases are distinctive within the RE process: the first one which consists of the data digitalizing and the second one, within which the 3D modelling of the object is done, based on the acquired data. Output of the first phase of the RE process represents the digital description of the object in the three-dimensional space, which is called the point cloud.

Today, a large number of methods are available for the 3D digitalization. As the most known ones, namely with the largest application in practice, can be enumerated the following systems for the 3D digitalization: coordinate measuring machines (with contact or contactless – laser measuring heads), then nowadays getting more popular hand controlled 3D pantographs, interferometry, photogravimetry, and in the recent times more used computer tomography (CT).

Digital data, usually presented as the point cloud, do not contain necessary topological information. They are further processed and modelled into some more convenient format, from the aspect of the further application, like: 3D polygonal model (obtained by triangulation), 3D geometrical model (obtained by application of the NURBS surfaces) or the CAD model. For the point cloud processing various software is used, like the Imageware, Rapidform or Geomagic. They transfer the point cloud into a form which is more convenient as the input into other systems (CAD/CAM/CAE, RP/RT/RM) or for visualization.

2.4 Virtual reality (VR)
Virtualna stvarnost (VR)

Natural continuation of the 3D computer graphics are the new VR technologies with advanced input-output devices, which were being developed intensively in the past decade, and are being applied in the leading research centers in the world. Through the VR technology one generates synthetic, namely virtual environment in which is enabled the three-dimensional presentation of the product, tool, process in the real time, in the real conditions and interaction with the user. Interaction and its power contribute to the powerful feeling of immersion – inclusion into the actions within the environment in which the user is placed. The user not only sees and manipulates graphical objects on the screen, but he can also touch them and even feel them. Research in this area goes as far as development of the adequate sensors for taste and smell senses.

By the application of the VR technologies those problems are eliminated, considering that the designer in the immersive VR environment has the feeling of the real interaction with the product and process model, which can be of natural size. That is especially significant in the product detailed design phase, virtual mounting of assemblies, or in checking characteristics of the complex products in the automobile and aerospace industries. Significant applications of VR technologies can also be found in biomedicine for diagnostic activities and pre surgery analyses through the 3D presentation of the virtual models generated based on the CT recordings of the patient's internal organs.

Wider application of the VR systems can be expected in the future, when all the deficiencies are removed, when the technology is more adapted also from the aspect of software and hardware support, but also when certain conservative manners in business are overcome in the key groups for introduction of the VR technology in practice.

2.5 Virtual manufacturing (VM)
Virtualna proizvodnja (VM)

The term Virtual Manufacturing is widely used in literature, with a few different definitions, which characterize the VM in the following way: "To manufacture virtual products defined as an aggregation of computer based information that... provide a representation of the properties and behaviors of an actualized product." [12]. Key words that associate with VM are "manufacturing in the computer". Like the application of the CAD/CAM technologies enables reducing the time in the product design, the VM has similar effects in design of technology and manufacturing processes for its production, through their modelling, simulation and optimization.

Frequently characterized as "The next revolution in the global production", virtual manufacturing assumes nonlinear FEM (Finite Element Method) or FVM (Final Volume Method) analysis and simulation of all the processes in manufacturing technology of a certain product. Technology simulation makes possible for companies to optimize key factors which directly affect the product profitability, like: formability, final form and accuracy, level of residual stresses, reliability in exploitation, etc. Profitability increases with reduction of production costs, savings in material, elimination of failures, reducing the time and costs of the product development and design of tools through reducing the number of unsuccessful attempts.

Application of numerical simulations is a very well verified and extremely useful tool for prediction of problems in industrial production and reducing the time and costs in development of the new products. Their basic advantage is the possibility of performing the "what-if" simulations, enabling designers to estimate different design alternatives on virtual models of processes which are planned in the product manufacturing [13]. Since the virtual process models are very flexible they enable investigation of design changes influences, both the product geometry and the process parameters, on the product quality and manufacturing costs. In such conditions it is possible to relatively quickly perform the sensitivity analysis in conditions of parallel processing and to establish areas of optimized design solution. Beside that, it is possible to predict failures and appearances of defects in the product, optimal use of the manufacturing equipment and tools, estimate wear and tool life-span and prevent fractures. Optimal choice of relevant production parameters has positive consequences on reducing the time-to-market, costs of manufacturing, material and tools, as well as increase of the final product quality.

2.6 Digital mock up (DMU)
Digitalni model (DMU)

DMU is a term which is in recent years being used as a key word for innovative product design by the application of the virtual engineering technologies. DMU is a platform for digital, virtual description of a product during its development, design and manufacturing, namely a platform for integration of all the aforementioned technologies of virtual engineering. The product development based on this platform is optimized from the aspect of time, costs and quality. The best example of the DMU application in the automobile industry is the Chrysler Corporation which resolved about 1200 potential errors before the trial manufacturing. Boeing decreased the number of errors and necessity of redesign by 70-80 %, thus saving 100 000 of design hours and millions of dollars.

2.7 Product data management (PDM)
Upravljanje podacima o proizvodu (PDM)

The high complexity of models and analyses, which as a basis has the multitude of various types of data, can lead to problems in digital information and data flow. The PDM technology offers a solution for reliable storage and monitoring of data, thus the real information and data are at disposal to the right person in the design team at the right time. Besides that, electronic data must be available in various formats, so it could be transferred without obstacles between the subsystems of the VE environment, via the corresponding interfaces (Figure 1). In development of the PDM system, which is to satisfy the previously mentioned basic function, existence of the following ought to be avoided: different users' interfaces, nonstandard approaches in data control in the CAD subsystem, unreliable control and storage of the meta-data, complex structures, unauthorized accesses and properties of data, incompatibility of different CAD systems, complex engineering processes and unreliable networking of numerous users.

2.8 Product life cycle management (PLM)
Upravljanje životnim ciklusom proizvoda (PLM)

In recent years, leading manufacturers have accepted the PLM as a means for powerful and reliable conducting of the business strategy and support to innovations in the process of the product development. Supporting the process of decision making in the product development, DMU is the key component in the PLM system. DMU allows the project team to create a digital product model and its environment in the real time, to analyze it getting into the essence of the key factors that are determining its quality, characteristics and price. This significantly decreases time and costs of the product development, with simultaneous optimizing of the product quality and manufacturability. The PLM system solutions, that are being offered today, are essential for creating the collaborative environment in which the product innovation occupies the central place in the process of its development. When the DMU is fully integrated with the advanced PLM tools, advantages and savings are more than significant.

2.9 Collaborative framework
Objedinjeno okruženje

Collaborative environment for integrated design makes possible for different groups, involved in the design process, to work together on development of the efficient virtual product model. Such an approach opens new possibilities and areas for the marketing analysis, multi-criteria estimate of the product design and versions of manufacturing, optimization of the product characteristics for ensuring the high quality, reliability and manufacturability, easy assembling and maintenance. In this way significantly reduced are the time and costs of development, product's life span, and improved its quality and exploitation characteristics. The leading software manufacturers offer industry as final users the complete solutions (the so-called Total solution) of the integrated VPD (Virtual Product Development).

2.10 Virtual quality control and verification
Virtualna kontrola kvalitete i verifikacija

It is known that metrology is the integral part of the production processes, and with development of the systems for digitalization of geometry and objects, which are also used in the RE technologies, it has a significant place in the early phases of the product design and verification of the design solutions alternatives. Selection of methods and techniques for product quality control and verification of the design solutions depends on physical scale (mili, micro, nano), shape of product components (complex, with or without inside features), colors and topography of surfaces, etc. Classification of methods of dimensional verification contains non-contact (magnetic, acoustic, optical) and contact methods (robotic and CMM), where the optical methods and the coordinate metrology are the most applied.

Contemporary trends are addressed at the application of systems that enables control and measurement by the application of several methods, i.e. sensors, like the multi-sensor CMM. They combine advantages of the optical and contact methods for obtaining abundance of information for dimensional analysis and verification of surfaces topography. Possibilities of modern metrological systems are to the greatest extent supported by the powerful softwares which control the process of data acquisition and measurements data processing up to automatized estimate of the measurement uncertainty. Additionally, CAD on-line and CAD off-line functions enable preparation of programs for measurement without the physical part, based on its virtual model.

3 Integration of virtual engineering technologies
Integracija tehnologija virtualnog inženjeringa

One of the basic problems in manufacturing is how to integrate engineering and production activities, considering that integration has to be based on interaction between designers, constructors, technologists, suppliers and buyers, throughout the product's life cycle, namely in activities of design, construction, manufacturing, testing, maintenance and marketing.

Virtual engineering technologies are integrating engineering and manufacturing activities, using virtual models and simulations instead of real objects and operations on them. That is some kind of "digital tool" for simulation and optimization of production, through models of products and processes developed in the virtual environment, with advanced possibilities for rapid prototyping and rapid manufacturing, presentation in 3D environment, collaborative functions for efficient communication of teams, even the remote ones, with reliable storage of all the electronic data, which describe the product and processes for its manufacturing, servicing and

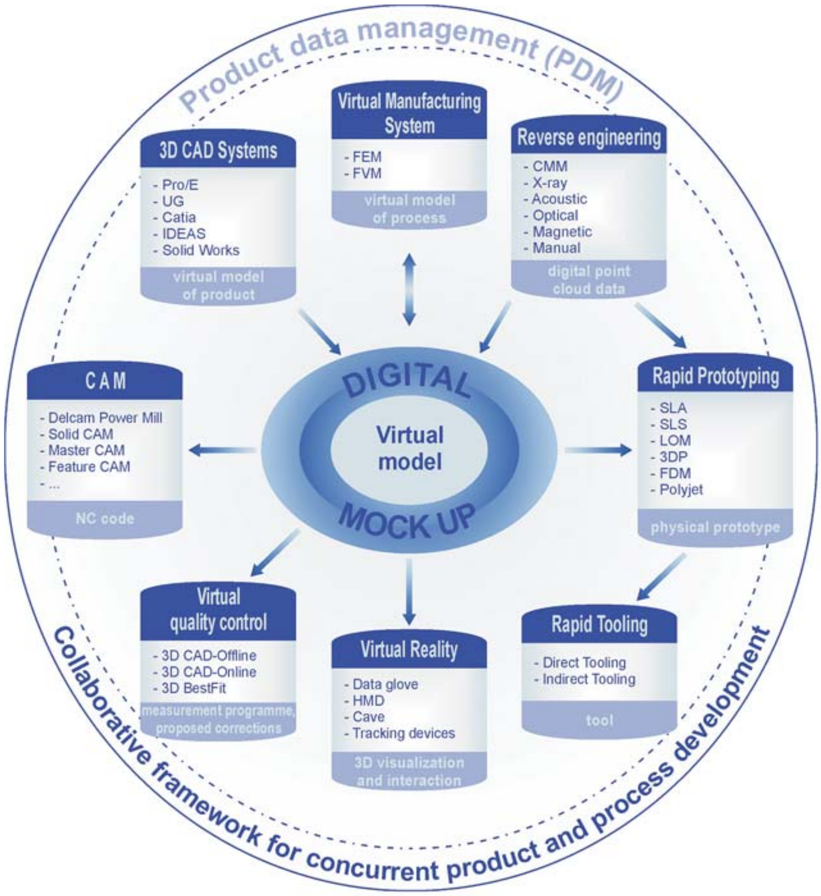

Figure 1 *Virtual engineering system components and their interconnections*
Slika 1. *Komponente sustava virtualnog inženjeringa i njihova povezanost*

sale. In Fig. 1 are presented the virtual manufacturing system components where the central position belongs to product virtual model, namely its complete description and all the generated digital data within the product life span, the so-called Digital mock up. As can be seen, the presented VE technologies are mutually inter-related and almost all are based on generating and application of the product virtual model.

In order to achieve the satisfying degree of integration it is necessary to have a model that covers all the engineering functions, information flow and precise characteristics of the manufacturing systems. Production companies are forced to digitalize product information and speed up the manufacturing innovativeness, so that they would improve their competitiveness at the global market. The VE system does not give the materialized output, namely the physical product, but it gives all the necessary information on them and it allows its estimate and verification. The virtual product and processes' models are flexible and they make possible the desired number of iterations until the optimal solution is reached. Besides that, by its application one can reliably predict business risks and by that support the management in decision making and strategic management of the company.

The integrated VE solution provides for unified environment for modelling, analysis and simulation of products and manufacturing processes and also prevents the loss of information and electronic data, which often happens in their transfer. It also enables easy data transfer from different systems, from design to their analysis and verification and it secures good foundation for virtual engineering based on models and simulations. Moreover, virtual environment offers designers and constructors' visualization of products and their better understanding, leading to improving of quality, reducing the time till the product sales, securing the design solution which is the right one, without the need for later expensive redesign.

With development of the CAD technologies, the reverse engineering becomes the sustainable method for creating the 3D virtual model of the existing physical object, which is further used as the input into different CAD/CAM/CAE systems. It is usually useful to make a rapid prototype of the scanned object, thus the digital model obtained by the Re technique is being transformed into the STL format, which represents the standard form of the input data for any RP process. Since the STL file is being read

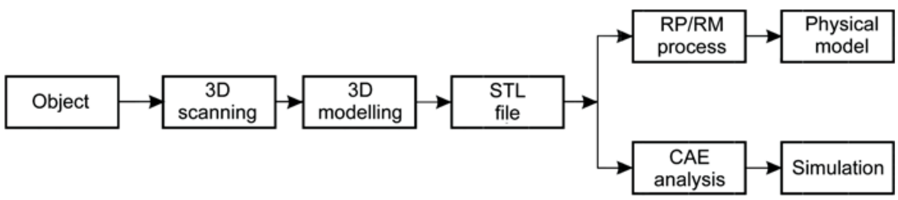

Figure 2 *Schematic representation of the RE technique integration into the CAD/CAE/RP/RM system*
Slika 2. *Shematski prikaz integracije RE tehnike u CAD/CAE/RP/RM sustav*

into the operative system of the machine for the RP process, the replica is being made of the scanned physical object. In Fig. 2 are schematically shown phases of RE techniques for their involvement in the CAD/CAM/CAE systems or the RP/RM processes.

4 Case study
Studija slučaja

The main objective of the presented case study is to apply, on the arbitrary chosen product, i.e. product component, the integrated VE approach in the re-engineering of technological processes in sheet metal forming and verification of the proposed tool design by the application of the virtual and physical prototypes. The handle made of this sheet, which is used in manufacturing different types of kitchenware, is obtained by processes of blanking, punching, deep drawing and bending. The last operation of bending and closing the handle could be unstable, depending on the shape of the blank and previous operation of deep drawing/bending and additionally caused by thin sheet anisotropy. If such a component is bought, there is no technological documentation for technological procedure and manufacturing of tool.

If the technology development and the tool design are done exclusively based on experience of the designer, a large number of physical prototypes of tools and try-outs is necessary. Virtual product development and optimization of technological processes give significant reducing of the development time and costs. In addition, the design teams can produce several solutions for different versions of styling of such products as consumer goods, what gives companies the possibility to competitively position themselves at the market with the redesigned products.

As the digital models of the product component is a basis for integrated application of the VE technologies, the applied re-engineering approach comprised the following technologies (see Fig. 3):

1. Reverse Engineering – for scanning of blank shape and free surfaces of handle
2. CAD modelling – for 2D model of blank and 3D model of handle
3. Virtual Manufacturing System – for virtual verification of the proposed technology and dies design
4. Rapid Prototyping – for physical verification of simulation FE model
5. Quality control – for comparison between real part and RP of simulation model
6. Virtual Reality – for 3D visualization and interaction with virtual models.

The start is the finished part made of thin sheet, obtained from the kitchenware manufacturer, which uses tools and technological manufacturing procedures whose development is realized as the outsourcing. The need existed to do the re-engineering of technologies and further redesign of the handle for other products, if the applied procedure is proven to be useful and reliable. In Fig. 4 is shown the handle and the blank which is cutout from the sheet C0146 (Fe P01 / St12), thickness 0,7 mm.

The applied technology for manufacturing the handle contains the following operations:

- Blanking and punching – by this operation from the sheet metal a blank is obtained
- Two-angle bending and deep drawing – represents the first operation of forming the bottom surface of the handle
- Bending – the final operation by which the top surface of the handle is obtained and final closing of the sheet to the required form.

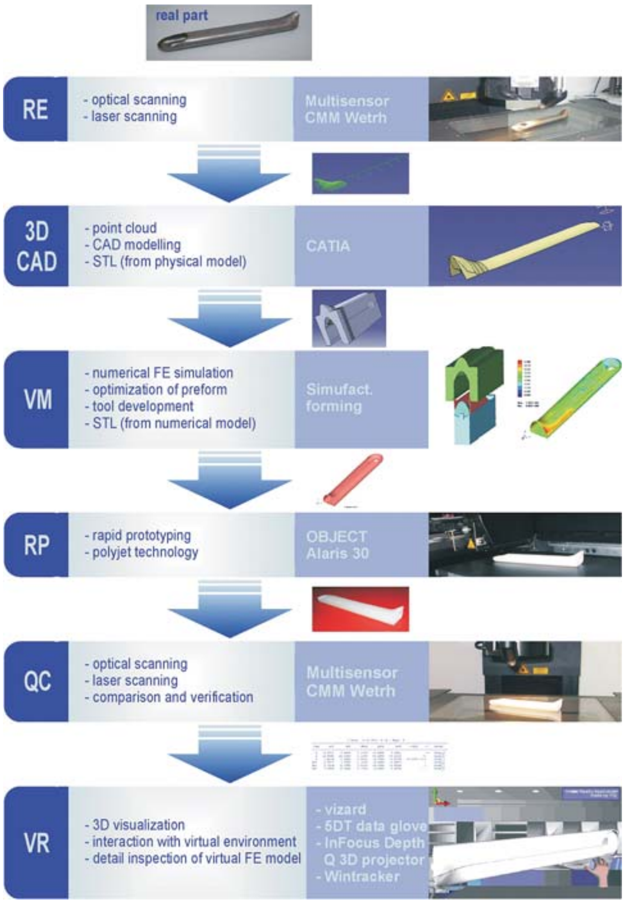

***Figure 3** Proposed re-engineering procedure in VE framework*
***Slika 3.** Predložena procedura re-inženjeringa u VE okruženju*

The finished part and the blank are scanned at the multi-sensor coordinate measurement machine WERTH VideoCheck IP 250, which is equipped with three sensors: optical, laser and fiber contact sensor. Since the blank is a planar figure the optical scanning of closed contour "2D" was done and as the output was obtained the ASCII file with coordinates of points at the edges of the cut-off blank. The option that was chosen there was backlighting when light that illuminates the workpiece comes from below, thus the contour edges are visible on the video screen as a shadow. In Fig. 5 is shown the blank on the CMM, and corresponding display of the scanning results on the screen.

***Figure 4** Final part and blank shape*
***Slika 4.** Finalni dio i oblik pripremka*

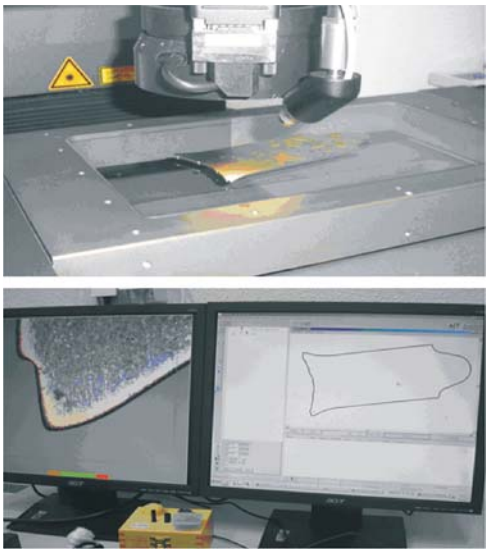

Figure 5 *Optical 2D scanning of blank contour on CMM*
Slika 5. *Optičko 2D skeniranje pripremka na CMM*

The point cloud in the ASCII format was imported into the programming package CATIA, in the Digitzed shape editor, where by connecting points the contour line of the blank is obtained. The contour line is used in the Part-design for obtaining the 3D model of a blank with defined sheet thickness. The prepared blank model was exported in the STL format for further use in the CAE software Simufact.forming.

Scanning of the finished part was done by use of the optical and laser sensors in the 3D scanning option. By optical scanning the contour shape was registered with the autofocus option, as presented in Fig. 6, while the top surface of the handle was scanned by the laser sensor. On the portion of the handle with the variable cross-section and complex surface, the laser scan lines were registered at a distance of 0,75 mm from each other, while at the flat part of the handle 3D scanning of the object was done by lines separated from each other by 20 mm. The result of scan was exported as the ASCII file, later imported into the Digitized shape editor.

In the Generative shape design are imported scan lines used for modelling the cross sectional surfaces, by what was generated the whole contact surface of the top part of the tool for the second operation of bending and final forming of the handle. The generated surface was used for modelling the upper surface of the mandrel. In the case of the CAD modelling mandrel surface is moved down for the sheet thickness of 0,7 mm. Imported point cloud and generated CAD surface are shown in Fig. 7.

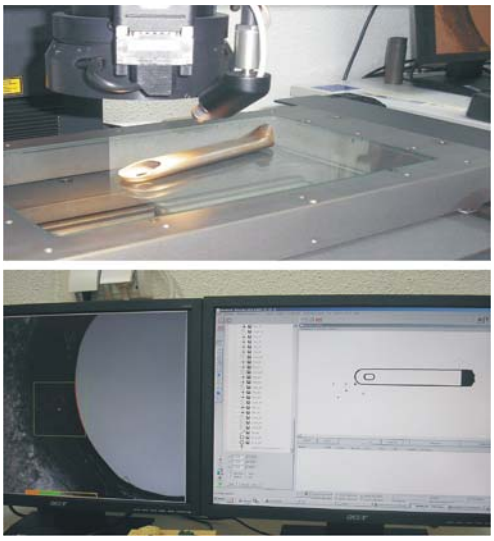

Figure 6 *Optical and laser 3D scanning of final part on CMM*
Slika 6. *Optičko i lasersko 3D skeniranje gotovog dijela na CMM*

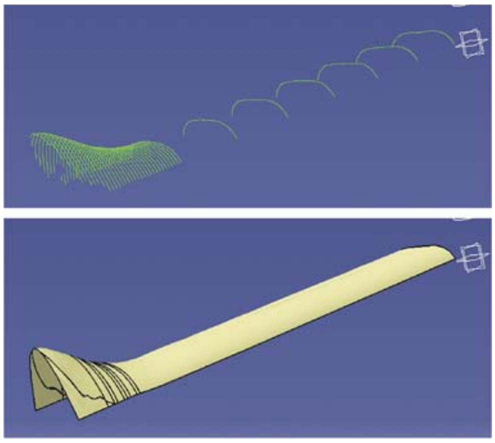

Figure 7 *Imported point cloud and CAD model of upper surface*
Slika 7. *Importiran oblak točaka i CAD model gornje površine*

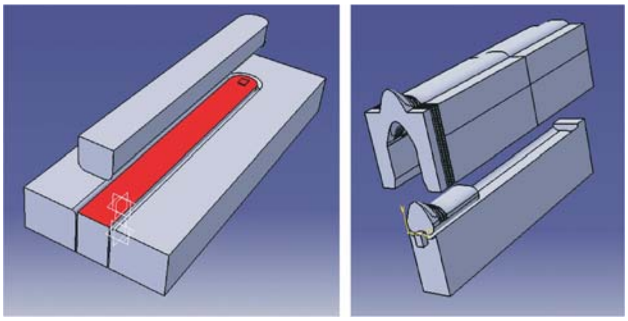

Figure 8 *CAD models of tools for 1st and 2nd forming stages*
Slika 8. *CAD modeli alata za prvu i drugu operaciju oblikovanja*

For operations of the sheet forming the CAD models of tools are done, shown in Fig. 8. For the first forming operation, based on the scan contour and measurement the top form of the upper die was defined. The geometry of lower die for the first forming operation corresponds to the shape of the upper die, taking into account the calculated clearances. The central part of the tool is supported by springs, thus providing the necessary holding force during forming, and afterwards it has a function of pusher. The tool for the second forming operation consists of the upper die, mandrel and the supporting plate which receives the preform.

Finite element simulations of both operations were performed by using commercial software Simufact.forming, as a special purpose process simulation solution based on MSC.Marc technology. Non-linear finite element approach was used with 3D solid elements (HEX), optimized for sheet metal forming using a "2½ D sheet mesher - Sheetmesh". In Fig. 9 is presented a blank on which was initially formed the FE mesh (element size 0,7 mm, two layers of thickness), virtual assembly for the first bending operation and deep drawing, the formed workpiece after the first operation with the FE mesh, virtual assembly for the second forming operation and finally the virtual model of a handle at the end of forming. The flow stress curve was determined by tensile test, defined by equation $\sigma = 180 + 350\varepsilon^{0,23}$, MPa. Interface conditions were described

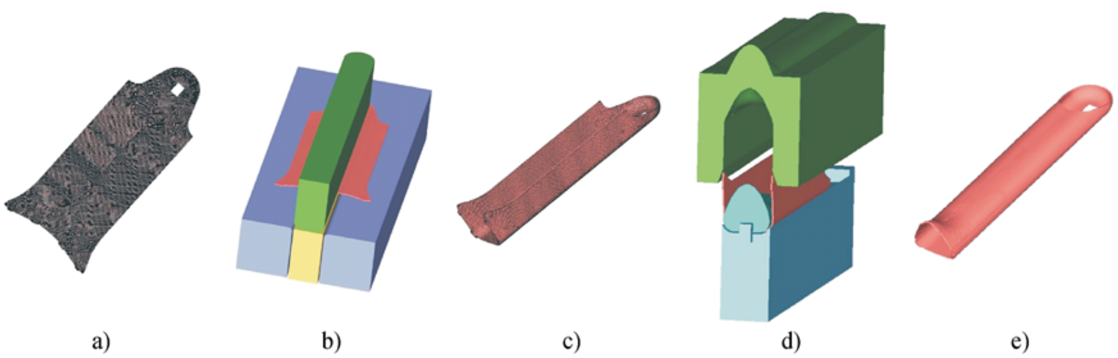

Figure 9 *Numerical models: a) FE mesh of blank b) tool assembly for 1st stage c) FE mesh of preform d) tool assembly for 2nd stage e) virtual handle*
Slika 9. *Numerički modeli: a) FE mreža pripremka b) sklop alata za 1. operaciju c) FE mreža međuoblika d) sklop alata za 2. operaciju e) virtualna drška*

by the Coulomb friction law, with friction factor 0,1.

In Fig. 10 are shown distributions of effective stress in three numerical steps in the first forming operation, while in Fig. 11 in the final forming operation. When the process is modelled numerically by the final element method, it is possible to analyze the large number of output variables, at any time of the process. In this way, besides the estimate of the material flow and appearance of defects in forming, the quality of product can be estimated as well as the forming tolerances and level of residual stresses.

Figure 10 *Effective stress fields during 1st stage*
Slika 10. *Polja efektivnog napona u toku 1. operacije*

Figure 11 *Effective stress fields during 2nd stage*
Slika 11. *Polja efektivnog napona u toku 2. operacije*

In this case of re-engineering of the process and technology of obtaining the handle from sheet metal, the form of the upper die and the mandrel, dimensions and shape of the blank are important from the aspect of proper filling of the tool, i.e. bending of the sheet and obtaining the final closed form without overlap at the top surface of the handle. The verifying of the sheet forming and "closing" of the handle in the final operation is analyzed in 8 characteristic cross-sections, shown in Fig. 12. In this paper are presented some results of the FE estimate for cross-sections 1 and 7, where it is evident that the proper filling of the tool is provided, as well as the forming of the handle, without appearance of defects – overlaps or holes in the seam.

No matter how the numerical models of processes and products, obtained by virtual manufacturing are complete and reliable, the need exists for such models to be transformed into physical models by RP techniques, in order to perform the final verification of dimensions and fitting. The virtual model of a handle, obtained by the FE simulation, was exported in the STL file (Fig. 13 a) and it was used for manufacturing the prototype made of plastics by application of the PolyJet technology and the 3D printer ALARIS 30. The PolyJet technology enables obtaining of prototypes with fine surfaces, small details with high resolution from the phototopolymer VeroWhite FullCure 830, by depositing thin layers of 28 μm, which solidify due to action of the UV rays. In Fig. 13 is presented the RP model of a handle, which besides for the visual control of

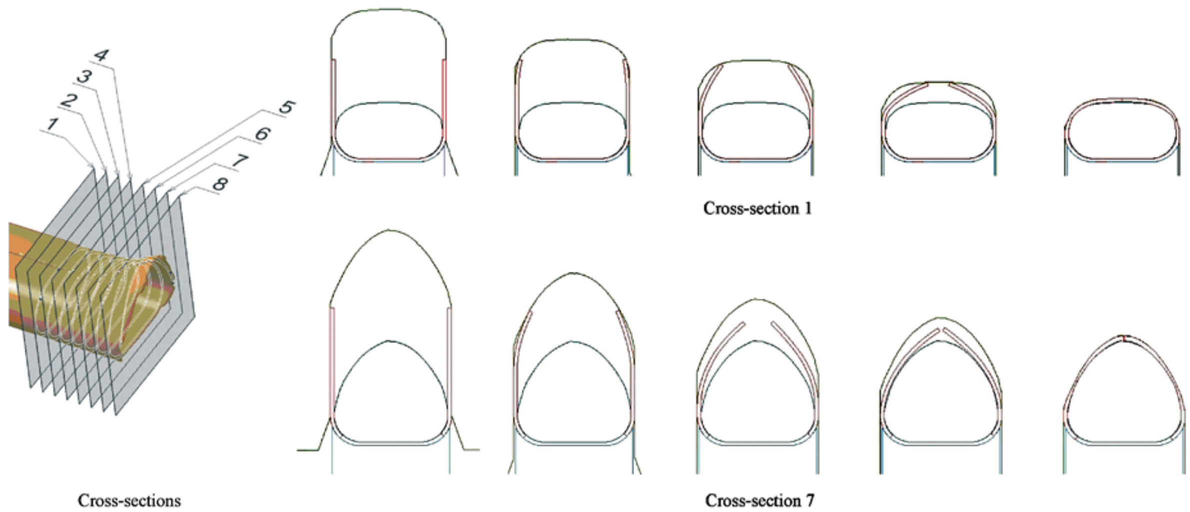

Figure 12 *FE results of final forming of handle, in cross-sections 1 and 7*
Slika 12. *FE rezultati finalnog oblikovanja drške, u presjecima 1 i 7*

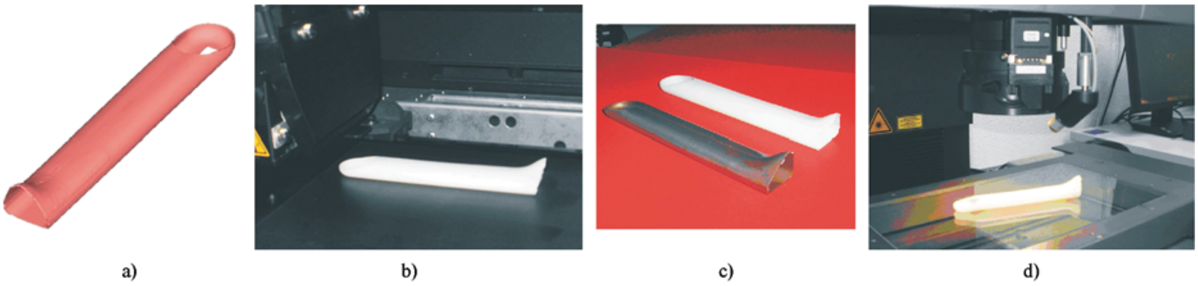

Figure 13 *Rapid prototyping from FE simulation result and control measurement on CMM: a) exported STL from FE simulation, b) RP model on the table of 3D printer ALARIS 30, c) real part and RP, d) RP model on CMM for control measurement*
Slika 13. *Brza izrada prototipa na osnovu rezultata FE simulacije i kontrolno merenje na CMM: a) generiran STL iz FE simulacije, b) RP model na radnom stolu 3D printera ALARIS 30, c) realni dio i RP, d) RP model na CMM za kontrolno mjerenje*

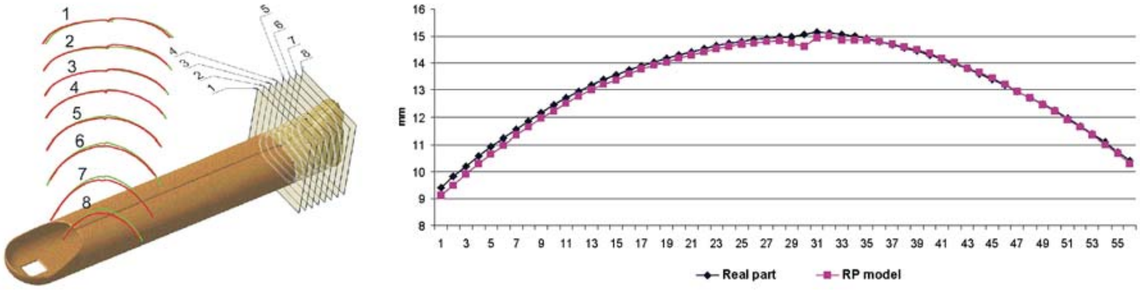

Figure 14 *Measurement results – comparison of RP-FE model and real handle, cross-section 4*
Slika 14. *Rezultati merenja – usporedba RP-FE modela i stvarne drške, presjek 4*

Figure 15 *Virtual reality equipment and 5DT gestures: a) Wintracker tracking system, b) 5DT data glove, c) used gestures and associated actions*
Slika 15. *Oprema za virtualnu stvarnost i 5DT geste: a) Wintracker uređaj za praćenje kretanja, b) 5DT rukavica, c) korištene geste i dodijeljene akcije*

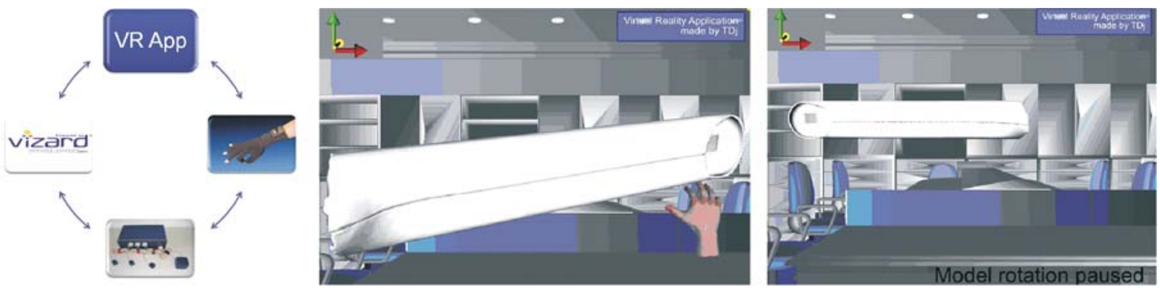

Figure 16 *Virtual reality application*
Slika 16. *Aplikacija virtualne stvarnosti*

surfaces was used for precise measurement of the model on the CMM machine WERTH. The measuring strategy was identical as for measuring the real part, for the reverse engineering of surfaces. The positions of cross-sections for comparison of forms and dimensions of the real part and the RP model, indirectly the FE model, are shown in Fig. 14. The graph in the same figure shows comparison of scanned lines for cross-section 4. Such an approach is also possible to be applied for reengineering of other types of processes, where the verification of the FE simulations results is desired and comparison of the physical model and the real product.

In the integrated VE environment the user can analyze processes, systems, products on relation virtual-physical -virtual, where the virtual model of the product is imported into the VR system for the 3D display and interaction with the user. The virtual model of a handle can be analyzed in more details in the VR environment. For those needs a VR application was developed by the use of the following software and hardware components:

1. Wizard VR Toolkit program for creating the VR environment, where the software application was done in the programming language Pyton. During development of the VR application, available module in Wizard was used, for realization of communication with 5 Data Glove.

2. 5DT Data Glove which enables recognition of gestures for certain operations on the object that is analyzed in the VR environment; in this paper are used 4 predefined

gestures, shown in Fig. 15, to which the following actions on object are assigned: translation, rotation, scaling and initial positioning.

3. Wintracker, magnetic 6DOF tracking device for tracking the data glove movements, namely for manipulating with the object in the VR environment. Based on the data that are obtained from one of the sensors from the motion tracking device, mounted on the hand, the virtual hand on the screen is moved, and by that movement of the virtual objects is possible by the user.

Some of the screens from the VR application are shown in Fig. 16. In such prepared application it is possible to import other 3D objects modelled in the CAD system or exported from the various CAE systems in the form of the STL or VMRL files.

5 Conclusion
Zaključak

In this paper are presented components of the VE system, which generates and/or uses the virtual/rapid prototypes of products and processes, whose analysis and verification are possible both in the physical and virtual sense. Each component of the VE system has its advantages and disadvantages, thus the integrated approach, which assumes their complementary application, became the powerful tool for designers and researchers. The start in the integrated development of products and processes by application of the VE technologies can be 3D CAD model prepared by the designer or modeled after the 3D scanning /digitalization of an object by application of the RE device. The virtual model (Digital Mock-up) occupies the central position in the collaborative environment for support to the integrated VE system considering that it is also used and improved through application of the virtual manufacturing, rapid prototyping, virtual quality control and finally, virtual reality system.

Through the presented case study of process re-engineering of making the handle from the sheet metal, advantages and possibilities of the VE technologies integration were demonstrated, through application of the CAD/CAM/CAE, VM, RP/RM and VR techniques. It was shown that, due to development of the IT technologies, software and hardware components, engineering design and development, as well as the other phases of the product life cycle, can be very successfully realized, with respect to quality, costs and time, by application of the virtual/rapid prototyping/manufacturing technologies of virtual engineering.

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ASCII – American Standard Code for Information Interchange
CAD/CAM/CAE – Computer-aided Design/Computer-aided Manufacturing/Computer-aided Engineering
CMM – Coordinate Measurement Machine
CNC – Computer Numerical Control
CT – Computer Tomography
DMU – Digital Mock Up
FE/FEM – Finite Element/Finite Element Method
FVM – Finite Volume Method
PDM – Product Data Management
PLM – Product Life Cycle Management
RE – Reverse Engineering
RP/RM/RT – Rapid Prototyping/Rapid Manufacturing/Rapid Tooling
STL – Stereolithography (file format)
VE/VM/VR – Virtual Engineering/Virtual Manufacturing/ Virtual Reality

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