Integrated Model-Based Manufacturing for Rapid Product and Process Development

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Abstract. The paper presents integrative model-based approach in application of virtual engineering technologies in rapid product and process design and manufacturing. This has resulted in integration of so called CA- technologies and Virtual Reality in product design and FE numerical simulations and optimization of production processes, as digital prototyping of product and processes, from one side, and rapid prototyping techniques as physical prototyping, on the other side. Reverse engineering and coordinate metrology have been also applied in re-engineering of sheet metal forming process of existing product, with aim at generation of initial digital information about product and final quality control on multi-sensor coordinate measurement machine.

Keywords: model-based manufacturing, virtual engineering, rapid prototyping, virtual manufacturing.

1 Introduction

Model-based manufacturing implies technological integration of CA technologies (CAD/CAM/CAE) in product development with VM technologies (Virtual Manufacturing) for modelling of manufacturing processes and application of rapid technologies (RP/RT/RM) for testing and validation purposes. It results in 3D digital model of a product/tool, but also in the virtual model of manufacturing processes in computer environment and physical prototypes of components and assemblies. VM is based on nonlinear finite element analysis and it enables optimisation of key factors of production for validation of different concepts of manufacturing processes and optimization of e relevant parameters for shop within the whole set of “what if” scenarios. In a word, a capability to “manufacture in the computer” is so powerful tool which reduces the errors, cuts the costs and shortens the time of design, because all modifications are made before the actual manufacturing process. Besides CAD modelling, 3D model of a product/tool can be also rapidly generated in digital form using reverse engineering, remodelled and exported to one of the systems for rapid prototyping (RP), rapid tooling (RT) or rapid manufacturing (RM). Virtual and rapid prototypes obtained in this way can be used for testing the functionality of product or assembly and different concepts in the early stage of design without expensive and long-term

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trial-and-error attempts in traditional design and production. Virtual manufacturing also uses virtual reality (VR) as advanced technology for 3D presentation of model's structure, composition and behaviour as if it were physically manufactured.

Large number of papers presents the most recent investigations and achievements in the area of virtual and rapid product and processes development, realized in the integrated model-based system, for modelling, simulation, optimization, control and verification of the real production systems and designed products [1-3]. This paper starts with description of the model-based manufacturing system components, i.e. technologies of virtual engineering, which are being applied in it. Through the case study is presented the proposed model-based manufacturing approach in the re-engineering of product and sheet metal multi-stage forming technology for its manufacturing. The proposed integrated system represents feasible and useful tool in engineering design, not only for researchers but for industrial engineers, too.

2 Components of Model-Based Manufacturing and Its Integration

Model-based manufacturing technologies are integrating engineering and manufacturing activities, using virtual models and simulations instead of real objects and operations. 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 sale. In Fig.1 are presented virtual engineering components and its interactions applied in model-based manufacturing approach, where the central position belongs to virtual model of product and manufacturing processes, namely their complete description and all the generated 3D digital data within the product life span, the so-called Digital mock up.

Virtual prototypes 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 within CAM technologies. 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.

Reverse engineering (RE) 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 from 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.

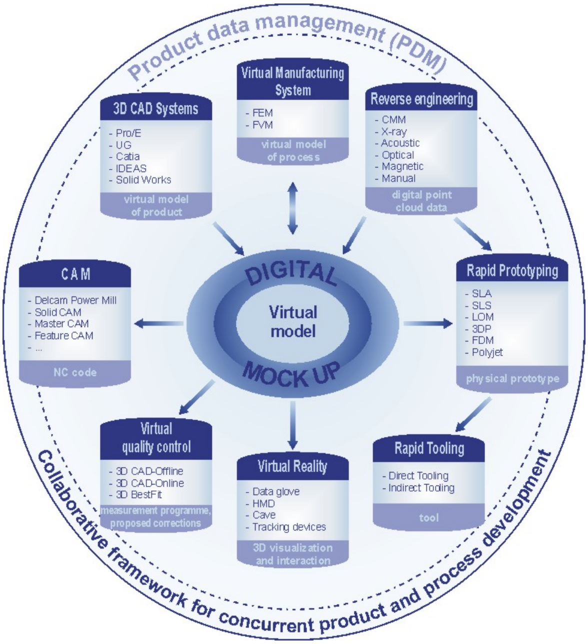

Fig. 1. Virtual engineering system components and their interconnections [4]

The Rapid prototyping (RP) technologies, through the physical model of a product/tool, enable an analysis of the product functionality within the assembly, checking of design, ergonomic analysis and other functional testing. 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. The trend of reducing the product development time in RP caused appearance of the Rapid Tooling (RT). All together, they make the integrated rapid approach RPM (Rapid Prototyping/Manufacturing).

Natural continuation of the 3D computer graphics are the new Virtual Reality (VR) technologies with advanced input-output devices. 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, with interaction with the user. Its application 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.

Application of Virtual manufacturing (VM), based on non-linear FE simulations, is a well verified and extremely useful tool for prediction of problems in manufacturing. Since the virtual models of processes are very flexible they enable investigation of design changes influences, both the tool layouts and the process parameters, on the product quality and manufacturing costs. 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.

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. Possibilities of modern metrological systems are to the greatest extent supported by the powerful software which control data acquisition, its processing up to automatized estimate of the measurement uncertainty. Additionally, CAD on-line and CAD off-line functions enable preparation of programs for measurement based on its virtual model.

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. The integrated solution provides for unified environment for modelling, analysis and simulation of products and manufacturing processes and also prevents loss of information and electronic data, which often happens in their transfer. Moreover, virtual environment offers designers and researchers visualization of products and their better understanding, leading to improving of quality, reducing the lead time, securing the design solution which is the right one, without the need for later expensive redesign.

3 Case Study

The main objective of the presented case study is to present, on the arbitrary chosen product, i.e. product component, the integrated model-based approach in the re-engineering of manufacturing processes in sheet metal multi-stage forming and verification of the proposed tool design by application of the virtual and physical prototypes [5]. The handle made of the sheet, which is used in manufacturing different type 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.

The applied re-engineering approach (Fig.2) comprises the following technologies:

- Reverse Engineering (CMM–optical&laser sensors) – for scanning of blank shape and free surfaces of handle
- CAD modelling – for 2D model of blank and 3D model of handle
- Virtual Manufacturing System (FE simulation) – for virtual verification of proposed technology layouts and tools design
- Rapid Prototyping (PolyJet) – for physical verification of simulation FE model
- Quality control (CMM) – for comparison between metal part and RP model
- Virtual Reality (Data glove, tracking system, 3D projector and stereoscopic glasses) – for 3D visualization and interaction with virtual models
- CAM modelling – for generating of NC code for CNC machining of tools

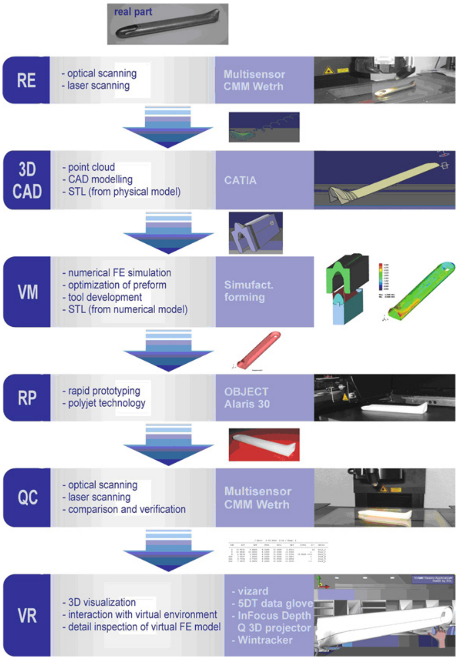

Fig. 2. Model-based engineering design and prototyping

Production processes for manufacturing the handle contains the following operations: 1) Blanking and punching 2) Two-angle bending and deep drawing 3) Bending – the final operation in which the final closure of top surface of the handle is obtained. 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 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 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.3 is shown the blank on the CMM table and corresponding display of the scanning results on the screen. The point cloud in the ASCII format was imported into the Digitzed shape editor. The contour line is used in the Part-design for obtaining the 3D model of a blank with defined sheet thickness.

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.4, 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 for 20 mm. As in the previous case, the results of both scans was exported as the ASCII file, later imported into CATIA through 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

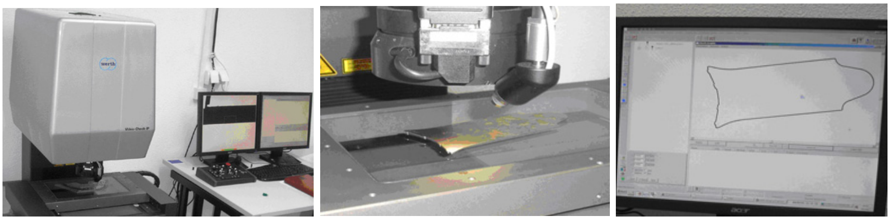

Fig. 3. Optical 2D scanning of blank contour on CMM

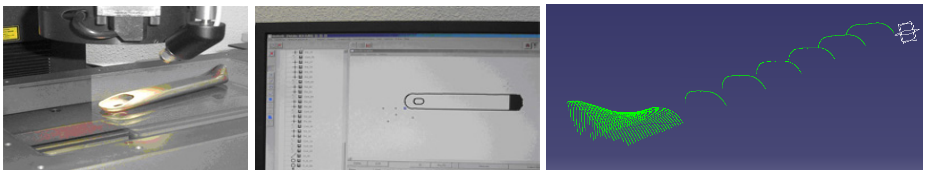

Fig. 4. Optical and laser 3D scanning of final part on CMM, and imported point cloud

the tool for the second operation. The generated surface was used for modelling the upper surface of the mandrel (Fig.5). The tool for the second forming operation consists of the upper die, mandrel and the supporting plate.

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.6 is presented a blank on which was initially formed the FE mesh (element size 0.7 mm), virtual assembly for the first operation, the formed workpiece after the first operation with the FE mesh, virtual assembly for the second forming operation and the virtual model of a handle. The flow stress curve was determined by tensile test, defined by equation $\sigma = 180 + 350\varepsilon^{0.23}$, MPa. Interface conditions were described by the Coulomb friction law, with friction coefficient 0.1.

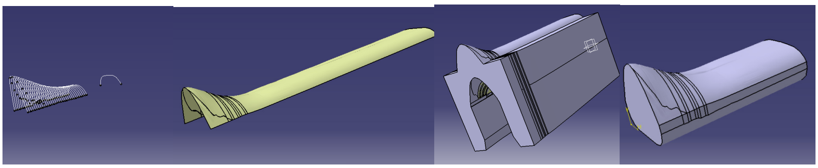

Fig. 5. Transforming scanned lines in CAD surfaces and 3D models (upper die and mandrel)

Fig. 6. Numerical models for FE analysis of virtual manufacturing

In Fig.7 are shown distributions of effective stress in the first forming operation, while in Fig.8 in the final forming operation. In this way, besides the estimate of the material flow and appearance of defects in forming, the quality of product, forming tolerances and residual stresses can be estimated.

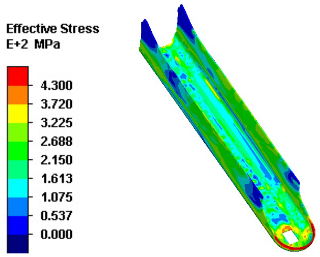

Fig. 7. Effective stress - 1st stage

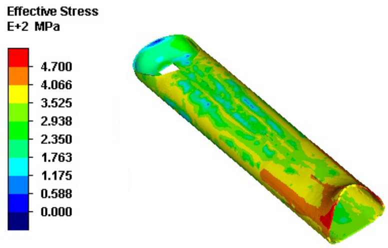

Fig. 8. Effective stress - 2nd stage

No matter how the numerical models of processes and products, obtained by virtual manufacturing are complete, the need exists for such models to be transformed into RP models, 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 (Figure 8 a) and it was used for the prototype made of plastics by application of the PolyJet technology. In Fig.9 is presented the RP model of a handle, which besides for the visual control of surfaces was used for precise measurement of the model on the CMM. The measuring strategy was identical as for measuring the real part. 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.10. The graph in the same figure shows comparison of scanned lines for cross-section 4.

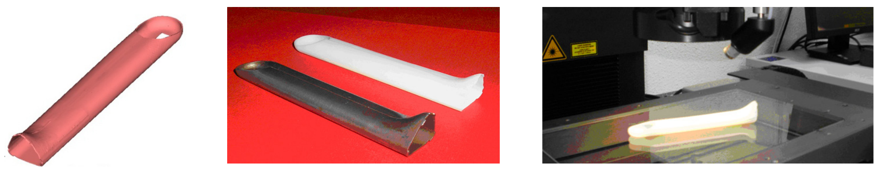

Fig. 9. Rapid prototyping from FE simulation result and control measurement on CMM

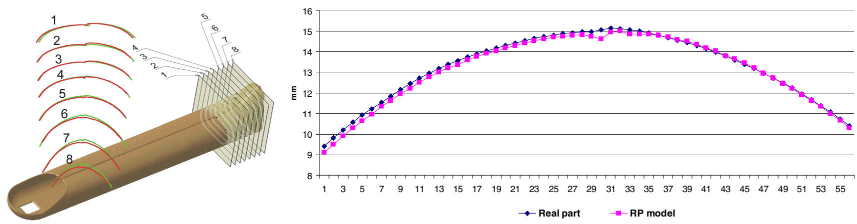

Fig. 10. Measurement results – comparison of RP-FE model and real part, cross-section 4

In the integrated 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 use of the following software and hardware components: 1)Wizard VR program, 2) 5DT Data Glove, 3) Wintracker, magnetic 6DOF tracking device. The screens form the VR application are shown in Figure 11. In such prepared application it is possible to import other 3D objects modelled in the CAD system or exported from the various VM systems in the form of VMRL files.

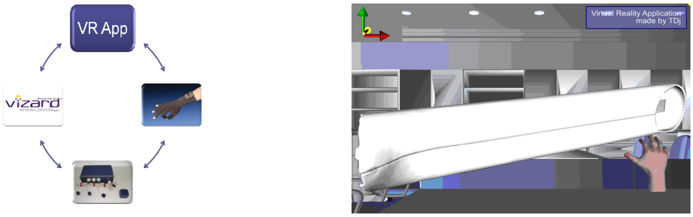

Fig. 11. Virtual reality application

4 Conclusion

In this paper are presented components of the model-based integrated 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 system has its advantages and disadvantages, thus the integrated approach, which assumes their complementary application, became the powerful tool for designers and researchers. Through the presented case study at the example 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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