Virtual Reality Solutions for the Design of Machine Tools in Practice

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Abstract
At the Virtual Reality Centre Production Engineering (VRCP) the Institute for Machine Tools and Production Processes (IWP) of the Chemnitz University of Technology and the Fraunhofer Institute for Machine Tools and Forming Technology (IWU) have developed several practical Virtual Reality (VR) based solutions for the industry. Some practical examples will show the benefits gained by the application of Virtual Reality techniques in the design process of machine tools and assembly lines.

Keywords:
Virtual Reality, machine tools, manufacturing facilities

1 INTRODUCTION

Virtual Reality (VR) solutions cover an increasingly broader range of applications in machine tool manufacturing and production engineering lately. For this purpose the VR forms an ideal visualization and communication platform for the specialized spreading discussion of different questions from the ranges construction, technology, production planning, maintenance and training. Latest research and development results permit the employment of the VR as an active development medium. That means that in the immersive environment models can be manipulated directly. These changes flow directly back into the classical (not VR based) development process.

In the following article some concrete sample applications for VR applications in the machine tool development and production engineering are presented.

- VRAx® - a research project for the VR based design of machine tool with parallel kinematics (PKM)
- Application of VR technology for the design of new components for the spin extrusion machine BDM2000
- Simulation and customization a universal grinding machine
- Visualisation and simulation of an assembly line for the manufacturing of machine tools

The practical solutions based on VR technology are explained. The additional value gained for the industry by the application of immersive stereoscopic visualization is especially emphasized. Furthermore some technical aspects are discussed. The last major point introduces a self-developed mobile VR system. Mobile high end visualization ensures maximum flexibility and customer value at low cost.

- **Mo**bile **V**irtual **E**nvironment (moVE) – a customer friendly mobile VR system

2 VRAX® - VR BASED DESIGN OF MACHINE TOOLS WITH PARALLEL KINEMATICS

2.1 Overview

VRAx® [1] denotes a platform for designing machine tools that is based on Virtual Reality (VR) technologies analogous to existing CAx tools. It provides an integrated workflow for the development, simulation and evaluation of machine tools with parallel kinematics [2]. The virtual reality based approach ensures a much larger transparency of the development cycle compared to the classic CAx tools. This allows the early integration of customers and users in the development process. VRAx® comes with a database driven building set of standard components for parallel kinematics. The building block based approach allows the fast prototyping of the machine structure with an easy to use immersive interface. One highlight of VRAx® is the real time online coupling of a CAD kernel with the VR system.

2.2 System Architecture

The system architecture of the VRAx® system comprises a three-layer model [3]. A VR system forms the visualization and interaction layer. The second layer is the application layer which implements and controls the workflow for the development of machine tools with parallel kinematics. And there is the data layer responsible for handling and synchronisation of the different model instances. Based on a digital product data model for machine tools with parallel kinematics, the design, simulation and calculation systems required during the development process (CAD, FEM, MBS, calculation algorithms for structure optimization, databases, ….) are integrated via a product data management system (PDM system). Instead of concrete models, abstract model descriptions and their parameters will be stored in the form of a model matrix. A VR system that is linked with the given design and simulation systems operates as an interface between the users and the digital data model and offers developers innovative opportunities for interactive stereoscopic or immersive analyses of the virtual production system.

The proposed modular design makes it possible to make interactive changes in the VR system and feed them back into the 3D CAD system. A graphical user interface (GUI) provides the input parameters (such as workspace, space requirements, process forces, etc.).

The parallel kinematical structure optimized for these parameters is configured using algorithms for the selection and optimization of assemblies such as the frame, joints and struts that are implemented in a knowledge base. The structural parameters of the calculated parallel kinematical structure are provided and form the basis for creating the explicit geometry of the parallel kinematical structure in a CAD system. This design does not have to be made in the traditional manual way but can be aided by a (semi)automatic tool for geometry generation.

2.3 Workflow

Software systems for the configuration and optimization of PKM have been developed in the past [4]. A new approach was designed for the holistic development of machine tools with parallel kinematics. It is characterized by the consistent use of VR technologies throughout the development process and by integration of VR, CAD, and optimization and simulation tools [5]. A workflow for developing machine tools with parallel kinematics was created as a result of analysing and structuring the developmental stages when designing PKMs. The basic workflow of developing a machine tool with parallel kinematics using a VRAx® system is explained below.

The requirements to be met by the machine tool are defined based on the workpieces it is to produce. The workpiece is visualized in the VR environment. The traversing paths of the tool (such as grinding paths) are transferred from the CAM system to the VR system. These traversing paths are input variables for a dynamic optimization process for the computation of the PKM structure. Points where particularly high machining forces occur can subsequently be marked by the manufacturing engineer. The machining paths define the workspace of the machine. It is represented in the form of a wire grid (see Figure 1). The size of the workspace can be changed interactively at any time. The recorded requirements regarding range of workpieces, processing technologies used and the workspace now define the required static and dynamic properties of the machine tool. These form the basis of the optimization process.

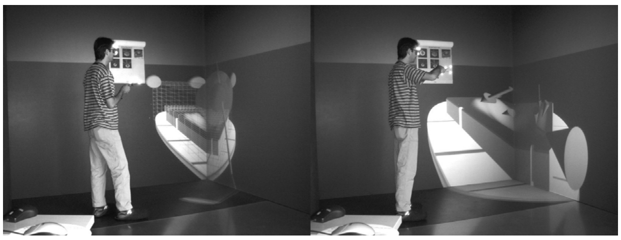

Figure 1: Definition of requirements.

The VRAx® system offers suitable templates for parallel kinematical structures as a result of the optimization. The template selected defines installation positions and requirements for the actual struts and joints. Suitable components are preselected from a building block system database. Now struts and joints from this preselection can be placed on the PKM structure with a snap-in mechanism (see Figure 2).

Figure 2: PKM structure selection and assembly.

Not all components of the machine tool are available in the building block system. This is why, in a third step, machine-specific components such as frame components or working platforms that receive working spindles are newly designed directly in the immersive environment. This opportunity of immersive geometry modelling [6] is a major innovation as compared to conventional modelling methods using native CAD systems. Immersive modelling means that an interaction device can be used to generate and manipulate geometry in all six spatial degrees of freedom in a virtual reality environment such as a CAVE system. This is highly beneficial, particularly when generating components with nonorthogonal geometric elements in an assembly context.

A real-time capable kinematics module was implemented for checking the machine concept. Real time means that all interactions can be performed without any delay perceptible by humans. The workspace can be checked and weak points in the kinematical buildup be located by integrating the module into the VRAx® system. Based on real-time capable transformation algorithms for calculating the position and orientation of all machine assemblies depending on their kinematical dimensions, the machine structures can be moved interactively and modified via templates. The parameters for transforming the assemblies are transmitted in real time to the VR system. Parallel kinematical structures consist of inverse kinematical chains that are coupled in parallel by the frame of the machine and the working platform. To take these particularities into account, additional algorithms for testing singularities and workspace redundancies are integrated into the real-time module. The kinematics module uses additional information from the construction kit to take into account the mechanical limits of joints and struts. These parameters on pivoting angles, strut length ranges etc. are stored as metadata with the assemblies in the construction kit. Interaction is supported by a function for displaying a graphic feedback. As a transparent machine structure is displayed outside the potential room of movement, even impossible positions of the structure can be visualized.

3 VR SUPPORTED DEVELOPMENT OF MACHINE COMPONENTS FOR THE BDM2000

Another example is the spin extrusion machine (BDM 2000) developed at the IWP and the IWU [7] [8]. This machine realizes a completely new forming technology for the manufacturing axial-symmetrical hollow components out of solid bars [9]. The hollow shape is generated by rollers, rolling on the outer shape of the raw bar and a shaping mandrel, simultaneously acting in axial direction. The material compressed by these tool units flows off against the direction of feed, forming a cup wall. The workpiece is clamped in a chunk mounted on a rotating spindle and by this rotates around its longitudinal axis. The whole process is simulated in VR.

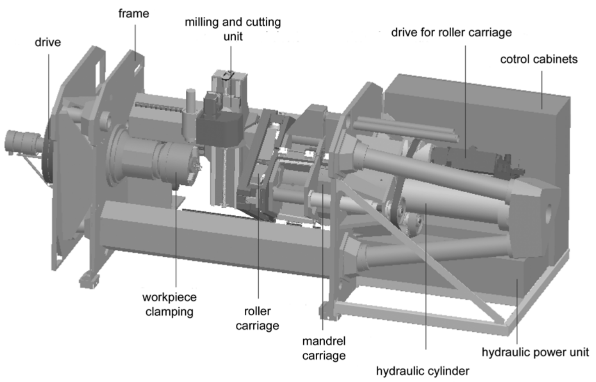

Figure 3: Spin extrusion machine BDM 2000.

For application in the industry it was necessary to design an extension unit for the BDM2000 that allows classical milling and cutting technologies in addition to the spin extrusion forming technology. These extension units should realize different pre- and postprocessing steps like:

- orthogonal milling of arbitrary outlines and slots on the front surface
- tangential milling and axis parallel milling
- arbitrary drilling in different directions, on the cylinder surface and on the front surface
- processing of planar surfaces
- thread cutting
- cutting the workpiece with a saw unit

To extend the machine with classic processing technologies like milling and cutting several extension units were developed and simulated in VR. VR significantly shortened the design process by early recognition of design errors. The final result is an easy to use VR based building set, where customized versions of the BDM 2000 can be realized interactively.

For the integration of the milling and cutting unit into the BDM2000 only a limited and unevenly shaped area was available. It had to be guaranteed that all processes can be realized witout collisions.

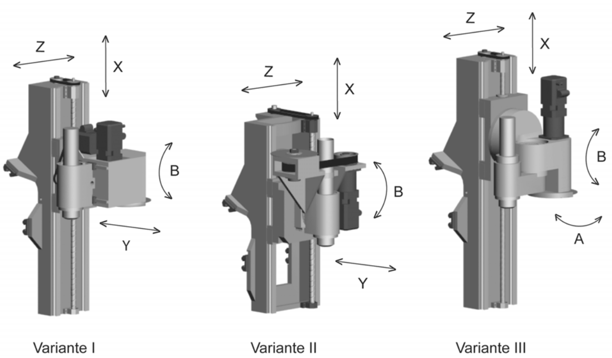

Figure 4: three variants of milling and cutting units

For the evaluation of different variants and collision detection a complete manufacturing process with multiple steps from spin extrusion to postprocessing was simulated in the VR environment [10]. With the help of a menu driven building block system [11] the user can choose between different variants of the extension unit. With the Virtual Reality it is possible to examine the whole process from an arbitrary point of view in the scale of 1:1. Furthermore the capabilities of the VR system like hiding of machine parts like housings and the navigation with six degrees of freedom give the direct insight into critical areas. The collision detection and the examination of the available mounting space is extremely simplified.

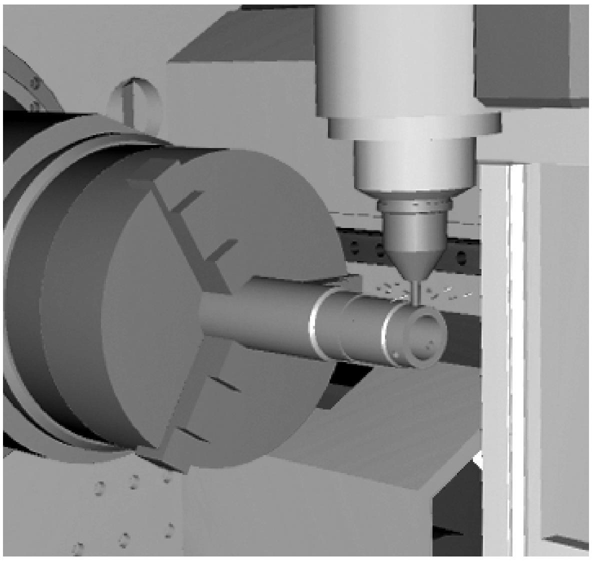

Figure 5: VR visualisation of drilling process.

The use of virtual prototypes already in an early phase of the design process made a premature detection of weak point in the overall concept possible. Above all the analysis of the space requirement is inevitable when extension units need to be fitted into an existing machine. By the integration of all designs of the milling and cutting unit into the virtual prototype of the spin extrusion machine a comparison could be accomplished. The final decision for a specific variant of the extension unit was supported by the VR based evaluation. For the determination of the optimal variant further criteria like computation of static rigidities, dynamics and modal analysis were consulted.

4 VR FOR CUSTOMER PRESENTATION AND MACHINE TOOL CUSTOMIZATION

A similar approach was chosen for the VR based customisation of a multi technology centre (MTC) WOTAN® for the manufacturer of machine tools WEMA Glauchau [12]. The VR model and simulation allows the demonstration of the various processing possibilities of this machine tool. The MTC WOTAN® combines the grinding technology with other chip removing processes:

- preturning and final turning of workpieces
- turning in combination with grinding
- milling of notches and planar surfaces
- internal grinding
- external grinding
- drilling
- thread cutting
- finish rolling
- processing of non axial symmetric elements like cams

By combination of these different processing technologies complex workpieces can be manufactured on a single machine. This allows comparatively short processing times because of the omission of different non-productive times.

4.1 Customization

The machine tool has a modular design. Different processing units for internal grinding, external grinding, drilling and milling can be mounted on two machine tables with ever two translation axes and one rotation axis. Figure 6 shows one possible configuration of the MTC.

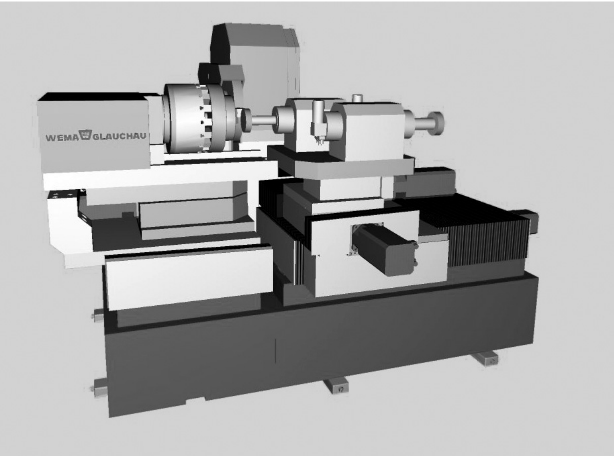

Figure 6: MTC WOTAN®.

The customer specific configuration of the machine tool can take place interactively in the immersive VR Environment. With thehelp of a menu the user can choose between the various processing units and place them on the machine tables. The placement of the parts is limited by constraints to the surface of the planned table.

4.2 Simulation

The virtual machine model can simulate the different processing technologies in an immersive VR environment to introduce the concept of the flexible machining centre to the customer. The VR animation shows the manufacturing of a workpiece with multiple processing steps. The customer realizes in an illustrative 1:1 visualization how grinding, milling and turning processing can be implemented with a single workpiece clamping.

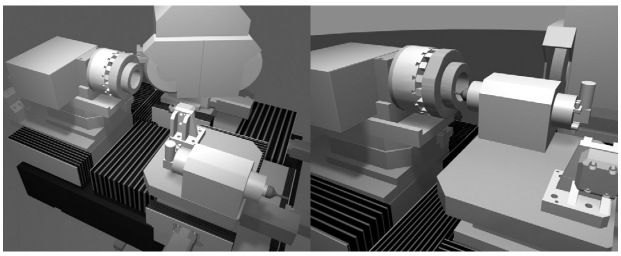

Figure 7: Visualization of external grinding and drilling.

5 VR FOR PLANNING OF PRODUCTION FACILITIES

The final example shows the application of VR technologies in the planning of production facilities. An assembly line for machine tools was visualized and simulated for the manufacturer DECKEL MAHO Seebach GmbH [13]. The manufacturer aimed for the integration of the assembly line for the DMU50 series of machine tools into an existing factory building. The CAD data of the DMU50, the operating facilities and the components of the flow assembly were processed to make the suitable for VR visualization in an immersive environment. Based on the 2D layout of the assembly line this data was integrated in a real scale virtual model of the factory building. The planned operating sequence was represented as a visual simulation of the single work cycles. Based on this VR model the placement of the material and the assembly process can be demonstrated very close to reality in 1:1 scale. Already during the first demonstrations of the virtual model deficits in the arrangement of the operating facilities were recognized with the help of VR. The planning was adapted accordingly.

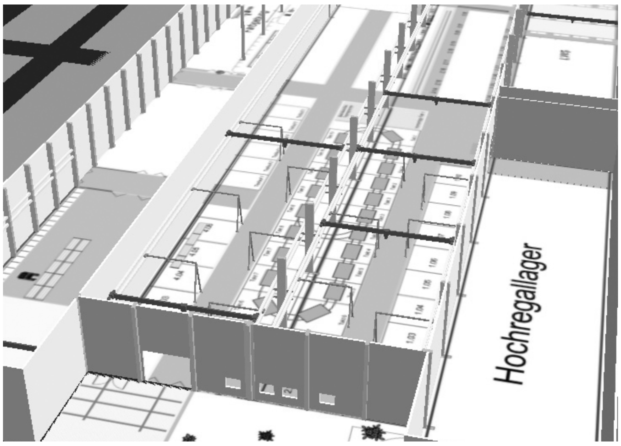

Figure 8 : Layout of the assembly line.

In summary the virtual model was used to support the following tasks:

- layout planning
- verification of the room and arrangement conditions
- material allocation and transport during the assembly process
- routing
- ergonomic investigations for accessibility and visibility of construction units, operational units and parts of the building (columns)

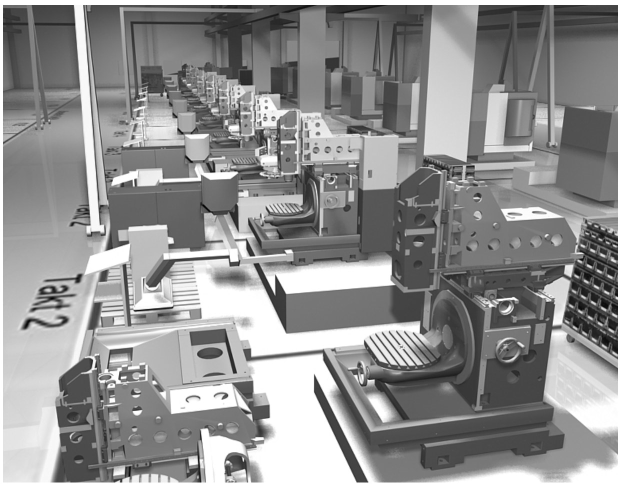

Figure 9 : Snapshot of the simulation.

The VR was a valuable instrument for the discussion of several different design aspects of the assembly line. Via the employment of VR a fast evaluation and a following optimization of the planned arrangements as well as the operational sequence was possible. This examinations took place before the real project implementation. So the investment risk could be minimized.

6 MOVE - A CUSTOMER FRIENDLY MOBILE VR SYSTEM

A major aspect in the introduced VR application scenarios was the interdisciplinary cooperation between developers and customers, the introduction of new concepts and the application specific configuration of machine tools. To realize such cooperation scenarios there is a stringent need for location-independent VR technology. It is necessary to present the virtual models directly at the customers site or at specialized fairs.

The IWP developed the **mo**bile **V**irtual **E**nvironment (moVE). This mobile VR solution is a powerwall system with passive stereoscopic projection. It can be combined with either optical or magnetical tracking systems. The VR system essentially consist of two projectors with linear polarisation filters, the portable canvas, the tracking system for head and hand tracking and two laptops for the rendering of the left and right eye images. As far as possible standard hardware components were used for the assembly of moVE. This ensures comparatively low acquisition costs and maximum flexibility for further extensions and improvements in case of increasing requirements. The whole system can be stowed away in three transport boxes. It takes only 30 minutes to be operational on site.

MoVE already worked satisfactorily for various customers from the industry and at different international fairs.

Figure 10: The mobile Virtual Environment (moVE).

7 CONCLUSIONS

The examples mentioned proved impressively that the VR is technology for the machine tool industry of increasing importance. Beside the classical Design Review arise as a result of the results of current research and development ever broader areas of application. These contain the simulation of processes in real time apart from pure visualization. The applications have shown that VR based building block systems are a promising approach to manipulate VR models interactively. These solutions are intuitively and easy to use and are applicable for different scenarios. One scenario is the design of machine tools with lots of repeating construction units like parallel kinematics (see chapter 2). Also in the customer-oriented assembly and configuration of machine tools (see chapter 4.1) and during the variant evaluation (see chapter 3) VR based building block systems worked satisfactorily.

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