CNC Technology in Woodworking - Nowadays and Future Trends

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1 Introduction

The introduction of CNC technology in woodworking has led to extensive changes in production technology. Previous mechanically controlled mass production was replaced by computer-based numerical controls. The use of computers for various processing methods, manufacturing and production logistics led to increased flexibility of the production process. A direct result of this is a reduction in both, door-to-door and processing time and therefore less capital tied up in stock.
However, CNC technology also has a strong influence on mechanical manufacturing methods in craftman´s business. Workpieces can be processed in one clamping, with the result that not only traditional manual manufacturing methods, but also flexible and fully automatic commission processing can be realised. In addition, multiple axis CNC manufacturing technology allows the production of complex three-dimensional structures, such as spiral staircases, windows, doors and solid wood furniture, which previously could not be produced cost-effectively without the computer technologies and control components.

Apart from production logistics and process control technology, the machinery for CNC processing is the evident for modern production technology. As a result, the efficiency of the production processes in most cases is heavily influenced by the choice of machinery [1]. CNC technology is based on several modular basic components. These can be seperated in terms of soft- and hardware for data structures, control components and mechanical engineering. The combination of individual basic modules generally leads to machine configurations which are optimally adapted to the processing task. Various interfaces are used here, some of which are internationally standardised, others have been recommendations of the VDMA (German Union of Machine Manufacturers) or else comply with manufacturer-specific interface norms. Examples of this are the recently standardised hollow taper shank interface and the furniture manufacturing exchange format (FMX) data interface.

Improved process qualities have been achieved through new processing methods, such as milling with truncated tools and front surface milling. These can be used in various related sections to produce finished surfaces without the need for subsequent grinding. Current research has produced promising results, that for serial use high cutting qualities and good processing integritiy can be expected.

The goal of increasing the productive capacity and processing quality is related to the development of machine technology. Detailed research into mechanical structures of woodworking machinery and the elimination of the weakest points of these structures has led in most cases to a steady increase in possible feed velocity and rapid motion speeds for machining centres. In addition to work already carried out on mechanical interfaces and high-speed spindles, this provides new chances for new machine structures and kinematics. Under aspects of economic efficiency of CNC machining centers, it is clear that in future gimbal-strut structures will become more and more important in multiple axle processing of wood and woodbased materials.

2 The Application of CNC Technologies in Woodworking

Today, CNC technologies are wide-spread in woodworking and wood processing industries. The most common application is for processing flat workpieces. It is also used in presses, sawing units and many other applications. A market review and performance comparison of CNC machining centers carried out by the Institute of Machine Tools in September 1995 [2], revealed considerable differences in performance between the machining centers on sale in Germany.

2.1 Design of CNC Machining Centers

The basic differences in design of machining centers is shown in Fig. 1. In the **gantry design** the machine table is firmly fixed to the base. The longitudinal movement of the gantry is relative between the bed and gantry. The gantry design is particularly suited for units with large extension of one axis. The support of the traverse on both sides provides extended widths to be achieved at low levels of deformation as well as projection of mass. The small base of the machine offers a general advantage. A disadvantage is the fact that at high accelerations the gantry tilts in the direction of movement. The causes of this are high moments of inertia and the compliance in the linear guideways and their surroundings. A further disadvantage is poor accessibility for manual workpiece supply.

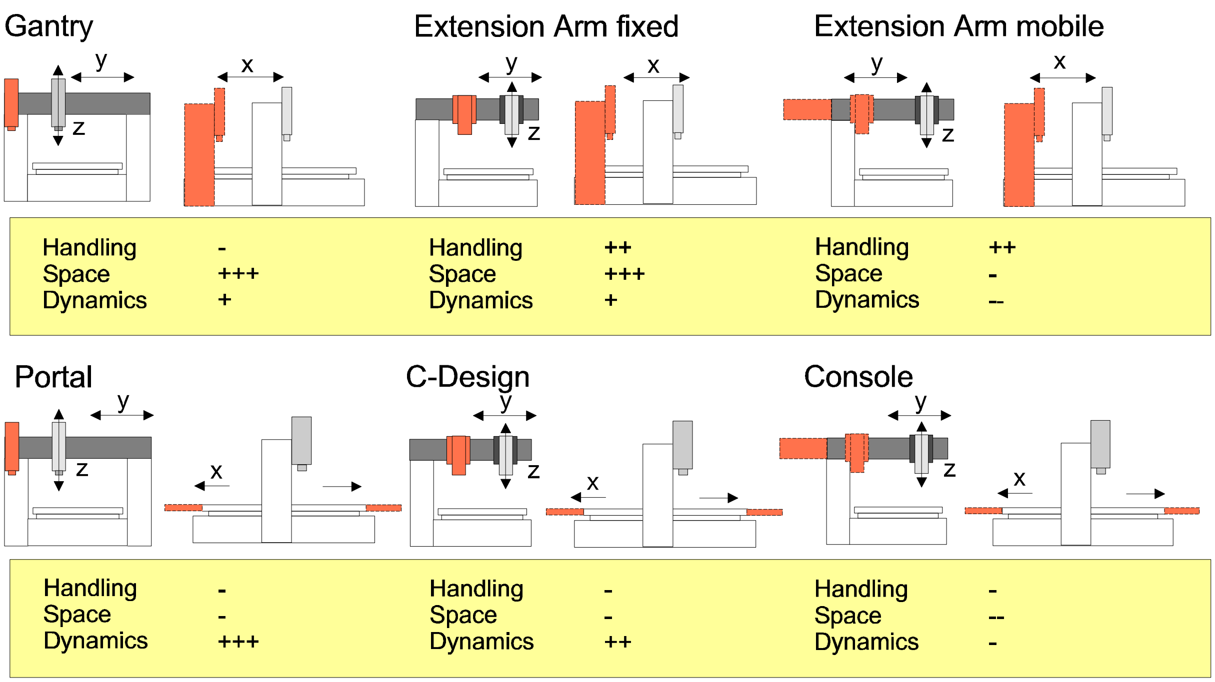

Figure 1: Designs of CNC Machining Centers for Woodworking

The **Portal design** is generally the stiffest machine design. The columns are fixed to the base and withstand the forces of inertia when the y-support is accelerated. The longitudinal movement of the workpiece takes place in the table, where the acceleration forces are applied to the base via very small lever arms. A disadvantage is the large amount of space required, which is twice of that of the machine's overall working area.

Extension Arm designs can be divided into those with **fixed** and **mobile** arms. They are ideally accessible for operation. A further advantage with the fixed extension arm design is that they require little space. The comparatively small moved masses are responsible for good dynamics. A disadvantage with the mobile extension arm design is, that they require greater space due to the movement of the y-support. A further disadvantage with this design are very poor dynamics, as there is no opportunity for the moved masses to be separated, forcing the y-support to move the whole mass of the extension arm.

The **C-Design** provides good dynamics, as the movement of the axles is largely divided. The masses in motion are low as the table is directly supported by the base and the y-axis by the standing cantilever. Less positiv however, is the space required, which is almost twice the size of of the machine's overall working area.

The **Console Design** is similar to knee-type milling machines used in metal processing. The disadvantage is the large amount of required space, some four times that required by Gantry designs with a similar working area. A further disadvantage is the very poor dynamics which, as with the mobile extension arm design, is limited by the mass of the processing head and the cantilever length of the y-support.

2.2 Machine prices and working areas

The design type does not give an exact clue to machine price. Fig. 2 compares the basic machine prices against design types and working areas. In order to allow for any exchange rate related deviations in the cost of machines, the machines have been distinguished between German and EU origin.

The main orientation of workpieces on CNC machining centers is plane, so that the basis in fig. 2 is not the available workspace but the working area. The majority of machines have working areas of between 3 and 4 m^2, another 23 percent between 4 and 5 m^2. It can be seen that in smaller machines, the EU portion increases compared with the German. With machines below 3 m^2 working surface, the EU share is above 50 percent. In addition, it can be seen that in terms of design, large machines are of the extension arm design and not the Portal/Gantry design.

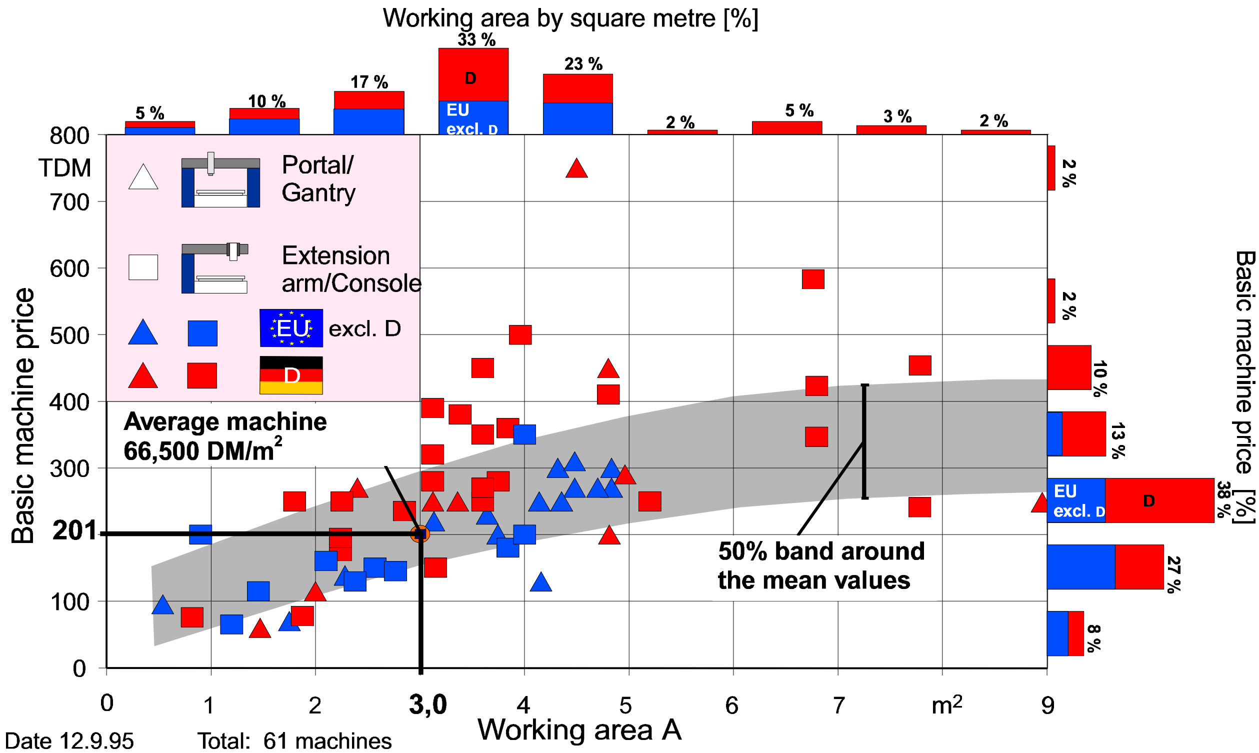

Figure 2: Market review of machining centers for woodworking on sale in Germany: Design types, working areas and basic prices

The average machine has a working surface of 3.0 m^2 at an average basic price of DM 201,000. From the market review data this results in an average machine price of DM 66,500 per m^2 working area.

Almost 40 percent of all machines on sale in Germany cost between DM 200,000 and DM 300,000, closely followed by almost 30 percent in the DM 100,000 - DM 200,000 price bracket. When comparing machine origins, it can be seen that the majority of machines in the lower price bracket (below DM 200,000) comes from the EU. A comparison of machine prices per square meter shows that EU machines are cheaper than their German counterparts. Comparing machine prices against designs reveals surprisingly higher average prices per square meter for extension arm machines compared with portal machines of the same size.

2.3 Processing speeds and accelerations

High rapid motion speeds alone do not shorten the total operation time. As important as the achievable speed is the possible axis acceleration. Fig. 3 shows on the example of drilling, how time savings can be reached. The feed motion into the drill hole is assumed to be constant and has not been taken into account. The comparison shows 1 and 4 m/s^2 at an rapid motion speed of 20 and 80 m/min. The distance between the holes is the independet variable.

By increasing the acceleration, time savings can be achieved for small distances between th holes, as is shown by the smaller initial rise for both curves at 4 m/s^2. For longer distances time benefits are attained by higher axle speeds.

With conventional drive technology, drives could not be used for both high accelerations and high rapid motion speed, with the result that it was always unclear which combination of acceleration and speed was the best for a given operation. Varying the parameters in Fig. 3 shows that for this example up to a distance of 387 mm even at low speed and with a high acceleration time savings can be expected compared with machines with high rapid motion speeds and low acceleration.

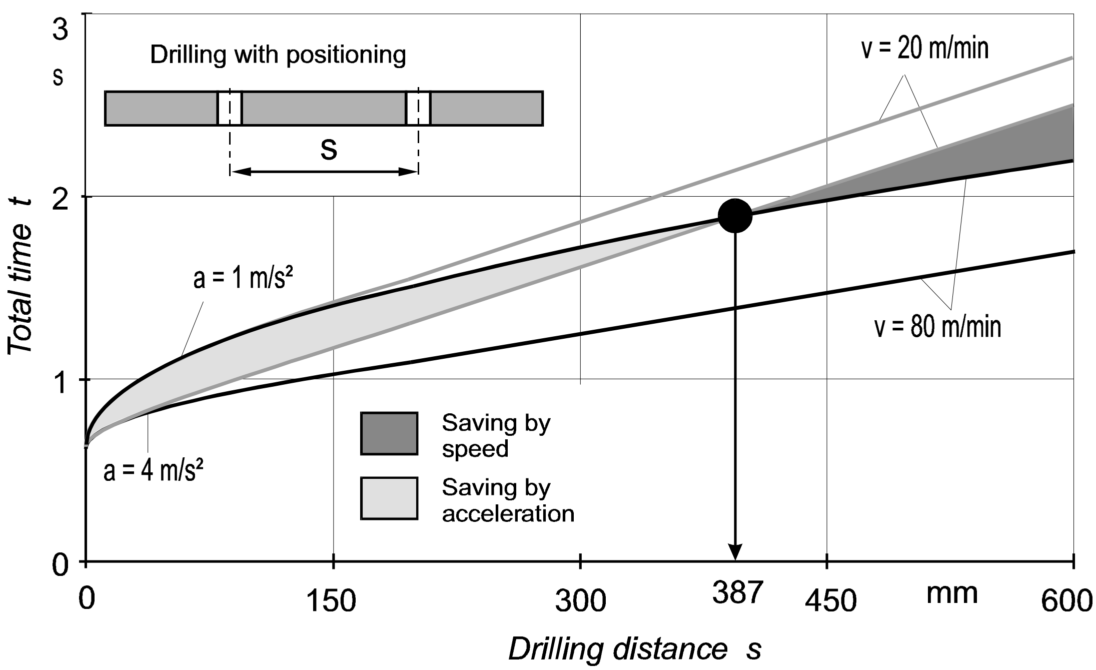

Figure 3: Influence of rapid motion speed and axle acceleration on the overall operation time

3 CNC processing modules

CNC technology involves not only machine design but also the operation and handling of the machine, as well as the automated manufacturing environment. Modern high performance systems are therefore built up modularly. In addition, various company-specific and standardised interfaces and modules are used.

3.1 Interfaces

An excellent example of interfaces in practice is the development of FMX data interfaces between the CAD system and machine control. The FMX interface was developed at Braunschweig Technical University [3,4,5] under the direction of Prof. Westkämper. It acts as a linking platform between design, planning and production. More recent developments in the FMX interface are also concerned with multiple axle technologies.

A different interface was successfully investigated in a research program aimed at increasing performance of routers [1]. The demands put on interfaces for automatic tool change have increased enormously in the last years. Recent trends are shorter cutting times and increased quality requirements made on the tool system. In addition to requirements concerning automation and the possibility of signal transmission, interfaces are judged by their radial run-outs, tool change repeating accuracy, static and dynamic behaviour both when idle and in operation. For manually operated interfaces the demands are intensified by the fact that long projecting tools are often required for very narrow radial tolerances and high tool change repeating accuracy [14].

The mechanical interface between spindle and tool, the DIN V69893 hollow taper shank interface, has set new standards in machining with spindles with automised tool changing [10]. Fig. 4 shows the technical features of the hollow taper shank interface. Apart from very good joint and radial run-out characteristics, the benefits of the hollow taper shank interface are its static and dynamic stiffness at high spindle speeds [6,7,8].

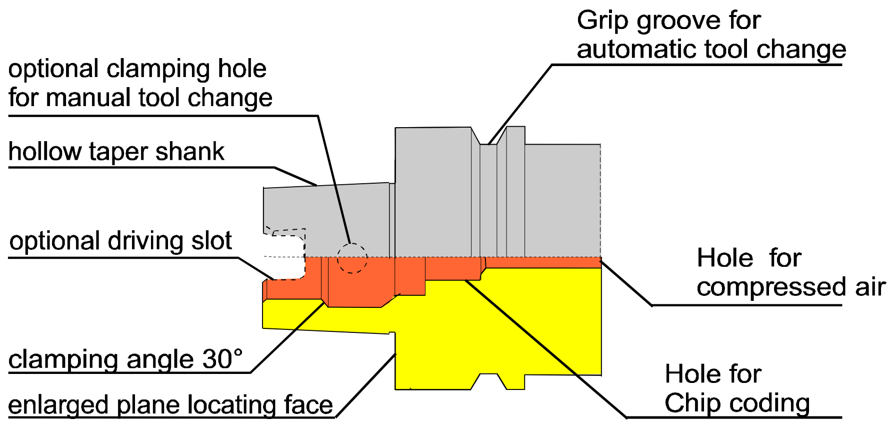

Figure 4: Hollow taper shank interface for automatic tool change (DIN V69893, part 6 [9])

The market review shows that the hollow taper shank is widely used in CNC machining centers for wood and woodbased materials. In fig. 5 the spindle interfaces of CNC machining centers on sale in Germany (as at 9/95] are shown by type and size.

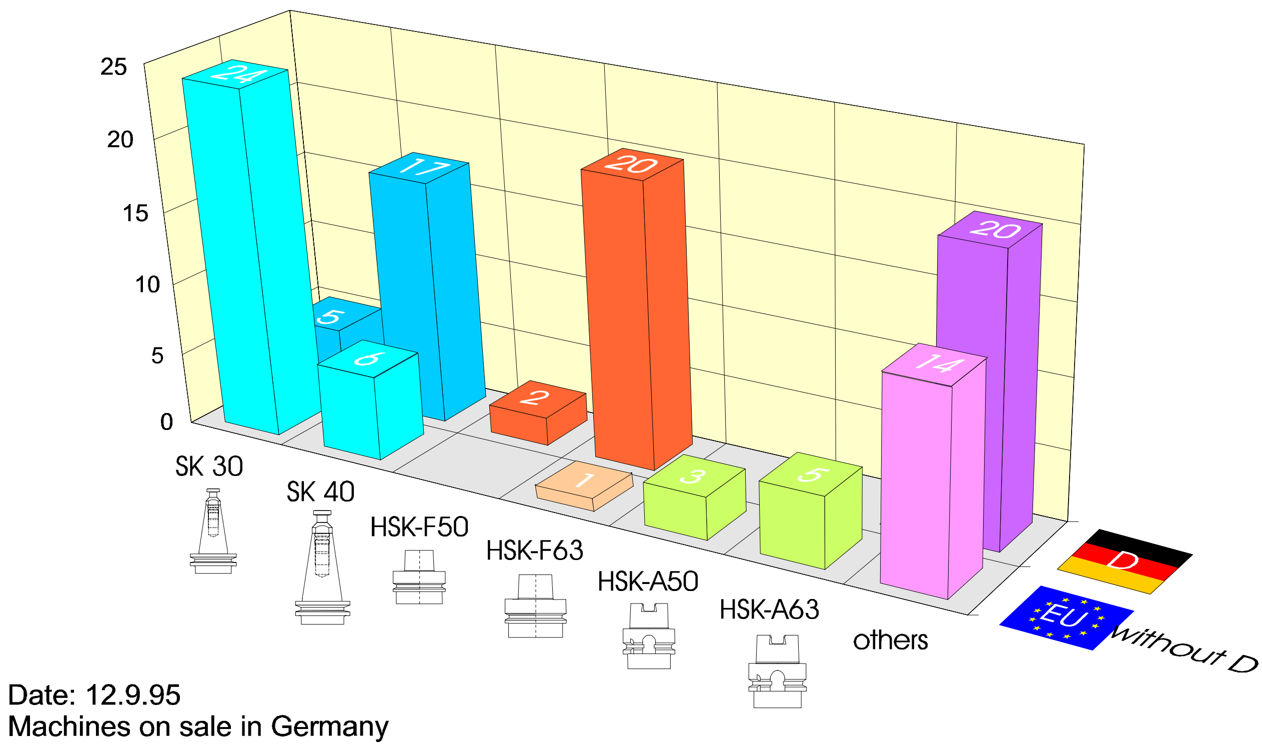

Figure 5: Spindle interfaces of CNC routers on sale in Germany

A diversification of the machine spindles on sale by the country of their origin shows the differences between machines from Germany and from the EU. The columns "others" include all automatic interfaces which cannot be classified as well as all manually operated clamping systems. A comparison of the automated interfaces reveals significant differences. In Germany, 50 percent of the systems used are steep cone interfaces and the other half are hollow taper shank interfaces. Of this, 91 percent of the hollow taper shanks are size HSK F63 and only 9 percent size HSK F50. 23 percent of steep cones employed are SK30's and 77 percent are the more rigid SK40.

The distribution with the EU machine manufacturers is completely different. Here, the hollow taper shanks account for only 23 percent. 77 percent of automatic spindles use the steep cone interface. Of these only 20 percent have the SK40 interface and 80 percent have the SK30 interface.

3.2 Control technologies and CAD-CAM coupling

The performance of CNC machines is supported by the coupling of CAD and CAM systems. to provide more flexibility, process controls with open architecture are used. The modular design of the control hard- and software simplifies the control configuration for new tasks. Fig. 6 shows an actual example for a manufacturing control for CNC machining of flat workpieces.

In single unit manufacturing more and more programming solutions with direct operation on site are being used. Workshop orientated programming is used by most machine manufacturers. The workpieces are programmed via a mainly graphical representation. In addition to the variety of technologies, such as drilling, milling, sawing and edge-banding, programming of modifications is also possible. WOP-generated programmes include not only the tool’s movement but also the positioning of the vacuum holders.

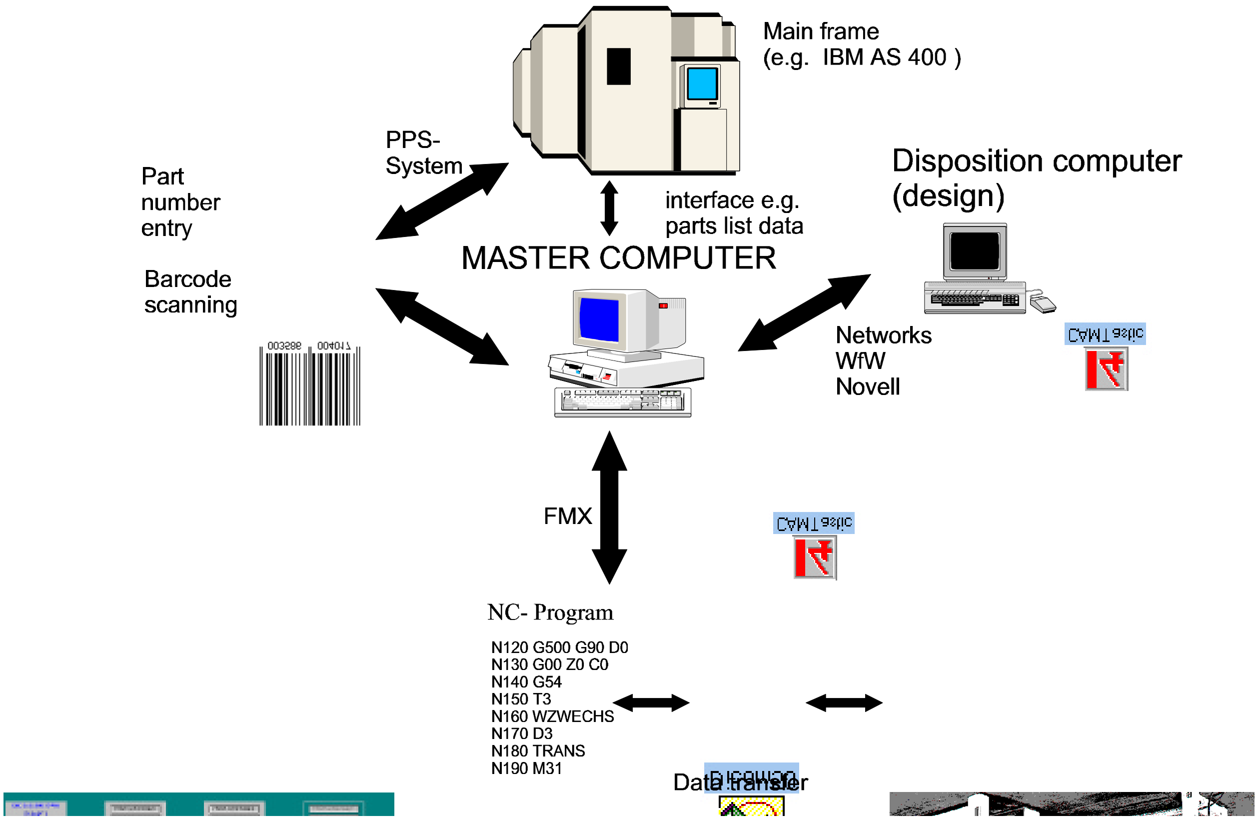

Figure 6: Manufacturing control for CAM in woodworking according to DIREKT

3.3 Units and Tools

For machining edges and sections, CNC manufacturing in woodworking relies on special units which are brought into the main spindle. Examples of this are exchangeable sawing, drilling and milling units. The HOMAG multi-functional spindle-tool interface represents an extension of the standardised mechanical hollow taper shank interface. In addition to the spindle-tool interface, the pneumatic supply and electrical signals for both, control and power are transmitted for these units equipped with an own drive. Examples for peripheral modules are the exchangeable edge-banding unit and the exchangeable trimmer unit.

In automated processing on CNC routers the tool geometry, projection length and diameter, are particularly important parameters. Not only collisions must be avoided, but also precise paths of motion must be defined and set. To calculate clearance distances and tool offset compensation for each tool exact values have to be entered into the control software. Previously, tool data were stored in a tool database, which involved an enormous amount of various types of user-specific administration. The use of tool coding systems in woodworking represents a further progression in automation and rationalisation.

The tool is used in the production circle of the machine and is re-sharpened and/or replaced in the service circle, fig. 7. Starting from the tool depot, the tools are identified by computer and made ready for production. After the tools have been placed in the tool magazine of the machine the tools' data is automatically read and the parameters such as length, diameter etc. are transferred to the machine control. By chosing these automatically loaded values, which can, depending on the individual tool, deviate from those established by practical experience, optimal production with optimal quality and maximum tool life can be ensured. The tool lives are reviewed in the control and in the computer by constant reading, writing and calculation cycles. The effort is to automatically replace the tool when the end of tool life is reached.

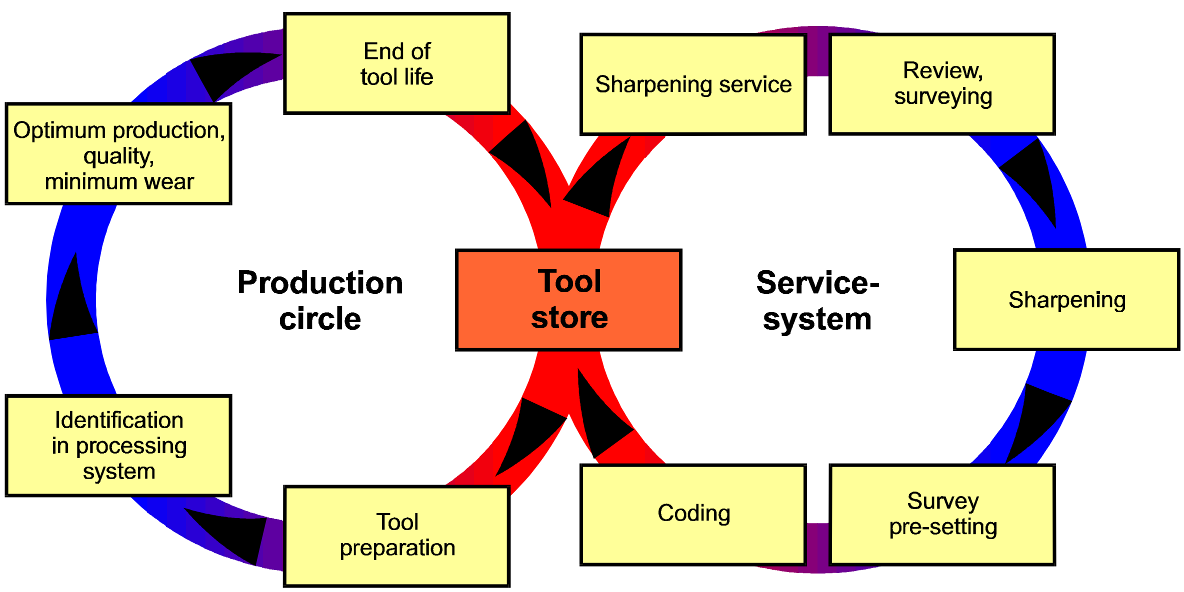

Figure 7: Tool operational circles using tool coding systems [12].

Blunt or cracked tools are taken from the stores and serviced. The sharpening service judges the edges and the tool base and either sharpens or replaces the worn cutting edges. The data required for this, such as edge geometry, operational life etc. is also stored on the chip in the tool shaft. After sharpening, the tools are re-balanced, the geometry measured again and the data on the chip updated. To attain uniform data, data strings and reading and writing cycles, an industry working group was set up at the Institute for Machine Tools.

4 Trends and Future Perspectives

4.1 New machine concepts

The market review carried out by the Institute of Machine Tools [2] shows the clear need for research into the low price sector of machining centers. One approach to reduce the costs of the mechanical structure is the use of machines based on gimbal-strut kinematics. Fig. 8 shows the design of a gimbal-strut kinematic machine (Neos Tricept HP1), which is currently under investigation at the Institute of Machine Tools.

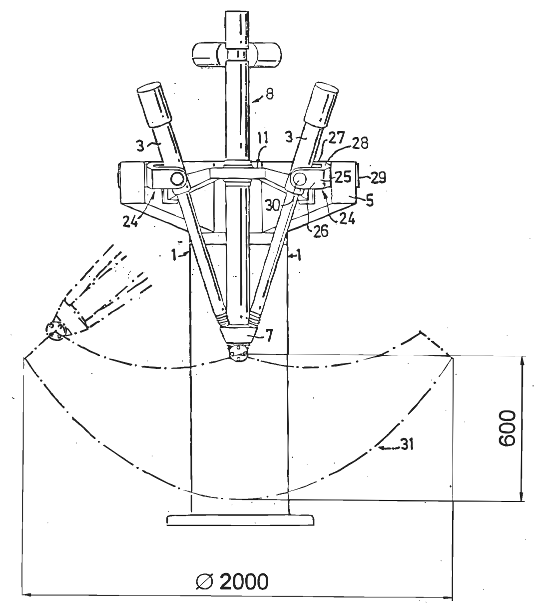

Fig. 8: Neos Tricept HP1 for milling with high feed rates and cutting speeds.

Due to the reduction of machine components and the struts, which are all equal in terms of design, machines with gimbal strut kinematics offer the possibility for cheaper machines. In addition to cost savings there is a further advantage which relates to the dynamic behaviour of these structures. The moved masses are almost minimised to the mass of the spindle itself, which opens new possibilities in terms of axle acceleration. With gimbal-strut kinematics, a pure compression-tension load of the struts prevents a bending of the machine structure. As a result, the Steiner's geometrical moments of inertia of 2nd order are not needed and the structural components only have to be designed for the necessary compression-tension strength. Disadvantages with these kinematics are the need for a comparatively complicated control and the nonlinearity of motions, both static and dynamic stiffness, and accuracy in the workspace.

The aim of the current investigations on the Tricept HP1 is to show how far this machine structure can be used in processing wood and woodbased materials. In addition to the static behaviour the dynamic behaviour of the machine equipped with a comparatively heavy high performance main spindle is to be investigated. Furthermore, the limits for the machine concept at a certain level of machining quality are to be shown.

4.2 Steel sheet lightweight design for high dynamic machine structures

Fundamental investigations on steel sheet lightweight structural components were carried out at the Institute of Machine Tools during the work on a special research project [16].

Successful applications showed the enormous potential of lightweight design for mechanical components in machine tools. Lightweight design in machine tools means a stiffness-orientated design. All components within the power flow must be able to carry the occuring forces, such as the process forces and the forces of inertia, without significant compliance. The modulus of elasticity related to the mass of these lightweight components is very high. Especially for moved components, such as machine tables, this advantage in terms of weight leads to an improvement in terms of axle acceleration.

To improve the dynamic behaviour of mechanical components, high damping levels as well as high structural stiffness and a low mass are required. Here a further advantage of sheet steel lightweight structural elements becomes obvious: because of the inner friction, the structural damping of these lightweight structures is comparatively high. Damping can be set already in the design phase.

Investigations have been undertaken on flat lightweight components, to which bending load was imposed. The optimum lightweight design is primarily based on the efficient use of material. This is done by a suitable arrangement of the steel components in the force flow. Sandwich plates created in sheet steel lightweight design which are mainly imposed by bending loads, are made of cover plates with a high modulus of elasticity and core layers with a low specific weight. As an example, flat machine tables were produced in conjunction with linear direct drive technology and linear guidings [16], fig. 9. The mass could be reduced by more than 50% compared with an aluminium design. The cover plates are welded with a laser after assembly, producing a homogenous core layer.

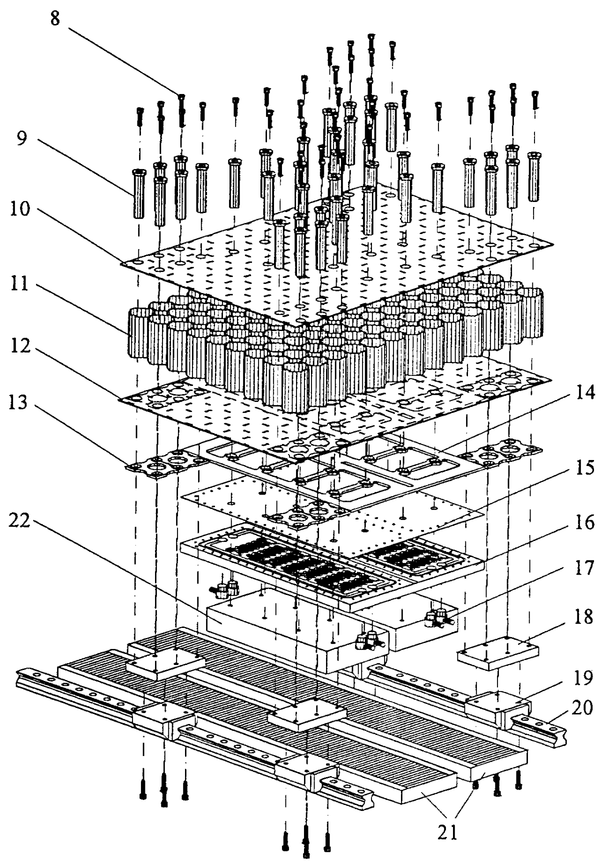

Figure 9: Machine table in sheet steel lightweight design with linear guides and linear direct drives

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