XXL-Milling Tool with innovative CFRP-structure

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This article describes the current status in the development of a very large milling tool with a diameter of more than 2.5 m which will consist of a newly investigated CFRP-structure. The material properties as well as light weight design permit a significant mass reduction compared to similar metallike tools. However, stiffness and damping characteristics have to maintain stable process conditions. Here, the structural layout, simulation results and model tests are presented. The developments are subject of a research project which is sponsored by the Federal Ministry of Education and Research (BMBF). Within this project the companies FOOKE and INVENT cooperate with the Institute of Production Engineering and Machine Tools (IFW) at the Leibniz University of Hannover and the European Center of Adaptive Systems (ECAS).

Introduction

Machining of large Aluminum slabs with high quality demands regarding surface roughness and planarity is a challenging task for high performance machine tools. FOOKE supplies sophisticated gantry milling machines with special cutting tools for face milling. These tools have diameters of up to 2.700 mm (Fig. 1).

![Figure 1: ENDURA800 by FOOKE](image1)

Normally, these tools consist of an optimized steel structure which carries several cartridges for the cutting inserts (Fig. 2).

![Figure 2: Steel structure of milling tool](image2)

High material removal rates and acceptable surface conditions can already be achieved with the steel structure tool. On the other hand, these tools are characterized by high masses (appr. 2,5 t) and relatively low damping. Both factors limit the productivity of the machining process and lead to high loads on the machine structure.

Within the collaborative research project “CFKspan”, which is funded by the Federal Ministry of Education and Research (BMBF) and managed by the European Center of Adaptive Systems (ECAS), FOOKE together with INVENT and the IFW currently develop a new light weight structure for the large milling tool. This structure will consist of CFRP materials and will be designed considering the special load scenario and boundary conditions of the milling processes.
Beside mass reduction, machining stability is of major interest during the design and layout phase.

**The conventional tool**

With the aim to define a starting point and a benchmark for the development of the CFRP-tool, the existing steel tool was analyzed by experimental vibration tests and Finite Element Analysis (FEA). Figure 3 shows principle vibration mode shapes in an exaggerated illustration.

The first eigenfrequency results from the setup of the tool during the measurements. The tool was mounted on the floor via the spindle flange. The higher eigenfrequencies show the typical behavior of a membranous structure. The static stiffness of the steel tool was identified as appr. 31.6 N/µm.

The measured frequency response functions can be used to identify a modal calculation model. A comparison between measured and calculated Frequency Response is shown in Figure 4. The real behavior can be simulated accurately. The calculation model allows further investigations of the process stability characteristics.

The performance of the steel tool could be improved by passive damping elements. Thus, robust machining with such a large milling tool becomes possible.

**Tests with a tool model**

The approach to apply a CFRP structure firstly possesses the potential of a significant mass reduction. In addition, the CFRP material offers the opportunity to adapt the tool characteristics to the specific requirements of the machining process. However, there are no experiences available concerning the behavior of CFRP structures under machining conditions. Therefore, a down-sized tool model was realized with a simple CFRP plate in order to allow milling tests (Fig. 5).

The CFRP tool model has a diameter of 400 mm and a thickness of 40 mm. The CFRP laminate
has a quasi-isotropic structure. The stiffness in z-direction (spindle axis) of the CFRP plate, calculated by FEA, is 14.6 N/µm. A modal analysis shows that above 1 kHz a significant influence on the dynamic behavior is given by the interfaces between tool holder (HSK63) or insert cartridge and CFRP structure.

The CFRP tool model was analyzed in vertical and horizontal machining tests (Fig. 6). In vertical milling ($Al$, $n = 2.000 \text{ min}^{-1}$, $f_z = 0.1 \text{ mm}$, $a_p = 1 \text{ mm}$, $a_e = 300 \text{ mm}$), roughness values ($R_z$) below 1.5 µm could be achieved. In order to calculate the stability characteristics, the dynamic behavior of the machine tool has to be considered.

With the aim to allow dynamic calculations of the process behavior of the large CFRP tool, the damping parameters of the material and structure have to be identified. In a first approach, a beam structure has been analyzed in experiments and FEA-calculations in order to derive a representative material damping parameter. Calculations of the frequency response lead to a comparatively high damping of the tool structure which is expected not to be realistic. As a result, a more complex model structure has to be analyzed for damping parameter identification.

**Conclusions**

In this paper the current status of the development of a large milling tool with CFRP structure is presented. CFRP structures permit a significant mass reduction compared to metallike components and an adjustable damping behavior. For machining applications, the specific loads and boundary conditions have to be considered in the design and layout. Here, a model tool has been used to explore the principal qualification of CFRP material. Experimental tests with a simple tool structure show good results with respect to process stability and surface quality. In order to achieve an optimized design of the aspired large tool, FEA-calculations have been carried out. These investigations show, that an acceptable stiffness of the tool can be achieved. With the aim to predict the dynamic tool characteristics, first attempts have been made to parameterize the material damping properties. It is obvious, that the structural layout has to be considered even in basic parameter identification test setups.

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**Layout of the XXL-tool**

In order to gain the full potential of a CFRP structure (regarding mass reduction and damping characteristics), the XXL-tool will not be manufactured with a simple CFRP plate. In contrast, an innovative structure is currently developed which exploits the adjustable material properties. The aim of the project is to utilize the experimental experiences and calculation approaches gathered with the smaller tool model and to transfer them to the large tool with a diameter of 2.700 mm. In a first step, a FEA model has been created in order to calculate stiffness and damping properties and to identify possibilities of an adapted design (Fig. 7).

The calculated stiffness values in z-direction for different layouts, laminates and fibers reach from 6.5 N/µm to 27 N/µm. The tool mass can be reduced below 500 kg.