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Composites in production machines

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Abstract

This paper gives an overview of the design and application of composite materials in machine tools. Some exemplary machine elements, tool structures and components are introduced and the technical potentials, requirements and challenges are discussed. The presented prototypes and industrial products show that besides the lightweight construction aspect furthermore the specific mass related stiffness characteristics and the advantageous damping properties as well as the thermal behavior of composite structures provide outstanding chances regarding the improvement of the machine performance and accuracy. New degrees of freedom in machine component design and layout can be exploited especially if material combinations are implemented.

Keywords: Machine tool; Design; Material

1. Introduction

The design, manufacturing and application of composite parts is mainly driven by the aerospace and automotive industry. Mass reduction in order to save fuel is the predominant goal and reason for the use of materials like carbon fiber reinforced polymers (CFRP) or similar composites with glass, aramid or basalt fibers. These materials can also be combined with cellular, foam or honeycomb cores as well as sheet metal elements. Various composite parts manufacturing processes have been and are still investigated and developed in order to achieve a cost efficient realization of the composite components. During the last two decades, a significantly increasing level of automation can be observed that is still improving thanks to the development work in industry and research institutions. Against this background, applications of composite parts become more and more interesting and relevant also in general machine construction and especially in the machine tool sector. Whereas for a long time, CFRP and other composite materials have been used predominantly in scientific works and prototypes of machine tool structural elements, tool components and spindles, nowadays a rising number of industrial implementations can be found [1] (Fig. 1 and Fig. 2).

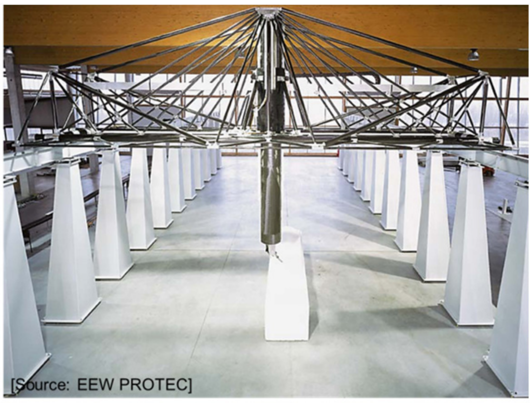

Fig. 1. High speed lightweight machine tool by company EEW Protec [2]

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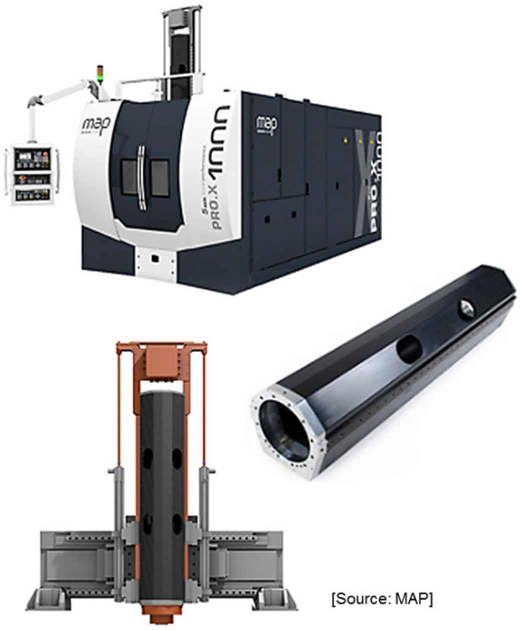

Fig. 2. High speed machining center by company MAP [3]

The lightweight construction potentials provide new possibilities to reduce moved masses (e.g. of slides, columns, rams), to lower inertia moments (e.g. of spindle or tool shafts), to relieve the drive systems of the machines, to enhance the feed motion dynamics and path accuracy, and to improve the energy efficiency of the machine tools during machining operations [2]. Furthermore, due to the higher material damping properties of composite materials, increased structural damping ratios can be achieved. In addition, the very low or even negative thermal expansion coefficients of CFRP parts can be utilized for a higher thermal stability of the machines [3, 4]. As a consequence of the buildup and internal structure of composite parts, including fibers and matrix, by exploiting the design degrees of freedom regarding the types of fibers, fiber orientation and layer composition, quasi-isotropic or targeted anisotropic mechanical and thermal characteristics can be created. This, on the other hand, requires sophisticated design, layout and optimization methods as well as related modelling and simulation approaches in order to gain the full potential of the material application but to implement an efficient design process. As an example, Lasova et al. investigated the use of Pareto optimization in order to find an optimal lay-up of a wound square tube including CFRP with high modulus fibers and cork composition damping layers [5]. Three dimensional numerical simulations were conducted considering the static bending stiffness, the natural frequency and the damping ratio as optimization criterions.

Considering the huge bandwidth of mechanical fiber properties but also of the associated price of the different types of fibers, comprehensive design optimization strategies must, in addition to the physical parameters, also take the related costs of design variants into account. The crucial question of the permitted price of a newly designed composite machine component with improved properties and performance can only be answered by an appropriate value benefit analysis.

Another aspect of composite material application in machine tool structures is the ability of functional integration. Especially sensor systems can be embedded during the composite part manufacturing processes. Furthermore, additive manufacturing and conductive material printing technologies allow an automated and cost efficient generation of the necessary wiring or realization of circuitry which can be integrated in the part production chain. By this functional integration, the performance of composite machine tool elements can be enhanced beyond the limits of conventional component design.

2. The use of composites in machine structures

A fundamental aim when using composite materials in production machinery – of course – is to reduce the mass and inertia of moved machine elements. This can exemplarily be seen in pick-and-place robot systems as depicted in figure 3. In these applications, the functional requirements regarding positioning and path accuracy are relatively low compared to machine tools.

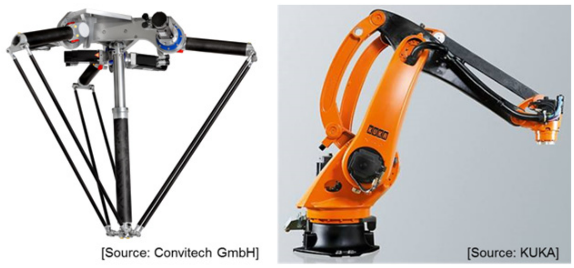

Fig. 3. Pick-and-place robots by Convitech (left) and KUKA (right)

In contrast, very high precision and the requirement of a maximum dynamic stiffness and damping capacity is demanded in metrology devices and inspection machines. Jung et al. investigated the design of a hybrid composite-aluminum beam structure with high modulus (HM) carbon/epoxy composites with respect to the design of a LCD glass panel inspection machine [6]. The layout was optimized in terms of the cross section shape of the beam, the stacking sequence and the thickness of the composite reinforcement with respect to the fundamental natural frequency and bending deformation (Fig. 4). A composite robot end effector for the handling of LCD glass panels is introduced in [7]. The beneficial dynamic properties of composites were exploited by Lee et al. with respect to the design of a guiding arm of an electrical discharge wire cutting machine [8]. With the support of Finite Element (FE) simulations, the detailed design regarding bonding length and number of reinforcing plies was conducted. Compared to the conventional arm, the mass was reduced to less than 50%, the static stiffness was maintained and the fundamental natural frequency as well as the damping ratio were significantly improved.