# A New Approach on Reducing Thermal Impacts on High Precision Machine Tools

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**Abstract**

This paper deals with a new thermal concept for high precision milling machine tools, that has been designed and verified at the KERN Microtechnik GmbH and is now part of the latest KERN machine tool series. By combining aluminum light weight construction with a high precision temperature management it was possible to overcome a traditional conflict of goals between machine dynamics and its temperature stability.

## 1 Introduction

In order to machine high precision parts within their tolerances it is necessary to cope with a multitude of different influences and their resulting errors. Bryan [1] and Weck [2] claim, that up to 70% of today's errors on machined parts are due to thermal effects within in the machine tool, the spindle, the work pieces, the cooling liquid, etc.

## 2 State of the art

Dealing with these effects, traditional guide lines for designing thermal stable machine tools have been established. Trying to configure the whole machine system as a thermal low pass filter, machine designers have always aimed at designing a system with a very low response to changes in the environmental conditions. Therefore materials with a very high thermal capacity and very low thermal conductivity have been chosen (e.g. heavy weighted iron casts, polymer concrete) not only for the machine basis but also for the axes and other moving parts. On the one hand theses designs are insensitive to short thermal disturbances and high frequency vibrations. On the other hand they have quite a high mass, resulting in long time thermal adaption cycles, the necessity of long term warm up phases and huge temperature gradients, that are very complex in terms of modeling, simulation and compensation. Research in the last 20 years has been focused on this problem [2, 3], generally resulting in compensations that are based on highly complex models with a large number of input variables.

## 2 A new concept

In our work a different approach is presented, that more or less reverses the design principles mentioned above. Designing “fast” thermal assemblies with low thermal capacity and high thermal conductivity leads to lightweight constructions with a very short thermal response time. The resulting, dynamic system is characterized by short warm up cycles and the avoidance of temperature gradients within the assembly.

### 2.1 Avoidance of temperature gradients – homogenous temperature

Thermal displacements in machines tools due to temperature gradients are much higher than due to homogenous warming. These effects are even worse on slim components such as spindle sleeves or portal frame bridges. Asymmetrical thermal loads on these parts lead to massive mechanical displacements being caused mainly by the emerging temperature gradients.

Therefore, the obvious first step towards thermal stable constructions is the avoidance of temperature gradients within the construction elements by choosing materials with a high thermal conductivity (e.g. aluminum alloys). Large cross sections within the affected components in combination with short distances to the next heat sink guarantee a fast heat transfer. Following these design principals, leads to components that, even when thermally asymmetrical loaded, tend to have a very homogenous temperature distribution and therefore a very predictable homogenous thermal displacement.

### 2.2 Keeping the homogenous temperature constant

In order to guarantee a stable machine tool behavior it is essential to keep the homogenous temperature as constant as possible. Conventional approaches therefore use components with high weight densities and materials with high thermal capacities. The biggest advantage of these designs is a very slow reaction due to thermal disturbances. The biggest disadvantage of these designs is the high mass of the components and the necessity of long warming up cycles.

The presented concept is based on the idea of using low weight density components with a low thermal capacity. By installing an accurate temperature management system the thermal capacity is virtually raised. Using the temperature management system to systematically deprive the heat out of the components the design works like it has got an infinite thermal capacity. That means a change in the environment conditions, only results in a negligible temperature change within the component. The temperature of the component is more or less completely controlled by the temperature management system and can be changed instantly. Therefore warm up cycles can be reduced to a minimum. Furthermore, this approach offers the possibility to use low weight density materials, leading to a lot of advantages such as less energy consumption and better dynamic behavior.

### 2.3 Dissipate the heat where it origins

The main heat sources within a machine tool are the working spindle, the drives, process heat and heat due to friction within the guides and bearings. Heat from these sources is unavoidable most of the times. In order to evade temperature gradients it is necessary to dissipate this heat as close to its origin as possible resulting in another big advantage of reducing the warm up cycles. Placing the heat sinks in proximity to the heat sources is the foundation of an accurate temperature management with fast and stable feedback control cycles (see chapter 2.4).

### 2.4 Temperature management

The temperature management system has specifically been adapted to the machine design and is based on the following principals:

- Temperature of the coolant fluid must be constant even on changing environment conditions and machine conditions.
- Flow rates must be high in order to ensure small temperature variations between the inlets and the outlets of the cooling circuit.

- High cross sections lead to low back pressures and lower pump capacities
- Heat will not dissipate into the tool shop but into central water chillers
- Cooling **and** heating of the coolant lubricant in order to achieve temperature controlled tools and work pieces

## 3 Machine design

The theoretical considerations as well as the results of practical experiments have been transferred to the design of the latest KERN machine tool. Despite all traditional design principles the axis components have been build in aluminum based light weight designs. High thermal conductivity of aluminum leads to lower temperature gradients. The increased wall thicknesses improve the vibration and thermal behavior of the design. By reducing the components mass (approx. 20%), drive forces could be reduced as well. This reduces energy consumption and the thermal loss of the direct drives which lead to thermal improvement of the whole machine tool.

## 4 Conclusion

Combining the four approaches mentioned in chapter 2 within a new machine tool, has created an exciting base for a long term stable production of high precision parts with short warm up phases and a minimum of thermal based positioning errors. By actually applying this concept to a serial machine tool KERN has created a worldwide novelty in the design and functionality of industrial high precision machine tools, that has been proven right by one year of experience (with several machines) and the consistently positive feedback of the machine operators.

**References:**

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