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QUALITY TESTING APPLIED TO THE THERMAL BEHAVIOUR OF MACHINE TOOLS AND ROBOTS

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Abstract: According to a CIRP evaluation, more than 50% of the machining errors even in the case of modern machine tools are due to the thermal phenomena. The thermal behavior of machine tools and robots is a very important part of a unitary quality testing concept who must pay attention to all factors, but proportional with their importance.

The author has studied the problem more than 25 years, and he had his doctorate in this field. The author has carried out for the first time in Romania, the thermographical study of machine tools. The author's improvements contributed to a better quality and a higher precision of Romanian machine tools.

The paper presents some of the author's results carried out at the Technical University of Cluj-Napoca and at the University of Stuttgart, Germany.

Keywords: Thermal behavior, quality testing, machine tools, robots.

1. INTRODUCTION

The thermal stability of industrial machine tools, robots and coordinate measuring machines (CMM' s) must be connected with quality and testing concepts. The importance of this problem was already emphasized worldwide by some new standards. Apart from static and dynamic stress, the behavior of machine tools is affected by internal and external sources of heat.

Actual manufacturing machines must follow a repeatable and accurate behavior. Unfortunately, thermal deformations up to 150 microns can be found e.g. in milling machines working at medium load. Thermal stability, as a global concept, is seldom mentioned, as a characteristic of machine tools, or robots, neither is it checked during acceptance tests.

The optimization of the thermal behavior of machine tools and robots is a very important part of a unitary metrology concept for testing, control and reception. [2]

The problem is also very actual for new types of machine tools. On of the research projects of the author ("Analysis of thermal behavior of new types of machine tools") were carried out at the University of Stuttgart. There, it was developed recently a new machine concept with preloadable gimbal-strut-kinematic and it was realized a new structure HEXACT-Parallel Kinematic Machine Tool. The new machine was presented also in some international fairs in Europe.

Due to the fact that the new machine type is also a worldwide innovation, its behavior must be studied with the whole concatenation of implications upon the machining precision.

The new HEXACT Parallel Machine Tool has some revolutionary, technical and economical properties.

The author takes also part at another research project in Stuttgart entitled “High dynamic beam direction and shape equipment for the spatial handling of laser beams”. This special research area (SFB) is a joint project of 6 Institutes of the University Stuttgart, it has been sponsored by the German Research Association and consists of 14 subprojects.

2. QUALITY AND TESTING CONCEPTS APPLIED TO THE THERMAL BEHAVIOUR OF MODERN MACHINE TOOLS AND ROBOTS

The research in the thermal field of machine tools and robots has been intensive in the last years. Some authors have dealt with theoretical approaches about the heat transfer in the machine or robot and their relationships with the thermal deformations. Others focused their researches on how to improve the design of the machine and robot to avoid thermal errors. Good design can minimize thermal deformations, but it is seldom possible to avoid these deformations completely. Other researchers have gone deeper in techniques to compensate the thermal errors using multivariable linear regression techniques, modeling techniques based on neural networks or the Fuzzy-Logic method.

In many cases solutions were produced from the work carried out, but they were limited to the specific machine tool or robot, and the basic working conditions were defined exactly.

The notional importance of this problem was already emphasized by a series of new standards issued worldwide. A new trend observed by standards improvement, is represented by a unitary concept for the reception and machine tools testing, as DIN V 8602, which integrates the thermal behavior into a global concept taking into account the simultaneous solicitations of machine tool (static and thermal).

Until now a general and complete description of thermal behavior of machine tools and robots, which is dependent on internal and external heat sources, particular under practical operating conditions, could not be found.

After more than 25 years of researches in this field, the author established that the optimization of the thermal behavior of machine tools, robots or coordinate measuring machines is determined by a great number of interconnected influencing factors and the recording of these factors regarding possible compensating methods is very difficult and uses complicated technology. The relationship is complicated from the evolution in time of this phenomenon [4], [7].

A large variety of methods for calibrating and checking machine tools, robots and coordinate measuring machines (CMM) have been applied during the last years. These methods either furnish comprehensive information on the machine condition, but require much time, effort and expensive equipment, or they are easy to use but give only a general impression of the machine or robot accuracy. The necessity of a quick method which is easy too use, low priced and which could be widely accepted by manufacturers and users, is mainly due to modern production metrology, which is taken more and more out of the hands of metrology and integrated into the manufacturing process.

The precision of manufacturing, handling, assembling or measuring and the flexibility concept have become an important requirement at all levels of manufacturing industry.

The thermal behaviour of robots was later explored as the thermal behaviour of machine tools. Only in the ‘70-th years were published studies about the behaviour of robots with electric and hydraulic drive. Especially the robots with hydraulic drive have

thermal problems. At the robots with electric drive are not serious problems with the TCP (tool center position). Otherwise in a period of 20 years (1973-1992) the robots precision increase between 70% and 100%, till 0,01-0,05 mm, in the year of 1992 [6].
In case of robots the thermal behaviour of different separate components is very important and with a great influence on the Pose of TCP (Pose = position and orientation of the robot's TCP; EN 29283). It is also necessary to develop special measure models to determinate the thermal displacements of the different components.
Most Departments of the Stuttgart University work out a lot of researches in the domain of thermal behaviour and the improvement of robots precision [7].

3. RESEARCH COURSE AND RESULTS

The author has studied the optimization of thermal behavior of machine tools, from the causes up to the final effects and the machining errors. He had also his doctorate in this interdisciplinary field.

Also the author has carried out, for the first time in Romania, the thermographical study of machine tools, and he has determined on this way the isothermal field and the thermal map for machine tools [3].

Other researches of the author were continued at the University of Stuttgart with regard to accuracy of a high dynamic laser machine. The aim of the research area "High dynamic beam direction and shape equipment for the spatial handling of laser beams" was to design and to check a prototype of a high dynamic laser machine with high accuracy and operating speed.

Therefore sheet metal lightweight design, optical elements and beam positioning systems, propulsion systems for a direct driven machine tool have been developed. For this machine some new sheet metal lightweight structures such plate/ and box shaped lightweight elements were designed and developed with regard to their dynamic, static and thermal proprieties.

Sheet metal is an innovative material for lightweight design, due to the machining technology "laser processing", which allows new design solutions, especially the so cold sandwich structures. The advantages of these solutions are the low costs accompanied by high stiffness as well practical and reliable use.

Other characteristics of the high dynamic laser machine are the high path speed combined with high acceleration of drives using linear direct drives. The features of linear direct drives are their high accelerating power in conjunction with a very high degree of accuracy [8].

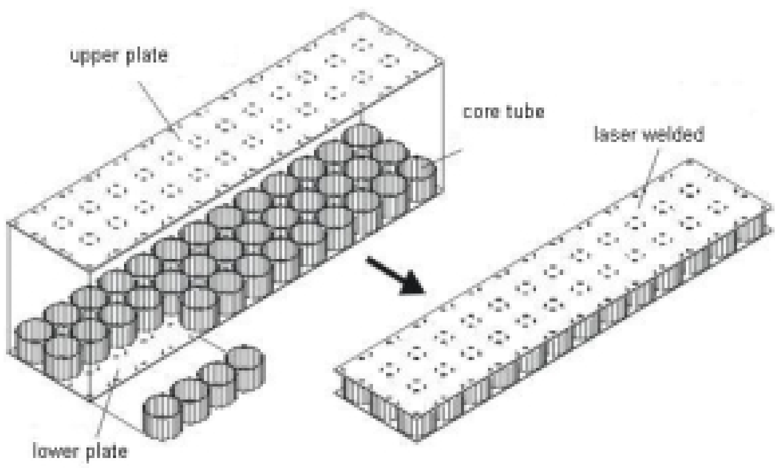

Figure 1. Sheet metal lightweight with core tubes

The material selection for lightweight designs is determined by specific weight material parameters, by the design style of the sandwich structure as well as by manufacturing technology. Figure 1 shows a sandwich structure, completely laser welded, with core tubes [8].

Also for the direct driven slides the researchers from University of Stuttgart have used sandwich lightweight structures. Comparing this structure to a solid aluminium plate, the lightweight plate shows a weight saving up to 60%, at the same stiffness of the plates.

Realizing some different kinds of lightweight structures, it was shown, that the laser is an universal tool to create new complex lightweight structures of sheet metal, with low mass and good dynamic proprieties. But the reduction of the moved mass arises new problems such low damping, local buckling and high noise emission. A solution can be additional implementation of new lightweight materials like foams (metal or plastic).

The author researches were concentrate on the thermal behavior of these new structures and on the thermal behavior of the whole laser-cutting machine.
The thermal field was registered for various types of tubes, sandwich structures and plates.
As tubes were used tubes with different high (30 to 95 mm) and different thickness (0,7 to 3,5 mm). Sandwich structures were with or without isolation between the two plates and from different dimensions. Finally the plates (laser welded) were with different dimensions and different design and position of the core tubes.

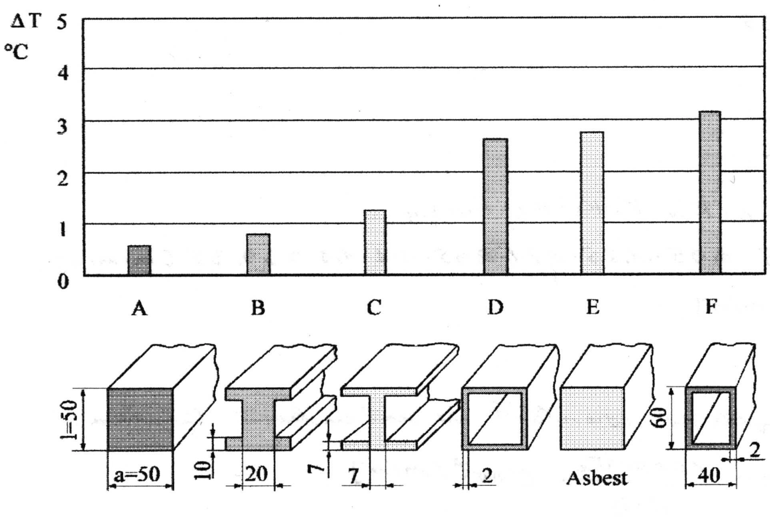

Figure 2. Temperature difference at the both ends of different structures

Figure 2 shows the influence of the design structure and of isolation. The 750-mm. high structures are heated at one end, where their temperature reaches 40^0 C, and the air temperature is 20^0 C.

At the different structures were measured also the thermal conductivity, thermal global coefficient and the influence of the type and position of the isolation.

At different tubes and sandwich structures were considered the influence of the wall thickness and the thermal field was measured (until stabilization) in different position of the structure with thermistors.

It was observed an important temperature difference between the two plates of the sandwich structure using two different isolation materials (Kapex C 50.60 and Herex C 70.40).

A very interesting modular investigated structure was a sandwich plate with core tube and laserwelded lateral panels. Such a structure is the probe nr. 23 with two plates of 750x178x2 mm dimensions and a 34 mm height core tube. The lower plate was heated and on the upper plate were disposed 9 thermal sensors with following numbers 39, 86, 32, (border line 0), sensors nr. 18, 2, 16 (medium line, at 375 mm distance from line 0) and sensors nr. 22, 63, 30 at 750 mm distance from line 0. Except the sensor nr. 2 all the thermal sensors are placed at equal distances from the upper plate border. The temperature was observed until stabilization, during 6 hours. The results are showing in the figure nr. 3.

Significant is the fact that the calculated results and the measured values are similar. It can be also observed that the temperature decreases starting from line 0, near the heating source (sensors nr. 39, 86, 32) than the line of sensors nr. 18, 2, 16 and finally the line with the sensors 22, 63, 30.

The highest stabilization temperature was 45.3 ^{0}C and was reached at the sensors nr. 39, 86, and 32.

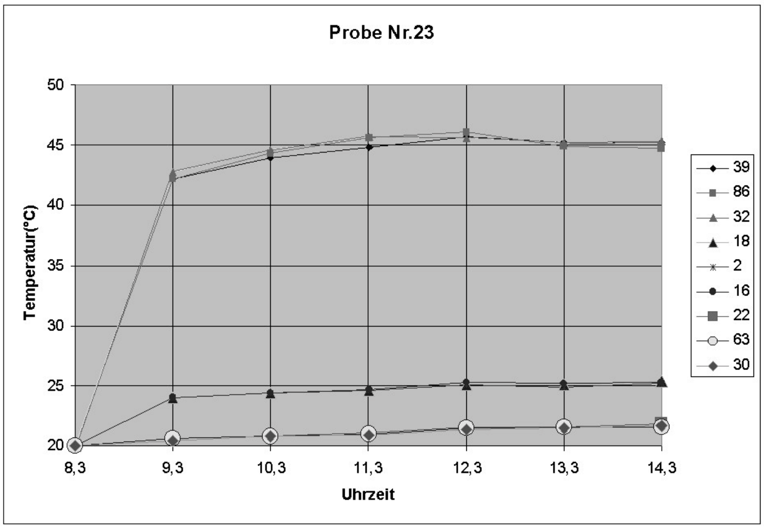

Figure 3. Temperature evolution of the probe number 23 starting from 8,30 a.m. until 14,30

Finally the thermal field and the thermal stability of the laser beam machine structure were analyzed with the thermographical method. Therefore we used a thermocamera from the firma JENA and the IRBIS software. The software offers various possibilities to analyze and to interpretate the results (e.g. at the same time the maximal and minimal temperature and some other temperatures of the structure).

4. CONCLUSIONS

Together with other static and dynamic measurements our thermal measurements offered the possibility to design and to optimize the new lightweight structures. Finally the whole high dynamic laser machine with high accuracy and operating speed was optimized regarding also the thermal stability.

First of all in the aim to optimize the thermal behavior of this machine are necessary some primary measures like to act at the thermal sources. After that is necessary to improve the heat transfer, and the new structures gives some new ideas in this sense. Finally we used the secondary measures e.g. to equalize and compensate the thermal deformation of the machine. Must be observed that the different kinds of new lightweight structures were selected in accordance with the structure of the high dynamic laser machine.

A new way can be also to utilize combined structures such metal plus different kinds of foams. The temperature measured results obtained with thermistors and the thermocamera are very similar.

A very important conclusion is to design and to realize a thermosymmetrical construction of the whole laser machine. Due to the big dimensions of the machine, different parts can be at different temperatures and finally to influence the machining precision.

First a Trumpf 1500 CO_2 Laser (1,5 kW) was used us source, after that another one with 5kW power [9].

The cutting leaser beam was conducted to the cutting head of the machine using copper coated mirrors. The cooling of the laser source and of the mirrors along the beam way is realized with a separate cooling unit. Also the laser command and the additional gas for cutting are separate from the laser source

Another conclusion is the importance, inside of the machine, of the laser source position, regarding once again the dimensions of the machine.

Due to the source quality the laser beam can 't be conducted through glass fiber. Therefore must be used an optical system, sensible at thermal deformations. These deformations can be finally be compensate through the NC system and the machining precision improved. Another measure can be to move the whole machine in a thermal stabilized camera.

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