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THE INFLUENCE OF THE THERMAL REGIME ON THE GUIDEWAYS OF THE MAIN ACTUATION OF A GANTRY TYPE CNC MACHINE

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Abstract: CNC Gantry Type Machine Tools with great distance between slides (gantry milling machines, plasma and laser gantry cutting machines, vertical lathe machines, etc) are used extensively in the manufacturing of large and long components. Because this type of Machine Tool it is used to machine large parts at high speeds, significant heat will be produce at the cutting tool level and transmitted thru the tool holder to the ram or spindled and then to the ream case guideways. Heat it’s also generated when using a ball screw actuation for the main axis because of the friction forces at the ball screw level. Due to material expansion, the heat generated during the machining process can influence the precision of the Machine Tool. In this paper, finite element analysis (FEA) was used to analyze the influence of the temperature on the rigidity of the Machine Tool guideways. The results of the studies performed will provide the machine tool builder with important information regarding the points that need to be address in order to help in improving thermal compensation.
Key word: kinematic feed chain, FEA, thermal analysis, deformation, CNC Machine Tool.

1. INTRODUCTION

CNC Gantry Type Machine Tools with great distance between slides (gantry milling machines, plasma and laser gantry cutting machines, vertical lathe machines, etc) are used extensively in the manufacturing of large and long components. Same important examples of where such CNC Machine Tools can be employed: machining of molds for the mold and cast parts industry, machining of large and complex parts from forged or cast monolithic blocks for the aerospace industry. Since the price per part, it’s directly affected by the speed of machining and because of the ever-increasing complexity of large parts, CNC Machine Tools with great distance between slides, have seen an increase in demand. Because this type of Machine Tool it is used to machine large parts at high speeds, significant heat will be produce at the cutting tool level and transmitted thru the tool holder to the ream or spindled, depending on type of machine, and then to the ream case guideways. Heat it’s also generated when using a ball screw actuation for the main axis because of the friction forces at the ball screw level. The spindle / main drive motor can also add to the heat produces during machining. Due to material expansion, the heat generated during the machining process can constitute around 50% to the overall error of a Machine Tool [1]. A study using finite element analysis (FEA) can be used determine the effect of temperature generated during machining on the rigidity of the Machine Tool guideways. For this we can use ANSYS® Workbench to perform a Static Structural analysis and Steady State Thermal analysis to determine the effect on the Machine Tool main actuation (ram and ram case) guideways rigidity.

2. MODELING AND FEA SIMULATION¶

2.1 Defining the machine and meshing the 3D model

For this paper the drawings from the machine book of a SC14 CNC carousel lathe where used to create the 3D CAD model. To make FEA calculations easier a simplified version of the 3D CAD model was used. The model complies with the overall dimensions of the Machine Tool. Has we can observe in Figure 1 the elements of the machine are: the fixed beam, the mobile beam, the ram slide, the ram, the tool/tool holder, the table and the bed/frame. This paper will analyze the behavior of the ram slide - ram assembly. The major elements are made out of gray cast iron except for the port-tool which is made of C45 improved to 75-85 daN / mm^2.

In order to obtain good results from the FEA analysis the mesh was improved by setting the element size of the mobile beam and the ram-ram slide assembly to 30, 10 for the tool holder and tool and 50 for the rest of the machine by using the “Body Sizing” method. In Figure 2 we can see the result, most of the elements are over 0.75, an acceptable result while keeping the number of elements low.

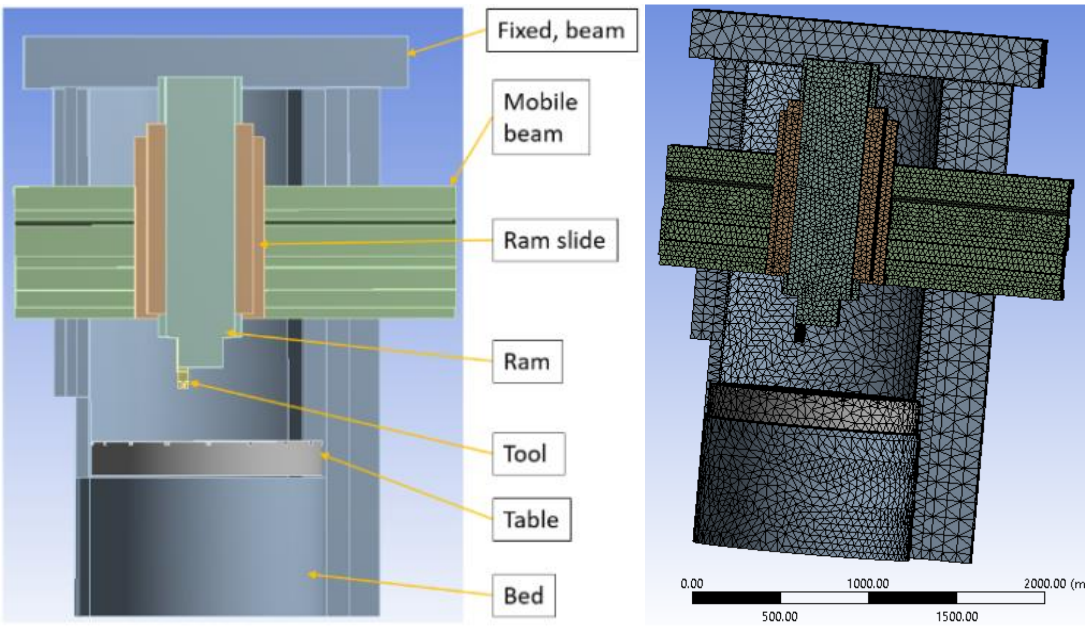

Fig. 1. SC 14 CNC carousel lathe and Mesh model

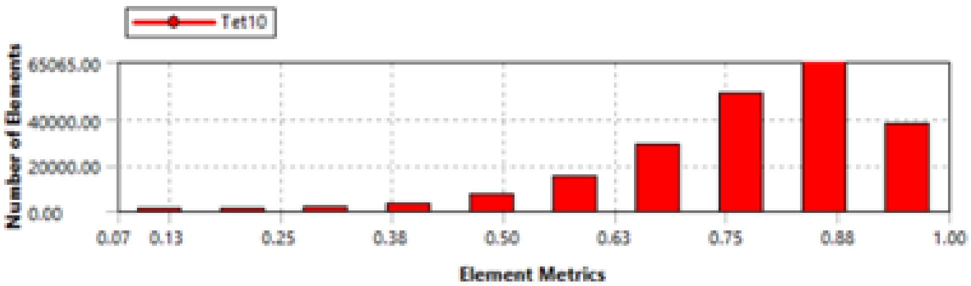

Fig. 2. Element quality plot

2.2 Initial static structural analysis

A static analysis was performed initially at room temperature set to 22 degrees in order to calculate the effects of the constant loading conditions on the machine, while ignoring damping effects. The result of this analysis will represent the rigidity of the machine relative the coordinate system. In Figure 3 we can see the loading conditions of the machine, the machine frame is fixed on the foundation, the weight of the machine is present on the direction of Y axis - 9806.6 mm / s², the cutting force of 2000 da N is divided into three elements: a moment of 400 da N (Y axis direction), a force of 800 da N in the –Z axis direction and a force of 800 da N in the X axis direction for better results.

In Figure 4 we can see the rigidity of the Machine Tool in relation to the coordinate system, a maximum deformation of 58.7 µm at the tool holder is within the Machine Tool precision grade.

In order to be able to better observe the deformations that appear at the level of the ram and ram slide guideways, the ram –ram slide assembly was extracted from the static analysis of the machine tool. This it's shown in Figure 5; the probes indicate local values for the total deformation.

3. THERMAL-STRUCTURAL ANALYSIS¶

3.1 Establishing initial condition and cases

The heat generated during mechanical machining operations is largely concentrated in the cutting area [2]. The temperature distribution during machining is based on the specific thermal capacities and thermal conductivity of the work-piece and the tool and the highest temperature occurs in the area of interference between the chip and the tool. The total heat generated in the interface area between the tool and the work-piece is generally distributed as follows: 80% goes to the chip, 10% to the tool, and the rest to the work-piece [3]. Two cases were chosen for this study, the first case represents the machining processing when cutting with coolant (both the work-piece and the tool are cooled by cutting fluids or emulsions). The second case it's dry machining, a process that uses no cutting fluids, emulsions, or lubricant for cooling of the tool or work-piece. For both cases the tool/tool inserts are made of Tungsten Carbide, this was chosen to better show the effects of the heat generated during machining process.

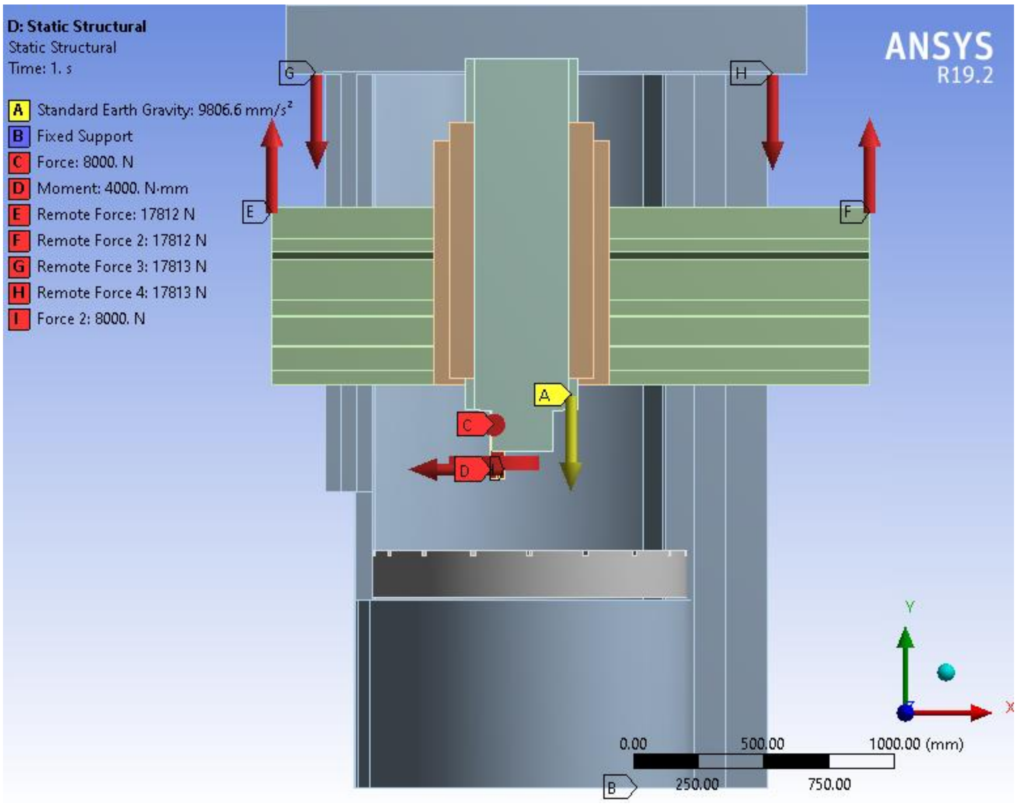

Fig. 3. Loading Conditions

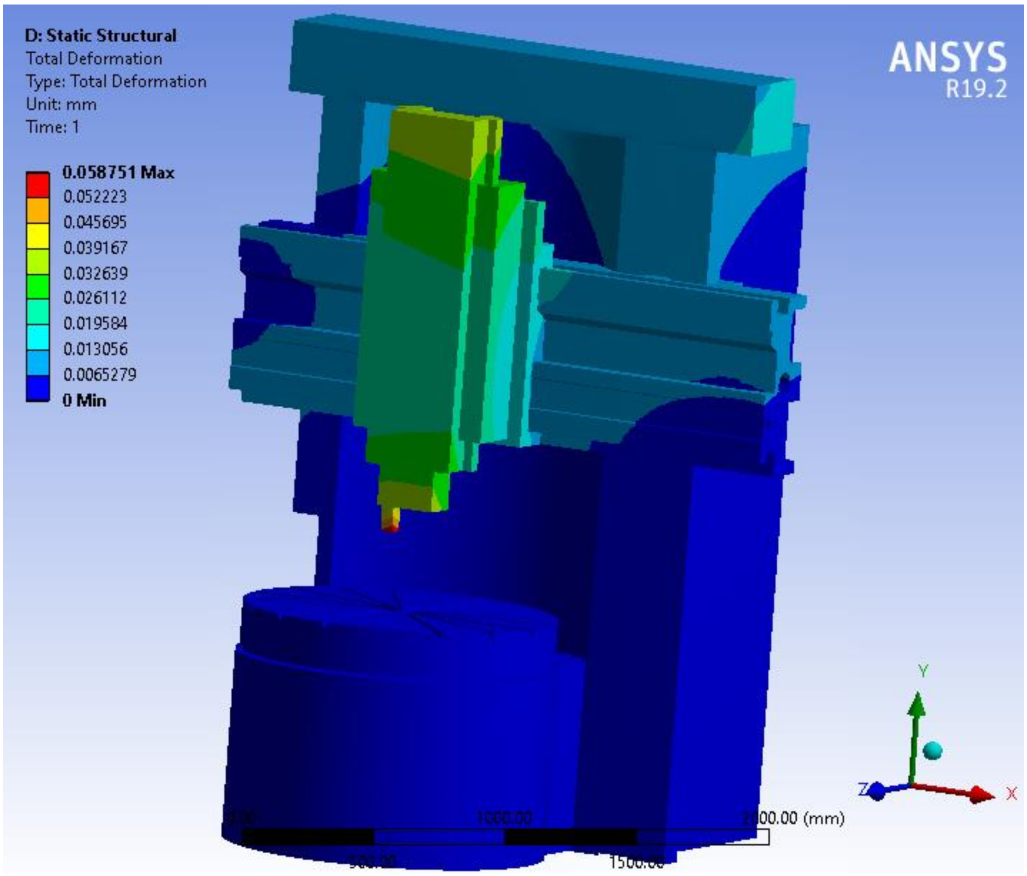

Fig. 4. Static analysis - total deformation

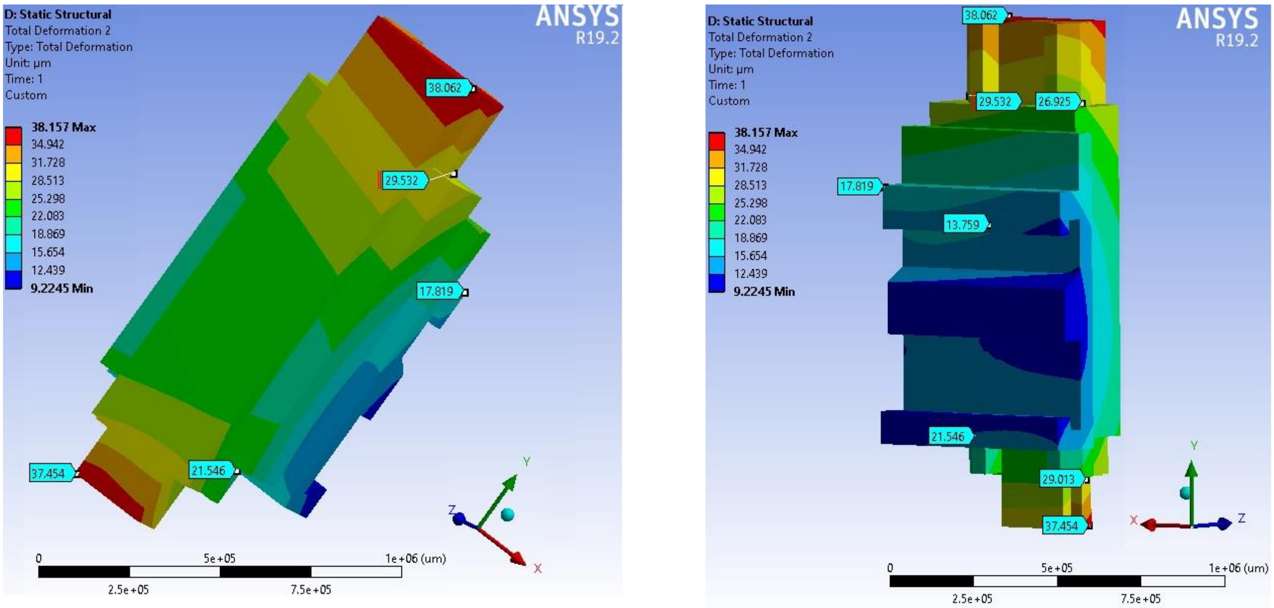

Fig. 5. Static analysis, total deformation of ram –ram slide assembly

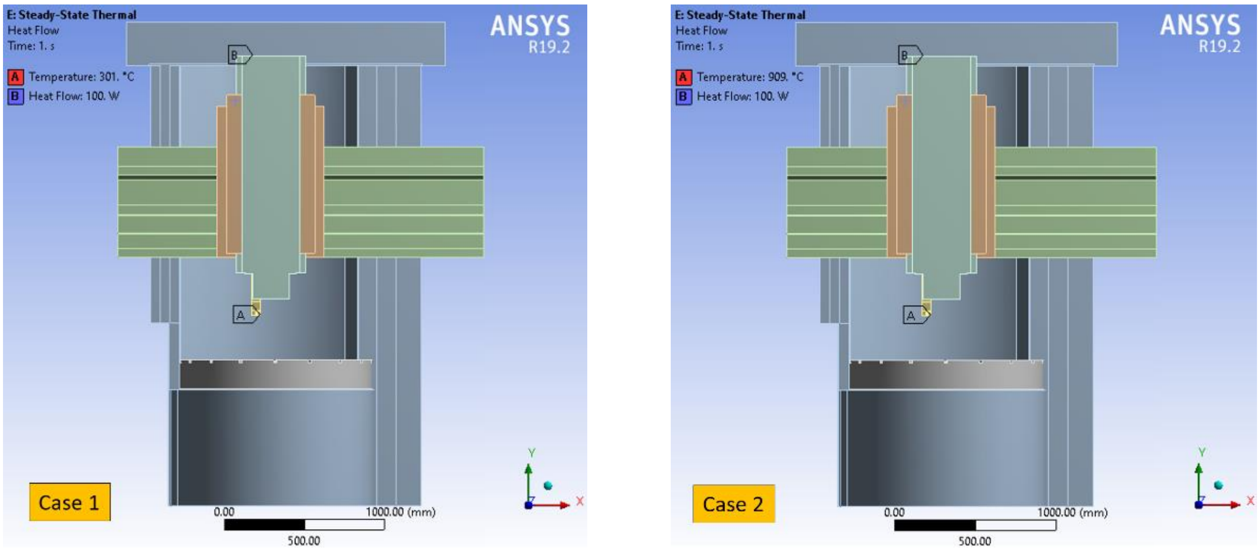

Fig. 6. Heat Loading Conditions for Case 1 and Case 2

In Figure 6 we can observe the thermal loading conditions. The temperature of 301 degrees in Case 1 represents the maximum temperature at the edge of the tungsten carbide insert according to the data from [4] for machining with coolant. For Case 2, the temperature of 909 degrees is the maximum temperature at the edge of the tungsten carbide insert according to the data from [4] for dry machining. A heat flux of 100 W, for both cases, was introduced to simulate the radiated heat from the friction forces at the ball screw level and from the actuation systems (motors, reducers) on the Y axis. Heat it's dissipated thru the machine structure by means of convection effect with the air around de machine (that is at 22 degrades) and with the machine foundation.

3.2 Thermal-stress analysis – Case 1

By performing a static thermal analysis and using the result as a load condition for a static structural analysis we can obtain a thermal stress analysis, through which the effect of temperatures on the rigidity of the machine can be observed.

Figure 7 shows that except for the tool holder/tool the thermal influence on the Machine Tool rigidity it's minimal. Yes, the total deformation in the area of the tool holder/tool is significantly higher compered to Figure 4, but the rest of the machine tool is still within the machine tool precision grade. The massive cast iron structure of the car allows a good thermal dispersion.

Comparing Figure 5 with Figure 8 we can see that at the level of the guideways of the ram –ram slide assembly the total deformations are below 6 µm. The largest deviation is found at the level of the tool holder support, around 35µm. This can be corrected, more in conclusions.

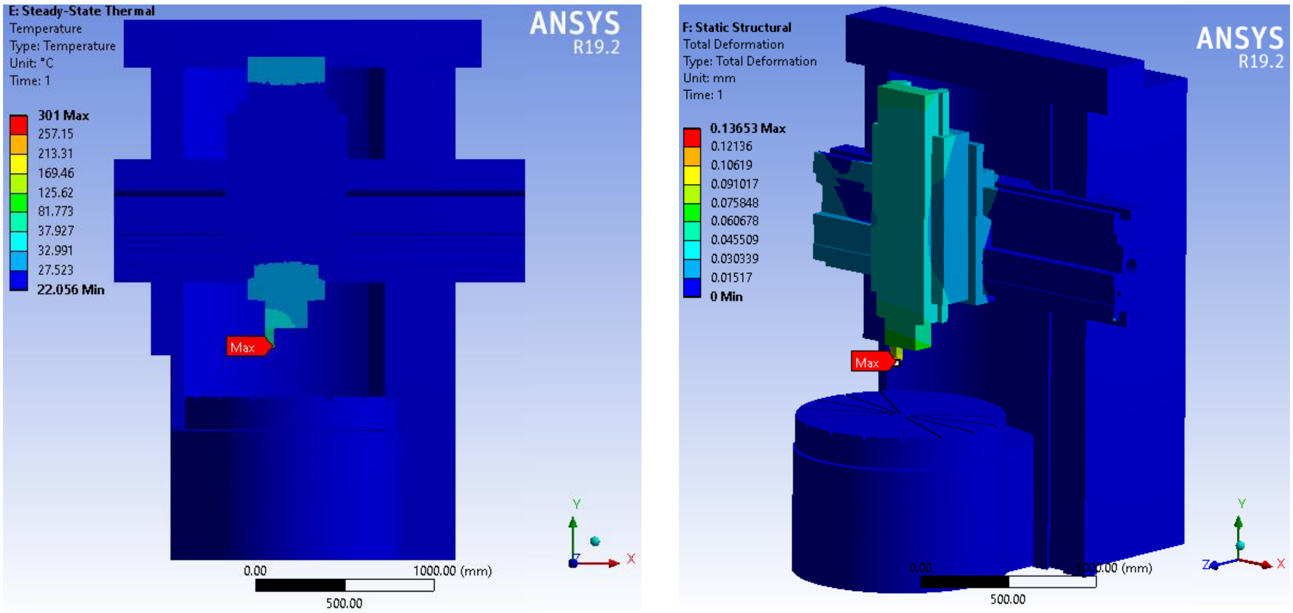

Fig. 7. Thermal dispersion and Static analysis that shows the total deformation

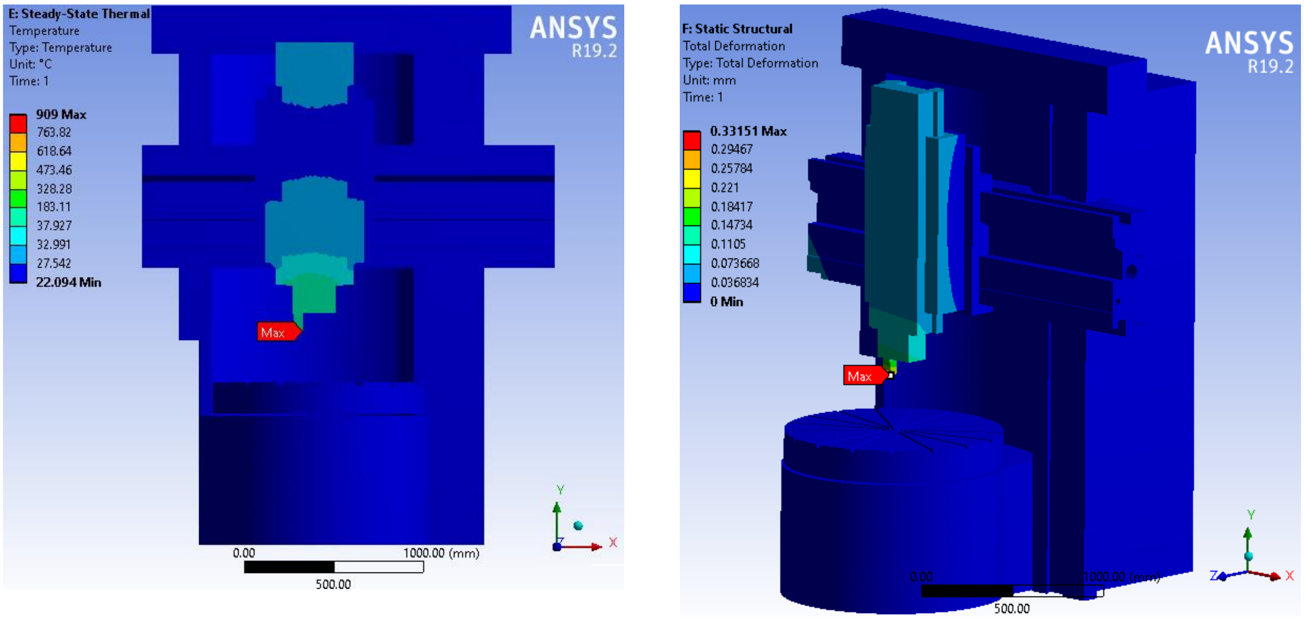

Fig. 9. Thermal dispersion and Static analysis that shows the total deformation

3.3 Thermal-stress analysis – Case 2

This case was chosen to better show the effect of the heat generated during the machining process on the rigidity of the machine tool, as can be seen in Figure 9, the dry machining regime has a significant effect on the rigidity of the machine, not only on the tool holder/tool but also on the entire Y axis.

In a real machining this scenario it's to be avoided, if dry machining it's required there are better cutting tool materials (High Carbon Steel -HCS) that produce less heat and a less aggressive cutting regime will also be employed.

By compering Figure 10 and 8 it can observe that at the level of the ram –ram slide assembly guideways the total deformation has increased by 6 ÷ 7 μm compered to Case 1 and the tool holder support has gained 69 μm in total deformation. Considering the significant effect on the machining accuracy and the life of the insert, this case can barely be recommended for even for roughing operations.

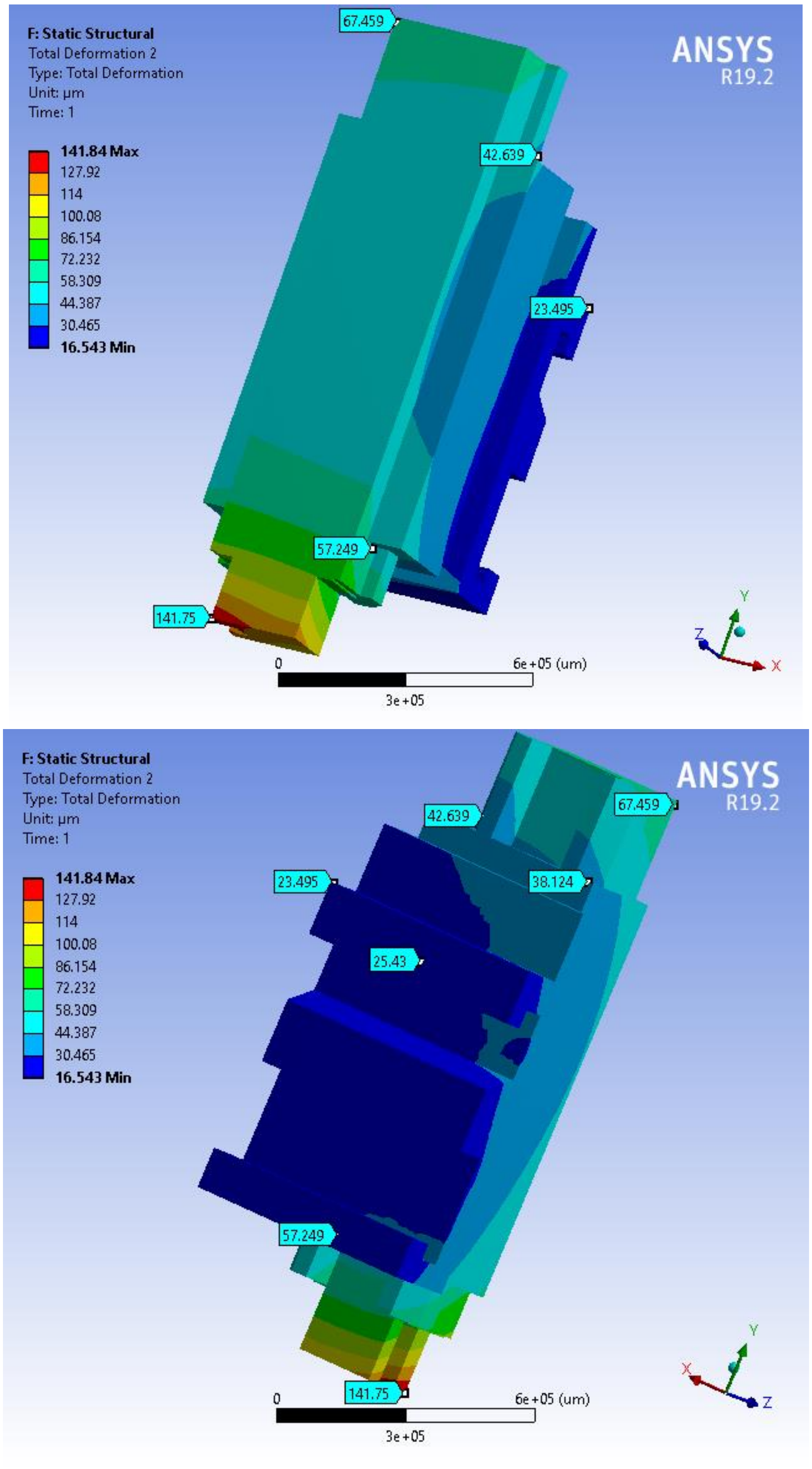

Fig. 10. Static analysis: total deformation of ram –ram slide assembly

4. CONCLUSIONS

By analyzing the results presented above we can draw some conclusions about the influence of temperature on the rigidity of the Machine Tool, especially on the elements that make up the Z axis (machine axis), and the points that need to be addressed to improve thermal compensation.

Basically, we can say that the influence of thermal factors on the machine rigidity translates into a similar influence on the Machine Tool accuracy thus one approach that works for case 1 where we can see from Figures 7 and 8 that the total deformations that are present in the structure of the machine are small, and the main problem it’s the cooling of the tool holder and the cutting tool which can be addressed by increasing the coolant pressure to 80 ÷ 100 bar and applying a internal cooling circuit inside the tool holder support and, if possible, tool holder.

Another direction to take for reducing the effects of thermal influences is focuses on the constructive and design part of the Machine Tool, as such during the

design of the Machine Tool thermal sensors can be placed at certain points in the cutting area, the signals from these thermal sensors are processed and transferred automatically, with corrections, to the two-direction materialized by the Machine Tool Y and Z axis.
Another approach to minimizing the effects of thermal influence on the two directions Z and Y is directed at the directional guidance system of the ram. In this if thermal deformation occurs the contact point between the tool and the work-piece it is placed between the two guideways so it can maintain its position. This situation it's possible by establishing direction guidance with the help of the two guideways (be it on the inside, outside or combined) thus resulting in a quasi-thermosymmetric element.

5. REFERENCES¶

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