# Study on analytical technique in a smooth design of multi-tasking machine

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**Abstract:**

In the development of multi-tasking machines, the speed of development has become faster over the years. To enable the efficient analysis methods, we must enhance design quality by the analysis and design in a short period of time alternately and repeatedly.

In this study, machine bed is set up in the environmental test chamber. Test room temperature can be controlled. We measured thermal deformations of the bed when the environmental temperature changes.

Analysis and experimental results were compared and evaluated. The purpose of this study is to suggest analysis conditions that are simple but highly accurate. Also, the bed's rib structure affects thermal change. This paper investigates the accuracy of analysis of deformation of machine tool bed.

**Keywords:** Multi-tasking machine, FEM, Thermal deformation, Smooth design method, Analysis conditions

## 1. Introduction

In designing large cast metal for a multi-turret and multi-tasking machine with several axes, FEM (Finite Element Method) is employed as an analytical method. This has brought high stiffness, damping capacity, and thermal stiffness to the structure of cast metal. Casting technique has been improved a lot today, and it is possible to make the internal structure more complex. As a result, cast metal itself is getting thinner, lighter, and more complex.

At the same time, we are required to increase the design speed with highly efficient analytical technique. We need to develop analytical methods that designers can carry out by repeating the analysis and design alternately. In this study, we focused on the efficiency in the analytical methods, and compared the results of the analytical methods and the real experiments.

## 2. Saving the design time on machine tools

The base of the machine tool is called a bed. Designing the bed is the most time-consuming task in the whole design process because the stiffness, damping capacity, and thermal stiffness are all indispensable to the bed. The stiffness is necessary to perform the machining accurately toward the large cutting resistance such as heavy-duty cutting. The damping capacity indicates damping characteristics to absorb the vibration caused from the turret and headstock during the machining. In addition, thermal stiffness means the heat stability to maintain the machining accuracy for a long time against the heat developed from motors and the machining.

At the same time, from the aspect of cost, we need to reduce the weight of the bed maintaining the best of its quality and functions.

Moreover, the shapes of the bed vary widely depending on the guidance systems. Compared to the beds employing the rolling guide or linear motion guide, the beds employing the sliding guide require highly larger stiffness around the sliding surfaces. Multi-tasking machines based on the opposed-spindle-type lathe can machine a much longer workpiece compared to the machining center. Therefore, the bed of such machine is horizontally long, so the accuracy in parallelism of the path where the cross slide moves and the spindle center line on the bed is also a very important factor.

Figure 1 shows a 3-dimensional model of the bed.

Figure 1: Bed of multi-tasking machine

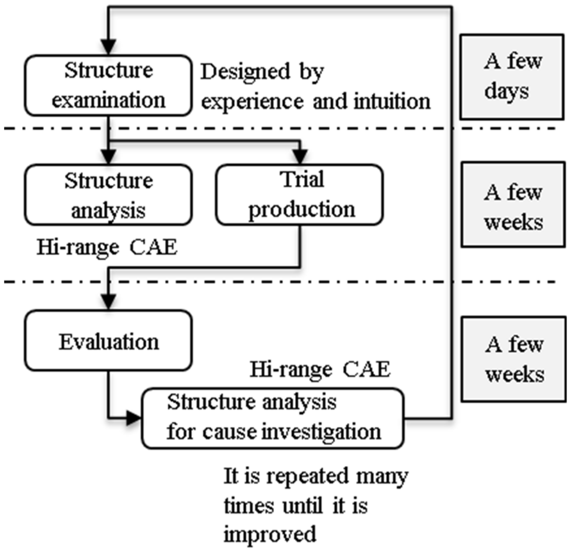



Figure 2: Past design process

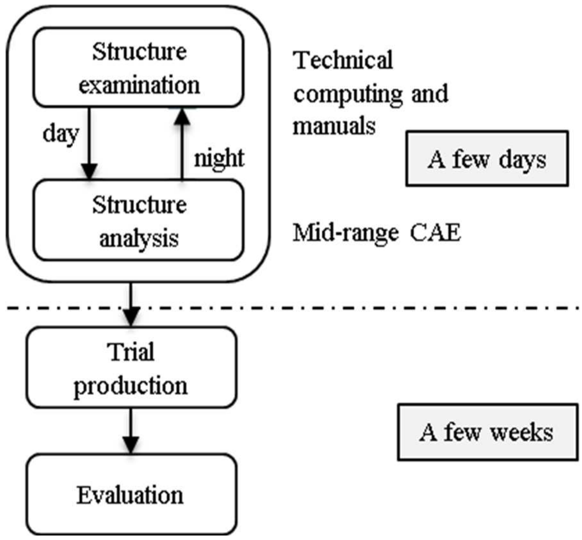



Figure 3: Proposed design process

As described, it takes a long time to design the bed. Figure 2 shows the past design process.

In the past process, designers used to model the internal structure of cast metal based on their experience and intuition. The model is reviewed, and put into a drawing. Then a trial piece is made, and the model is sent to a person in charge of analysis.

The model undergoes a series of analysis there, such as static stiffness, thermal deformation, natural frequency, nonlinear analysis, and coupled analysis of frequency response analysis and transient calculation with high-spec software. However, it takes quite a long time to complete all the analysis. Evaluation of the trial piece often starts before the output of all the analysis results.

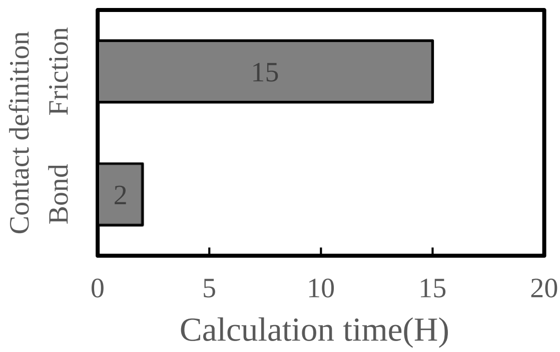
If the trial piece does not meet the required standard, or leaves a lot of room for improvement, analysis is carried out again to find faults, build the structure, and make another trial piece. This process is repeated until the trial piece meets all the factors to achieve higher quality in the product. Instead of producing a better product, huge cost and time have been consumed to get ready for manufacturing.

Figure 3 shows the design process that we propose in this study. In this process, the designers also carry out the analysis, or the analysts have skills equivalent to the designers and are capable of changing models. Also, the design is performed based on a design plan and procedures prepared in advance. The designers check the structure of the model during the daytime and the analysis is carried out in the nighttime. The software used for the analysis is a mid-range CAE, which corresponds to the 3D-CAD.

The analysis can be continued without interruption in this process. The direction of designing is given to the analyst so that the designer can receive a reasonable response to alter the design next morning. When the design meets all the factors by repeating this process, it's time for making a trial piece.

All you have to do for the evaluation of the trial piece is to check the specifications, and this will save a lot of workload compared to the past process.

To put this process into effect, the analytical process has to be made simpler but accurate.




Non-steady heat deformation analysis
DOF = 4,253,889
Amount of contacts = 1,433,341
Amount of elements = 974,230

Figure 4: Calculation times when contact definition is bond or friction

One of the reasons of making the analysis a time consuming task is contact definition. Figure 4 shows the results of analysis time with and without the contact definition. There is an obvious difference between these two. To save the design time, we carried out the analysis and experiment of thermal deformation on the bed without the contact definition.

## 3. Proposal of the analyzing methods of the bed

Designing machine tools must be done in a very short time. To improve the machine development from both design and analytical aspects, models and methods must be simple, but are faithful to the real in the analysis. These opposed ideas must always be considered.

Figure 5 shows the analysis model. The bed is placed on a disk-shaped floor made of concrete, and is adjusted with levelling blocks to contact the floor completely.

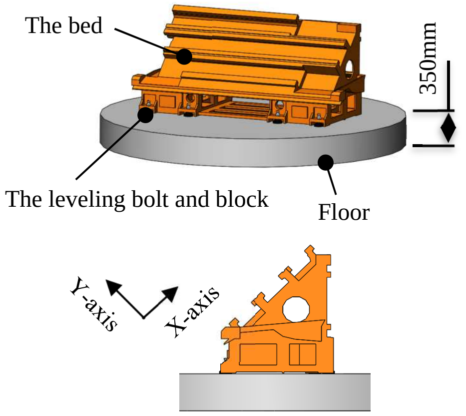



Figure 5: Analysis model

The thickness of the concrete is 350 mm, which is as thick as the floor of the laboratory. The center of gravity is set just on the center of the concrete disk. It is supposed that the bottom surface of the concrete disk is fixed, but the concrete disk itself is affected by thermal expansion.

Table 1: Property of materials

| | Cast iron (FC300) | Steel (S45C) | Reinforced concrete |
|---|---|---|---|
| Young's modulus [N/m²] | $6.62\times10^{10}$ | $2.1\times10^{11}$ | $3.0\times10^{10}$ |
| Poisson ratio | 0.27 | 0.28 | 0.2 |
| Thermal conductivity [W/mK] | 45 | 43 | 1.6 |
| Linear expansion coefficient [1/K] | $1.11\times10^{-5}$ | $1.3\times10^{-5}$ | $1.0\times10^{-5}$ |
| Heat transfer coefficient [W/m²K] | 5 | 5 | 5 |

Table 1 shows the physical properties of the materials involved in the analysis.

We raised the temperature around the bed by 7 degrees in 4 hours, and kept it for 14 hours. Then lowered the temperature by 7 degrees in 4 hours, and kept it for 14 hours. We carried out the unsteady thermal analysis under that circumstance. Figure 6 shows the results of the analysis. We used Solidworks simulation for the analysis.

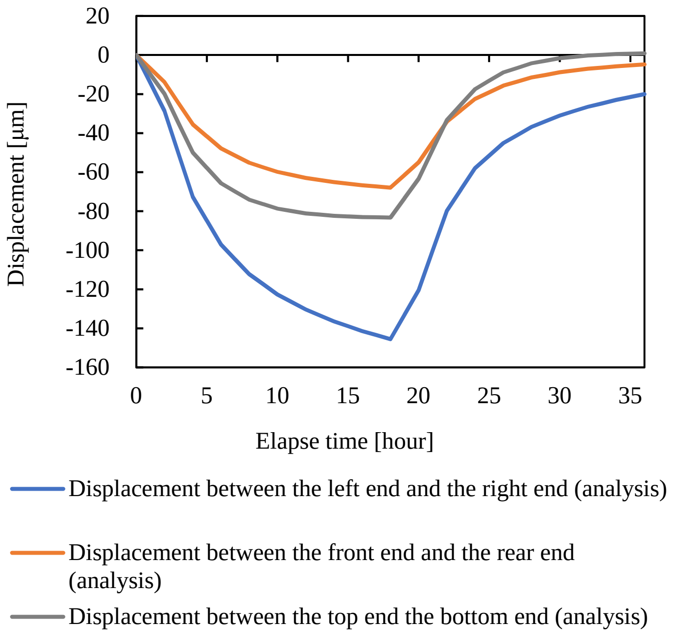



Fig.6 Analytical result

## 4. Measuring experiment of thermal deformation

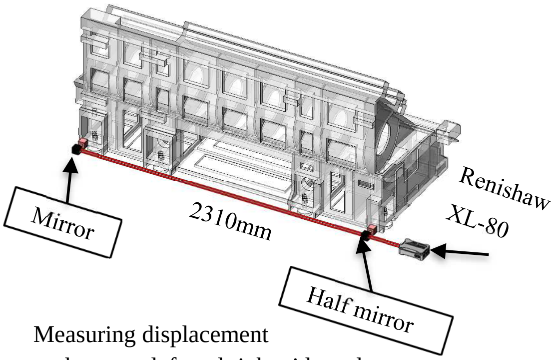
Next, we moved the multi-tasking machine into the environmental test chamber, and carried out the experiment to measure the thermal deformation.

In the experiment, we used Ranishaw XL-80 to measure the distance between two points. An environmental temperature compensation unit for the measuring device was not working then. Figure 7 shows the sites of the experiment.

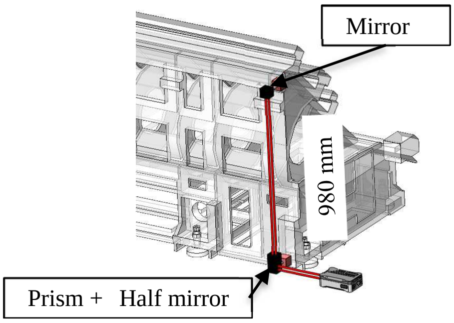
Width, depth, and height are the measuring objects on the bed.

Figure 8 shows the thermal transition under the circumstance the same as in the analytical process previously mentioned.

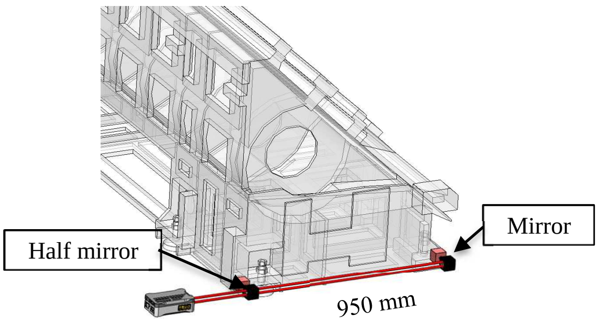
The results of the experiment are almost the same as those of the analysis. That means it makes sense to carry out an analysis in the nighttime for more effective design and analytical process leaving less extra trial pieces. We ignored the contact definition in carrying out the analysis for efficiency this time, but actually the results of the analysis and experiment show that they are almost the same. It can be said that even if the contact is not taken into consideration, the new analytical method has attained the level of a practical use for designing.




Measuring displacement between left and right-side end




Measuring displacement between top and bottom side end




Measuring displacement between front and rear side end

Figure 7: Measurement methods

However, a certain amount of difference may occur between the values of mechanical damping in the analytical method and experiment because the coefficient of friction has much to do with damping. That is the future task.

## 5. Conclusion

We proposed the efficiency-oriented method in analysis, and compared the results of the analysis and the experiment with the actual machine.

Designing and analyzing methods that we propose are an effective way of analyzing the thermal deformation.

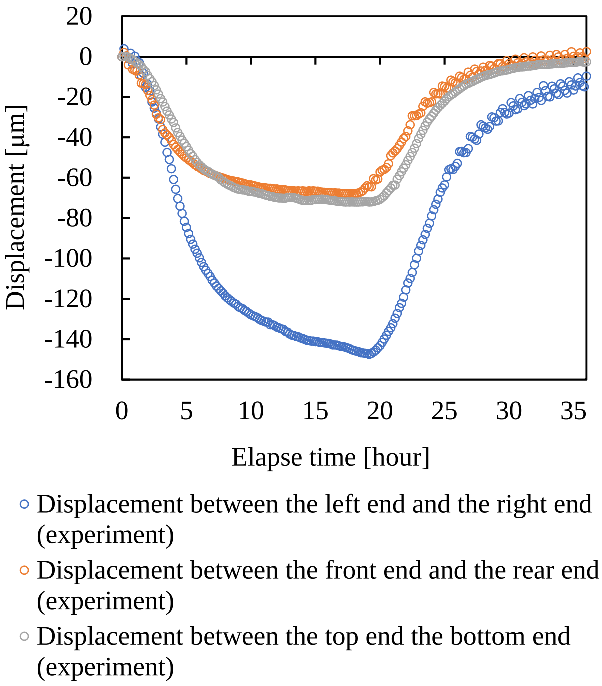



Fig.8 Experimental result

**Reference**

[1] Manabu SAWADA, Kenichi NAKANISHI, Principle and machining case of combined processing machine, The Japan Society for Abrasive Technology Journal, Vol.51(2007), No.7. pp391

[2] Kouetsu YAMAZAKI, Manabu Sawada, Makoto TSUCHIHASHI, Kenichi Nakanishi, Minimization of Thermal Deformation of Machine Tool, JSME annual meeting 2000(1), pp129-130

[3] Kenichi NAKANISHI, Jiro SAKAMOTO, Estimating thermal deformation from rotation history for machine tool, Proceedings of International Conference on Leading Edge Manufacturing in 21st century : LEM21 2015(8), "0307-1"