DE GRUYTER OPEN

ADVANCES IN MANUFACTURING SCIENCE AND TECHNOLOGY
Vol. 41, No. 2, 2017
DOI: 10.2478/amst-2017-0008

ANALYTICAL STUDIES OF STATIC STIFFNESS OF CARRYING SUBSYSTEM SADDLE-TABLE OF MACHINE TOOL

Beata Niesterowicz, Daniel Jastrzębski

S u m m a r y

The paper demonstrates results of analytical researches on carrying subsystem of machine tool in designation of its static stiffness characteristics. Varied kinds of models that differ in solid structure simplifications have been considered. The aim of researches was to find effective, considering designing needs, modeling methods of this subsystem and an attempt to formulate general recommendations in terms of analysis and modeling of carrying subsystems of machine tools.

Keywords: analytical MES researches, carrying system of machine tool, stiffness characteristics

Analiza sztywności statycznej podukładu nośnego stół-sanie centrum obróbkowego

S t r e s z c z e n i e

W pracy przedstawiono analizę wyników badań dla określenia charakterystyk sztywności statycznej podukładu nośnego stół-sanie centrum obróbkowego. Przyjęto w badaniach różne warianty modelu z uwzględnieniem określonego zakresu uproszczeń obejmujących jego strukturę bryłową. Celem jest ustalenie efektywnych metod modelowania tego podukładu nośnego. Sformułowano ogólne zalecenia dotyczące analizy i modelowania układów nośnych obrabiarek.

Słowa kluczowe: badania analityczne MES, układ nośny obrabiarki, charakterystyki sztywności

1. Introduction

Developing construction of machine tool carrying system is an essential issue in machine tool designing process. The supporting system of machine tool is an implicitly separated group of carrying machine parts, linked together by guideway systems. Especially, demand of high stiffness of these systems should be taken into consideration when new machine is being designed. Using computer simulation methods in this process enables prediction of mechanical properties, inter alia static properties, particularly stiffness. It can be demonstrated that because of constructional specifics of machine tool carrying system,

Address: Beata NIESTEROWICZ, MSc Eng., Daniel JASTRZĘBSKI, DSc Eng., West Pomeranian University of Technology, Faculty of Mechanical Engineering and Mechatronics, 19 Piastów Av., 70-310 Szczecin, e-mail: Beata.Niesterowicz@zut.edu.pl, Daniel.Jastrzebski@zut.edu.pl

commonly used methods of modeling and construction analysis, including classically interpreted finite element method, are not effective tools. The area of analysis application extends due to demand of implementation of computations in various configurations of carrying subsystems. It significantly multiplies the number of computational researches conducted. For these reasons we should look for compromise between effectiveness of modeling (effort into building model and time of computations) and sufficient, in terms of designing, accuracy of results.

2. The subject of examinations

We analyzed subsystem table-saddle of typical supporting system of machine tool (Fig. 1). This subsystem has guideway system, where commonly used guideway rolling subassemblies of THK (type SVR 25RW) were used (Fig. 2) [1].

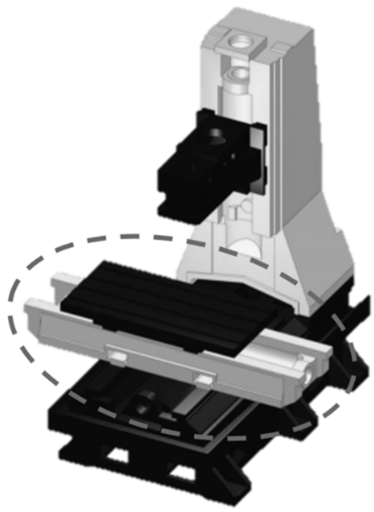

Fig. 1. Machine tool carrying system with marked analyzed subsystem of saddle-table

Geometry of analyzed subsystem (table-saddle) was made in SolidWorks [2]. Models were simplified because of complicated shapes of table and saddle. Simplifications included omission chosen geometrical elements such as: fillets, chamfers, screw holes, etc. (Fig. 3). Such process is reasonable solely, when we can predict that they will not have significant influence on final results [3]. Other kind of simplifications were applied into the model of screw-nut connection between mounting surface of rolling guideway systems and solid of table and saddle. In this kind of strongly clamped connections contact interaction of solids can be neglected and considered as continuous solid, according to the suggestion in work [4], because of its high stiffness.

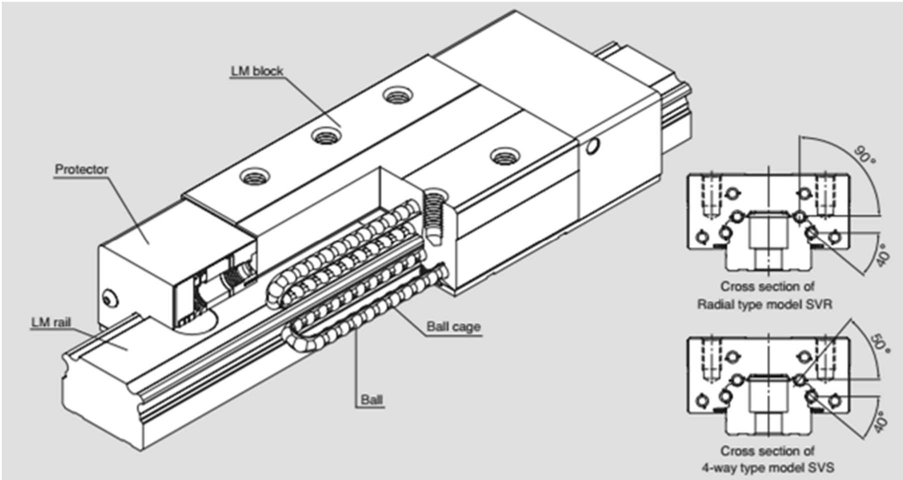

Fig. 2. Rolling guideway subsystem THK SVS/SVR 25RW, based on [1]

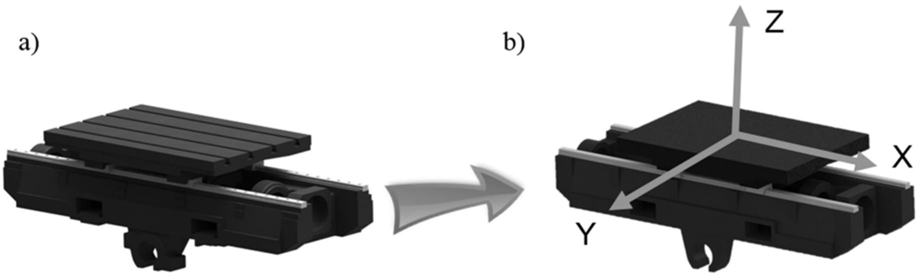

Fig. 3. Simplification of the geometric form of the saddle-table unit: a) form before simplification, b) simplified form with the selection of the coordinate system

3. Modeling methods

Taking into account the modeling capabilities used in the machine tool carrying systems analysis [5], computationally efficient variants of carrying system models were sought. We assumed classical finite element method (FEM) models as a reference ones. Each component of FEM model is flexible. In considered example table and saddle corps as well as guideway tracks and carriage were discretized as flexible finite elements [FF]. The most simplified model was made using rigid finite element method (RFEM) [RR], which assume that all corps are ideally rigid elements. Elasticity of the entire object was focused on the area of contact joints occurring in rolling guideway subsystems [4]. Moreover, hybrid models, that combine flexible and rigid bodies, were build. In these variants some preselected construction parts were modeled as flexible, the other were considered as rigid [FR] [RF].

In calculation process we used program Helicon which is dedicated to this subject. It had been developed on Faculty of Mechanical Engineering and Mechatronics of Westpomeranian University of Technology in Szczecin [6]. This program enables static analysis of supporting systems of machine tools, implementing GS method (correction of external loads) [7].

4. Results of the calculations

In the first step we developed two basic variants, the first with respect to flexible FEM, designated FF, and second as a rigid finite element model, designated RR. Moreover we elaborated two hybrid variants. First of them assumed flexibility of machine tool table, whereas rolling guides and carriages as well as saddle solid were created in RFEM, this hybrid model was designated FR. Whereas second hybrid model, designated RF, consist of flexible carriages and rigid table. In all models, contact interactions between track and rolling element of guideway systems, were modeled in the same way. Both the distribution structure and parameters were identical.

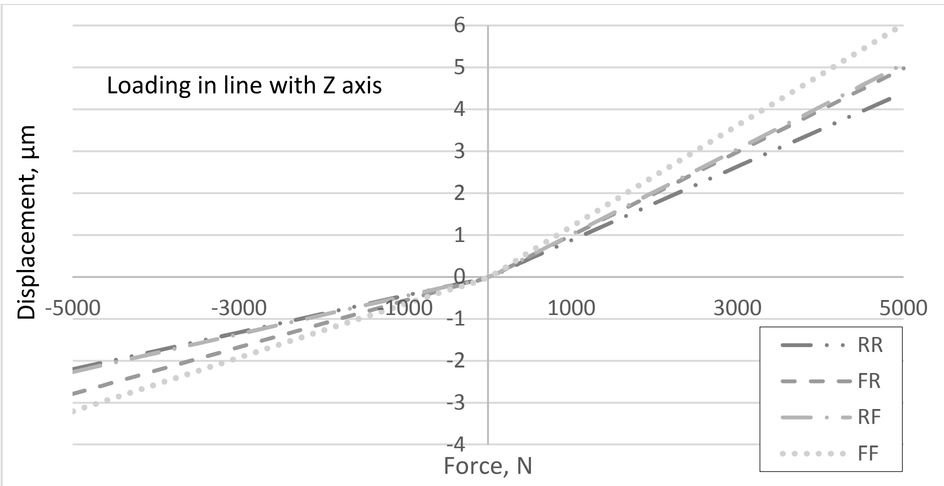

Fig. 4. A summary of the characteristics obtained for four variants of the model at Z axis load

During research an object was loaded by the vertical load (axis Z – Fig. 3), distributed over limited part of table surface, on the area adequate to the workpiece holder contact surface. Load values were chosen in the range –5000÷5000 N, negative values correspond to the case where the force was returned to the table surface, while positive values – when the force was opposite. The method of loading was chosen just for research, but in the selection of the range of values we were guided by the values actually occurring during the various cutting conditions. Fig. 4 presents results of calculations of displacement characteristics of point of force application, depending on the force, for four different models.

Curves for each models are very similar, according to the characteristics presented on Fig. 4. It was expected that the largest displacements would be obtained for FF model („fully deformable”), whereas the smallest for „fully rigid” RR model. Both hybrid models curves (FR and RF) were comprised between these extreme curves. However, it is noted that the biggest difference between curves for the maximum strength in this area does not exceed 2 µm.

The next stage of research concerned two series of calculations for forces applied similarly as in the first case, but directed in line with axis X, and then with axis Y. Fig. 5 and Fig. 6 show received curves of displacements in point of force application, depending on the value of force for four models, respectively in directions Y and Z.

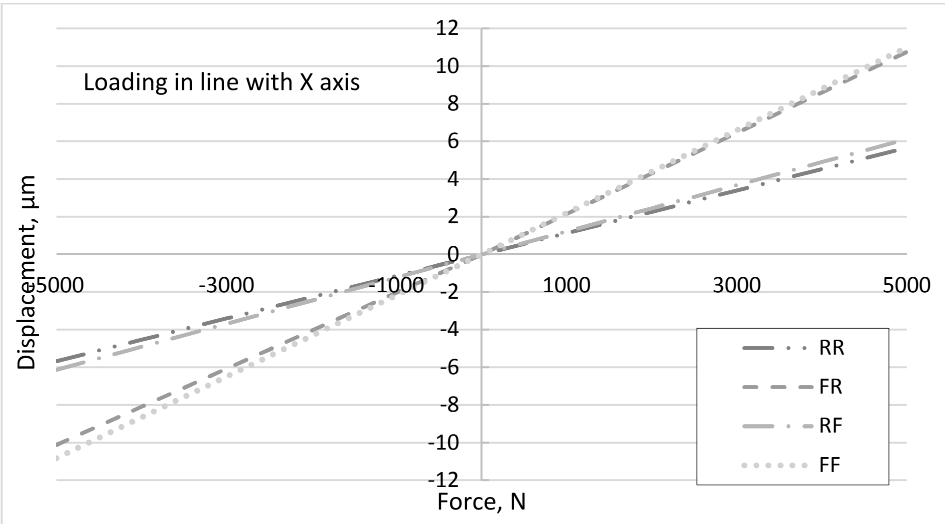

Fig. 5. A summary of the characteristics obtained for the four variants of the model at the X-axis load

Based on Fig. 5 and Fig. 6 you can conclude that curve that respond to force direction coherent with Y axis is similar to curve responding to direction coherent with Z axis. But in case where force is applied in direction of X axis we

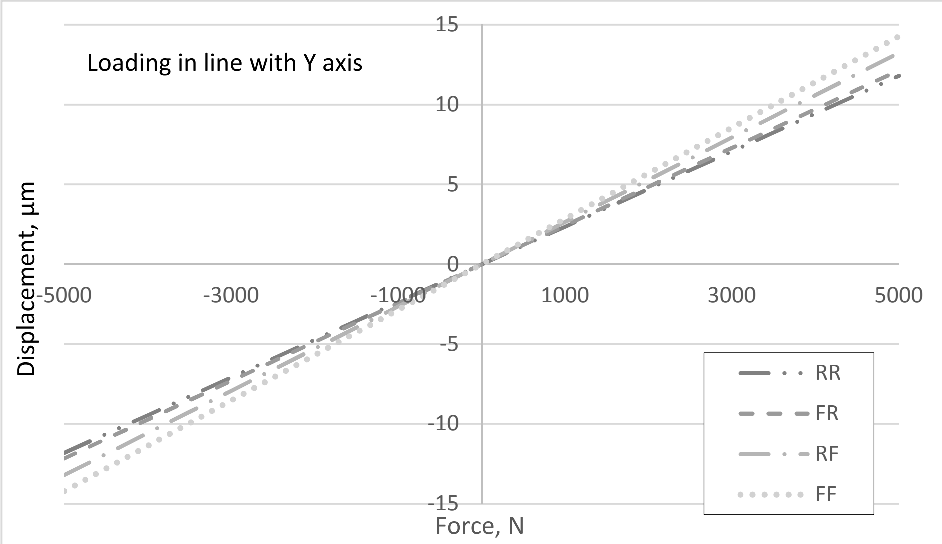

Fig. 6. A summary of the characteristics obtained for the four variants of the model at the Y-axis load

can observe significant discrepancies between variants, which assumed rigidity of table and those which consider its flexibility. It can suggest relevant influence of this flexibility on displacement in direction of X axis, in point of force application. Therefore we decided to conduct additional analysis, which contained changes in method of modeling table. Through thorough analysis of the problem one can conclude that the most significant influence on the displacement in the direction of the axis X can be the stiffness of the entire feed drive corresponding to that direction. Taking into consideration fact that in all of considered model variants, both the modeling method and the parameters of the contact elements which were used in modeling this drive system are identical, it can be assumed that the construction of the same table can cause undesirable depletion in stiffness. In order to test this hypothesis, an additional variant of the model was developed (Fig. 7). In this model it was assumed that the part of the table body, to which the screw nut housing is directly attached, is deformable. Whereas the remaining part of the table is modeled as a perfectly rigid body. The model variant created this way was designated as RRnF and subjected to analogical analysis as previously described variants. The results are shown in Fig. 8.

By analyzing the characteristics shown in Fig. 8, it can be observed that the characteristic curve for the RRnF variant (solid line) is similar to the variants marked as FF and FR. On the basis of this observation, it can be assumed that the way of idealizing the body of a table can significantly influence the results of the analysis of static properties. Assumption of rigidity of such structural parts of the construction, where there is a substantial change in shape (in this case the handle of rolling nut holder), leads to excessive simplification which undermines the reliability of the calculation results. The conclusion formulated this way encourages a more general view of how the simplified geometric form of an object affects the results obtained. In order to estimate this effect, an additional analysis, in which the geometry of the table was not simplified, was performed. The table body was treated as deformable and FEM discretized. It was designated as tableNP.

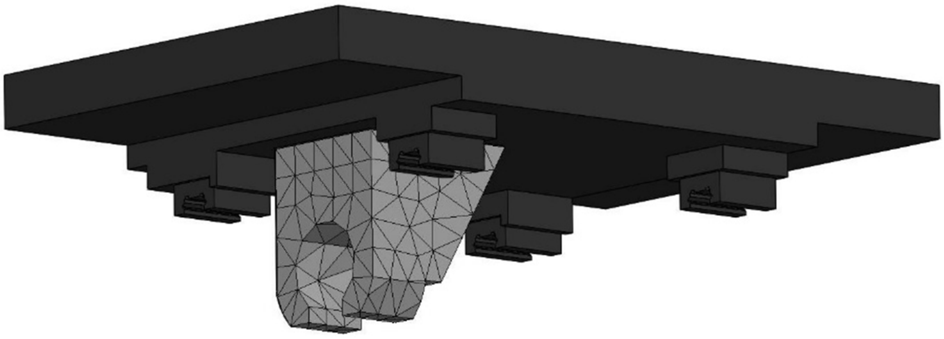

Fig. 7. Table model for RRnF variant

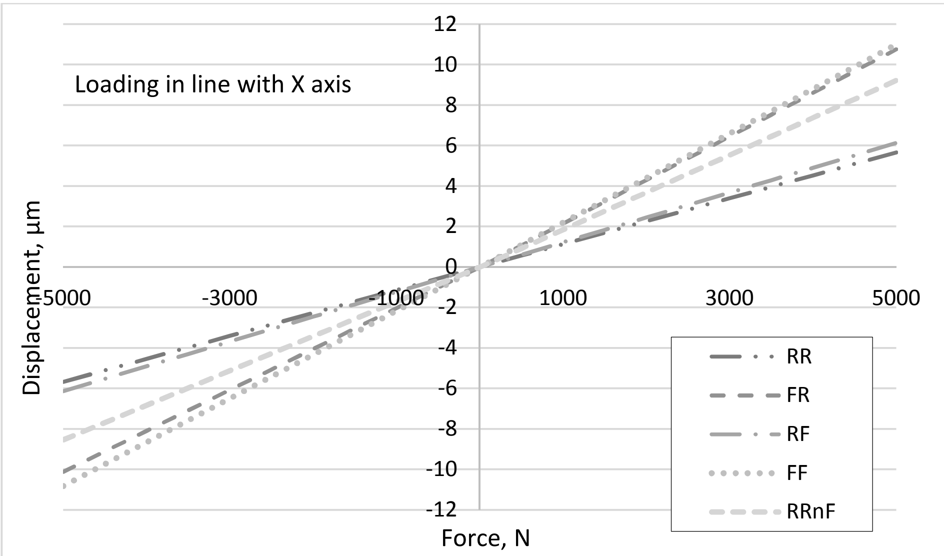

Fig. 8. A summary of the characteristics obtained for the four basic variants of the model and for additional one(RRnF) with loading in ilne with X axis

In the calculation of this variant, the method of loading the object was analogous to those in previous cases. The results are presented on Fig. 9.

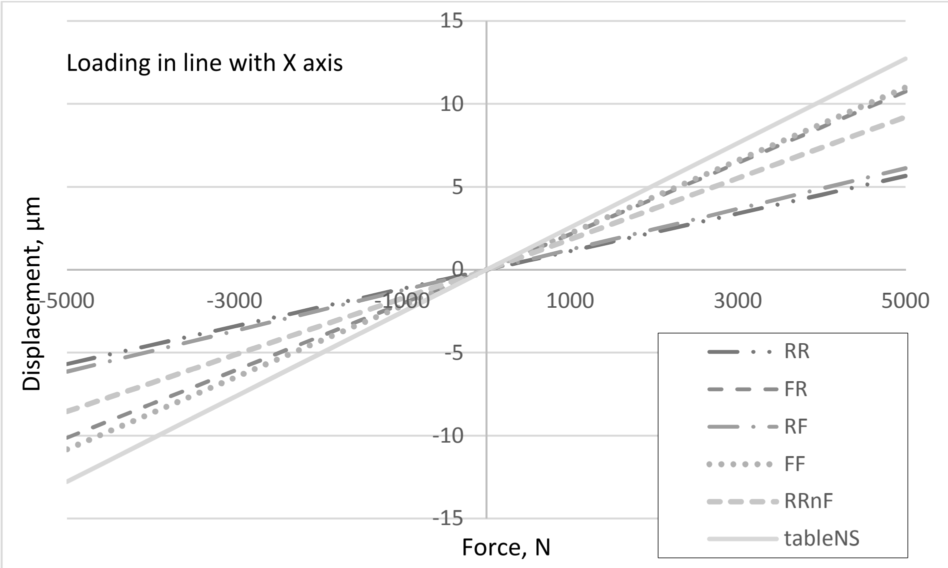

Fig. 9. Comparative comparison of the characteristics obtained for all examined variants of the model with loading in line with X axis

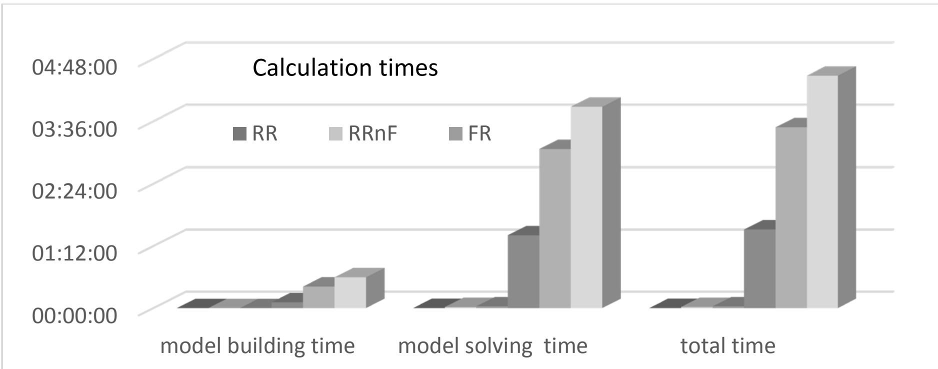

Fig. 10. Comparisons of computation times for all variants of the model

Fig. 9 presents the characteristics of the model without simplifications (marked with a solid line) and it is seen that it has an extreme course (the displacements are the largest). This allows us to formulate the opinion that modeling of geometrically complex solid objects should be preceded with particular comparative analysis of models with and without the simplifications.

In order to prove the significance of the discussed considerations, Figure 10 shows the compilation of modeling and calculation time for each variant of model.

Comparing the height of the bars corresponding to the computational time, one can notice fundamental disparity between each variants of models.

5. Conclusions

The article presents analytical studies on static stiffness of table-saddle subsystem present in typical supporting system of machine tool. In the conducted analysis the basic purpose was to show the influence of idealization of solid structure methods on the stiffness characteristics of the examined object. It has been shown that the impact of these simplifications can be significant however, taking into account great effort required to develop the model and very long computational time, the compromise between the level of model simplifications and the time spent on computation should be sought. Hybrid variants can be developed in a compromise solutions to achieve the required credibility of the results while maintaining rational calculation times. Reducing computation time is particularly important in a wide range of studies that result from the need to perform computations in a variable configurations of body assemblies.

References

[1] THK: Catalogue: Carged Ball LM Guide. THK Co. Ltd., Tokyo Japan, 2016.

[2] M. LOMBARD: SolidWorks 2011 Parts Bible. Wiley Publishing Inc. 2011.

[3] D. JASTRZĘBSKI: Application of the hybrid finite elements method in modeling of static properties of machine tools load-carrying subsystems. *Advances in Manufacturing Science and Technology*, **32**(2008)2, 5-20.

[4] B. WATYCHOWICZ, D. JASTRZĘBSKI: Impact of certain engineering methods on results of computational analyses of rolling guideway subassemblies. *Advances in Manufacturing Science and Technology*, **39**(2015)2, 29-29.

[5] D. JASTRZĘBSKI: Modelling of Static Properties of Load-Carrying System of Machines Tools Using Hybrid Finite Element Method. *Advances in Manufacturing Science and Technology*, **32**(2008)1, 9-28.

[6] D. JASTRZĘBSKI: Obliczenia projektowe układów nośnych obrabiarek metodą elementów skończonych. ZAPOL, Szczecin 2012.

[7] G. SZWENGIER: Modelowanie i obliczenia projektowe układów prowadnicowych obrabiarek. Prace Naukowe Politechniki Szczecińskiej, nr 512, Wydawnictwo Politechniki Szczecińskiej, nr 13, Szczecin 1994.

Received in February 2017