VIRTUAL PROTOTYPING AND OPTIMIZATION OF HEAVY MACHINE TOOLS

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Abstract

This paper deals with virtual prototyping and optimization of heavy machine tools. Main focus is on static and dynamic stiffness of heavy lathe. Analysis of virtual models of heavy lathes is very specific because the great influence on machine stiffness has workpiece and machine base. In most cases the weight of workpiece is greater than the weight of machine tool. The influence of workpiece and machine base on static and dynamic stiffness of heavy lathe is analysed in this work. CAx software Siemens NX 10.0 is used for numerical analysis and optimization of heavy lathe.

Keywords: Machine Tool Design; FEM; Virtual Prototyping; Heavy Machine Tool; Optimization

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1. Introduction

Czech Republic has a long tradition in the production of heavy machine tools. University of West Bohemia in Pilsen cooperates with Skoda Machine Tool which produces the largest machine in the world (maximum workpiece up to 350 tons) (Table 1). More than 90% of the production is made for export. The most important export territories are China, Finland, The Netherlands, India, Japan, Canada, South Korea, Germany, Austria, Russia and Ukraine. Production program of Skoda Machine Tool is heavy boring and milling machines and heavy lathes. The use of modern design methods is necessary to achieve high quality products.

1.1. Heavy lathe

My research activity is focused on the issue of heavy lathes. Main parts of heavy lathe are machine bed, headstock, tailstock and carriage saddle with cross slide. All of these parts have influence on stiffness of lathe. The aim of my work is to propose a design methodology of heavy lathes.

	SR 1000	SR 2000	SR 3000	SR 4000	SR 5000	SR 6000
		1000	1300	2000	3000	3600
Diameter over carriage [mm]	1000	1300	1600	2500	3300	4200
		1500	2000	3000	3600	5200
		1-1000	1-700	1-400	1-400	1-400
Torque [Nm]	12 000	1-700	1-400	1-250	1-250	1-200
			1-250	1-200	1-200	1-120
					1-120	
Max. workpiece length [mm]	Up to 6000	3000-20000	4000-20000	4000-20000	4000-20000	10000-20000
		25	25	25	56	56
			56	56	100	100
Max. workpiece weight [t]	16			100	160	160
				160	250	250
						350
		60	60	60	60	60
		100	100	100	100	100
Power of main drive [kW]	51		140	140	140	140
				200	200	200
						330

Table 1. Parameters of heavy lathe

2. Literature overview

Design of heavy lathes is very specific. The analytical computations are good described in literature [3] but most of information about virtual prototyping of this machines are not public. All our knowledges are from cooperation with manufacturer [1, 4, 5]. Some authors wrote about numerical analysis of similar machines [6, 7, 8, 9]. This information will be useful in future work.

3. Numerical analysis of heavy lathe

First step of this work is basic numerical analysis of simple virtual model of heavy lathe. The virtual model including basic part of lathe (machine bed, tailstock and headstock). Main goal of this analysis is give the answers to the two questions:

- a)How to model connection between foundation and machine bed?
- b)Is the model of workpiece replaceable by load?

3.1. Finite element model

For analysis only full solid body models of machine bed, headstock and tailstock are used. Material of all parts of lathe is iron casting G40 (Young's Modulus = 140 000 MPa, Poisson's Ratio = 0.25, Mass Density = 7150 kg/m³)

3.2. Boundary conditions

Connection between foundation and machine bed

The connection between the foundation and the machine bed is realized using fixators. The BW-Fixator Series RK for the levelling, adjustment and fixation is used (Fig. 1). Only information about axial stiffness is available in catalog. Stiffness of this fixators (RK III) is 8000 kN/mm [2]. Radial stiffness of fixator is 25% of axial stiffness [1].

Fig. 1. BW-Fixator RK-III

This paper compares two methods of modeling of connection between the foundation and the machine bed:

- Absolutely rigid connection.
- Flexible connection (spring with stiffness)

Connection between headstock and machine bed

The connection between the headstock and the machine bed is realized using bolt connection. The numerical analysis model using gluing connection.

Connection between tailstock and machine bed

The connection between the headstock and the machine bed is sliding connection with rack and pinion for linear motion. During machining position is fixed. The numerical analysis model using gluing connection. In the future work gluing will be replaced by contact connection.

Force load

Analysis includes force from the weight of the workpiece and the force of workpiece preload. The mass of workpiece is 56 tons.

- The force of the weight of the workpiece is divided into two halves. Force applied to headstock is $F_Z = - 274\,680\text{ N}$ and force applied to tailstock is also $F_Z = - 274\,680\text{ N}$.
- The force of workpiece preload is 75% of weight of workpiece. Force applied to headstock is $F_X = - 412\,020\text{ N}$ and force applied to tailstock is also $F_X = + 412\,020\text{ N}$.
- Gravity is not included.

This paper compares two methods of applying of force loads to numerical model.

- Analysis not including the geometry of workpiece.
- Analysis including the geometry of workpiece.

Fig. 2. Finite element model with boundary conditions

4. Results

Most important result is displacement on tailstock and headstock. This value has great influence on precision of machining. The figures 3, 4 and 5 shows displacement in X,Z,Y directions.

4.1. Displacement

Fig. 3. Displacement X

Fig. 4. Displacement Y

Fig. 5. Displacement Z

4.2. Reaction force

Fig. 6. Reaction force Z

Number of series of fixators is from left to right (Figure 6). Graph of reaction force versus position of individual fixators is on Figure 7. This result is important for numerical analysis of fixator.

Fig. 7. Reaction force on series of fixators

4.3. Force (machine bed)

Reaction force on face of machine bed will be used for optimization of this part (Figure 8).

Fig. 8. Force on face of machine bed

4.4. Utilization of material

Figure 9 shows utilization of material. The colored area shows new shape of the main parts of the machine. This result can be an inspiration for the design.

Fig. 9. Utilization of material

Table 2 shows displacement on headstock and tailstock. The most important result is displacement Y which is shown on Figure 10.

		Rigid connection		Flexible connection	
		Without workpiece	Including workpiece	Without workpiece	Including workpiece
Displacement X	Headstock	-0.029 (0)	-0.036 (+24%)	-0.048 (+66%)	-0.063 (+117%)
	Tailstock	0.030 (0)	0.038 (+27%)	0.049 (+63%)	0.063 (+110%)
Displacement Y	Headstock	0.016 (0)	0.017 (+6%)	0.019 (+19%)	0.020 (+25%)
	Tailstock	0.019 (0)	0.019 (0%)	0.021 (+11%)	0.022 (+16%)
Displacement Z	Headstock	-0.009 (0)	-0.008 (+11%)	-0.006 (-33%)	-0.003 (+77%)
	Tailstock	-0.010 (0)	-0.009 (+10%)	-0.006 (-40%)	-0.004 (+60%)

Table 2 . Results - Displacement

5. Conclusion

Main goal of this paper was investigate the connection between foundation and machine bed. The influence of FEA model of workpiece was also investigated. The basic FEM analysis of heavy lathe was made using by Siemens NX CAX software. The result is that numerical model must include the flexible connection with real stiffness of fixators. The results of displacement indicate significant differences between models with flexible and rigid connections. This differences are from 11 to 66% depend on axis. Modeling of workpiece is also very important. The differences between models without workpiece and models with workpiece are from 0 to 117% depend on axis and type of connection (rigid or flexible). The results of this paper will be used to precise virtual model of heavy lathe. Next tasks is analyze the connection between tailstock and machine bed and the connection between tailstock and workpiece.

6. Acknowledgements

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