High Revolving Speed Spindles Definition Due to Transient Vibration Conditions

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Summary: Spindle is the main part of Machine tools that their products face finishes are influenced by vibrations through cutting process. With consideration of a conventional turret spindle and new production conditions through a Finite Element Transient Analysis (FEA), terms of new spindles, their bearing types and arrangement was defined; Stiffer material for spindle must be used and the bearing sets number must restricted to two sets, Angular trust and Taper roller bearings must be used.

INTRODUCTION

World manufacturers continue to face increased production and quality requirements. Trends towards tighter tolerance specifications further could the picture. In particular, turret products tolerances are becoming smaller and creating new quality challenges. Turret spindle is a very sensitive element which is terribly effective on quality and precision of products. Its role became very important when high revolving speeds which are very common in CNCs are used. Although the spindle precision is important, precision durability which causes steady products is a term of economic production. In manual turrets, the highest revolving speed is around 2400 RPM [1] that is rarely used, whereas in CNCs higher speeds are up to 7500 RPM [2] and they can be reasons for great vibration amplitudes. Vibration can be a sign of imbalance some where inside the machine and that downtime for maintenance and tool changes is probably higher than it need to be, so distribution of mass is important for minimizing the amount of vibration generated by spindle [3].

MODELING

The spindle model was prepared in SolidWorks2003 considering a true prototype turret model TN50 [1]. Mechanical properties were considered isotropic as Possion's ratio $\upsilon = 0.3$, density $\rho = 7850\ kg/m^3$ and Young modules $E = 210 \times 10^9$ Pa. Boundary conditions are result of bearing types and lengths that were used: a) Roller bearings b) Trust ball bearings. (Fig. 1)
In order to calculate force acting on spindle, the following equation was used [4]:

$$F = Cp.t^x.s^y.Ke.K\varphi.K\gamma.Km$$

The definition of above mentioned parameters are; Ke: coolant factor, $K\varphi$: entrance angle factor, $K\gamma$: sweeping angle factor, Km: σ_{ult} factor and Cp, x, y: Machine tool type factor. t: cutting depth (mm) and s: feeding rate (mm/rev).
For this purpose the following analysis must have been done in advance:

- Natural frequency analysis: Ten first natural frequencies and relative mode shapes were obtained using subspace method. The present system has one degree rigid motion around its axis [5-7].
- Harmonic analysis: In resulted frequency range showed which of the natural mode shapes would be excited. In this way the transient time step could be determined ($\Delta t = 1/20 f_{n,i}$). For harmonic analysis full method was used [5-7].

Transient analysis [5-7]:
A) Shock: The mathematical function for shock was as below :(Fig. 2)

$$F(t) = \begin{cases} F & t \le \Delta t \\ 0 & t \ge \Delta t \end{cases}$$

B) Step: The mathematical function for step was as below:

$$F(t) = \begin{cases} F & 0 \le t \le t_1 \\ 0 & t > t_1 \end{cases}$$

As resulted graphs and table show:

- The harmonic resulted graph shows the third, sixth and ninth natural frequencies were excited as the result of entry force [7].
- The results showed that only chuck part is affected. The result has two patterns; a) When the force is acting, only the chuck tip is affected, b) After eliminating force and chuck has free vibration and whole chuck is affected. (Fig. 3)
- As the resulted graphs show, the response is a composition of some harmonics means sixth and ninth mode shapes were excited as well as the third one [7].
- The results showed type, time duration and force amplitudes affect the response amplitude.

CONCLUSION

Bearings are mechanical devices that can strongly influence vibration response of spindle system so; they have to be minimized in number. It means that it is sufficient to use bearings sets in two points, first near chuck position, second next

to driving gear or other spindle end. The first bearing set as it was shown by finite element analysis, prohibits transferring vibration effects, both axial and radial , therefore other bearing set is only used for both leveling and bearing other acting forces [2, 8]. (Fig. 4)
In recent machine tools higher revolving speeds are used so using conventional spindles causes huge energy waste therefore lighter spindles must be used. To prevent great vibrations amplitude due to light weight spindles stiffer materials have to be used [2, 8].
Above mentioned alterations lead us to use different types of bearings. Because of them for the first set, Angular trust bearings and for other set, Taper roller bearing must be used.
In the following some specimens for new spindle generations and their function versus conventional ones are bought [2, 8]. (Fig. 5, Table 1)

Table 1: Vibration amplitude for conventional and modern spindles (FEA)

	Vibration amplitude for conventional spindle(m)				Vibration amplitude for modern spindles (m)			
Force amount	F=300 N	F=400 N	F=500 N	F= 600 N	F=300 N	F=400 N	F=500 N	F= 600 N
Shock	0.396e-6	0.528e-5	0.573e-5	0.791e-5	0.205e-5	0.273e-5	0.341e-5	0.410e-5
Step	0.419e-6	0.559e-5	0.698e-5	0.838e-5	0.205e-5	0.281e-5	0.341e-5	0.371e-5

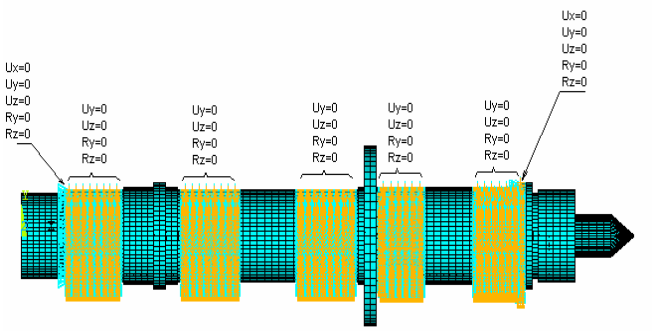


Fig 1: Applied boundary conditions on conventional spindle (Five bearing sets)

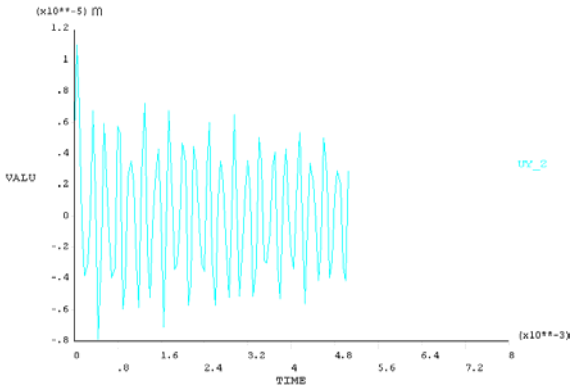
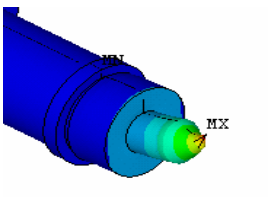
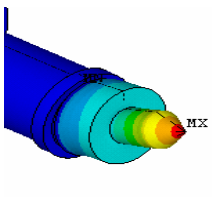


Fig 2: chuck vibration amplitude due to shock force (FEA)



(a)



(b)

Fig 3: Displacement contour a) in acting force b) Free vibration

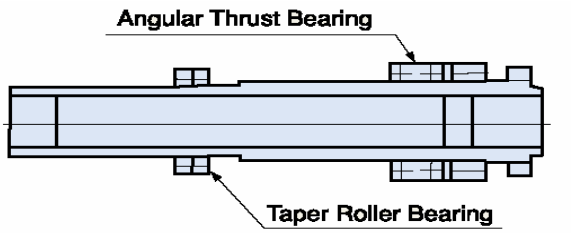


Fig 4: Z340 SM spindle

(a)

(b)

Fig 5: a) Modern spindle cutting specimen b) Conventional spindle cutting specimen

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