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Study on Spindle System Static and Dynamic Characteristic in Grinding Head Based on Finite Element Analysis

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Abstract: With the spindle system of M8400A type roll grinding machine as the object of the research. On the basis of the establishment of the three-dimensional solid model of the roll grinder grinding head spindle system, carry out finite element static analysis, with the spindle structural stress and strain diagram, study its static characteristics, carry out modal analysis in the properly simplified spindle system with the finite element method, analyze the calculated natural frequency value, study dynamic characteristics of the spindle system, lay the foundation for the realization of the dynamic design of product.

Key words: Roller grinding machine, static and dynamic analysis, finite analysis

INTRODUCTION

Roll grinder is an in dispensable important production equipment and with the improvement of product quality requirements, the precision of roll grinders is increasing (Yin *et al*., 2005). In order to ensure good static and dynamic stiffness, dynamic characteristics, stability, processing technology of the roll grinder, need to adopt modern design methods to achieve the dynamic design of the structure and improve performance. The spindle system static and dynamic performance directly affects the roll grinder comprehensive performance and the roll machining accuracy and surface quality (Wu *et al*., 2012). With M84100A type roll grinding machine spindle system as the research object, by the study of the structure and performance of the roll grinding machine spindle system, lay the foundation for the realization of the dynamic design of the product.

FINITE ELEMENT METHOD

The established finite element model has a direct impact on the later analysis of the calculation accuracy and computational speed (Rehorn *et al*., 2004). The finite element model can be directly modeled in finite element analysis software,the other 3D solid modeling software can also be used to establish a three-dimensional solid model of the Spindle system, then import into finite element analysis software. The latter method (Ast *et al*., 2009) is used in this article, create three-dimensional model in Pro/E software. The establish finite element model of the spindle is depicted at Fig 1.

SPINDLE FINITE ELEMENT MESH DIVISION

In accordance with the requirements of the above model analysis, the axis entity model use Solid92 unit (Fig. 2). The unit is the parameter space unit analog spindle unit for space 10 node, for simulating a three-dimensional solid element. The unit has the following characteristics: A second-order displacement model, able to adapt to the irregular grid, each node has three spatial degrees of freedom and the unit characteristics has plasticity, creep, large deformation and large tension (Wu *et al*., 2005). The inputted parameters is shown in Table 1.

Input parameters in the above table, the obtained spindle finite element meshes are shown in Fig. 3.

Table 1: Unit division inputted parameter

Parametric	Elastic modulus (N m)	Poisson's ratio	Density (kg m^{-3})	Grid level
Input values	2.06E+11	0.3	7850	6

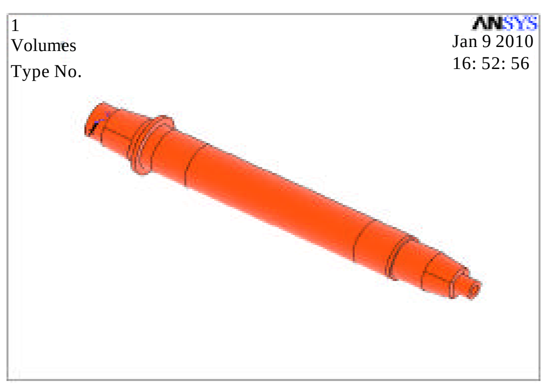

Fig. 1: Spindle finite element model diagram

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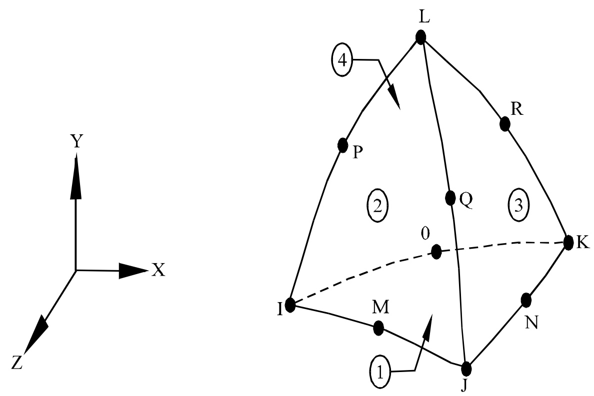

Fig. 2: Solid92 unit

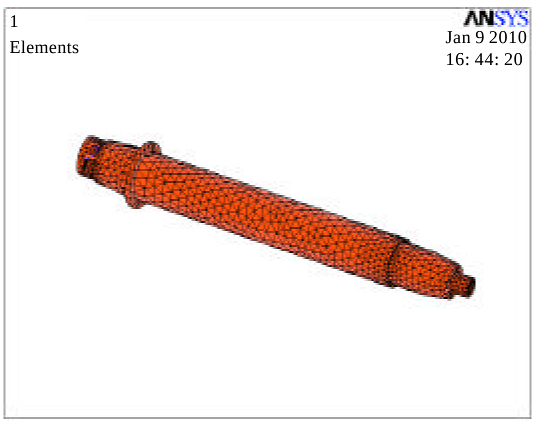

Fig. 3: Spindle finite element meshes

CALCULATED SPINDLE LOAD

The Force acting on the spindle is mainly composed of three parts: The tangential grinding force F_t which working wheel generate (Chen *et al.*, 2012), the grinding force F_n (1.6 to 1.8 times F_t) along the radial direction of the grinding wheel and the force F_p (finale Force) which the transmission belt act on the shaft:

- The calculation of the grinding force F_t

$$F_t = F_d a_p^{\alpha} f_a^{\beta} v_w^{\gamma} = 453\times0.05^{0.9}\times2.5^{0.62}\times40^{0.76} = 884(N) \quad (1)$$

- The calculation of the shaft force Fx and Fy which the belt act on

Since, the size of the shaft finale force F_p is 5750N (M84100A type), the force acting on shaft angle γ with the horizontal is 8°, therefore:

$$F_y = F_p \sin 8 = 5750\times\sin 8 = 800\ (N) \quad (2)$$

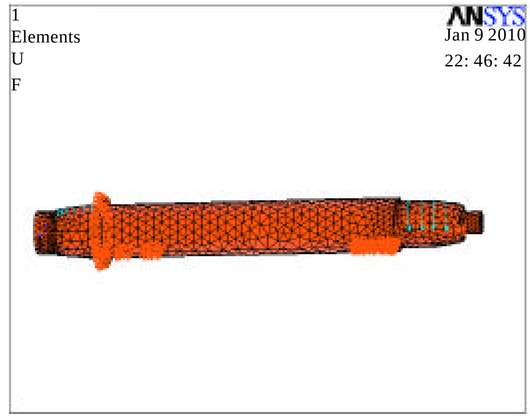

Fig. 4: Spindle limited load figure

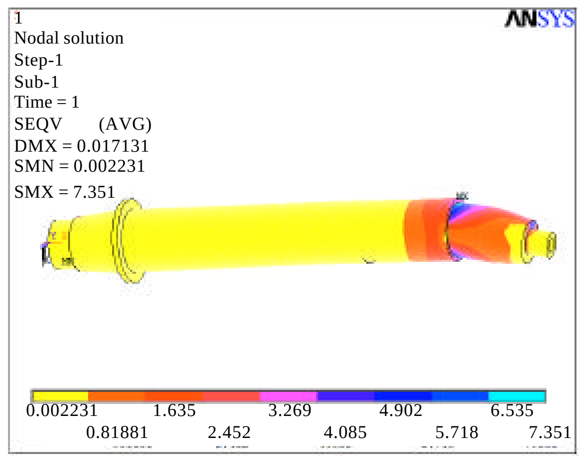

Fig. 5: Spindle finite element stress cloud

$$F_x = F_p \sin 8 = 5750\times\sin 8 = 5694\ (N) \quad (3)$$

ANALYSIS OF SPINDLE STATIC CHARACTER

According to the analysis of the actual situation can know. The radial support of the spindle is the surface support, the portion of the spindle coincides with the bearing surface is divided prior to the analysis and then apply constraints in a contact surface of the spindle and the bearing oil film (Zhi, 2012). The thrust portion of the sliding bearing is the spindle axial constraint. Figure 4 is the Spindle limited load Figure.

Strength analysis of the spindle is synthesized by bending and torsion strength to be checked. According to the above model diagram and the size and location of the force, calculate the spindle stress and deformation, the spindle finite element stress cloud is shown in Fig. 5.

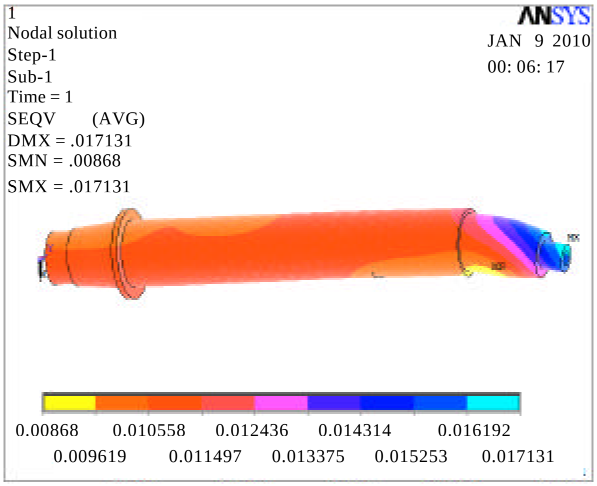

Fig. 6: Spindle finite element deformation

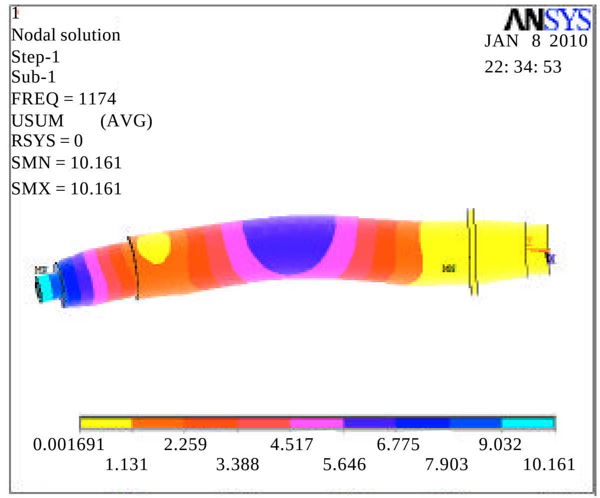

Fig. 7: Spindle first-order modal calculation

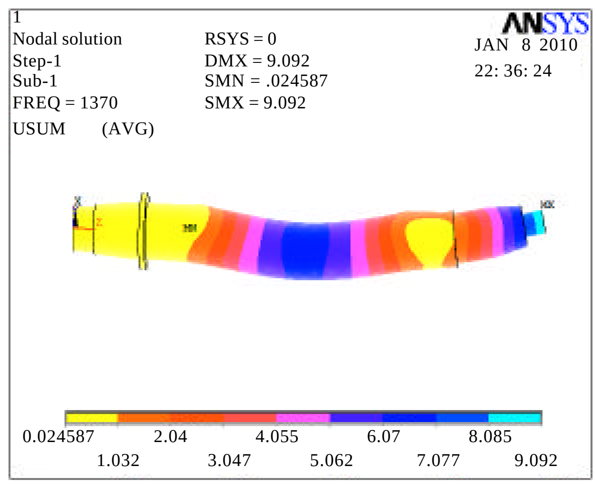

Fig. 8: Spindle second-order modal calculation

Through the analysis of Fig. 5, we can know the maximum spindle stress (bending and torsion synthesis) σ_{max} = 7.351 Mpa. The spindle allowed bending stress [σ] is about 198~~275 Mpa, σ_{max} <[σ], the strength of the spindle meet the design requirements and has a large margin of safety.

Bending and torsional deformation occurs in the roll grinder wheel spindle which have external loading. When these deformations excess the predetermined maximum, cause the roll grinder poor working conditions, affect the quality of the processing of the work piece and seriously the grinder is not working properly. So, the rigidity checking on the grinding wheel spindle is very necessary. According to the finite element model established above, the spindle finite element deformation is shown in Fig. 6.

Based on the finite element deformation diagram, the maximum deformation of the spindle are the minimum spindle pulley minimum journal on the input end, the maximum amount of deformation is f_{max} = 0.017131 mm<f_p.

Among them: The spindle allowable deflection f_p = (0.0002l) = 0.2132 mm. l is the length of major axis, l = 1066 mm.

After analysis, the bending stiffness of the spindle meet the design requirements and has a large margin of safety.

FINITE ELEMENT ANALYSIS OF SPINDLE DYNAMIC CHARACTERISTICS

Modal analysis: In this study, damped law is chosen based on the needs, the method is used for problem solving that the damping effect can not ignore, it is an effective method for solving the matrix eigenvalue problem. Need to be set in the following analysis of the process of load step options. The main steps of the modal analysis: Model, loaded and solving extended modal and results post-processing. The system will be handled in accordance with the linear unit, the only load is zero displacement load in modal analysis.

Modal analysis results: Figure 7 is the results of spindle first-order modal calculations, Fig. 8 is the results of spindle second-order modal calculations. From the figure, we can be seen that the first-order natural frequency of the spindle is 1174 Hz, the second-order natural frequency of the spindle is 1370 Hz. The first modal deformation performance is spindle bending

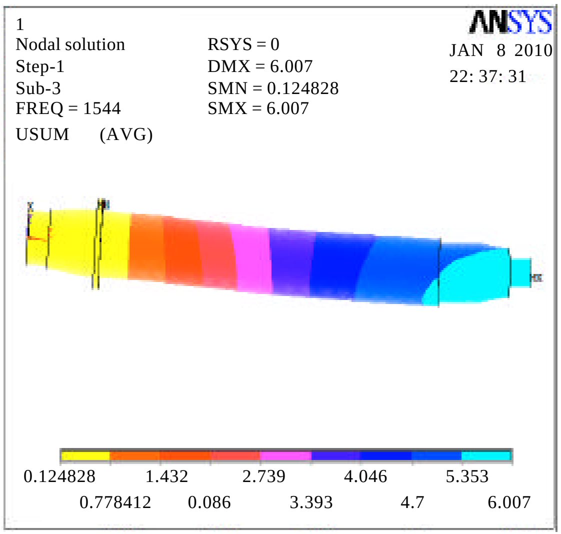

Fig. 9: Spindle third-order modal calculation

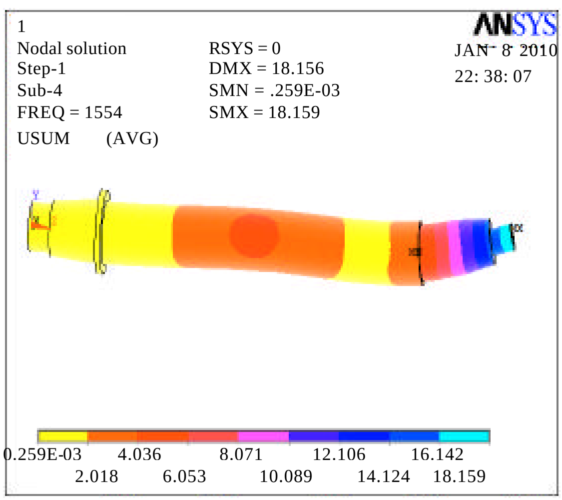

Fig. 10: Spindle fourth-order modal calculation

deformation, the second-order modal deformation performance the spindle other direction bending deformation.

Figure 9 is the results of spindle third-order modal calculations, Fig. 10 is the results of spindle fourth-order modal calculations. From the figure, we can be seen that the third-order natural frequency of the spindle is 1544 Hz, the fourth-order natural frequency of the spindle is 1554 Hz, then. The third-order modal natural frequency compared with fourth-order modal natural frequency, the difference is only 10 Hz.

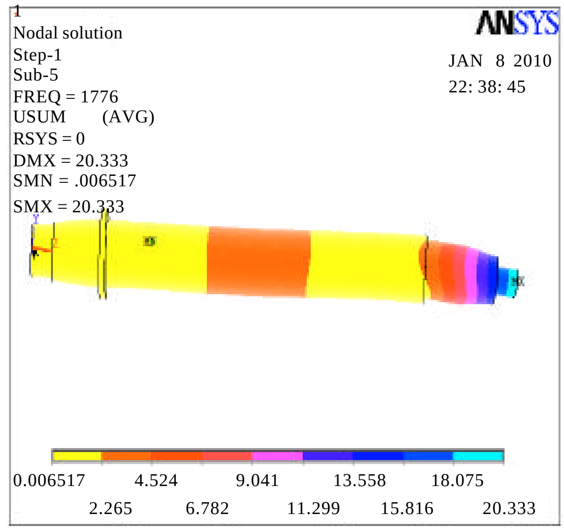

Fig. 11: Spindle fifth-order modal calculation

Figure 11 is the results of the spindle fifth-order modal conclusion, the natural frequency of the spindle is 1776 Hz.

HARMONIC RESPONSE CALCULATION RESULTS

Resonance affects the grinding quality and even causes damage to the grinder, it is important to study the dynamic response in kinetic analysis.

The harmonic response analysis is a linear analysis, this article uses the modal superposition method. the problems is similar to pay attention to modeling and modal analysis. During post-processing, the harmonic response analysis starts with POST26 to find critical forcing frequency (to generate maximum displacement or stress frequency (point of concern in the model) and then to deal with the entire model in these critical mandatory frequency using POST1, the results can to represent the color map, vector map and list. In the spindle harmonic response analysis process, the exciting force is applied on the wheel and the spindle position coinciding, defined as the wheel point., the exciting force size is 1400 N, the direction is UX, the frequency range is from 0-3000 Hz, calculate the response in the first order natural frequency, calculation are shown in Fig. 12.

It can be seen that the maximum displacement of the spindle in the vicinity of the operating frequency is 1.5 μm, Resonance generates near the first order frequency, the maximum resonance displacement is 1.5 μm, the minimum dynamic stiffness: 1400/1.5 = 933N μm.

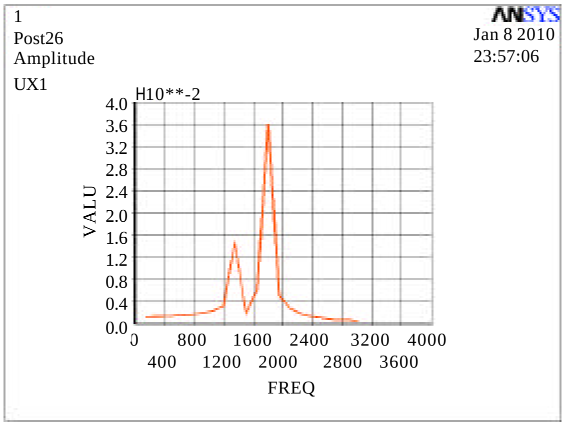

Fig. 12: Amplitude-frequency curve of spindle wheel point response

CONCLUSION

In this study, the finite analysis method is applied in the modal analysis of the spindle system, while use finite element software ANSYS for the spindle system static analysis, modal analysis and harmonic response analysis:

- Get he natural frequency of the spindle, the first order frequency 1174 Hz. The result is away from the working frequency. So, the operating speed is safe
- The spindle unit static analysis and harmonic response analysis are carried using ANSYS, analysis spindle strength and stiffness, the result show that the strength and stiffness has a large margin, the further optimization can be done. Get the harmonic response near the spindle order frequency and maximum dynamic displacement of the spindle, proved that the design is safe and reliable

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