

Finite element analysis on mechanical properties of 120 billet tension leveler

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Abstract. To analyze and solve deformation, cracking and other problems of tension leveler working rolls, a three-dimensional model of a working roll is established with the ANSYS software, and static finite element analysis and modal analysis are conducted on this basis. The results show that the maximum stress is concentrated on shaft shoulders on both ends of the working roll, the maximum deformation occurs at the body of the working roll, and both the strength and stiffness meet the requirements; the natural frequency of the working roll is larger than the operating frequency of the tension leveler, and no resonance is caused when the tension leveler is in normal operation. Finite element analysis on mechanical properties of the tension leveler offers important guidance for the design and operation of tension levelers.

1. Introduction

As important core equipment of arc caster, tension leveler is located behind the crystallizer and mainly compresses and processes casting billets in the operating line of continuous caster, namely withdrawing and straightening the dummy bar and solidified casting billets. A steel company put a set of six-machine six-flow full-arc small-billet multi-point straightening continuous caster into operation in 2003 with a casting arc radius of 6m and billet section size of 120mm×120mm. The caster has a design capacity matching the production of three 90-ton converters and can provide downstream wires and steel pipes with high-quality flawless casting billets[1]. Ever since the 120 billet tension leveler was put into operation, production technique accidents and quality accidents frequently occurred in operation, and internal cracks and other phenomena occasionally occurred. Since the tension leveler is long working in the high-temperature and dusty environment in the process of continuous casting, and affected by its own vibration, fatigue, heating and other factors, the working roll of the tension leveler may easily deform, crack, etc., which not only seriously affect the service life of the tension leveler, but also greatly reduce the production efficiency of the entire continuous casting production line, and therefore cause serious economic losses to the plant[2]. With the tension leveler working roll as the research object, this paper mainly conducts static analysis and modal analysis on the working roll, which has important practical significance for extending the service life of the tension leveler, reducing production costs, etc.

2. Main Technical Parameters

The 120 tension leveler is a small billet tension leveler, which, according to different sizes of billets, adjusts the differences between rolls through up-and-down movement of the hydraulic cylinder piston rod and compresses billets, thus realizing withdrawal and straightening of billets. Its withdrawal and straightening speed is 1~5m/min, four working rolls are driven by a DC motor (speed regulation)



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through chain transmission, and the leveler is equipped with a set of hydraulic cylinder adjusting device. The leveler mainly processes billets with a section size of 120mm×120mm and different lengths within the range of 4m~12m[3]. It has a large volume with much space occupied and complex structure, its weight is about 2.5 tons, the 120 tension leveler is shown in Fig.1.



Figure 1. 120 tension leveler

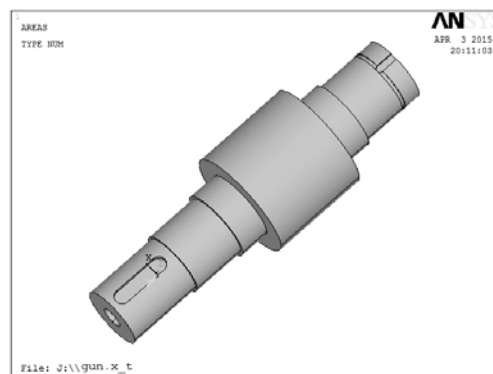


Figure 2. Finite element model of the working roll

3. Finite Element Modeling and Result Analysis

A three-dimensional solid model of the working roll of 120 tension leveler is established with SolidWorks software, and then the established three-dimensional model is imported into ANSYS and transformed into a finite element model[4]. Due to some small structural parts and small characteristics, including bosses, holes, fillets, chamfers, etc, a large number of small finite element units will be generated in the finite element mesh generation, which will greatly increase the amount of calculation and reduce the mesh quality and accuracy of structural analysis, thus reducing the operating efficiency[5]. Therefore, before the model of SolidWorks is imported into ANSYS, the model is appropriately simplified[6]. The three-dimensional model of the working roll imported into ANSYS is shown in Fig.2.

The main material of the working roll is 30CrMo steel, which has high thermal fatigue strength and therefore can meet the operating requirements of the tension leveler at high temperature. Its material property parameters include elastic modulus EX2.06e11 (Pa), Poisson's ratio PRXY0.3, density 7900 (kg/m³) and yield strength 785 (MPa) [7].

Units are generated in the way of smart mesh generation. The accuracy level is set as 4 by Smartsizes, then the meshes are refined, and finally the mesh model of the working roll is established. A total of 240,947 units and 46,095 nodes are obtained from the mesh generation.

Billet withdrawal forces of the tension leveler mainly include the crystallizer resistance, secondary cooling device resistance, straightening resistance, friction resistance and other resistances [8]. It is obtained by calculation that the total pressure on the billet is 179,178.6N, namely the external load applied to the working roll. When the tension leveler withdraws and straightens a billet, minor face

contact exists between the working roll and the billet, and such minor face contact can be regarded as line contact, which is equivalent to applying the load to the roll line of the working roll. Because the section size of the billet is 120mm×120mm, the same length as the width of the billet is extracted on the roll line of the working roll, and external load is applied to all the nodes on this length. Applying the boundary constraints is one of the most important steps throughout the analysis. In the 120 tension leveler, the working roll is fixed on the frame supported by two bearings on the front and back. According to this motion characteristic of the working roll, full constraints are applied to the position of bearings on the front and back of the working roll.

After static calculation of the working roll, the equivalent stress figure and equivalent strain displacement fringe of the working roll are obtained, which are respectively shown in Fig.3 and Fig.4.

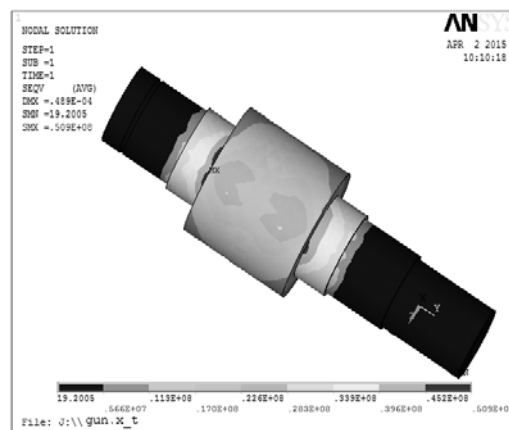


Figure 3. Equivalent stress

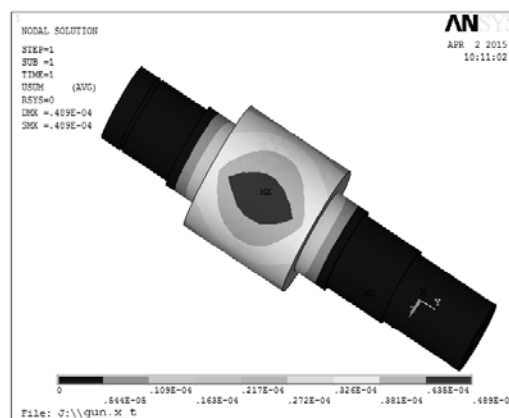



Figure 4. Displacement fringe

It can be directly seen from Fig.3 that the maximum stress occurs on shaft shoulders on both ends of the working roll, the maximum stress is 50.9MPa, and the maximum stress is below the allowable stress and meets the requirement of strength; it can be seen from Fig.4 that the maximum deformation occurs at the body of the working roll, the maximum deformation is 0.0489mm, and the maximum deformation is within the range of allowable elastic material deformation and meets the requirement of stiffness.

4. Modal Analysis

For the reason that both the direction and magnitude of load on the working roll are periodically changing during the operation process of the working roll, resonance will be caused if the natural frequency of the working roll is the same as the forced vibration frequency, which will directly affect the withdrawal and straightening quality of the tension leveler [9]. Block Lanczos is adopted as the

extraction method of modal analysis on the working roll[10]. In the 120 tension leveler, the working roll is fixed on the frame supported by two bearings on the front and back. According to this motion characteristic of the working roll, full constraints are applied to the position of bearings on the front and back of the working roll, the face constraint is selected, and then Solve-Current LS is selected for modal solution. Based on modal analysis and calculation, the natural frequencies of the working roll and vibration mode figures are obtained, which are respectively shown in Fig.5 and Fig.6.

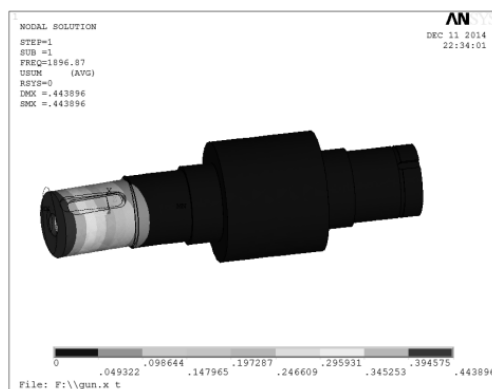

 SET,LIST Command

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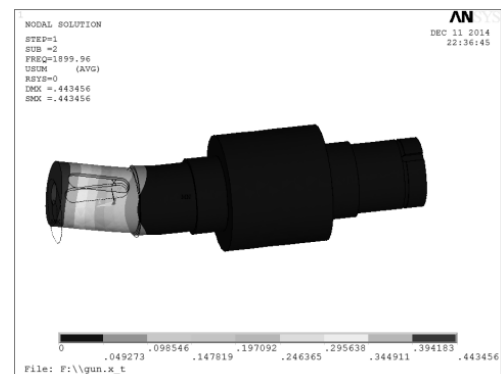
***** INDEX OF DATA SETS ON RESULTS FILE *****

SET	TIME/FREQ	LOAD STEP	SUBSTEP
CUMULATIVE			
1	1896.9	1	1
2	1900.0	1	2
3	2584.2	1	3
4	3227.3	1	4
5	3233.2	1	5
6	3938.6	1	6
7	4763.1	1	7
8	5212.4	1	8
9	5241.6	1	9
10	5848.8	1	10

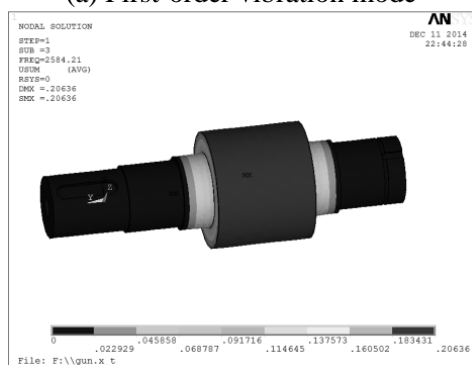
Figure 5. Natural frequencies of first ten order vibration modes



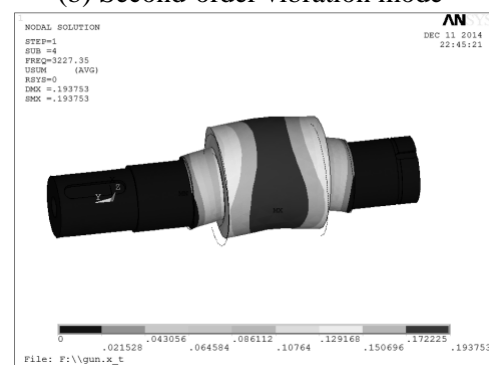
(a) First-order vibration mode



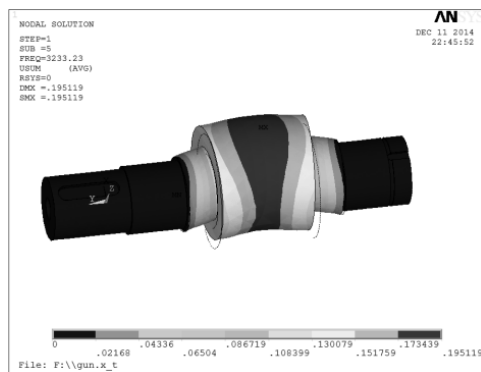
(b) Second-order vibration mode



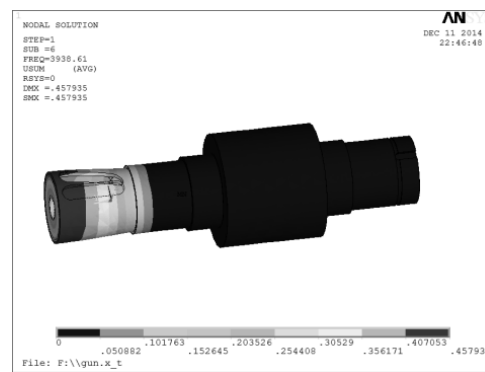
(c) Third-order vibration mode



(d) Fourth-order vibration mode



(e) Fifth-order vibration mode



(f) Sixth-order vibration mode

Figure 6. First six order vibration modes**Table 1.** Vibration frequencies and vibration mode characteristics of first six orders

Modal Order	Frequency (Hz)	Maximum displacement (mm)	Position of maximum displacement	Vibration mode characteristics
1	1896.9	443.896	Front end of the working roll	Swinging on the XOZ plane
2	1900.0	443.456	Front end of the working roll	Swinging on the YOZ plane
3	2584.2	206.36	Body of the working roll	Modal rotation
4	3227.3	193.753	Middle of the body	Overall bending deformation
5	3233.2	195.119	Middle of the body	Overall bending deformation
6	3938.6	457.935	Front end of the working roll	Expanding deformation

As can be seen from the vibration modes in Fig. 6 and vibration mode characteristics in Tab.1, the range of first ten order natural frequencies of the working roll is 1800~4000Hz, which is obviously high and indicates that the structure of the working roll is fairly stable since the issue of resonance is considered in design. For the first six order vibration modes, the natural frequency of the working roll in the first-order vibration mode is 1896.9Hz, which is much higher than the maximum operating frequency of the tension leveler, so no resonance will be caused. In the figure of first-order vibration mode, the working roll swings upward along the XOY plane, the maximum deformation occurs at the front end of the working roll, and the maximum deformation is 443.896mm.

In the figure of second-order vibration mode, the working roll mainly swings upward along the YOZ plane, the maximum deformation occurs at the front end of the working roll, the maximum deformation is 443.456mm, and almost no changes can be seen at other parts of the working roll.

The natural frequency of third-order vibration mode is 2584.2Hz, and the working roll is in a rotation mode without large deformation in the vibration mode figure. The maximum deformation occurs at the body of the working roll, and the maximum deformation is 206.36mm.

The natural frequency of fourth-order vibration mode is 3227.3Hz. As can be seen from the figure of fourth-order vibration mode, the body of the working roll bends and deforms along the X direction, the maximum deformation occurs below the middle of the body, and the maximum deformation is 193.753mm.

In the figure of fifth-order vibration mode, the body of the working roll bends and deforms along the X direction with a natural frequency of 365.79Hz, the maximum deformation occurs above the

middle of the body, and the maximum deformation is 195.119mm.

The natural frequency of sixth-order vibration mode is 3938.6Hz, expanding deformation occurs at the front end of the working roll in the vibration mode figure, and the maximum deformation is 457.935mm. Connected to the chain wheel by keys, the front end of the working roll shall not only bear large weight of the chain wheel, but also bear large torque, so its strength shall be emphasized to prevent resonance caused by distance swinging.

5. Conclusions

(1) This paper establishes a three-dimensional model of 120 tension leveler working roll with SolidWorks software, which is then imported to ANSYS and transformed into a finite element model. Based on static analysis, the maximum stress is concentrated on shaft shoulders on both ends of the working roll, and the maximum stress is 50.9MPa; the maximum deformation occurs at the body of the working roll, and the maximum deformation is 0.0489mm. The maximum stress of the working roll is within the range of allowable yield limits and meets the requirement of strength; the maximum deformation is within the range of allowable elastic material deformation and meets the requirement of stiffness.

(2) This paper conducts modal analysis on a working roll of the 120 tension leveler with ANSYS software, obtains the natural frequencies and vibration mode characteristics of the working roll and develops a detailed analysis. The natural frequencies of the working roll are larger than the operating frequencies of the working roll, and no resonance would be caused in normal operation of the tension leveler. In addition, by analyzing the vibration mode characteristics of the working roll, weak positions under low-order frequencies are discovered, thus providing theoretical reference for effectively avoiding the resonance region in the future.

References

- [1] Baoheng Liu. Design and Implementation of 150×150 Billet Caster Computer Control System [D]. Shenyang: Northeastern University, 2008.
- [2] Xi Wang, Bing Han, Shi Chen. Analysis and solution to increase the service life of tension leveler[J]. Metallurgical Equipment.2005:149
- [3] Shulin Chen, Anguo Fan, Chaixue Wang. Application of Length and Weight Cutting System in Small Billet Caster [J]. Casting. 2007(4): 34-36.
- [4] HuiPeng Li, JanQiang Zhang,XiaoHong Sang. Application of Soldworks Software in Mechanical Processing[J]. Aerospace Manufacturing Technology. 2011(1): 61-63
- [5] Wensheng Li. The Generation of Quadrilateral Mesh Based on Face Clustering [D]. Dalian: Dalian University of Technology, 2005.
- [6] Junyong Zhan, Jianmin Huang. ANSYS Parametric Modeling Realized by Solidworks Import [J]. MW Metal Cutting. 2010(4): 71-72.
- [7] DaTong Qin, LiYang Xie. Modern Mechanical Design Manual [M]. Beijing: Chemical Industry Press.2011
- [8] Zhiling Zeng. Thermal-Structural Stress Analysis of A New Continuous Caster Pulling-Straightening Roller [D]. Changsha: Central South University (2008).
- [9] Bailin Rui. Control Optimization of 2130 Pickling and Rolling Line Tension Leveler [J]. Journal of Anhui Vocational College of Metallurgy and Technology. 2012(2): 28-30.
- [10] FanPing Deng.Self-study manual of ANSYS12.0 finite element analysis [M]. Beijing. People's Posts and Telecommunications Press, 2011.