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Finite element error analysis on transmission shaft parts and application of local mesh refinement

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Abstract—In view of the strength problem of the transmission shaft parts in the swinging and punching structure of the forging press, based on the finite element analysis theory and the mesh refinement method, the accuracy of the finite element calculation in the whole mesh refinement process is analyzed by comparing the element strain energy error and the energy percentage error of different node numbers. The results show that the edge length of the discretized element is reduced and the calculation accuracy is improved correspondingly, but the calculation amount of the whole mesh refinement is large.Therefore, local mesh refinement is applied to improve the calculation accuracy. The results show that the error of energy percentage tends to be 10%, and the calculation accuracy is high. The accuracy analysis method and the application of local grid refinement provide the theoretical basis for the structural optimization of mechanical products.

1. INTRODUCTION

The transmission shaft is mainly used to transmit torque in the working process. It is the main transmission part in the auxiliary punching structure of hydraulic press (swing punching structure is shown in Fig 1). Its mechanical properties directly determine the torque output. The transmission shaft not only transmits the power, but also transmits the torque fluctuation generated by the hydraulic motor to the subsequent structural system, which results in the torsional shear stress and strain of the transmission system, resulting in certain torsional deformation. It has a great influence on the stability and safety of the swing process.

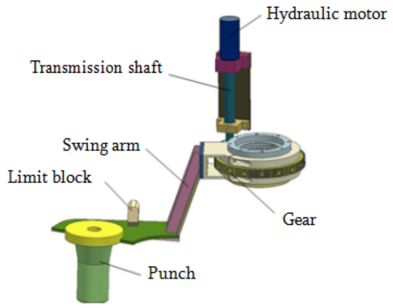

Figure 1 Swinging structure diagram

2. Finite element calculation error analysis of transmission shaft

2.1. Analysis of stress calculation results when the side length of element is 6.0mm

The length of cell side is 6.0mm, and the axis is meshed. After discretization, the total number of nodes is 87498, and the total number of cells is 59683. Through connection analysis, boundary constraints are applied in radial, axial and circumferential directions, and finite element analysis is carried out for the transmission shaft parts. The partial distribution of the joint equivalent stress keyway is shown in Fig 2, and the element equivalent stress distribution is shown in Fig 3. It can be seen that the maximum joint equivalent stress is 21.7mpa and the maximum element equivalent stress is 24.0mpa.

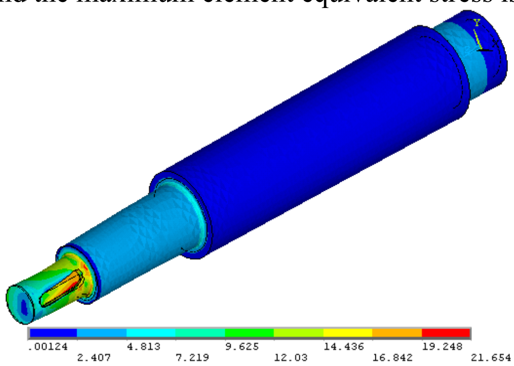

Figure 2. Stress nephogram of nodes

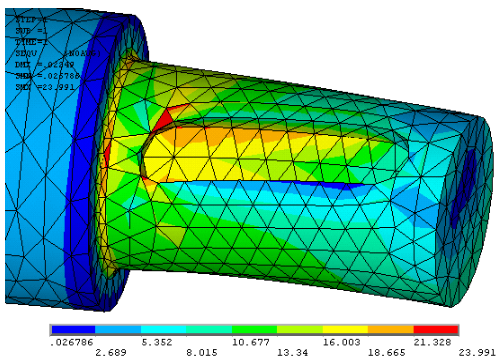

Figure 3. Stress nephogram of element

The maximum joint stress difference of the element is shown in Figure 4. The maximum joint stress difference is located at the outer edge of the keyway. The absolute value of the maximum joint stress difference is 13.3mpa. The stress error of the element is the maximum value of the difference between the six stress component values of all nodes on the element and the average stress value of the node, which reflects the grid discrete stress error of a certain position[1]. It can be seen from Fig. 2 and Fig. 3 that the element stress is discontinuous, which is the error caused by the displacement finite element method. Even though the stress appears to be continuous when it is displayed as a node by averaging, this error still exists[2]. The larger the difference of stress calculation values of the same node in different elements, the larger the error of structural calculation. Therefore, the difference of stress calculation values of the same node in different elements reflects the structural calculation error from one aspect[3].

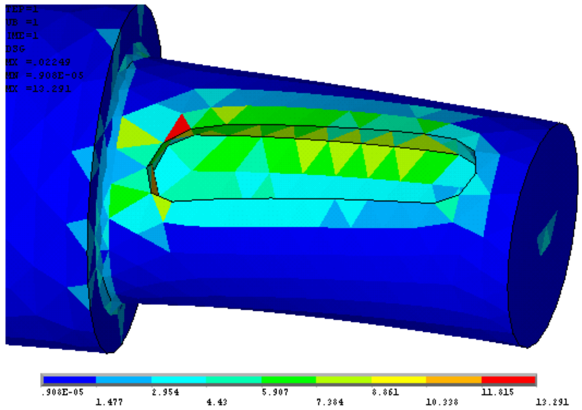

Figure 4. Maximum joint stress difference

The error of strain energy of element is shown in Fig 5, and the maximum error of strain energy of element is 0.007.

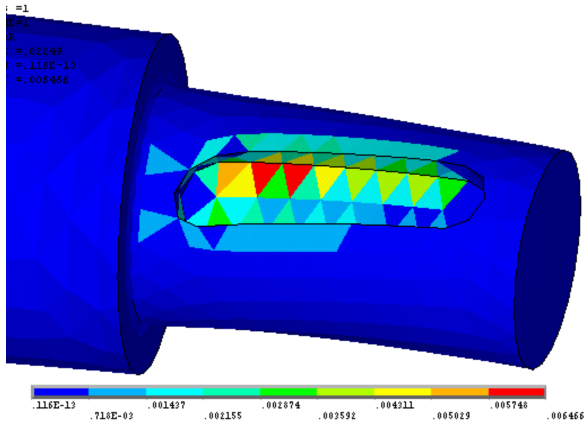

Figure 5. Strain energy error of element

At this time, the error of energy percentage is 14.363%. The energy percentage error is the approximate value of the grid discretization error related to the finite element solution. The larger its value is, the larger the grid discretization error is[4]. The error of energy percentage can be calculated according to the following formula

$$E = 100\sqrt{\left(\frac{e}{U+e}\right)} \quad (1)$$

in the formula, is $U=\sum_{i=1}^{M}E_{ei}^{po}$ the strain energy of the whole model, E_{ei}^{po} is the strain energy of element i; e is the energy error of the whole model,it is the sum of strain energy errors of all elements.

2.2. Analysis of stress calculation results when the side length of element is 5.5mm

The edge length of the cell is 5.5mm, the total number of nodes after discretization is 103660, and the total number of cells is 71183. According to the same boundary conditions, the finite element analysis of the transmission shaft parts is carried out. The local layout of the joint equivalent stress keyway and the local layout of the element equivalent stress keyway are shown in Fig 6 and Fig 7 respectively. It can be seen that the maximum joint equivalent stress is 22.246mpa, and the maximum element equivalent stress is 24.619mpa.

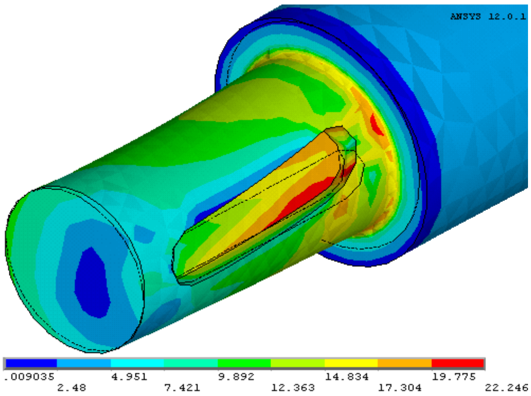

Figure 6. Stress nephogram of nodes

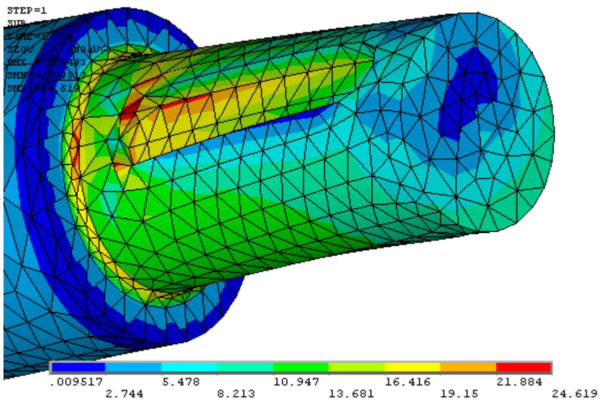

Figure 7. Stress nephogram of element

As shown in Fig 8, the maximum joint stress difference is located at the outer edge of the keyway, and the absolute value of the maximum joint stress difference is 15.25mpa. The maximum error of structural strain energy is 0.006. The error distribution of structural strain energy is shown in Fig 9. At this time, the percentage of energy error is 14.159%.

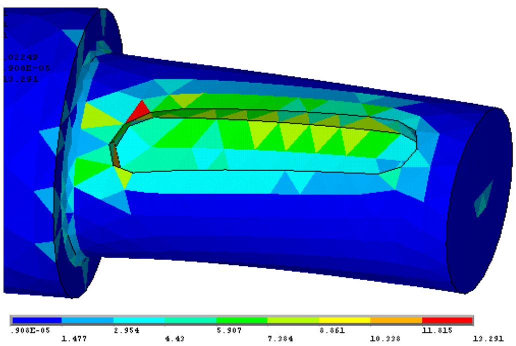

Figure 8. Maximum joint stress difference

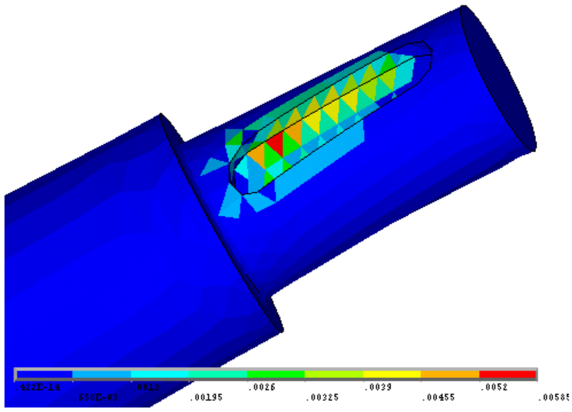

Figure 9. Strain energy error of element

2.3. Analysis of stress calculation results when the side length of element is 5.0mm

The cell side length is 5.0mm, the total number of nodes after discretization is 133352, and the total number of cells is 92200. According to the same boundary conditions, the finite element analysis of the transmission shaft parts is carried out. The partial layout of the joint equivalent stress keyway is shown in Fig 10, and the partial layout of the element equivalent stress keyway is shown in Fig 11. It can be seen that the maximum joint equivalent stress is 24.245mpa and the maximum element equivalent stress is 24.613mpa.

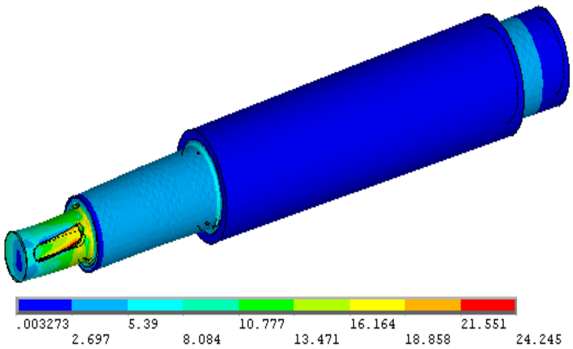

Figure 10. Stress nephogram of nodes

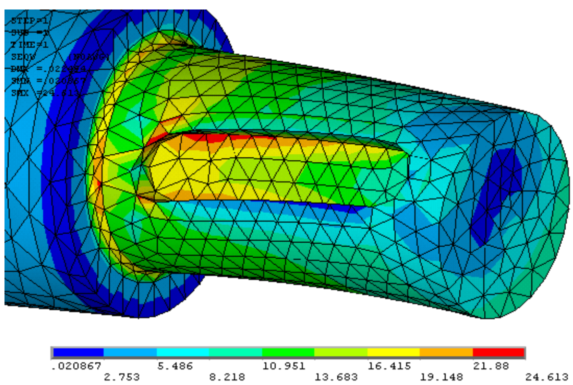

Figure 11. Stress nephogram of element

As shown in Fig 12, the maximum joint stress difference is located at the outer edge of the keyway, and the absolute value of the maximum joint stress difference is 11.215mpa. The maximum error of structural strain energy is 0.004. The error distribution of structural strain energy is shown in Fig 13. At this time, the percentage of energy error is 13.2%.

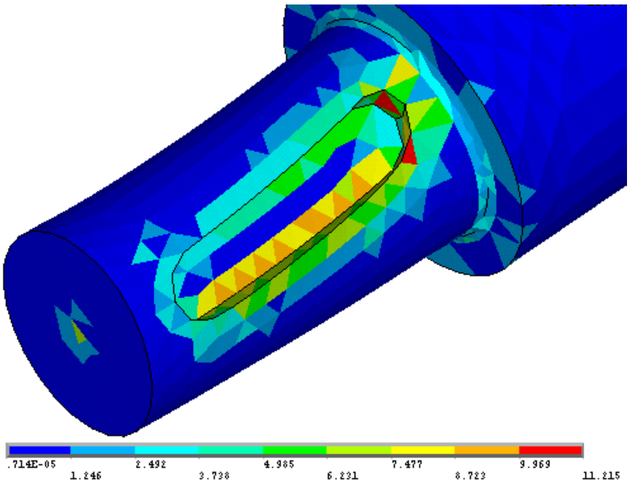

Figure 12. Maximum joint stress difference

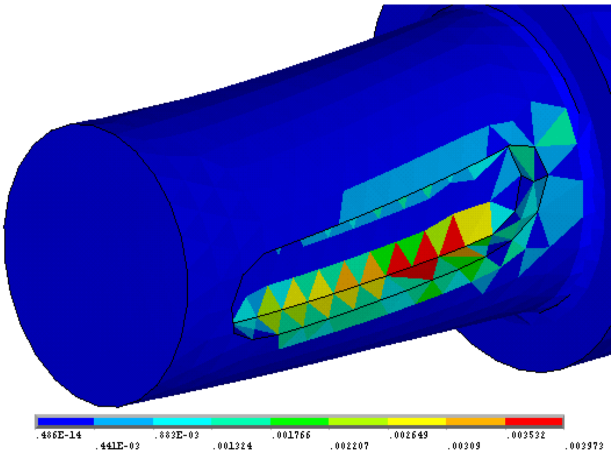

Figure 13. Strain energy error of element

The comparison of the above three analysis results is shown in Table 1.

TABLE 1. ANALYSIS RESULTS UNDER THREE SIDE LENGTHS

Unit side length (mm) **Parameter**	**6.0**	**5.5**	**5.0**
Total number of nodes	87498	103660	133352
otal number of units	59683	71183	92200
Maximum joint stress (MPa)	21.654	22.246	24.245
Maximum unit stress (MPa)	23.991	24.619	24.613
Maximum joint stress difference (MPa)	13.291	15.242	11.215
Element strain energy error	0.007	0.006	0.004
Energy error percentage (%)	14.363	14.159	13.200

It can be seen from the above analysis that with the decrease of cell side length in discretization, that is to say, the number of divided cells increases, the error of strain energy decreases gradually, and the error of energy percentage also decreases gradually[5].

When the grid is divided by homogenization method, the cell side length is reduced from 6.0mm to 5.0mm, the cell number is increased from 59683 to 92200, the node number is increased from 87498 to 133352, the node stress and cell stress are increased by 2.591mpa and 0.622mpa respectively, while the energy percentage error is reduced from 14.363% to 13.2%. Because the maximum stress of the transmission shaft is located at the bottom of both sides of the keyway, it is not effective to reduce the energy percentage error by using the method of uniform mesh encryption. So we should refine the local grid to improve the calculation accuracy.

3. FINITE ELEMENT ANALYSIS OF LOCAL MESH REFINEMENT

From the previous analysis and calculation, it is known that the maximum stress of the transmission shaft is located at the bottom of the two working sides of the keyway, so the unit side length is 6.0mm, the transmission shaft is divided into uniform grids, and then the local grids of the transmission shaft keyway are refined according to the level 2 precision[6-7]. 83434 local nodes and 59668 cells are added for keyway mesh refinement. The total number of nodes is 170932 and the total number of cells is 119351. The processed finite element model is shown in Fig 14. See Fig 15 for the cloud chart of equivalent force of local nodes of keyway[8].

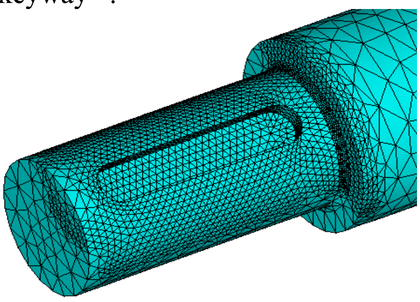

Figure 14. Finite element model

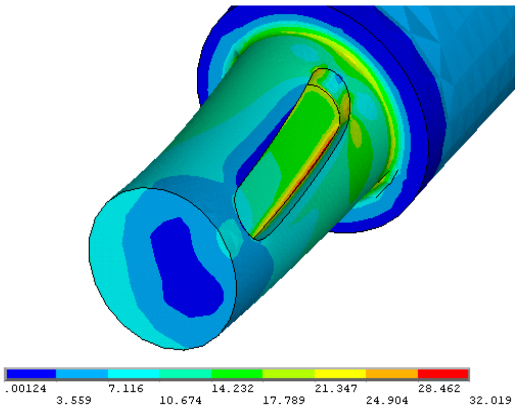

Figure 15. Cloud chart of equivalent force of local nodes in keyway

It can be seen from the figure that the maximum equivalent stress is 32.1mpa. The error of energy percentage is 10.031%, close to 10%. Basically meet the requirements of engineering accuracy.

4. CONCLUSION

Comparing element stress with node stress, the accuracy of finite element analysis results of transmission shaft parts is analyzed by calculating the error of energy percentage. Finally, the local mesh refinement method is used to analyze and check the equivalent force more accurately.

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