DOI: 10.13434/j.cnki.1007-4546.2014.0407

The Influence of the Straightening Velocity on the Evolution of Heavy Rail Roller Straightening Stress

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Abstract: It has established the FEM model of nine roller horizontal straightening for 60 kg/m heavy rail, and simulated the straightening process by using ANSYS Workbench. The comparative analysis of residual stress after straightening with the reference of the straightening speed at 1.2 m/s was done, which was found that the conclusion that the residual stress of straightening effects with straightening velocity range fom 1.4 m/s to 1.6 m/s can satisfy the requirement on the scene. A further comparative analysis of the state and distribution of the stress during straightening process was also done, and there was a comprehensive result on the influence with the change of the straightening velocity in heavy rail straightening stress at the same time. Thus it is really an important reference value on the set of the straightening velocity on the scene.

Key words: rail; deformation; velocity; stress; finite element method

1 Introduction

High-speed rail which is a necessary product with development of economy has an highly effective social and economic value on economically developed and densely populated areas. High-speed rail has become a common trend in the most of countries and areas all over the world by a series of technical advantages such as high speed, safety, running all day, confort, low consumption, less pollution and so on, but the quality and productivity restricts the development of heavy rail. As the last deformation process, Straightening has a decisive effect on residual stress and straightness of heavy rail. In heavy rail straightening production site, the setting of straightening velocity is just based on the experience, and what we now is the straightening velocity could and should be improved [2].

Internal residual stress as an important indicator decides the quality of heavy rail, and has significant effects on its safety use and fatigue life. Production at scenes are always take the longitudinal residual tensile stress should be under 250 MPa in the rail footas a criteria of heavy rail residual stress [3].

In this paper numerical simulation for the heavy rail straightening of 60 kg/m with velocity of 1.2 m/s(on site), 1.4 m/s and 1.6 m/s is made, the stress evolution during the straightening process with these three straightening velocity is compared and of the

Received 16 November 2014

The paper is supported by Natural Science Fundation of Inner Mongolia Autonomous Region(2012MS0717)

state and distribution of residual strees to judge whether the straightening effects meet the criteria is analyzed. The result could be as a reference in field production.

2 Modeling

Using a factory production data of nine roller horizontal straightening, the distance between straightening roller is 1600 mm, roller diameter is 1200 mm. The model is established by Pro/E, select 3500 mm as a length of model, straightening diagram shown in Figure 1, each straightening zone is consist of three rollers, there are seven straightening zones and seven reverse bendings. To get more practical results there is no simplification in the modeling of heavy rail cross-section, established FEM model shown in Figure 2.

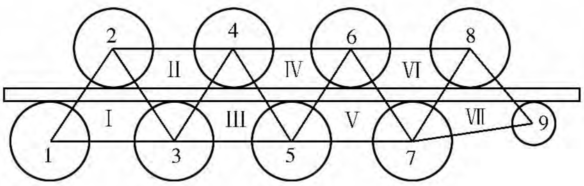

Figure 1 Schematic diagram of nine roller straightening schematic

Figure 2 Finite element model of heavy rail for horizontal straightening

The numerical simulation in this paper is based on ANSYS Workbench, calculating with LS-DYNA solver. The Roller is simplified as a ring and set as rigid body in the simulation of straightening process because its deformation is very small, thus the computational time can be greatly saved and computational efficiency is corresponding improved.

ANSYS Workbench will automatically give priority to use the highest element type as a principle. The roller and rail in this paper adopt the default allocated element type in order to improve accuracy. Since the straightening roller was set as a rigid body, therefore its tangent module and yield strength is not needed to input. Parameters of rollers are as follows: density $\rho = 7.9 \times 10^3$ kg/m^3, Young´s module $E = 210$ GPa, poisson´s ratio $\mu = 0.3$. The rail was set an a flexible body, a bilinear kinematic hardening model is selected. Parameters of the rail are as follows: density $\rho = 7.83 \times 10^3$ kg/m^3, Young´s module $E = 210$ GPa, Poisson´s ratio $\mu = 0.29$, tangent module $Y = 525$ MPa, yield strength $E_T = 1.18 \times 10^4$ MPa. The model mesh was divided into 7928 elements with 12 000 nodes, including 7040 elements and 9348 nodes in the mesh of heavy rail. The mesh of heavy rail cross-section is shown in Figure 3.

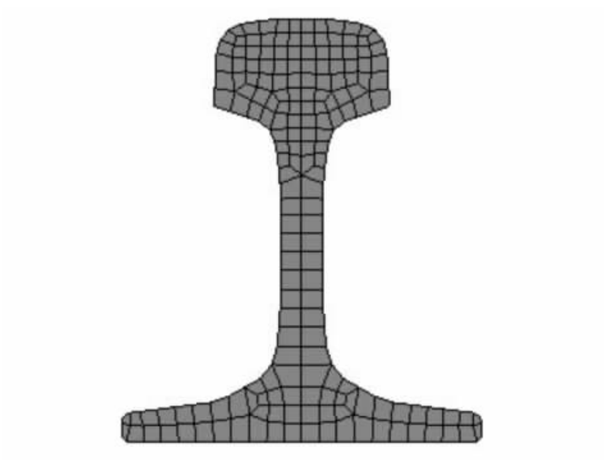

Figure 3 Heavy rail cross-section mesh

Heavy rail is given an initial velocity at the beginning of straightening process, and rollers keep rotation with a constant angular velocity, the rail goes forward rely on the friction between rollers in straightening process. In the simulation, the friction between rail and rollers is frictional contact, and friction coefficient is 0.14 [5].

3 Stress of the heavy rail during straightening

There is the straightening regulation which a factory is using on site, the reduction of 2nd roller, 4th roller, 6th roller and 8th roller is 19 mm, 11 mm, 7.5 mm and 3.5 mm. Now just change the velocity of heavy rail straightening and analyse its effect on the stress during straightening.

In the process of straightening, there exist a blind straightening zone which is two-thirds distance between rollers on the heavy rail both sides, so we firstly select the cross-section which is 1750 mm away from the entrance of heavy rail as the object in the study. The residual stress with the straightening velocity of 1.2 m/s which is used in field production is shown in Figure 4.

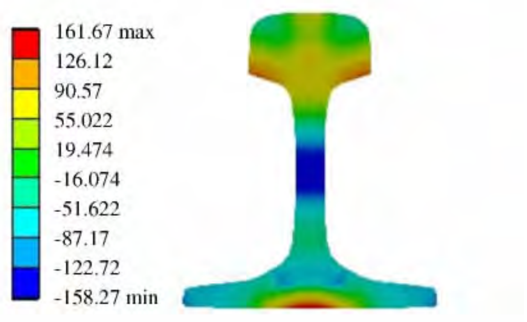

Figure 4 Longitudinal residual stress distribution of heavy rail section after straightening

3.1 Longitudinal residual stress of the heavy rail

With the increasing of straightening velocity, as a result, resistance of deformation is often improved with the increasing of deformation velocity, thus in the case of other conditions unchanged, straightening velocity increased to a certain degree will not be able to guarantee the straightening effects of heavy rail [2]. There is no theoretical calculation method in the setting of straightening velocity so far, and the straightening velocity is always set with experience, thus it is possible to find a reasonable range of straightening velocity setting by means of the simulation.

Firstly, the symmetrical line of the cross-section is defined as a path, and the distribution and magnitude of longitudinal residual stress in this path with four different straightening velocity shown in Figure 5. As seen from this figure, residual stress in the head and foot of the rail is with tensile stress, and the residual stress distribution in the path are C-shaped, that is, the state of stress varies in tension-compression-tension, this is consistent with the actual measurement in production site, and the distribution of residual stress from simulation coincides with field measurement, thus proving the reliability of results.

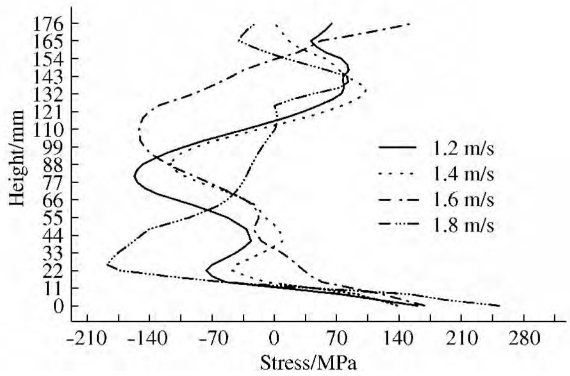

Figure 5 The longitudinal residual stress of heavy rail

From the view of distribution and magnitude of residual stress, the straightening effects with the velocity of 1.2 m/s, 1.4 m/s and 1.6 m/s are satisfactory. The straightening residual tensile stress in the rail foot is 253.4 MPa exceeds the standard 250 MPa with straightening velocity of 1.8 m/s, its longitudinal residual stress can not meet the criteria that´ s a reason that it can not guarantee the straightening effect in field production.

3.2 Longitudinal stress during the process of straightening

Figure 6 shows that at 1st straightening zone, that is when the cross-section is passing the second roller, the longitudinal stress from rail head to foot with three straightening velocity varies gradually from compressive stress to tensile stress, the change trend is identical and smooth.

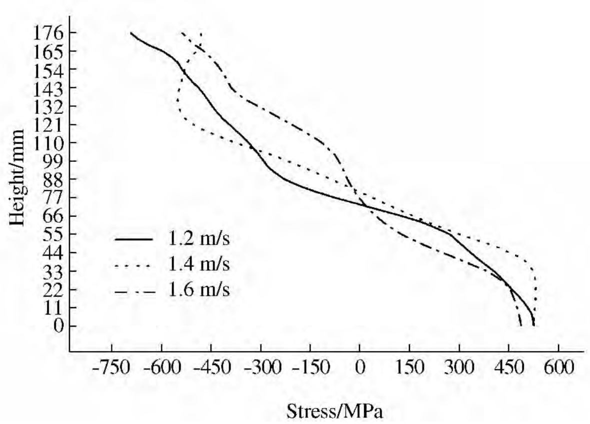

Figure 6 The longitudinal stress in the 1st straightening zone

Figure 7 shows the longitudinal stress distribution of heavy rail at 2nd straightening zone (the section is passing the third roller) from rail head to foot varies from tensile stress to compressive stress. Asseen from the figure, these three stress curves are substantially coincide.

The heavy rail longitudinal stress at 3rd straightening zone shown in Figure 8, from the rail head to rail bottom, the stress varies from compressive stress to tensile stress, and the distribution curves of the stress with these three different straightening velocity have good linearity. The range of stress with the velocity of 1.2 m/s is smaller than other two curves.

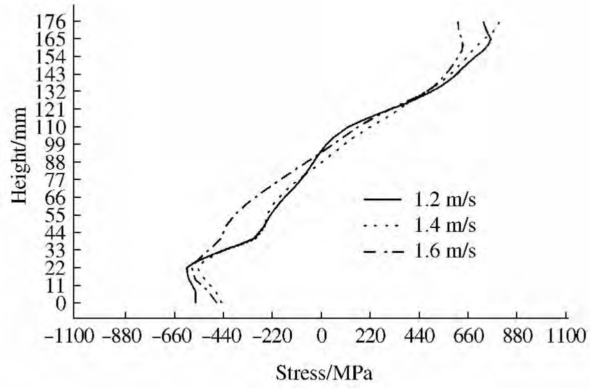

Figure 7 The longitudinal stress in the 2nd straightening zone

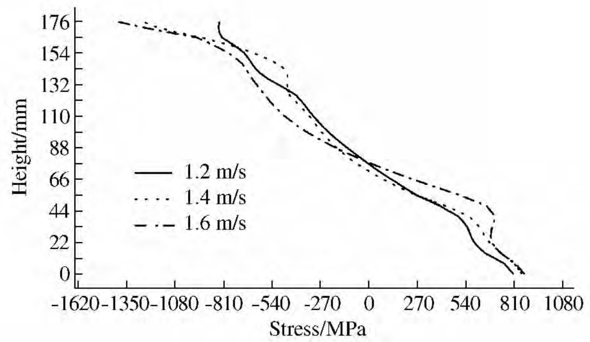

Figure 8 The longitudinal stress in the 3rd straightening zone

At the 4th straightening zone, the cross-section is passing the fifth roller, it is shown on Figure 9 that from rail head to foot the stress varies from tensile stress to compressive stress. The curve with the straightening velocity of 1.4 m/s shows a smaller range of stress, and the variety of stress at rail waist is relatively small. The other two curves have a similar trajectory and stress range.

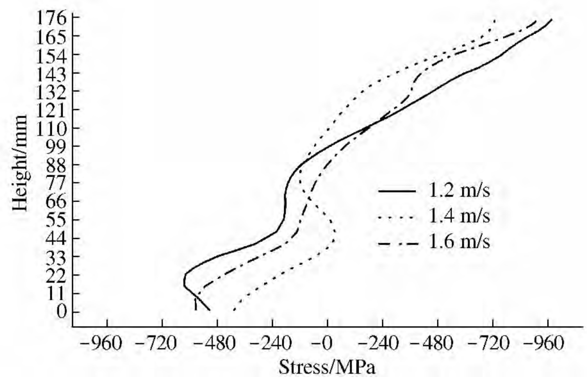

Figure 9 The longitudinal stress in the 4th straightening zone

Figure 10 shows that when the cross-section is passing the sixth roller, the section is at 5^{th} straightening zone, the state of stress varies from compressive to tensile, these three stress curves on the figure display a similar trend of stress variety, comparing with former straightening zones, the curves have more inflection points. In this straightening zone, the stress range with straightening velocity of 1.4 m/s is smaller than the other two.

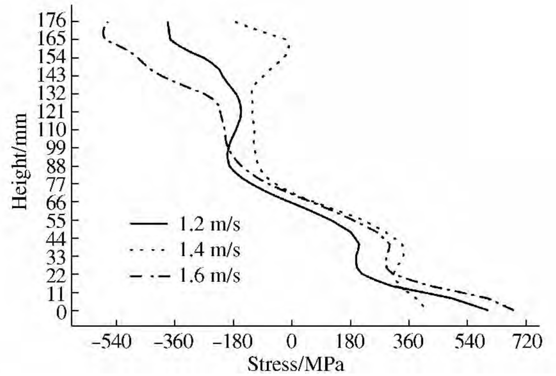

Figure 10 The longitudinal stress in the 5^{th} straightening zone

The stress varies from tensile to compressive at the 6^{th} straightening zone according to Figure 11, these three curves have an similar trajectory. From rail head to waist, the variety of stress is smooth, but there are two inflection points between rail waist and bottom.

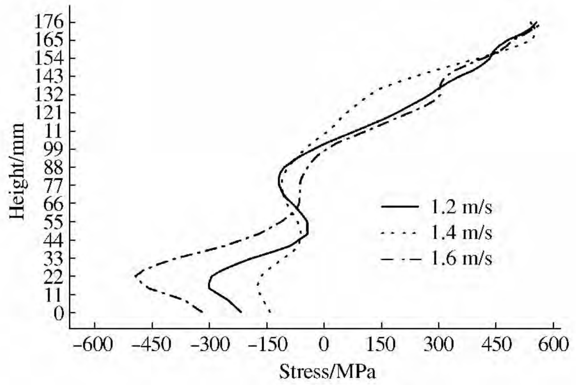

Figure 11 The longitudinal stress in the 6^{th} straightening zone

The longitudinal stress of heavy rail at 7^{th} straightening zone shown in Figure 12. The stress gets more complex, there are six infection points in the curve of the distribution of stress with the straightening velocity of 1.4 m/s and 1.6 m/s, and there is also five inflection points with the velocity of 1.2m/s. It is the last straightening zone in nine rollers straightening, the distribution of stress from rail head to foot varies from tensile to compressive.

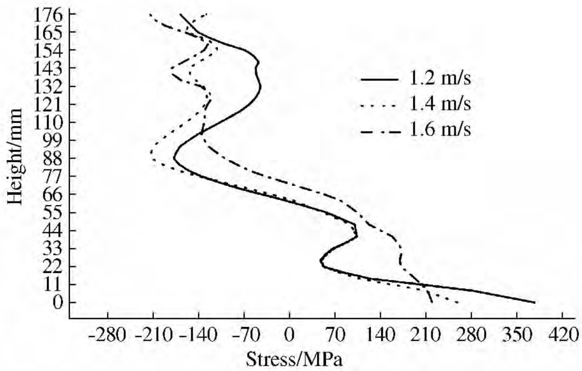

Figure 12 The longitudinal stress in the 7^{th} straightening zone

4 Conclusions

In this paper, the straightening model for heavy rail with 60 kg/m have been established 60 kg/m and the simulation of straightening process has been made, by comparing with the longitudinal residual stress with four different straightening velocity. There are some conclusions we are gotten in the following paper:

1) From the view of straightening residual stress, just changing the straightening velocity with other conditions unchanged, the distributions of residual stress are C-shaped.

2) In the numerical simulation of heavy rail straightening, the distribution of stress in each straightening zone is in an accord are with actual situation, the longitudinal stress rising and falling appeard alternately from rail head to foot in each straightening zone, the increase and decrease in the stress is approximately linear.

3) The direction of straightening development is to

constantly improve straightening velocity. The straightening velocity is improved from 1.2m/s to the range of 1.4 m/s to 1.6 m/s, thus the production efficiency can be improved from the range of 16.7% to 33.3%, it is of great value as a reference for field production.

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