International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 3 Issue 11 ǁ November. 2015 ǁ PP.17-22

Thermal Analysis of the Wheel for Urban Rail Vehicle Considering Emergency Braking Condition

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ABSTRACT: A straight-plate wheel model for urban rail vehicle considering emergency braking condition is presented in the study.The thermal loads of urban rail vehicle wheel were calculated. The superposition rule of the temperature and the stress was obtained, and the maximum temperature and the maximum thermal stress of the new wheel and the abrasion to the limit wheel were compared. The results show that the maximum temperature and the maximum thermal stress of the wheel tread appeared in the process of braking; the maximum thermal stress of the wheel plate appeared in the end of braking; under the process of braking, the temperature and thermal stress of abrasion to the limit wheel was greater than the new wheel. The work is not only suitable for the research of the thermal fatigue, but also has an important reference value to the optimizationdesign of rail wheels.
Keywords: Urban Rail Vehicle, Wheel, Thermal Analysis,Emergency Braking

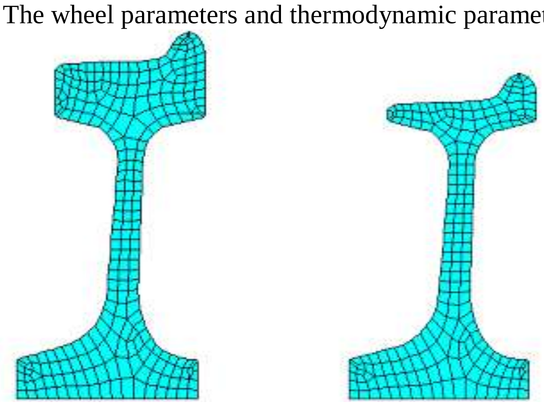
I. INTRODUCTION

As a part of the significant carrier of vehicle body, the performance of the urban rail vehicle wheel is directly related to the safety operation of the vehicle. Under the process of the tread braking, wheel has a friction effect between the wheel tread and the brake shoe, which produce a large amount of heat. The heat load has an important influence to the life of the wheel[1].

There has been intensive research on the thermal fatigue of the wheelforurban rail vehicle recently. Zhang Ping[2] discussed the loading way of the heat flux density, which provided the important reference for the thermal analysis of wheel; ZhengHongxia[3] simulated the temperature field and thermal stress field of the wheel using the finite element method considering the emergency braking. Their work provided the load conditions for fatigue strength assessment of wheels. Shahab[4] investigated the problem of the thermal fatigue on wheels, and discussed the methods of the thermal fatigue lifeBased on the above research;we focus on the investigations ofa straight-plate wheel model for urban rail vehicle. Due to considering two abrasion states, the analysis of temperature field and thermal stress analysis was carried out, and the position and time of maximum temperature and the maximum thermal stress were discussed, and the rules of temperature and thermal stress according to the time were investigated.

II. WHEEL MODEL

Atypical rail wheel model for urban rail vehicle wheel is shown in Fig.1. In the process of modeling, some details such as little impact on the calculation of the rounded are ignored. The R9T is selected as the material of wheel. The 3D discrete unit SOLID 70 is used in the wheel. In Fig.1, the Fig.1(a) is new wheel, the Fig.1(b) is the abrasion to the limit wheel. The wheel parameters and thermodynamic parameters are shown in Table 1.



(a) New wheel(b) Abrasion to the limit wheel
Fig.1 Wheel model

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Table 1 Wheel parameters and thermodynamic parameters

	Name	Value
Wheel parameters	Axle load	16 t
	New wheel diameter	840 mm
	Initial speed of braking	80 km/h
	Brake shoe width	85 mm
	Braking deceleration	1.3 m/s^2
	Brake shoe friction coefficient	0.3
	Brake shoe pressure	42778.1N
Thermodynamic parameters	Specific heat	450J/(kg·K)
	Coefficient of thermal expansion	1×10^{-5} K^{-1}
	Distribution coefficient	0.9

III. LOADS CALCULATION

According to the working condition of the urban rail vehicle wheel, the ambient air temperature is 24℃, and the wheel itself surface temperature is 40℃.

3.1 HEAT FLUX

The method of instantaneous power is used to calculate the heat flow density. That is, first calculate the brake wheel by force of brake shoe, and then calculate the speed of the wheel, the brake thermal power $Q(t)$ can be expressed as

$$P(t) = F_f v = \mu F_N v \qquad (1)$$

Where F_f is brake shoe friction, μ is brake shoe friction coefficient, F_N is brake shoe pressure, v is the running speed of the vehicle.

The urban rail vehicle shoes will lose power transfer to the corresponding wheel by n brakes in the process of braking. As a result, the coefficient should be introduced in the calculation of the heat flux distribution, namely the wheels absorb heat as a percentage of the total friction heat. In the calculation, by the definition of heat flow density, thus the heat flow $q(t)$ can be expressed as below

$$q(t) = \eta \frac{Q}{St} = \frac{\eta \mu F_N v}{n \pi D l} \qquad (2)$$

Where S is the contact area between tread and brake shoe, D is wheel diameter, l is brake shoe width.

3.2 COEFFICIENT OF HEAT TRANSFER

During the emergency braking of the urban rail vehicle, the speed of the vehicle can be assumed to change linearly with time. Due to this point, the vehicle speed is the main factor which affected surface convective heat transfer coefficient of the size of the wheel. The convective heat transfer coefficient can be obtained by the experimental method, the empirical formula as

$$h = 14.39v + 0.3828 \qquad (3)$$

IV. SIMULATION RESULTS

Wheel simulations are divided into temperature field simulation and thermal stress field simulation.According to theadd speed and initial velocity of Table.1, it can be known that the braking time isabout17s.The simulationsof temperature field and thermal stress in 17s can be seen as follows.

4.1 TEMPERATURE FIELD SIMULATION RESULTS

The changes of temperature of wheel tread in the process of brake is shown in Fig. 2.The maximum temperature of the new wheel appears in 10s moment, the highest temperature is 195.6℃, the maximum temperature of the abrasion to the limit wheel also appears in 10s moment, the highest temperature is 205.1℃.

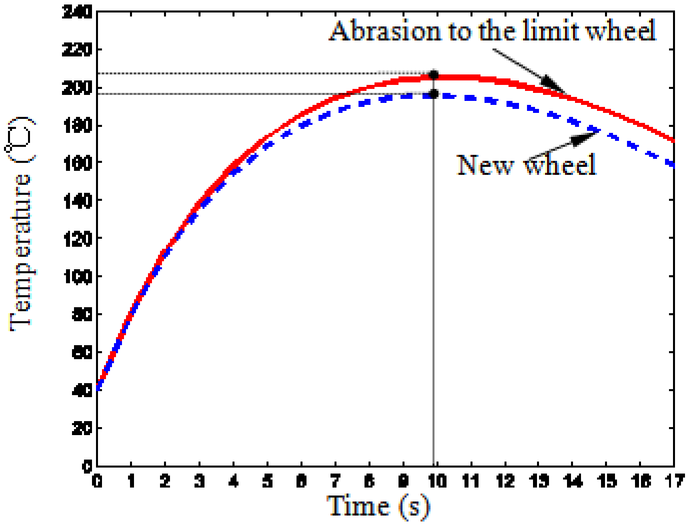
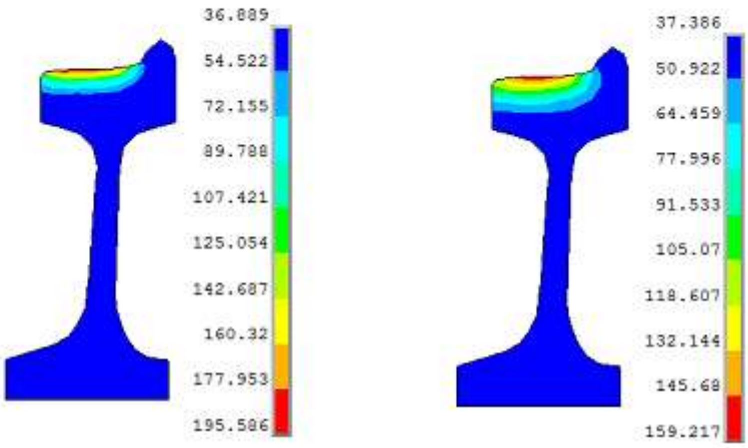


Fig.2 Temperature changes of wheel tread

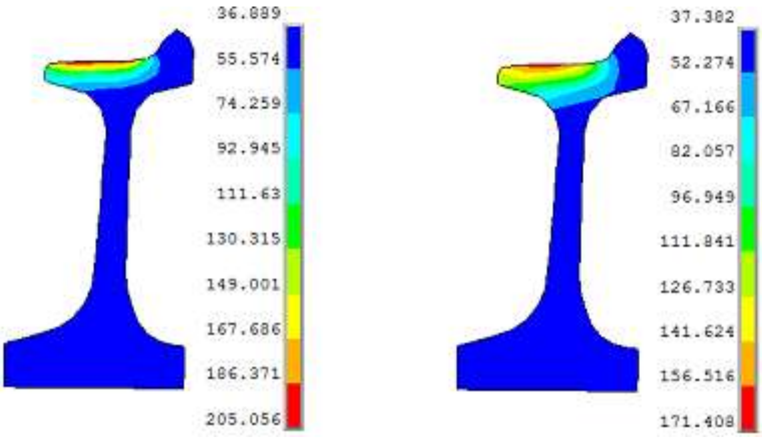
Fig.3 shows the temperature cloud picture after braking.The high temperature area mainly concentrated in the tread and rim of wheel after the braking. Due to the heat transmitslowly to the spread of rim and plate, making the rim temperature existingthe radial temperature gradient. And the braking time of the vehicle is shorter, the temperature of vehicle wheel transmitto the wheel plate will take a lot of time, so the wheel plate temperature is close to ambient temperature at the end of braking.

Sincethe rim of the abrasion to the limit wheel is thinner, the temperature of the abrasion to the limit wheelis easierthan the temperature of new wheel transfer to the wheel plate. Therefore, the temperature of the abrasion to the limit wheel passes to the wheel plate much quickly.



(i) t=10s (ii) t=17s

(a) New wheel



(i) t=10s (ii) t=17s

(b) Abrasion to the limit wheel

Fig.3 Temperature cloud pictures of the wheel

4.2 THERMAL STRESS SIMULATION RESULTS

SOLID70 thermal unit is transformed into SOLID185 structure unit in the finite element software, and the material properties of the structural analysisaresetproperly. Then the thermal analysis of the load of each node temperature as a body load is applied to the wheel[5].

The wheel thermal stress in 17s is shown in Fig.4.The thermal stress of wheel tread is always the biggestduring the process of brake. The maximum thermal stress of new wheel tread appears in 10s moment, the maximum thermal stress is 207.5Mpa. The maximum thermal stress of new wheel plate appears in 17s moment, the maximum thermal stress is 58.5Mpa.The maximum thermal stressofthe abrasion to the limit wheeltread appears in 8s moment, the maximum thermal stress is 243.6Mpa. The maximum thermal stress of the abrasion to the limit wheel plateappears in 17s moment, the maximum thermal stress is 86.2Mpa.

New wheels or abrasion to the limit of the wheel tread thermal stress are increased firstly, after reaching a maximum at a certain moment in the lower, and car spokes board of thermal stress has been increased, reached the maximum at the end of the braking moment. Due to their high abrasion to the limit of the wheel surface temperature, the temperature gradient is relatively new wheel is bigger. Therefore, abrasion wheel of thermal stress in each moment are greater than the new wheels.

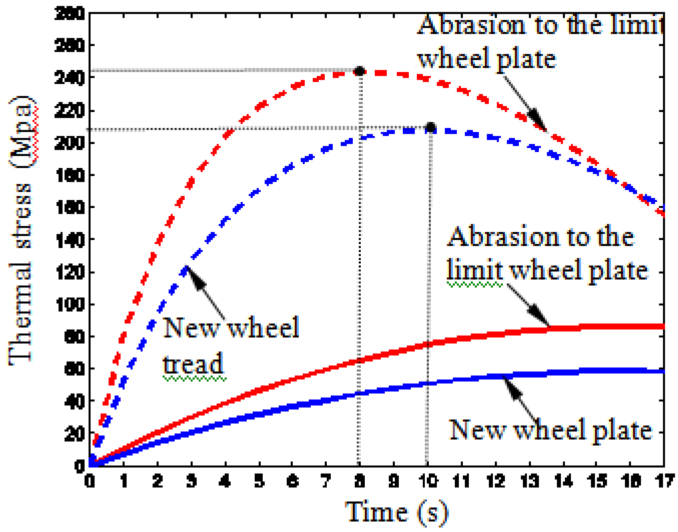
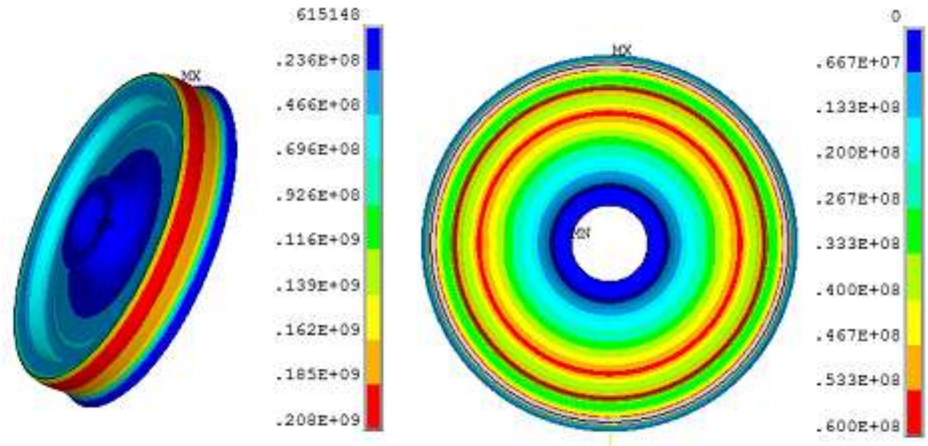
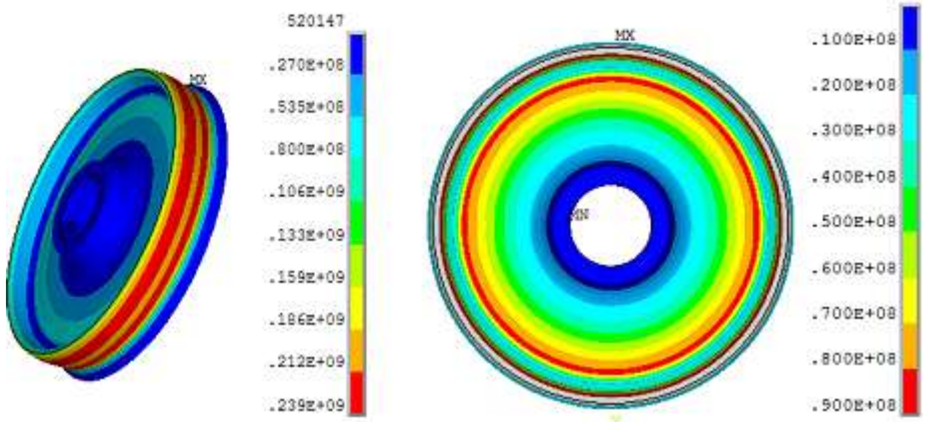


Fig.4 Thermal stress changes of wheel



(i) t=10s (ii) t=17s

(a) New wheel



(i) t=8s (ii) t=17s

(b) Abrasion to the limit wheel

Fig.5 Thermal stress cloud pictures of the wheel

The thermal stress cloud pictures of wheel are shown as Fig.5,which list thetime and locationof the maximum thermal stress of the wheel tread. Since applying heat flux density with uniform heat source method,andassumingthatthe wheelisstatic state, the thermal load is applied to the wheel tread evenly, so it can be seen from Fig.4 that there are the samethermal stress of the wheel with the same diameter. The maximum thermal stresses of new wheeltread and abrasion to the limit wheel tread are in different time. The maximum thermal stresses of new wheelplate and abrasion to the limit wheel plateare in different location.

V. CONCLUSION

The study presents new wheelmodel and abrasion to the limit wheel model basing on an urban rail vehicle wheel. Throughthe analysis of the temperature field and thermal stress field, the characteristics of temperature and thermal stress, the rule of temperature field and thermal stress field is obtained. The results show that the highest temperature on the wheel tread in the process of braking and the maximum thermal stresson the wheel plate in the end of braking. The new wheel and the abrasion to the limit wheel tread appearthe highest temperature at the same time.The maximum thermal stress of the new wheels and abrasion to the limit wheel tread appearin different time.The maximum thermal stress appears at the end of the braking, butthe maximum thermal stress of the new wheelplate and abrasion to limit wheelplate appear in different location. In the process of braking, the temperature and thermal stress of the abrasion to the limit wheel are greater than the new wheels.

VI. ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of National Natural Science Foundation of China (Grant No. 11472176), Natural Science Foundation of Shanghai (Grant No. 15ZR1419200) and Discipline Construction Project for Transportation Engineering (Grant No. 13SC002).

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