

## THERMAL CAPACITY OF LOW-STRESS HEAT-TREATED WHEELS

by

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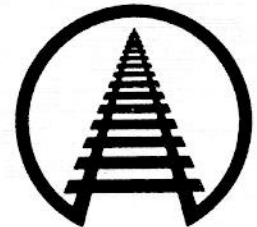
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### Summary

*A series of dynamometer tests conducted by the AAR showed that the amount of brake shoe thermal input required to thermally damage heat-treated, low-stress wheels is far in excess of that of normal brake application. The tests were undertaken to determine the limiting power required to produce wheel thermal damage. Thermal damage is the neutralization of the "as manufactured" rim circumferential residual compressive stresses. Tests were conducted on low-stress, heat-treated CE-28, CH-36 and CB-38 freight car wheels. Additionally, the effect of rim thickness on the resistance of wheels to thermal damage was investigated.*

*The tests show that low-stress, heat-treated freight car wheels can resist at least 60 horsepower of brake shoe input without thermal damage. Therefore, the current guidelines for grade braking power input are extremely conservative. However, because of the occurrence of large variations in actual brake shoe forces experienced in service, it would appear to be unwise to increase current limits. Upward revision of the guidelines must depend on improving brake system reliability.*

*The introduction of low-stress, heat-treated wheels has helped to decrease the incidence of wheel thermal failure by more than an order of magnitude over the last ten years. There are however a number of other contributing factors, such as the increased use of dynamic braking, improved train handling procedures, the increased usage of composition brake shoes, and the increasing number of unit train operations which reduce the incidence of wheel thermal damage.*



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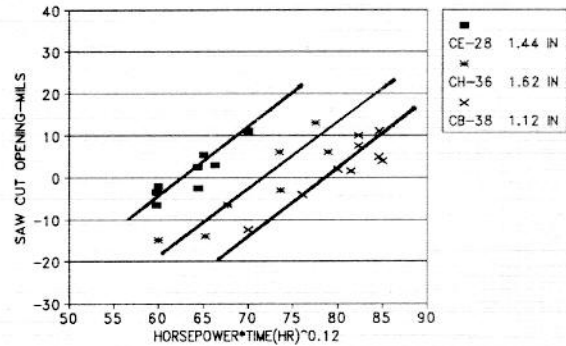
## INTRODUCTION AND CONCLUSIONS

The standardization of the use of low-stress, heat-treated wheels in North America is projected to help in reducing the number of derailments due to wheel thermal failure to about eight per year when the car fleet is fully equipped with these wheels. There are approximately 9.5 million wheels in service, and 8 failures represent a probability of failure of less than 0.000001, or literally one in a million. This represents a significant improvement in that fifteen years ago there were 150 such derailments per year.

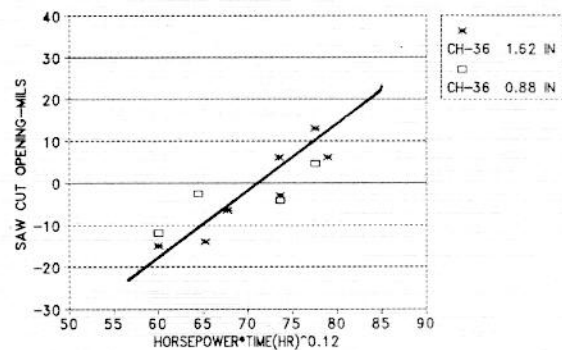
The level of improvement in the resistance of wheel thermal damage that low-stress, heat-treated wheels produce was determined. A number of unused low-stress CE-28, CH-36, and CB-38 Class C one-wear freight car wheels were subjected to high heat inputs with high friction composition brake shoes on the AAR's dynamometer. Following testing, the wheels were saw cut to assess their residual stress states. The results show that low-stress, heat-treated wheels can resist at least 60 horsepower (hp) of brake shoe input without thermal damage.

Exhibit 1 shows rim saw cut opening as a function of power and time input for the full thickness CE-28, CH-36, and CB-38 wheels that were tested in context with the track wheel at levels above 30 hp. The horsepower/time parameter chosen for this plot is the empirical hp times time (hrs) to the 0.12 power. This figure shows that saw cut opening is proportional to power input and that the larger the wheel, the higher the power input needed to produce a change in the saw cut opening. The intercepts with the zero opening line appear to be 62, 72, and 80  $\text{hp}\cdot\text{hr}^{0.12}$  for the 28, 36, and 38 inch diameter wheels. The slopes appear to be the same for the three wheel sizes.

The thick and thin rim CH-36 wheels are compared in Exhibit 2. The data for the thin rim straddles that for the thick rim indicating that they are similar. Data for a thin rim CE-28 wheel (not plotted) also fell in with the data for the thick rim CE-28. This is an unexpected result because theoretical studies generally indicate that thin rim wheels are less heat resistant than thick rim wheels.



**Exhibit 1. Dynamometer Tests with Track Wheel. Horsepower - Time vs. Saw Cut Opening Showing Effect of Wheel Size.**

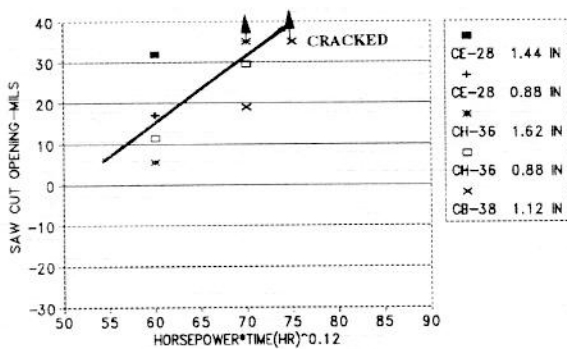


**Exhibit 2. Dynamometer Tests with Track Wheel. Horsepower - Time vs. Saw Cut Opening Showing Effect of Rims Thickness.**

Exhibit 3 shows the data for wheels that were tested without the track wheel. This clearly shows that all of the saw cuts opened and two of the wheels cracked during sawing as indicated. The horsepower inputs are lower and the saw cut openings are higher than for the data in Exhibits 1 and 2. Thus the data show that



dynamometer tests conducted without the track wheel produced substantially greater thermal damage than tests with the track wheel. This indicates that the rail/wheel interface is an important area of brake heat dissipation.



**Exhibit 3. Dynamometer Tests without Track Wheel. Horsepower - Time vs. Saw Cut Opening.**

The maximum temperatures depend upon the wheel size, horsepower input, and whether or not the track wheel was used. It is apparent that all of the data, regardless of wheel size, horsepower input and track wheel, fit in the same group. Thus, the saw cut opening increases with increasing tread temperature.

**DISCUSSION**

The text, *Engineering Design of Railway Brake Systems*, recommends a set of average brake horsepower levels for practical safe operation as shown in Exhibit 4. It is clear that the suggested brake horsepower levels are well below the projected levels necessary to impart thermal damage. However, recent tests have indicated that these levels are frequently exceeded. The BHP values in Exhibit 4 were based on extensive dynamometer and road train wheel heat test experience with straight plate wrought and cast steel wheels. These criteria were for an average tread temperature of less than 600° F for brake applications held steadily for one hour with AAR high friction composition or iron brake shoes.

Wheel Diameter (inches)	Brake Horsepower
28	20
33	25
36	30
38	35
40	40

**Exhibit 4. Nominal Wheel Diameter and Average Brake Horsepower for Practical Safe Operation.**

However, the problem is that the brake shoe forces are anything but uniform. A recent statistical analysis using the thermal data limit for 36-inch wheels and in service wheel temperature variations estimates that thermal damage is present in about 0.2 percent of low-stress, heat-treated wheels as the result of highly unusual braking conditions.

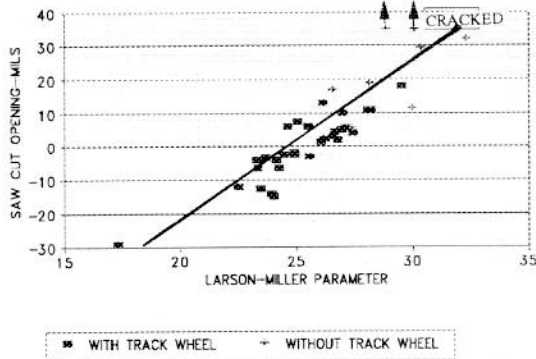
Another way to examine the dynamometer and saw cut data is to incorporate power output (the maximum tread temperature and time at temperature) into a Larson-Miller Parameter. The Larson-Miller parameter has the form:

$$C=(T+460)(20+\log t)$$

where:

T is the temperature, °F,  
t is time, hr.

Exhibit 5 is a plot of maximum saw cut opening versus the Larson-Miller Parameter, C. Notice that the data fit this relationship quite well indicating the presence of stress relief kinetics.



**Exhibit 5. Saw Cut Opening as a Function of the Larson-Miller Parameter.**

Sixty bhp is consistent with the experimental data, and would not damage a wheel, but represents a level of energy in excess of three times the recommended level given in Exhibit 4. It should, however, be noted that these guidelines were empirically established at a time when the standard wheels were non-heat-treated and of a "high stress" design that would yield in the plate and rim at lower thermal inputs than the new standard heat-treated, "low stress" designs.

The extremely low levels of the presence of thermal damage and high power levels associated with the formation of thermally damaged wheels suggests that some combination of unusual events is needed to damage wheels. Examples of such combinations may be a stuck brake and an unreleased hand brake, or a

stuck brake and a brake shoe with an unusually high coefficient of friction. The recent adoption by the AAR of the repair track air brake test may provide for the near elimination of the stuck brake problem with a further reduction, if not elimination, of thermally damaged wheels. Additionally, a design change in the brake system to prevent the application of shoe forces beyond a one or two standard deviation limit could also provide, when coupled with the full application of low-stress, heat-treated wheels, a 100-percent reliability against wheel thermal failure.

The following issues were identified during this study:

1. Low-stress heat-treated freight car wheels can resist at least 60 hp brake shoe input without thermal damage.
2. Tests without the track wheel, where heat cannot be conducted away from the wheel, caused stress reversal at lower energy levels. This indicates the value of the rail/wheel interface as a point of brake heat dissipation.
3. The current guidelines for grade braking power input appear to be extremely conservative. However, because of large variations in actual brake shoe forces experienced in service it would appear to be unwise to raise current limits.
4. Upward revision of the guidelines must depend on improving brake system reliability.

Note: Contact D. H. Stone at (312) 808-5806 with questions or comments about this document.

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