TESTING FOR CURRENT FREIGHT CAR BRAKING RATIOS ON UNION PACIFIC RAILROAD

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ABSTRACT

This paper describes the static dynamometer brake force (Jim Shoe®) testing performed on freight cars at a car repair facility of the Union Pacific Railroad. Several freight cars were selected for testing, and cars were given a complete air brake system test. The current hand-braking ratio, loaded braking ratio and empty braking ratio values were determined for each car and the values were then compared to established Association of American Railroads (AAR) braking ratio requirements for newly constructed and rebuilt cars. Brake related wheel defects are reviewed and the implications of current freight car braking ratios are discussed with regard to wheel removals and safety related issues.

INTRODUCTION

Railroads in North America remove large numbers of wheels each year for brake related wheel defects such as shelling (AAR why made code 75), tread built-up (why made code 76) and tread slid flat (why made code 78). Car Repair Billing (CRB) data from 1999 show that 80,298 wheels were removed for shelling, 27,018 wheels were taken out of service for built-up tread and 9,131 wheels were removed for slid flats (Ref. 1). It is well known that shelling has increased dramatically in recent years and represented 15.5% of CRB wheel removals in 1999. Built-up tread and slid flat wheel removal percentages have remained in the 2% and 5-6% range, respectively, for the last several years. Out-of-round wheels (why made code 67) constituted another 2,554 wheel removals (0.5% of total) in 1999 (Ref. 1).

Since AAR CRB data represent only a portion of total North American wheel removals, the true totals are even higher. System wheel repairs and wheel repairs performed by most private car shops are not included in AAR CRB data. Therefore, AAR CRB figures should be multiplied by a factor of 2.5 to obtain an estimate of the total number of North American wheel removals. These removals represent an extremely large, and in the authors' opinion, partially avoidable cost to rail carriers. Authors from AAR/TTCI recently estimated the annual cost of wheel shelling to be $180 million, excluding costs for lost service time for equipment and the impact on customer service (Ref. 2). Efforts to reduce the numbers of wheels being removed for brake related defects will free capital for other projects and will improve safety by eliminating high impact wheels with tread damage from service.

BACKGROUND - BRAKE RELATED WHEEL DEFECTS

Wheel shelling is condemnable under AAR rules according to the following definition in the 2000 AAR Field Manual (Ref. 3):

> When the shell or spall is ¾ inch in diameter or larger and the shells or spalls are more or less continuous around the periphery of the wheel or whenever any shell or spall is 1 inch or more in diameter the wheel must be removed from service. Islands of original tread surface metal contained in the shell or spall will not be considered as part of the area of shell or spall.

This AAR definition is accompanied by an illustration in Rule 41 showing that the above dimensions apply to a circle and showing what constitutes a condemnable shelling defect. In recent years there has been some confusion regarding the rejectable shell defect size and the AAR thus made clarifications. A circular letter in June of 1999 indicated that the dimensions applied to a square defect (Ref. 4).

True wheel shelling is a rolling contact fatigue phenomenon that leads to damage on the wheel tread and eventually small pieces of the wheel tread break off. Thus, true shelling is not related to braking systems or braking ratio, and is limited to certain specific heavy-haul service lanes. A complete description of shelling, which is described in several references including some listed here, is beyond the scope of this paper (Ref. 5-9). It is now generally accepted that most wheel shelling in North America (why made code 75) is actually wheel spalling.

Thermal mechanical shelling, known to exist in some service lanes, is a process that requires elevated temperatures in conjunction with contact stresses (Ref. 10). In thermal mechanical shelling, the fatigue cracking is a result of elevated temperatures (which reduces the strength of the tread material) and the high contact stresses, which would do no damage if the wheel tread was at its room temperature strength. Spheroidized pearlite at the tread surface, resulting from brake shoe heating, can be an important clue when looking for thermal mechanical shelling. No martensite is formed during thermal mechanical shelling and the cracks initiate at the surface. Often, these cracks are found on wheels with heat checks and the cracks appear to be closely related. Note that in the case of spalling, the crack network is either perpendicular or parallel to the surface (Ref.8).

Wheel spalling occurs in service after the wheel slides on the rail and patches of martensite are formed on the tread. The wheel slide generates very high temperatures at the contact patch and the steel is austenitized. However, the large heat sink of the remaining cold wheel quickly quenches the small tread patch and untempered, hard, brittle martensite is then formed. The combined effects of the localized contact patch heating during the slide (compressive upset plastic deformation) and the 4% volume increase due to the martensitic transformation result in a tensile stress field around the martensite patch. Subsequent in-service loading leads to eventual cracking and fracture of pieces from the wheel tread. Due to the brittle nature of martensite and the stress concentrations formed when pieces come off the tread, wheel spalling can result in severe progressive damage to the wheel. The appearance of shelling, spalling and thermal mechanical shelling can be very similar, particularly if the spalling extends around the wheel tread from repeated sliding and skidding, but spalling can often be corroborated by slip marks/patches on the wheel tread. A number of excellent papers have been written on the subject of wheel spalling and some are listed as references here (Ref. 7-13).

For built-up tread (why made code 76), the AAR (Ref. 3) specifies that "A wheel is condemnable whenever the tread has built-up metal 1/8 inch or higher on the wheel tread." This defect is the responsibility of the car owner. Slid flat wheels (why made code 78) are the responsibility of the handling line and are condemnable if the flat spot is "two or more inches in length" or there are "two or more adjoining spots each 1-1/2 inch or over in length." Clearly, these defects can cause high impact loads and damage to wheels, rails, lading and the freight car. As for out-of-round wheels (why made code 67), Canadian National found that out-of-round wheels with "healed" shells could produce impact loads up to 199 kips (Ref. 14). To be condemnable under AAR rules, out-of-round wheels must register at least 90,000 pounds on a wheel impact load detector and have a verified out-of-round "runout" of 0.070 inches (Ref. 3).

AAR BRAKE SHOE FORCE TESTS

AAR requirements for freight car air brakes are outlined in S-401-99 (Ref. 15). Cars that are new, rebuilt or converted from cast iron brake shoes to composition brake shoes must have braking ratios in accordance with this document. The relevant net braking ratios for cars with high friction composition brake shoes, non-lever hand brakes, and a 30 psi brake pipe reduction from 90 psi brake pipe pressure are shown in Table 1.

Car Type	**Loaded Net Braking Ratio**		**Maximum Empty Braking Ratio**	**Minimum Hand Braking Ratio**
	Minimum	**Maximum**		
TOFC/COFC	11%	13%	38%	10%
All Other	8.5%	13%		

Table 1. Net braking ratios required for new and rebuilt freight cars (Ref. 15).

Braking ratio is defined as the ratio of braking force against a car's wheels to the car's weight (Ref. 16). The empty braking ratio is defined as the braking force divided by the car's light weight. Wheel sliding occurs when a car is empty and this phenomenon is responsible for creation of tread defects such as spalling. For the loaded braking ratio and hand-braking ratio, the gross rail load (GRL) of the freight car is used in calculations.

PREVIOUS BRAKING RATIO INVESTIGATIONS

A number of studies have been conducted to determine the root cause of brake related wheel defects. Although certain past efforts have primarily focused upon details of the air brake system itself (Ref. 17, 18), or have discussed improper use of handbrakes (Ref. 19, 20) causing brake related wheel defects, this paper deals primarily with the issue of braking ratios on equipment currently in service.

Bartley of Canadian Pacific (Ref. 9) reported that the amount of wheel spalling is inversely proportional to car weight. Janshego and Lonsdale (Ref. 17) reported that two coal cars with wheel shelling/spalling problems had a current empty braking percentage greater than the level required by AAR for newly constructed or overhauled cars. Further, Butler, Lonsdale and Luke (Ref. 18) found that five out of seven steel Conrail coal cars had a current empty braking ratio greater than the 38% level required by AAR for new cars. These cars had lost considerable weight from their “as constructed” weight. Weight changes can occur due to corrosion, a change in wheel weight, or from a modification to the car such as different bottom-dump gates. The two of seven cars that were below the 38% empty braking ratio level were within three percent and four percent of the 38% limit, respectively. Also, five of the seven cars did not have a sufficient loaded braking ratio.

More recent testing found that although four older steel coal cars had an acceptable current empty braking ratio (below 38%), two of the four cars were within three percent of the 38% AAR specified maximum, and all four were above 30% (Ref. 21). Also, all four of the cars had a loaded braking ratio below the minimum 8.5% specified for new/overhauled cars, and one car had an insufficient hand-braking ratio. Although the latter two braking ratios do not contribute to wheel damage, they are clearly important from a safety point of view.

WHEEL SLIDING AND BRAKING RATIO

A wheel will slide on a rail when the retarding force between wheel and brake shoe is greater than the force between the wheel and rail (adhesive force) (Ref. 16). The retarding force is a function of brake shoe force and friction between the shoe and wheel tread. If a car is empty, there is less adhesive force between wheel and rail and the tendency for wheel slide increases, particularly if the car has lost weight. Also, if the amount of braking force delivered to the wheel tread increases, wheel slide is more likely. Other factors affecting the adhesive force include rail condition and lubrication, wheel/rail profiles, etc.

A paper presented at the 1999 Air Brake Association Conference suggested that the maximum requirement for empty braking ratio should be lowered significantly (Ref. 22). This paper describes brake retarding force, adhesion demand and available rolling adhesion. The author states that it is necessary to keep adhesion demand ([coefficient of friction] X [net brake shoe force/car weight]) less than the available adhesion between wheel tread and rail to prevent wheel sliding. The author discusses a conservative approach to minimize wheel sliding where the design net braking ratio is made low enough to keep the adhesion demand below the available wheel/rail adhesion - even when the rail is wet. Therefore, the maximum effective (emergency) net braking ratio must be below 28% to prevent wheel sliding. However this means that the empty car design net braking ratio must not be more than 23.5%. The author recommends that the range of empty car net braking ratios be between 22% and 30%. Note that the author’s suggested 30% maximum empty net braking ratio is significantly lower than the 38% maximum now specified by the AAR. The paper also has tables of net braking ratios for different empty car weights and empty/load proportioning (60%, 50% and 40%) showing “safe” empty car net braking ratios to prevent wheel sliding. As empty car weights decrease and loaded car net braking ratios increase, additional empty/load brake proportioning is needed.

DE SOTO TESTING RESULTS AND DISCUSSION

The authors recognize that the static dynamometer brake shoe test outlined in AAR S-401 is not designed to be used for equipment currently in service and that there is no AAR or railroad requirement to perform testing on such cars. However, due to potential changes in braking systems over time in service, the test was applied to used equipment. The goal was to determine if current empty braking ratios exceed the 38% maximum empty braking ratio standard for newly constructed cars, and to relate this to the creation of wheel defects. Additional information would also be gathered with respect to loaded braking ratio and hand braking ratio.

A total of nine cars were selected for static dynamometer brake shoe testing (using Jim Shoe® devices) at the Union Pacific De Soto, MO freight car shop on May 30-31, 2000. Four of the cars were steel hoppers; four were aluminum hoppers; and one car was a coil steel trough car. All cars had a foundation air brake system except for the coil steel car that had truck mounted air brakes. Car information is contained in Table 2 and results of the static dynamometer brake shoe force testing are contained in Table 3.

Car Initials	Car Number	Car Type	Car Builder	Date Built	Empty/ Load?	Gross Rail Load (lb.)	Listed Empty Weight (lb.)
CTRN	373	Steel Hopper	Beth. Johnstown	5/79	No	263,000	61,200
CTRN	935	Steel Hopper	Pullman Std.	2/75	No	263,000	60,200
CTRN	461	Steel Hopper	Pullman Std.	1/76	No	263,000	60,100
CTRN	648	Steel Hopper	Pullman Std.	1/76	No	263,000	60,000
MCHX	30237	Alum. Hopper	Beth. Johnstown	9/91	Yes	286,000	44,000
MCHX	30528	Alum. Hopper	Beth. Johnstown	9/91	Yes	286,000	44,300
MCHX	30004	Alum. Hopper	Beth. Johnstown	5/91	Yes	286,000	44,000
MCHX	30483	Alum. Hopper	Beth. Johnstown	9/91	Yes	286,000	44,100
CNW	39778	Coil Steel Car	----	7/68	No	263,000	63,400

Table 2. Car information from De Soto, MO testing.

Car Number	Original Light Weight (lb.)	Current Empty Brake %	Current Loaded Brake %	Current Hand Brake %*
CTRN 373	61,200	44.0	10.2	9.6
CTRN 935	60,200	46.2	10.6	10.4
CTRN 461	60,100	38.6	8.8	13.3
CTRN 648	60,000	42.4	9.7	11.9
MCHX 30237	44,000	33.3	8.0	11.3
MCHX 30528	44,300	31.2	8.0	11.3
MCHX 30004	44,000	32.2	7.7	10.6
MCHX 30483	44,100	31.8	8.5	11.2
CNW 39778	63,400	41.6	10.0	7.9

*Note: Due to a testing error all current hand brake percentages were obtained by extrapolation of applied force.

Table 3. Results of De Soto, MO testing.

All four of the steel hoppers and the coil steel car have a current empty braking ratio that exceeds the AAR new/overhauled car requirement of 38%. Therefore, wheels on these cars are more likely to slide in service when the car is empty and brakes are applied. All of the steel hoppers and the coil steel car have acceptable current loaded braking ratios. Note that three of the four aluminum hoppers do not have the required minimum loaded braking ratio (8.5%) for new equipment, while the fourth car just makes the minimum. All four aluminum hoppers have acceptable empty braking ratios, thus showing that the empty/load device was functioning properly during the testing.

During testing to find the hand-braking ratio, an error was made and an incorrect force value was applied for each car's chain. Therefore, the corrected hand-braking ratio was obtained by extrapolation using the proper chain force value. Note that two of the seven cars (one steel hopper and the coil car) have a current hand-braking ratio less than the 10% minimum required for new cars in AAR S-401.

A visual examination of wheel treads showed that MCHX 30237 had the worst tread condition of the aluminum cars. Evidence of skidding and sliding was noted. The CTRN 461 had the worst wheel tread condition of the steel hoppers with many non-condemnable spalls. If wheels on these nine cars are periodically inspected in the future, progressive tread damage could be noted.

COMMENTS ON CAR REPAIR RECORDS

We examined UP car repair records for the nine tested UP owned cars to see if the cars have received a greater than normal number of mechanical component replacements in the past. A review of repair records for the nine cars showed a strong correlation between empty braking ratios and changes of brake shoes and wheel sets. Pertinent data are listed in Table 4. Note that there were more than *2-1/2 times* as many brake shoes used and *3 times* the brake-related wheel defects on the four CTRN (high empty braking ratio) cars as compared to the four MCHX cars.

Car Number	Current Empty Brake %	Brake Shoes Changed	Wheel Sets Shelled or Slid-Flat	Number of Previous Air Tests	Other Notable Data --- (all cars tested with brake cylinder tap prior to Jim Shoe® testing at DeSoto, MO)
CTRN 373	44.0	39	2	2	
CTRN 935	46.2	60	1	2	ABDS Emergency Portion Replaced 6/1/00
CTRN 461	38.6	30	1	2	
CTRN 648	42.4	72	5	5	
CTRN TOTAL		**201**	**9**	**11**	
MCHX 30237	33.3	9	1	1	ABDX Service Portion Replaced 6/1/00
MCHX 30528	31.2	19	0	1	ABDX Service Portion Replaced 6/1/00
MCHX 30004	32.2	18	1	2	ABDX Service Portion Replaced 6/1/00
MCHX 30483	31.8	31	1	2	ABDXR Emergency Portion Replaced 6/1/00
MCHX TOTAL		**77**	**3**	**6**	
CNW 39778	41.6	7	0	5	

Table 4. Car repair billing data (6/1/95-6/1/00).

It must be noted that the entire build series of UP owned CTRN cars (581 total) and MCHX cars (550 total) were later compared for the total number of shelled and slid-flat wheel removals. The MCHX cars were billed for more than twice as many wheel defects (997) as the CTRN cars were (432 wheel defects).

We also note that five of the nine cars tested at De Soto received a new air brake valve portion following completion of an air brake test that included a brake cylinder pressure test. Three of the cars that received new valve portions had each been air tested twice before while the other two cars that received new valve portions had each been air tested once before. However, none of these older air brake tests consisted of the brake cylinder pressure test. This information, and the data shown in Tables 2, 3 and 4, leaves much room for discussion regarding the variables affecting wheel and brake shoe usage.

Over the last five years, "UP" series cars have experienced 126,243 single-car and repair track air brake tests which has resulted in the replacement or repair of 13,559 emergency and service valve portions (10.7%). Since billing began for air brake testing with the brake cylinder pressure gauge (July 1998), 936 tests on "UP" series cars have resulted in 215 service and emergency portion repairs (23.2%). This evidence indicates that the brake cylinder pressure test finds defective brake valve portions that would not have been removed without that test. This evidence also suggests that leakage into the brake cylinder is a significant contributing factor to wheel problems.

CONCLUDING REMARKS

Static dynamometer brake force testing using the Jim Shoe® device is useful for determining the current braking ratios for equipment in service. Such testing can find equipment that has an excessive empty braking ratio, a low loaded braking ratio or a hand braking ratio that is too low. Further testing of additional car types and a review of mechanical repair records will allow railroads to find freight cars with braking problems and will allow for savings of maintenance dollars.

Development of a new static dynamometer brake force test device that is easier to use (particularly one where brake shoes do not need to be removed) will make field testing easier and will allow for "problem" cars to be found. We recommend that efforts continue to develop such a device.

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