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A Review of Forces on a Unit Brake Beam

Harry M. Tournay

Summary

An analysis has been performed by Transportation Technology Center, Inc. (TTCI) of the forces between the brake shoe and the wheel. It reveals that there is a compromise point at which forces should be applied and reacted on the beam in order to avoid tapered shoe wear.

If the beam is not designed according to this optimum position, accelerated beam wear and tapered shoe wear on worn beams will occur. This analysis includes an approximation of the amount of tapered shoe wear that may occur with the current brake beam configuration if the beam extension is not constrained to rotate in the brake beam slide (simulating a worn beam).

These predictions are based on analyses on the forces on the beam for different shoe thicknesses, wheel/shoe rubbing directions and brake shoe friction coefficients.^{1,2}

A more optimal solution to these problems would be to introduce hanger brakes. This is patently a more expensive solution and does not address the safety against derailment associated in the past with hanger brake beams.

A hybrid hanger/slide brake beam is suggested in which the conventional beam extension design in slides is retained; however the frictional reaction would be taken through reaction links similar to hangers. This would address safety against derailment but would result in increased cost.

TTCI suggests that brake beam suppliers be approached for information on their particular designs so that a detailed analysis may be made to establish how closely these designs conform to the suggested compromise position to reduce tapered shoe wear.

This *Technology Digest* (TD) is the last of a series of four TDs investigating the effect of the forces in the truck brake rigging on tapered shoe wear and uneven wheel temperatures.^{1,2,3} They:

- Develop an analysis of the forces and reactions on the shoe for zero tapered shoe wear
- Use this analysis to predict tapered shoe wear in generic brake rigging
- Suggest a compromise approach to minimize tapered shoe wear

This research has been conducted as part of the Association of American Railroads' Strategic Research Initiatives Program.



INTRODUCTION

A literature review performed by TTCI suggests railroads experience poor brake rigging component and wheel performance, which have been attributed to poor brake rigging design associated with:⁴

- Tapered shoe wear, resulting in wastage of friction material and the cost of unnecessarily frequent replacement
- Brake beam and side frame pocket liner replacement as a consequence of unbalanced moments on the shoe/beam assembly and resulting point loading
- The introduction of lateral forces on the shoes and beam through the truck lever due to lateral force imbalances in the truck rigging
- Binding of the brakes as the truck rotates relative to the carbody; this motion activates the connections between the truck and body rigging
- Binding of the brake beam extension in the side frame pocket, producing uneven shoe forces that may be exacerbated by truck warp in curves

Total costs attributable to poor design may be as high as \$150 million per year.

The literature review concludes that the forces in the brake rigging have been adequately defined while the required forces and reactions on the shoe, especially the force distribution between wheel and shoe for even shoe wear, are currently not well understood.⁴

Consequently, the forces on a shoe for zero tapered wear were developed for a shoe that is rigid, homogeneous (with respect to wear rate and friction coefficient), and pin-jointed at the point of application of the actuating forces and resultant reactions.¹

TTCI provided a model to develop a methodology for evaluating improved brake beam designs. This TD discusses the results of the force analyses conducted on a unit brake beam, based on an analysis of the forces on a shoe for zero tapered wear.^{1,2,3} It:

- Suggests the development of a possible optimum point of application of the beam actuating force
- Uses the results of the analyses to date to predict the degree of tapered shoe wear observed to date; this is done to:^{1,2,3}
 - Provide some form of validation of the method used
 - Suggest the sensitivity of any “offset” force on the shoe to the amount of tapered shoe wear to be expected
- Suggests alternative beam designs with their respective advantages and disadvantages
- Proposes a way forward

Determining the Optimum Point of Application of the Actuating Force for the Current Unit (nonhanger) Type Brake Beam Design

An analysis has been presented that suggests that for nontapered brake shoe wear, the shoe ideally should be pivoted at a particular position relative to wheel and shoe.¹ This position enables even shoe wear irrespective of the sense of rotation of the wheel and is independent of applied load and coefficient of friction. It does depend on wheel and shoe wear, and thus a point for “average” wheel diameters and shoe thicknesses must be chosen.

The analysis presented in two associated TDs suggests that the point of application of the brake force to a unit beam, resting in pockets defined by AAR specifications, should be a distance, h , below the intercept of the center line of these pockets and the tread surface of the wheel (Figure 1).^{2,3} This is because the forces and reactions on the beam do not pass through the “ideal” point defined in reference 1.

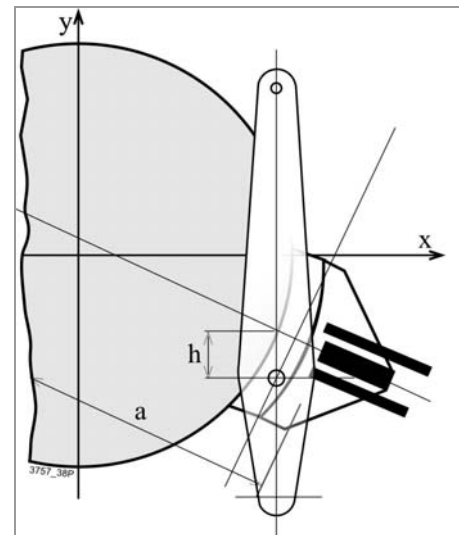


Figure 1

The nonideal position, apart from depending on the wheel diameter and shoe thickness, is a function of the sense of rotation of the wheel as well as the coefficient of friction (μ) of the shoe (in turn a function of specific shoe pressure and rubbing speed).

Preliminary calculations suggest that “optimal” positions for the unit brake beam vary between 1.37 inches and 0.5 inch below this reference (depending on wheel rotation sense and μ). A point approximating the mean between these positions (0.9 inch) is suggested as a first approximation. A more complete analysis is advised, using actual brake rigging dimensions and including the effect of the weight of the rigging.

Notwithstanding these caveats, the analysis suggests:

- The arrangement has merit since it would seem obvious that pressure lower on the shoe should reduce tapered wear at the top of the shoe
- That a more optimal rigging geometry than the present is possible as the current design, producing tapered wear to the top of the shoe, must be subject to the same variables

A Prediction of Tapered Shoe Wear

As a test of the analysis method, as well as to determine the sensitivity of the position of the point of application of the brake shoe force, a prediction is made as to the amount of tapered shoe wear to be expected.

As a rough first approximation, the ratio of top to bottom eccentric wear as a function of h and shoe length, l may be expressed as:

$$W_{\max}/W_{\min} = \Delta w = (l/2 + h) / (l/2 - h) \quad (1)$$

For $l = 13$ inch and $h = 1$ inch, $\Delta w = 1.4$. This suggests that there may be a 40-percent difference between the wear on the top of the shoe and the bottom, with the estimated eccentricity that is possibly inherent in the current design.

However, according to TD-01-002 and TD-01-027, Carlson measured an average difference of between 20 and 25 percent.^{5,6} The difference between Carlson’s observations and the calculated results may be attributed to:

- The constraints to tapered wear provided by the brake beam pocket and beam extension
- The eccentricity of the brake beam pocket/beam extension to the wheel center²

Obviously, the “spread” of Carlson’s observations can be attributed to:

- Different wheel and shoe wear conditions
- Different brake beam pocket and beam extension wear conditions

Notwithstanding the differences between observations and calculated results, the comparison is encouraging as an indication of the validity of the methods presented.^{1,2,3}

This comparison also emphasizes the importance in maintaining the correct point of application of the shoe — a ½ inch eccentricity can lead to an 18-percent difference in tapered shoe wear, if the shoe is not constrained

A corollary to this is that this eccentricity develops high constraining moments on the beam extension and within the brake pocket; the resulting point loads can rapidly wear this connection.

Discussion of the Hanger Brake Design

This and two associated TDs suggest that a solution to tapered wear may be to alter the position of the applied load to the brake beam as described.^{2,3} This may indeed solve much of the tapered wear problem but may not totally improve the beam

wear problem and force differential between shoes in the train. This is because:

- The force position is never “perfect” for all conditions of wheel and shoe wear an friction coefficient
- Under the “imperfect” conditions, moments will still probably be taken between the beam extension and the brake pocket

Moments taken on wearing surfaces in the slides will eventually result in “free play” of the beam in the pocket as wear and directional differentials take place.

The “ultimate solution” may be the use of the brake hanger to take the brake reaction force at the point defined by the theory developed in Equation 7, found in reference 1. This design is explored notwithstanding the fact that the industry has experienced problems with this design in the past:

- Derailments with beams coming loose and falling on the track
- The fact that the hanger does not resist lateral forces developed by some rigging

The optimal position to react the brake forces is at the distance, a , from the wheel center.^{1,2,3} This position, however, is under an inch from the tread surface of the wheel. Given typical pin diameters and boss sizes for links, this becomes an impractical design. Consequently, a hanger design resorts to “focusing” the link’s line of action on the optimal point, as Figure 2 shows.

The hanger needs to be focused on the average optimal position for dimension, a , given the variations in wheel diameter and shoe wear. The link acts along the center of the tread, in line with the side bearers thus:

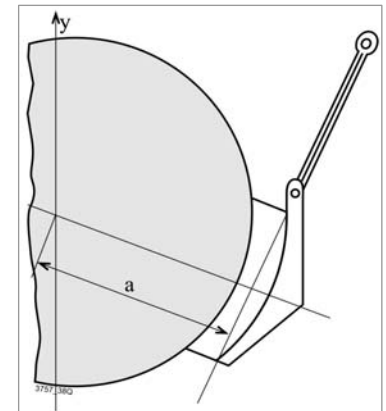


Figure 2

- The lower pin on the link must be designed not to interfere with the brake shoe key
- The length of the link must accommodate the angular differences in its alignment associated with wheel and brake shoe wear and, at the same time, not be capable of attaining a position so as to induce self-locking of the brake, a situation obtained when the angle of the frictional reaction exceeds the coefficient of friction
- The upper portion of the link must not interfere with the action of the side bearers

The designer must also decide whether to react the brake force to the side frame or to the bolster.

A reaction to the side frame has the following advantages and disadvantages:

Advantages:

- No relative vertical motion to the wheel
- No short-circuit of the suspension forces across the secondary suspension

Disadvantages:

- The need for a bracket on the side frame
- Brake rigging on an unsuspended mass (as at present)
- Relative motion between rigging and bolster

A reaction to the bolster has the following advantages and disadvantages:

Advantages:

- Easier attachment of hanger brackets
- Suspended truck brake rigging
- Motion of rigging relative to the bolster allows for lesser clearance problems

Disadvantages:

- The need for a bracket on the side frame
- Relative vertical motion to the wheel
- Short-circuit of the suspension forces across the secondary suspension
- Brake forces apply a rotational moment about the bolster longitudinal center line

The introduction of hanger brakes thus requires a major redesign of the truck system and, probably, a more expensive brake rigging.

A further compromise might be a hybrid hanger design. The wheel/shoe frictional forces on a conventional beam could be reacted by links to the side frame along the lines of a hanger system; the beam extensions in the slides would support the weight of the beam and ensure securement within the truck structure and avoid derailments. Again, this design would be more expensive than the current design.

CONCLUSIONS

There is an optimum point on the shoe at which forces should be applied and reacted in order to avoid tapered shoe wear and the generation of imbalanced moments. Poor design can result in imbalanced moments that are reacted through point loads between the brake pocket and brake beam extension, resulting in accelerated beam wear and tapered shoe wear on worn beams.

For the typical North American unit brake beam, there may be a compromise position for applying the load to the brake beam that, for minimal cost, may improve tapered shoe wear and beam wear. This compromise position may, in turn, reduce the tendency to overheated wheels although binding of the beam in the pocket may still occur under certain wheel and shoe wear conditions as well as under truck warp. The latter effect has not been included in this analysis.

A more optimal solution to these problems would be to introduce hanger brakes, either in the form of reaction links to the current unit beam, removing the derailment issue as the beam extensions remain, or to suspend the beam completely from the hangers. This is surely a more expensive solution than the current unit brake beam and retains the safety issue. Notwithstanding these suggestions, the hanger system would require a truck rigging that does not introduce lateral forces.

Consequently, it is recommended that brake beam suppliers first be approached for information on their designs so that a detailed analysis of their current brake rigging designs may be made to establish how closely they conform to the suggested compromise position, and whether there is an opportunity for performance improvement. If so, alterations should be made and prototypes tested and resulting in-service performance monitored. Resulting benefits in terms of tapered shoe and beam wear should be evaluated before further work is done to pursue the use of hanger brake systems.

The "link support system"⁷ acts as a pseudo-hanger system on the center of the brake beam to counter the moment imbalances defined in this investigation as well as to counter lateral forces on the beam. It is definitely a possible alternative approach and possibly using both the link support, as well as incorporating a more optimal value for h , would assist with tapered shoe wear and beam wear. It is recommended that the link support system also be tested and resulting in-service performance monitored and reported.

REFERENCES

1. Tournay, Harry M. December 2008. "Analysis of Wheel and Brake Shoe Forces and Reactions for Zero Tapered Shoe Wear," *Technology Digest* TD-08-054 AAR, TTCI, Pueblo, CO.
2. Tournay, Harry M. December 2008. "Forces on a Unit Brake Beam I," *Technology Digest* TD-08-055, AAR, TTCI, Pueblo, CO.
3. Tournay, Harry M. December 2008. "Forces on a Unit Brake Beam II," *Technology Digest* TD-08-056, AAR, TTCI, Pueblo, CO.
4. Tournay, Harry M. November 2008. "A Review of the Performance of Brake Rigging in Three-Piece Trucks," *Technology Digest* TD-08-046, AAR, TTCI, Pueblo, CO.
5. Carlson, Fred. January 2001. "Survey of Taper-Worn Brake Shoes in Revenue Service, Interim Report," *Technology Digest* TD-01-002, AAR, TTCI, Pueblo, CO.
6. Carlson, Fred. December 2001. "Brake Shoe Wear Study," *Technology Digest* TD-01-027, AAR, TTCI, Pueblo, CO.
7. Malachowski, J. & D. Cline. April 22-23, 2008. "Brake Rigging Analysis and the Development of Link Brake Stabilizers," Proceedings IEE/ASME, Delaware.

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