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Forces on a Unit Brake Beam I

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Summary

An analysis of the forces on a unit brake beam, when the wheel rubs on the brake shoe from top to bottom, suggests that tapered shoe wear would be eliminated if the point of application of the braking load on the beam were to be approximately 1.4 inches below the intercept of the center line of the pocket/brake beam end extension and the wheel tread.

A subsequent analysis[1] suggests another optimum point of application when the wheel rubs on the brake shoe from bottom to top. This leads to the conclusion that there may be a compromise position for zero taper shoe wear.[2]

This analysis is based on a previous study by Transportation Technology Center, Inc., reported in *Technology Digest* (TD) titled “An analysis of Wheel/Brake Shoe Forces and Reactions for Zero Tapered Shoe Wear.”[3]

These analyses have been made to establish reasons for tapered shoe wear and excessive beam wear.

Tapered shoe wear and brake beam wear are considered two of the root causes for poor brake performance; this results in unnecessary shoe wastage and beam replacement It may also contribute to uneven brake shoe forces, the presumed contributory cause, through overheated wheels, for wheel replacements as a consequence of shelled treads.

This TD is the second 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]

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

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INTRODUCTION

Railroads experience poor brake rigging component and wheel performance, both of which have been attributed to the need for improved rigging design.

TTCI conducted a literature review that suggests total costs attributable to the need for improved rigging design may be as high as $150 million per year and that variations in shoe force, beam, and tapered shoe wear are caused by a combination of:[4]

- Rigging designs that apply unequal and lateral forces to the brake beams and shoes
- A brake beam slide system that, while it requires tight tolerances and clearances in an attempt to eliminate tapered shoe wear can:
  - Bind within side frame and brake beam twist tolerances and warp deflections of the truck
  - Rapidly wear, resulting in tapered shoe wear.

The literature review concluded that the forces in the brake rigging have been adequately defined, whereas 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.

Consequently, the forces on a shoe for zero tapered shoe wear were developed for a shoe which is:[2]

- Rigid
- Homogeneous (with respect to wear rate and friction coefficient)
- Pin-jointed at the point of application of the actuating forces and resultant reactions

It is assumed that there are no elastic residual forces in the shoe support system. For example, residual forces as a consequence of:

- shoe guide misalignment and
- beam twist.

This latter property implies an analysis that assumes a worn beam and that no restraint remains in the system to "force" conformal/nonconformal contact of the shoe with the wheel.

This development was performed to provide a model to be used to develop a methodology for evaluating improved brake beam designs. The model has been completed.

This TD describes the analysis of forces on a hypothetical brake beam considering typical variables associated with beam, beam extension, and brake beam pocket design.

In this TD, the case for the wheel rubbing on the shoe from the top of the shoe to the bottom is examined. Associated TDs examine forces due to a rubbing action in the opposite sense.[1,2]

METHODOLOGY

The methodology in this analysis uses the superposition of forces:

- The forces developed for zero tapered shoe wear are superimposed on the model of the unit brake beam to be analyzed.[3]
- Forces and moments are then superimposed on this model to account for the actual lines of actions of the forces based on the beam and brake pocket geometry.
- The difference between the actual force field and the theoretically correct one is then analyzed.
- The model is 2-dimensional: forces and moments on the beam are projected onto a plane orthogonal to the center of rotation of the axle.
- A sum of forces and moments on the beam is then made; this sum should then be zero for zero tapered shoe wear.
- Any resulting moment can be quantified and serves as an indication of the tapered shoe wear to be expected.

Arrangement of a Typical Unit Brake Beam, Extension and Side Frame Pocket

Unit brake beam assemblies used in three-piece North American trucks all have the following basic characteristics (Figure 1):

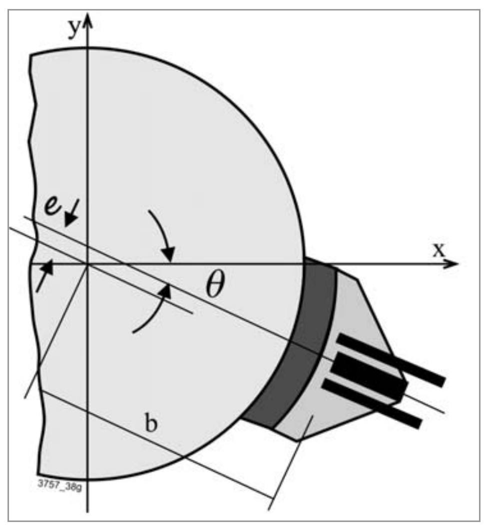

Figure 1

- A brake beam pocket in the truck side frame that has a center line that focuses on the wheel center with an eccentricity, e, orientated at an angle θ to the horizontal.
- A brake beam extension, engaging with the pocket to provide a sliding joint.

- The reason for the eccentricity, e, is possibly to counter tapered shoe wear as it "forces" contact at the bottom of the shoe, if the free play between the brake beam extension and the pocket is limited.
- The brake beam extension can be "twisted" relative to the pocket center line at an angle Φ (Figure 2). The reason for this twist is to prevent "droop" of the brake beam in the slide. It also "forces" contact at the bottom of the shoe, if the free play between the brake beam extension and the pocket is limited.

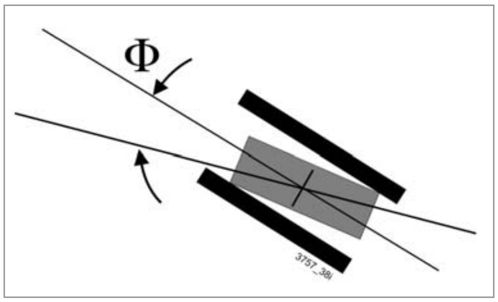

Figure 2

Neither the effect of e or Φ will be considered. It is argued that both, although possibly initially effective, will result in beam and shoe wear that will negate their effect over time.

An important dimension is the distance, b, from the leading edge of the brake beam extension to the wheel center (Figure 1). Reactions to the brake forces will occur at this leading edge. Also, b varies with shoe wear and this effect will be taken into consideration.

Analysis of Brake Beam Forces

The analysis is based on the model depicted in Figure 3. All force vectors are drawn as if acting on the shoe/brake beam assembly.

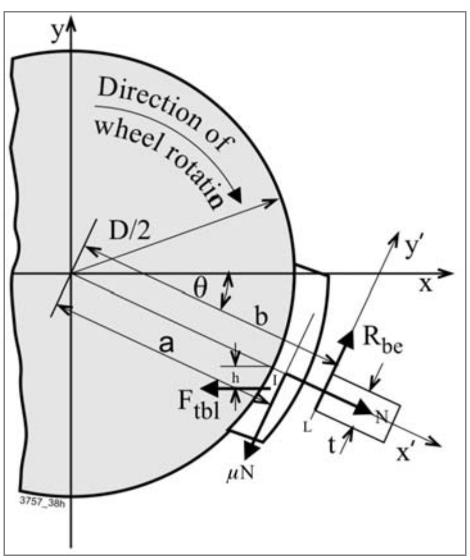

Figure 3

The forces reacting to the brake shoe/wheel interface for even shoe wear and developed in TD-08-054 are represented by N and μN.[3] They act at a distance, a, from the wheel center as defined in Equations 3 and 7.[3]

In order to generate these forces, the truck brake lever must apply a force, F_{tbl}, to the center of the beam. In this analysis, F_{tbl} is assumed to act at a height, h, below the intercept, I, of the wheel tread and the center line of the brake pocket/brake beam extension. In many beam assemblies, h = 0, although rough measurements on one beam assembly suggests that h approximates to ½ inch.

F_{tbl} is assumed to act horizontally in this analysis. This is not necessarily so. The effects of a vertical component on the vertical brake lever as well as the effects of the weight of the truck brake rigging must be included in a specific and more detailed analysis.

The reaction to the frictional braking force, μN, must occur at the leading edge of the brake beam extension, L. This force is denoted by R_{be}. This point, I, is where the component of F_{tbl}, acting at right angles to the center line of the brake pocket/brake beam extension, reacts on to brake beam extension. Contact is assumed to be frictionless; it is argued that vertical vibrations in the unsuspended rigging will result in relief of frictional forces.

The component of F_{tbl}, acting parallel to the center line of the brake pocket/brake beam extension, equals N.

Using the x'y' axes:

ΣFy':

$$R_{be} = \mu N + F_{tbl} \sin\theta \qquad (1)$$

ΣFx':

$$F_{tbl} \cos\theta = N \qquad (2)$$

ΣM about L:

$$(b-a)\mu N + [(b-D/2)\sin\theta + (t/2 - h)\cos\theta]F_{tbl} = U \qquad (3)$$

Where:

U = The "unbalanced moment" on the shoe/beam assembly that must be balanced by a wheel/shoe force distribution that must, in turn, produce tapered shoe wear

D = wheel diameter

t = thickness of the brake beam extension

b = distance from the wheel center to the leading edge of the brake beam extension

From Equations 2 and 3:

$$(b-a)\mu N + [(b-D/2)\sin\theta + (t/2 - h)\cos\theta](N/\cos\theta) = U \qquad (4)$$

Or:

$$N\{(b-a)\mu + [(b-D/2)\tan\theta + (t/2 - h)]\} = U \qquad (5)$$

If U = 0:

$$(b-a)\mu + (b-D/2)\tan\theta + (t/2 - h) = 0 \quad (6)$$

Or:

$$h = (b-a)\mu + (b-D/2)\tan\theta + t/2 \quad (7)$$

DISCUSSION

For the case of:

a = 18.84 inches[3]

b = 20 inches (This dimension varies with wheel diameter and shoe wear between approximately 21 inches and 18.5 inches)

D = 36 inches

T = 2 inches

θ = 14 degrees

μ = 0.3

h = 1.848 inches for a new shoe or

h = 0.89 inch

Consequently, in order to ensure even brake shoe force, the applied load on the beam should be positioned between 1.85 and 0.89, or, on average, 1.37 inches *below* the intercept of the pocket (or brake beam extension) center line.

Generally, the applied load on the beam is positioned on this center line.

This may be the cause for shoes worn tapered to the top. Before this conclusion is drawn, an analysis must be made of the forces on the beam when the wheel rubs on the shoe from bottom to top.[1]

CONCLUSION

Equation 7 suggests that there is a brake beam arrangement, other than the ideal defined in reference 1, in which moment equilibrium (and thus zero shoe tapered shoe wear) can be approximated. This is under the following conditions:

- The brake shoe frictional force is reacted at a distance, b, from the center of the wheel
- For the specific case of the wheel rubbing across the shoe from top to bottom
- For the case of the brake beam activating force being applied at a height, h, beneath the intercept of the center line of the brake pocket/beam extension and the wheel tread

The resulting optimal position is estimated to be approximately 1.37 inches *below* the intercept of the pocket (or brake beam extension) center line.

Equation 7 also indicates that this arrangement is a function of the coefficient of friction of the brake shoe material. This is a less than an ideal solution; the equation developed in TD-08-054 is independent of shoe force and friction coefficient and only a function of shoe geometry.[3]

This arrangement is also a function of the thickness of the brake shoe; as a shoe wears in service, a mean thickness will have to be assumed.

Forces for the case of the wheel rubbing from the bottom of the shoe to the top are analyzed in TD-08-056.[1] This will define further values for h.

TD-08-057 discusses solutions to address the effects of rubbing direction as well as other possible designs to provide an improved brake rigging and address the issues of:[2]

- Tapered shoe wear
- Beam wear
- Uneven brake forces

This TD will also utilize the results from Equation 7 to predict the rate of shoe tapered wear as a partial verification of the analysis method described in this series of TDs.

REFERENCES

1. Tournay, Harry M. December 2008. "Forces on a Unit Brake Beam II." *Technology Digest* TD-08-056, AAR, TTCI, Pueblo, CO.
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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.