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Forces on a Unit Brake Beam II

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Summary

The forces on a unit brake beam, when the wheel rubs on the brake shoe from bottom to top, suggest that tapered shoe wear would be eliminated if the point of application of the braking load on the beam were to be approximately ½ inch below the intercept of the center line of the pocket/brake beam end extension and the wheel tread.

This is in contrast to the findings by Transportation Technology Center, Inc. for the case of the wheel rubbing from top to bottom of the shoe, where this optimum was found to be 1.37 inches[1] and has led further to the determination of a compromise position.[1]

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 *Technology Digest* (TD) is the third 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]

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

This research is a 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.

A literature review performed by TTCI 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:[3]

- 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 taper 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 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.[1]

Consequently, the forces on a shoe for zero tapered wear, were developed for a shoe that is:[3]

- 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
- 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.

TTCI provided a model to develop a methodology for evaluating improved brake beam designs.

A first phase in the further development; i.e., the analysis of forces on a hypothetical brake beam considering typical variables associated with beam, beam extension, and brake beam pocket design is described in TD-08-054 for the case of the wheel rubbing on the shoe from the top to the bottom.[3] This TD analyzes forces due to a rubbing action in the opposite sense.

METHODOLOGY

As described in TD-08-055,[2] the methodology used 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 model is 2-dimensional; forces and moments on the beam are projected onto a plane defined by rotating by the taping line on the wheel tread.
- 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 taper 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, as Figure 1 shows.

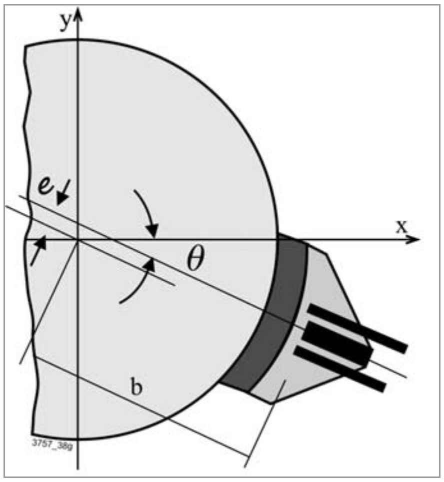

Figure 1

- 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.

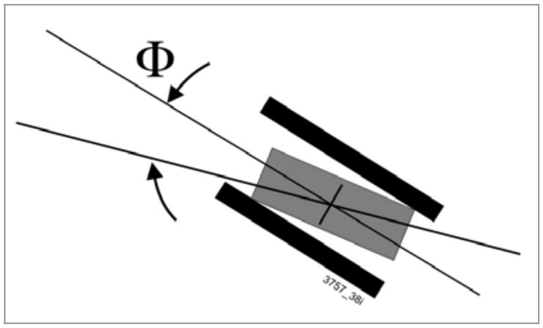

Figure 2

Neither the effect of e or Φ will be considered. It is argued that both, although possibly initially effective, will result in beam or 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: it will be seen that 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 and reference 1, excepting that the direction of rotation of the wheel and the frictional shoe force are reversed.

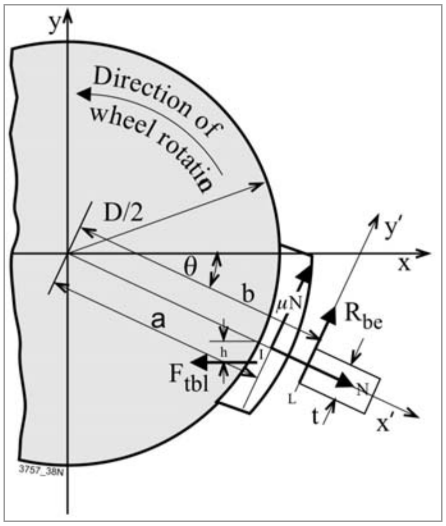

Figure 3

The reaction vector, R_{be}, can be either up, zero, or down, depending on the magnitude of the coefficient of friction (μ), as will be shown later in this analysis.

All forces are drawn as if acting on the shoe/brake beam assembly.

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.

Up to this point, the analysis has been identical to that in TD-08-055 where wheel rotation was in the opposite sense. In this instance, where the wheel rubs the brake shoe from bottom to top, reactions at the brake pocket can be complex to analyze.[2] The reason for this is the beam *may* “float” in the pocket with little in the way of reaction forces. Under these conditions sum of forces in the x’ and y’ directions:

ΣFy’:

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

ΣFx’:

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

Substituting Equation 2 into Equation 1:

$$\mu = \tan\theta \qquad (3)$$

θ is typically 14°, giving tan θ = 0.25.

μ ranges typically between 0.2 to 0.4 depending on the specific pressure between the shoe and the wheel as well as the rubbing speed. The beam thus experiences anything in the range of limited reaction forces upwards on the beam, to zero force, as described above, to downward reaction forces. Each of these conditions needs to be analyzed separately.

(i) Consider, first moment equilibrium when the beam “floats” in the pocket, $\mu = 0.25$, $R_{be} = 0$, and equations 1, 2 and 3 apply:

ΣM about L:

$$(b-a)\mu N - [(b-D/2)\sin\theta - h]F_{tbl} + t/2\, N = U \qquad (4)$$

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 wheel 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

for U = 0 and $F_{tbl} = N/\cos\theta$:

$$(b-a)\mu\cos\theta - [(b-D/2)\sin\theta - h + t/2\cos\theta = 0 \qquad (5)$$

or:

$$h = (b-a)\,\mu\cos\theta - (b-D/2)\sin\theta + t/2\cos\theta \qquad (6)$$

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

$\theta = 14$ degrees

$h = 1.6$ inches for a new shoe or $h = 0.16$ inch

Consequently, in order to ensure even brake shoe force for $\mu = 0.25$, the applied load on the beam should be positioned between 1.6 and 0.16, or, on average, 0.88 inch *below* the intercept of the pocket (or brake beam extension) center line.

(ii) If μ is less than 0.25, the beam will react to the bottom of the pocket as a consequence of F_{tbl}, and R_{be} will be directed upwards at L.

$\Sigma Fy'$:

$$F_{tbl} \sin\theta = R_{be} + \mu N \qquad (7)$$

$\Sigma Fx'$:

$$F_{tbl} \cos\theta = N \qquad (8)$$

ΣM about L:

$$(b-a)\mu N + t/2\, N - [(b-D/2)\sin\theta - h]F_{tbl} = U \qquad (9)$$

For $U = 0$ and $F_{tbl} = N/\cos\theta$:

$$h = (b - a + t/2)\cos\theta - (b - D/2)\sin\theta \qquad (10)$$

Consequently, in order to ensure even brake shoe force for $\mu = 0.2$, for example, the applied load on the beam should be positioned between -0.25 and 0.13 inch, or, on average, on the intercept of the pocket (or brake beam extension) center line.

(iii) If μ is greater than 0.25, the beam will react to the top of the pocket as a consequence of Ftbl, and Rbe will be directed downwards towards L.

$\Sigma Fy'$:

$$F_{tbl} \sin\theta = \mu N - R_{be} \qquad (11)$$

$\Sigma Fx'$:

$$F_{tbl} \cos\theta = N \qquad (12)$$

ΣM about L produces the same equation for h as in Equation 10 with results that are different based on the value for μ.

For $\mu = 0.4$:

Again, in order to ensure even brake shoe force for μ up to 0.4, for example, the applied load on the beam should be positioned between 0.35 and 0.4 inch, or, on average, 0.375 inch below the intercept of the pocket (or brake beam extension) center line.

CONCLUSIONS

An analysis of the forces on a unit brake beam, with the wheel rubbing on the shoe from bottom to top, suggest that the point of application of the beam force should be generally closer to the intercept of the pocket/beam extension center line and the surface of the wheel. The position is a function of the coefficient of friction.

For friction coefficients equal to or greater than 0.25, the value for h should be between 0.88 inch and 0.375 inch, or, for example, 0.5 inch. Considering the requirement for rotation in the opposite direction, a possible optimum for h is about 1 inch.[2] Interestingly, a rough measurement of a car's brake rigging suggests that in that design the value for h might have been ½ inch. If this is so, it might be expected that the shoes on that car might still wear tapered to the top of the shoe.

TD-08-057 discusses this matter in more detail.[1]

REFERENCES

1. Tournay, Harry. December 2008. "A Review of Forces on a Unit Brake Beam," *Technology Digest* TD-08-057, AAR, TTCI, Pueblo, CO.
2. Tournay, Harry. December 2008. "Forces on a Unit Brake Beam I," *Technology Digest* TD-08-055, AAR, TTCI, Pueblo, CO.
3. Tournay, Harry. December 2008. "Analysis of Wheel / Brake Shoe Forces and Reactions for Zero Tapered Shoe Wear," *Technology Digest* TD-08-054, AAR, TTCI, Pueblo, CO.
4. Tournay, Harry. November 2008. "A Review of the Performance of Brake Rigging in Three-Piece Trucks," *Technology Digest* TD-08-046, AAR, TTCI, Pueblo, CO.