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Analysis of Wheel and Brake Shoe Forces and Reactions for Zero Tapered Shoe Wear

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Summary

The forces acting between wheel and brake shoe for even (nontapered) shoe wear are developed for a brake shoe with homogeneous material. The optimum position for both applying the shoe force as well as reacting the frictional forces developed at the wheel/shoe interface is developed for zero tapered shoe wear. Nonhomogeneous shoes (e.g., TreadGuard®) may require a modified analysis depending on the wear rates, coefficients of friction (μ), and geometry of the materials used in this shoe.

Transportation Technology Center, Inc. performed this analysis to further analyze the forces within the brake beam and truck brake rigging as presented in associated *Technology Digests*^{1,2,3} so that the reasons for tapered shoe wear, excessive beam wear, and uneven shoe forces (and wheel temperatures) can be established.

Tapered shoe wear and brake beam wear are considered two of the root causes for poor brake performance and result 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 information can now be used to establish the role of other forces on the brake beam and their role in relation to all the forces acting on the rigging of the three-piece truck. Full analyses of these forces are presented in references 1, 2, and 3.

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



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 conducted by Transportation Technology Center, Inc. suggests total costs attributable to the need for improved rigging design may be greater than \$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 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 forces in the brake rigging have been adequately defined, whereas the required forces and reactions on the shoe for even shoe wear are currently less than well defined.⁴

This TD provides a fundamental analysis of the forces at the wheel/shoe interface as well as the resulting reactions required to ensure even brake shoe wear. It forms the basis for subsequent analysis of the forces on brake shoes and head assemblies in three-piece trucks. This will, in turn, form the basis for a comprehensive evaluation of alternative rigging designs prior to soliciting suitable designs for further analysis and test.

GENERAL DESCRIPTION OF THE ANALYSIS

(See pages 3 and 4 for a detailed analysis.)

The analysis was performed to develop and understand the relationship between the forces at the wheel/shoe interface and the forces and reactions on the brake shoe to ensure even brake shoe wear. Below is a general description of the analysis approach used.

The definition of the specific radial pressure (lb/in²) between the wheel and the shoe for even shoe wear.

The shoe is assumed to be rigid and to press on the wheel with force acting along the x-axis, as Figure 1 shows.

For even wear of the shoe in the x-direction, the specific radial pressure is developed:

$$P_n = K \cos \alpha \tag{1}$$

This implies that the specific radial pressure between wheel and shoe decreases from a maximum of:

$$P_n = K \text{ to:}$$

$$P_n = K \cos (\beta/2)$$

Where the length of the shoe:

$$\ell = (D/2) \times 2\sin (\beta/2) = D \sin (\beta/2) \tag{2}$$

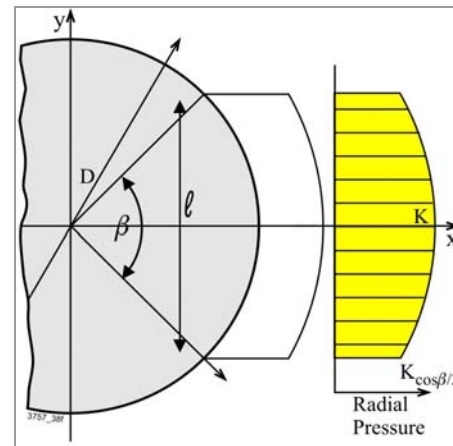


Figure 1

The shoe is assumed to be pin-connected at the point of application of the brake force.

The position of the pin joint, O, relative to the shoe and wheel for even shoe wear

For even shoe wear, the moments generated by the forces between wheel and shoe must be equal and opposite to those generated by the reactions at the pin joint at O. Consequently, and with reference to Figure 2:

- By inspection
 - The y (vertical) components of the radial pressure, p_n , are equal and opposite and do not contribute to the sum of moments or of y-forces
 - The x (horizontal) components of the radial pressure, p_n , are equal to the applied shoe force, N with zero moments about any point on the horizontal axis
 - The x (horizontal) components of the frictional forces, $\sum \mu p_n$, are equal and opposite
 - The y (vertical) components of the frictional forces, $\sum \mu p_n$, are equal to the shoe pin reaction, μN

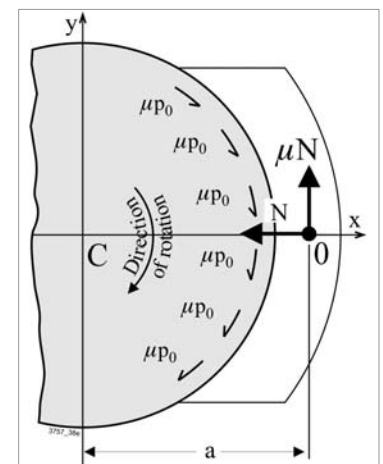


Figure 2

- The remaining equality to be determined is the overall sum of moments, which, for convenience, are taken about the wheel center, C. From this equality, the position of the pin joint, O, is a distance, a, from the wheel center where:

$$a = 2D \sin(\beta/2) / (\beta + \sin \beta) \quad (3)$$

By inspection, this relationship holds true for either sense of rotation of the wheel.

Consequently, there is only one position for the pin of a pin-jointed shoe relative to the wheel that will result in even shoe wear. Any other pin position requires the shoe to be constrained in rotation and the application of a moment. By inspection, this moment reverses with a reverse in the sense of the rotation of the wheel.

Interestingly, from Equation 2, for a wheel diameter of 36 inches and a shoe length of 13 inches:

$$a = 18.84 \text{ inches, or } 0.84 \text{ inches off the surface of the wheel tread}$$

The brake beam extension engages with the unit brake beam pocket in the side frame a minimum of approximately 2 inches further away from the tread of the wheel than the ideal point (0.84 inches from the surface of the tread). This will induce uneven wear on the shoe given that all other effects are zero, which they are not. The total effect of this finding together with other forces on the shoe will be discussed in a future TD.

CONCLUSIONS

The fundamental forces generated at the wheel/brake shoe interface have been developed for a shoe with homogeneous shoe material.

The ideal position of the brake shoe action and reaction forces for even shoe wear has been calculated.

This information can now be used to establish the role of other forces on the brake beam and their role in relation to all the forces acting on the rigging of the three-piece truck. Full analyses of these forces are presented in references 1, 2, and 3.

REFERENCES

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Derivation of Optimum Position for Application of Forces and Reactions to a Brake Shoe for Even Shoe Wear

Consider the resulting forces for even shoe wear. This wear, W_h should be equal over the surface of the shoe in a direction parallel to the normal force applied to the shoe (Figure 3).

For this to occur, the radial wear, W_r , will decrease from a maximum (equal to W_h) to a minimum at the ends of the shoe where α is a maximum.

The rate of wear in the radial direction:

$$W_r = K v p_n$$

Where:

- C = Constant, v = circumferential velocity,
- P_n = normal (radial pressure in units of force/unit area)

The rate of wear in the direction of the normal load applied to the shoe, W_h :

$$W_h = W_r / \cos \alpha = C v P_n / \cos \alpha$$

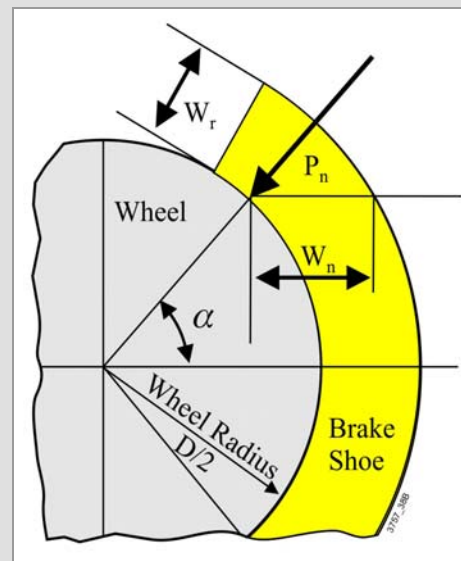


Figure 3

Therefore:

$$P_n = \cos \alpha (W_h / C v)$$

$$\text{or: } P_n = K \cos \alpha \quad (4)$$

thus, if:

$$K = (W_h / C v), \text{ the maximum } P_n = K \text{ if } \alpha = 0$$

Examine, now, the forces on the complete shoe (Figure 4):

In order to avoid rotation of the shoe (which would result in more rapid wear at A or B, depending on the direction of rotation of the wheel), the shoe is pin-jointed at a point, O. At this point all moments, either as a result of the applied or frictional forces and reactions, are zero. The position, O, is defined as the distance, a, from the wheel center.

Consider the applied force, P, as a function of the radial pressure, P_n:

$$N = 2 \int_0^{\beta/2} (p_n)(D/2)(\partial\alpha)(w)(\cos\alpha)$$

from (1):

$$N = 2 \int_0^{\beta/2} (p_n)(D/2)(\partial\alpha)(w)(\cos\alpha)$$

from (1):

$$N = 2 \int_0^{\beta/2} (K \cos\alpha)(D/2)(\partial\alpha)(w)(\cos\alpha) \quad (5)$$

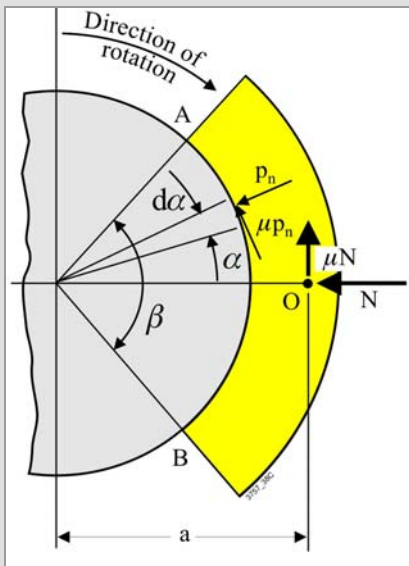


Figure 4

Where w is the brake shoe width.

$$N = DwK \int_0^{\beta/2} \cos^2 \alpha d\alpha$$

$$N = DwK \int_0^{\beta/2} (1/2 + 1/2 \cos 2\alpha) \partial\alpha$$

$$N = DwK [\alpha/2 + (\sin 2\alpha)/4]_0^{\beta/2}$$

$$N = DwK (\sin \beta + \beta)/4 \quad (6)$$

For moment equilibrium about C:

$$\sum M_C = (\mu N)(a) - 2 \int_0^{\beta/2} (\mu)(p_n)(D/2)(\partial\alpha)(w)(D/2)$$

or :

$$\mu Na = (D^2/2)(\mu)wK \int_0^{\beta/2} (\cos\alpha) d\alpha$$

$$\mu Na = (D^2/2)(\mu)wK (\sin \beta/2)$$

or :

$$a = \frac{2D \sin \beta/2}{\beta + \sin \beta} \quad (7)$$