Means for Improving the Steering Behavior of Railway Vehicles

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Railway transportation has two basic advantages that provide powerful incentives for expanding its use. First, the railroad can be considered an open-face roller bearing. Heavy loads are moved with very little friction. Second, the operation of transportation vehicles in trains is economical in terms of the labor and land required, and the wind resistance of a train is very low.

One of the leading concerns of the designers of early coal hauling systems was the reduction of the rolling resistance by moving the vehicle wheels up out of the mud (1). The high cost of a hard running surface led to the use of curbs, and in time the guidance was transferred to the wheel in the form of a flange. The first cars were two-axle wagons that operated much better on straight track than on curves. The curving problem and the need for more axles led to the invention of trucks that swivel with respect to the car body. This reduces the curving problem by reducing the angle of attack between the flange and the rail, but the two axles are still parallel and at least one of them continues to have an angle of attack.

Flange wear can be a problem on straight track also. With a metal wheel and rail, alignment is very critical. For example, it is difficult to obtain adequate precision for independently rotating wheels such as were used on the early vehicles. The solution to this problem was the development of rotating axle wheelsets in combination with a tapered wheel tread. The self-aligning tendency of such wheelsets acts to prevent flange contact on straight track and helps to reduce flange pressure in curves. Unfortunately this steering moment also causes a hunting oscillation of the wheelsets at high speeds.

Wheel and rail manufacturers have made many major improvements in the metallurgy of these items over the years, but there is little opportunity to make further improvements, and the interaction of the wheel and rail must now be improved.

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CURRENT ACTIVITIES

Three specific means to improve the steering behavior of railway vehicles are under development.

1. An all new truck is being tested by the research department of the Canadian National Railways (Figure 1) (2, 3, 4). This design provides for a steering motion of the wheelsets in curves and a damping of the wheelset hunting. This truck was designed with the aid of computer studies of curving and stability, and the tests are confirming the computer predictions in both areas. The running position of the axles under loaded car conditions is nearly radial in curves up to 6 deg, and there is a substantial reduction of the angle of attack in sharper curves. No wheelset instability has been observed at speeds up to 124 km/h (77 mph), the fastest test run performed to date.
2. A modified conventional freight car truck now designated the DR-1 (Figure 2) is being tested on the DOT test track at Pueblo. The parameters of this truck that govern curving and high-speed stability are virtually identical to those of the Canadian National test truck, but because these trucks use standard truck side frames, the radial curving is limited by the existing side frame clearances to about 4 deg of track curvature. However, there is still a substantial reduction of the angle of attack even in sharper curves, and therefore much lower values of flange forces than for conventional trucks.
3. A high-speed transit car that uses a positive steering arrangement in addition to the basic construction feature of the two truck designs described above (Figure 3) has been designed. The addition of the positive steering provides a greatly expanded range of radial curving and lowers the flange forces below the values achieved with the freight car designs.

All of these designs use load-carrying members similar to the side frames of conventional three-piece trucks. In addition, they use two members called steering arms, each of which is attached to the bearings of one of the axles. The steering arms are connected to one another in the center of the truck. This connection is flexible in the sense that it permits the yaw motion of the individual axles that is required for the axles to be radial in a curve:

It is rigid in the sense that it transmits the forces generated by steering (and traction and braking) from one axle to the other, while allowing only small independent yaw movements of the axles.

All of these designs incorporate flexible means for transmitting weight from the side frames to the axles without excessive restraint on steering motion. In the simpler designs, this stiffness is the primary source of yaw stiffness. In trucks designed for transit cars, it is supplemented by the positive steering arrangement.

In all of these designs, the steering motions within the truck take place across elastomeric members that are not subject to friction and wear. The stiffness of these members has been chosen to give the desired curving and high-speed stability with the worn wheel profile that will exist for most of the service life of the vehicle so that the performance of these vehicles should not vary materially during their lifetime.

TRUCK STEERING MECHANICS

The steering problem can be summarized as consisting of two parts: the wear and noise associated with operation around sharp curves (Figure 4) and the wheelset hunting behavior. Recent theoretical studies and test work indicate that these problems can be solved.

In the mid 1960s, an increasing number of investigators (5, 6, 7, 8) began to analyze the dynamics of wheelsets and the flange-free steering of rail vehicles, and a series of experimental and theoretical studies with truck steering (9) was begun. All of these investigators agree that the wheel tread profile or conicity is an important component in determining the curving and stability characteristics of any truck, that low conicity reduces the hunting problem, and that high conicity increases curving capabilities and reduces wear.

However, the truck designer is really not free to choose a profile. There is a tendency for a common worn-wheel profile to develop that is independent of the initial profile. This profile has a slightly hollow shape that matches the profile of the rail head. Other profiles will have higher contact stresses and will wear more rapidly. A truck designer must accept this profile and choose the other parameters available to accommodate it.

The two major parameters that can be selected arbitrarily are the interaxle lateral stiffness and the interaxle yaw stiffness. Wheelset stability requires greater interaxle lateral stiffness than is available with a conventional three-piece truck. To improve curving ability, the interaxle yaw stiffness must be lower than that of conventional trucks. (Most theoretical studies of these two parameters are limited to the region of flange-free operation because of the mathematical difficulties involved in representing flange contact.)

The experimental studies of curving, however, have considered flange contact and show that, with high values

Figure 1. New steering-type freight car truck (Canadian National Railways).

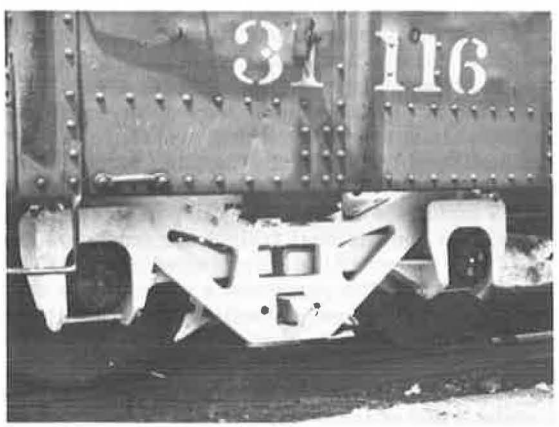


Figure 2. Three-piece freight car truck modified to include steering arms.

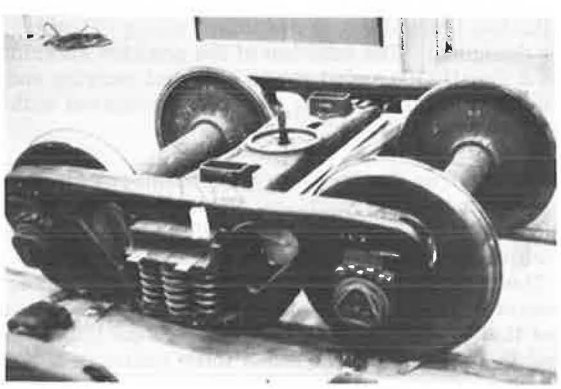


Figure 3. Model of radial type transit truck using a steering linkage.

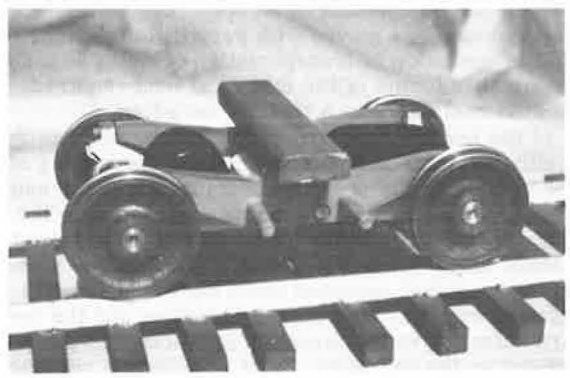
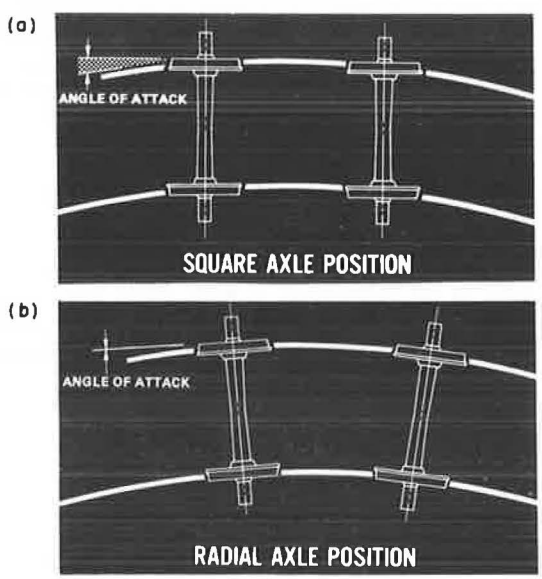


Figure 4. (a) Wheel-axle position of square truck, showing angle of attack; (b) wheel-axle position of radial truck, showing elimination of angle of attack.



of interaxle lateral stiffness, a pair of wheelsets tend to align themselves radially even with flange contact if the wheel conicity is insufficient to permit the individual wheelsets to run freely in a radial position. This self-aligning effect can be used by itself in a simple truck to provide the steering, or in a more sophisticated truck to refine the precision of a steering linkage.

It has also been shown experimentally and analytically that steering arms must be used to obtain the desired high value for interaxle lateral stiffness. If the axle restraints are only to a rigid frame, the contribution to the interaxle lateral displacement made by the rotation of the frame against the finite yaw stiffness between the frame and the axles will be so great that the interaxle lateral stiffness will not be high, even if the lateral stiffness between the ends of the axles and the frame is made infinite.

CONCLUSIONS

The accumulated experimental and theoretical data on the steering behavior of railway car trucks indicate that the truck designs described in this paper can effect a considerable reduction in wheel wear, rail wear, truck component wear and fatigue, car body component wear and fatigue, derailments, noise, traction power consumption, and constraints on the layout of rail transportation systems.

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