DISCUSSION

S. G. Guins

Mr. Wickens represented a very comprehensive analysis of lateral dynamics of railroad vehicles. Although his analysis and experimental data deal primarily with single axle suspensions, I am sure the method can be extended to truck mounted cars.

In our own experience, dynamic instability of a four-wheel truck was manifested as early as 1947, when we introduced the first lightweight streamlined passenger train on the Northern Region. The schedule called for covering 150 miles between Grand Rapids and Detroit, Michigan in 150 minutes or at the average speed of 60 mph. To do this, the train operated at 80 to 100 mph whenever possible. These cars developed very annoying 3 to 3.5 cps lateral oscillations. We later observed similar action in freight cars equipped with roller bearings operating at speeds above 60 mph. In both cases, we learned to control this action by introducing angular damping into the system.

Our approach to this problem started by a series of tests designed to pinpoint the source of disturbance and lead us to the conclusion that this phenomenon was a case of self-excited vibration with forces developed between the wheel and rail.

In the case of passenger cars, starting profile of wheel thread controlled the length of service before the instability would occur:

- with 1/80 taper 18,000 miles
- with semicylindrical 33,000 miles

and this was very consistent.

In developing corrective means, we applied the Caster theory developed for the nose wheel of the tricycle landing gear for airplanes. This is a so-called kinematic shimmy that was controlled by the introduction of angular damping and described in references [26, 27, and 28].

To apply this theory to a railroad truck, we had to make some simplifying assumptions based on the symmetry of truck. Fig. 9 shows the two steps of the logic we used. Lateral flexibility of the wheel and rail was developed experimentally [30].

The results of this analysis, as far as damping requirements and frequency of movement, corresponded closely with experimental results in the field.

We applied this Caster theory later to the design of suspensions for what we called Train "X." In this case, by inclining tie rods (Fig. 10), we achieve stability by allowing the axle to adjust its angular position relative to the truck and the car body.

Later when we designed Roadrailers (Fig. 11), we again built in lateral, longitudinal, and angular freedoms by suspending the axle on swing hangers.

While the approach to the solution of dynamic instability we encountered was different from the one described by Mr. Wickens,

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2 Numbers in brackets designate Additional References at end of Discussion.
In keeping with his main theme that railway vehicles should be designed such that guidance is achieved by creep forces rather than flange contact, Mr. Wickens states that linearized disturbance analysis is relevant. While this is usually true, there are certain instances where nonlinear effects may markedly affect the dynamics. A case was illustrated by Dr. Matsudaira in [32]. For certain designs and small rotations, the moment opposing track rotation relative to the car was proportional to angular displacement. However, for large angular displacements the friction due to the side bearers became important. Thus, for a certain range of speeds below the critical speed (calculated on the basis of linear theory), the hunting motion would be stable for disturbances having small amplitudes but could have a stable limit cycle of large amplitude if the disturbances were sufficiently large. This point is made to emphasize that careful thought should be given to the possible occurrence and effects of nonlinearities in a system before linearized techniques are applied.

There is a lack of information on the range of values of creep to be expected in practice. This raises two possible questions. First, how sensitive to variations in the creep characteristics are the boundaries for the limits of free curving shown in Figs. 7 and 8? Second, do the stability boundaries in Figs. 7 and 8 (which are assumed to be for tangent track) change when the vehicle runs on curved track?

It is not immediately apparent that "...to achieve stable running at very high speeds and flange-free curving on existing main-line track curvatures, a two-axle vehicle with flexible, damped suspension is superior to a bogie vehicle." One of the reasons given for this statement by Mr. Wickens is that for a truck to be stable at high speeds, the rotational stiffness between the truck and car body must be high. Unpublished work by Professor D. E. Newland and work by Dr. N. K. Cooperrider [33] indicate that for their truck models, the rotational stiffness of the truck relative to the car body does not significantly affect the critical speed. On the other hand, both Newland and Cooperrider show that the primary suspension stiffness between axles and truck frame have a major influence on the critical speed. Dr. Matsudaira in [32] indicates that a critical speed of about 200 mph can be obtained with zero rotational stiffness of the truck with respect to the body (although he shows a large increase in critical speed with a large increase in rotational stiffness). These other works thus seem to indicate that the critical speeds could be made sufficiently high with low rotational stiffness of the truck relative to the car. If this is true, this low stiffness should also help provide flange-free curving. Thus, this throws some question on the statement that two-axle vehicles are superior to "bogie vehicles."

The wheelset or truck and associated suspension may be analyzed as a closed-loop mechanical guidance system. The input to this system, even for curved track, would be the error between the track centerline and the lateral position of the wheelset or truck. Such an approach has been applied to a single wheelset by Mr. C. K. Benington [34]. It emphasizes the guidance function of the suspension and indicates how the various parameters affect the response. In so doing, it helps to illustrate how the response may be improved. It may be fruitful to extend this analysis to include additional degrees of freedom and wheel profile effects. This may lead to new techniques for achieving stability with good guidance.

Additional References

34 Benington, C. K., “The Railway Wheelset and Suspension Unit as a Closed-Loop Guidance Control System: A Method for
T. Matsudaira

1. In your paper you state the basic theory to design a vehicle with good dynamic stability and satisfactory steady-state curving performance. Yours is an excellent idea, to which we too fully agree.

Our experience, however, tells that the designing of such a vehicle is extremely difficult because in general, good dynamic stability is incompatible with good curving performance. We shall be very much obliged if you would be kind enough to demonstrate an actual calculation for such designing.

2. You treat the dynamic stability of a vehicle with linear theory, to which also we agree.

In this case, however, do you not think it necessary to consider the effect of lateral vibrational amplitude of wheelset upon the stability? Fig. 12 shows a part of the results of our calculations carried out about the hunting stability of a two-axle wagon with wheels having similar tire profile as shown in your paper. According to this figure, the stability of the wagon, particularly to the secondary hunting, decreases with an increased vibrational amplitude of wheelsets. Thus we are of the opinion that the behavior under large amplitude must be checked in the use of profiled wheels.

What do you think about this?

H. B. Weber

I would like to congratulate and at the same time thank Mr. Wickens for giving us this fine paper.

This paper is certainly a more than comprehensive review of the research work which has been done to investigate this complex problem of lateral stability of railway vehicles. I believe there is no doubt in anybody's mind about the tremendous importance of this work especially for high speed railroad operation.

Other participants in this conference have commented about their experience in the field of high speed passenger trains operating at speeds in excess of 100 mph. My comments are based on experience in freight service and high speed tests of freight cars at speeds up to 95 mph.

Is lateral instability, which as defined by Mr. Wickens is a gross sliding of the wheels on the rails, a problem in freight service? I like to answer this question with a definite and unqualified yes.

Light freight cars or lightly loaded freight cars equipped with conventional trucks having a worn-in tread profile are, in general, laterally unstable at speeds above 55 mph. Under full load the critical speed is raised approximately 15 mph. Road tests which our company has run recently in cooperation with the Santa Fe Railway have confirmed these factors clearly. Reports received from one railroad indicate that some types of cars experience this instability at speeds as low as 40 mph. If operating speeds are to exceed these critical speeds, a serious problem is developed.

The effects of lateral instability or unstable hunting have been known to all of us for many years. Fairly and excessive equipment, that is, wheel, truck, and car component wear, of freight cars operated in passenger service have been known for a long time. The same uneconomical wear characteristics were also found within the last few years on high speed freight trains. However, according to my knowledge, it was not recognized as being related to lateral instability. I believe we can now say that lateral instability or unstable hunting is the major cause of this accelerated wear. Our own experience confirms the statements of the author with respect to the importance of lateral stability relative to wear.

Further, our experience also justified the addition of lading damage due to unstable hunting as an important factor. When, due to unstable hunting, lateral accelerations can become almost twice as large as vertical accelerations on a car equipped with conventional freight car trucks, we have a lading damage problem. This was also found in our recent tests.

Can we, in our freight service field, use the results of these advanced research studies outlined in the author's paper? Again I would like to answer with an unqualified yes. When these methods are applied for analysis, critical speeds of lateral instability can fairly accurately be calculated and predicted. When these methods were applied as an aid in the design of an improved high speed freight truck, lateral instability was completely avoided in our recent tests at operating speeds up to 95 mph, which was the operational speed limit. These tests were conducted with light and loaded cars having new and worn wheels. If at all necessary, our test results could serve as confirmation in addition to the results achieved by the British Railway to which Mr. Wickens refers.

In conclusion, I would like to say that we not only can, but must, use a design approach as outlined by the author if we are interested in designing equipment with the best possible performance at higher speeds. Again we want to congratulate Mr. Wickens and at the same time thank him and the other researchers for their great contribution in this field.

Author’s Closure

I am grateful to Mr. Weber for his kind remarks and his description of his experience with freight cars. It is very encouraging that relatively complex theories can be related to practical experience in so direct a way. In addition, the writer is very pleased to learn of the application of these techniques in the design of new vehicles, and looks forward to hearing of the results of service experience with them.

I would like to thank Mr. Guins for his kind remarks and for his interesting comments. The description of the dynamic instability given by him corresponds very closely to the indications of the theoretical analysis, and the effect of wear is very representative of results that I am familiar with. The similarity between the hunting of railway vehicles and the shimmy of aircraft landing gears has often been brought to the attention of the writer, but I was previously unaware that the shimmy theory had been applied in the direct way described by Mr. Guins.

I would also like to thank Mr. Law for his most useful remarks.
Of course, I agree completely that nonlinear aspects must not be overlooked, and it is our practice at Derby to assess the influence of nonlinearities on vehicle dynamics such as: (a) wheel-rail geometry including flange contact (b) creep saturation (c) solid friction and limiting in the suspension. One of the most comprehensive nonlinear analyses of a railway vehicle so far carried out is described in reference [11] of my paper.

The question concerning the range of values of creep coefficients can be answered in relation to Mr. Law's comments on calculations made on stability of bogie vehicles made by others. For a given set of values of effective conicity and creep coefficients it is comparatively easy to demonstrate by calculation the attainment of high critical speeds even with zero rotational stiffness of the bogie with respect to the body. Indeed, the suggestion that a freely pivoted bogie could be designed with a high critical speed and good curving ability was suggested by the present writer in 1965 and also in the paper under discussion. Recent calculations carried out for the U.S. Department of Transportation by my group on the L.I.M. test vehicle have shown that critical speeds of over 250 mph are attainable for optimum choices of suspension parameters assuming a fixed value of effective conicity of 1.40. This is perfectly satisfactory for a test vehicle, but for revenue earning trains, the variation of effective conicity as the wheel treads wear must be considered. In addition, the variation of creep coefficients must be taken into account. As effective conicities can vary over a range of 10 to 1 and creep coefficients can vary over a range of 2 to 1 it will become apparent that the choice of suspension parameters must be based on a very comprehensive set of calculations. My statement that a type of two-axle vehicle is superior to bogie vehicles in this respect is based on such calculations, carried out for a variety of configurations, and based on a considerable background of experimentation.

Both the limits of free curving and stability boundaries must, of course, be evaluated in studies of this kind.

Mr. Law's final point concerns the analysis of the wheelset as a closed loop guidance system. I agree that this can be very fruitful and has, in fact, been carried out by my group from time to time.

I would like to thank Dr. Matsudaira for his remarks and to refer him to references [12] and [13] of my paper for an example of a vehicle designed according to the prescription suggested for a two-axle vehicle. These references also include experimental results.

I agree that it is necessary to consider the effect of nonlinearities and specifically the influence of amplitude on the effective conicity. However, it is my belief that such calculations can only follow a thorough examination of the purely linear case. It is difficult to see how nonlinear effect can be exploited to give a radical improvement in performance although more research is required in this area.