Research on Optimization of Track Dynamics Performance for the DC-32 Tamping Machine

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Abstract. After a certain number of years of use, the line dynamics performance of the DC-32 tamping car has declined. Aiming at the poor dynamics performance of the DC-32 tamping car, combined with the structural characteristics of the DC-32 tamping car and the specific index parameters affecting the dynamics performance, by optimizing the selection of herringbone rubber shock absorbers and hydraulic shock absorbers, and re-adjusting the compression of the side bearings, a solution to solve the car shaking problem by adding anti-hunting dampers on the basis of the original bogie was proposed. The feasibility of the solution was further proved by experiments on the improvement of critical speed, stability index, vibration acceleration, and the changes of influencing factors such as derailment coefficient, wheel weight reduction rate, and wheel axle lateral force when the 08-32 tamping car passed through the curve.

Keywords: DC-32 tamping car; dynamic performance; anti-hunting damper; bogie.

1. Introduction

With the rapid development of China's railway industry, the demand for railway line maintenance technology is increasing. In 1984, China's railway system introduced the 08-32 type tamping and lifting tamping machine from Prassey and Toir Company [1], marking the beginning of the modernization of China's railway line maintenance equipment and laying a solid foundation for subsequent railway construction and maintenance. In 1990, China mastered the production technology of the 08-32 type tamping machine and achieved mass production and wide application in China Railway High-tech Equipment Co., Ltd. To date, the 08-32 type tamping machine [2] has become the main force in the tamping operations of China's ballasted railway lines, with a market stock of hundreds of units. It has played an irreplaceable role in ensuring railway line quality and improving transportation efficiency, making significant contributions to the rapid expansion and operational safety of China's railway network.

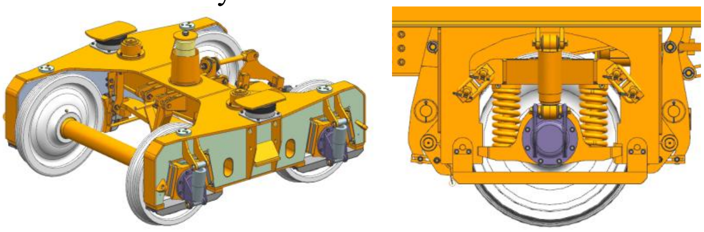
The 08 - 32 type tamping machine, with its unique 32 - tamper design, can efficiently tamp two sleepers at the same time. It's essential for new railway construction, old line overhaul, and daily maintenance. By precisely controlling processes like tamping, lifting, leveling, ballast tamping, and shoulder ballast compaction, it ensures track direction, level, and elevation meet or exceed design standards. This significantly increases ballast density and track stability, guaranteeing safe, smooth, and high - speed train operation.

However, with the increase of service years and the complexity of operating environment, some 08 - 32 type tamping machines have gradually shown the problem of declining dynamic performance indicators in operation, especially at high - speed operation (around 60 km/h), vehicle oscillation phenomenon occurs frequently [3], which is manifested as lateral swaying, vertical bouncing or composite swaying. These failures not only affect the comfort of the operating personnel, but also pose a potential threat to the safety of train operation, and need to be taken seriously.

Therefore, it is crucial to conduct in-depth theoretical research and practical optimization on the dynamic performance issues of the DC-32 tamping car during high-speed operation. This study aims to analyze the dynamic characteristics of the DC-32 tamping car [4] , identify key factors affecting its stability, and explore effective optimization and improvement measures. The goal is to enhance the overall performance of this model, reduce vehicle oscillation, and further ensure the safety and efficiency of railway operations. This research is not only an important upgrade to the existing tamping machine technology but also a key step in advancing China's railway maintenance equipment to a higher level.

2. Dynamic Simulation Model of the DC-32 tamping car

The DC-32 tamping car has two two - axle bogies, and the material car uses single - axle wheelsets for load - bearing and traveling, with an axle formula of B - A1 - 1. As shown in Figure 1 (a), the main car's front and rear bogies have similar structures. The front bogie has two hydraulic drive axle gear box wheelsets, while the rear one has one hydrostatic drive axle gear box wheelset and one passive wheelset. The single - axle suspension system of the material car is shown in Figure 1 (b). The bogies and single - axle suspension system support the car body, transmitting various loads and forces between the frame and wheelsets, or from the wheel - rail to the frame. They also ensure even axle load distribution, safe operation, flexible travel on straight tracks, and smooth curve negotiation. The vibration - reduction performance of the suspension device directly impacts the train's running smoothness and safety.



(a) Main bogie of the DC-32 tamping car (b) Single-axle suspension system of the DC-32 tamping car's material car

Fig. 1 Partial Structure of the Tamping Machine

The main parameters are introduced as follows：

Table 1. Technical parameters of the car

components	value
The weight of the whole machine/t	About 57
The weight of the bogie/t	About 4.6
The weight of the axle/t	≤12.5
The weight of the axle Material carts’axle/t	About 7.5
Fixed gauge/mm	11000
Coupling speed/km/h	100
Self-propelled speed/km/h	80
Wheel diameter/mm	φ840
Tread profile	LM
Wheelbase/mm	1500
Distance between axle neck centers/mm	1800
Distance between side bearings/mm	1950

In dynamic studies, models are tailored to specific research questions, with minor factors simplified. The DC-32 tamping car, a complex system of interconnected components, involves interactions, movements, and wheel-rail relationships. Thus, the analytical model makes assumptions to focus on key aspects:

- The car body, wheelsets, frame, and axle boxes are considered rigid due to their high stiffness and low elasticity.
- The rails are treated as rigid bodies, with only track irregularities considered, excluding low-frequency disturbances.
- The vehicle is modeled as an ideal symmetric system, disregarding structural deviations

like wheel eccentricity or assembly errors.

As shown in Figure 2, the dynamics model of the DC-32 tamping car consists of 5 wheelsets, 10 axle boxes, 2 frames, 2 steel spring beams, 2 car bodies, and other components, totaling 21 rigid bodies. Since the vehicle moves at a constant speed, parallel translations along the x-axis are ignored. The car body, frame, and wheelsets have five degrees of freedom: lateral movement, vertical movement, lateral rolling, pitching, and yawing. The axle boxes only have pitching, and the steel spring beams only have vertical movement. The entire vehicle system has a total of 57 degrees of freedom.

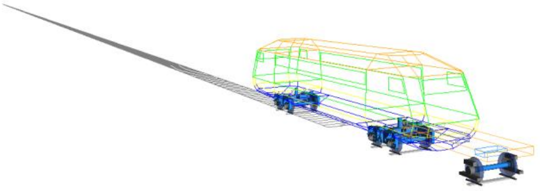


Fig. 2 Dynamic calculation model of the DC-32 tamping car

By adjusting component parameters in the model and conducting dynamic analysis, the main factors causing instability in the DC-32 tamping car are identified as rail surface irregularities, wheel shape issues, weight differences between wheels, friction variations between wheels, and hunting motion.Rail surface irregularities can result from uneven rail joints, large gaps, loose fastenings, vertical track deformation, local irregularities, or random irregularities.Wheel shape problems are typically caused by wheel eccentricity or tread scoring. Friction variations between wheels are generally due to tread scoring. Hunting motion is mainly caused by the clearance between the wheel flange and the rail side, as well as the wheel flange taper.

3. Analysis of the Causes of Vehicle Instability

Based on the dynamic analysis of the DC-32 tamping car in the previous Section, the main factors affecting the operation of locomotives and vehicles are track conditions and vehicle status, which are interrelated and together impact the train's stability, safety, and efficiency.

Analyzing the causes of instability helps implement effective mitigation methods to enhance train operation. Track - related main factors include:

Rail Joints: As a critical connection in track structures, the quality of rail joints directly influences train operation stability. Irregularities, large gaps, or loose fastenings at rail joints can cause impacts and vibrations when trains pass, increasing dynamic wheel - rail forces. This not only reduces passenger comfort but may also accelerate wear on tracks and vehicles and even create safety hazards.

Track Vertical Deformation: Over time, tracks undergo vertical deformation due to train loads, temperature changes, and soil settlement. This deformation involves changes in track geometry (such as gauge, level, and elevation) and elastic deformation of the track structure. Excessive vertical deformation can lead to unstable train operations, increased contact stress between wheels and rails, and reduced service life of tracks and vehicles.

Local Track Irregularities: Usually caused by improper track maintenance, dirty ballast, or loose/damaged fastenings, local track irregularities can trigger wheelset vibrations, especially high - frequency ones, impacting the train's operation quality and ride comfort.

Random Track Irregularities: These are random irregularities on the track surface, mainly due to errors during manufacturing and laying, uneven wear of track materials, and natural environmental factors (like wind, sand, rain, and snow). Although their amplitude is relatively small, their widespread existence and difficulty in complete elimination mean they still affect the stability and safety of train operations.

Vehicle - related main factors include:

Wheel Eccentricity: Wheel eccentricity refers to the phenomenon where the center of mass deviates from the rotation center due to uneven mass distribution during wheel rotation. It can cause periodic vibrations and noise during train operation, affecting ride comfort and potentially increasing wheel-rail wear.

Uneven Wheel Load Distribution: Uneven wheel load distribution refers to the phenomenon where the vertical loads on wheels of the same bogie or wheelset are unequal. It is mainly caused by errors in vehicle manufacturing and maintenance, uneven payload distribution, or uneven wheel wear. This unevenness exacerbates wheel-rail contact stress and reduces the service life of wheels and rails.

Wheel Tread Scoring: Wheel tread scoring, caused by friction between wheels and brake shoes/disks during braking, alters the tread shape and roughness. This worsens the wheel-rail contact relationship, increasing impacts and vibrations, and compromising train stability and ride comfort.

Wheelset Hunting Motion: Wheelset hunting motion is an inherent lateral oscillation of wheelsets on straight tracks, caused by the clearance between the wheel flange and rail side and the wheel flange taper [5]. Excessive hunting motion can increase lateral wheel-rail forces, affecting train stability and safety.

Combined with the common problems in the operation of the DC-32 tamping car, this paper mainly analyzes the hunting motion of the wheelset. For railway vehicle wheelsets with a certain tread profile, when rolling along straight rails, a unique motion with an increasing amplitude occurs —— the wheelset experiences lateral movement coupled with rotation about a vertical axis through its center of mass, known as hunting motion. The hunting motion of the wheelset induces lateral vibrations in the bogie and car body, referred to as bogie hunting (secondary hunting) and car body hunting (primary hunting). The theoretical critical speed formula for calculating hunting motion is as follows:

$$v_c^2 = \frac{rs[P(\zeta\delta_0 + \varepsilon - \delta_0)s + 2K_y s^2 + 2K_x b^2]}{j_e(m\rho_z^2 + ms^2)} \tag{1}$$

Kx and Ky respectively represent the lateral positioning stiffness and the lateral positioning stiffness of each side of the wheelset.

It can be seen from the formula that on straight and level tracks, increasing the wheelset positioning stiffness Kx and Ky, the wheel radius r, the positioning spring span b, and the axle load P, reducing the tread equivalent slope je and the unsprung mass m, can all improve the stability of the wheelset hunting motion. The critical speed of wear - shaped tread wheelsets is lower than that of conical tread wheelsets. Although wear - shaped treads have higher lateral positioning stiffness (under the same suspension type), which is beneficial for stability, they also have a larger equivalent slope that increases the destabilizing effect. The latter effect is much more significant. However, increasing the wheelset positioning stiffness and reducing the tread equivalent slope are not conducive to curve negotiation. Therefore, it is necessary to reasonably set these parameters and comprehensively consider all performance indicators. In addition, reasonably setting anti - hunting dampers and lateral dampers, selecting appropriate axle spacing to increase the wavelength of hunting motion, reasonably choosing the longitudinal and lateral clearances between the wheelset and the frame, selecting built - in gearboxes to reduce the bogie's moment of inertia, positioning the gearbox's center of gravity as centrally as possible to minimize the wheelset's radius of gyration about the Z - axis, and increasing the lateral span of the axle box, can all enhance the critical speed of hunting motion.

Based on theoretical analysis and practical experience with large - scale maintenance machinery, the main reasons for instability in the DC - 32 tamping machine are as follows:

Primary Suspension: This mainly affects wheelset positioning stiffness, thereby influencing bogie hunting. Mismatches in the three - directional (vertical, longitudinal, lateral) stiffness of chevron rubber dampers and the damping coefficient of hydraulic dampers can lead to instability.

Rotational Damping Moment: This mainly influences the car body's tilting and rotational movements. Insufficient compression of side bearings results in inadequate frictional rotational damping moment between the car body and bogie, causing instability.

Wheelset: Tread wear or defects lead to wheel out - of - roundness or changes in tread equivalent taper, resulting in instability.

4. Oscillation Suppression Experimental Methods

4.1 Component Replacement and Parameter Optimization

For a company-assigned DC-32 tamping car experiencing oscillation at 65 - 70 km/h, the following measures were taken on-site:

1) Inspect wheel treads and perform turning if abnormal wear or defects are found.
2) Re - match chevron rubber dampers to ensure the vertical stiffness of dampers across the vehicle is as close as possible, with a maximum difference of no more than 2 kN/cm for the same wheelset.
3) Adjust side bearing compression towards the upper limit.
4) Select and match hydraulic dampers according to the indicator diagram.

After the treatment, the vehicle was retested on the road. When the vehicle's self - running speed reached above 80 km/h, no oscillation occurred. Measurements with a ride quality meter on straight tracks, R600 curves, and 12" turnouts showed all vibration and stability indicators met technical and evaluation standards.

4.2 Installation of Anti-Hunting Dampers

Two anti - hunting dampers [6] are added between each bogie and the car body, arranged symmetrically about the car body's centerline. The system mainly consists of the dampers and upper/lower mounting seats. The upper seat is welded to the underside of the car frame's outer side, and the lower one to the bogie's outer side, as shown in Figure 3.

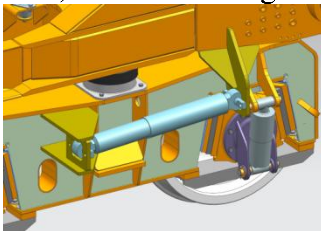
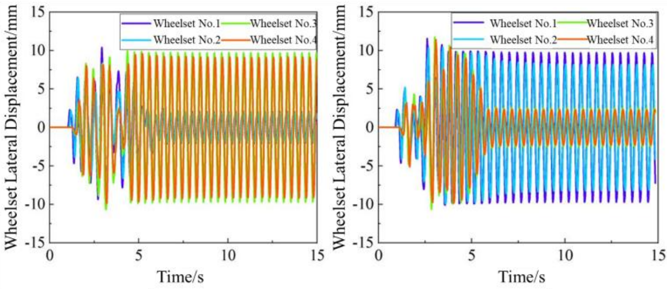


Fig. 3 Schematic Diagram of Installing Anti - Hunting Dampers on the DC - 32 Tamping Machine

According to GB/T 17426 - 1998 "Dynamic Performance Evaluation and Testing of Railway Special Vehicles and Track - Mounted Machinery" [7], the original tamping machine scheme and the modified one with added anti - hunting dampers are compared and analyzed based on US Class V track conditions.

4.2.1 Critical speed

The vehicle system's instability critical speed was 117 km/h before installing the anti - hunting damper, and increased to 140 km/h after installation.



(a) Without the anti - hunting damper v=117km/h (b) With the anti - hunting damper v=140km/h
Fig. 5 Lateral Motion Time - History Curve of Wheelset Near Critical Instability State of DC - 32 Tamping Machine

4.2.2 Ride Stability Index

Simulation results show that at 80 km/h, 90 km/h, and 100 km/h on straight tracks, the ride stability index of the tamping machine with added anti - hunting dampers is significantly improved, and the maximum vibration acceleration is also markedly reduced [8].

Table 2. Vehicle Ride Stability Index (without anti - hunting dampers)

Speed（km/h）	Measurement Locations	Sperling Index		Maximum Vibration Acceleration	
		Wy	Wz	Ay	Az
100	Front	3.841	2.02	4.445	0.735
100	Back	3.689	1.997	3.946	0.716
90	Front	3.339	1.786	2.922	0.503
90	Back	3.369	1.776	2.959	0.498
80	Front	2.981	1.583	2.044	0.347
80	Back	3.112	1.598	2.294	0.355

Table 3. Vehicle Ride Stability Index (with anti - hunting dampers)

Speed（km/h）	Measurement Locations	Sperling Index		Maximum Vibration Acceleration	
		Wy	Wz	Ay	Az
100	Front	3.237	1.862	3.144	0.694
100	Back	3.303	1.881	3.267	0.713
90	Front	2.989	1.658	2.467	0.495
90	Back	3.126	1.682	2.689	0.509
80	Front	2.657	1.45	1.774	0.333
80	Back	2.786	1.463	2.047	0.341

4.2.3 Curve Negotiation Performance

When the tamping machine passes through a R300m curve with 100mm superelevation at 40 km/h, 50 km/h, and 60 km/h, the derailment coefficient slightly improves, the wheel load reduction rate slightly increases, and the lateral wheel axle force increases by about 3%, all within acceptable limits.

Table 4. Curve Negotiation Performance (anti - hunting dampers is abbreviated as AHD)

Speed（km/h）	Derailment		Wheel Load		Lateral Wheel Axle	
	Without AHD	With AHD	Without AHD	With AHD	Without AHD	With AHD
40	0.43	0.424	0.429	0.434	27.586	29.412
50	0.556	0.552	0.573	0.571	34.018	36.479
60	0.671	0.552	0.613	0.62	43.333	47.146

5. Conclusion

In response to the poor dynamic performance of the DC-32 tamping car, practical experience shows that optimizing the selection and matching of chevron rubber dampers and hydraulic dampers, and readjusting the side bearing compression, can somewhat resolve the oscillation issue. Theoretical analysis suggests that adding anti - hunting dampers to the existing bogies can significantly improve the critical speed, ride stability index, and vibration acceleration, with minimal impact on the derailment coefficient, wheel load reduction rate, and lateral wheel axle force during curve negotiation. This can solve the oscillation problem, and further in - service verification tests will be conducted.

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