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Investigating the noise and failure response of suspension spring of metro trains by rail corrugation process

Dr. Kailas V. Chandratre[1] ,
[1]Principal, KVN Naik LGM IEE&R, Nashik, Maharashtra, India.

Dr. Yashwant R.Kharde[2],
[2]Professor, Sir Visvesvaraya Institute of Technology, Nashik , Maharashtra, India.

Prof.Suyash Y.Pawar[3]
[3]Assistant Professor MVPs KBT College of Engineering, Nashik, Maharashtra, India.

Abstract

In rail vehicle systems, helical springs are employed as a principal suspension to mitigate vibration and shock, which necessitates examination into failure reaction due to varying loading circumstances. The structural vibration of metro bogies generated by rail curvature is investigated experimentally and numerically in this work. Elastic energy is used to absorb and discharge external loads, and springs, due to their structure and material, prefer to return to their original length when discharged. Coil bands are no exception to the automotive industry's trend of ongoing weight loss while improving performance. Coil springs today are exposed to far greater strains than those employed in prior generations of automobiles. In the springs, irregularity of the material interface and impurities are two major strain raisers. Defective microstructure, in addition to the existence of stress absorption raisers, was another major cause of spring collapse. The numerical findings suggest that simple rail corrugation reduces the coil spring's fatigue life and that increasing the absorption value of the major vertical absorbers reduces the severe vibration caused by short-pitch rail corrugation. This study examines the impact of rail corrugation on metro bogies' vibration and provides some solutions for minimizing metro bogies' severe vibrations and the occurrence of main coil spring collapse, which might be useful in the development of modern railway bogies and track repair operations.
Keywords: fatigue failure, rail corrugation, vibration, spring, metro

INTRODUCTION

Railway vehicles are one of the most widely used modes of transportation for both people and goods [1]. Indian railways are widely distributed across the country, transporting people and freight over long distances and functioning for 4–5 days at a time. One of the most difficult dynamic processes was the railroad automobile. Automotive parts, wheelsets, and transitional elements that are elastic and linked by segments, such as dampers and springs are used to assemble a dynamics method of a railway locomotive [2]. Dispersions are an important machine part of railway vehicles that help to keep the vibration and stock in check when monitoring, bending, and securing axle movement. The compressive load spring was used to allow for axial distortion as well as some horizontal bending during rising and fall. A cargo rail vehicle's main damper fails regularly, with a particular emphasis on the failure of the compound spring of the center axle of the two enclosures. If an alteration in load or deflection occurs only a few times over the spring's natural life, for instance, under 9999 cycles, the spring was considered static. A dynamic spring can be loaded for an indefinite amount of time. Suspension spring strain or fatigue damage can be induced by a variety of factors, including static rail car movement.

Coil springs, also known as helical rods are utilized widely as one of the key elastic parts of the vehicle stabilization system in the automotive industry. They act as a link between the wheel and the vehicle's body, dampening the vibrations which would sometimes be conveyed from the road's uneven texture to the body. Elastic energy is used to absorb and discharge external loads, and springs, due to their structure and material, prefer to return to their original length when discharged. Coil bands are no exception to the automotive industry's trend of ongoing weight loss while improving performance. Coil springs today are exposed to far greater strains than those employed in prior generations of automobiles. In the springs, irregularity of the material interface and impurities are two major strain raisers. Defective microstructure, in addition to the existence of stress absorption raisers, was another major cause of spring collapse. Appropriate material qualities and manufacturing quality become increasingly critical as spring levels of stress rise. Failure analysis of damaged coil springs was a useful tool for producers and car materials distributors to enhance coil spring architecture and increase their integrity.

This paper includes an investigational and computational examination into the effect of rail curvature on the mechanical resonance of metro vehicle–track interface systems to understand the relationship between track corrugation and main coil spring stress breakage. The following provides a breakdown of the paper's structure. (Sec. 2). On a China subway line, the peculiarities of rail corrugations are examined. The parametric study for the metro vehicle–track contact is described in Sec. 3. The impact of rail curvature and bogie characteristics on the dynamic behavior of coil shocks was highlighted. Sect. 4 is an initial consideration of the effect of rail curvature on coil band fatigue damage.

MOVEMENT OF METRO BOGIES CAUSED BY TRACK CORRUGATION IN THE FIELD

Since rail strips developed on a China subway route, fatigue breakage of main coil shafts in metro cars has been noticed often. Many dynamic and static studies were conducted to determine the relationship between the collapse of the rail corrugation and the main coil springs. To begin, researchers measured and evaluated rail corrugations on both curved and straight lines. According to the data collected, rail corrugation with prevailing wavelengths of 45–50 mm and capacitances of 0.07–0.15 mm (Fig. 1) mostly took place on curved and straight paths with radii greater than 750 m,

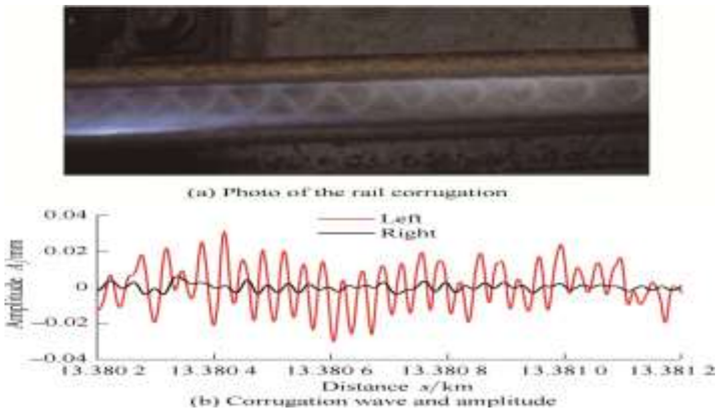


FIG. 1. SHORT-PITCH RAIL CURVATURE ON A STRAIGHT RAIL

and many rail fastenings were broken as a result of these short-pitch train line curvatures. On strongly curved rails with radii of 400–550 m, another form of rail curvature with lengths of 75–245 mm and capacitances of 0.19–0.8 mm was mostly seen.

The velocities of a metro train's bogie frameworks and axle-boxes were tested sequentially in the field on rail areas with short-pitch rail curvature. The sensor configuration on the evaluated bogies is shown in Figure 2. The metro vehicle's dynamic axle-load with a crushing capacity was around 15 T. The train velocity in the testing was around 140 kilometers per hour. The tested vehicles' wheel tracks were re-profiled to avoid the impact of wheel deterioration. Before rail sharpening, the corrugation length was around 30–35 mm, and the thickness was around 0.08 mm.

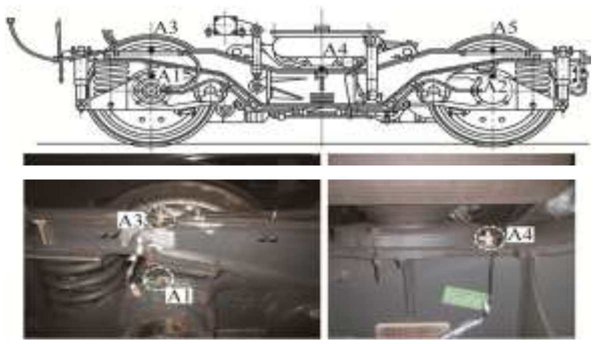


FIG. 2. VIBRATION MEASUREMENT OF THE METRO BOGIES

The findings reveal that short-pitch track curvature has a considerable impact on metropolitan bogies blockchain. The reduction proportions of the vertical velocities of the axle-boxes are about 15%–30% after rail sharpening on the curved track portions and the reduced levels of the vertical velocities of the bogie layers were roughly 9%–40%.

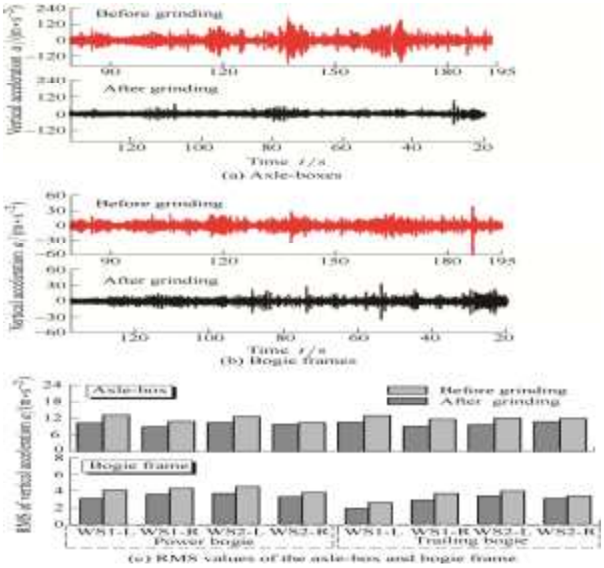


FIG. 3. METRO BOGIES' VERTICAL VELOCITY

The vertical velocity spectra of the power bogie's axle-boxes and bogie structures are shown in Fig. 4. The bogie structures and axle-boxes have high sound maxima in the frequency regions of 35–90 Hz, 450–565 Hz, 750 Hz, and 945–1000 Hz. The imperfections at the rail joints are responsible for the peaks at 45–95 Hz. The passing speeds of rail curvature with lengths of 45–60 mm corresponded to the peaks of 754 Hz and 940–1000 Hz. The resonance peaks of 480–560 Hz must be attributed to the rail curvature, which has lengths of 55–75 mm.

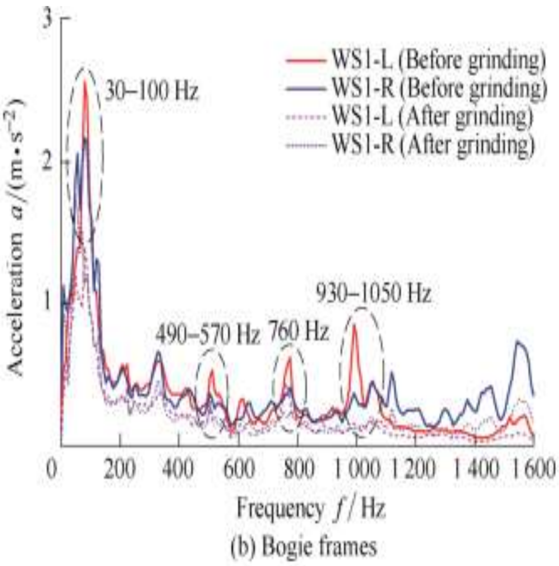


FIG. 4. BOGIE COMPONENT VERTICAL DISPLACEMENT SPECTRA

The vibration behavior of bogie structures and axle-boxes is particularly reactive to rail curvatures, as shown by the above test findings. After rail sharpening, the vibration maxima around 945–1000 Hz and 745 Hz vanish completely. Rail sharpening also greatly reduces the peaks at 45–90 Hz and 485–556 Hz. As a result, it's simple to see how short-pitch rail strips can expedite the failure mechanism of field coils springs by causing severe shocks in bogie structures and axle-boxes in the range of frequencies of 760 Hz to 950 Hz..

The association between short-pitch track curvature and main coil spring breakdown cannot be completely defined based on the restricted field trials due to the limited spending and operating hours on the existing subway lines. As a result, numerical experiments were done utilising a metro vehicle-track interface framework.

A. Numerical model

The performance of the rail network was a complicated linked time-varying static issue that is frequently addressed with a numerical analysis based on a static framework for the automobile

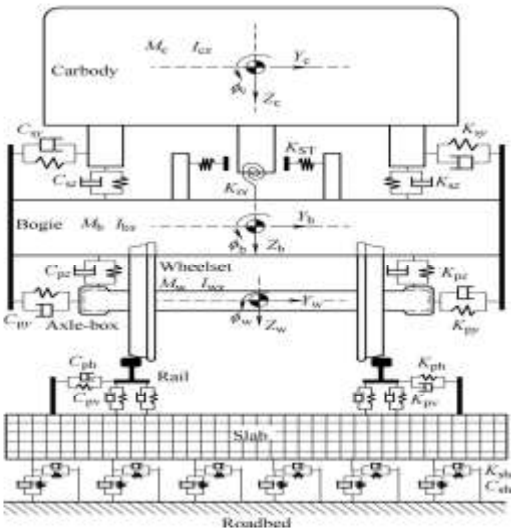


FIG. 5. NONLINEAR METRO VEHICLE-TRACK INTERFACE SIMULATION

system[18–21]. A 3D static simulation of a metropolitan vehicle connected to a concrete rail was created for this investigation, as shown in Fig. 5. The metro vehicle is made up of fifteen rigid structures, including a car body, 2 bogie frameworks, 8 axle boxes, and 4 wheelsets. The axle-boxes have four DOF: vertical Z, longitudinal X, pitching slope, and lateral Y, while the other components have six: lateral Y, longitudinal X, vertical Z, [17] yawing, pitching angle, and rolling slope. As a result, the metro automobile is a 74-degree-of-freedom multi-body device. The metro vehicle's motion equations are as follows [19]:

When using numerical approaches to simulate the dynamic behavior of a linked vehicle–track network, a moving vehicle on a lengthy track framework should be represented. In this study, the authors used a model called a "tracking window" that they developed[27]. The model appears to show the action of a vehicle traveling along a rail via a window with a size of lTW. The window advances at the same rate as the car. It is supposed that the car being observed shakes in the window at all times. As demonstrated in Fig. 6, the track goes through the glass in the opposite direction as the car speeds up.

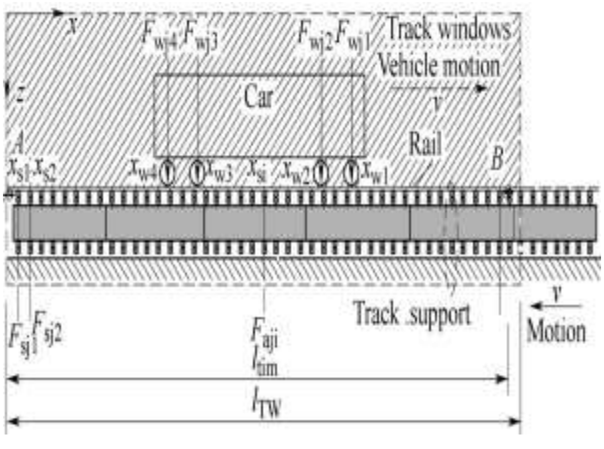
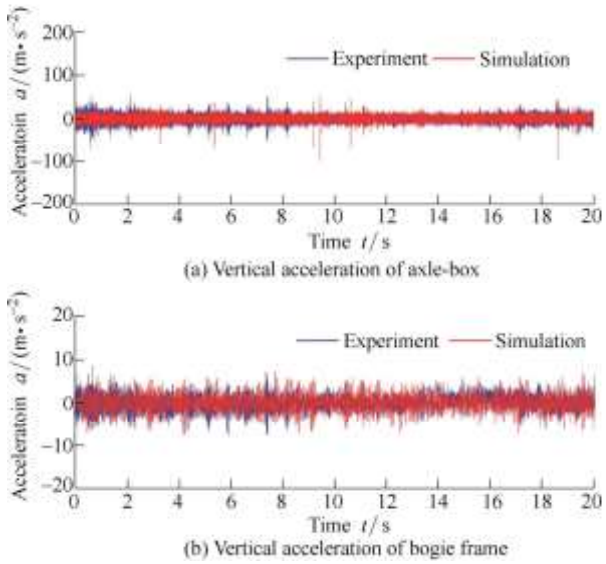


FIG. 6. EXCITATION PARADIGM FOR VEHICLE-TRACK SYSTEMS



B. Validation of the statistical model

The vibration effects produced using the static model were evaluated to those acquired from field experiments to evaluate the metro vehicle–track concept suggested in this study. The time records of the vertical velocities of the bogie frames and axle-boxes while the test automobile navigated an 800-meter-long curving track are shown in Fig. 8. The vehicle velocity was 115 km/h, and the examined metro line's normal rail imperfections and rail slabs were observed. The lengths between the two bogies' centers were 13 meters, while the ranges between the bogies' axles were 4 meters. The rigidity of the rail pad was around 15 MN/m. The results in Fig. 8 indicate that the observed vehicle speeds are very similar to those obtained by simulation results.

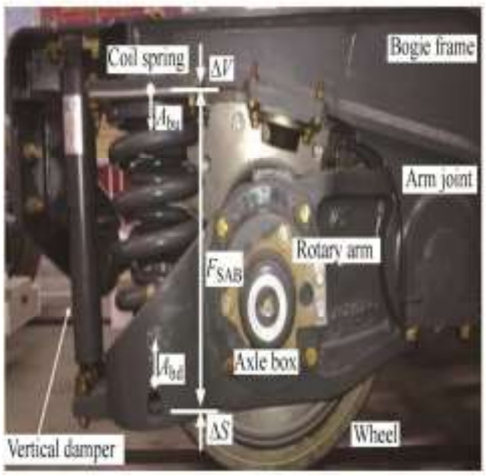


FIG. 7. COMPARISON OF BOGIE VELOCITY TIME RECORDS

The variations between the calculated and measured findings are appropriate for the structural applications, according to the comparisons given in Fig. 7. The slight disparity between observed and simulated findings is attributable to unavoidable variations in the computation of vehicle elastic motion and track static performance as well as the variables employed in the calculation.

C. Discussions and statistical results

The dynamic simulation presented in section 3.1 has been used to investigate the impact of rail curvature on metro bogies architectural vibration and main coil spring breakdown in this part. The rail corrugation was treated as periodic sine-wave deviations with length and intensity, making it simple to evaluate the effect of rail curvature amplitude and wavelength on vehicle-track resonance. The principal damper of the evaluated B-type metro car is shown in Figure 8. Wheelsets, vertical dampers, bogie structures, helical springs, axle-boxes, and rotor arms make up the vehicle's principal suspension. Different from other metro bogies are the rotating arms attached to the bogie frameworks, axle-boxes, vertical absorbers, and springs which can spin a large angle across the arm joint. The vibration behaviors

FIG. 8. METRO BOGIE'S MAIN SUSPENSION MECHANISM

of the bogie frameworks and rotor arms attached to the wire springs have a significant impact on the coil springs' dynamic behavior.

Figure 9 depicts the coil spring forces' static response as the automobile travels down a parallel track part with and without short-pitch corrugation. The findings in Fig. 9(a) reveal that short-pitch rail curvature has a limited effect on the coil spring pressure, while standard track defects determine the fluctuation of the coil spring distortion. However, as shown in Fig. 9(b), the short-pitch rail curvature has a considerable impact on the coil spring distortion oscillation frequency. A significant rise in the coil spring expanding and squeezing motion's oscillation speed would drastically reduce its service life. The time records of coil spring distortion speed for the identical scenarios as in Fig. 9 are shown in Fig. 10. The coil spring distortion speed on the curved track improved by roughly 75% when contrasted to the results without rail curvature, as illustrated in Fig. 10. (b). Figures 11–14 illustrate the maximum distortion velocity V of all axle shafts, as well as the rotating speed of the rotor arms and the vertical speed of bogie structures and axle-boxes. In the experiments, typical lengths of 40 mm, 130 mm, 170 mm, and 190 mm were used.

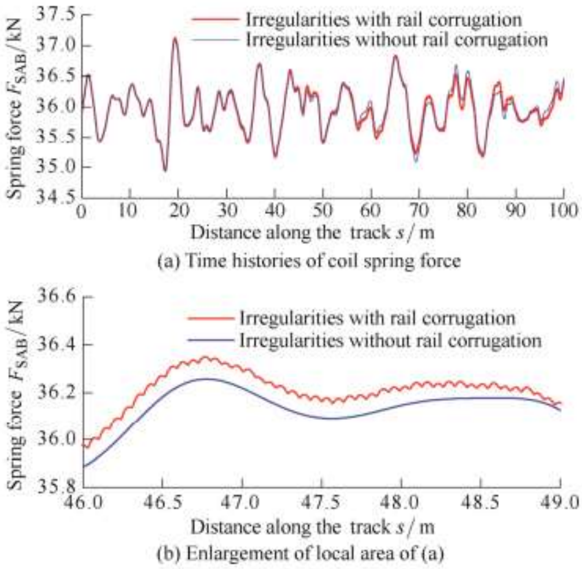


FIG. 9. COIL SPRING STRAIN STATIC RESPONSE

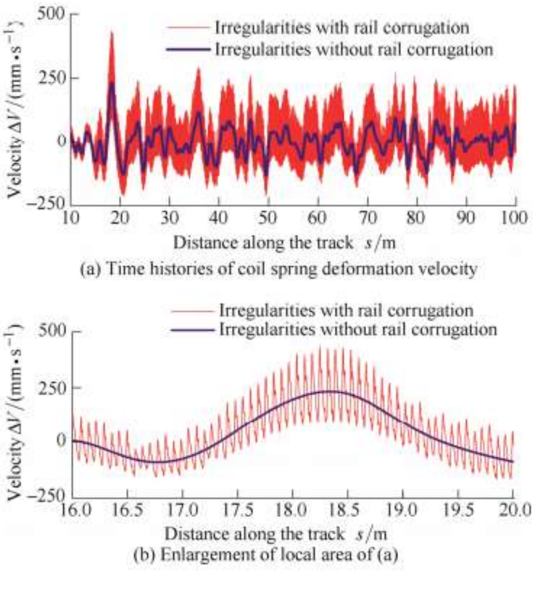


FIG. 10. COIL SPRING DISTORTION VELOCITY STATIC RESPONSE

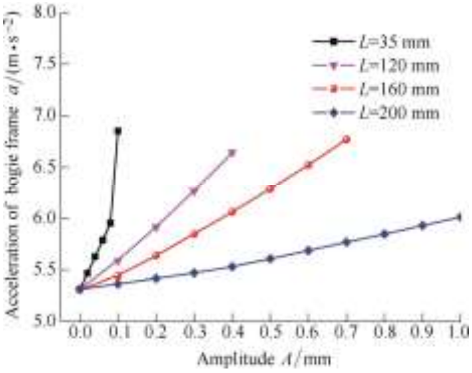


FIG. 11. COIL SPRING DISPLACEMENT VELOCITIES

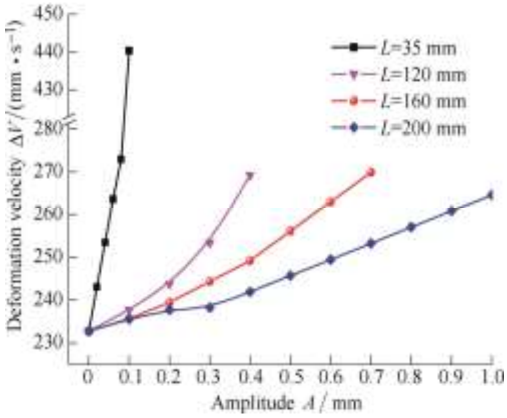


FIG. 12. THE ROTATING ARMS' ACCELERATIONS

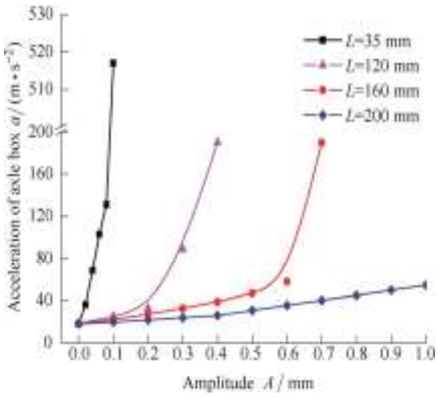


FIG. 13. THE AXLE-BOXES' ACCELERATIONS

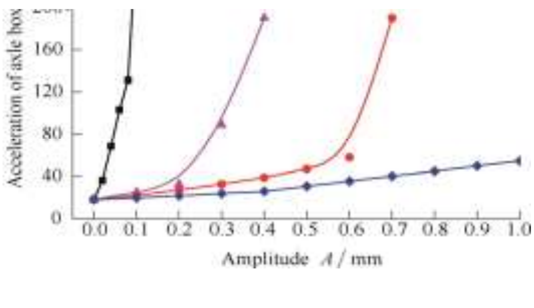


FIG. 14. THE BOGIE FRAMES' ACCELERATIONS

Figures 11–14 illustrate that the lengths and accelerations of rail corrugation have a considerable impact on the stiffness of the primary support unit. As the rail curvature amplitude enhances, the spectral of the displacement speed V the rotating velocity of the motor arms, and the vertical speed of the bogie frames and axle-boxes increase, and as the rail curvature wavelength rises. When the subway train operated on the curved track with short-pitch rail curvature at a speed of 130 km/h, the coil spring distortion velocity improved by roughly 90 percent contrasted to the findings without curvature, as shown in Fig. 12. The capacitances of the rotary arms' rotational speed, the vertical velocity of axle-boxes, and the bogie structures' vertical speed are about 2340 percent, 2560 percent, and 30 percent, respectively, as illustrated in Figs. 12–14.

D. Statistical sensitivity evaluation on the main suspension

A parametric sensitivity evaluation on the main suspension was performed out to uncover some techniques for minimizing the severe vibration and rupture in main coil shafts. The impacts of the coil springs' equivalent rigidity, the vertical dampers' damping level, the coil springs' and vertical dampers' longitudinal placements, and the rotor arm joints' equivalent rigidity were all studied in depth. The simulation results show that the vertical damper lowering value has a significant impact on the structural instability of metro bogies moving on corrugated rails, but the impacts of the other factors are minor. The metro vehicle's top speed was 90 kilometers per hour.

The length of the investigated rail corrugation was 40 mm, and the thickness was 1 mm. When short-pitch curvature is present, increasing the absorption value of the vertical dampers reduces the distortion and resonance of the bogie main suspension (Fig. 15). The vertical dampers' designed absorption value is 9 kN • s/m. As a result, increasing the damping level of the vertical dampers was anticipated to reduce fatigue rupture in the main coil springs during short-pitch curvature stimulation.

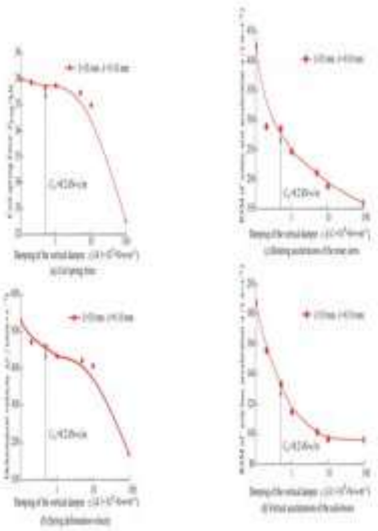


FIG. 15. VIBRATION OF THE MAIN SUSPENSION (DAMPENING LEVEL OF THE VERTICAL ABSORBERS)

THE EFFECT OF RAIL CURVATURE ON THE PROGRESSIVE COLLAPSE OF COIL SPRINGS IN METRO BOGIES

Two difficulties, according to the findings of the current analysis, can reduce the coil springs' fatigue span when subjected to corrugation stimulation.[24] The first could be coil spring twisting resonances induced by rail curvatures of specified lengths. To resolve this problem, a 3D FE simulation was created via the FE code for business Fig. 17. (a). As per the site analysis, the red spot in Fig. 17(a) illustrates the major fracture position of the coil springs. The tested metro trains' operating speeds typically range from 85 to 130 km/h.[25] The excitation levels of metro cars passing through short-pitch rail curvatures with lengths of 35–50 mm can be computed by:

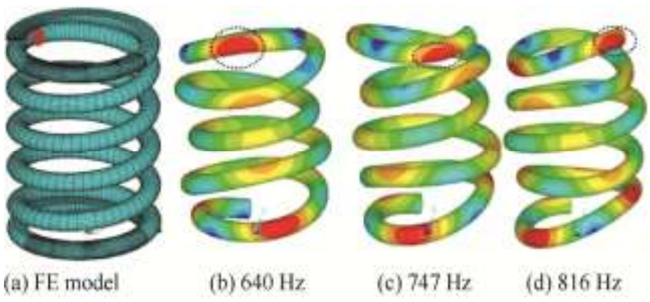


FIG. 16 COIL SPRING'S FE DESIGN AND ELASTIC MODES

In the frequency ranges of around 640–1090 Hz, three resonant forms of the coil exist, the normal tensile of which exist in the area where coil spring breaking occurs, as shown in Fig. 16. When short-pitch rail curvature causes bending vibrations in axle shafts, the resonance level at the tension region (red regions in Fig. 16) will be substantially higher than in the normal state. This suggests that the breakdown of the coil springs could be caused by short-pitch rail curvature with lengths of 35–50 mm. This conclusion was supported by the field test findings and the on-site observation. The 2nd issue to consider is the high fluctuation velocity of coil spring distortion caused by short-pitch curvature, which has a significant impact on coil spring failure life.[26] The rainflow phase counting technique and the S-N curve[28] may be used to determine the coil spring's fatigue life in Fig. 16. The deflections of the coil spring determined using the vehicle–track coupling model was used as inputs to the FE model's structural analysis (Fig. 16(a))

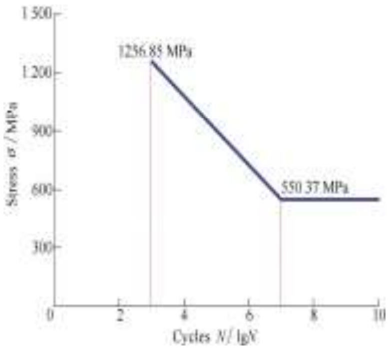


FIG. 17. COIL SPRING'S FUNDAMENTAL S-N CURVE

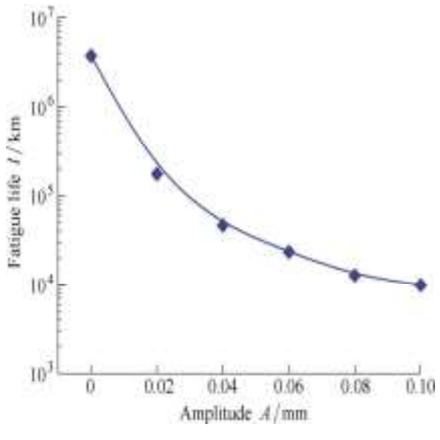


FIG. 18 COIL SPRING'S PREDICTED FATIGUE DURATION

The rail corrugations in Fig. 18 have a length of 40 mm and accelerations of 0–0.2 mm, and the vehicle velocity is 140 km/h. If there is no corrugation on the track surface, the coil spring's durability is estimated to be 4.89. 109 km. As the curvature depth rose, the coil spring's fatigue life decreased significantly. The coil spring's endurance lifespan is only 9.78 103m for rail curvature with a length of 40 mm and a thickness of 0.2 mm, which is significantly less than that under normal circumstances.

CONCLUSIONS

The numerical and experimental results demonstrate that short-pitch rail strips with lengths of 35–50 mm can significantly diminish the coil spring's fatigue life, which could be a contributing factor to the coil springs' failure. The failure mode of axle shafts may be shortened due to two factors. One example is the short-pitch rail corrugations, which create bending vibrations in axle shafts utilized in metro bogies. Coil springs, also known as helical rods are utilized widely as one of the key elastic parts of the vehicle stabilization system in the automotive industry. They act as a link between the wheel and the vehicle's body, dampening the vibrations which would sometimes be conveyed from the road's uneven texture to the body. Elastic energy is used to absorb and discharge external loads, and springs, due to their structure and material, prefer to return to their original length when discharged. Coil bands are no exception to the automotive industry's trend of ongoing weight loss while improving performance. Coil springs today are exposed to far greater strains than those employed in prior generations of automobiles. In the springs, irregularity of the material interface and impurities are two major strain raisers. Defective microstructure, in addition to the existence of stress absorption raisers, was another major cause of spring collapse. Appropriate material qualities and manufacturing quality become increasingly critical as spring levels of stress rise.

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