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Noise emissions of transit trains at curvature due to track lubrication

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The flanging and squealing noise generated by transit metro trains while crossing a curvature path has been studied. The noise emission at curvature is analyzed in case of non lubricated and lubricated track for wayside and interior of the train. The gauge face lubrication does not have a significant effect on the A-weighted noise generated by the train transit system while passing through a curved track. The negation of lubrication effect in controlling the overall A-weighted noise emission is attributed to an additional reaction force component, which accentuates the wheel/rail interaction comparatively more than the reduced high frequency squeal and flanging noise for the lubricated track. This additional force component is generated due to longitudinal and spin creepage on the flange while encountering a curved track and is observed to cause an increase in noise emission in the frequency range 250-400 Hz, where the rail/wheel interaction is dominant; in both way side as well as interior noise levels.

Keywords: Lubricated track, Normal track, Wheel/rail interface

1 Introduction

Railway noise in curves is an area of continuous research and development. Noise and vibration issues from train transit systems not only bring discomfort to the passengers but also to residents in close proximity. So, it is imperative to have noise and vibration reduction either at the source side or at the path to minimize the impact to the local community. Curve tracks may cause squeal noise, excessive wear at gauge corner of rail and subsequently lead to rail corrugation. Both top-of-rail squeal and flanging noise are associated with curves, particular sharp curves (R<500 m), whereas rolling noise is generally associated with tangent track[1]. A large proportion of squeal noise originating from the top of rail is associated with stick-slip lateral motion at contact between the wheel tread and rail head[2,3]. The axial bending resonances of the wheel surface and tread are excited when the stick-slip process at the patch or at the flange becomes unstable, resulting into radiation of highly tonal noise called squeal. Three possible excitation mechanisms should be considered: longitudinal slip between inner and outer wheels on a solid axle; wheel flange rubbing against the rail; and lateral creep of the wheels on top of the rail[4]. The phenomenon of lateral creepage has been analyzed by Rudd[4], according to which squeal will occur when track radius of curvature is less than 100 times vehicle or bogie wheel base for normal steering axles. Remington[5] discussed about squeal due to lateral creepage of wheel tyre. Curve squeal originates from unstable response of wheel objected to large creep forces in region of contact, which excite the wheel particularly at frequencies corresponding to wheel's axial (and radial) mates and thus the noise generated is strongly tonal in nature in the frequency range 250 Hz to 10 kHz [6]. Flanging noise is the high frequency, broadband or multi-tonal noise which is common on tight curves. The flange contact generates a different form of squeal noise, referred as flange squeal, which has considerably higher fundamental frequency and is often intermittent in nature[7]. The lateral creep on the top of rail is major culprit in generating the squeal noise, though the flange rubbing and longitudinal slip are also contributing factors to the overall noise radiated while negotiating a curved track. Table 1 shows the frequency ranges for the various types of railway noise. Other forms of noise associated with curving as reported in literature include a low frequency 'graunching' at crossings due to flange rubbing and 'juddering' due to unstable dynamic behaviour of the vehicle.

Lubrication on tight curves is a simple and effective approach to control the friction as high control of friction (COF) tends to cause squeal and corrugation. The most popular greases used to lubricate rail and wheel flanges are calcium-based graphite grease and lithium-based grease with molybdenum disulphide. Too low COF or too high COF leads to wheels or rail troubles such as skid at

Table 1 — Frequency range for different types of railway noise [8]

Noise Type	Frequency range (Hz)
Rolling	30-5000
Flat spots	50-250 (speed dependant)
Ground borne vibrations	4-80
Structure borne noise	30-200
Top of rail squeal	1000-5000
Flanging noise	5000-10,000

braking, overrun at a station, wheel/rail wear and corrugation for example[9]. Lubrication of interface between wheel tread and top of rail has been focused on to decrease the large lateral forces and to reduce wear of wheel/rail interface, low rail corrugation and squealing noise as a result[10]. On the other hand, high positive friction modifiers have demonstrated the ability to change the negative friction characteristic of wheel-rail interfacial layer to positive, and reduce and control friction to levels consistent with braking and traction requirements of the system, and can always reduce top of rail noise by at least 3-4 dB and in some instances by as much as 25 dB[11]. Successful implementation of friction modifiers in mitigating flanging and squealing noise as well as corrugations has been reported so far by various researchers.

In the present paper, effect of greasing the top of rail surface on a curved track by an electronic rail greasing machine has been studied. The rail lubricating system consists of system core, lubrication strips and sensor station, which registers an approaching rail bound vehicle and signals control system which immediately trips lubrication process. The lubricant is conveyed through high pressure hoses from system core to lubrication channels of grooves rails, applied exactly between wheel flange and rail running surface. The special geometry of ports through which grease is emerging causes lubricant to climb up the rail and fill the space between rail running surface and wheel flange. A part from lubrication of running surface, an appropriate additional flow controller allows head of rail to be greased.

2 Experimental Details

The sound pressure level measurements were made to access the noise reduction effect of the electronic rail lubricating system being deployed on Delhi metro rail corporation tracks on elevated corridor between Netaji Subhash and Keshavpuram stations. The rail lubricating system was operational on one of the train tracks while other track was normal. The methodology employed was to access; the wayside

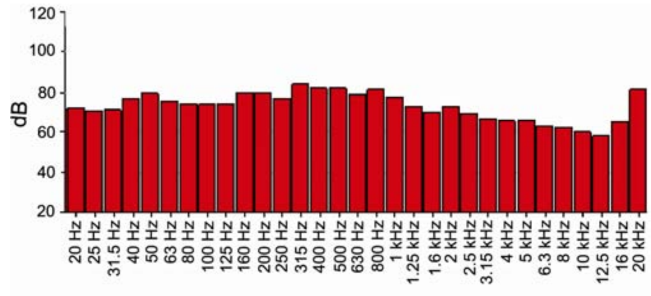

Fig. 1 — Spectrum of train pass by on normal track

noise reduction, and inside coach noise reduction. In the first case, the sound pressure level measurements were taken with a sound level meter installed on a pneumatic platform moved on either side of the track and in level with the elevated corridor via duct wall parapet. The sound level meter was 5 m distance away from the wall parapet. The near side and far side train pass-by sound pressure levels were monitored for both the normal and the lubricated tracks. In the second case, the sound level meter was installed in the coach of the train at 1.4 m above the floor level. The inside coach sound pressure level measurements were again monitored for normal and lubricated tracks. In both the cases, a number of measurements were taken to average out the uncertainties involved due to individual train traction speed, loading, auxiliary equipments noise, variable conditions of wheel/rail and residual noise. Fig. 1 shows the spectrum of the train passing on the normal track at curvature.

The prominent sources of the air borne noise radiated by elevated transit trains are the wheel/rail noise also referred as 'rolling noise', auxiliary and propulsion equipment noise and noise and secondary noise radiated by vibrating components of elevated structure. Excitation of the wheel/rail noise is attributed to rail and wheel surface roughness leading to axial bending resonances of wheel at low frequencies and out-of-plane motion of the wheels at higher frequencies[12]; wheel squeal due to negative friction and flanging noise due to high coefficient of friction. The spectral distribution of train pass by on normal track clearly shows an increase in the levels of noise between 160 Hz to 1 kHz, due to wheel/rail interaction, 1 to 5 kHz due to rail squealing and 5 to 20 kHz due to flange rubbing. Figure 2 shows the difference in spectrum of the sound pressure level monitored on the far way side for normal and lubricated track at a distance of 10 m from the track.

The measurements reveal increased wheel/rail interaction and squealing noise on lubricated track causing an increase in sound pressure level in the range 160 Hz to 4 kHz; the maximum increase is observed in frequency range 200 to 800 Hz. However, when both the near side and far side measurements are taken into account, it is observed that the increase in sound pressure level is dominated in frequency range 250 to 400 Hz. This unusual behaviour is observed due to reduced adhesion levels on account of rail head and wheel tread contamination due to lubrication of track and low friction coefficient eventually causing an increase in the elastic surface shear deformation of the mating surfaces. Thus, slip process is instigated in lateral and longitudinal direction due to the shear deformation exciting the resonant modes both axial and radial of the wheel especially in bands 160 Hz to 4 kHz. The acoustic energy is radiated by the wheel and track and also induces vibrations in coach. These lateral forces generated cause rail far corrugation, and in severe cases may result into derailments and poor braking duet low friction. Thus, it is imperative to have an efficient friction management for combating the lateral forces and squealing sounds generated by transit trains while negotiating a curved track. Figure 3 shows the sound pressure level in interior of coach for both the normal and lubricated tracks.

A similar behaviour is observed in the inside coach like the wayside measurements, as the wheel/rail interaction leads to increase in sound pressure level by maximum 3 dB in the range 250 to 400 Hz. The noise emissions get accentuated by 2% on far way side at lubricated track, while it decrements by 0.1% only in case of inside measurements in the coach at lubricated track. At higher frequencies (>5 to 16 kHz), the flange rubbing gets enhanced leading to more noise emissions in this band in case of wet track unlike as observed in wayside noise. The cause is supposed to be due to the bending resonances of bogie being excited by lateral creep forces. However, the other sources of noise in interior are rolling noise, air conditioning noise, boundary layer noise due to airflow on roof and sides of coach and due to passengers. The rolling noise transmitted into car interior may be attributed due to airborne noise coming from windows, doors and structure borne noise transmitted through car body floor. The vibration spectrum on axle is wideband in nature; the resonant modes of vibration inside coach lie in frequency range 1-7 Hz and sidewalls have an additional frequency component of 30 Hz and its harmonics. Figure 4 shows the sound exposure level (SEL), L_{eq} and L_{max} values for wayside and interior of the coach. It is observed that noise radiated in terms of SEL, L_{max} and L_{eq} is more in case of lubricated track which is due to the increased creepage on account of reduced adhesion that increases the creep force to a maximum extent until it reaches saturation, after which the slope becomes negative inculcating an unstable dynamic behaviour of the vehicle[13].

3 Results and Discussion

While negotiating a curvature, the surface speed of the outer wheel is higher than the inner wheel as it crosses a large radius of curvature. The flanges of the inner wheel touches the track avoiding the train from de-railing. However, a large radial (or axial) force is exerted on wheel and rails which is transmitted to the bogie and excite the bending resonances of the bogie. The difference in wheel speed and pressure exerted by

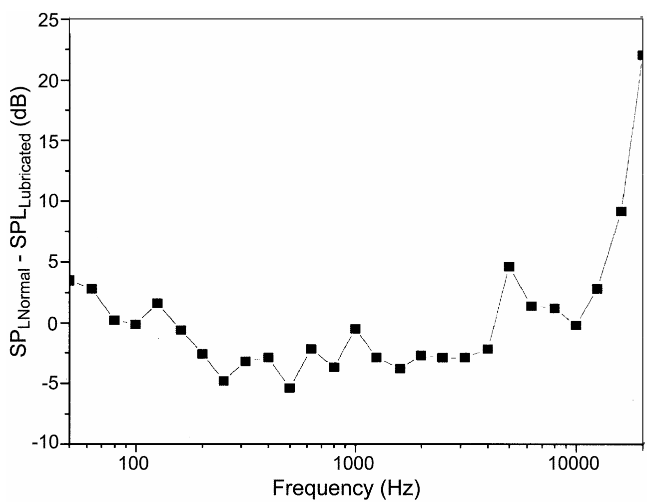

Fig. 2 — Difference in sound pressure level monitored on normal and lubricated track on far wayside

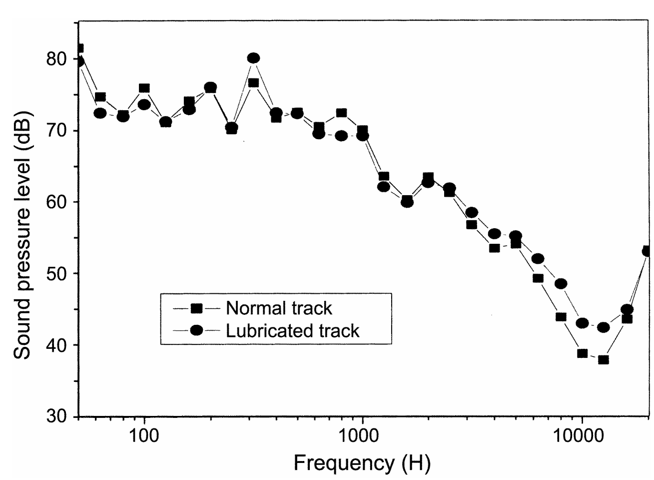

Fig. 3 — Comparison of sound pressure level monitored in coach interior

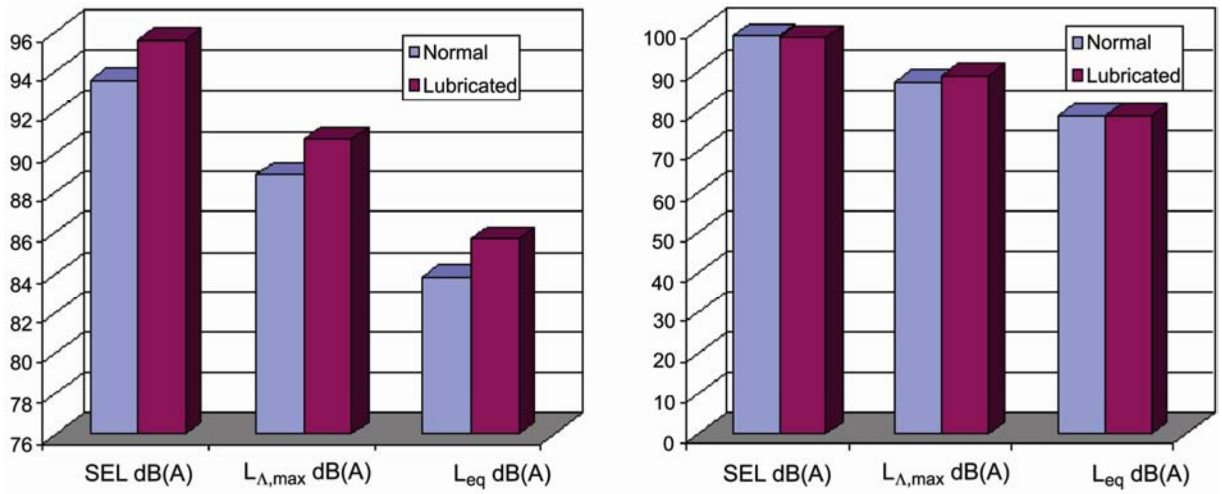

Fig. 4 — Comparison of sound exposure level (SEL) and L_{eq} for wayside noise (LHS) and interior of coach (RHS)

wheel flange cause screeching sound. The centripetal force required for the curvature motion is along the surface of track, and is provided by the component of the contact force between the track and the train wheels along the track. As the outer rail is inclined relative to inner rail by an angle α, the resultant of centrifugal force and weight is directed towards the center of track.

This component is provided by the friction force of kinetic friction as:

$$f \leq \mu_k N \qquad \ldots(1)$$

$$mv^2/R \leq \mu_k N;\ v^2 \leq \mu_k R\, N/m \qquad \ldots(2)$$

$$v^2 \leq \mu_k Rg;\ v_{max} = \sqrt{\mu_k Rg} \qquad \ldots(3)$$

where f is the frictional force, μ_k is the coefficient of kinetic friction, R is the radius of curvature, N is normal reaction and m is the mass of train. When the track at curvature is lubricated, then the kinetic friction is reduced along the track forcing the train to reduce the speed. In case, the speed is not altered, the imbalance cause the train to go off the track to gain larger radius R. So, to restrain the train on track, the imbalance reaction is along the acceleration due to gravity which subsequently results in impacting the rail track with a net imbalanced force. This enhanced rail/wheel interaction accentuated the sound pressure level in the bands where rail/wheel interaction dominates as is evident from Fig. 5, showing the average spectra for both dry and lubricated (wet) tracks.

The probable cause of origin of the net imbalance force arises from the longitudinal and spin creepage on the flange. Due to lubrication, the squealing noise

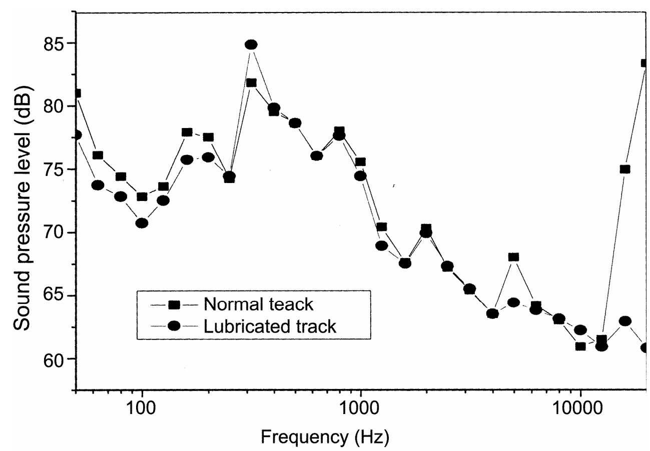

Fig. 5 — Comparison of average sound pressure level monitored on wayside

is reduced to comparatively lesser extent, with a highest attenuation of 4 dB at 5 kHz. The flanging noise generated due to rubbing of the wheel flange against the track is attenuated maximum by 22.5 dB at high frequency of 20 kHz and 12 dB at 16 kHz. The lateral forces excite the mode shapes of wheels between 400 and 8000 Hz[14]. These lateral slip forces have a longitudinal counterpart as well, which is not affecting the squeal generated by train[15] and also as revealed by studies, squeal decreases by increasing longitudinal slip[16]. The elastic surface shear generated in contact area between rail and wheel results in varying torque components in the longitudinal direction exciting both rail and wheel resonant modes. This longitudinal slip causes an increase of sound pressure level in frequency range 250 to 400 Hz. Figure 6 shows the interacting forces between rail gauge corner and wheel flange[17]. The longitudinal slip

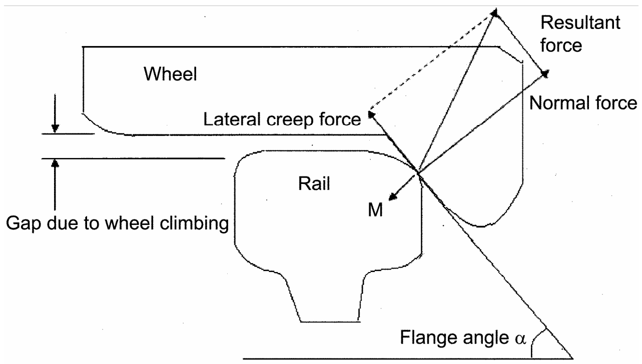

Fig. 6 — Inter-acting forces between rail gauge corner and wheel flange[17]

is more predominant in case of the inner wheel as compared to the outer wheel as the outer wheel experiences less normal reaction. Thus, the net impact on rail is along the inner wheel causing wear and screeching sound.

4 Conclusions

The present work shows the non effectiveness of gauge face lubrication in combating the squealing and flanging noise. It is also observed that parameters such as A-weighted noise level, SEL or L_A are not sufficient to determine the effectiveness of noise reduction measurement due to lubrication. The noise spectrum can only reveal the true picture of any noise mitigation programme at rail track curvature. Flange lubrication carries with it the risk of rail head and wheel tread contamination leading to reduced levels of adhesion, which can result in 'rail burn' and 'wheel flats' due to wheel slide during braking. So, lubrication process is limited in controlling the squealing and flanging noise as the loss of adhesion and poor braking cannot be avoided after lubrication of the track. Thus, introduction of positive friction modifiers particularly causing high positive friction at the contact area is the optimum solution of encountering the negative friction characteristics at creepage saturation and stick slip instability. Fundamentally, the effectiveness of the lubrication system shall be established only when it eliminates the squealing noise and not just reduces the amplitude.

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