Reductions in environmental noise emissions from Dublin's light rail system following a rail grinding campaign on embedded track

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Summary

Luas is Dublin's modern light rail system. Similar to the majority of urban electrical tramways, the system is relatively quiet when compared to diesel locomotives with similar power output. However, electrical rail systems do produce airborne noise. The principle source is the interaction of the wheels with the rails; termed "rolling noise". Rail roughness, including corrugation, has a substantial influence on rolling noise. To remove rail roughness the rails are ground. To investigate grinding on the network pre- and post-rail grinding, noise measurement surveys were undertaken at eight locations on the network, subject to a rail grinding programme in May 2016. Noise surveys were undertaken monthly from January/February 2016 to October/November 2017 to capture both pre and post-rail grinding noise emissions. Monitoring was undertaken at different track forms (embedded, embedded grass and traditional slab track) with trams passing at different speeds (30–70km/hr). Control locations, not subject to rail grinding, were also monitored. This paper details the results at two locations with embedded and embedded grass track forms. The grinding campaign was successful with reductions of 4.8dB ($L_{Aeq,Tp}$) achieved at both locations. In specific one third octave bands, reductions of up to 13.5dB were achieved. At both locations reductions achieved have largely remained over the monitoring period. However, increases in noise emissions at one of the locations (Location 7) in October and November 2017 indicate that rail grinding may be again required within the next six to twelve months.

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1. Introduction

Environmental noise is a major environmental health problem. The World Health Organization categorizes noise as being the second-worst environmental cause of ill health, behind only ultra-fine particulate matter air pollution [1]. In the European Union (EU), more than 100 million citizens are affected by noise levels above 55dB L_{den} [2]. Road traffic is the most prominent source for such noise; however, railways are the second most dominant source of environmental noise [1].

Luas is Dublin's light rail system. Operations commenced in 2004 with the opening of the Luas Green and Red Lines. In December 2017, Luas Cross City, a 5.6km extension of the Luas Green Line, commenced passenger services providing a link between the two lines and extending the network to Cabra in north Dublin. The system is currently serviced by Nr.36 Citadis 401 trams, operating on the Luas Red Line, and Nr. 4 Citadis 401 trams, Nr.26 Citadis 402 and Nr.2 Citadis 502 trams, operating on the Luas Green Line. Both the Citadis 401 and 402 trams are four-bogied vehicles with three motor bogies and one trailer bogie. The Citadis 502 trams are five-bogied vehicles with four motor bogies and one trailer bogie.

Similar to the majority of urban electrical tramways, Luas is powered by electricity supplied by an overhead catenary system and is relatively quiet when compared to diesel locomotives with similar power output. In addition, due to its relatively slow maximum speed of 70km/hr, noise emissions are low when compared to faster heavy rail vehicles. However, electrical light rail systems do produce airborne and/or structure-borne noise and vibration which may require abatement. Sources of operational noise and vibration in the light railway system include traction noise from auxiliary equipment fitted to the tram vehicles, curve squeal, joint impact noise and warning signals from trams (chimes, etc.). However, the main noise source is the interaction of the wheels with the rails, termed "rolling noise".

Photograph 1: Luas tram on embedded track

Ensuring smooth wheels and rails aids minimal noise generation. Hardy and Jones [3] report that normally the rail head will exhibit "broadband" surface roughness but at some locations there are periodic wear patterns, known as corrugations, which can have significantly greater amplitudes than the general broadband roughness. Rail corrugation is one of the most serious and expensive problems experienced by transit systems [4]. Wheels can also suffer from corrugation. In relation to rail, once a rail has reached an unacceptable level of roughness, the only way of removing the existing corrugation is to grind its surface. It is important to note that grinding is mostly undertaken for reasons of preventing rail defects and fatigue cracks, and not for acoustic reasons [5]. However, in Germany, rail grinding is undertaken according to acoustic criteria [6]. Grinding should focus only on the areas exhibiting significant corrugation or high corrugation growth levels as part of a cost effective corrugation management strategy.

In 2012, the acoustic benefits of rail grinding were investigated on the Luas Red Line at one location. The track form at this location was traditional slab track with trams travelling at a speed of approximately 70km/hr. The gradient at this location was approximately 4%. A reduction of 10dB ($L_{Aeq,Tp}$) was achieved following the grinding campaign. Upon review of the measured one third octave data, reductions of 10–12dB were achieved between 400 Hertz (Hz) and 630Hz. However, this study was limited and findings were based on only two pre-grinding trackside measurements and three post-grinding measurements. Between January/February 2016 and October/November 2017, Transport Infrastructure Ireland (TII) undertook a more comprehensive investigation into noise reductions following a rail grinding campaign. The aim of this current study was to determine the acoustic benefits following a rail grinding campaign on the Luas network at eight locations on the network with different track form, speed profile i.e. steady or accelerating/decelerating and tram pass-by speeds. Control locations were also surveyed over the monitoring period. This paper presents and discusses the results at two of these locations, Location 7 and Location 8, with embedded track.

2. Methodology

2.1 Corrugation survey

Prior to every planned rail grinding campaign, the Infrastructure Maintenance Contractor (IMC) undertakes a corrugation survey of the entire network using a Corrugation Analysis Trolley (CAT). The CAT is supplied with software that enables interpretation and analysis of the recorded data in various ways, including analysis of corrugation wavelength and amplitude. Pre-rail grinding corrugation amplitudes (measured in micrometres (µm)) at the two monitoring locations and control location are included in Table I.

Table I. Pre-rail grinding corrugation levels.

Location	*Amplitude*
Location 7	122µm
Location 8	90µm
Control Location	<80µm

2.2 Monitoring locations

Noise monitoring locations were selected following a desktop review of available historic noise survey data, an onsite review of track form types on the network and a review of the 2015 corrugation survey undertaken by the IMC. Table II provides details of track form, tram pass-by design speed and distance to the nearest side rail under consideration for each of the two monitoring locations considered in this paper.

Table II. Noise monitoring location details.

Monitoring Location	*Track form*	*Speed profile*	*Distance to nearside track*
Location 7	Embedded	30km/hr	2.0m
Location 8	Embedded (grass)	30km/hr	2.0m
Control Location	Embedded	30km/hr	2.0m

Photograph 2: Tram on embedded (grass) track

2.3 Measurement campaign

The acoustic parameters measured during each monitoring event were (i) $L_{Aeq,Tp}$ (ii) L_{AE} (iii) L_{AFMax} and (iv) linear one third octave frequencies (20Hz–20kHz). Three tram passes were monitored at each location. All measurements were attended and undertaken in general accordance with ISO 3095:2013 [7]. In addition, the following supportive information was noted during each tram by pass (i) tram direction (ii) tram number (iii) estimated tram speed and (iv) exposure time. During the majority of surveys, a number of events were dismissed due to obvious contamination, e.g. two trams approaching at the same time. Noise measurements were made using Class 1 data logging integrating sound level meters, fitted with 1:1 and 1:3 Octave Band Filters. A stop watch was used to record the speed of all trams and an anemometer was utilized to measure wind speeds.

2.4 Rail grinding campaign

In May 2016, the IMC undertook a rail grinding campaign on approximately 10.5km of the network. A grinder, fitted with six grinding stones, was used for the grinding programme. Results of the pre-grinding corrugation survey were reviewed and locations identified requiring treatment. The number of passes ranged from 2–16. Both Location 7 and Location 8 were ground as part of the May 2016 campaign.

Photograph 3: Rail grinder on slab track

3. Results

3.1 Location 7

The broadband parameters and one third frequency analysis for Location 7 are presented in Figures 1 and 2.

Between February and April 2016, the L_{AE}, $L_{Aeq,Tp}$, and L_{AFMax} had averages of 92.8dB, 80.0dB and 88.5dB respectively (Figure 1). Following the May 2016 grinding campaign, average reductions of 4.8dB, 4.8dB and 6.1dB were achieved respectively with logarithmic averages of 88.0dB (L_{AE}), 75.3dB ($L_{Aeq,Tp}$) and 82.4dB (L_{AFMax}) measured in May 2016. Over the 17 month period between May 2016 and September 2017, post-grinding levels have remained relatively constant with logarithmic averages of 86.9dB (L_{AE}), 75.1dB ($L_{Aeq,Tp}$) and 81.9dB (L_{AFMax}) measured. However, a noticeable increase was evident in sound pressure levels in October and November 2017 with logarithmic averages of 89.0dB (L_{AE}), 78.4dB ($L_{Aeq,Tp}$) and 84.6dB (L_{AFMax}) measured. In March 2017, a clear upward spike is evident for the L_{AFMax}. It is hypothesised that this spike is due to wheel-related damage, e.g. a wheel flat on one of the monitored trams.

Due to the moderate speed of tram pass bys at this location (30 km/hr), the rolling noise caused by corrugation had a low frequency content, i.e. 200Hz. A reduction of approximately 13.5dB was identified in this 200Hz band following the May 2016 rail grinding campaign (Figure 2). Post-grinding levels remained relatively constant between May 2016 and September 2017. However, increases are evident in the period October-November 2017. Average levels measured from 800Hz to 12.5kHz are higher for the period October-November 2017 when compared to the pre-grinding period February-April 2016.

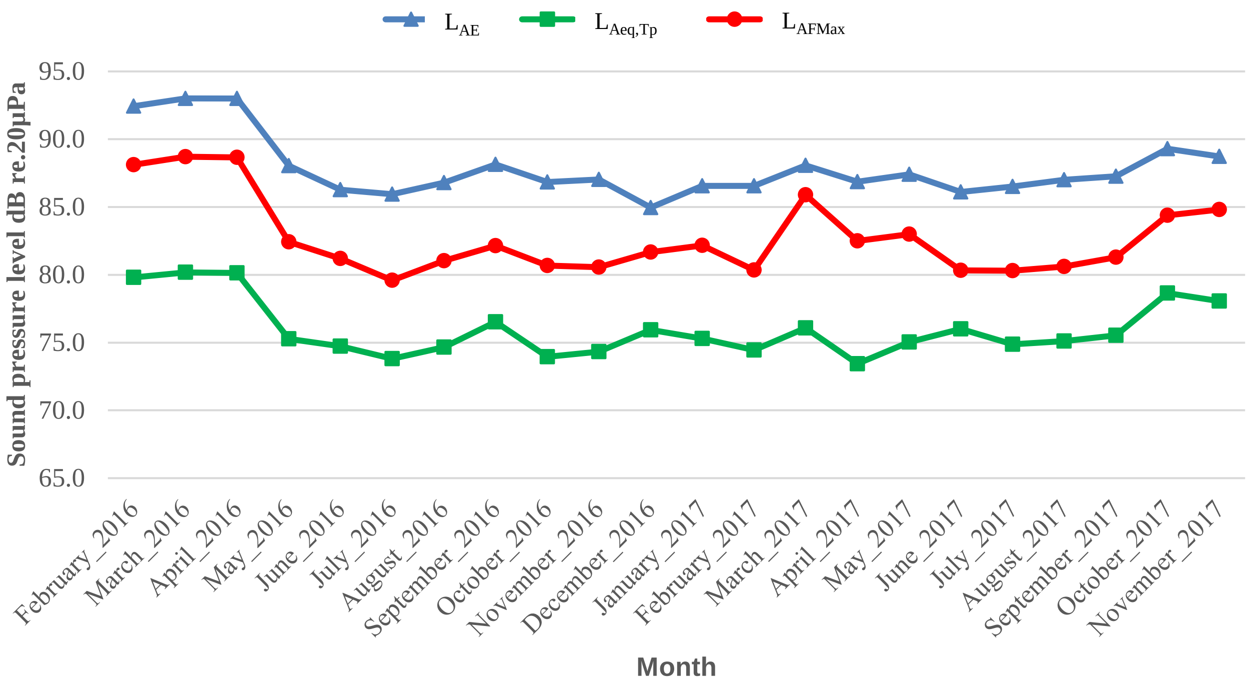

Figure 1 Pre-grinding and post-grinding measured monthly average broadband parameters at Location 7

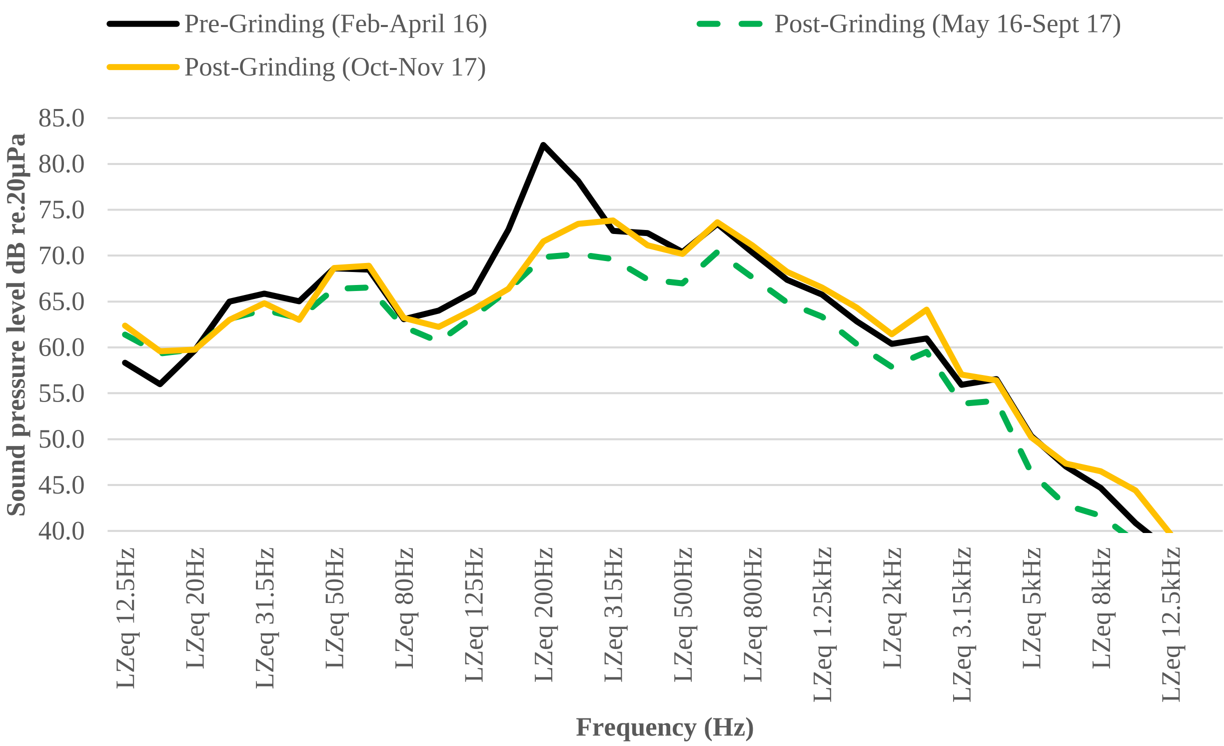

Figure 2 Pre-grinding and post-grinding 1/3rd octave band analysis at Location 7

3.2 Location 8

The broadband parameters and one third frequency analysis for Location 8 are presented in Figures 3 and 4. At Location 8, the May 2016 monitoring campaign was undertaken prior to the grinding of rail at this location, which was undertaken in late May 2016.

Between January and May 2016, the L_{AE}, $L_{Aeq,Tp}$, and L_{AFMax} had averages of 90.8dB, 80.5dB and 88.5dB respectively (Figure 3). Following the May 2016 grinding campaign, average reductions of 4.4dB, 4.8dB and 6.0dB were achieved respectively with logarithmic averages of 86.6dB (L_{AE}), 75.7dB ($L_{Aeq,Tp}$) and 82.5dB (L_{AFMax}) measured in June 2016. Over the 17 month period between June 2016 and October 2017, post-grinding levels have remained relatively constant with averages of 86.1dB (L_{AE}), 76.3dB ($L_{Aeq,Tp}$) and 82.3dB (L_{AFMax}) measured. A slightly increasing trend is evident in sound pressure levels when comparing June 2016 - January 2017 and February-October 2017. June 2016-January 2017 had averages of 85.5dB (L_{AE}), 75.3dB ($L_{Aeq,Tp}$) and 81.7dB (L_{AFMax}) measured whilst February-October 2017 had averages of 86.6dB (L_{AE}), 77.1dB ($L_{Aeq,Tp}$) and 82.8dB (L_{AFMax}). Therefore, increases of 1.2dB (L_{AE}), 1.8dB ($L_{Aeq,Tp}$) and 1.1dB (L_{AFMax}) were measured.

In September 2016, a clear upward spike is evident for the L_{AFMax}. It is hypothesised that this spike is due to wheel-related damage, e.g. a wheel flat on one of the monitored trams.

Reductions were achieved across all one third octave band frequencies from 100Hz-20kHz (Figure 4). The highest reduction (8.5dB) was achieved at 400Hz. Post-grinding levels remained relatively constant between May 2016 and October 2017.

Two clear peaks are evident in Figure 4 at 100Hz and 200Hz. Pre-grinding average levels (February-May 2016) of 86.2dB at 100Hz and 83.3dB at 200Hz were measured at Location 8. Between April 2016-October 2017 average levels of 81.5dB at 100Hz and 76.3dB at 200Hz were measured. It is interesting to note that whilst reductions are clearly achieved following the May 2016 rail grinding campaign, the peaks remain from June 2016 to October 2017.

3.3 Control Location

Between February and May 2016, the L_{AE}, $L_{Aeq,Tp}$, and L_{AFMax} had averages of 88.9dB, 80.0dB and 84.6dB respectively at the Control Location. The Control Location was not subject to grinding. Between June 2016 and October 2017 the L_{AE}, $L_{Aeq,Tp}$, and L_{AFMax} had averages of 89.7dB, 81.1dB and 85.6dB respectively at the Control Location. Increases at the control location are considered negligible.

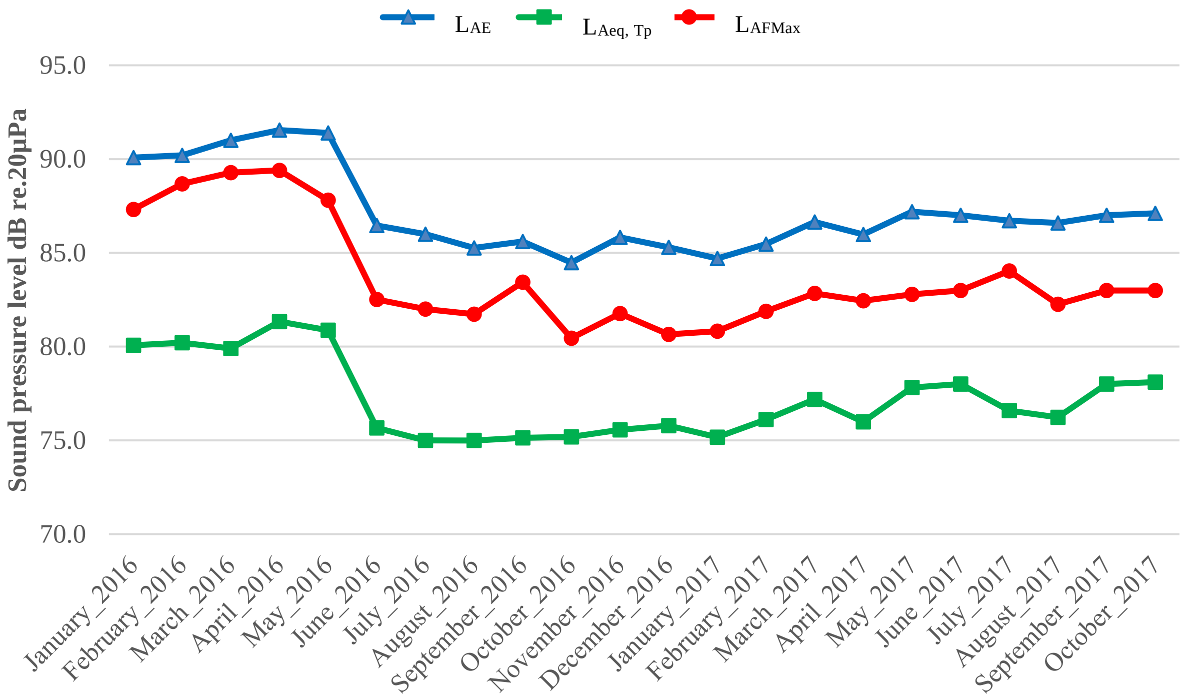

Figure 3 Pre-grinding and post-grinding measured monthly average broadband parameters at Location 8

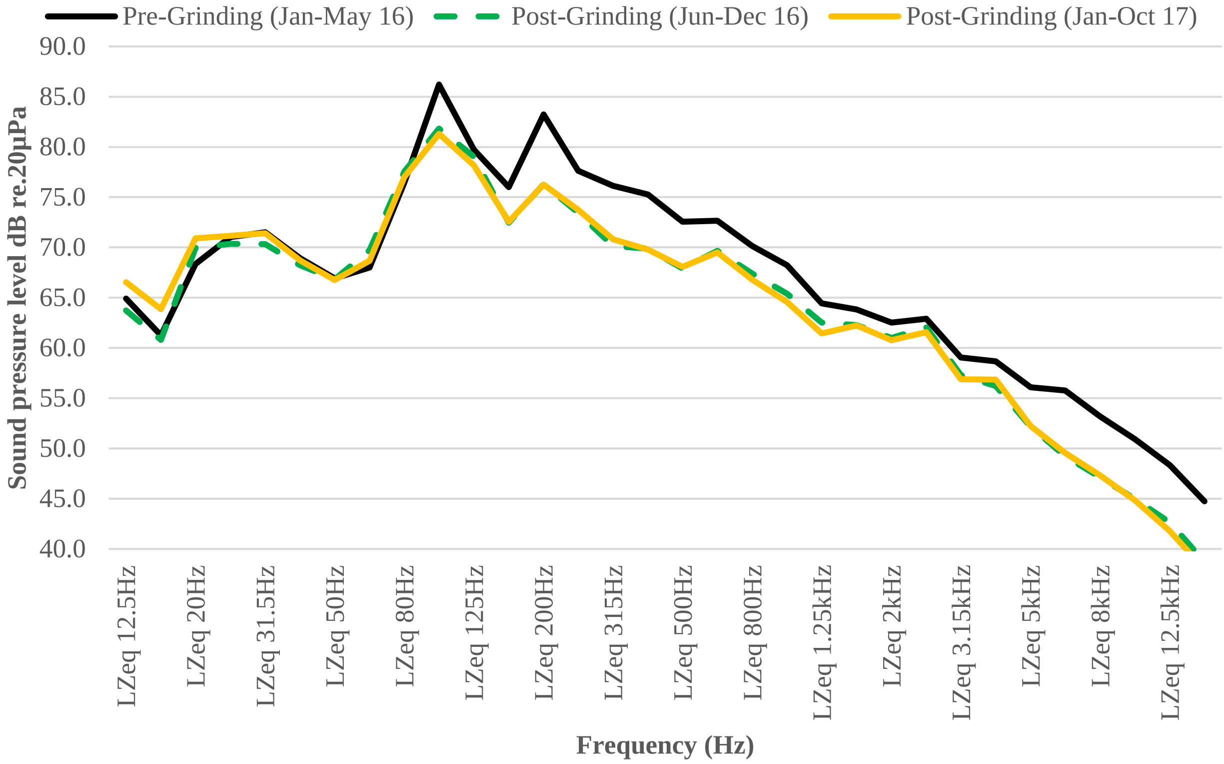

Figure 4 Pre-grinding and post-grinding 1/3rd octave band analysis at Location 8

4. Discussion

The results of this study have demonstrated that effective grinding of corrugated rail on embedded track can result in moderate noise reductions.

At Location 7, the 2015 pre-rail grinding corrugation study reported an amplitude of 122µm. Monitoring results between May 2016 and November 2017 has demonstrated that the grinding campaign was a success at Location 7. However, increases in noise emissions at this location in October and November 2017 indicate that rail grinding may be again required within the next six to twelve months. This is not unexpected as the Luas Maintainer undertakes a rail grinding campaign every 18-24 months.

At Location 8, the 2015 pre-rail grinding corrugation study reported an amplitude of 90µm. Monitoring results between December 2016 and October 2017 has demonstrated that the grinding campaign was a success at Location 8. Increases noted at Location 7 in October and November 2017 were not noted at Location 8. However, a rail corrugation survey will be undertaken prior to the next planned rail grinding programme to determine if Location 8 will require treatment.

Research reported by the EU Corrugation Project [4] indicated that existing corrugation is one of the main contributors to the development of further corrugation and the importance of the quality of the grinding process cannot be overstated. Insufficient grinding, i.e. remaining roughness, leads to a rapid increase of roughness levels and associated noise levels. It is essential that all corrugation is completely removed after grinding. The author has previously published results for rail grinding undertaken on traditional slab track in which not all corrugation was removed resulting in a more rapid regrowth of corrugation and associated environmental noise emissions [8]. Based on the acoustic evidence presented in this paper, it is hypothesised that a significant quantity of corrugation has been removed at both Location 7 and Location 8.

It is interesting to note that at both monitoring locations, pre-grinding corrugation levels and environmental noise emission results were similar. Both locations were positioned at approximately 2.0m from the track and pre-rail grinding corrugation levels were quiet similar i.e. 122µm a Location 7 and 90µm at Location 8. The pre-grinding average L_{AE} and $L_{Aeq,Tp}$ at Location 7 were 92.8dB and 80.0dB respectively. At Location 8 pre-grinding averages of 90.8 L_{AE} and 80.5 $L_{Aeq,Tp}$ were measured at Location 8. Following the grinding campaign reductions of 4.8dB were achieved at Location 7 for both L_{AE} and $L_{Aeq,Tp}$. At Location 8 reductions of 4.4dB (L_{AE}) and 4.8dB ($L_{Aeq,Tp}$) were achieved. In October 2017 levels of 89.3dB (L_{AE}) and 78.6dB ($L_{Aeq,Tp}$) were measured at Location 7 and levels of 87.1dB (L_{AE}) and 78.1dB ($L_{Aeq,Tp}$) were measured at Location 8. The above results aid in demonstrating the level of consistency, and ultimate success, of the rail grinding survey undertaken by the Maintainer on the two embedded sections of track considered in this paper.

5. Recommendations and further research

The results detailed in this paper and other publications associated with this research [8] have demonstrated that effective grinding of corrugated rail will result in moderate-significant noise reductions depending on track form and the level of corrugation present on the rail.

Further research into the areas of corrugation and rail grinding is planned by TII. A number of recommendations and possible future research is considered in the sections below.

5.1 Optimized rail grinding regime

To help ensure that achieved roughness and acoustic reductions remain for a sustainable time period, it is recommended that TII, working with maintenance partners, develops an optimized rail grinding regime. Such a regime will increase rail life and reduce costs with the added benefit of improving the noise environs for the local population. As part of this optimized regime, a comprehensive post-rail grinding corrugation survey should be undertaken within a set timeframe to confirm that grinding has met the desired campaign targets.

5.2 Proactive maintenance

It is important to note that rail grinding is a reactive maintenance activity. Once a contractual roughness limit is reached on a particular stretch of rail, as identified by a corrugation analysis survey, a 'red flag' is raised and rail grinding is scheduled. However, the need for such reactive maintenance may be reduced by the use of proactive condition monitoring and inspection. The use of remote monitoring systems facilitates maintenance optimization. Systems are now available to provide near continuous updates on the condition of the track and should be considered as part of an optimized grinding regime.

5.3 Mixed fleet on the Luas Green Line

Grassie [9] concluded that the more consistent the speed of trains and the less varied the rolling stock, the more consistent the wavelength of any corrugation that results from excitation of a particular wavelength fixing mechanism. However, it has been demonstrated that changes in vehicle speed can actually wear out pinned-pinned resonance corrugation [10]. Until September 2017, the Nr.26 Citadis 402 trams were the only rolling stock in operation on the Luas Green Line. However, with the extension of the Luas network and increased capacity demand associated with the economic upturn in Ireland, the fleet on the Luas Green Line is now mixed. Nr. 4 Citadis 401 trams have been moved from the Luas Red Line to the Luas Green Line. Nr. 2 newly purchased Citaids 502 trams have been brought into service with a further six 502 vehicles to be brought into operation later this year. The introduction of the mixed fleet to the Luas Green line has provided an opportunity to investigate if there will be a reduction in corrugation levels and environmental noise emissions over time.

5.4 Lubrication

Friction is potentially significant for all types of corrugation in which wear is the damage mechanism [9]. Lubrication works by reducing the coefficient of friction. However, when lubricants are used it must be ensured that they do not lead to loss of adhesion as this could compromise safety [5]. TII have previously investigated the acoustic benefits of top-of-rail lubricators on tight curves and reductions of 8.4dB (L_{AE}) have been achieved (unpublished results). The benefits of lubrication, both water and biodegradable oil, should be investigated on corrugated track.

6. Concluding remarks

The importance of effectively managing environmental noise emissions associated with Luas operations cannot be overstated.

In recent years, TII has investigated a number of noise abatement approaches including rail dampers and absorbing mats covering the slab track, bogie shrouds and top-of-rail lubricators, for example. Effective rail maintenance through rail grinding will continue to form part of this suite of acoustic mitigation measures.

Acknowledgement

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