FRICTION MODIFIER AND GREASE NOISE REDUCTION EVALUATION TRIAL REPORT

– BCRTC OMC –

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Executive Summary

A proof of concept trial evaluating the effectiveness of KELTRACK® friction modifier supplied by L.B. Foster to mitigate problem wheel squeal noise has been successfully completed at the British Columbia Rapid Transit Company Ltd.'s Operations and Maintenance Centre (OMC). This trial was completed to examine products that could resolve noise events that were occurring on their sharp curves (<100mR) located within the OMC. Trial evaluation work involved analysis of sound measurements recorded in the body of a 35mR curve being treated with manually applied top of rail KELTRACK® friction modifier, as well as the gage face rail grease, SYNCURVE™ Transit.

Reductions of up to 12dBA were recorded through the 35mR test curve when comparing baseline 'dry' runs (i.e. no KELTRACK®) to train passes over rails treated with KELTRACK® friction modifier (Figure 1). SYNCURVE™ Transit, on the other hand, not only did it not mitigate the noise issues, but rather the trains were found to produce more rail-borne noise with this product (Figure 2).

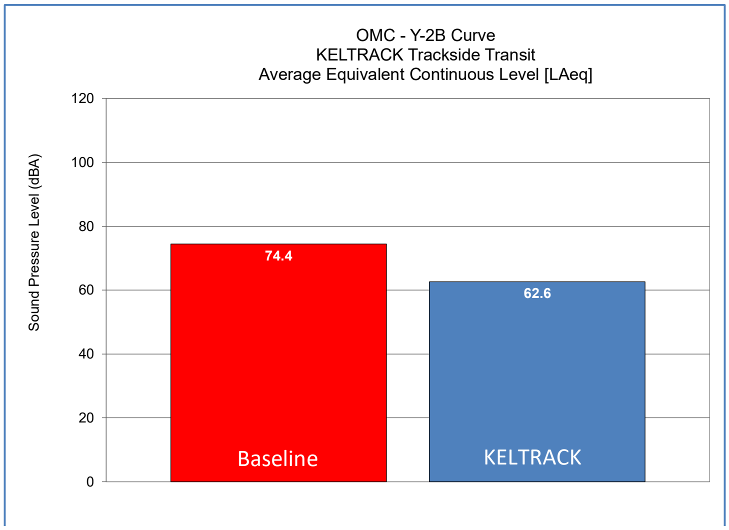

Figure 1. Average sound levels for trains travelling on dry (red) and KELTRACK®-treated (blue) rails.

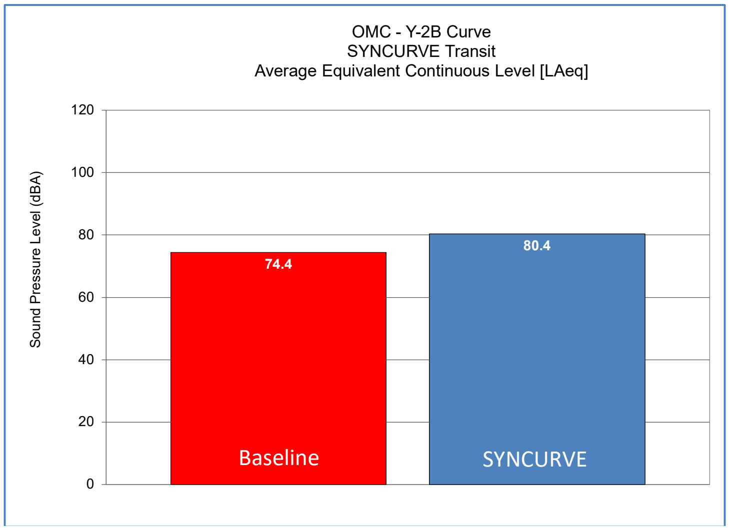

Figure 2. Average sound levels for trains travelling on dry (red) and SYNCURVE-treated (blue) rails.

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1 Background

British Columbia Rapid Transit Company Ltd. (BCRTC) is currently testing L.B. Foster Rail Technologies' top of rail (TOR) friction modifier in their Translink Noise Study. During a stakeholder's meeting, it was mentioned that the Skytrain Operations and Maintenance Centre (OMC) is also experiencing noise development from trains returning to the yard. The presence of this noise is a common phenomenon for severe curvature locations, precipitated by the following conditions to generate the noise types noted:

- Surface roughness of the wheel and rail (Rolling noise - 12.5 to 800 Hz)
- Stick-slip oscillations induced by the combination of rolling radius excess/deficiency and the negative friction characteristics of wheel steel/rail steel interfaces (Wheel squeal noise: 1000 to 5000 Hz)
- Wheel flange contact with the rail (Flanging noise: 5000 to 10000 Hz)

There is often a misconception that the application of gage face (GF) grease will reduce the rail-borne noises. However, this depends on the source of the noise, i.e. wheel squeal versus flanging. Inspection of the proposed test curve showed that there did exist wear on the high rail gage corner along the curve (Figure 3). Corrugation was also observed at some locations on the low rail.

Figure 3. Gage face wear on the high rail of the test curve.

Hence it was decided that a noise trial be conducted at this test curve using both TOR friction modifier as well as gage face rail grease, albeit separately. The TOR products tested were the commercially available KELTRACK® Trackside Transit and the next generation prototype KELTRACK® Transit Extend. The gage face rail grease tested was SYNCURVE^{TM} Transit. This trial was a "proof of concept" trial and so it should be noted here that the amount of product applied to the rails is not representative of what is normally applied. In order to perform a more accurate test that is representative of real-world application, a wayside TOR friction modifier or GF grease applicator would be required.

2 Test Site Description

This trial phase involved noise data collection specific to the Y-2B curve located on the North outer track within the OMC as the test curve (Figure 4). Details of the Y-2B test curve are listed in Table 1.

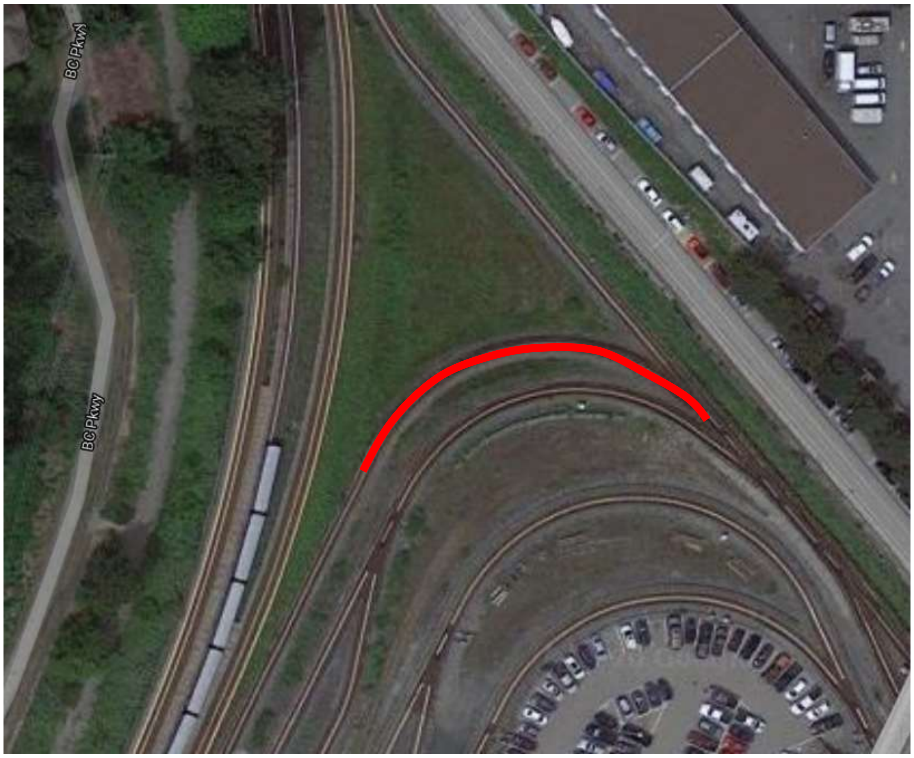

Figure 4. Y-2B curve (red) selected for KELTRACK® and SYNCURVE™ noise mitigation evaluation.

Table 1. BCRTC Skytrain OMC Y-2B test curve details.

Curve Radius	35mR
Curve Length	60.618m
Track Structure	Concrete ties and ballast

KELTRACK® was manually applied to the top of both rails by firstly pouring the product onto the rail, followed by dispersing the product using a paint roller to ensure that the running band was saturated with KELTRACK® (Figure 5). For both KELTRACK® Trackside Transit and KELTRACK® Transit Extend, the product the applied from station marker 3281/3282 to the end of the curve at the switches, which was considered the sound collection zone.

Figure 5. KELTRACK® Trackside Transit applied to the rail.

SYNCURVE^{TM} Transit was also applied manually, however, the grease was painted onto the gage corner and gage face of the rails with the use of a paint guide to ensure that no grease was applied to the top of rail (Figure 6). SYNCURVE^{TM} Transit was only applied on the high rail where gage face contact was evident along the curve.

Figure 6. SYNCURVE^{TM} Transit application using a paint guide (left) so that the grease was only applied to the gage corner and gage face (right).

3 Noise Data Measurement Parameters and Sound Meter Set-up

For each sound measurement collection, the following information was recorded:

- Weather conditions: temperature (^{o}C), % relative humidity
- Train type (Mark I, Mark II, or Mark III)
- Train ID numbers
- Train pass occurrences on the main line

All sound measurements were collected using a B&K Hand-held Analyzer 2270. The sound meter was placed in the body of the curve closer to the start of the curve in the direction of traffic when the trains enter the yard (Figure 7). The sound meter was positioned facing towards the low rail side of the curve with the microphone approximately 1.5m above the ground. Since the ground sloped upwards towards the track, it is not known what the height difference was from the microphone to the top-of-rail surface. Similarly, as the track permit did not include the tracks laid between the sound meter location and the test curve, the actual distance between the sound meter and test curve could not be measured. Sound measurements were collected from the moment the front of the train entered the sound collection zone (track section marker 3281/3282) until the back of the train exited the sound collection zone (end of the curve at the switches).

Figure 7. B&K 2270 sound meter setup.

The following acoustic parameters were used when analyzing noise data:

- L_{Aeq} : A-weighted equivalent continuous sound level
- L_{Zeq} : Equivalent continuous sound level with no frequency weightings

The non-weighted (Z-weighted) sound pressure level, measured in decibels (dB), assumes a linear response to all frequencies. A-weighting (measured in dBA) applies a filter to non-weighted data by attenuating low and high frequencies. This creates the greatest sensitivity in the 1000Hz to 5000Hz range, corresponding to the range of the greatest sensitivity of the human ear. Essentially, applying an A-weighted filter to a sound's intensity approximates its audibility, a human ear's non-linear response to noise.

4 Results

Sound measurements of trains travelling to and from the yard along the Y-2B 35mR test curve were collected over the course of a week (September 29 to October 07, 2020). All sound measurements were collected by the same person to ensure consistency in the data collection technique.

4.1 Baseline (Dry Rail)

The first day (September 29) consisted of baseline/dry rail noise monitoring (no TOR or GF product application). The temperature and relative humidity were approximately 25°C (sunny) and 55%, respectively, during this day. During the sound collection, because the trains were moving slowly on automatic train operation throughout the curves, it was inevitable that sounds from the trains travelling on the mainline were present. For this reason, baseline sound measurements were also collected on October 06 and October 07 in order to get a good representation of trains travelling on dry rail. The key difference for the latter 2 days was that the weather was foggy, and the temperature was lower (16-18°C) while the relative humidity was higher (70-80%). Upon reviewing the sound data, it was noticed that the majority of the rail-borne noise were occurring at the start of the curve. Hence, it was decided that for the analysis, only the portion where rail-borne noise was present would be analyzed, rather than the entire test curve. For the majority of the trains, the rail-borne noise lasted approximately 13 seconds, prior to the trains slowing down significantly as it was about to enter the switches.

Despite the differences in weather, it was found that for each of the baseline sound collection days, there existed a high variance in the sound levels of each train. Table 2 lists the train types associated with each train number for the different collection dates. For the table and figures below, Day I is September 29, 2020, Day II is October 06, 2020, and Day III is October 07, 2020.

Table 2. Train types for the baseline sound measurements.

Train Number	Train type	Train Number	Train type	Train Number	Train type
Day I Train 1	Mark III	**Day II Train 1**	Mark I	**Day III Train 1**	Mark II
Day I Train 2	Mark III	**Day II Train 2**	Mark II	**Day III Train 2**	Mark I
Day I Train 3	not noted	**Day II Train 3**	Mark II	**Day III Train 3**	Mark III
Day I Train 4	Mark I	**Day II Train 4**	Mark III	**Day III Train 4**	Mark III
Day I Train 5	Mark I	**Day II Train 5**	Mark II	**Day III Train 5**	Mark I
Day I Train 6	Mark II	**Day II Train 6**	Mark I	**Day III Train 6**	Mark III
Day I Train 7	Mark I	**Day II Train 7**	Mark I	**Day III Train 7**	Mark II
Day I Train 8	Mark I	**Day II Train 8**	Mark III	**Day III Train 8**	Mark II

Figure 8 shows the equivalent continuous level for each train pass on all three collection dates. While the large variance in the sound levels are clearly visible, for each collection date, the overall average noise level is constant from day to day (Figure 9).

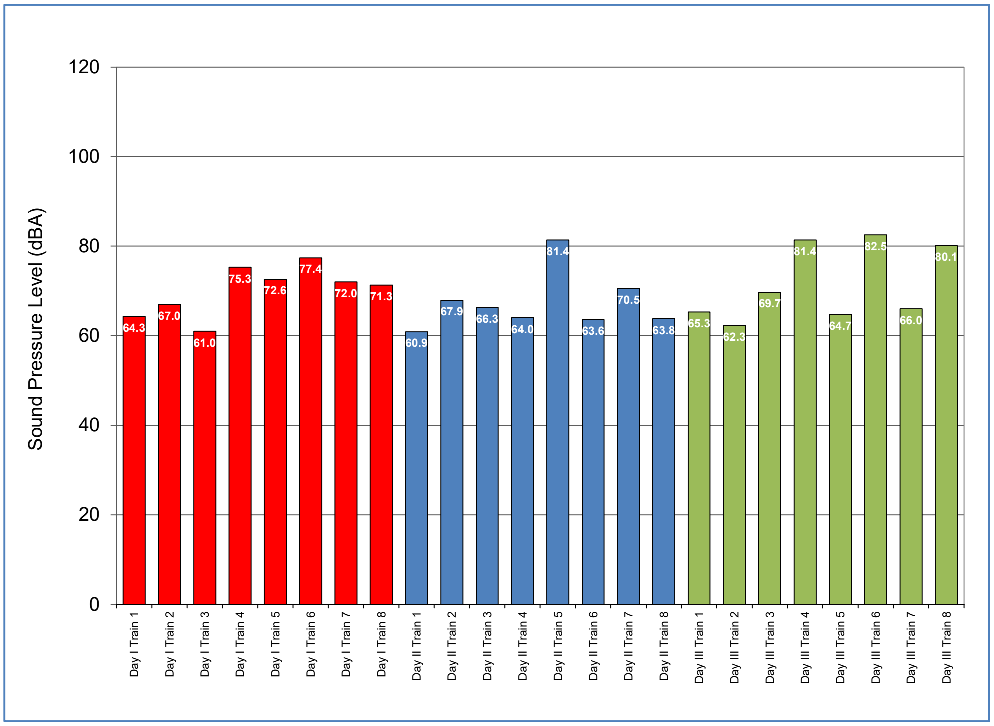

Figure 8. Equivalent continuous sound levels of rail-borne noise occurrences for each train on dry rail.

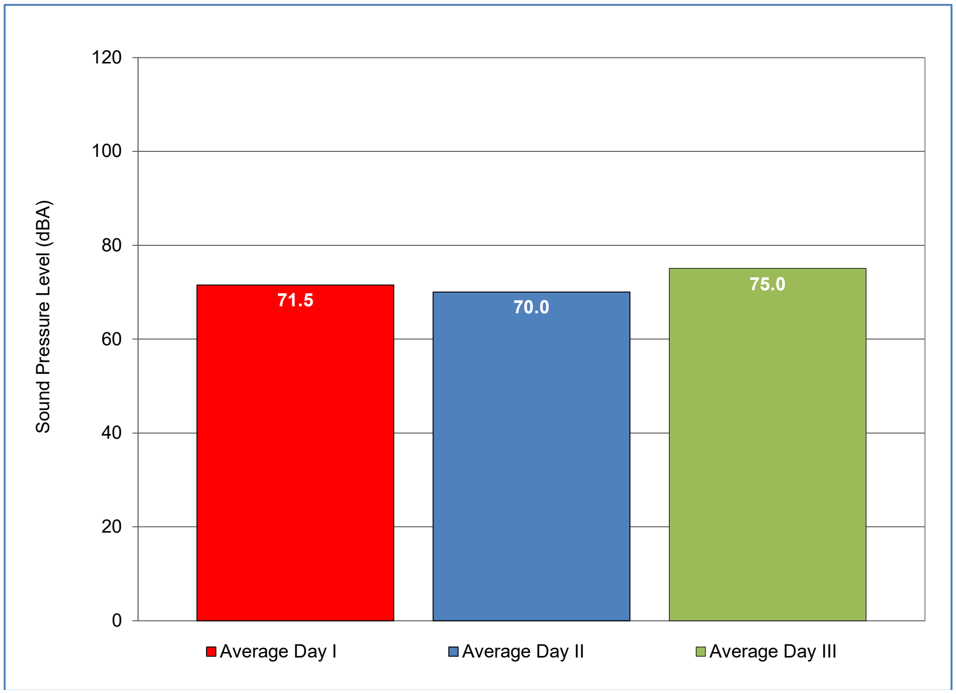

Figure 9. Average equivalent continuous sound levels of rail-borne noise occurrences of trains on dry rail for each collection date.

Similar trends were also observed for the maximum sound levels, where the per train data exhibited a large variance in the sound level (Figure 10) and yet the overall average for each day was fairly constant from day to day (Figure 11).

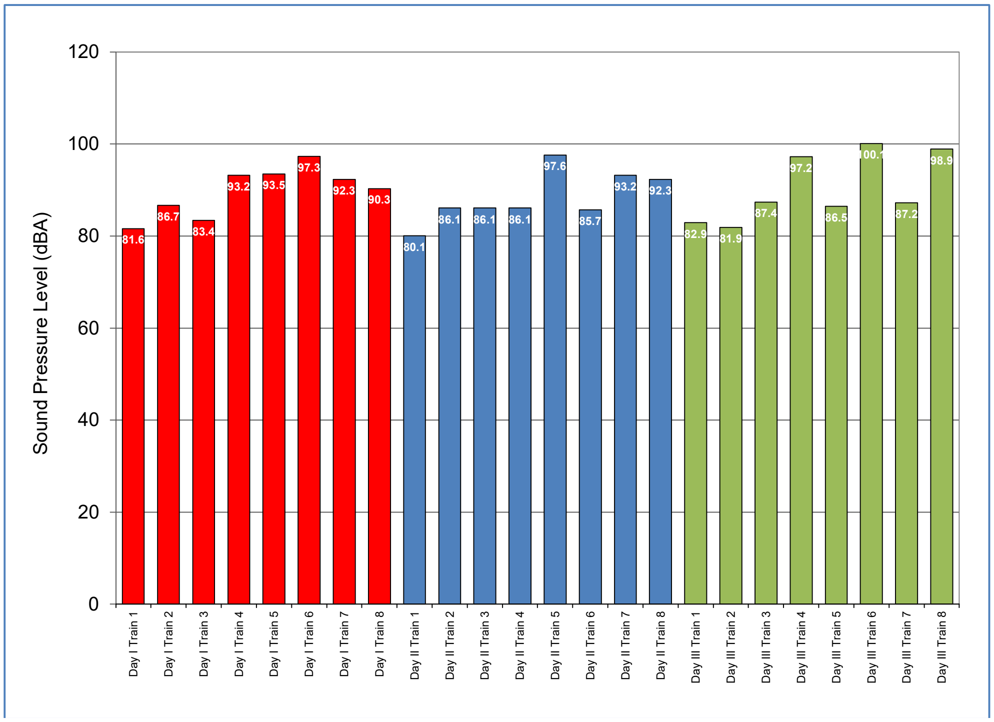

Figure 10. Maximum sound levels of rail-borne noise occurrences for each train on dry rail.

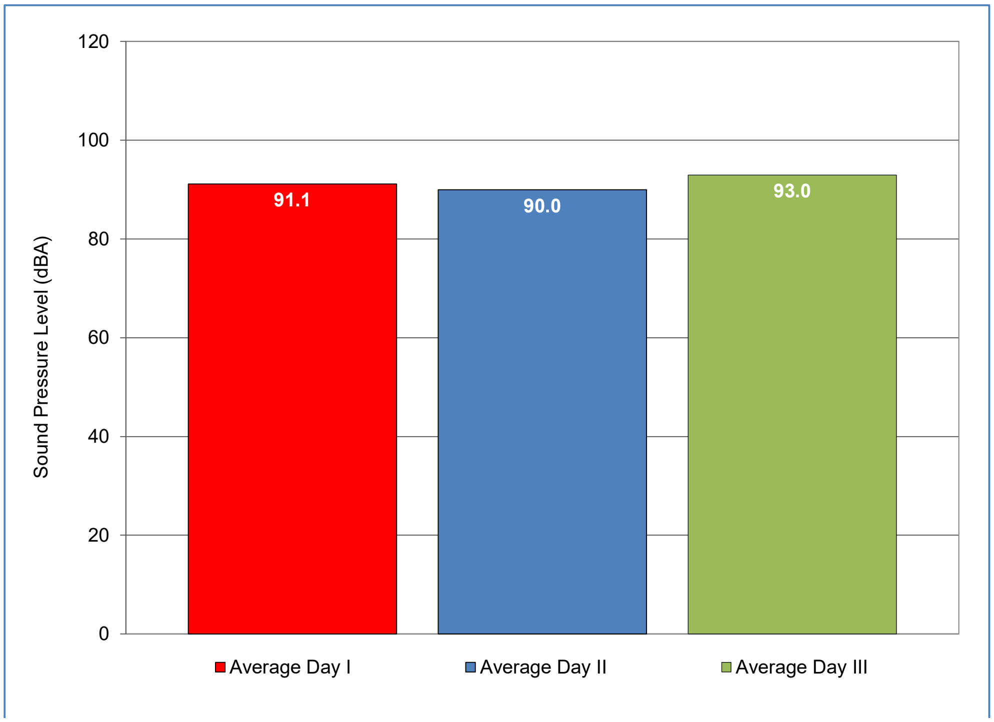

Figure 11. Maximum sound levels of rail-borne noise occurrences of trains on dry rail for each collection date.

Further analysis of the rail-borne noise generated showed that the majority of the noise is a combination of TOR wheel squeal and flanging, forming a plateau at the high frequency end of the spectrum (Figure 12). For the foggy days, there existed a distinct peak at 3150Hz, which is caused by wheel squeal.

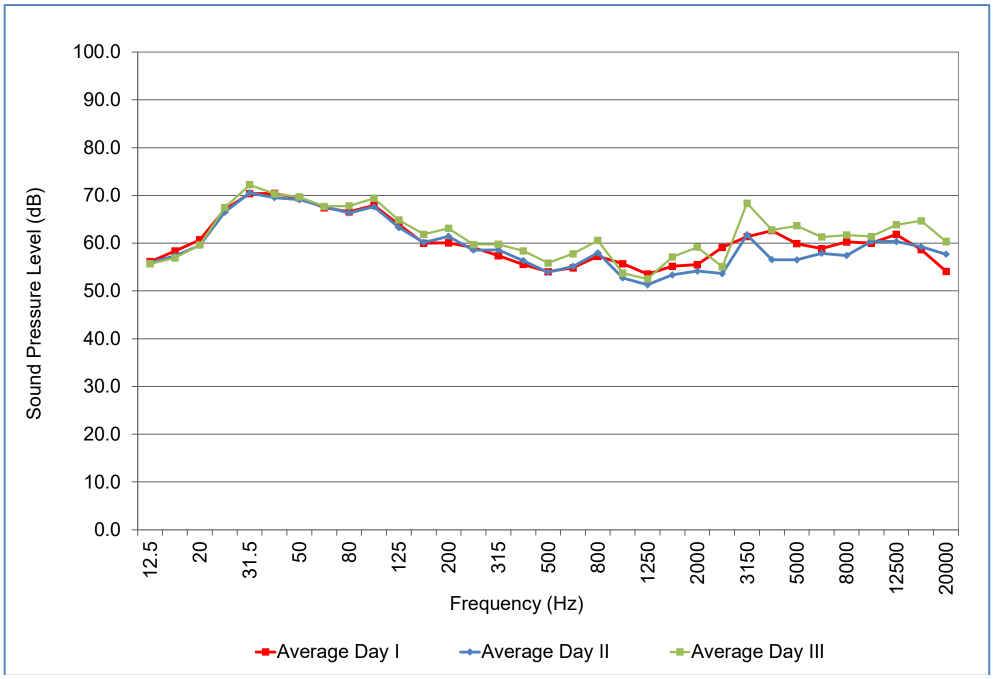

Figure 12. Average frequency distribution levels of rail-borne noise occurrences of trains on dry rail for each collection date.

In order to compare the sound levels of rails treated with TOR or GF products, the average baseline sound level of all the trains was calculated. This average will be used for the analyses hereafter.

4.2 KELTRACK® Trackside Transit

KELTRACK® Trackside Transit (KTT) was manually applied to the top of rails on the morning of September 30, 2020 prior to the trains returning to the yard. The temperature and relative humidity were approximately 20-25ºC (sunny) and 50-60%, respectively. Approximately 1 hour had passed when the first train passed over the KTT-applied rails. This first train had actually travelled in the opposite direction where it had entered the test curve from the yard side rather than from the mainline side. Furthermore, it had stopped just as it was about to leave the curve, only to reverse its direction and return to the yard. In the graphs below, these events are listed as Train 1a and 1b where the "a" is designated for the first direction of travel and "b" is designated for the reverse direction. For both the forward and reverse direction, no rail-borne noise could be heard. In fact, it was only after the 6th consecutive train pass when the sound levels had returned to baseline levels. The majority of the trains returning to the yard were Mark I trains with a few Mark II and Mark III trains. Table 3 lists the train types associated with each train pass number.

Table 3. Train types for the KELTRACK® Trackside Transit-treated sound measurements.

Train Number	Train type
KTT Train 1a	Mark II
KTT Train 1b	Mark II
KTT Train 2	Mark II
KTT Train 3	Mark I
KTT Train 4	Mark I
KTT Train 5	Mark I

As no rail-borne noise could be identified on the data for the first 6 train passes, the 13-second sound measurement segment prior to the trains slowing down for the switches were used as it was mentioned in Section 4.1 above that this was the time when the rail-borne noises could be heard on the baseline noise collections. Figure 13 show the average maximum sound levels and the average equivalent continuous sound levels for when KTT was still considered to be treating the test curve. Figure 14 shows the equivalent continuous sound levels for each consecutive train pass.

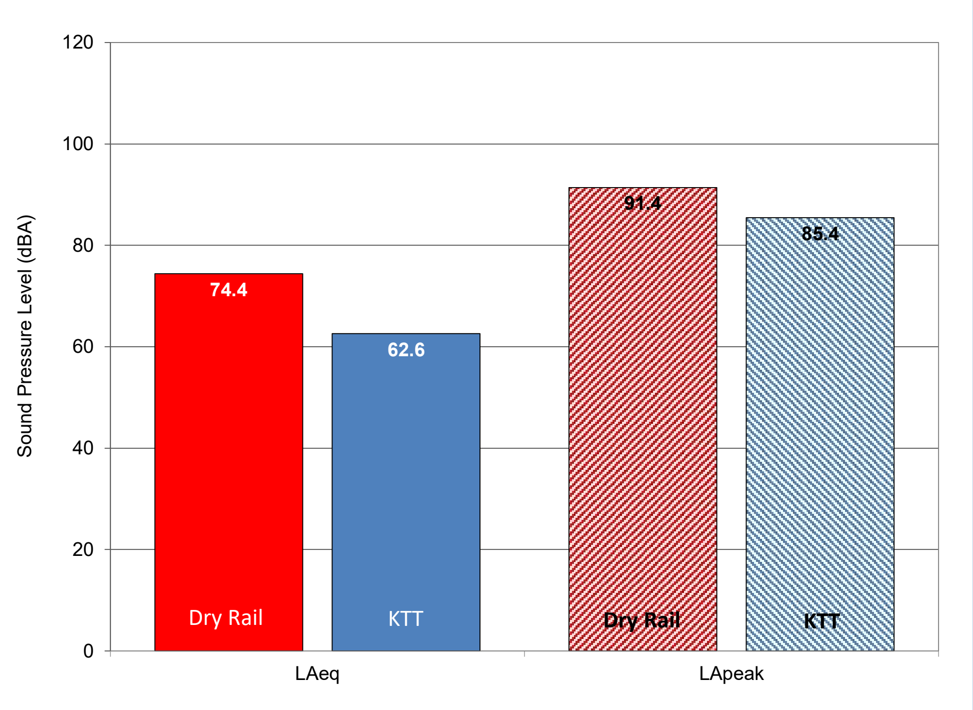

Figure 13. Average equivalent continuous sound level (solid) and maximum sound level (hashed) for trains travelling on dry (red) and KTT-treated (blue) rails along the sound monitoring test curve.

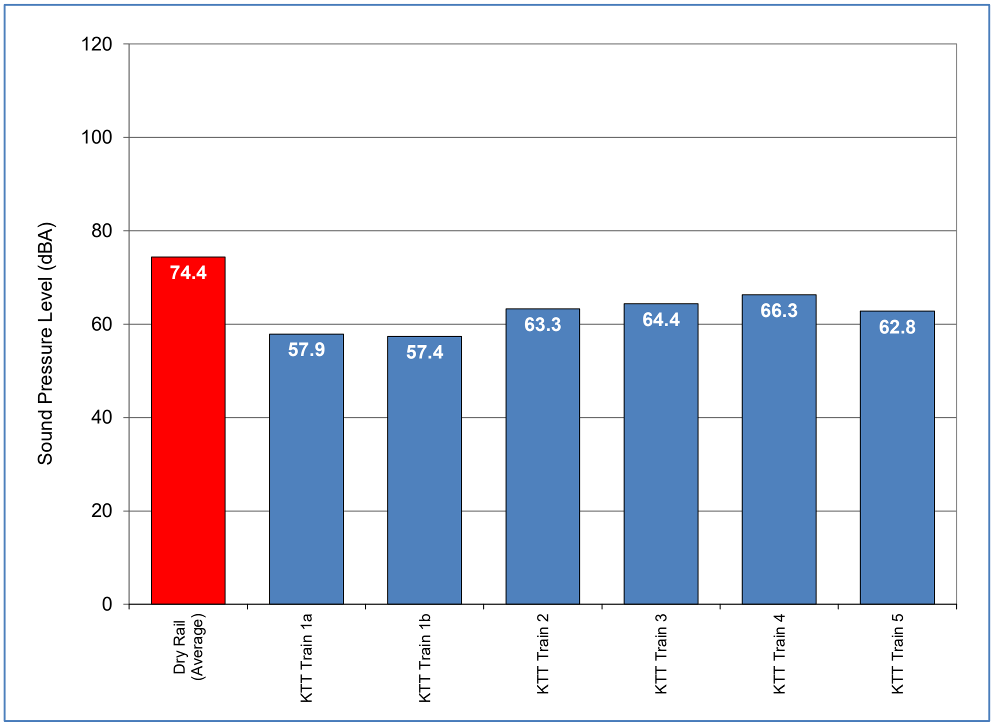

Figure 14. Equivalent continuous sound level for each train pass along the KTT-treated rails on the sound monitoring test curve.

The frequency distribution graph shows an overall sound level reduction with KTT in the higher frequency range, typically associated with rail-borne noise (Figure 15). A 15-20dB sound level reduction is achieved in the frequency range typically associated with wheel squeal. As perspective, a 10dB sound level reduction roughly corresponds to the half of the intensity of the perceived volume.

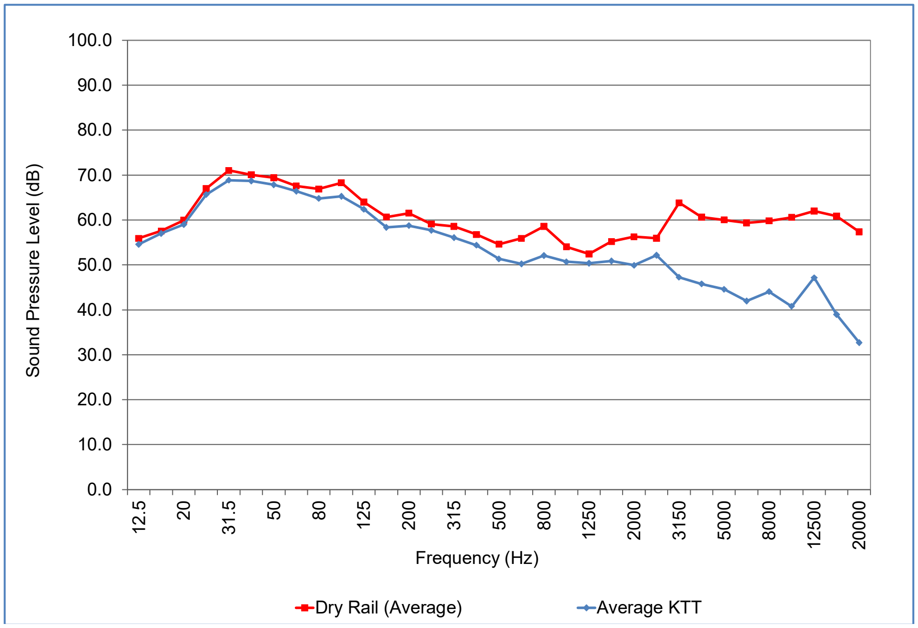

Figure 15. Average frequency distribution levels of rail-borne noise occurrences for trains travelling on dry (red) and KTT-treated (blue) rails.

4.3 *KELTRACK® Transit Extend*

KELTRACK® Transit Extend (KTEX) was manually applied to the top of rails on the morning of October 01, 2020 prior to the trains returning to the yard. The temperature and relative humidity were approximately 18-23ºC (sunny) and 55-65%, respectively. Approximately 1.5 hours had passed when the first train passed over the KTEX-applied rails. Similar to the previous day, the majority of the trains returning to the yard were Mark I trains with a few Mark II and Mark III trains. Table 4 lists the train types associated with each train pass number.

Table 4. Train types for the KELTRACK® Transit Extend-treated sound measurements.

Train Number	Train type
KTEX Train 1	Mark I
KTEX Train 2	Mark I
KTEX Train 3	Mark III
KTEX Train 4	Mark III
KTEX Train 5	Mark I
KTEX Train 6	Mark I
KTEX Train 7	Mark I
KTEX Train 8	Mark I
KTEX Train 9	Mark II
KTEX Train 10	Mark I

The sound measurement results of KTEX-treated rails were as expected since laboratory results showed a higher retentivity of this prototype product compared to KTT. Indeed, in this noise trial, rail-borne noise was not observed for the first 10 train passes. Figure 16 show the average maximum sound levels and the average equivalent continuous sound levels for when KTEX was still considered to be treating the test curve. Figure 17 shows the equivalent continuous sound levels for each consecutive train pass.

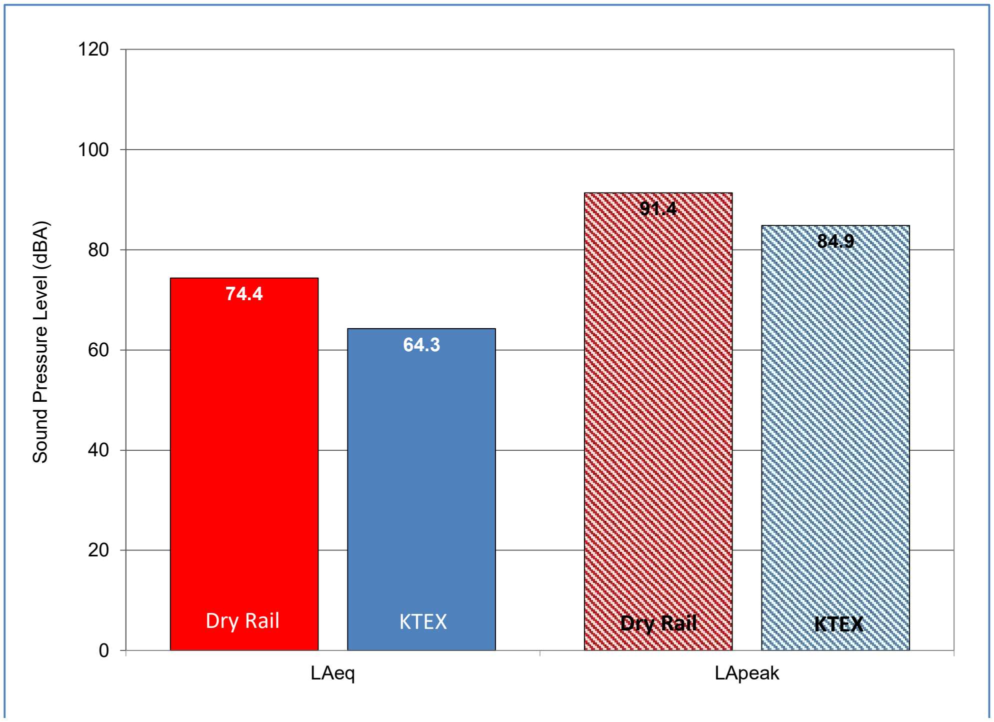

Figure 16. Average equivalent continuous sound level (solid) and maximum sound level (hashed) for trains negotiating the dry (red) and KTEX-treated (blue) rail along the sound monitoring test curve.

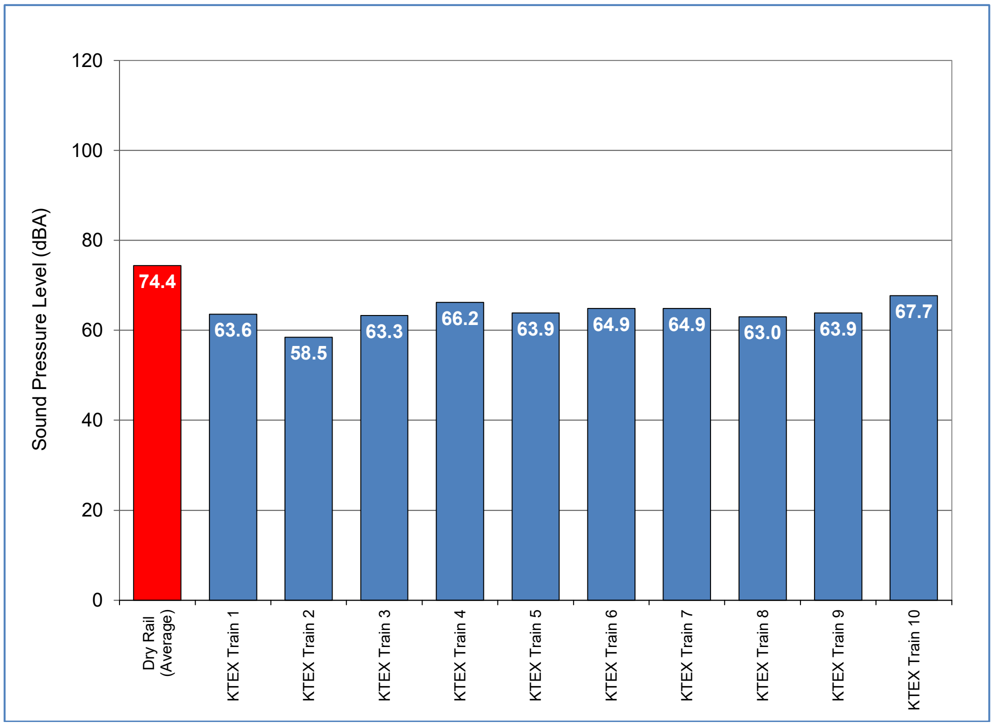

Figure 17. Equivalent continuous sound level for each train pass along the KTEX-treated rails on the sound monitoring test curve.

As with KTT, the frequency distribution graph for trains traveling on KTEX-treated rails also shows a 15-20dB reduction in the higher frequency range typically associated with rail-borne noises (Figure 18).

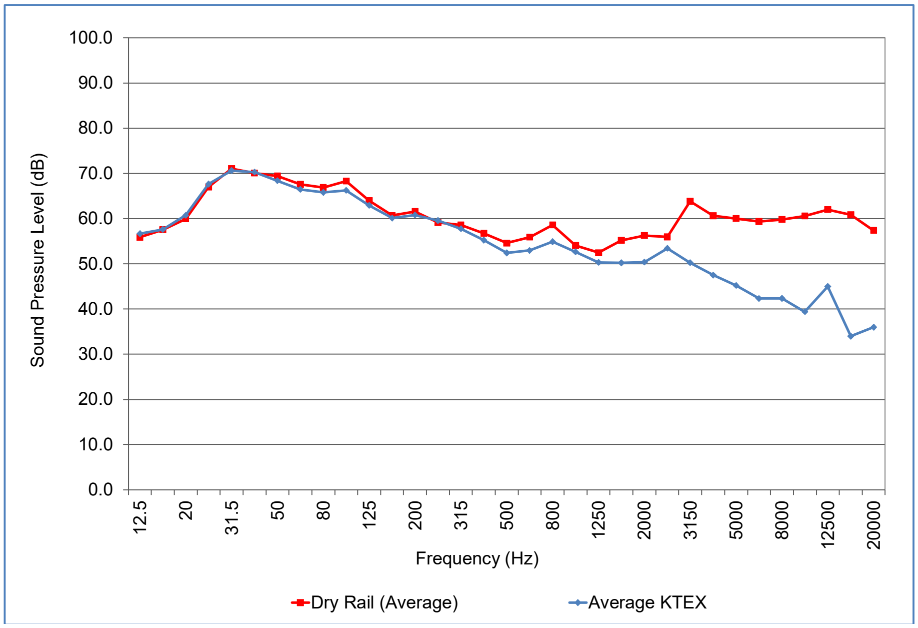

Figure 18. Average frequency distribution levels of rail-borne noise occurrences for trains travelling on dry (red) and KTEX-treated (blue) rails.

4.4 SYNCURVE^{TM} Transit

SYNCURVE^{TM} Transit was manually applied to the gage corner and gage face of the high rail on the morning of October 02, 2020 prior to the trains returning to the yard. The temperature and relative humidity were approximately 15-25ºC (sunny) and 55-65%, respectively. Approximately 1 hour had passed when the first train passed over the SYNCURVE-applied rails. The train traffic was slightly different where the majority of the trains returning to the yard were Mark III trains with a few Mark I trains. Table 5 lists the train types associated with each train pass number.

Table 5. Train types for the SYNCURVE^{TM}-treated sound measurements.

Train Number	Train type
SYNCURVE Train 1	Mark III
SYNCURVE Train 2	Mark III
SYNCURVE Train 3	Mark III
SYNCURVE Train 4	Mark I
SYNCURVE Train 5	Mark I
SYNCURVE Train 6	Mark III
SYNCURVE Train 7	Mark III
SYNCURVE Train 8	Mark III
SYNCURVE Train 9	Mark III

There is often a misconception that applying gage face rail grease to the rails would help mitigate rail-borne noises. While it is true that applying gage face grease will help with reduction of flanging noise, flanging needs to exist. In most cases, however, there is a likelihood that the application of gage face rail grease would increase rail-borne noise as it may worsen the train steering, thereby increasing the angle of attack. This ultimately leads to an increase in the severity of stick/slip, which is made evident by the increase in the sound levels. Figure 19 shows this phenomenon in the average maximum sound levels and the average equivalent continuous sound levels for trains travelling over the SYNCURVE-treated curves. Figure 20 shows the equivalent continuous sound levels for each consecutive train pass.

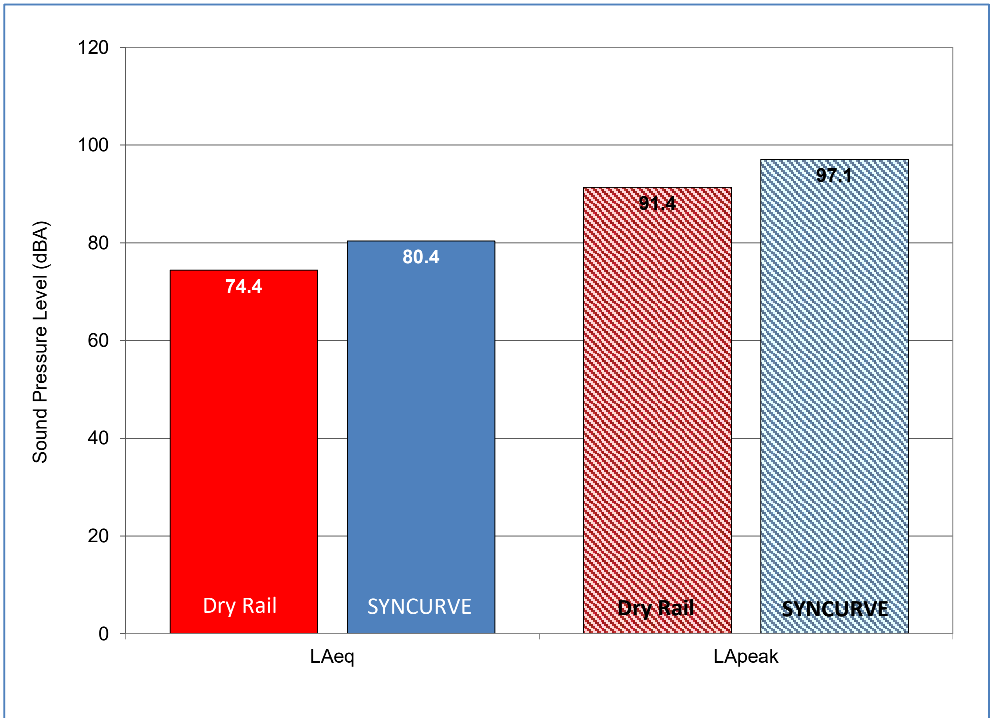

Figure 19. Average equivalent continuous sound level (solid) and maximum sound level (hashed) for trains negotiating the dry (red) and SYNCURVE-treated (blue) rail along the sound monitoring test curve.

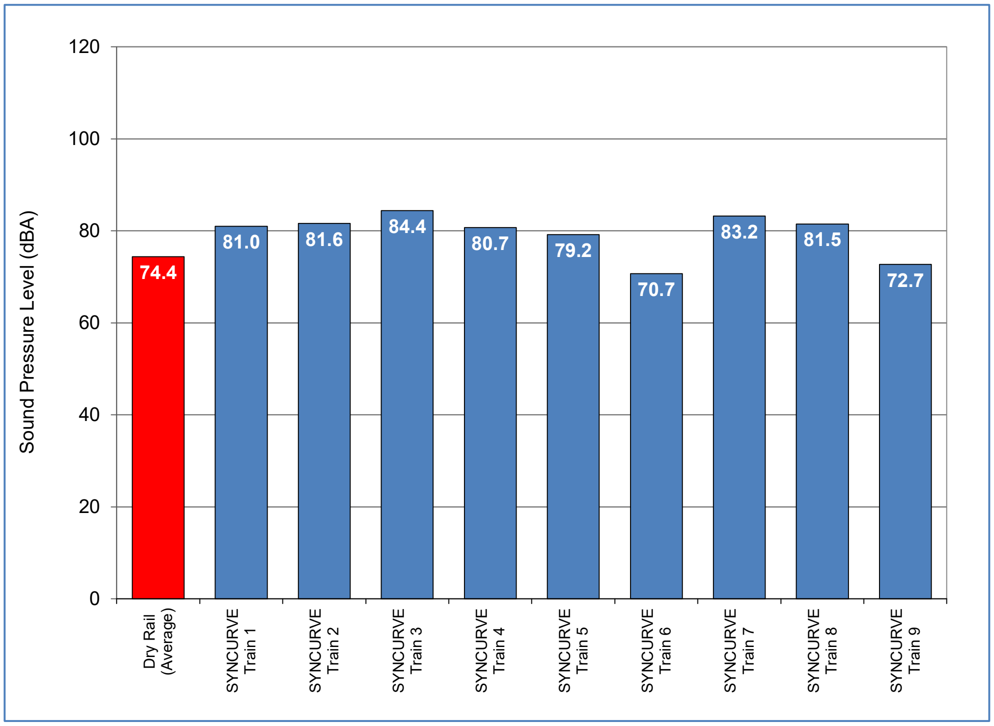

Figure 20. Equivalent continuous sound level for each train pass along the SYNCURVE-treated rails on the sound monitoring test curve.

The frequency distribution graph for trains traveling on SYNCURVE-treated rails shows a distinct peak at 3150Hz which is associated with wheel squeal (Figure 21). Furthermore, the sound level in the higher frequency range is higher than the baseline sound level, which indicates an overall increase in the sound levels of the rail-borne noises.

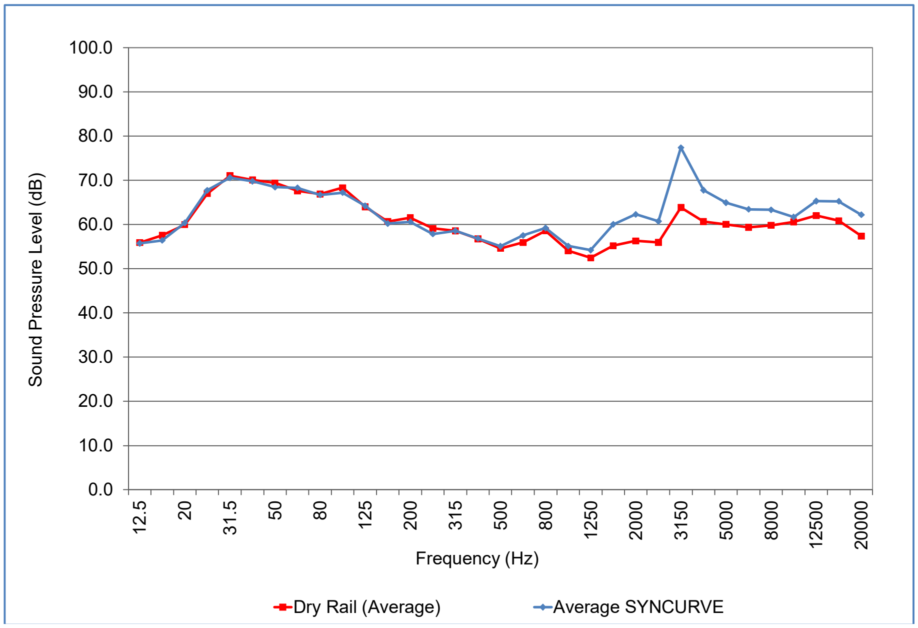

Figure 21. Average frequency distribution levels of rail-borne noise occurrences for trains travelling on dry (red) and SYNCURVE-treated (blue) rails.

5 Conclusions

The following observations were noted on the train noise recorded at the BCRTC OMC test curve:

- Baseline dry conditions have an average maximum sound level of 91 dBA. There is a range to the different trains from heavy squeal to quiet.
- KELTRACK® Trackside Transit and KELTRACK® Transit Extend had similar noise reduction, with an average maximum sound level of 85dBA. All trains were quiet until the TOR friction modifier film degraded. This was after 6 train passes for KELTRACK® Trackside Transit and 10 train passes for KELTRACK® Transit Extend.
- Gauge face rail grease produced the loudest trains with an average maximum sound level of 97dBA, mainly caused by heavy wheel squeal.
- The frequency distribution for the baseline has a large scatter between the different trains but has clear TOR and flanging noise measuring around 60dB between 1,000-20,000Hz.
- Both KELTRACK® Trackside Transit and KELTRACK® Transit Extend have dramatic reduction in these high frequencies and a much tighter range between the trains.
- The gage face rail grease has a similar frequency range for the flanging noise as baseline (+5dB) but has a severe increase in TOR squeal noise focused around the 3150Hz band.

In order to address the noise issues experienced at this curve, L.B. Foster would recommend the TOR friction modifier as a solution to mitigate the noise. Furthermore, a wayside application system would be recommended to optimal application of the KELTRACK® friction modifier.