TE MIHI GEOTHERMAL POWER STATION – FAR-FIELD NOISE MITIGATION TO THE TE MIHI COOLING TOWERS

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ABSTRACT

The Te Mihi geothermal power station is located within a rural / lifestyle area with inherently low levels of background noise. The resource consent compliance requirements have a 40dBL_{Aeq} night time noise limit at the closest neighbours.

Following commissioning of the power station, complaints from some of our closest neighbours to the north-west of the power station were received.

This case study reviews the investigation and subsequent implementation of mitigations to the Te Mihi cooling towers to modify a narrow band tonal component of far-field noise.

Assessing the actual noise emissions from Te Mihi proved to be particularly challenging because the actual measured emissions were very close to the background noise levels. Addressing neighbour concerns and managing a noise budget to maintain a noise buffer for other steamfield activities is important so as to maintain our social license to operate and / or expand the geothermal generation from the Te Mihi field.

1. THE CASE STUDY ENVIRONMENT

Following commissioning in 2015, nine immediate neighbours to the west and north of Te Mihi power station raised noise complaints with Contact Energy (CE) and the Taupo District Council.

Acoustic investigations identified the source of the errant noise as the Te Mihi cooling towers (CT) and a number of potential mitigation options were identified to reduce the nuisance noise. The mitigations implemented addressed reduction of the identified problematic characteristics / frequencies and the total noise emission at source from the CT gearboxes and motor enclosures. Noise investigation and mitigation measures for the Unit 1 gearbox modification and installation of noise attenuation enclosures on all 16 motors on Units 1 & 2 exceeded $1million.

Te Mihi is a rural environment with relatively low levels of background noise. Noise from the power station is more noticeable at night and is exacerbated under following winds and during periods of temperature inversion.

1.1 The Receiving Environment

Local geography, south-easterly winds, cloud and temperature inversions contribute to atmospheric conditions where apparent exceedance of consent limits can be observed. The most affected neighbours are almost direct line of sight with the CT (Figure 1). There is an elevation difference with the Te Mihi site at a nominal elevation of 516masl and the neighbours downhill at approximately 483masl. There are no hills or ridges between the power station and neighbours to form any passive noise barrier.

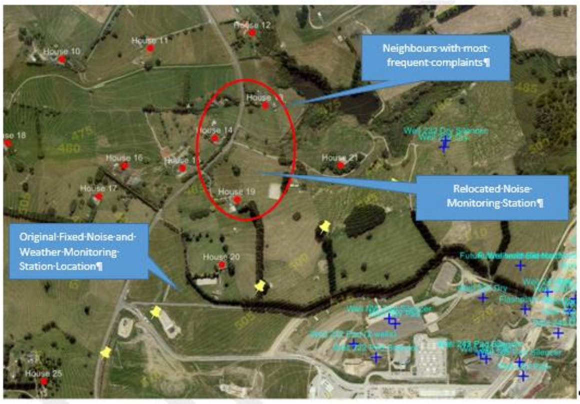

Figure 1: Te Mihi power station and neighbours.

The operation of Te Mihi is at a continuous rated output base load operation 24 hours per day, 7 days per week for approximately 97% of the year. As a noise source in the environment the power station is a steady state noise source. The power station has two cooling towers and is operated with all 8 fans per CT in continuous operation and there is no cycling of fans nor other equipment to vary source noise emission levels.

The actual noise emissions measured adjacent to neighbour notional boundaries are very close to the low background noise levels (known as residual sound). This background level was assessed from a large historical data set prior to the power station construction and commissioning and during prolonged complete plant outages.

Demonstration of compliance at the affected neighbours has been complicated due to the infrequency of environmental conditions that enable NZS6108.2 compliant noise measurements to be taken. South-east wind conditions with light wind speeds (<3m/s) only occur approximately 6% of total time. The noise can only be heard and measured during night time while avoiding any extraneous sounds. Even under these conditions, vehicle traffic from the more than 2.5 km distant State Highway 1 and local farm animals affect the quality and validity of the measurements, especially when unattended recordings are being used. The specifically required atmospheric conditions historically only occur for about 2.5-3% of time per year (some 250 hours per year). Therefore it is quite difficult to experience the required night-time conditions to carry out valid far-field noise measurements. We acknowledge that noise will be received at the neighbours from time to time during other conditions resulting in annoyance, but those conditions are excluded from an assessment of compliance.

Given the limitations on actual atmospheric conditions that need to prevail to make them valid for inclusion in an assessment, the actual data set for post commissioning operation from the permanent fixed noise monitor (unattended recordings) was reasonably small. Obtaining attended recordings has also resulted in a small data set.

1.2 Resource Consent Requirement

The power station far-field noise limit is governed by the power station land-use consent (RM070304) with a night-time (10pm – 7am) limit of 40dBL_{Aeq}/70dBL_{AMAX}, day-time limit of 55dBL_{Aeq}, which apply at the notional boundary to rural dwellings. (i.e. 20 metres from a persons house or legal boundary if this is closer)

The consent was granted on the basis of the Assessment of Environmental Effects by the Board of Inquiry where the assessment predicted that there would be a *"...sound level increase..."* but the *"...scale is quite minor ...and not expected to exceed 5 dB over ambient sound levels at existing houses..."*. Additionally noise levels from the operation of the station, at the time of the resource consent application, were predicted to be 40 dBA at all existing dwellings.

1.3 Approach taken with Neighbours

In addition to ensuring compliance with all resource consent conditions, CE considers it has a responsibility as a good corporate citizen to address neighbour concerns and is prepared to go the "extra mile" to maintain relationships. Our approach was to first address any issues on our side of the fence, at source, before looking at any additional measures that could be implemented at the neighbours' properties.

During the long investigation period frequent community notification, consultation and interaction with neighbours and the Taupo District Council was held. Our internal 'Tikanga', commitments and principles, helped guide these conversations. This includes a commitment by CE to respect the rights and interests of the communities in which we operate by listening to them, understanding and managing the environmental, economic and social impacts of our activities.

To assist with identification of environmental conditions which were causing annoyance, a facility was provided for neighbours to text when they felt the power station was particularly noisy. This text message triggered the permanent noise monitor to take an additional remote recording. Good neighbour response using this facility assisted with capturing and understanding their concerns.

Given the extended duration of time for the assessment to be completed and CT mitigation works to be trialled, CE offered double glazing to the affected neighbours to meet our company purpose of helping New Zealanders live more comfortably with energy.

1.4 Noise Budget

Prior to compilation of the Te Mihi EPC contract, an acoustic assessment of contributory effects was used to determine a noise budget for the contractually allowable contribution of noise from the 2 Unit power station works. This noise budget was intended to provide an allowance for a future third Unit at the Te Mihi power station site and allow for additional future developments in the steamfield while maintaining compliance with the 40 dBA limit for the power station. It should be noted that there are no specific noise limits for steamfield operations, which complicate the issue of assessing legal compliance. Additionally some of the steamfield is located in a rural zone and other areas in industrial zones with different noise limits applying.

Mitigation works to the CT outlined in this case study are to address neighbor concerns about nuisance noise and to maintain an adequate noise buffer. Post Te Mihi power station construction there have been additional steamfield works with the development of well pads WK 270 / 271 / 272 located between the power station and the affected neighbours. Acoustic mitigation measures have been applied to these point source steamfield activities so as to maintain the ability to continue to operate and / or provide the opportunity to expand the geothermal generation from the Te Mihi steamfield.

2. ACOUSTIC INVESTIGATIONS

2.1 Acoustic Camera

Initial investigation was undertaken using an Acoustic Camera. (HW Technologies – Sydney). The camera was of limited use for forensic evaluation of point source noise on the CT structure. However the camera survey identified the CT as a significant noise source and demonstrated that there was no significant breakout noise from the turbine generator building nor from the generator step up transformers.

2.2 PRO-Acoustics GmbH

PRO-Acoustics GmbH of Switzerland were engaged to carry out a forensic acoustic investigation including post processing analysis. PRO-Acoustics used Norsonic Sound Level Meter and Soundbook multi-channel analyser equipment for acoustic measurements.

Comprehensive noise measurement and spectra were taken around the CT in the near, medium and far field at the following locations:

- Basin level air inlet
- Motor
- Torque tube
- Fan stack perimeter
- Periphery of stack discharge
- Beneath fan
- Vertical traverses of north wall
- Reference location 120m north west of CT
- Far-field measurement at neighbours (approximately 1000m).

PRO-Acoustics prepared an acoustical model of the power station using the "as-measured" sound power levels using landscape and worst case meteorological conditions (downwind or inversion). The model was validated with reference measurements at 125m. This model indicated that noise levels at the affected neighbours was within the resource consent limits prior to CT mitigation works.

2.3 Far-Field Noise Spectra

The detailed monitoring and assessments carried out concluded that the far-field noise emission from the power station was dominated by noise from the cooling towers with specific nuisance noise frequencies generated from the motor / gearbox / fan assemblies.

As illustrated in Figure 2 the spectral assessment in the far-field reading at neighbours notional boundary (blue line) and adjacent to the fan motor C (red line) identified frequencies present associated with the harmonics of the CT motor speed and the gearbox. The results of the acoustic measurements highlight that the noise source originated from the gearbox.

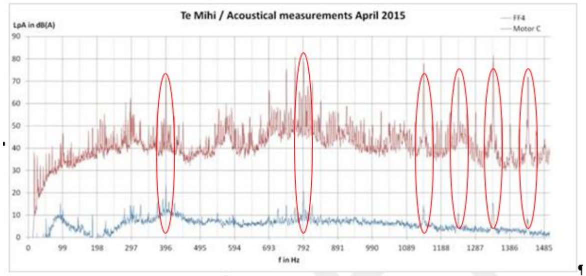

Figure 2: Initial Far-Field and Local Spectra

For electric motors the frequency of magnetostriction is usually double the rotational speed (second harmonic). As the fan motors are 4 pole, the magnetostriction would result in a 16th harmonic of the rotational speed. As shown in Figure 3, the dominant frequency peaks observed at 396 and 792Hz (twice 396Hz) are the 16th harmonic and 32nd harmonics of motor speed and are coincidental with the 1st and 2nd harmonics of the first 16 tooth pinon gear sets. A 48th harmonic is not observed (i.e. 3rd harmonic of magnetostriction / 16 tooth pinion gear set). The observed 1,138Hz, 1,237Hz 1,336Hz and 1,435Hz tones are the 46th, 50th, 54th and 58th harmonics of rotation speed but not of the magnetostriction / pinion gear meshing.

The gear mesh frequency could be clearly identified; furthermore the highest noise levels were measured close to the gearbox when extending a microphone to the gearbox across the plenum beneath the fan.

The acoustic data had significant variation between individual fan cells with the amplitude for the two primary tones varying by more than 15dB.

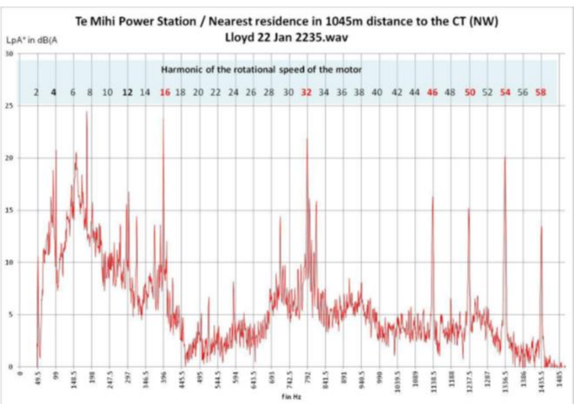

Figure 3: Harmonics of rotational speed.

The acoustic modelling indicated that breakout sound from the fan stack discharge is the major contributor to the far-field noise. This is illustrated in the following Figure 4 for noise distribution for the elevation section at 90 degrees to the CT centerline. Note that Figure 4 is a calculation for a single CT fan cell and not the entire CT.

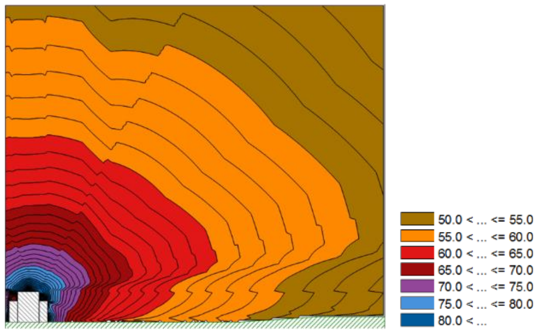

Figure 4: CT breakout noise – single cell.

The detailed evaluation and acoustic modelling identified that the noise emission from the façade and air intake plenum of the CT did not have a significant impact at the far-field. Although the FRP casing is light with minimal attenuation, increasing the specific mass of the CT casing was not identified as a mitigation to far-field noise.

2.4 Cooling Tower Noise Emissions

Although the CT was specified and procured as a low noise tower, the actual noise emissions from the tower exceeded the Original Equipment Manufacturer (OEM) expected noise emissions.

Although the OEM were appraised of all investigations and remedial works by CE no support was provided in the mitigation of CT noise.

The "as-measured" sum value for the sound power level for the CT was 122.2dB(L) and 116.4dB(A). The table provides dB(L) which is similar to dB(Z) for comparison with the original expected sound power levels. The unmodified CT did not fulfil the OEM guarantee schedule nor the OEM expected sound power levels. The as measured indicates an exceedance of 8.3dB linear and 7.2dB for the A-weighted sound power level.

3. ACOUSTIC MITIGATION

3.1 Cooling Tower Noise Reduction Methodologies

Where CT noise is identified as an issue there are typically three broad ways of addressing noise reduction:

- Reduce noise level at source (water, fan, gearbox, motor)
- Attenuate the noise at the emission area
- Place barrier obstacles between noise source and the reception point.

The noise emission from the CT is a function of emission areas:

- Fan Outlet
- Motor on fan deck

- CT casing
- Air inlet.

The CT design incorporated a number of features to minimise noise emissions.

The OEM had provided splash fill pack to minimise the water noise from the impact of droplets on the basin water surface. Water spray nozzles in the water distribution system and water flowing in the fill were not identified as present in the far-field. Water noise sources are typically higher frequencies which are attenuated over distance in air and hence not identified in the far-field.

Fan noise is a function of both the fan rotation speed and the fan type. The OEM had selected low noise fans using large profiled wide chord fans with a low rotation speed (74rpm) to minimise fan noise.

The acoustic investigation followed up concerns with reverberation and resonance and potential contributors to the noise emissions from the motor and gearbox. The overall mitigation methodology adopted was to reduce noise level at source.

3.2 Gearbox Modification

Inspection of the original Amarillo gearbox by AH Gears (Auckland) identified that the original spiral bevel gear set was manufactured to an industrial quality finish and was generally fit for service. The gears were case carburised then, as a finishing process, the mating gears had been lapped together to reduce the errors caused during manufacture and by distortion during the heat treatment process. As shown in Figure 5 the contact pattern between gear and pinon varied tooth to tooth and flank to flank and was not considered by AH Gears to be an ideal contact pattern on any of the teeth on either flank.

Prior to proceeding with the gearbox upgrade, a testing program using the VSD data and also with the bump test data was performed to assess the potential for CT structure excitation associated with a shift in gear mesh frequency.

Figure 5: Original pinion drive face (concave) showing different contact pattern from flank to flank.

Improvements to the gearbox to reduce the forcing power of the meshing frequencies were achieved with:

- Replacing the spiral bevel gear set with new gear set incorporating post heat treatment machining with precision ground gears
- Changing the number of teeth from 16/65 to 19/77 to move the meshing frequency
- Increased number of teeth increasing tooth contact.

Additionally, the gear mesh frequency of the original first gear set was the same frequency (396Hz and its harmonics) as the electrical motor. Hence changing the ratio of the first gear set to 470Hz offered the most promising improvement while maintaining the overall speed of the fan.

High quality gear sets were specifically designed and imported by Auckland based AH Gears and manufactured in Finland (ATA Gears Ltd). There is no capability in New Zealand or Australia for the manufacture of the required high quality parts.

The gearbox refurbishment included replacement of all bearings, metal spraying of the output shaft to make good grooves cut into the shaft by hardened Nitrile seals; replacement of inlet and outlet seals from Nitrile to Viton. Additionally a hydroscopic filter was fitted to the gearbox breather to prevent moisture ingress into the gearbox.

The inlet drive bearing was also replaced. The use of carbon fibre shaft indicated that there was insufficient radial load on the bearing and hence bearing slip occurred. The bearings were changed to a roller bearing. While bearing slip was audible at the CT this had no impact to the far-field noise.

3.3 Motor Enclosures

Location of the fan motors on the north side of the cooling towers provided a direct line of sight path for fan deck noise emissions to affected neighbours. Ideally the CT configuration would have been improved if the motors had been located on the south side of the CT so that the discharge stack would have provided passive screening to affected neighbours.

Initial noise testing trials used fabricated plywood structures to provide superficial mass and lined with a mineral wool acoustic insulation for attenuating reverberation.

The temporary motor enclosures were initially fitted to the fan A, B & C. Testing demonstrated a significant reduction in tones at the fan deck and a 2-3 dB reduction at the north-west 125m reference point.

The trials were sufficiently successful that temporary motor enclosures were fitted to all Unit 1 fans until permanent noise enclosures were installed to both Units 1 and 2.

Prior to commitment to permanent enclosures, testing was done with ventilation penetration sizing to minimise the temperature rise on the motors.

The permanent noise enclosure design (Figure 6) was developed to allow for rapid crane removal and installation of the entire enclosure for major maintenance. Access doors were provided for routine inspection. A larger access door was provided on the west side to facilitate operator / maintenance access for oil routines etc. Inlet and outlet ventilation to motor enclosure used indirect flow path with oversized acoustic lining. The inlet air is fitted with a flexible rubber shroud to direct air to the motor cooling fan inlet. Rubber shrouding was used to eliminate gaps for noise emission to the discharge stack and to isolate the enclosure from the CT structure.

Figure 6: Permanent motor noise enclosures.

3.4 Torque Tube

Initial concerns were the potential for the torque tube to contribute to resonance in the structure. A preliminary trial was conducted installing a baffle within the torque tube as a Helmholtz resonator. No discernible effect was identified.

Bump tests were also performed on the torque tube to ascertain if there was any natural resonance of the CT structure. The bump tests were performed on several fans and locations at the motor end, mid span and gearbox end of the torque tube. A lever at mid span was also fitted for a torsional bump test.

The torque tube had 30mm neoprene rubber installed to the inner wall and the cavity filled with expanding foam. Its purpose is to dampen resonance of the torque tube and minimize structure borne noise.

Testing on Fan H indicated that the torque tube acoustic dampening reduced tones at the fan stack outlet by 2-3 dB hence this modification was rolled out on all CT fan stacks.

3.5 Post Mitigation Works Acoustic Assessment

On completion of the gearbox upgrades to the Unit 1 CT and the installation of permanent noise enclosures to both Unit 1 & 2, near field and far-field measurements were taken over a period of time to assess the impact of the modifications.

As demonstrated in the spectra in Figure 7, (red line original, blue line after modification) the change in gearbox meshing frequency eliminated the narrow band nuisance tones at 396 and 792Hz. Amplitudes of narrow band frequencies have been reduced and the noise spectra is characterised as broad band. The acoustic modelling did not identify a material benefit for modifying the Unit 2 CT gearboxes at this time and the Unit 2 gearboxes remain unmodified. Modification of the Unit 2 gearboxes for far-field acoustic reasons is not currently necessary in terms of its impact on our neighbours, and is not expected to be required until such time as a future Unit 3 is developed. Although it is recommended that Unit 2 gearboxes be modified individually if / when they require major maintenance overhaul.

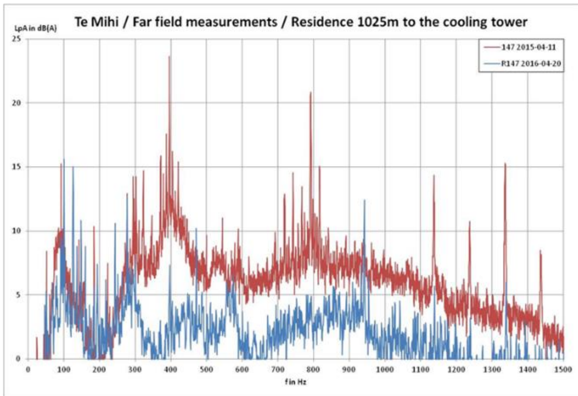

Figure 7: Far-field spectra before and after modification.

The tones at higher frequencies (which are higher harmonics i.e. prior to the modifications 1,138Hz, 1,237Hz, 1,336Hz, 1,435Hz) did not shift in frequency with the modification of the gearboxes. This means they are not related to the gearboxes but to the motor. However these tones have a lower amplitude now and have no material impact at the residential locations.

The revised acoustic model in Figure 8 shows that post modification improvement in the far-field with most of the affected neighbours assessed as being at or below 35dBA.

4. OTHER MITIGATION CONSIDERED

4.1 Variable Speed Drives

The use of Variable Speed Drives (VSD) was considered as a means of addressing noise mitigation at source so as to move the gear meshing frequency away from the harmonics of the motor magnostriction.

A test was performed by temporarily retrofitting a 250kW PDL Elite VU480 VSD to the Unit 1 CT Fan “H”. This test was used to assess resonance within the CT with change in frequency by varying the fan speed to determine if changing the drive frequency would reduce the amplitude of tones should there be an associated resonance of the CT structure.

The test was performed over VSD speeds from 47Hz to 52.5Hz. This was equivalent to a range of gearbox 1st spiral pinon bevel gear set teeth meshing frequencies from 15 to approx. 17 teeth. As the test was not performed with varying the blade pitch, the test was confined to a limiting maximum of 249amp current on the motor. The test regime established that no excitation of resonance of the CT structure was observed over the speed range tested. This provided adequate confidence to proceed with the gearbox modification. Near-field and far-field acoustic measurements were taken at the motor, fan stack discharge, CT basin and north east survey marker reference location for each motors. The motor shaft speed was varied to simulate +50Hz change in spiral bevel gear meshing frequency (12.5% change in motor shaft speed).

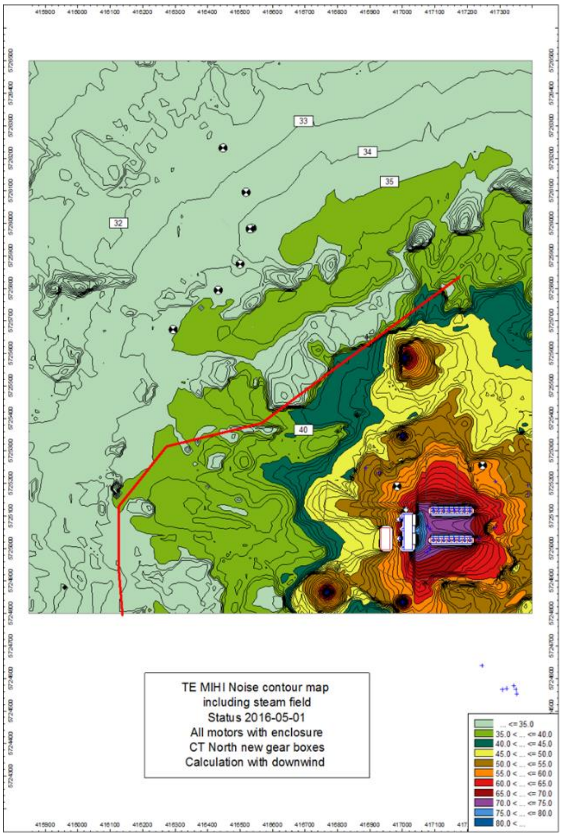

Figure 8: Acoustic model corrected for as measured noise after gearbox modification and motor enclosures.

Installation of VSDs on all fan motors was not developed. The VSDs could have been used to reduce the level of the annoying frequencies by running all motors at slightly different speeds. It does not address the source of the nuisance frequencies, however by running all motors at slightly different speeds this may change the characteristics to a more broadband characteristic. There is also a significant risk that a worse situation develops, also known as drumming, while operating a number of identical motors out of synch.

This option also would have had a significant cost to implement on all motors and did not address the gearbox, so it was rejected as not being the best practicable option in the circumstances.

4.2 Fan stack discharge screens

The monitoring on site confirmed that a significant amount of noise is being emitted from the top of the fan stacks. This was also confirmed by modelling by PRO-Acoustics.

A brief trial was undertaken that saw the installation of three temporary 'deflectors/baffles' above the Unit 1 CT fan cowls 1 to 3. The plywood baffles were offset 1m from fan cowl discharge with 120deg arc coverage from west to north-east sector. The plywood baffle extended 1800mm above top of cowl to 600mm below cowl. See Figure 9. The purpose was to deflect (but not absorb) horizontal noise emission at the fan outlet.

Near and medium-field measurement combined, with modelling, confirmed a 2dB improvement at the north-west 125m reference location. However far-field measurements could not be undertaken at the time because the baffles could only be left in-situ for a very short period of time to avoid the additional wind loads and because the wind direction during the trials was not suitable for far-field measurements.

The fan cowl outlet baffle shroud had a significant reduction in tonal components at the north-west 125m reference point. However there was significant concern that the far-field effect may be reduced by diffraction of the sound wave and that the shroud may have the effect of elevating the stack discharge noise source.

This option was not developed further as the addition of supporting structure for the shroud would create significant additional wind and seismic loads for which the CT structure was not designed.

Figure 9: Temporary fan shroud to fans A, B & C.

4.3 Barrier Wall

Noise emission from the CT air inlet and the FRP casing could have been mitigated with the use of noise baffles on the air inlet or an offset barrier screen wall.

Consideration was given to a test installation of a barrier wall to place an obstacle between the CT noise source and the near field test reception point. The proposed test installation was to have been a temporary scaffold adjacent to the CT with superficial mass using plywood for the western 3 fan cells. Concern with wind loading transfer from bracing onto the CT structure made the proposed test a high risk exercise and this potential mitigation was eliminated from further consideration.

This type of noise mitigation option has a negative impact on inlet air flow and recirculation effects on CT performance and is ineffective for far-field protection due to the effect of noise diffraction at the top and sides of barrier wall screens:

- Barrier wall height needed to be taller than CT
- To minimise overall height this had to be close to the CT
- The barrier wall would have a significant impact on air flow into the CT increasing losses and decreasing CT efficiency
- Barrier wall would increase recirculation in cross wind conditions

- Far-field impact at neighbours likely to be limited due to noise diffraction over top and sides of a barrier wall

- Acoustic investigation indicated that noise emission from air inlet and cladding were not a significant noise contributor at the far-field.

4.4 Direct Drive Motor

Replacement of the motor and gearbox assembly with a direct drive permanent magnet variable speed drive motor was considered as a retrofit option for eliminating the gearbox and reducing noise at source. If feasible, this would provide a very low noise option (about 30dB at source less than the originally installed gearbox and 25dB less than the AC motor). This would reduce the overall far-field noise level in addition to eliminating existing nuisance noise.

The replacement of the motor/gearbox assembly with a direct drive motor would, if feasible, be the ultimate solution for addressing the issue at source. The technical feasibility for a retrofit was investigated by ABB Baldor Electric, the only reputable vendor of such equipment with motors of a comparable capacity.

Retrofitting direct drive motors would also have offered an additional benefit of reducing the fault rating of the existing 400V boards as a new distribution board and VSD would be required adjacent to the cooling towers.

Following extensive consideration, retrofitting of direct drive motors to an existing CT was not progressed due to cost and significant technical risk:

- Motors would be operating at the top end of the largest motor sized developed by ABB Baldor

- These motors do not have any significant operational history relating to reliability and durability in this environment/application

- Adequacy of cooling air for the high motor loading was a significant technical risk and may have required an untested/unproven water jacket solution

- Potential structural modifications to accommodate weight and loading.

For future power station applications with low noise requirements, cooling towers with direct drive motor appears to have considerable promise.

5. OTHER FACTORS

5.1 Tonal Noise

The quantitative measurement techniques in the applicable NZS standards indicate that the far-field cooling tower nuisance noise does not meet the threshold for "tonality" (1/3 octave band assessment). Should nuisance noise be considered "tonal" there is potential for a 5dB penalty to be applied to the "as measured" noise which would potentially result in a consent breach.

Narrow band FFT analysis showed tones at the 1st and 2nd harmonics of the gearbox first gear set meshing frequency and harmonics of the motor magnostriction (i.e. around 396 and 792Hz). The 1/3 octave band assessment required by the standard has a much wider spectrum than this narrow band, hence the noise is not considered 'tonal' as defined by the standards.

The implemented cooling tower noise mitigations were targeted to reduce the amplitude of narrow band nuisance tones. The overall reduction in far-field noise was relatively small overall, but without the express nuisance frequencies.

The steady power station noise emission is now very close to the residual sound level of the environment and therefore very difficult to assess under the methods required in the standards.

NZS6802 identifies

6.3.1 "*Where the sound being assessed has a distinctive character which may affect its subjective acceptability (for example, it is noticeably impulsive or tonal), the representative sound level shall be adjusted to take this into account.*"

B4.1 "*Sound that has special audible characteristics, such as tonality or impulsiveness, is likely to cause adverse community response at lower sound level that sound with such characteristics. Subjective assessment can be sufficient in some circumstances to assess special audible characteristics."*

CB4.1 "*Special audible characteristics may be:*

(a) Tonal, for example, a hum or a whine, examples include transformers, cyclone fans, gearbox whine;"

Should there be an assessment of tonality a 5dBA penalty (Adjustment k2) is applied to the L_{Aeq}. Where the reference method is used, Clause B4.5 allows for the k2 adjustment to be 6dB where justified.

The standard identifies two methods to provide an objective measure for tonality. Neither the Simplified test method which uses comparing level of neighbouring one third octave bands nor the Reference test method for tonality gave an objective indication of tonality.

However there is potential for a subjective assessment (non-quantitative) to trigger a penalty for tonality which is a risk that all projects need to be aware of.

Where residual sound level is within 10dB of sound under investigation a correction (adjustment k1) is made for "contamination" of the measured sound level by the residual sound level. Above 10dB difference there is no correction. At 3dB difference between the total sound level and the residual sound level, an adjustment k1 of 3dB is subtracted from the total measured sound level.

If the far-field noise measurements are less than 3dB above the residual sound level a valid assessment of compliance in accordance with NZS6802 cannot be done.

The results provided in this case study are "as measured" and no k1 correction has been applied.

5.2 Final Compliance Assessment

Te Mihi power station formal noise compliance was confirmed following the completion of all mitigation works by using a combination of unattended fixed monitor data logger analysis and attended field hand held measurements as agreed with Taupo District Council.

This agreed method was a variance from the NZS6802:2008 requirement and uses an L_{A90} analysis for the unattended monitoring rather than 15 minute L_{Aeq}. This approach has been used as the residual noise at the neighbour notional boundary and the total noise from the power station is within 3dB and hence a valid assessment in accordance with NZS6802 is not possible.

The data logger analysis showed that the background sound level while Te Mihi is operating in weather conditions suitable for monitoring (NZS6802:2008) is 33dBL_{A90}. In stable meteorological conditions, the L_{Aeq} level is expected to be approximately 2dB higher than the L_{A90} level. Therefore, the typical sound attributable to Te Mihi at the noise logger position is 35dBL_{Aeq}. This level suggests that Te Mihi is compliant with the more stringent night-time noise limit of 40dBL_{Aeq}.

Independent attended measurements for noise compliance were completed by Marshall Day Acoustics Ltd using hand held field measurements during which time Te Mihi was operating at 170MW (typical level of generation). The measurements were taken at 5 locations representative of the notional boundary of our closest neighbours and complainants. All measured noise levels comply with the resource consent night-time criteria of 40dBL_{Aeq} and 70dBL_{AMAX}.

The unattended monitoring measures all noise present in the environment with no discrimination between noises generated by Te Mihi power station or by other sources. The unattended monitoring demonstrates that if the total noise measured, i.e. the noise from Te Mihi power station plus any residual noise, is less than 40dB then Te Mihi power station must be compliant at those times.

The Figure 10 shows a valid environmental assessment period which has a continuous background noise level of 28 to 32 dB when the power station is operating. The power station is a steady state noise source and has no variable operation to result in a noise fluctuation. The sharp spikes are short term noise events such as bird or animal calls. The triangular shaped peaks are typically due to vehicles where there is a rise in noise level as a vehicle approaches to a peak as it passes followed by a drop off as it moves away. L_{Aeq} is the average noise level over a 15 minute period and greatly influenced by short term high energy noise peaks such as traffic noise. L_{A90} provides a better measure of the steady state continuous noise that is present 90% of the time and is not influenced by short term noise events such as traffic. In the Figure 10 example L_{Aeq} was 39dBA whereas the L_{A90} was 28dBA.

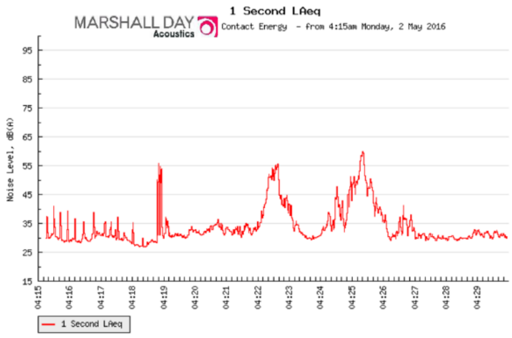

Figure 10: Typical unattended fixed noise monitor.

Additional compliance analysis of the unattended noise monitor considered that under stable environmental conditions the $L_{Aeq} - L_{A90}$ for a steady state noise source would be 2dB. During light variable meteorological conditions (light wind, no rain) the L_{Aeq}-L_{A90} may be up to 5db. Where analysis of the unattended monitor between midnight and 6am is less than 35dB L_{A90} this implies that the L_{Aeq} due to Te Mihi power station will only be up to 40dB (35 + 5 dB for variable meteorological conditions) and is therefore compliant with noise limits. The further the measured noise is below 35dBL_{A90} implies a higher level of compliance. This analysis method takes away the requirement to consider k1 correction.

5.3 Outcome

The results of the mitigation works and the final compliance assessment were communicated to the Taupo District Council and all complainants. This showed that we had been successful in removing the annoying component of the noise from the Te Mihi cooling towers and that any further mitigations would have limited results in the far-field.

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