Progress in Silencing ORC Turboexpanders in Geothermal Service

Thomas R. Norris, P.E., and Kier DeAnda

Consultants in Engineering Acoustics, Orinda, California USA

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ABSTRACT

Noise from the outlet pipe of large Organic Rankin Cycle (ORC) turboexpanders can impact acoustical permitting and employee job satisfaction at geothermal power plants. Specific acoustic concerns are environmental permit noise requirements, protection of hearing, and site-wide employee verbal communication ability. Until now, silencers for this service have often degraded within months to a year or two, or they have not provided as much noise reduction as desired. This paper describes progress on a new technology that successfully addresses both issues.

This paper is a progress report, documenting long-term silencing. The reported silencer is based on acoustic resonators, so there are no conventional acoustical materials, a potential problem area. This resonator technology has now been proven satisfactory over a four year period on four nominally 14 MW rated centrifugal Organic Rankin Cycle (ORC) turboexpanders. After four years of use, the silencers show no detected degradation of acoustical performance. Periodic inspections have found no damage, such as cracking due to acoustical fatigue.

The ORC working fluid is isobutane. One silencer was an insert type that could be pushed into an existing pipe. The other three silencers replaced a pipe section. Before silencing, noise levels can be 105-110 dBA at about three feet (about one meter) from the turbine outlet pipe. With the silencer, pipe noise was reduced approximately 20 dBA, and more near the blade passage frequency. Backpressure is judged satisfactory. Acoustic insulation of condenser inlet header piping was not required.

Introduction

A 30 MW geothermal power plant startup occurred in 2009. While startup was successful, neighbors did request that sound levels be reduced. Acoustic studies showed that a common impression was correct - not only was sound from pipes downstream of the turboexpander dominant; it was also the only noise source requiring reduction. Insulation of noisy pipes was not preferred by the owner, because these pipes provide an increment of heat transfer area, and these pipes also had required direct visual inspections due to sonic fatigue and other vibration concerns.

A turboexpander is another name for a centrifugal turbine, basically a centrifugal fan or pump run in reverse. However, a turboexpander is sophisticated, has a high rpm, and uses variable inlet nozzles to keep pressure and velocity within desired ranges as flow conditions vary. Geothermal service, especially if the condensers are air cooled, will show wide variations in turbine exhaust pressure, so highly refined turboexpander designs are needed. These designs, while efficient, can generate significant noise near the downstream exhaust pipes.

Sonic fatigue (noise-induced vibration) had been a probable cause of observed damage to expansion joints, small pipes and fittings, valve handles, and various attached hardware such as pipe support bolts. We know of no further damage occurring since the silencer installations.

Before silencing, personal hearing protection was required for the entire site. Now, personal hearing protection is only required adjacent to various equipment, large pumps, and the first section of pipe downstream from the turboexpanders.

Description of Silencers

Two designs were installed. The first design is an acoustical element insert, intended to be installed into a section of the existing 36 inch outside diameter (0.914 meter) diffuser outlet pipe. The second design is a complete silencer of 42 inches (1.07 meter) in outside diameter, so is an expanded section of pipe with a gradual conical inlet. The first silencer installed was the insert type, and the other three were complete silencers. Acoustical performance is about equal for both types. The larger diameter silencer has lower flow velocity and thus, is predicted to have lower backpressure compared to the insert. However, the complete silencer weighs more than the simple insert, so has higher fabrication and material costs.

The available space for a silencer is about 18 feet long, longer than needed for a silencer, so a section is potentially unused. Since this pipe section was available, this section received an acoustical liner also made of resonators to provide some additional noise reduction. This acoustical liner cost was small compared to the silencer proper, and is believed a good investment.

Figure 1 shows a section view of the silencer. It consists of the outer pressure pipe, and two concentric rings within. Supports are not shown. The acoustical resonator elements are shown as dashed lines.

Figure 2 is a March 2015 dated photo of the in service silencer, in an insulated jacket. The turboexpander is to the right, and flow is from right to left. The turbine outlet diffuser is the conical section of pipe attached to the turboexpander. The silencer, in center of photo, is bolted directly to the outlet end of the diffuser cone flange. On the left side of photo is a vertical riser pipe with an expansion joint. Just out of the photo, this vertical pipe leads to a "Tee" junction and elevated condenser "header" pipe. The large header pipe runs the full length of the condenser, and is not insulated. Small purple rectangles on bottom of silencer in the photo are noise measurement positions used in 2015.

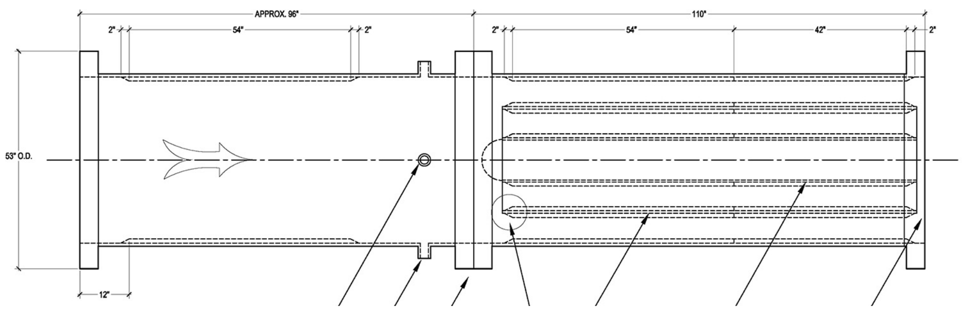

Figure 1. Drawing of 42 Inch Diameter Silencer Showing Locations of Resonant Acoustic Elements (Dashed Lines). Dimensions are in inches. Flow is left to right.

Figure 2. Photo of In-Service Silencer, Fully Insulated, with Turboexpander on Right Side. Flow is right to left.

Acoustical Design Issues

The dominant power plant sound, if no silencers are used, is noise emitted by the turbine outlet pipe surfaces. This sound is perceived as a "roar" with some tonality. The tone at the turbine blade pass frequency and next two harmonics are not prominent enough to be audible as tones, but (to the authors) seem part of the roar. The uneven spectrum shape, in the authors' subjective judgement, causes a distinctive, slightly "hollow" sound.

A 20 dBA reduction of outlet pipe noise was desired. Both high internal sound levels and turbulence were believed to be potentially destructive to conventional sound absorbing materials, such as various fiberglass insulation products and organic fabrics. Porous metallic products also had some vulnerability of losing their sound absorptive properties should there be any oil-like liquids present, such as might escape past bearing seals. (the authors have seen such seal failures occur in gas turbines.) We found that acoustic Helmholtz resonators were an effective noise reducing element. The resonators could be made rugged enough to withstand sonic fatigue, vibration induced by turbulence, and could be made to work acceptably well when saturated with turbine oil. Test resonators were fabricated. Some care was required to achieve the required noise reduction. The major disadvantage is that the number of resonators required is large, each requiring several attachment welds. This large number of welds was a cost issue that could not be addressed during the time available.

Resonators were assembled into a small test silencer, and evaluated with and without flow. These performance tests, at near actual Mach number, suggested that the 20 dB noise reduction goal could be exceeded.

Backpressure

Backpressure is always an economic concern in silencers. Backpressure was estimated to be below 0.5 psi, but was not measured.

Silencer Installation and Tests

The first full-scale silencer was of the "insert" style, intended to be slipped into an existing 36 inch (0.914 meter) outside diameter pipe. However, due to plant downtime concerns, a new section of pipe was used instead of the section of existing pipe. This new section could be installed in only a few hours of downtime. Acoustic performance was excellent-the 20 dBA reduction goal was at least met and very likely was exceeded.

The following three silencers were installed and later checked for acoustic performance. Sound levels were measured at ear height under the elevated condenser inlet "header" pipe. Unfortunately, there are no directly comparable before and after noise measurements from which to evaluate the noise reductions achieved. However, there are "clean" data that comparing 2010 and 2015 sound levels.

Test Results

The noise reduction achieved in 2010 has not degraded four years later, in 2015.

Table 1 shows noise levels in dBA measured at ear height for a person walking on the ground under the long, elevated condenser header pipe. The "Fan Numbers" refer to the large fans of the Air Cooled Condenser. The data were collected in November of 2010 and again in March of 2015. The silencer was already installed before the first measurements.

Table 1. A-Weighted Noise Levels at Ear Height under Condenser Header Pipe (Uninsulated), 2010 and 2015

Location along header pipe	Turbine Pwr (MW)	Fan 23 S.End of Header	Fan 24	Fan 25	Fan 26	Fan 27	Fan 28 Even with Turbine	Fan 29	Fan 30	Average
October 2010	10	85.0	85.5	88.0	90.0	90.0	92.0	90.0	89.0	88.7
March 2015	13	86.0	87.2	86.3	87.6	88.8	92.0	89.1	87.2	88.0
2010 less 2015 Noise Levels		-1.0	-1.7	1.7	2.4	1.2	0.0	0.9	1.8	0.7

The last line in this table shows the noise level differences between 2010 and 2015 at each location. Any degradation in silencer performance would show up as a noise increase in 2015, compared to 2010. There are no significant increases shown. The average is a 0.7 dB decrease, compared to 2010. This is difference is judged by the authors as not significant. Sound levels nearest the turbine outlet pipe show slightly higher noise in 2010 than in 2015. This is believed due reasons mentioned below.

Known insulation and operation differences between 2010 and 2015 are:

1. In 2010, insulation on the silencer and adjacent pipes had been pulled away at several seams to allow close-up measurements of locally uninsulated, pipe-emitted noise. This emitted noise would have contributed a small increment (two dB or less, most likely) at the closest measurement locations in 2010, but not 2015 without these gaps.
2. In 2010, turbine power was about 10 MW, and in 2015, between 13 and 14 MW (Higher power is known to increase outlet pipe noise, see next item.)

3. In 2015, the pressure ratio across the turbine was near 5.5 to 1, but was less in 2010. (Higher pressure ratio is known to increase outlet pipe noise.)
4. Pump noise was prominent near the south end of the header in 2015, but not noted in 2010.

The maximum noise level difference is 2.4 dB louder in 2010, at the location closest to the silencer. This location is directly under a "T" junction where the turbine outlet pipe and silencer joins the condenser header pipe at its mid-point. This location receives noise from the uninsulated overhead header pipe, but also receives noise from the close-by turbine outlet pipe. The acoustical insulation on the turbine and silencer was fastened tightly in 2015, but was pulled apart locally at a seam in 2010, leaving several exposed noise-emitting gaps about 6 inches wide along the bottom of the silencer. Resulting noise emission would increase noise measured under the header, and was plainly audible there in 2010.

Table 2 documents octave band and A-weighted sound levels close to the silencer. The right-most column is the A-weighted noise levels at 6-inches distance from exposed steel pipe surfaces. The lowest sound levels shown is 104 dBA, confirming that silencer shell and pipe noise is still of concern.

Table 2. Octave Band Sound Levels at 6 Inches (150 mm) from Surfaces, 2010 and 2014, both with Silencer Installed.

Microphone Location	Year	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	16000 Hz	dBA	Comment
Diffuser Support Post	2010	85	84	106	108	100	86	75	112	Post penetrates thru insulation
	2015									(No Data)
Diffuser Wall at Outlet Flange, undr Insulation	2010									(No Data)
	2015	76	82	114	112	110	100		117.2	Mic in 3 Inch gap under Insulation
Silencer Inlet Support Post #1	2010	84	85	104	107	104	97	87	110	Insulation Pulled away from post
	2015	73	79	105	105	104	98		110.3	Post penetrates thru insulation
Mid Silencer	2010	84	81	103	103	101	93	84	104	Insulation Opened for Measurement
	2015	72	75	88	87	82	74		91.2	Insulation Closed Tightly
SuprtPost2ft Downstrm of Silencer	2010	85	84	104	104	96	89	78	107	Insulation Pulled away from post
	2015	75	81	99	100	95	91		104	Post penetrates thru insulation
Large Blind Flange rotated to Down position	2010								95	Not Insulated
	2015	75	80	86	85	84	77		91	Not Insulated

Future Development

The silencer technology is under continuing development to address cost, and further attenuation.

Conclusion

The noise changes over time shown on Table 1 are well within the differences expected only due measurement uncertainty and to the changes in plant operating and insulation conditions noted, and not due to increases or decreases in silencer attenuation performance. The silencer continues to provide satisfactory noise reduction after four years of operation. Inspections have reported no known physical degradation.

Acknowledgements

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