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DIAGNOSIS OF SCREW PUMP FLOW INSTABILITY FROM CASING VIBRATION – A HOLISTIC MACHINERY DIAGNOSTIC APPROACH.

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ABSTRACT

This paper discusses the diagnosis, further analysis and resolution of abnormally high vibration and noise detected on Lube Oil (LO) screw pumps A & B supplying a Turbo Expander Compressor (TEC).

During the initial investigation on-site, on 22nd September 2021, the portable data collector was used to capture individual samples across the LO Pump B train. At Stage 5, the Pump vibration was measured as satisfactory. However, when the TEC entered Stage 7 operation increased vibration and noise were observed at the machine skid (Figure 5). A significant number of harmonics were generated during this time, as well as amplitude and impacts in the acceleration time waveform (Figure 6). The conclusion from the vibration data was that the flow was being disrupted, and the potential root cause was the new style LO filters or contamination resulting in blockages of the LO pipework, the former being the more likely theory.
The end user requested further confirmation of this theory, and thus a multi-channel analyzer and temporary casing velocity/acceleration transducers were deployed across the train and pipework. This would allow a further picture of the rotor dynamic behavior of the trains to be developed and allow identification of any apparent malfunctions and meaningful, actionable recommendations for future work and/or operation of the trains in question. Investigation of LO Pump A using the DSPI, low-level spikes were observed in the vibration data (Figure 13). Overall, the frequency components for LO PUMP A were comprised of 1X and harmonics of 1X (Figure 15 to Figure 17). The impulse events were seen to cause very slight increases across multiple harmonics (Figure 18). During the test run of LO Pump B, elevated vibration was observed across the Pump, Motor Axial and pipework during Stage 7. Examination of the spectral data showed increased activity in 1X and harmonics of 2X (Figure 21 to Figure 26). Overall, the behavior measured at LO Pump A & B indicated an issue with the flow through the pump. The high-resolution data from the DSPI verified the initial conclusions of the portable data collector, that an issue with the flow through the pump was occurring.
It was recommended to the end-user that the filters be exchanged with those of the original design. Several weeks later, the LO filters were replaced with a design comparable to that of the original filters, and the vibration levels returned to normal levels. Overall, this confirmed the inappropriate filter design was causing an excessively high filter DP which resulted in disruption of the flow regime through the LO pumps, with high vibration merely a symptom of this behavior.

INTRODUCTION & BACKGROUND

During periodic monitoring of machine trains at an onshore Oil & Gas terminal using a portable vibration data collector, abnormal high vibration and noise were detected on Lube Oil (LO) pumps A & B supplying the Turbo Expander Compressor (TEC), as Figure 1 shows.

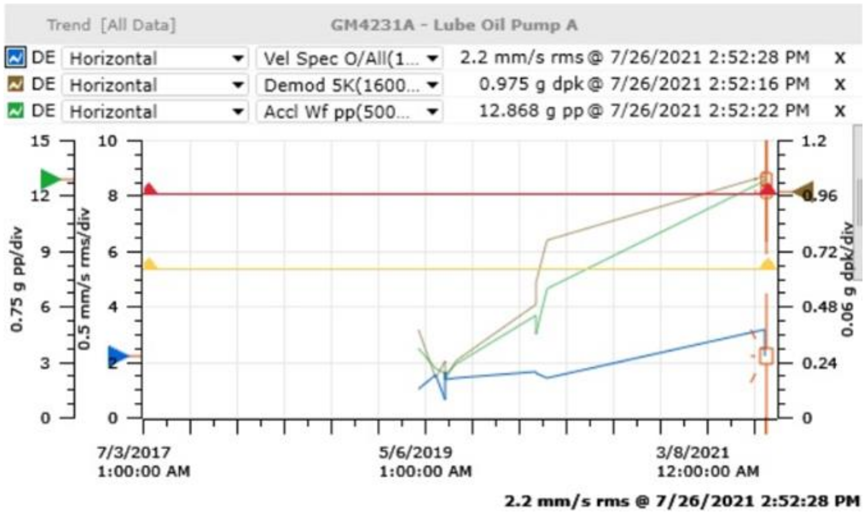

Figure 1: Pump, Drive End, Direct vibration trends 2017 to 2021.

LO Pumps A & B consist of a fixed speed synchronous motor operating at 3000 rpm (50 Hz) directly coupled to a screw pump with an anti-friction bearing on the Drive End (DE) and metal bush on the Non-Drive End (NDE) of the Pump (Figure 2). These units operate individually to supply lubricant to the TEC train through a downstream dual filter bank arrangement (Figure 3).

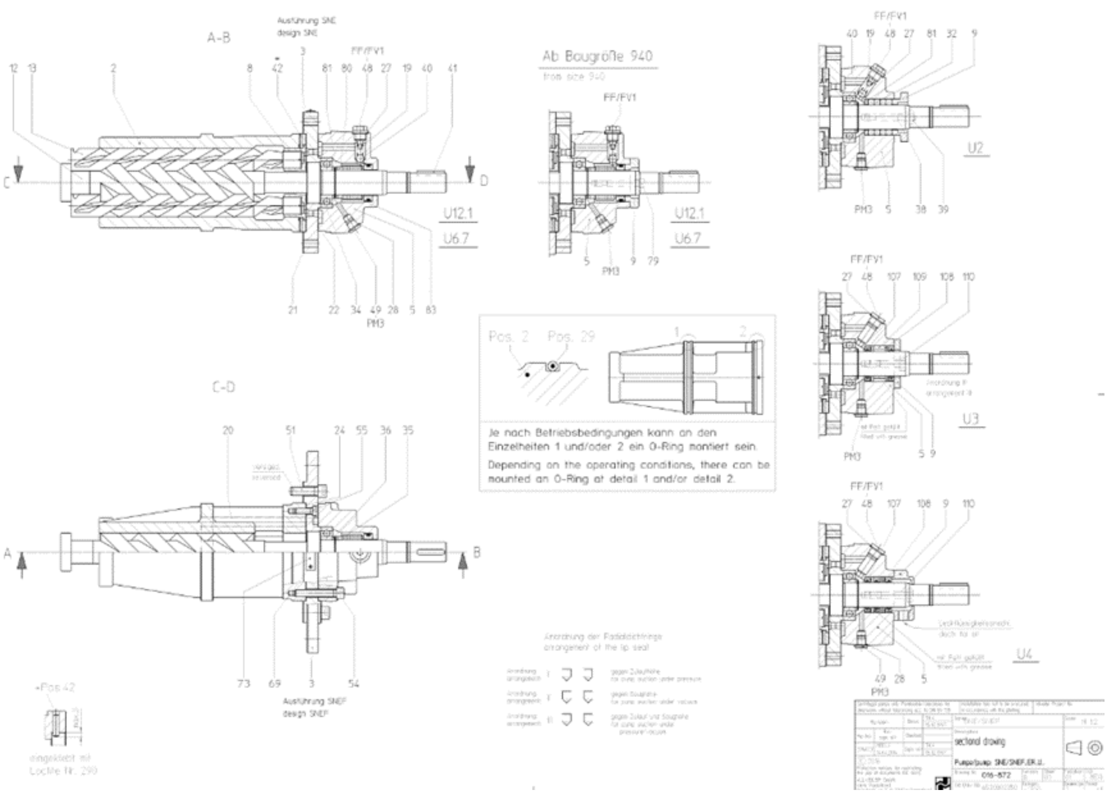

Figure 2: Sectional Drawing Pump SNE/SNEF[1].

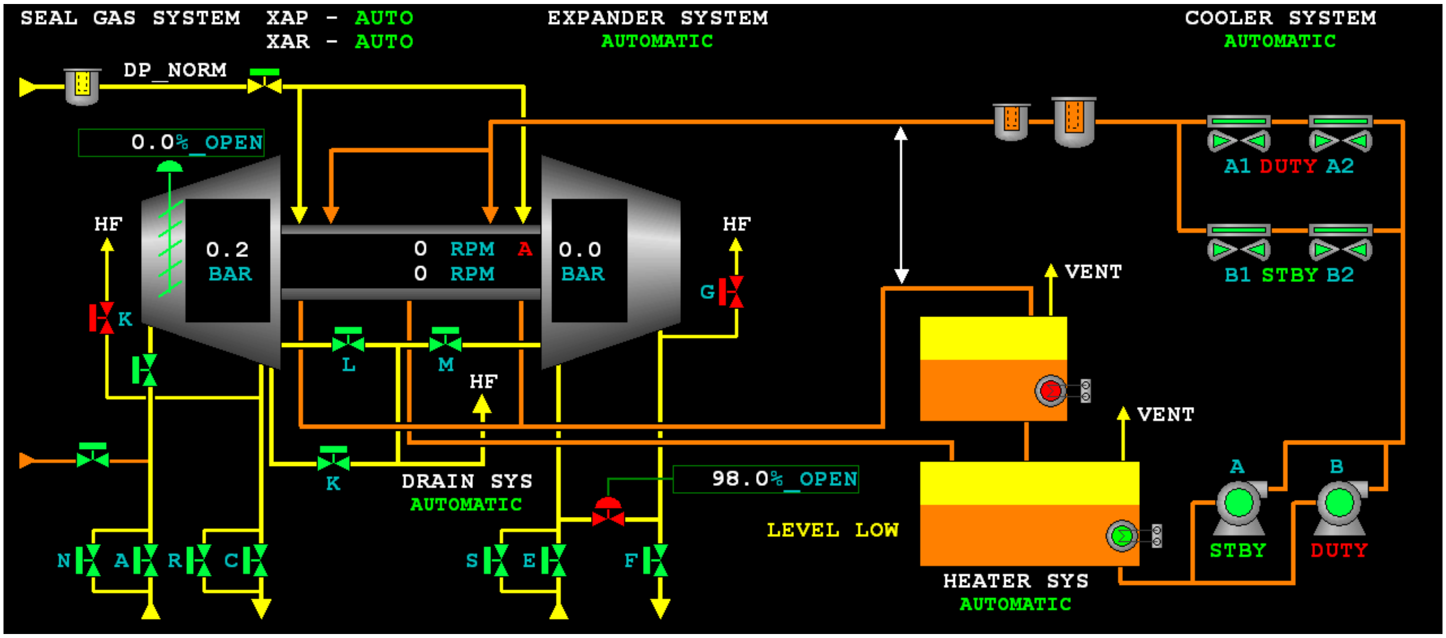

Figure 3: Turbo Expander Compressor Control System HMI.

Prior to the detection of abnormal vibration maintenance, work was carried out on the LO cooler's structure for LO Pumps A & B. The LO cooler was removed on 18 May 2021 and replaced with a "like for like" cooler on the 1st of July 2021. At this time, the filters (original design) were replaced and the LO was topped up, but the tank was not fully drained or flushed. On recommissioning the system, the operations team reported high differential pressure (DP) across the LO filters together with suspected high vibration on LO Pump A. High vibration was confirmed with the portable data collector. On inspection of the filters from both element banks, these were significantly contaminated with visible metal particulate/ swarf. This was attributed to inadequate flushing of the LO cooler and it was now believed that this contamination was cleared.

The filters were then replaced, but these were of a new design (Figure 4), on the 20th of September 2021. This filter design was said to be comparable, however Beta rating was not provided for confirmation, these were slightly smaller dimensionally and also featured a perforated metal tube cover where the older filters paper/resin element was exposed. The downstream guard filters were also inspected and confirmed to be clean. However, these were replaced (without a change in design) as a precautionary measure. Following the second attempt at commissioning of the LO System on 22nd September 2021 – the Filter DP again reported higher than previous levels (0.84 bar vs. 0.4 to 0.6 bar). LO Pump B was stopped due to high vibration & noise levels observed at the skid. Such behavior only occurred when the TEC 2 was online, known as "Stage 7". On running LO Pump A, the high vibration reported when the filters clogged had not returned during the initial running. However, several minutes after operating the TEC at "Stage 7," an intermittent vibration impulse was heard.

The Machinery Diagnostic Services (MDS) Engineer was tasked with investigating and diagnosing this behavior to allow continued operation of a critical production train providing 50% of the plant's 20 MSCM per day (7.58 therm/day) capacity.

Figure 4: "New" LO Filters with protective plating.

TECHNICAL DATA SHEET

DESCRIPTION.................	PLEATED PAPER ELEMENTS
PERFORMANCE DATA:	
Micron Rating...............	25.00 NOMINAL
Beta Rating.................	N/A
Collapse Pressure Rating....	75 PSID
Maximum Temperature.........	250 F
Direction of Flow...........	OUTSIDE->IN
DIMENSIONAL DATA:	
(A) Outer Diameter, Top.....	4.25 (108.0 mm)
(B) Outer Diameter, Bottom..	4.25 (108.0 mm)
(C) Inner Diameter, Top.....	1.75 (44.5 mm)
(D) Inner Diameter, Bottom..	1.75 (44.5 mm)
(E) Length..................	17.88 (454.2 mm)
PHYSICAL DATA:	
Handle......................	NONE
Seal Material...............	BUNA-N
Type of Adhesive............	EPOXY
Type of Endcap..............	PLATED STEEL
Centertube..................	PLATED STEEL
Type of Media...............	PAPER
Filter Area.................	20 SQ FT.
Plating.....................	ELECTROTIN PLATED
Outer Jacket................	YES
Configuration...............	DOUBLE OPEN END

Figure 5: "New" Filter Specification.

NOMINAL EFFICIENCY, MICRONS ------------	5	MODEL NUMBER:	BP-513-1
RECOMMENDED INITIAL PRESSURE DROP, PSI --	1.5	PART NUMBER:-------------	600095
MAXIMUM PERMISSIBLE FLOW RATE, GPM ------	50	FILTER AREA SQ.IN.:------	2635
OPERATING TEMPERATURE RANGE, °F ---------	-30+300°F	OUTSIDE DIAMETER IN.:----	4-3/8
RECOMMENDED REPLACEMENT PRESS PSI ΔP ----	20	INSIDE DIAMETER IN.:-----	1-13/16
ELEMENT COLLAPSE PRESSURE, PSI ΔP -------	100	LENGTH IN.:--------------	18
ELEMENT QUALIFIED TO --------------------	SAE J905	WEIGHT OUNCES:-----------	32

ELEMENT CONSTRUCTION:

- FILTER MEDIA: ----Resin impregnated, pleated cellulose
- CENTER TUBE: -----Perforated steel
- END CAPS: --------Tin plate steel
- OUTER COVER:------Perforated oil board tube
- END GASKETS:------Composition cork

Figure 6: "Old" Filter Specification.

INITIAL INVESTIGATION

During the initial investigation on-site, on 22nd September 2021, the portable data collector was used to capture individual samples across the LO Pump B train.

For reference, there are several operational Stages for startup and steady-state operation of the TEC:

- Stage 1: Seal gas on.
- Stage 4: Cooling fans online. LO system pressure 10 bar(g).
- Stage 5: begin pressurization of LO system, supplying at 50 bar(g). Filter DP 0.74 bar.
- Stage 7: Turbo Expander Compressor (TEC) startup and idle at 2000 rpm.

At Stage 5, the pump vibration was measured as satisfactory, indicating no mechanical issues with the pump as well as the DE bearing. However, when the TEC entered Stage 7 operation, increased vibration and noise were observed at the machine skid (Figure 7). A significant number of harmonics were generated during this time. Examination of the acceleration waveform showed a significant increase in amplitude and impacts (Figure 8). It was also noted that although the LO supply pressure remained at 50 bar(g) on the gauge at the skid, a drop in motor current from 48 A to 42 A was observed, indicating a change in rotor dynamics.

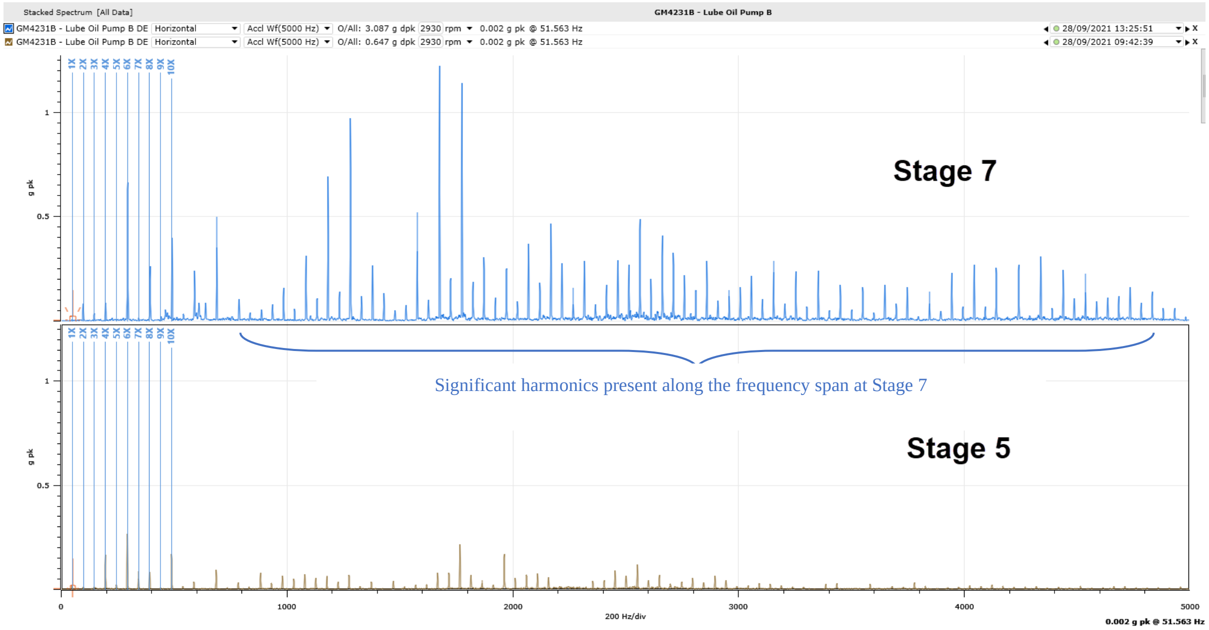

Figure 7: LO Pump B, Pump DE, acceleration stacked spectra, 28th September 2021.

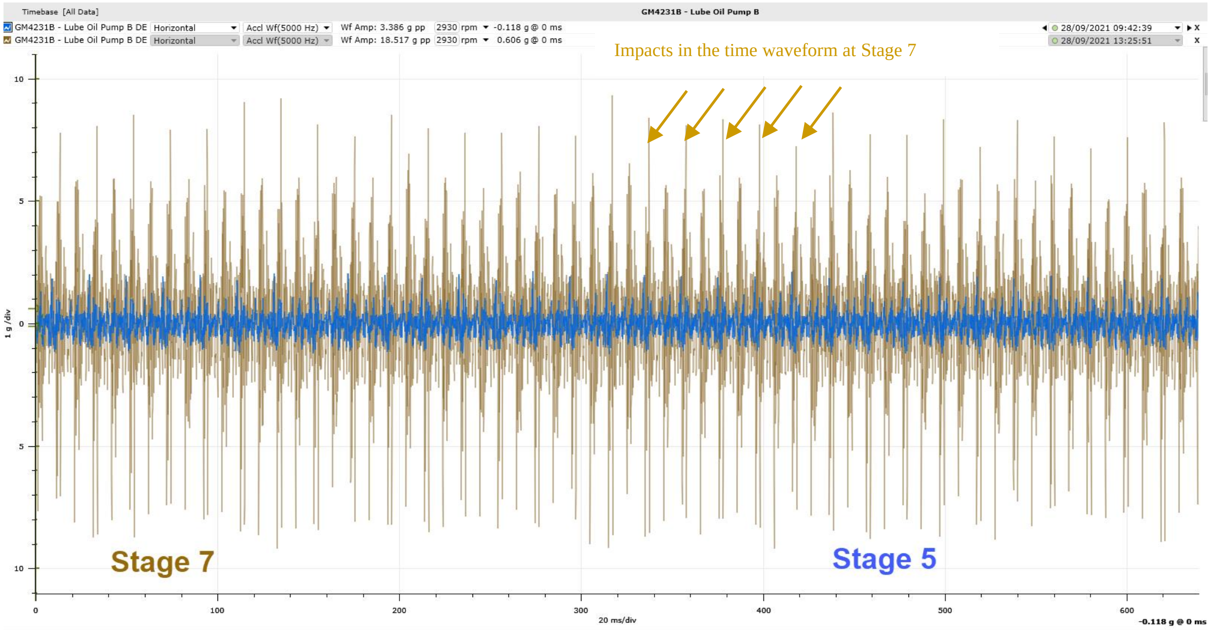

Figure 8: LO Pump B, Pump DE, acceleration Waveform, 28th September 2021.

Overall, the data suggested that a disruption in screw pump flow was occurring. The root cause of this was unclear, as with the changes to the LO cooling system, there were several potential causes:

- Debris within the suction piping and filters.
- The New filter design with protective plating was causing a higher filter DP, resulting in variations of flow through the pump.

To ensure that the issue was with the pump, the end-user decided to perform an uncoupled run of the motor. Vibration levels were satisfactory with no apparent mechanical or electrical problem detected in the measured data.

In addition to the above, the following checks were carried out by the end-user:

- Several LO analysis samples were taken upstream and downstream from the filters, which confirmed the oil quality was "within specifications".
- The suction strainer baskets were checked, finding no debris, and replaced as precautionary measure.
- The operation of the LO Pump A/B discharge NRV's were verified with no evidence of blockage or poor operation.
- During the uncoupled motor runs, both pumps were free to turn by hand.
- Alignment checks carried out – both pumps within spec. Radial lift checks were carried out whilst in situ – readings confirmed as 8 mil.
- LO Pump A/B and LO coolers bled for air.

The recommendation from the MDS team was to borescope the pipework, flush the system and to perform further testing with filters that were of the original design.

FURTHER INVESTIGATION TEST SETUP

These represented a significant effort for the end-user, so the request was made to perform further verification using a Dynamic Signal Processing Instrument (DSPI) multi-channel analyzer. With the DSPI temporary casing velocity/acceleration transducers at the skid for the Lube Oil Pump trains and associated pipework up and down stream, real-time high-resolution casing vibration data would be collected through a transient to steady state operation (Stage 5 to 7) for each pump. This would allow an additional picture of the rotor dynamic behavior of the trains to be developed and allow identification of any apparent malfunctions and meaningful, actionable recommendations for future work and/or operation of the trains in question.

Transducer locations were kept consistent across LO Pump A & B test runs. For LO Pump A, only the pump was instrumented as the motor was known to have no abnormalities from previous data collection and from LO Pump B test. Locations are shown in Figure 9 to Figure 15.

Figure 9: TEC & LO Pump A/B Skid, LO Pump side with process pipework marked up.

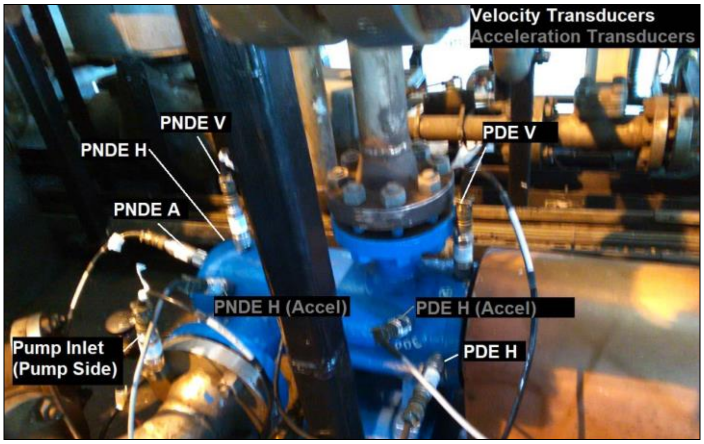

Figure 10: LO Pump A with transducers.

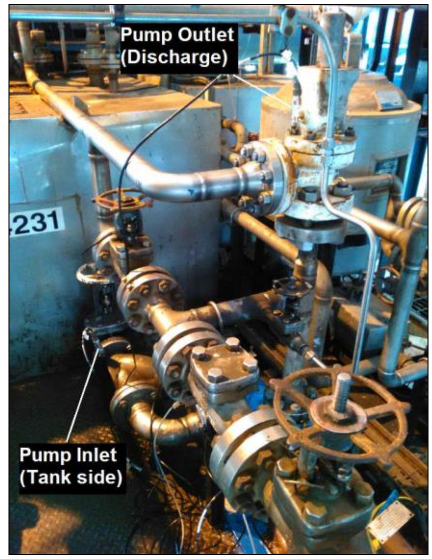

Figure 11: LO Pump A pipework with transducers fitted.

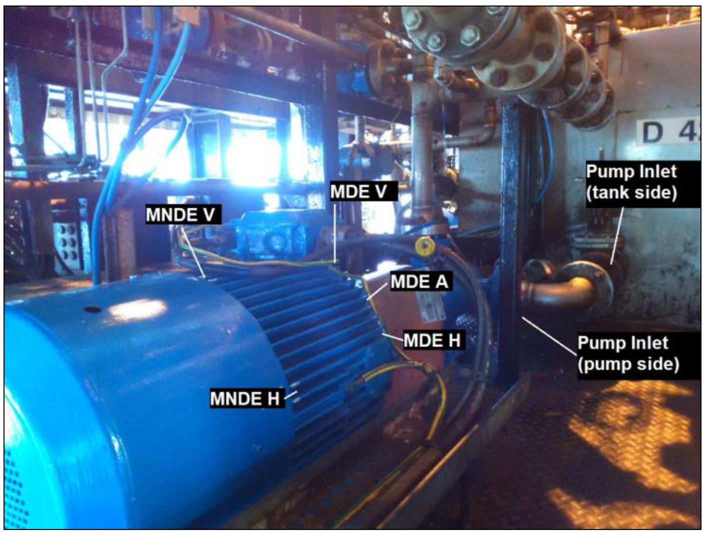

Figure 12: LO Pump B with transducers locations (prior to fitment) for Motor & suction pipework.

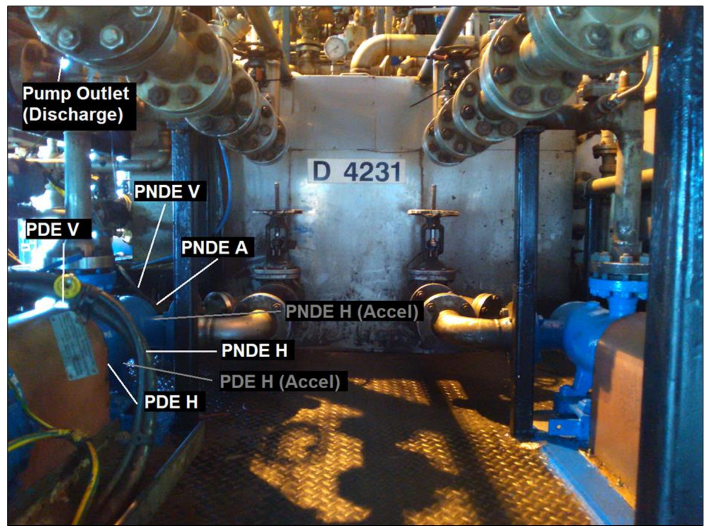

Figure 13: LO Pump B with transducers locations (prior to fitment) for Pump & discharge pipework.

Figure 14: LO Pump A transducers connected to seismic “power box”.


Figure 15: LO Pump A / B skid with transducers connected to DSPI.

ANALYSIS OF LO PUMP A

During the test run of LO Pump A, the intermittent low-frequency impulse type noise previously reported was observed. These coincided with low-level spikes in the vibration data (Figure 16). These events were most notable at the Pump NDE axial position then Pump NDE radial positions, and with very low magnitudes in the pipework (Figure 17). At this time, the LO filter DP was reading 0.80 bar on the gauge at the machine skid. Overall, the frequency components for LO PUMP A were comprised of 1X (50 Hz) and harmonics of 1X, with the 2X (100 Hz) the slightly dominant component (Figure 18 to Figure 20). The impulse events were seen to cause very slight increases across multiple harmonics (Figure 21).

This behavior was not driven from a mechanical or structural malfunction. The slight increase in activity across multiple harmonics during the “impulse noise” and elevated vibration indicate a behavior related to the LO flow.

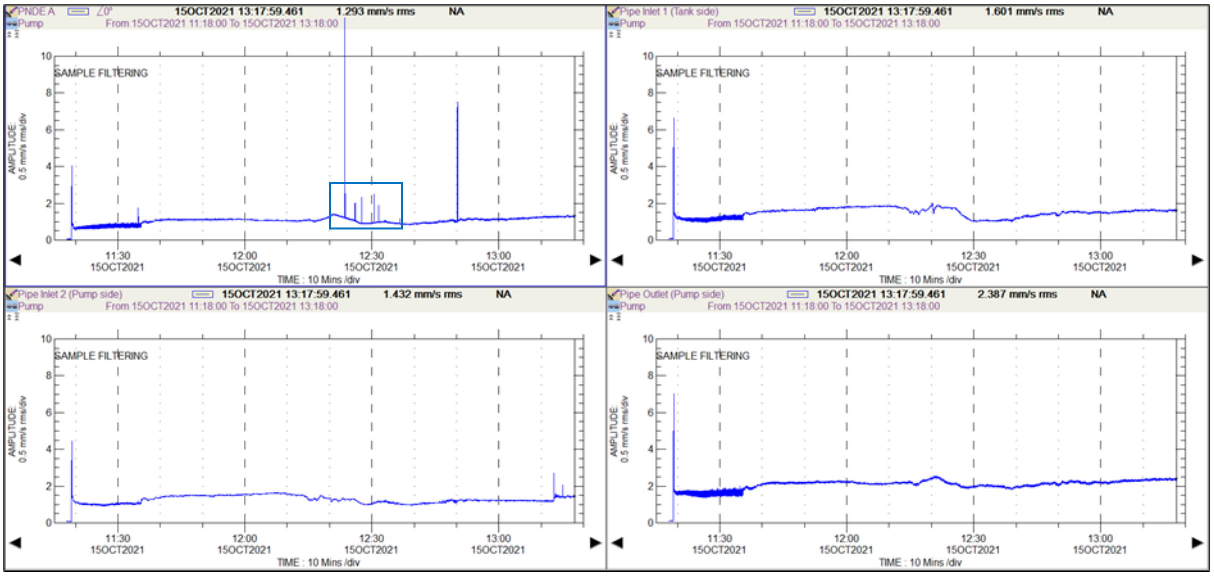

Figure 16: LO Pump A, PNDE A vs. Pipework, Direct Velocity Trends, 15th October 2021. Note small spikes occurring in NDE measurements correlating with observed impulse noise.

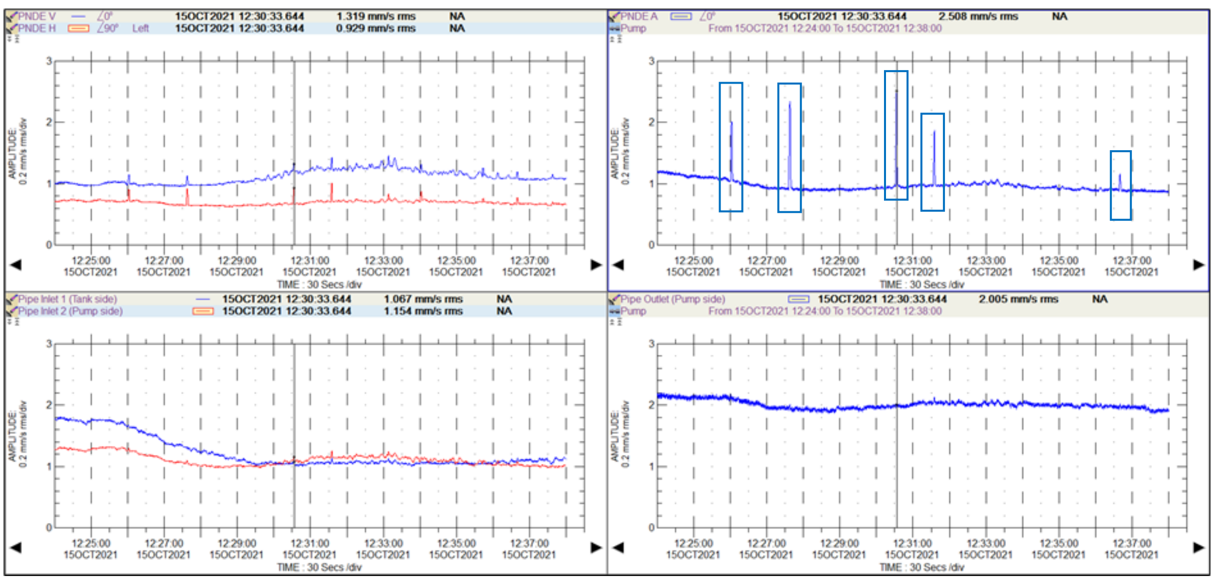

Figure 17: LO Pump A, PNDE V & H vs. PNDE A, Pipe Outlet & Pipe Inlet 1 & 2 (clockwise from top left), Direct Velocity Trends, 15th October 2021 12:24 to 12:38. Note scale reduced compared to previous plots and small spikes occurring in NDE measurements correlating with observed impulse noise (blue box).

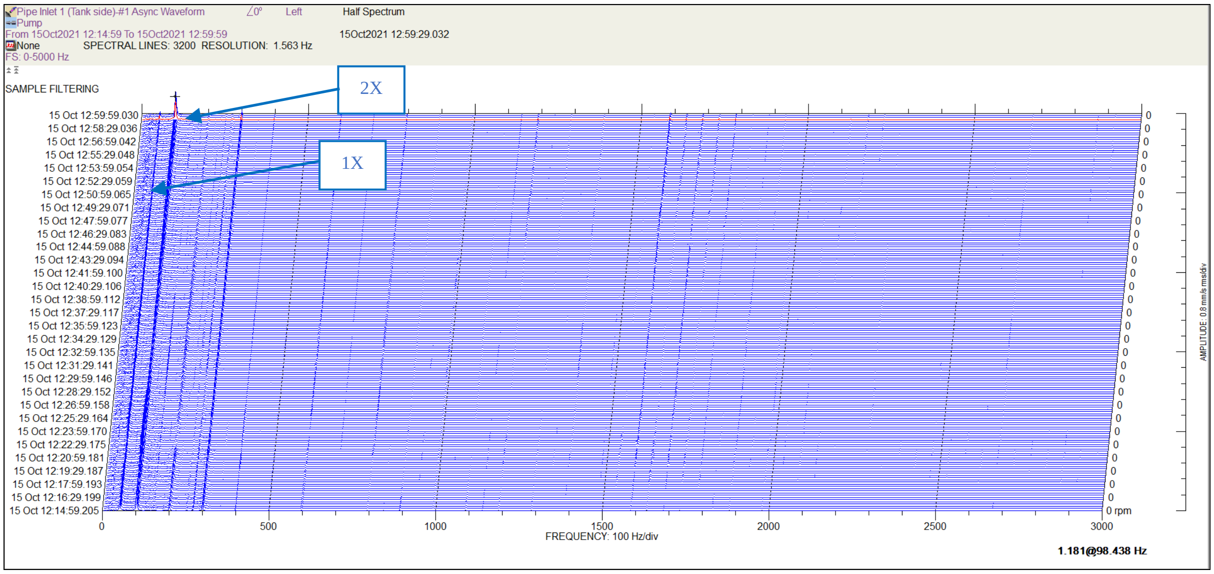

Figure 18: LO Pump A, Pipe Inlet 1 (Tank side), Asynchronous Half Spectrum Waterfall, 15th October 2021 12:15 to 13:00.

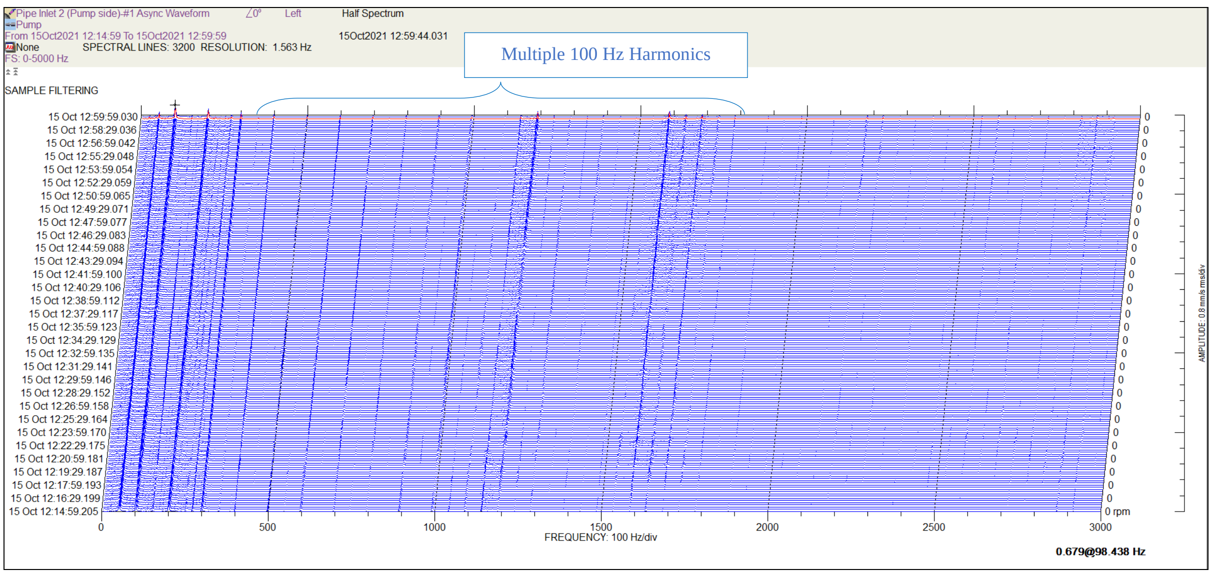

Figure 19: LO Pump A, Pipe Inlet 2 (Pump side), Asynchronous Half Spectrum Waterfall, 15th October 2021 12:15 to 13:00.

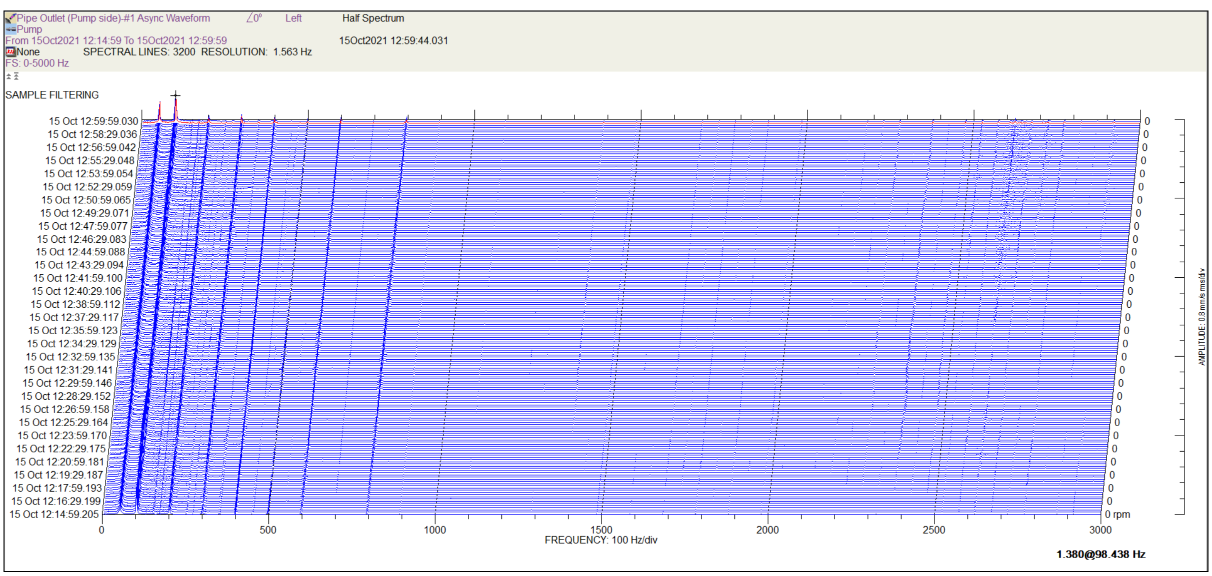

Figure 20: LO Pump A, Pipe Outlet (Pump side), Asynchronous Half Spectrum Waterfall, 15th October 2021 12:15 to 13:00.

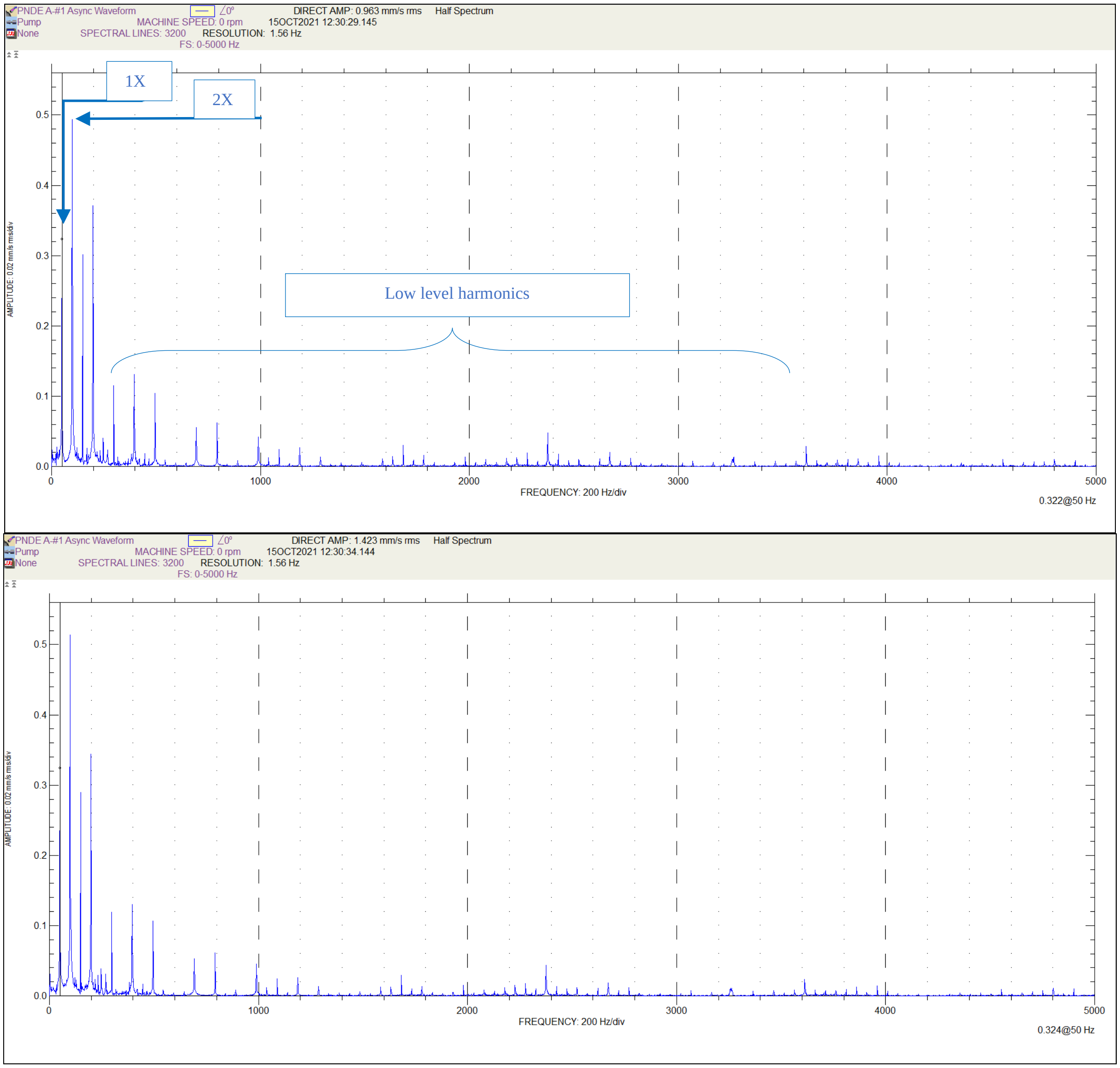

Figure 21: LO Pump A, Pump NDE A, Asynchronous Half Spectrum, 15th October 2021 12:30:29 (upper spectrum – prior to 3rd spike in axial vibration) vs. 12:30:34 (lower spectrum – near to 3rd spike in axial vibration).

ANALYSIS OF LO PUMP B

During the test run of LO Pump B, the consistent noise previously reported was observed. Twelve minutes after TEC reaching steady state operation at 11300 rpm the noise developed, increased, and then remained until shutdown at 17:14. This correlated with an increase in vibration measured across the motor DE axial and pipework transducers (Figure 22). After correction of pump measurement locations, similar behavior was observed (Figure 23). Examination of the spectral data showed increased activity in 1X and harmonics of 2X across the pump DE (Figure 24 and Figure 25). These were also detected in the pipework (Figure 26 to Figure 28 and Motor axial spectrums (Figure 29). The behavior measured at LO Pump B indicated an issue with the flow through the pump.

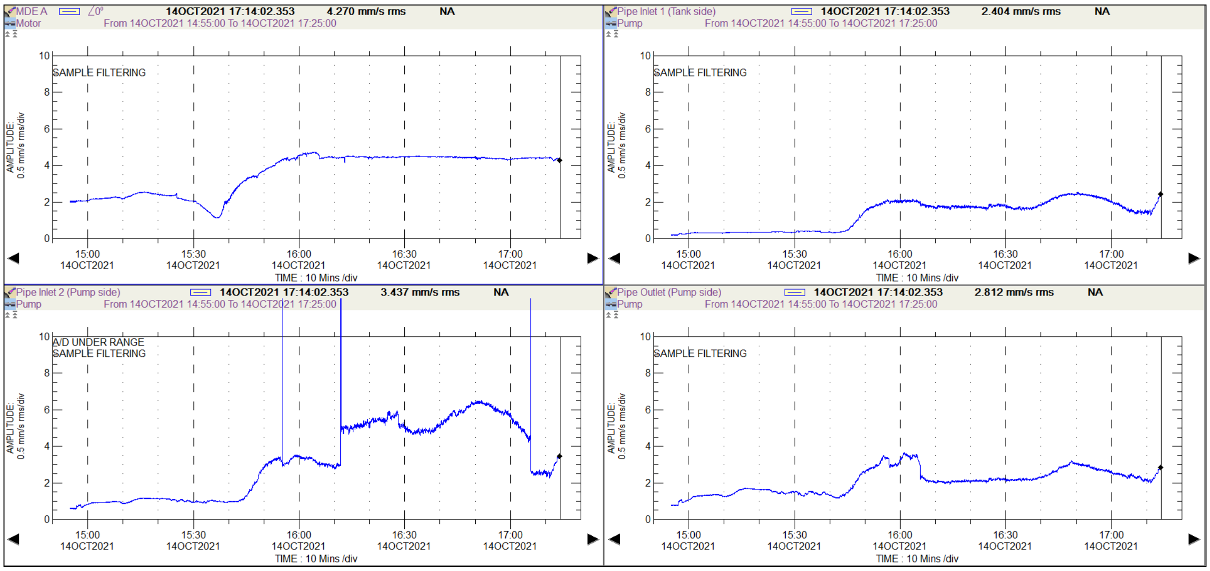

Figure 22: LO Pump B, Motor DE Axial vs. Pipework, Direct Velocity Trends, 14th October 2021.

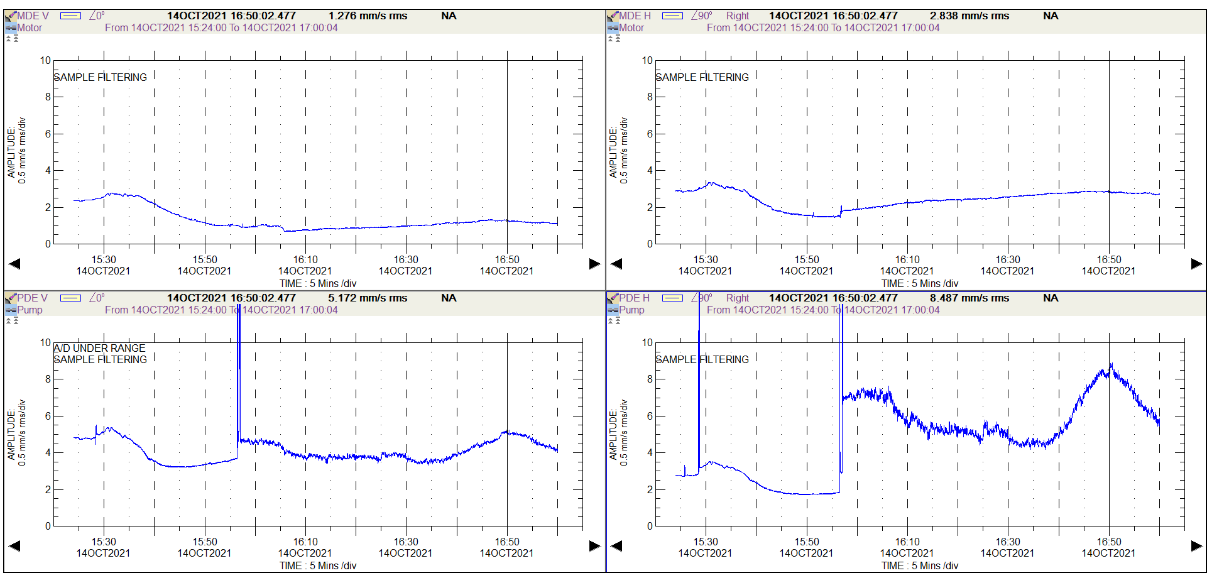

Figure 23: LO Pump B, Motor DE vs. Pump DE, Vertical & Horizontal, Direct Velocity Trends, 14th October 2021. Note spike at 15:56 occurred due to transducer location adjustment.

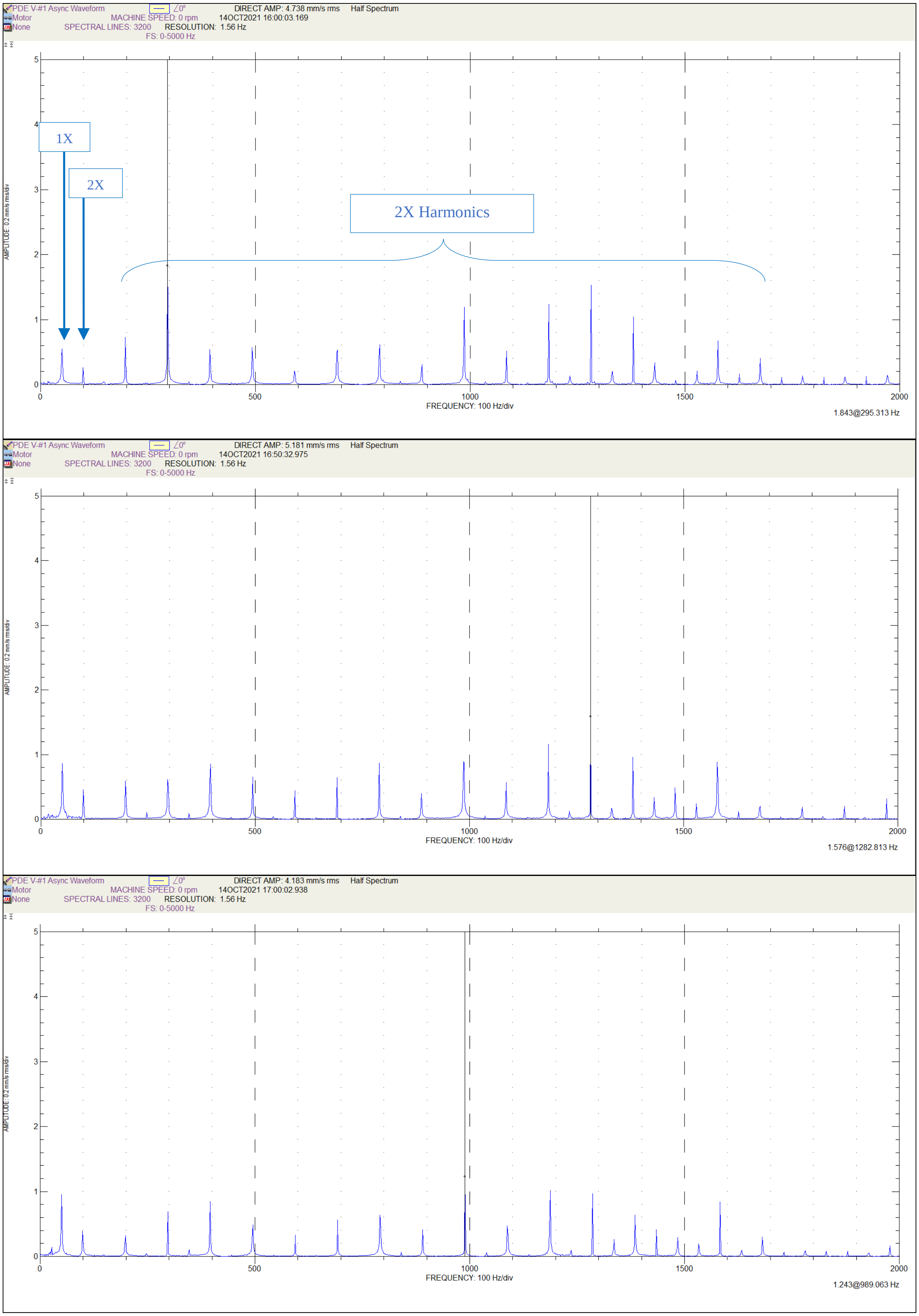

Figure 24: LO Pump B, Pump DE V, Asynchronous Half Spectrum, 14th October 2021 16:00:03 (upper spectrum – noise plateaued, TEC 11300 rpm) vs. 16:50:32 (middle spectrum – peak vibration, TEC 12500 rpm) vs. 17:00:02 (lower spectrum – TEC 11000 rpm).

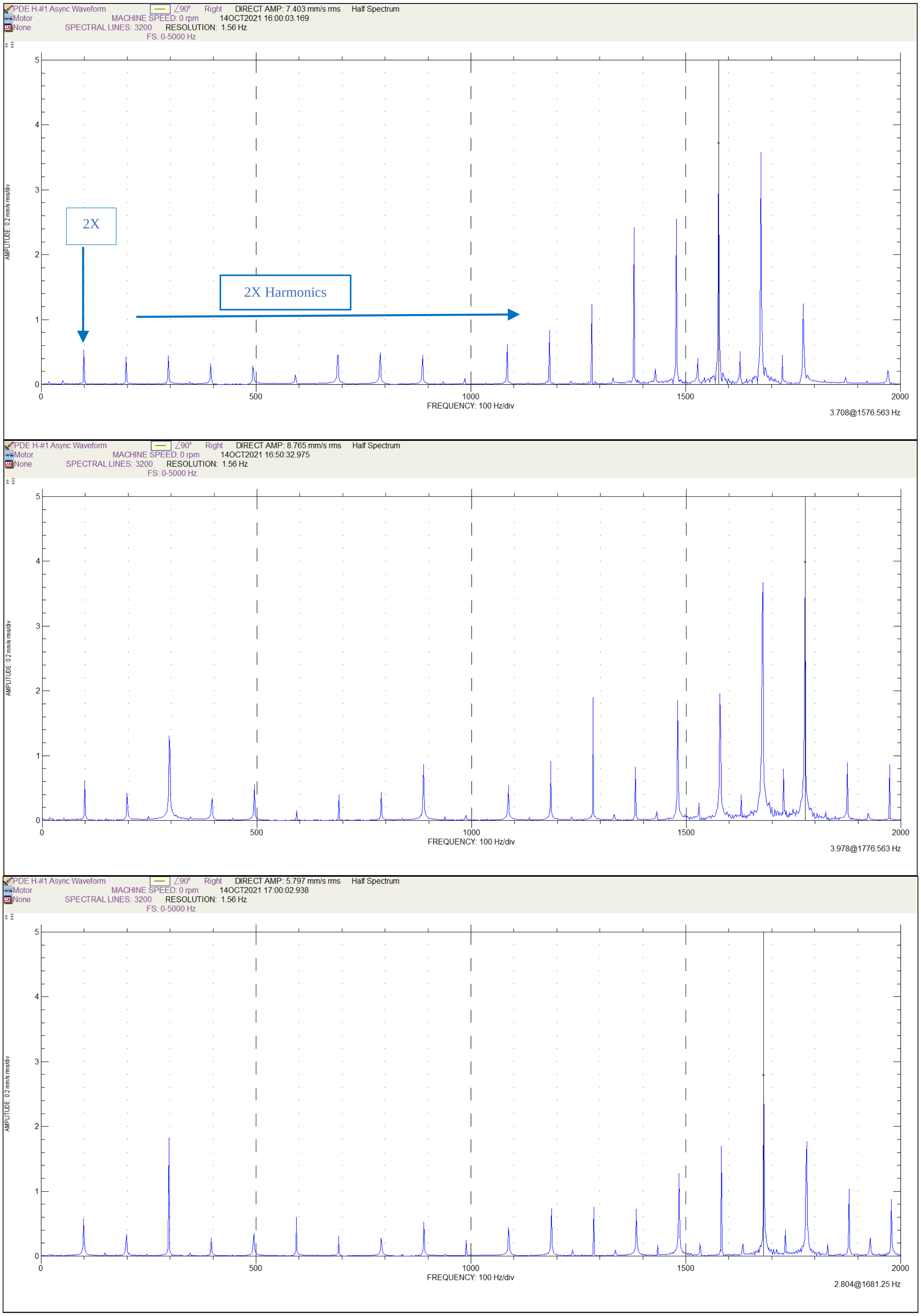

Figure 25: LO Pump B, Pump DE H, Asynchronous Half Spectrum, 14th October 2021 16:00:03 (upper spectrum – noise plateaued, TEC 11300 rpm) vs. 16:50:32 (middle spectrum – peak vibration, TEC 12500 rpm) vs. 17:00:02 (lower spectrum – TEC 11000 rpm).

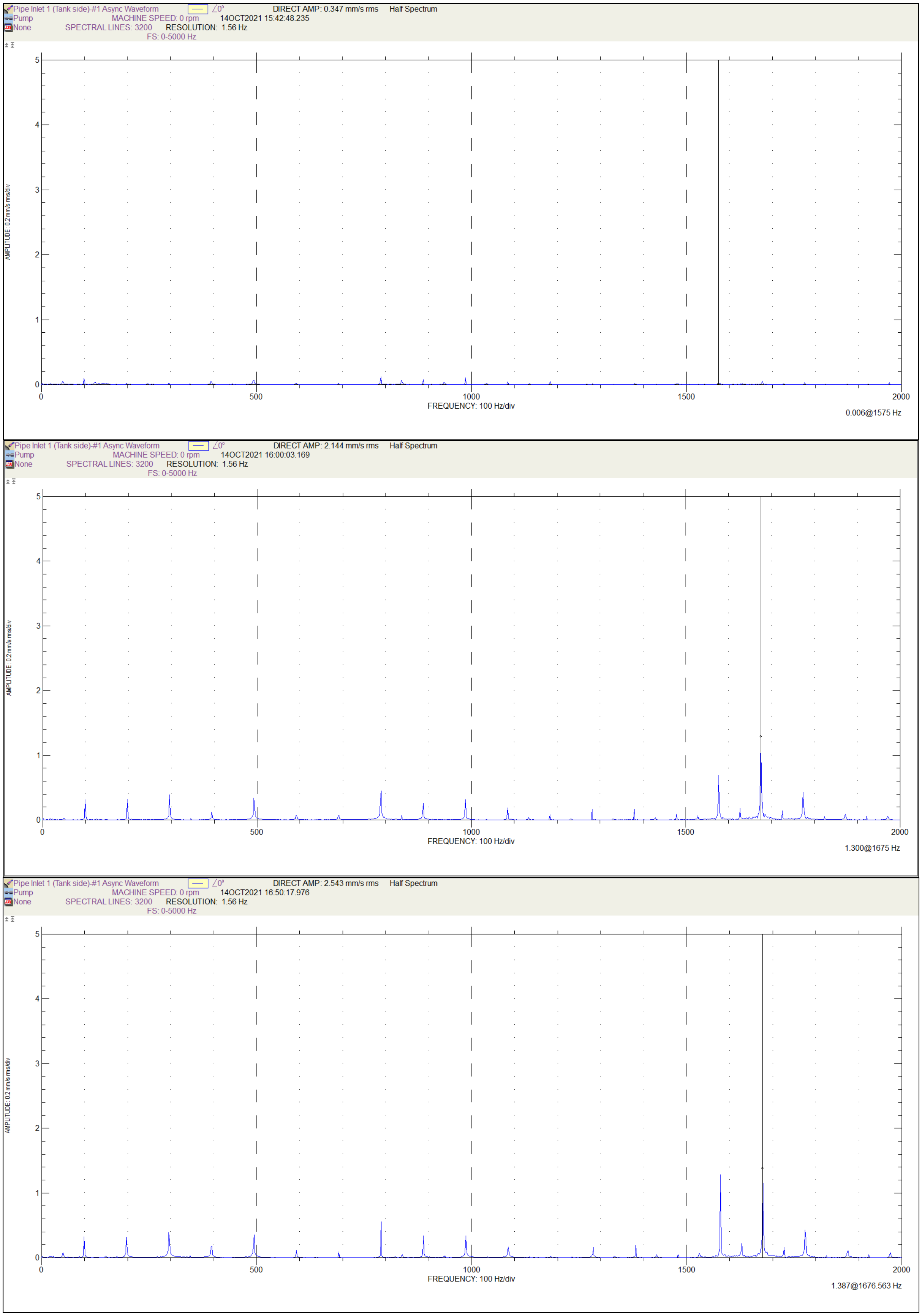

Figure 26: LO Pump B, Pipe Inlet 1 (Pump Side), Asynchronous Half Spectrum, 14th October 2021 15:42:48 (upper spectrum – prior noise) vs. 16:00:03 (middle spectrum – noise plateaued) vs. 16:50:17 (lower spectrum – peak vibration).

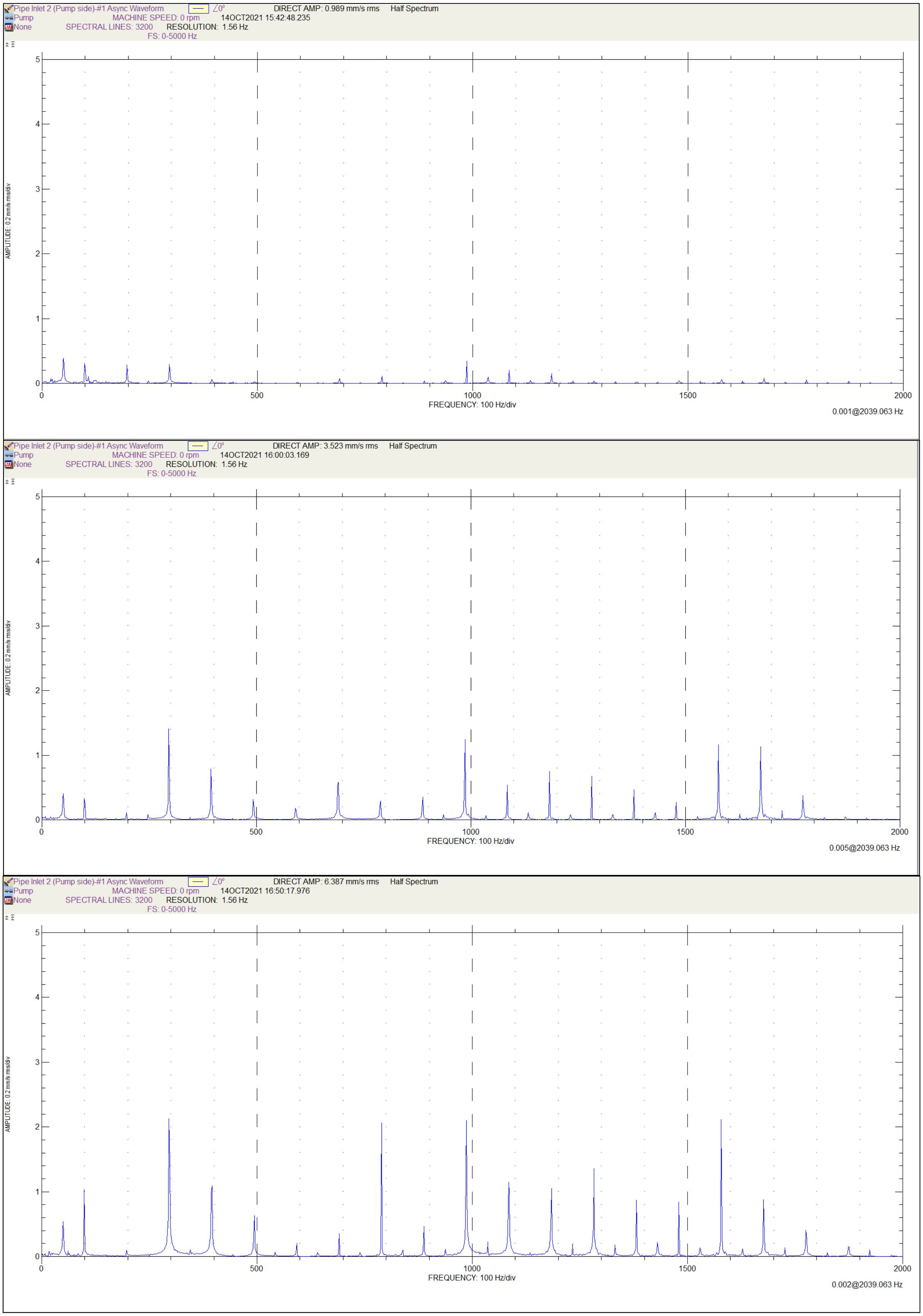

Figure 27: LO Pump B, Pipe Inlet 2 (Pump Side), Asynchronous Half Spectrum, 14th October 2021 15:42:48 (upper spectrum – prior noise) vs. 16:00:03 (middle spectrum – noise plateaued) vs. 16:50:17 (lower spectrum – peak vibration).

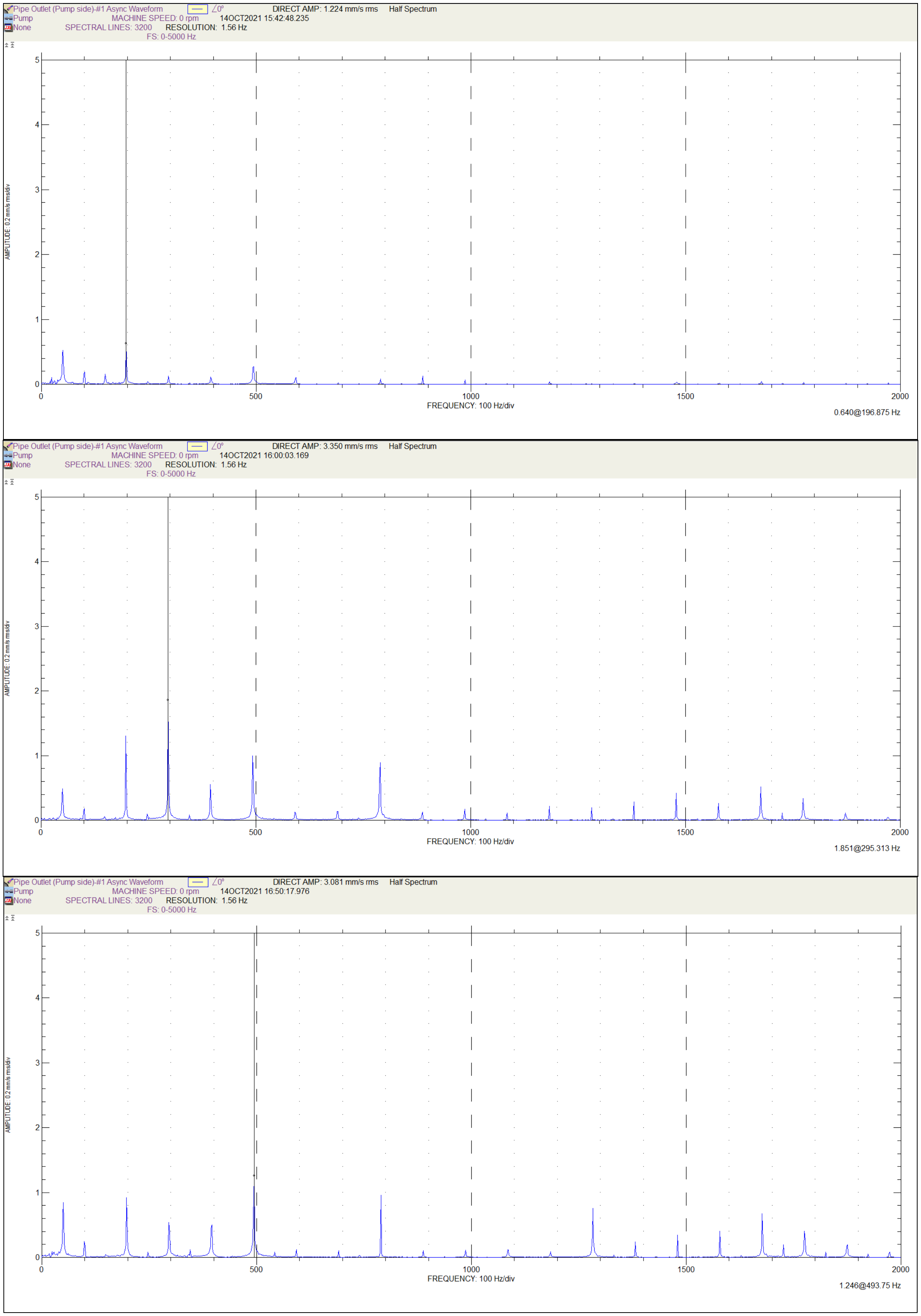

Figure 28: LO Pump B, Pipe Outlet (Pump Side), Asynchronous Half Spectrum, 14th October 2021 15:42:48 (upper spectrum – prior noise) vs. 16:00:03 (middle spectrum – noise plateaued) vs. 16:50:17 (lower spectrum – peak vibration).

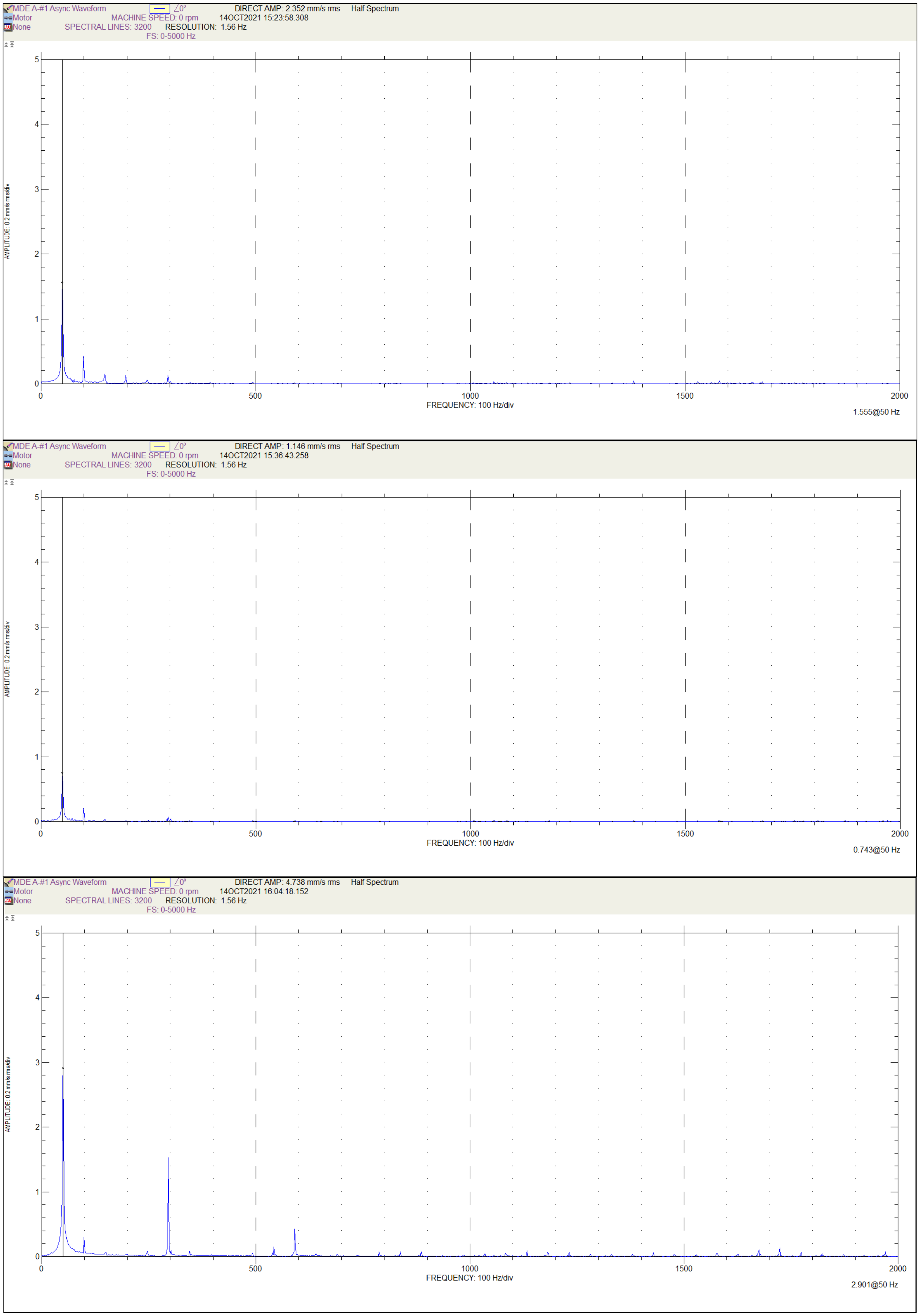

Figure 29: LO Pump B, Motor NDE Axial, Asynchronous Half Spectrum, 14th October 2021 15:23:58 (upper spectrum – TEC 2500 rpm) vs. 15:36:43 (middle spectrum – reduced vibration, prior to noise, TEC 11300 rpm) vs. 16:04:18 (lower spectrum – peak vibration, noise present, TEC 11300 rpm).

ANALYSIS OF PROCESS DATA

Process data provided from LO differential pressure was plotted in Figure 30 and Figure 31 for LO Pump A and B respectively. LO Pump A operated within a range of 0.785 to 0.880 bar where LO Pump B operated, slightly higher, within a range of 0.795 to 0.887 bar(g) during steady state. Similar fluctuations were apparent during operation of both Pump however LO Pump B did appear to have a slightly higher DP during the first hour of running.

Overall, the comparison of this to the vibration observed is inconclusive but the LO DP fluctuations are abnormal and would indicate intermittent decreases in flow across the filter.

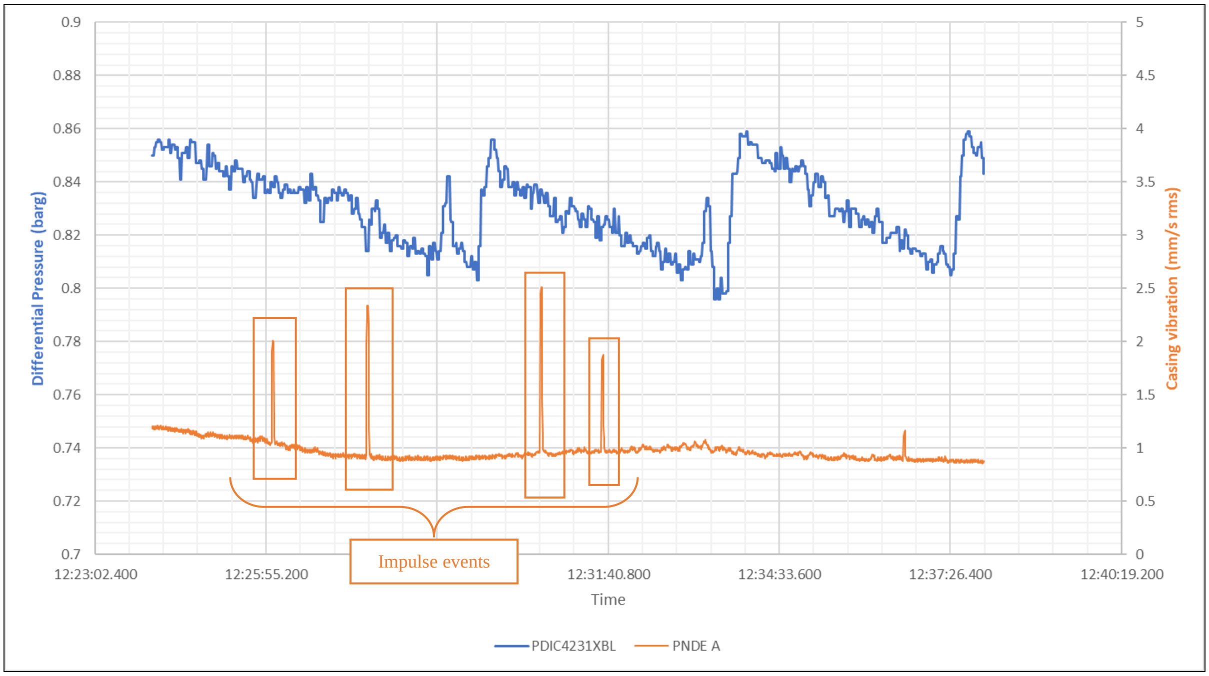

Figure 30: LO Pump A DE Axial vibration vs. TEC Lube Oil Differential Pressure Trends, 15th October 2021.

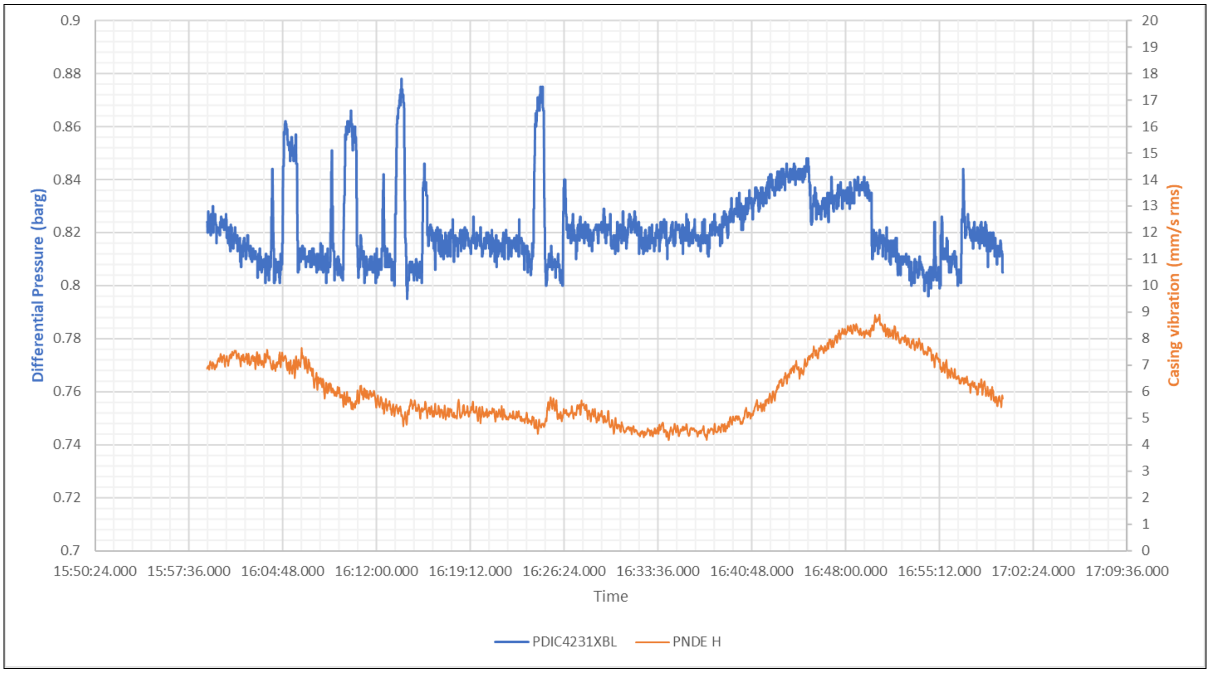

Figure 31: LO Pump B DE Axial vibration vs. TEC Lube Oil Differential Pressure Trends, 14th October 2021.

CONCLUSIONS

The high-resolution data from the DSPI verified the initial conclusions of the portable data collector and when comparing the vibration experienced at the pump with the operating speed of the TEC, confirmed the vibration experienced at the pump was influenced by the loading of the TEC. Increased loading of the TEC will result in a change in LO demand, specifically pressure and flow from the pump. This would be expected, however the vibration experienced at the pump and pipework was abnormal and in the case of a screw type pump, this behaviour was indicative of an issue with the flow through the pump.

It was recommended to the end-user that the filters were exchanged with those of the original design.

Before these filtered were changed LO Pump B was returned to service on 21st October 2021 by the end-user against the recommendation of the MDS team to meet process requirements. Observations and measurements on-site found the LO DP had decreased to 0.80 bar from 0.84 bar, the vibration level reduced with the noise changed to mirror LO Pump A. This indicated that even a slight reduction in LO filter DP was having a notable effect on pump vibration. The cause of this very slight LO filter DP reduction was potentially driven by the filter “bedding in” or initially debris on the filter casing dropping off when the Pump was offline.

Several weeks later the LO filters were replaced with a design comparable to that of the original filters (not shielded as per Figure 4) with the LO filter DP reducing to ~0.53 bar, within the previous range of 0.40 – 0.60 bar. Examination of the vibration behaviour using the portable data collector after this change confirmed velocity and acceleration levels had returned to low, normal levels and no indications of abnormal noise were found at the machine skid.

Overall, this confirmed would indicate the inappropriate filter design was causing an excessively high filter DP which resulted in disruption of the flow regime through the LO pumps with high vibration merely a symptom of this behaviour. This conclusion may have been able to be drawn earlier, before the filters were installed within the loop, if the specification of the filter including beta ratio was available for the existing and the replacement filter.

NOMENCLATURE

°	= Degrees (angle of, in refence to phase).
°C	= Degrees Celsius
A	= Axial (in context of PNDE A, Pump Non-Drive End Axial measurement location)
Barg	= bar (gauge)
DE	= Drive End
DSPI	= Dynamic Signal Processing Instrument
H	= Horizontal (in context of PNDE H, Pump Non-Drive End measurement location)
LO	= Lubrication Oil
MDS	= Machinery Diagnostic Services (a division of Bently Nevada)
MMS	= Machinery Management System
MPS	= Machinery Protection System
µm	= microns
mm	= millimeters
MSCM	= Million Standard Cubic Meters
M	= Motor (in context of MNDE A, Motor Non-Drive End Axial measurement location)
NDE	= Non-Drive End
OEM	= Original Equipment Manufacturer
psi	= pounds per square inch
P	= Pump (in context of PNDE A, Pump Non-Drive End Axial measurement location)
rpm	= revolutions per minute
TEC	= Turbo Expander Compressor
Therm	= Standard Thermal Unit
V	= Vertical (in context of PNDE V, Pump Non-Drive End Vertical measurement location)

REFERENCES

[1] ALLWEILER GmbH, Sectional Drawing Pumpe SNE/SNEF..ER..U.. , ALLWEILER GmbH , Radolfzell, 2016.

ACKNOWLEDGEMENTS

The Machinery Diagnostics Services (MDS) team would like the end-user and the local Mechanical team for their efforts and support of this scope of work. The authors would also like to acknowledge the contributions of EUR ING Nicolas Peton PhD, Global Director of Machinery Diagnostic Services, and Gary Wright MDS Technical Leader, both of Bently Nevada for their support and guidance with execution of this scope.