Case History

SETPOINT Boost Mode

Overview

A pilot implementation of SETPOINT CMS data acquisition hardware and software has been in place at a major North American refinery since March 2015 and operating continuously to date. The system is being used to collect and archive data from two machine trains:

- Turbine-driven centrifugal compressor (direct coupled)
- Motor-driven pump (through speed increasing gear)

These trains were specifically identified by the customer as good pilot system candidates for two reasons:

1) The compressor train exhibits unknown interrelationships between daily process changes and machinery vibrations. The ability to collect comprehensive vibration data in the PI System would allow it to be correlated with process data, also in the PI System via the plant's DCS.
2) The pump train is typical of several similar pumps with the potential for rubs and consequent seal leaks. The machines start very rapidly (5 seconds or less) due to electric motors as the prime movers. The customer wanted to assess SETPOINT's transient data collection performance on machines such as these that start very quickly.

The pump train exhibits extremely fast startups, normally lasting 5 seconds or less. Rubs can be identified by collecting transient (startup) data and examining suitable waveform and spectral plots. However, the ability to acquire data with adequate resolution from such a short-duration startup is a known deficiency in all online systems, including Bently Nevada System 1. Consequently, users routinely use offline instrumentation, such as a Bently Nevada ADRE® system, to acquire startup data on such machines.

Knowing this, the customer established a formidable stretch goal for SETPOINT engineers. Namely, could we deliver the performance of an offline system – like ADRE – in our online system? Within a week, the customer had their answer: yes. Within a month, the new functionality was prototyped and tested. Within 2 months, it was delivered. This new functionality will be released as a standard capability for all customers, beginning with rack firmware versions 3.8 and later. The feature is known as "Boost Mode" and is described on pages 2-4. Pre-release firmware and software were supplied in the pilot system described here to enable Boost Mode capabilities and perform testing; the results of this testing are detailed on pages 4-7.

System Description

The subject machines used for the pilot have Bently Nevada 3500 Series machinery protection systems (Figure 1).

Figure 1 – Workstation half-height cabinet containing SETPOINT pilot system (right) and Bently Nevada 3500 series racks (left). 3500 rack #4 (bottom-most) is for the compressor train; rack #3 (second from bottom) is for the pump train.

The customer does not currently have online condition monitoring software on any of their critical machine trains. There are 41 API 670 machinery protection systems in place at the customer site, the majority of which are Bently Nevada 3500. However, several are SKF-DYMAC M800A, and one is an Emerson CSI6500. All provide analog buffered outputs and could thus have been used for the pilot system.

As shown in Figure 1, the SETPOINT pilot system is physically situated within 5 feet of the Bently Nevada 3500 racks. The half-height cabinet contains a SETPOINT rack, a touchscreen monitor, a pullout tray with keyboard and mouse, and a workstation-grade laptop running PI Server software along with the SETPOINT display client. Connections between the SETPOINT system and the subject 3500 racks are via front-panel BNC connectors as can be seen in Figure 1, allowing the SETPOINT system access to the raw (buffered) transducer signals. Permanent installations, unlike this temporary pilot, would instead use buffered output connections on the back of the 3500 racks.

In this particular instance, the SETPOINT system is being used as data acquisition hardware, similar to a Bently Nevada communications processor, and can be thought of as a gateway device for introducing comprehensive vibration data into the customer's PI ecosystem. However, it is important to note that SETPOINT is a fully API 670 compliant system in its own right, containing protective relays and all other 670 features. In this sense, it can be easily used to replace the underlying protection system(s). The particular racks shown in Figure 1 were installed in Dec 2000, and are nearing 15 years of age. An advantage of SETPOINT when used as a "PI Gateway" is that it can also serve as a hot standby for the underlying machinery protection system.

SETPOINT CMS software does not require a dedicated vibration data infrastructure and instead uses the OSIsoft PI System already in use at the customer's site and throughout their organization. The customer has a global enterprise agreement with OSIsoft such that all necessary PI software (tags, servers, clients, interfaces, etc.) is available to any facility without additional costs. The savings to the customer by using the PI Systems it already owns versus stand-alone software can be significant and one of the purposes of this pilot is for the customer to assess the efficacy of a PI-based system relative to a stand-alone system.

Test Scheduling

Although Boost Mode capabilities were available at the time the pilot system was deployed in March 2015, the candidate machine requiring this functionality was not available at time of initial installation – the machine was being rebuilt following a motor failure. The train was returned to service on Tuesday, 22 June 2015. SETPOINT engineers were on site to witness the startup and examine the data collected by our system. Data from the same transducer suite was simultaneously collected by customer personnel using a Bently Nevada ADRE 408 system, allowing a benchmark for the SETPOINT system.

Boost Mode Description

The extremely short duration of electric motor startups presents unique challenges for any online vibration monitoring system.

Practical considerations preclude online systems from saving everything as the volume of data would be unwieldy. For example, this pump train has 14 proximity probes. If the SETPOINT system were to continuously save every waveform and static data parameter measured, these 14 probes would collectively consume 300 GB of disk storage every week. Currently, there are 41 major machine trains being monitored by API 670 systems at the customer's facility. If one assumes a conservative 12 sensors per machine train, this equates to more than 1 PB (10^{15} bytes) of disk storage requirements every two years.

To circumvent the problems associated with storing and navigating through such volumes of data, most online systems have three primary operating modes: delta time, delta RPM, and alarm buffering. Delta time stores data based on pre-configured time intervals, generally ranging from several times an hour to several times a day. Delta RPM is intended for machine startups and shutdowns and collects data at preconfigured RPM increments as the machine changes in speed. Alarm buffering stores a higher resolution data set in a rolling buffer – usually with a 10-minute capacity – allowing the 10 minutes of data prior to an alarm event to be captured and analyzed. In this manner, snapshots of data are saved under various operating regimes rather than a continuous record as would be obtained from an analog tape recorder. The goal is to capture data when warranted rather than continuously.

"Boost Mode is a state in which the rack suspends normal data acquisition based on i-factor™ criteria and instead begins saving every waveform from every channel continuously. It is intended for transient events of duration 2 minutes or less, and is ideally suited for electric motor startups which are measured in seconds rather than minutes."

During an electric motor startup, the rotational speed is accelerating so quickly that a mere 4-5 shaft revolutions can take the machine from a dead stop to more than 1000 rpm, particularly when the driven machine is coupled to the motor through a speed-increasing gearbox (as is this pump train). Although users can configure other online systems for delta rpm data collection, the machine speed can be accelerating so fast that each turn of the shaft can exceed the delta rpm threshold and by the time 8 or 16 shaft revolutions have elapsed, the system is struggling to keep up. For a startup duration of 3 seconds, users can generally expect 2-3 waveforms* rather than waveforms at (for example) evenly spaced 100 rpm increments. Further, the first synchronous waveform will often not be collected until the motor is at least halfway to its rated speed due to issues associated with triggering on a shaft that may be accelerating at 200-300 rpm per revolution. For this reason, asynchronously sampled data that does not rely on a speed trigger can be important coupled with change detection (such as in SETPOINT) to begin saving waveforms from the very first shaft rotation. As will be seen shortly, the data collected from this pump train (which runs at approximately 6670 rpm) showed that within 1 second, the machine had increased in speed from a dead stop to 2850 rpm, or to 42% of rated running speed within the first second. When waveforms on competing systems cannot be collected more than once per second – even when in delta RPM mode – substantial critical data will be missed. In this case, it would amount to missing the vibration information spanning the first 42% of the machine's rated speed. As was noted previously, the industry has been conditioned to accept this state of affairs as unavoidable for online systems and they routinely use an offline system instead, such as a Bently Nevada ADRE.

SETPOINT engineers considered the unique characteristics of short-duration startups and reasoned that there was adequate memory in the SETPOINT hardware to simply treat the entire transient event as one long waveform. Thus, the system could save the waveforms from each and every shaft revolution rather than trying to capture

* **NOTE**: Bently Nevada communications processors such as TDXnet and TDI are typically only able to store 10 vectors per second and 1 waveform every 10th vector under their fastest possible data acquisition regimes. This equates to approximately 1 waveform per second. Allowing for latency to sense a valid trigger (Keyphasor®) signal from a dead stop, a 5-second motor startup could be expected to return 3-4 waveforms and 30-40 vectors.

snapshots at discrete RPM intervals. Currently SETPOINT hardware has sufficient solid state memory for each channel to store more than 900 waveforms of 2048 samples each, which is adequate to continuously collect more than 2 minutes of data, let alone a 3-second startup.

Boost Mode is thus a state in which the rack suspends normal data acquisition based on i-factor™ criteria and instead begins saving every waveform from every channel continuously. It is intended for transient events of duration less than 2 minutes, and is ideally suited for electric motor startups which are measured in seconds rather than minutes.

Boost Mode is currently invoked whenever the machine's phase trigger is between configurable RPM thresholds. For example, on an 1800 rpm machine, these would typically be set at 50 rpm and 1790 rpm. This would ensure the unit was collecting boost mode data only when the machine was ramping, not when stopped or upon reaching synchronous operating speed.

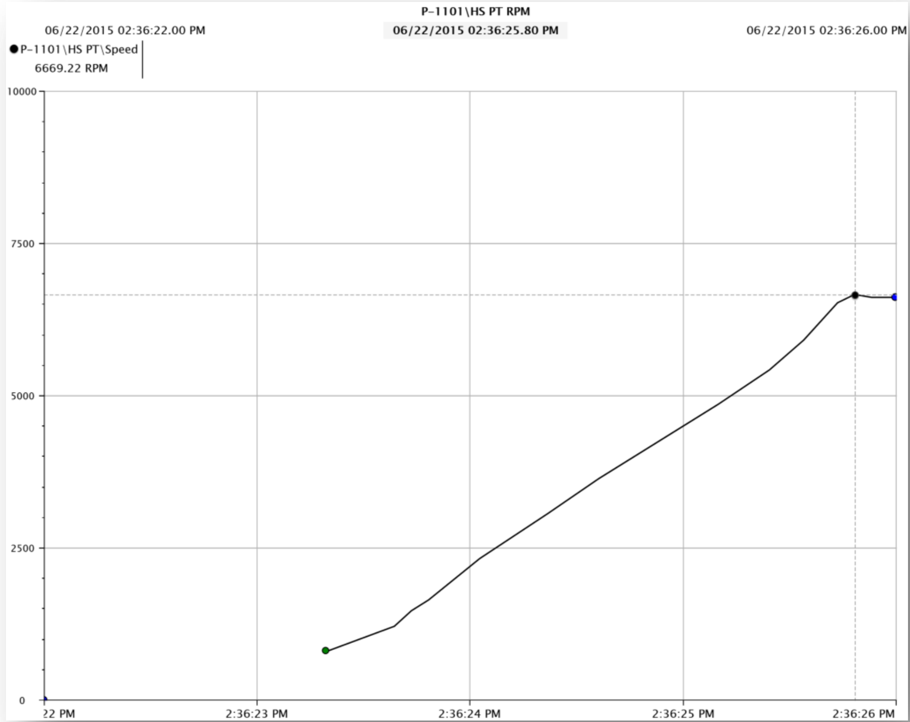

Figure 2 – Trend of rpm from phase trigger probe on high-speed rotor (pump speed). Green dot indicates first valid speed reading (808 rpm). Cursor position (black dot) shows inflection point where synchronous speed is achieved (6669 rpm) at 2:36:25.80. Total startup duration is approximately 3 seconds (dead stop to rated speed) and can be ascertained by consulting timebase plot of Figure 3 showing every phase trigger pulse spanning the entire startup.

Test Results

The machine was started at approximately 2:36:23 PM PDT. The RPM profile (trend) from the phase trigger on the high-speed shaft is shown in Figure 2 along with the timebase in Figure 3. Using the cursor on each of these plots, salient information on shaft rotative speed and the rate at which it was changing was obtained. This has been summarized in Table 1 for the first 20 shaft rotations.

Consulting the data in Table 1, several noteworthy observations can be made. First, by the time the initial phase trigger pulse occurs, the rotor is already at 296 rpm. By the second phase trigger pulse, the rotor is turning in excess of 500 rpm and is accelerating at a rate of nearly 1900 rpm/sec. Once the third pulse occurs (third shaft revolution), the speed exceeds 700 rpm and is accelerating at nearly 2300 rpm/sec. At this point, the system can begin collecting speed-dependent data such as synchronous waveforms and 1X, 2X, nX vector values (3 successive phase trigger pulses within OK range are required to initiate speed-dependent data acquisition). However, the system did *not* wait for the third phase trigger pulse to being collecting asynchronous waveforms. These began the instant the machine started and a bump in the vibration amplitude occurred – a feature of the SETPOINT system's i-value™ algorithm. Because the system collects both synchronous and asynchronous waveforms, plots such as Figure 3 are possible showing the entire startup from 0 rpm to rated speed (6669 rpm). Without this capability, no waveforms would have been captured until a valid speed reading had been obtained (i.e., after the third phase trigger pulse).

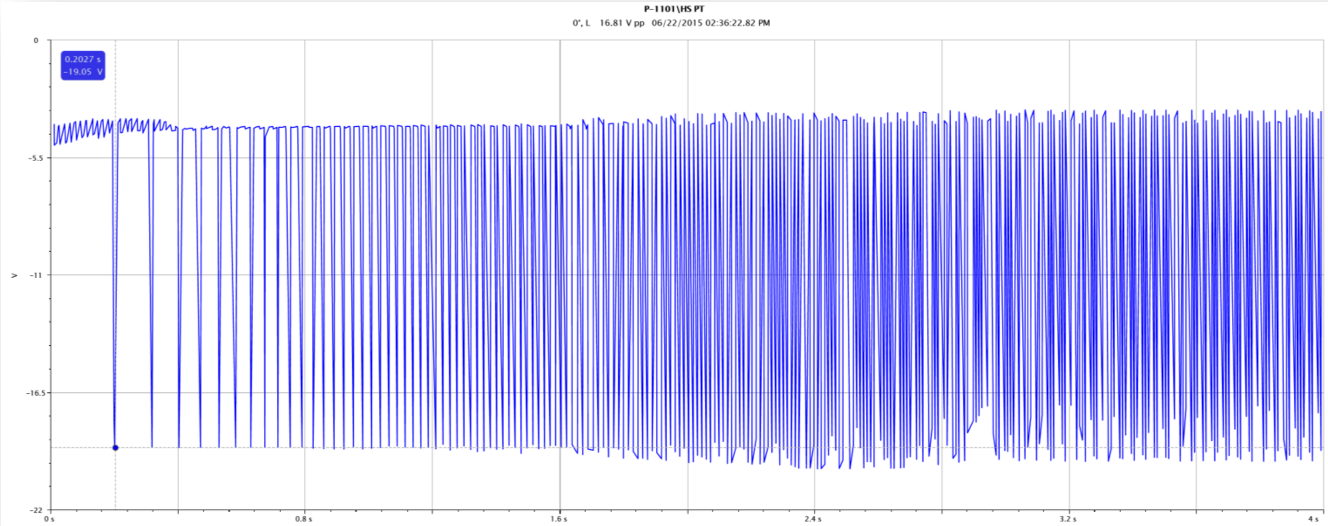

Figure 3 – Timebase plot for phase trigger on high-speed shaft (pump speed). Horizontal axis spans 4 seconds, encompassing entire startup and showing data collected as a contiguous asynchronous waveform. Cursor position shows first phase trigger pulse (0.2027 seconds). SETPOINT requires 3 valid phase trigger pulses to begin collecting speed-dependent data such as synchronous waveforms and filtered vector data (1X, 2X, etc.). This occurred after trigger pulse #3, corresponding to a shaft rotative speed of 808 rpm.

Table 1 – Phase Trigger Data for Shaft Rotations 0-20

Time (sec)	Trigger Pulse #	Period (sec)	Speed (rpm)	Acceleration (rpm/sec)
0.0000	0	N/A	0.00	N/A
0.2027	1	0.2027	296.00	1460.31
0.3191	2	0.1164	515.46	1885.39
0.4037	3	0.0846	709.22	2290.26
0.4715	4	0.0678	884.96	2591.97
0.5297	5	0.0582	1030.93	2508.11
0.5820	6	0.0523	1147.23	2223.70
0.6297	7	0.0477	1257.86	2319.37
0.6736	8	0.0439	1366.74	2480.20
0.7148	9	0.0412	1456.31	2173.98
0.7535	10	0.0387	1550.39	2430.93
0.7904	11	0.0369	1626.02	2049.56
0.8254	12	0.0350	1714.29	2521.98
0.8590	13	0.0336	1785.71	2125.85
0.8912	14	0.0322	1863.35	2411.17
0.9223	15	0.0311	1929.26	2119.18
0.9522	16	0.0299	2006.69	2589.58
0.9813	17	0.0291	2061.86	1895.76
1.0094	18	0.0281	2135.23	2611.23
1.0367	19	0.0273	2197.80	2291.97
1.0637	20	0.0270	2222.22	904.45

Using a technique known as spectral overlapping (see next section), extremely rich waterfall plots are available because an unbroken time series of data (rather than non-contiguous snapshots) is available for the duration of the startup. Figures 6-8 show the full spectrum waterfalls for the three bearings on the high-speed rotor. Notice that approximately 100 spectra can be generated in this manner, providing a high-definition, 3-dimensional contour of the startup for enhanced ability to detect and isolate anomalies. Although not shown here, these plots can be rotated along any of the 3 axes, allowing subtle features within the dataset to be revealed.

A total of 11.3 seconds of data was acquired as shown in Figure 4. The first 3 seconds of data comprised acceleration to steady-state speed and the remaining 8.3 seconds were with the train at steady-state speed. Table 2 summarizes the number of waveforms captured from each probe on the high-speed shaft during these 11.3 seconds (data from the low-speed shaft is not shown as the system was not configured to collect this).

Figure 4 – Time slider showing 11.3 seconds over which data was acquired (2:36:22.81 to 2:36:34.14). The faint orange vertical lines under the trends indicate where waveforms were collected. Black line shows rpm profile based on valid speed signal from phase trigger probe. Blue lines show direct vibration values for 6 radial vibration probes on high-speed shaft.

Table 2 – Number of Waveforms Collected from Each Radial Probe on High-Speed Shaft			
Time (sec)	Sync	Async	TOTAL
0 - 3.1 (ramping)	11	8	**19**
3.1 - 11.3 (steady-state)	18	60	**78**
TOTAL	**29**	**68**	**97**

Referring to Table 2, it is important to note that these waveforms were *contiguous*; i.e., when adjoined end-to-end they provide an unbroken time recording (each and every shaft revolution) of the entire startup and subsequent steady-state plateau.

Synchronous waveforms were set for 16 shaft revolutions @ 128 samples per rev. Asynchronous waveforms were set for a sample length of 2048 samples @ 5120 samples per second.

Using the above, it took approximately 176 shaft revolutions (11 sync waveforms @ 16 revs/waveform) for the pump to reach rated operating speed.

The system collects static data (including vectors) once every 80 ms under all operating regimes and is independent of Boost Mode. Vector resolution was set extremely high (0.01X) which requires a minimum of 100 shaft revolutions to resolve. Recall that vector data is only available once a valid speed reading is available; in this case, once the machine reached 808 rpm. For comparison, the ADRE system did not return a valid speed for vector computations until above 1100 rpm.

Spectral Overlapping

Fully capturing a 3-second startup requires a surprisingly small number of waveforms. Consider that a single asynchronous waveform that is 2048 samples in length at 5120 samples per second lasts 0.4 seconds.

3 seconds x 5120 samples/sec ÷ 2048 samples/waveform = 8 waveforms. So how do we get waterfall plots such as those in Figures 6-8 from just 8 underlying waveforms? The answer lies in understanding that these 8 waveforms are contiguous. Because this is a continuous record of samples, we can place a window spanning 2048 samples anywhere within this dataset to compute a spectrum. The concept is illustrated in Figure 5.

Conclusions

The real-world conditions imposed by the ramp profile of the pump were even more aggressive than the test conditions in our SETPOINT R&D lab, where the fastest we were able to accelerate a rotor kit from a dead stop to operating speed (4400 rpm) was approximately 5 seconds.

Boost Mode performed as designed, capturing the 3-second startup of the pump with excellent resolution, reminiscent of analog tape recorded data. The ability of the system to collect synchronous and asynchronous data from all probes simultaneously resulted in an extremely rich dataset, on par with the Bently Nevada ADRE system.

The ability to examine timebase data spanning the entire duration of the startup and from all probes (including phase triggers) allowed additional insights into the data typically not available from online systems. In particular, examination of the asynchronous timebase from the high-speed phase trigger gave a pulse train from which an extremely accurate rpm profile could be determined, including rotative speed and rotative acceleration.

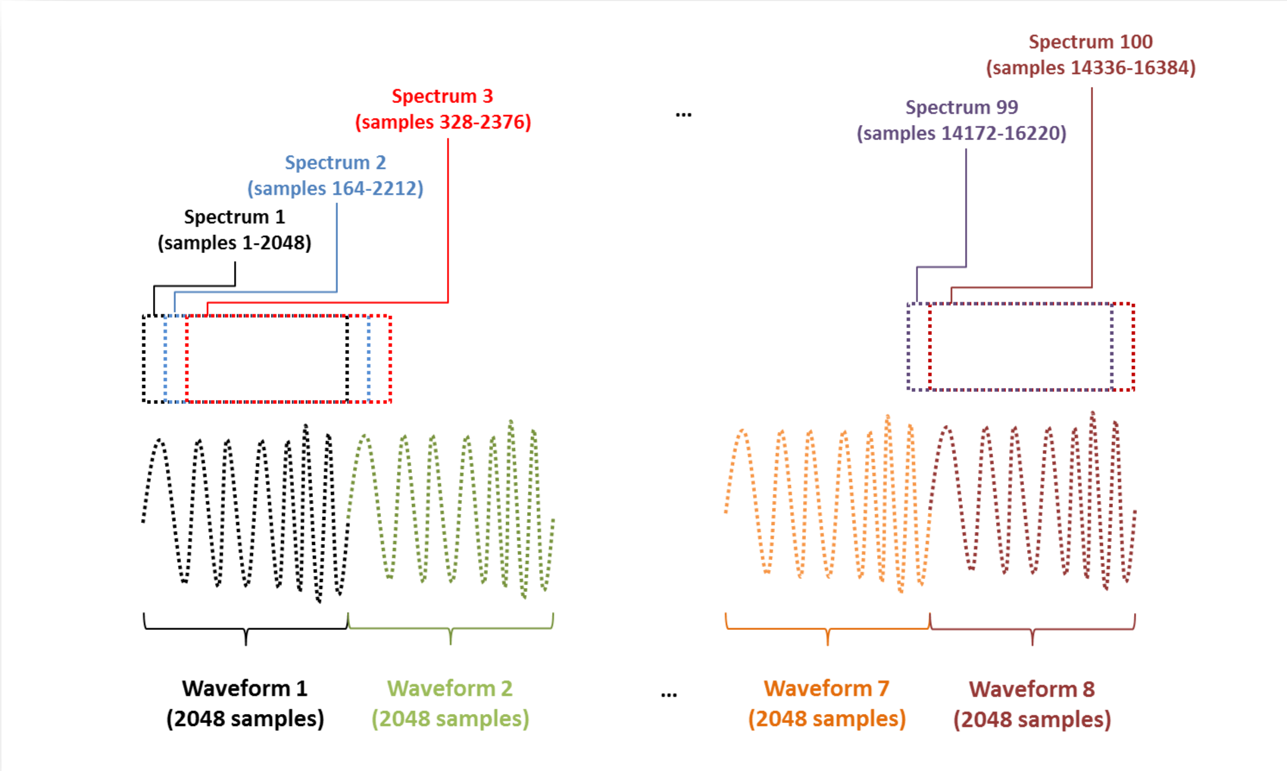

Figure 5 – Spectral Overlapping. By offsetting and incrementing the spectral window (2048 samples in length), more spectra than waveforms can be generated. In this example, 100 spectra have been obtained from 8 waveforms.

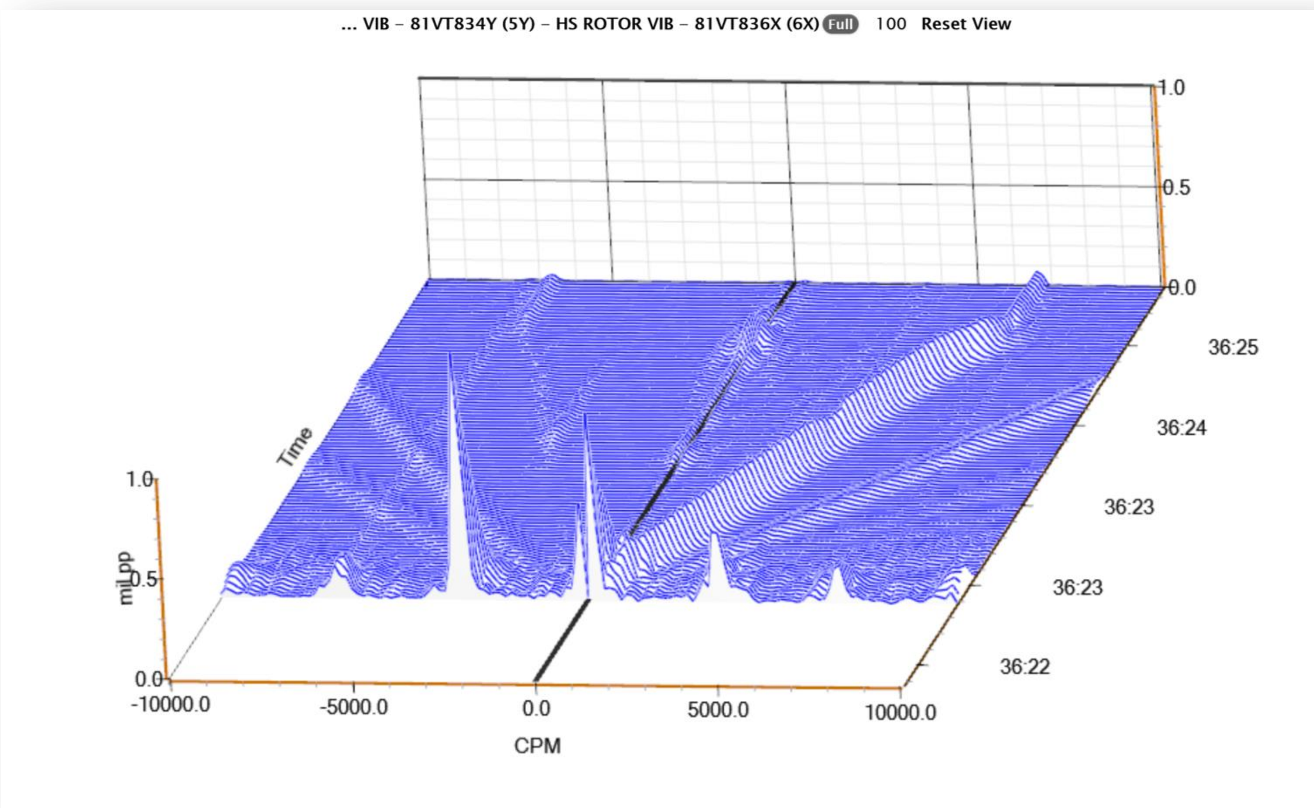

Figure 6 – Full spectrum waterfall for gearbox bearing, high-speed shaft.

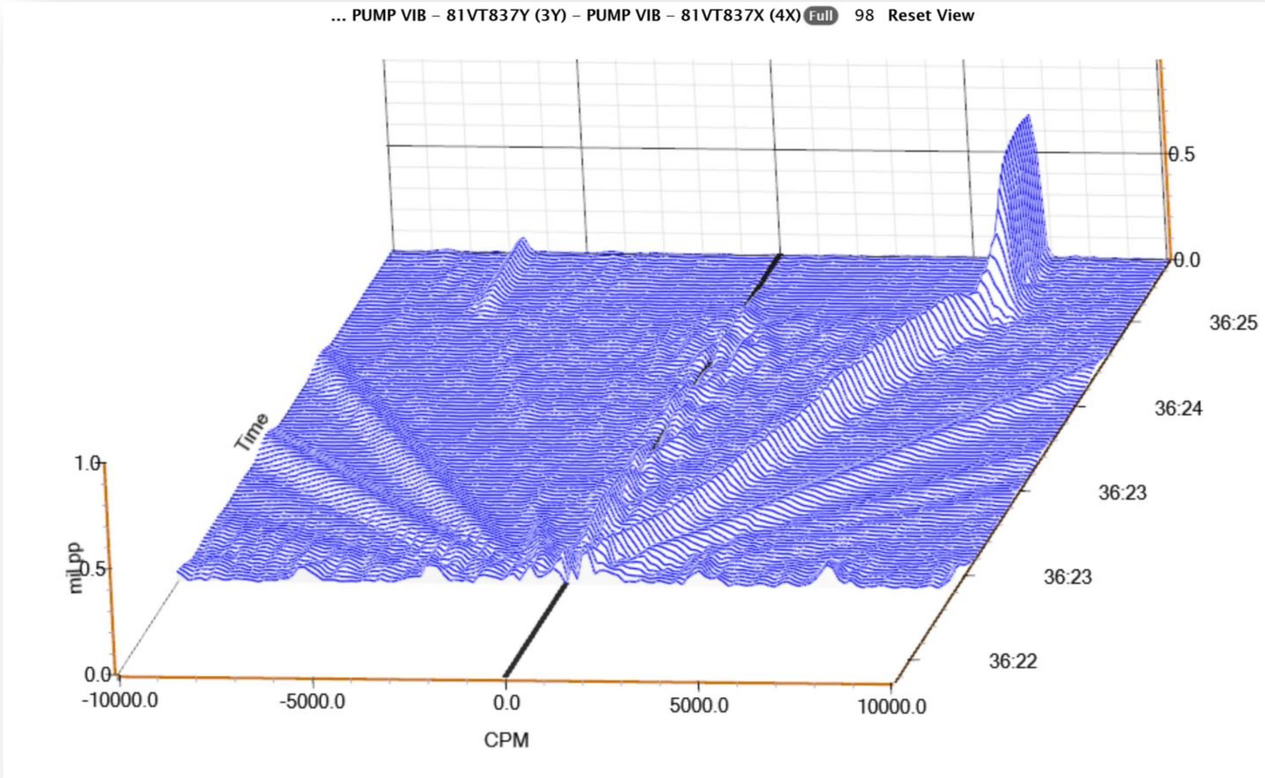

Figure 7 – Full spectrum waterfall for pump inboard bearing.

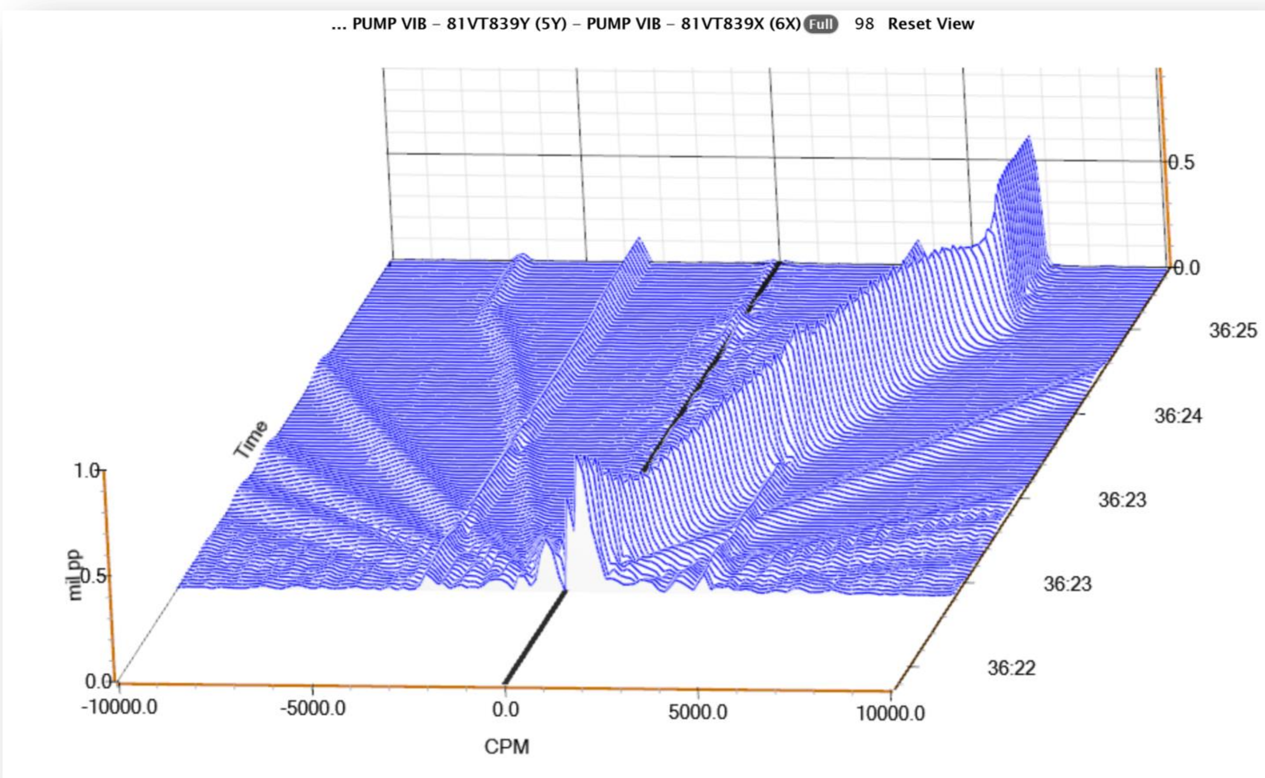

Figure 8 – Full spectrum waterfall for pump outboard bearing.

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