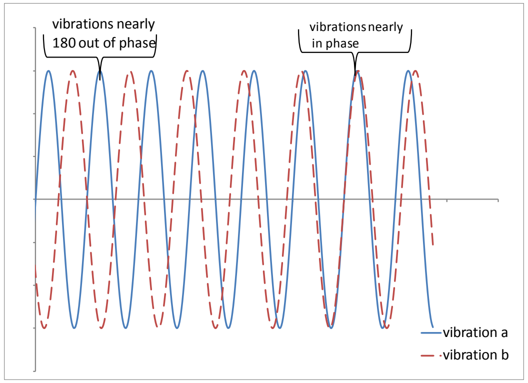
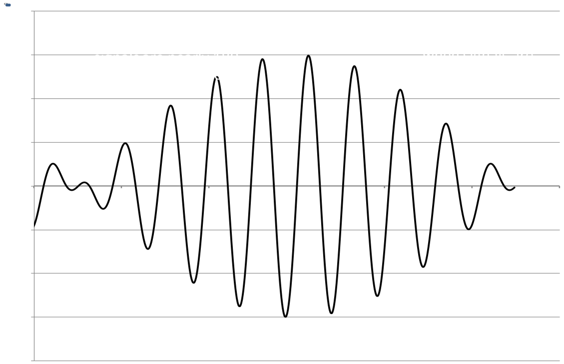
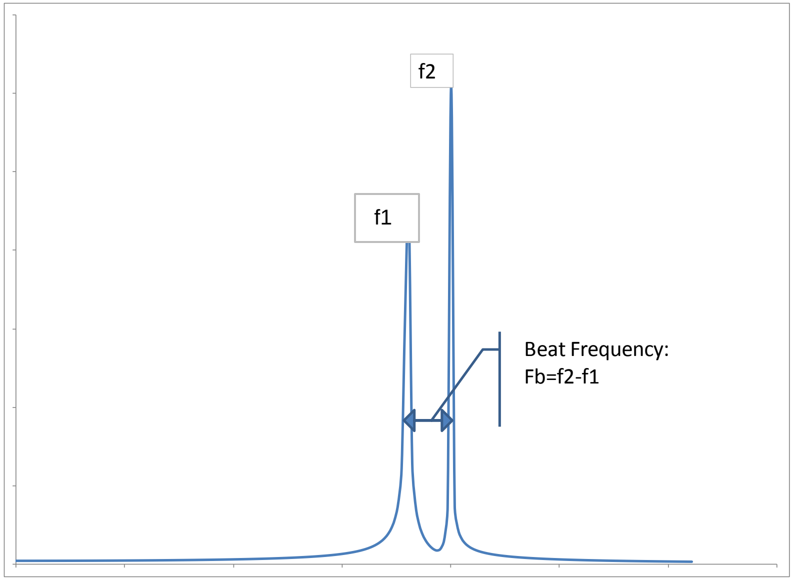
"Beating" Effect Caused by Two Closely Spaced Mechanical Frequencies Observed on Two-Shaft, Gas Turbine Drive







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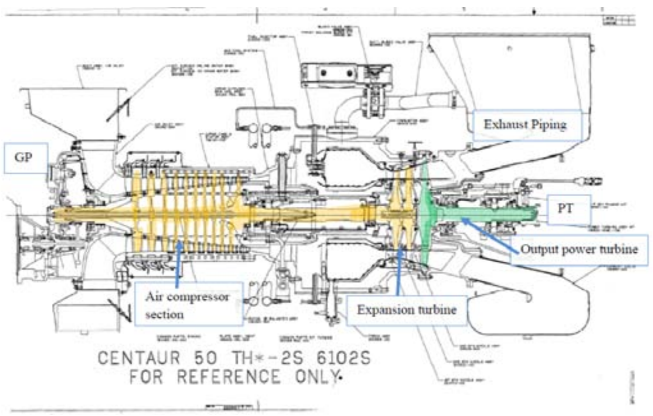
Two Shaft Gas Turbine Configuration

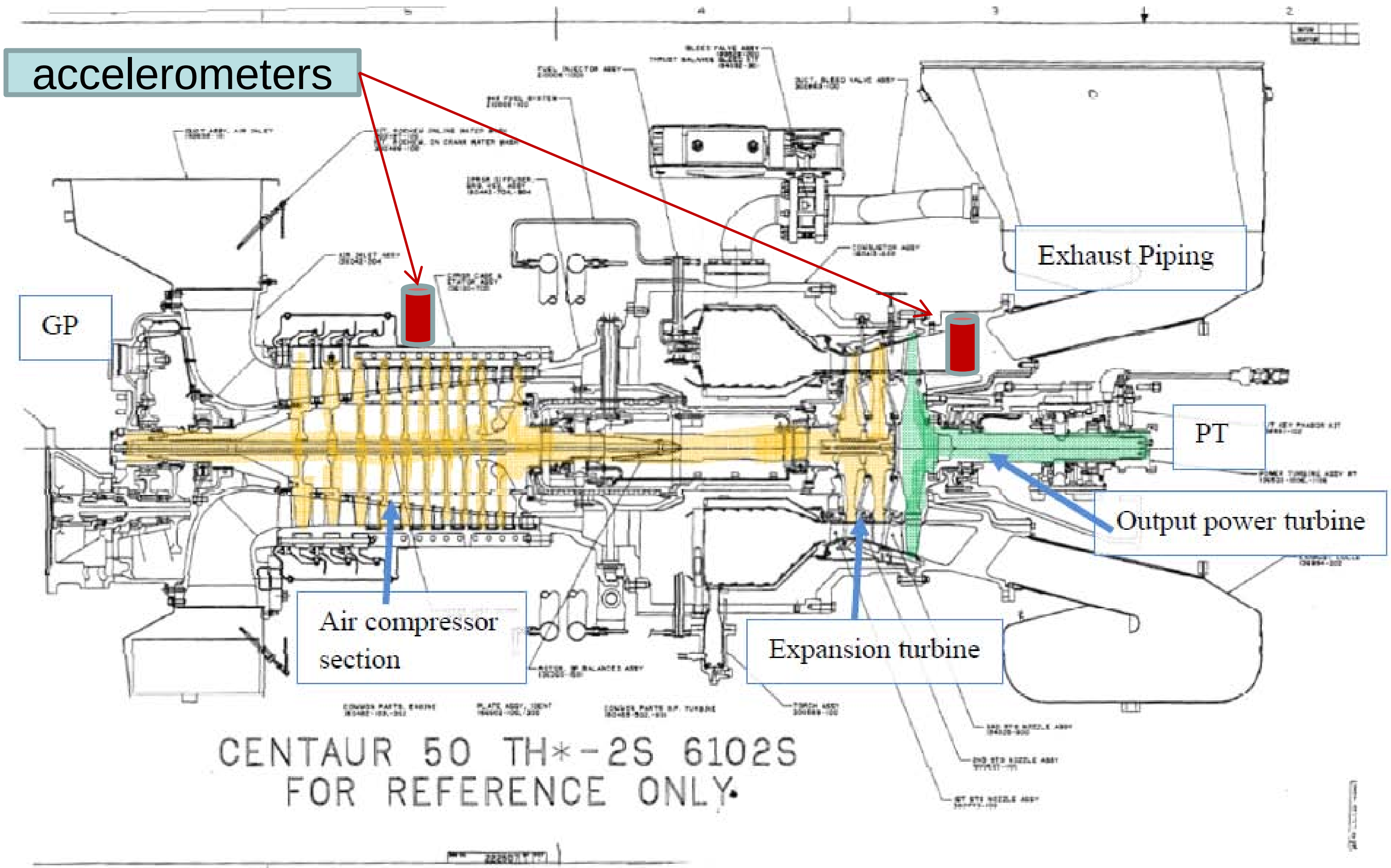
The subject gas turbine drive is a Solar Centaur 47 Gas Turbine located at a gas processing facility in South Texas.

The gas turbine is rated at 4700 HP (63 kW) and constructed in a two-shaft design

- The forward rotor of the gas turbine is called the gas producer (GP), which has a rated speed of 15,000 rpm (250 Hz), consists of the air compressor, combustion section, and two expansion stages.
- The combustion gases produced by the GP are directed to the aft end of the gas turbine, called the power turbine (PT),
- PT has a rated speed of 15,500 rpm (258.33 Hz).
- The PT, which consists of a single expansion stage and an exhaust gas diffuser, directly drives a multistage centrifugal compressor.



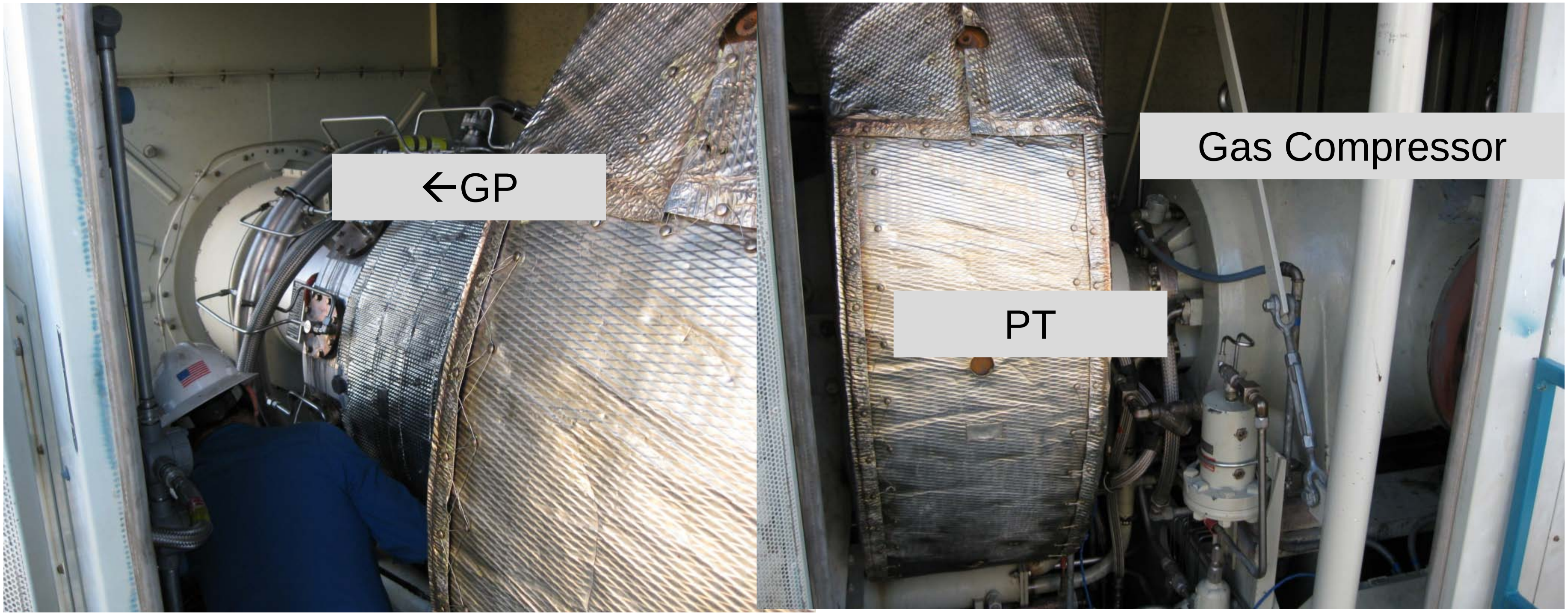
Cross section of a similar two-shaft gas turbine



- Output power turbine (PT) and gas producer (GP) are on separate shafts.
- Share common housing.
- Only two accelerometers used for monitoring.

Photo of Gas Turbine/Compressor Enclosure

Photo of Gas Turbine-Compressor



Background Information

•A rebuilt gas producer (GP) and power turbine (PT) were put into service on June, 2009, along with a controls upgrade and compressor overhaul.

• After installation the gas turbine field representative trim balanced the PT and the system ran with vibration levels ranging from 0.14 to 0.18 ips (0.0055 to 0071 mm/s).

• On December 2, 2009, a routine crank wash on the GP was performed to maintain gas turbine efficiency. Immediately after start-up, PT vibrations rose to 0.28 ips (0.011 mm/s) and stayed there, sometimes reaching 0.32 ips (0.013 mm/s).

•It was soon discovered that vibration levels began swinging from 0.20 to 0.40 ips (0.0079 to 0.0157 mm/s) whenever the PT operated at a speed ranging from 91.0 % to 92.7 % of its maximum speed, but remained steady above or below this speed range .

Vibration Response Analysis

After studying the nature of the oscillations of the overall amplitude in the 91.0% to 92.7% range of PT rated speed, it was agreed by those present that it appeared to be caused by a “beat” phenomenon.

Beating of the overall vibration level becomes noticeable whenever two closely spaced vibration frequencies are present.

The vibration spectrum for the **PT spectrum** had two peaks that were slightly separated. The frequency of the peaks corresponded to the speed of the PT and the GP.

It was noticed that whenever the two 1X vibration peaks **in the PT spectrum** were separated by about 1 Hz or less, the periodic variation on the control room monitor became obvious. This is because the beat frequency period became greater than the one second sampling period of the vibration monitor.

Beating Issues

The observed signal from a beating phenomenon might appear to be a varying signal. This can arise due to the relation between the sampling window and when the signal is observed.

Example: two sine waves, one with a fixed frequency and one with a varying frequencies. Want to look at

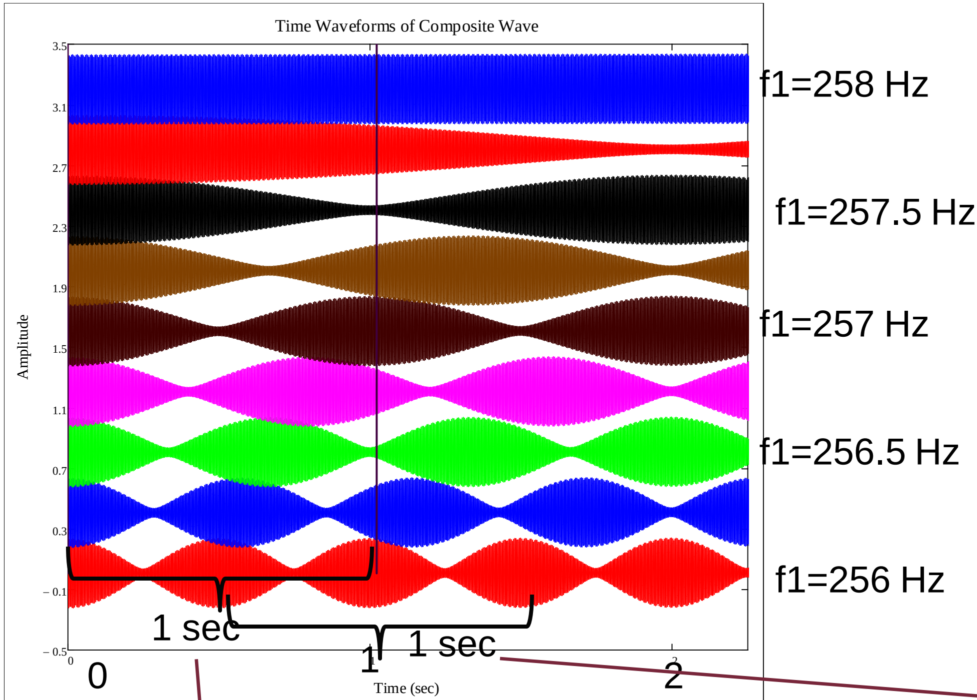
- when the time sample is taken (phase relation to beating amplitude)
- The resulting rms of the time waveform during sample
- The resulting spectrum of the sampled time window

Sample rate: 2kHz, no windowing, 2048 data points

Wave one: initial frequency: 256 Hz, step 0.25 Hz, ampl=0.1

Wave two: fixed frequency: 258 Hz, ampl=0.13

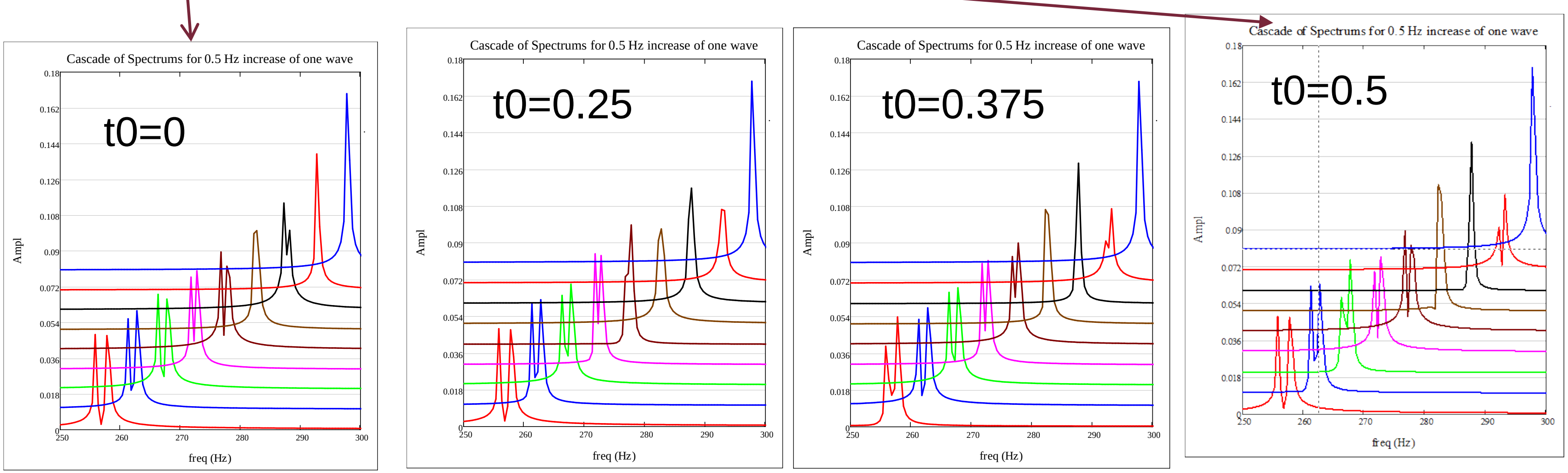
Resulting Graphs: Set 1



The time waveforms on the left are the composite wave as the first waves' frequency changes.

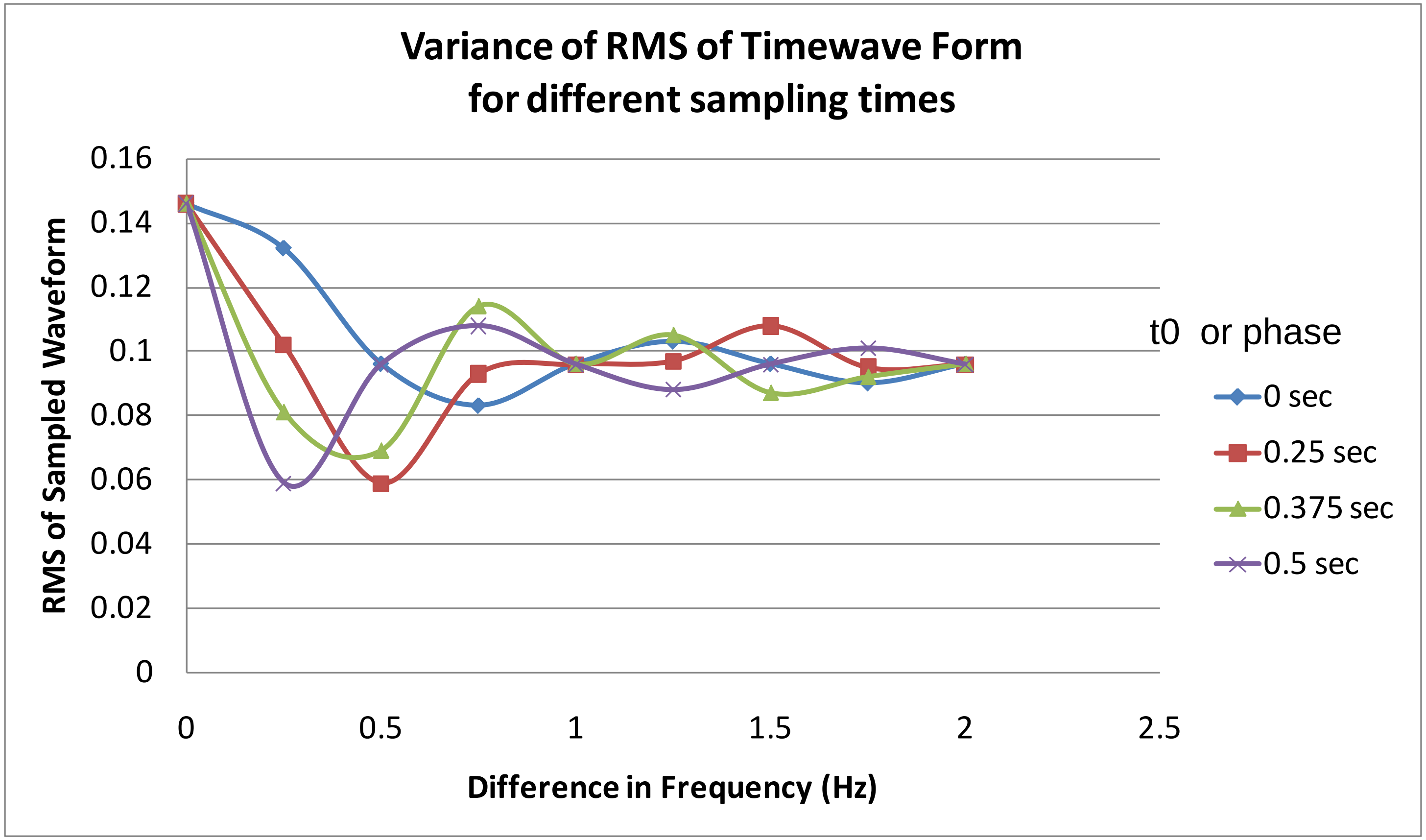
The four figures on the bottom are the spectrums if the start time of the 1 sec. sampling shifts to the right. This is essentially a phase change. No 1X pick up on PT-GP system.

Fixed frequency f2=258 Hz



Resulting RMS Graphs: Set 2

If the rms of a 1 second time waveform sample is examined, and the time as to when the sample is measured is changed, there can arise a wide swing of the rms value when the difference between the two signals is less than 1 Hz.



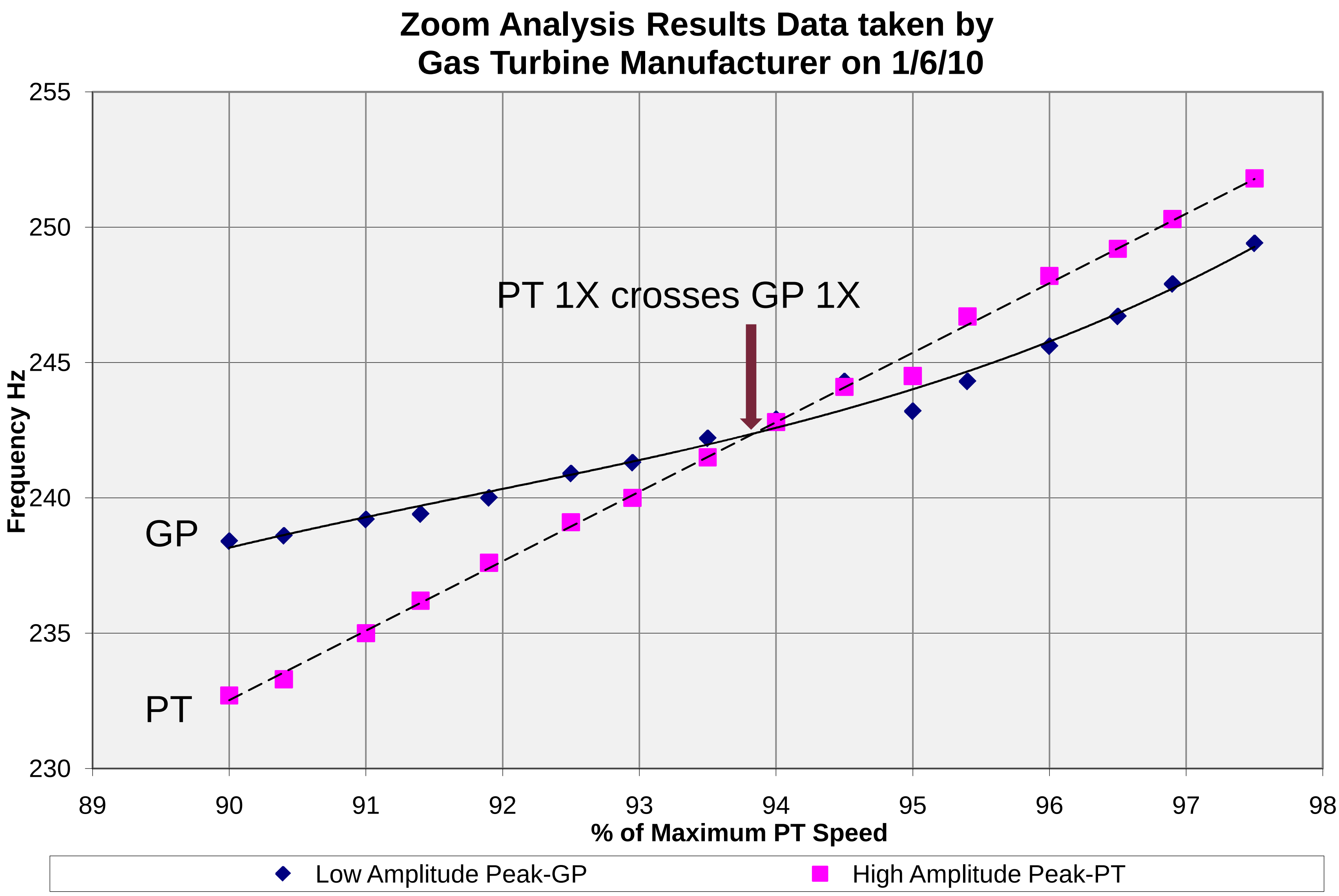
Investigation of System and Analysis

To better understand the phenomenon occurring between the GP and the PT, two curves were generated by varying the PT speed from 90% to 97.5% of the PT rated speed and recording the spectral characteristics of the two predominant peaks in the 230 to 250 Hz range.

These curves were created by collecting and then plotting the amplitudes and frequencies of the larger component and the smaller sideband with the frequency analyzer set at a 230 to 250 Hz frequency span with 1600 lines of resolution.

It was soon discovered that the larger of the two peaks related to the PT 1x frequency and the smaller sideband peak corresponded to the GP 1x frequency.

Zoom Analysis Results from PT Speed Sweep



Frequency Analysis

Normally, the predominant vibration frequency on the GP casing is one times (1x) the GP rotating speed. Similarly, the predominant vibration frequency on the PT bearing housing is typically one times (1x) the PT rotating speed.

We would not expect to see a significant GP vibration peak on the PT bearing housing vibration spectrum due to the fact that two shafts are independently supported.

However, at that time of our initial analysis, we found the larger of the two vibration peaks corresponding with the power turbine (PT) operating speed and a smaller but significant peak corresponding to the gas producer (GP) running speed on the PT bearing housing spectrum (see Table I below).

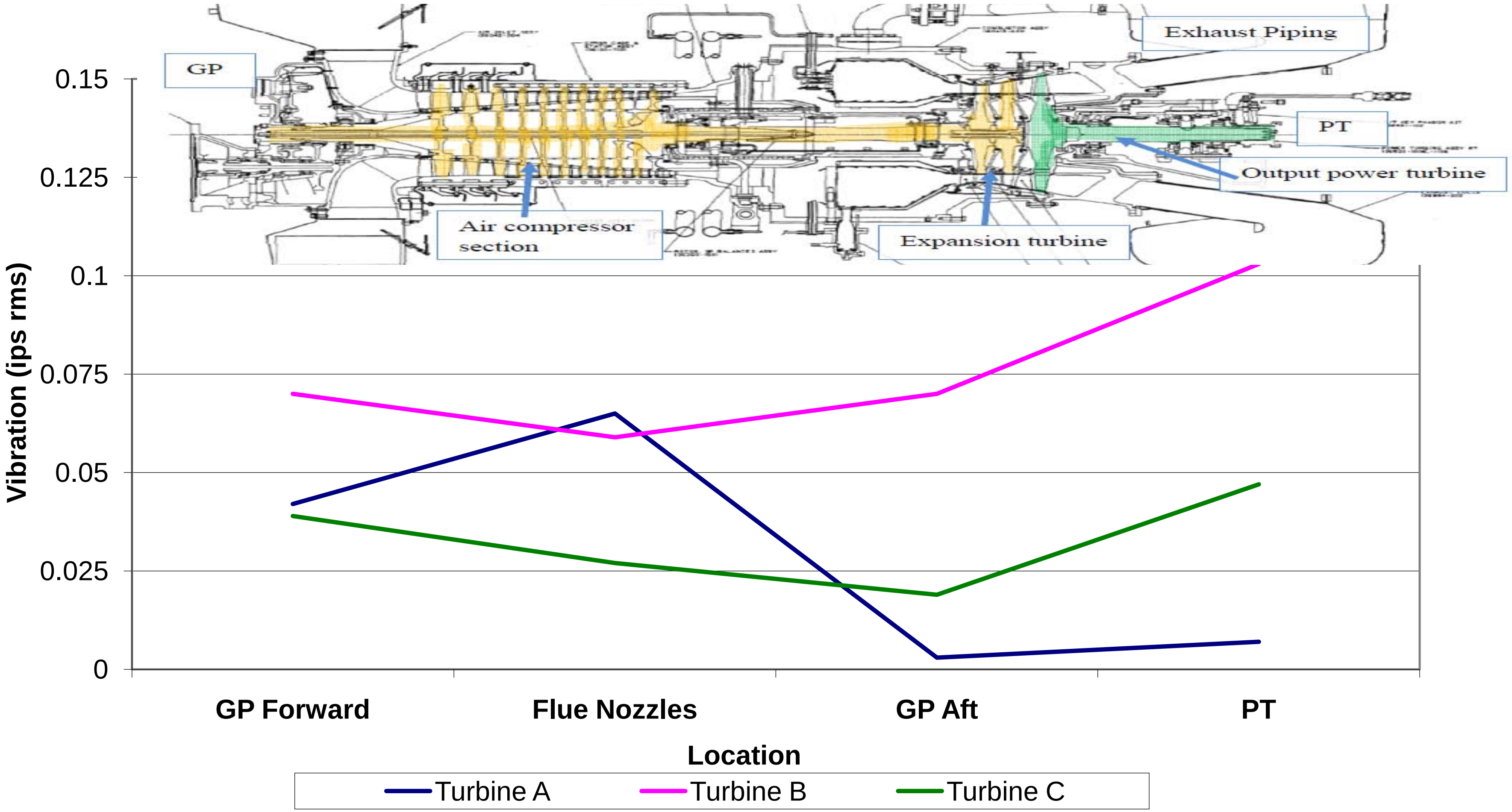
It is believed the appearance of the predominant GP peak is an indication that there had been a change in the mechanical condition of the GP's back end around the time of the December 2009 crank wash. In addition, there was unusually cool weather which can impact the performance of the GP and PT .

Vibration Response Across Similar Turbine Setups

Three (3) similar gas turbines at the site were running at the time of this comparative analysis. Here is a plot showing GP vibration at various locations along the three engines analyzed. Note: Turbine B below is the engine described in the case study. Notice that for some unknown reason it transmits the highest level of GP vibration to the power turbine end.

Gas Producer Vertical Vibration Levels at Different Train Locations

Turbine B is the gas turbine in the case study



Solution

The manufacturer's field representatives recommended that we trim balance the power turbine (PT) in order to reduce the overall PT vibration level to acceptable levels. After several balancing attempts, we arrived at the following vibration level see in the table below.

	PT Peak	GP Peak	Overall	Comment
Before balancing	0.24 to 0.35 ips	0.12 to 0.15 ips	0.20 to 0.40 ips	Varies depending on separation of GP & PT frequencies
After balancing	0.11 ips	0.15 ips	0.234 ips	PT @ 88%
After balancing	0.19 ips	0.12 ips	0.280 ips	PT @ 92%

After trim balancing,

- Vibration levels fell below the manufacturer's limit of 0.40 ips for overall vibration in the PT vertical direction and below the manufacturer's limit of 0.33 ips for 1x vibration in the PT vertical direction.
- For this reason, we recommended that the unit remain in service.
- We continued to closely monitor both the PT and GP vibration amplitudes to ensure they remain steady and below recommended manufacturer's guidelines.

Conclusions and Lessons Learned

- The observed beating effect was caused by closely spaced GP and PT vibration peaks
- This effect will likely only be observed on newly refurbished engines on colder days. It was later revealed that the first time the beating effect was seen was immediately after an engine crank wash.
- New engine, cold weather, and crank washing all led to the coincidence of GP and PT speeds at the time beating phenomenon was first observed
- Transmission of GP 1x vibration amplitudes to the PT varies significantly from one engine to the engine next. A high level of GP x1 vibration at the PT end of this engine contributed to the severity of the beating effect.
- Field trim balancing of the PT can mitigate the effects of this phenomenon by significantly reducing the amplitude of one of the offending frequencies
- Beating effects observed on a PT should be investigate to determine what has changed

Questions?