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Unit #3 Resonance Vibration Evaluation

Introduction

STEP Combustion, performed diagnostic testing and evaluation of Unit #3 vibration on September 27 and 28, 2006. Since the last outage in the fall in 2005, Unit #3 has been subject to severe vibrations associated with fluid dynamic frequencies matching the natural frequency of the boiler (Resonant Frequency). The resonant vibration was reported at loads exceeding approximately 180 MWn when firing oil. Testing and monitoring were performed in order to determine the extent of the problem, the probable and potential source of vibration, and to evaluate potential solutions.

Measurements of the vibration spectrum (Acceleration, and Velocity) were taken using a RION VA-11 vibration analyzer equipped with a magnetic accelerometer. Measurements were taken along various positions on the buck-stays to best determine the period of vibration of the furnace. The recorded vibration spectrums are based on the maximum amplitudes of vibration during a 30 second sample period.

Unit Description

Unit #3 is a CE T-Fired boiler with a maximum rated generating capacity of 220 MWn. The CE T-fire corners (burners) were replaced with twenty-eight (28) Forney wall-firing type burners in the 1970's, which are oriented in 7 elevations of 4 burners. Typical auxiliary and primary air buckets were removed and sealed, such that all combustion air enters through the rectangular burner throat. Unit #3 has the capability of firing both natural gas and #6 fuel oil. Fuel oil burners are steam atomized and utilize the OEM 8 hole atomizer configuration operating with an atomizing steam to fuel differential pressure of approximately 20 psid. Additionally, the burners are equipped with relatively large swirl-type flame stabilizers. Also, the unit typically operates with wind box to furnace differential pressures of approximately 11 to 15 inH2O with reported spikes as high as 20 inH2O.

Testing

On September 27, 2006 boiler operation at high load was observed and vibration measurements taken. A maximum load of 208 MW was achieved without undergoing resonance vibration. Although, resonance was not attained, it is important to note that there was an audible rumble noted through-out the load range. Figure 1 provides a sample vibration spectrum at the high-load non-resonant condition.

Subsequent testing on September 28, 2006, began with a low load evaluation of boiler vibration. Low load testing was performed in an attempt to identify a correlation between burner airflow and boiler vibration. At a load of 110 MWn data were taken with 11 oil and 3 gas burners in service (BIS), and with all burners out of service (BOOS) combustion air dampers closed. At the baseline condition vibration measurements were taken and operating data documented. Subsequently, all BOOS air dampers were opened, thereby reducing combustion airflow into and through the BIS, and the test was repeated. Figure 2 provides a comparison of vibration spectrums for both test conditions. As shown, there was an identifiable reduction in the peak acceleration of vibration, suggesting that the vibration is related to airflow through or into the burners (Total air flow remained constant, therefore upstream and downstream flow characteristics were unchanged).

Load was then increased to approximately 190 MWn when resonance was achieved and severe vibrations were encountered. A vibration spectrum was obtained at the resonance condition and is shown in Figure 3. Several attempts were made at reducing the vibration:

- Burners were changed
- Atomizing Steam to Fuel Differential pressure was decreased
- Combustion Air temperature was reduced (By approx. 30 degF)

None of the implemented changes were shown to significantly impact the vibration characteristics.

Discussion

As mentioned previously, the vibration issue has become problematic since the last outage, where the following were done:

- New air heater baskets were installed
- New handcuffs were installed on the superheater
- Upgrades to the BMS system were implemented
- Fans were cleaned

Of the items listed above, it is believed that of particular importance is the air heater basket replacement. Based pre and post-outage data, the upgraded air heater has resulted in an approximately 100 ^{o}F increase in the combustion air temperature. Based on air density calculations this increase in air temperature would result in a significant increase in combustion air velocity, on the order of >10%. Obviously, this increased velocity is present both within the windbox and through and around the burner.

Test data and observations taken during the September 27 and 28, 2006 testing suggested that:

- Combustion air velocity into and around the burners appears to impact the magnitude of boiler vibration
- Burner changes (To correct potential burner instabilities) had little/no impact on vibration
- Reducing the burner atomizing steam to fuel differential pressure had little/no impact on vibration
- Reducing combustion air temperature by less than 30 ^{o}F (And accordingly, a slight reduction in combustion air velocity) did not have a significant impact on vibration.

Results

In general, furnace rumbling was audible throughout most of the load range. Supporting this observation, it has been reported that Unit #3 has "always been a noisy unit". Accordingly, it is believed that the vibration issue has been present for quite some time, however previous operating conditions did not perfectly align with the resonance frequency and the vibration was never considered an "issue". Furthermore, STEP Combustion feels that the rumbling and now resonance vibrations are related to burner/windbox changes made by Forney, and that the vibration has now been exacerbated by a change in operating conditions (Discussed below). STEP Combustion's evaluation of the Forney burner configuration identified a potential source of vibration. Based on good burner design practice the combustion air velocity through the burner should fall within a particular range for proper burner stability. This parameter can also be examined in terms of burner throat area versus normalized fuel flow (fuel flow x combustion air temperature ratio). The Forney burner design for Unit #3 does not provide sufficient throat area (As shown in Figure 4), and as a result, the combustion air velocity through the burner is excessive (As evidenced by the high windbox to furnace differential pressures). When burner combustion air velocity is excessively high, flame stripping can result; that is, the high velocity of combustion air strips the flame back and forth along the flame front inducing pulsations. When the period of this "flame stripping" matches the period of the boiler, resonant vibrations would result. It is important to note that the increase in combustion air temperature due to the air heater basket replacement would result in even higher combustion air velocities thereby potentially magnifying pulsation or "flame stripping" issues.

Likewise, the vibration issue may be due to air flow through the modified windbox (Forney modification implemented during the burner change). If the airflow distribution within the windbox results in aerodynamic vortex shedding, the alignment of the vortex shedding frequency and the natural frequency of the boiler would also cause the experienced vibration. Vortex shedding may result if large obstructions are present in the path of the combustion airflow or if the airflow is forced to undergo quick changes in directions (e.g. Sharp corners) with insufficient turning vanes.

The identified vibration sources proposed above are also supported by observations made by plant personnel which suggests that reducing the total combustion air flow (I.e. lowering the boiler excess O_2), reduces or minimizes the magnitude of vibration.

Recommendations

Several case studies have been performed where a correlation between the use of 8-hole atomizes and T-fire boiler vibrations have been identified. Accordingly, STEP Combustion recommends the trial of a equal capacity 10-hole atomizer as a cost effective first attempt to rectify the vibration issue. The ten-hole atomizer configuration will provide a different flame frequency and should alter the period of flame stripping, thereby changing the combustion frequency eliminating coincidence with the boilers natural frequency. If the atomizer change is found to have no impact to current vibration characteristics, it may suggest that the vibration is related to windbox/burner aerodynamics and not to flame frequency. To evaluate windbox aerodynamics a computational fluid dynamics model of the windbox would be recommended in order to determine the location of vortex shedding and design the required baffles to eliminate it.

Alternately, an inclusive approach to identifying the source of vibration and evaluating proposed changes would include a complete computational fluid dynamics (CFD) model of the windbox, burner and furnace, including combustion chemistry modeling. STEP combustion has been successful in identifying burner instabilities and/or aerodynamic instabilities in combustion systems using the CFD modeling approach.

Unit #3: Vibration Evaluation

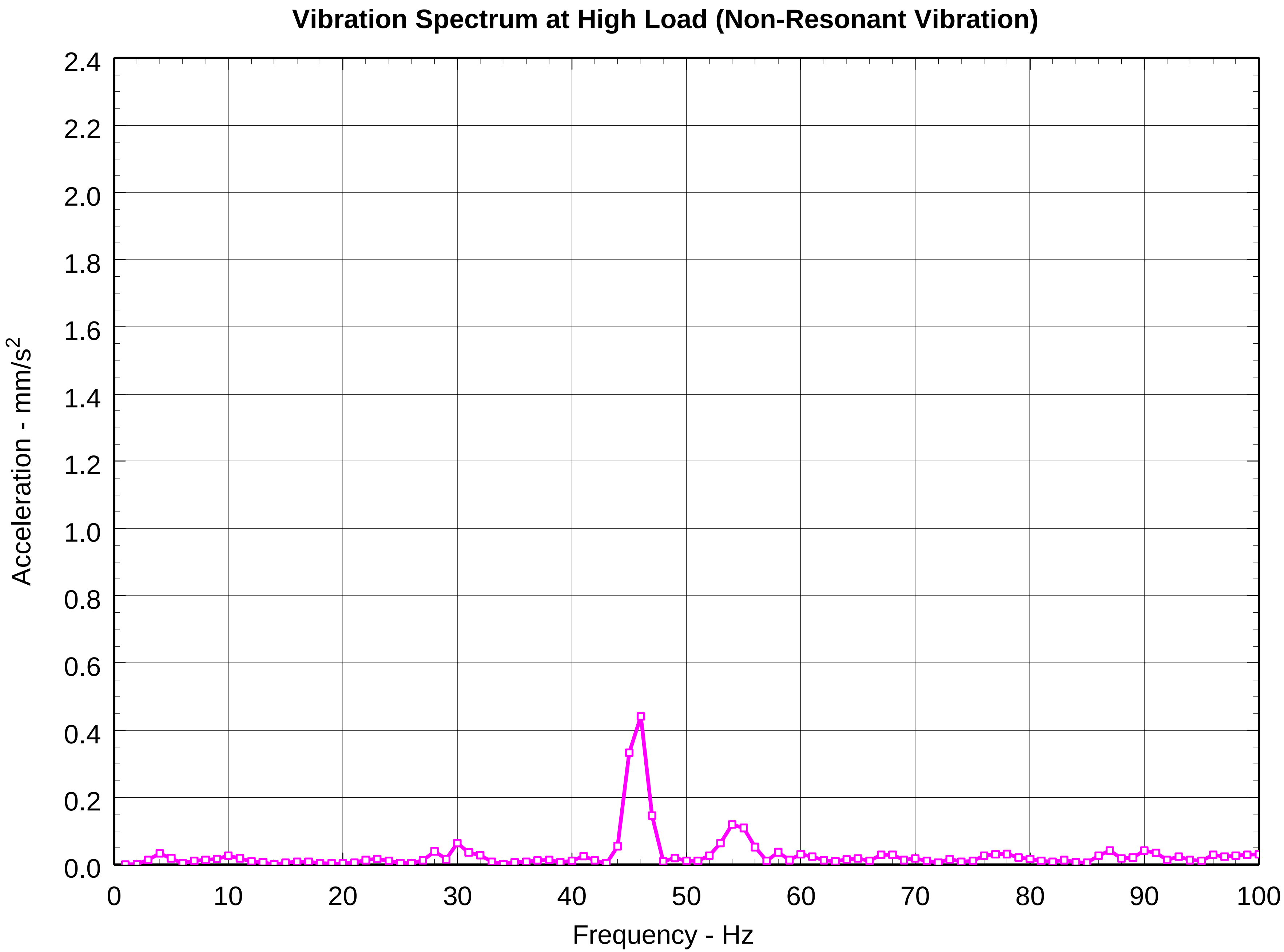

Figure 1 - Vibration Spectrum at High Load (Non-Resonant Vibration)

Unit #3: Vibration Evaluation

Vibration Spectrum at Low Load (Non-Resonant Vibration)

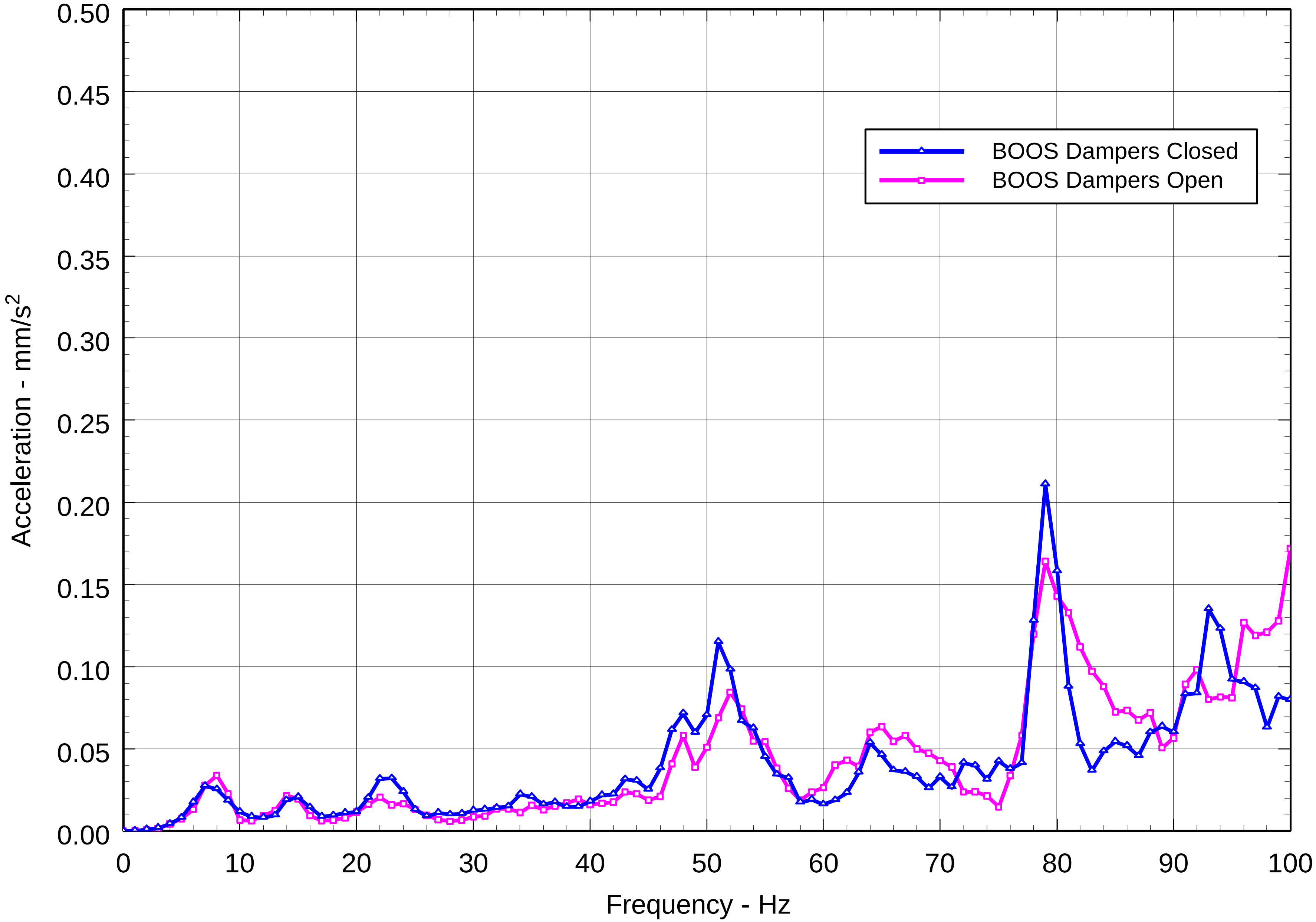

Figure 2 - Vibration Spectrum at Low Load (BOOS Dampers Opened and Closed)

Unit #3: Vibration Evaluation

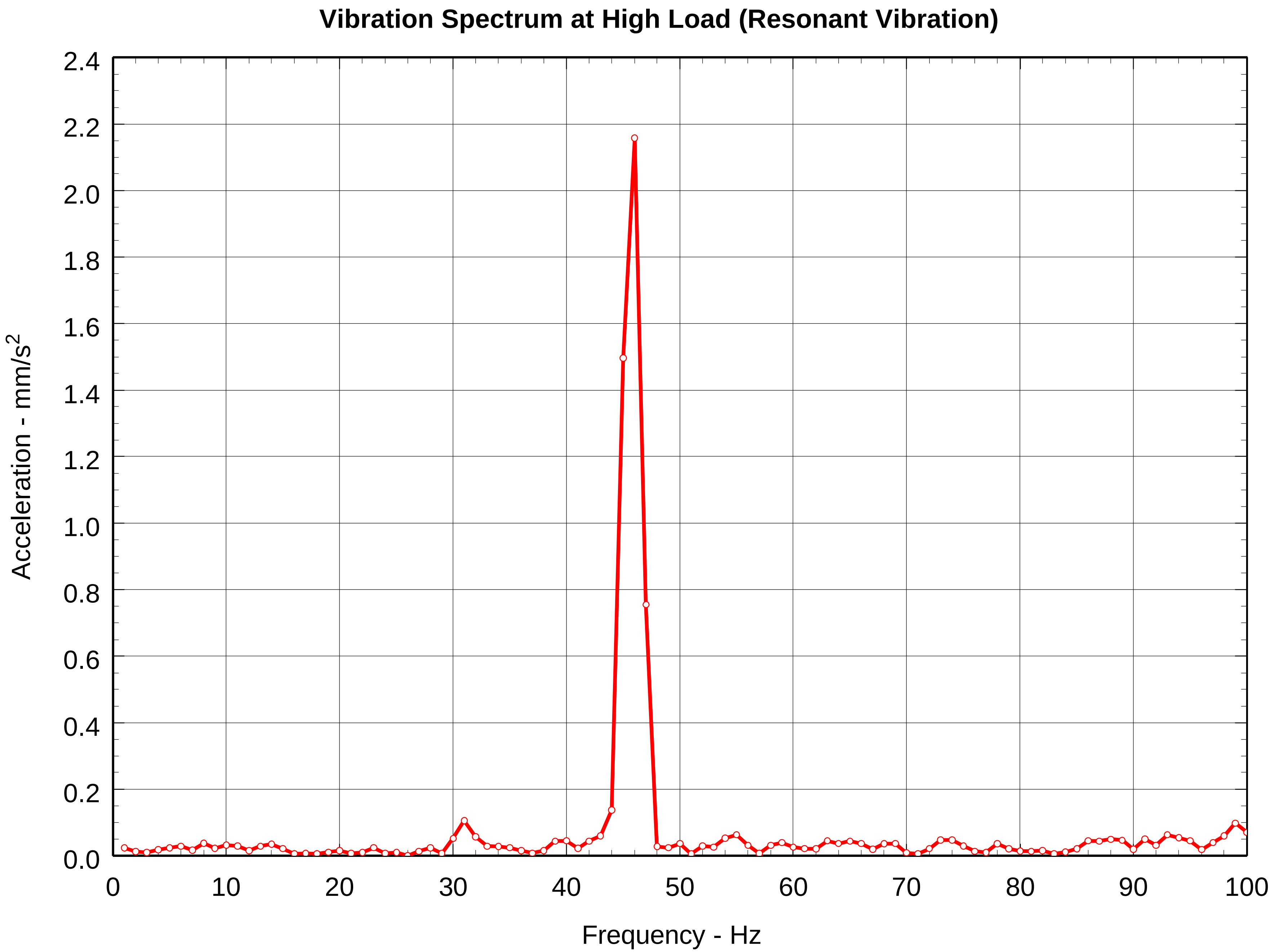

Figure 3 - Vibration Spectrum at High Load (Resonant Vibration)

Progress Energy - Bartow Unit #3: Vibration Evaluation

Burner Throat Area versus Normalized Air Flow (Throat Loading)

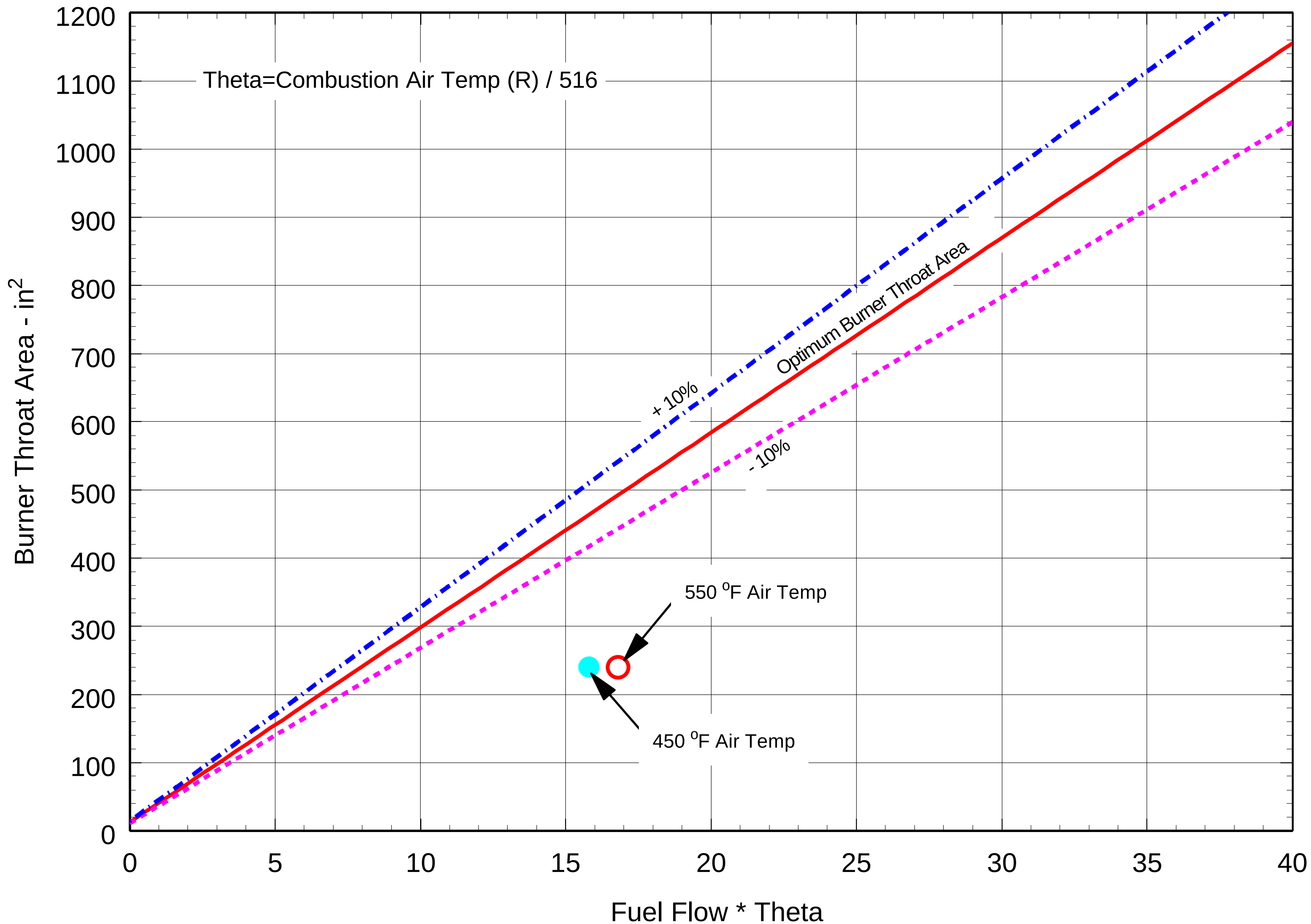

Figure 4 - Optimum Burner Throat Loading with Forney Burner Comparison