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Pressure Fluctuations as a Diagnostic Tool for Fluidized Beds

Technical Progress Report for the Period
January 1, 1996 - March 31, 1996

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Abstract

Additional pressure fluctuation data was recorded from the ISU power plants two CFB boilers. Absolute pressure fluctuations were measured immediately above the distributor nozzles and near the top of the CFB boilers. The fluctuations measured near the bottom of the bed exhibit a highly oscillatory (0.25-0.3 Hz) phenomena. This "square wave" pressure signal is observed at all times of the day and under different boiler loadings. Steps were taken to insure that aliasing was not the cause of the observed pressure dynamics. It is hypothesized that these fluctuations are the result of the coal feed system, and are not related to the CFB hydrodynamics.

Pressure fluctuations measured near the top of the bed do not show this dominant periodic behavior attributed to the coal feed system. The Bode plots of pressure fluctuations in this region show a near -40 dB/decade roll-off, and a cornering frequency of around 0.07 Hz. This result suggests that the pressure dynamics in industrial scale CFBs may be governed by a wave phenomenon similar to that observed in the laboratory scale circulating fluidized beds. This result cannot be confirmed until more is known about the boiler control dynamics, and more extensive boiler instrumentation is available.

Pressure Fluctuations as a Diagnostic Tool for Fluidized Beds

Robert C. Brown and Ethan Brue

Objective

The purpose of this project is to investigate the origin of pressure fluctuations in fluidized bed systems. The study will asses the potential for using pressure fluctuations as an indicator of fluidized bed hydrodynamics in both laboratory scale cold-models and industrial scale boilers.

Progress

ISU Power Plant CFB Boilers

A number of experiments were completed to determine the nature of industrial scale CFB Boiler pressure fluctuations. These tests were developed to determine whether CFB pressure fluctuations can be used as diagnostic indicators in industrial scale CFB boilers, and also whether these signals can be related to similar pressure fluctuations observed in small-scale cold-model CFBs. Two 170,000 lb/hr steam Pyropower CFB boilers are located on the campus of Iowa State University. ISU's CFB Boiler #1 and CFB Boiler #2 both had two transducers installed along the CFB wall to monitor absolute pressure. All four transducers in the two boilers had an output of 1 to 4 volts. The transducers that measure what was referred to as the bed pressure record static pressure fluctuations immediately above the gas distribution plate. These transducers have a range of 0 to 60 inches of H_20. The transducers in the combustion chamber measure the static pressure fluctuations at an elevation of 60 feet above the distributor plate. These transducers have a range of -3 to 17 inches of H_20. The boilers have a square cross-section of 4.3 x 4.3 meters (14'x14'), and a height from distributor to top of CFB riser of around 20 meters (65 feet). Under standard operating conditions, the boiler operates with 137,000 lb/hr fluidizing air and 74,000 lb/hr secondary air. The bed material (ash, limestone, and coal) consists of particles which predominantly range between 100 and 1000 micrometers in diameter. The pressure measured at the bottom of the bed under these conditions approximately ranges from 15-25 inches of H_20, and the bed temperature is maintained between 1400-1600 °F. The fluctuation data was sampled at 20, 50, 90, 200, 400, and 1000 Hz, with data set sizes ranging from 70,000 to 620,000 data points to insure adequate Bode plot resolution. Using a portable computer with a 12 bit A/D (0-5V) board, the output voltage from the boiler transducers was recorded and stored.

Pressure Fluctuations in Industrial Scale CFB Boilers

Discussion of low elevation CFB boiler fluctuations - Although there is some variation in the structure of the lower bed fluctuations, as seen in time domain plots of Figures 1 and 2, they always exhibit a signal similar to a 0.25 - 0.3 Hz square wave. It is evident that the lower bed signal has a dominant period, on the order of a cycle every 3 to 4 seconds. This dominant frequency at 0.25 - 0.3 Hz is very pronounced in the power spectral density of these signals shown in Figures 3 and 4. Examining the Bode plot of the bed pressure fluctuations in Figure 3b, the low frequency region of the Bode plot seemingly exhibits a system behavior that rolls-off at around -40 dB/decade (or greater). This does not lead to the definitive conclusion that the boiler fluctuations are governed by second order phenomena. The Bode plots are difficult to interpret due to the presence of strong harmonics as illustrated in the full spectrum of Bode plots (see Figure 3c).

These strong harmonics can be explained by recognizing that the fluctuations in the time domain exhibit a square wave behavior. Subsequent harmonics observed in the PSD appear at odd multiples of the fundamental frequency (see Figure 4). These harmonics are expected as the Fourier transform estimates a square wave with multiple sinusoids at odd multiples of the fundamental frequency. Before the conclusion can be made that the pressure fluctuations are indicative of CFB boiler hydrodynamics, the nature of the dominant 0.25 - 0.3 Hz phenomena must be examined further.

Experiments were conducted to better understand the nature of the 0.25-0.3 Hz dominant frequency measured at the bottom of the boiler. First, an analog anti-aliasing filter was used while recording data to insure that the dominant frequency observed in the spectrum was not simply the result of a frequency phenomena higher that the sampling frequency (e.g. 60 Hz line frequency) being manifest in the low frequency spectrum. A

3rd-order Butterworth filter was designed and constructed with a 16 Hz (100 rad/s) cut-off frequency. Figure 5 compares the Bode plot of filter data to that of the unfiltered data. Although it is also evident that the filtered data begins to attenuate the signal slightly as the spectrum approaches 100 rad/s, as expected, there is no significant difference in the plots. It can be concluded from this result that the 0.25-0.3 Hz phenomena is not the result of aliasing. Data recorded at sampling frequencies of up to 1000 Hz confirms this conclusion, since no dominant frequency phenomena between 0-500 Hz (other than the 0.25 - 0.3 Hz phenomena) is observed in the spectrum.

It was hypothesized that this dominant frequency was not the result of the CFB hydrodynamics but of a standard periodic operation of the CFB Boiler. It was believed that oscillations in the limestone or coal feed systems were the origin of the square wave signal. If this was the case, any dynamics resulting from fluidization fluctuations would be hidden within the dynamics of boiler operation. By analyzing only the part of the signal that resides between subsequent 0.25-0.3 Hz oscillations, this hypothesis was tested. The Bode plots that resulted from this analysis did not show any dynamic behavior that could be attributed to CFB hydrodynamics. The resulting plots were typical of the Bode plots of a white noise signal, containing no important dynamic information. It is assumed that all observed dynamics contained in the spectrum are related to the 0.25-0.3 Hz oscillation.

The most likely explanation for this periodic behavior is the coal feed system. Coal is fed into the boiler at two locations; via the loop seal and directly into the bed on a cleated conveyor belt. Due to the spacing of the cleats and the typical speed of the conveyor, a cleat reaches the entrance of the boiler every 3 to 4 seconds. Assuming that the coal will have a tendency to pile up near the cleat, the rate at which coal enters the boiler will not be continuous. Rather, the feeder will input a batch of coal every 3 to 4 seconds.

By observing boiler fluctuations under high and low loading conditions, this hypothesis is supported. Figure 2 shows bed fluctuations measured mid-afternoon while Figure 1 represents the fluctuations measure during peak operation 8:00-9:00 a.m. During this period of high load, the fluctuations appear less dominated by the "square wave" coal feed fluctuations. This is expected since an increased circulation rate increases the solids suspended in the bed and decreases the observed effect of the coal feed directly into the CFB. The more dilute the operation of the CFB is, the more evident the periodic coal feed will be in the frequency spectrum.

Discussion of upper CFB boiler fluctuations - The combustion chamber pressure fluctuations differ from the lower bed fluctuations because the periodic nature of the coal feed no longer is sensed as strongly at the top of the bed (see Figure 6). At this elevation, the periodic batches of coal entering the combustor have been more evenly dispersed in the upward moving gas flow. The Bode plot of the combustion chamber pressure fluctuations shown in Figure 7 does seem to exhibit an initial roll-off of around -40 dB/decade. This characteristic frequency occurring at around 0.4-0.5 rad/s (0.06 - 0.08 Hz) may be a wave phenomena similar to that previously observed in the CFB models.

The equivalent diameter of the CFB boilers is 4.85 meters. This is 47.5 times greater than the 10.2 cm diameter CFB model. If a wave phenomena observed in the CFB models was observed in the CFB boiler, it would appear at a frequency inversely proportional to the square root of the diameter. Observing a frequency at around 0.5 Hz in the 10.2 cm CFB model (absolute pressure fluctuations), the predicted wave frequency for the boiler would be 0.07 Hz, as is observed. It is difficult to asses how much of an effect the periodic coal feed has on the combustion chamber fluctuations, therefore this hypothesis that a dilute phase phenomena similar to that observed in the models is acting in the CFB boilers cannot be definitively supported. Additionally, this combustion chamber pressure is a controlled pressure. Exhaust fans are used to keep this pressure at acceptable levels. More must be known regarding the control system dynamics before any definitive conclusions can be drawn regarding the relation of pressure fluctuations to fluidization hydrodynamics in industrial scale CFB boilers.

Future Work

The next objective of this study will be to identify the phenomena responsible for pressure fluctuations in CFBs. To do this the pressure fluctuations in bubbling and turbulent fluidized beds will be related to those observed in CFBs.

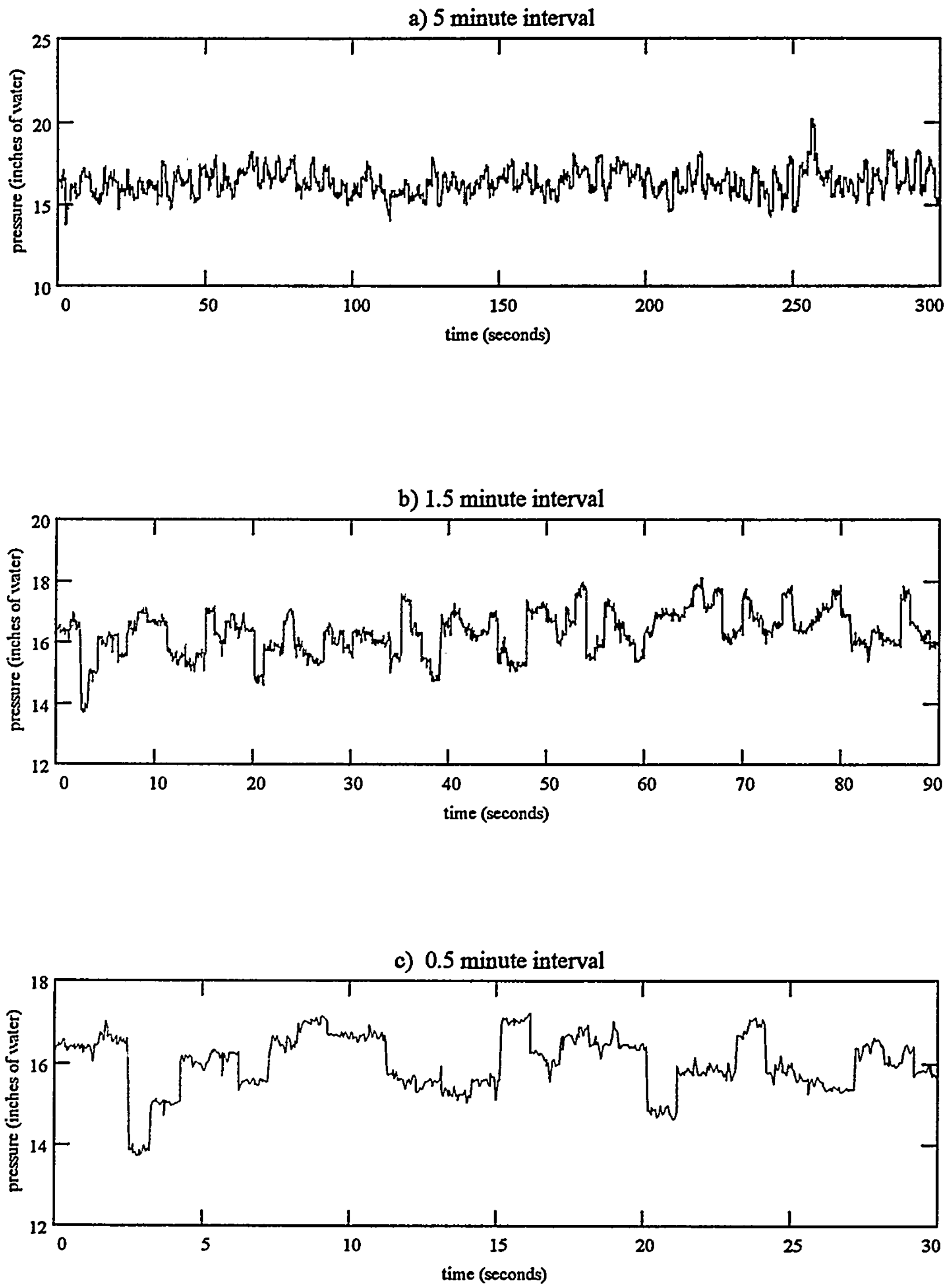


Figure 1: ISU CFB boiler lower bed pressure fluctuations (peak load - morning)

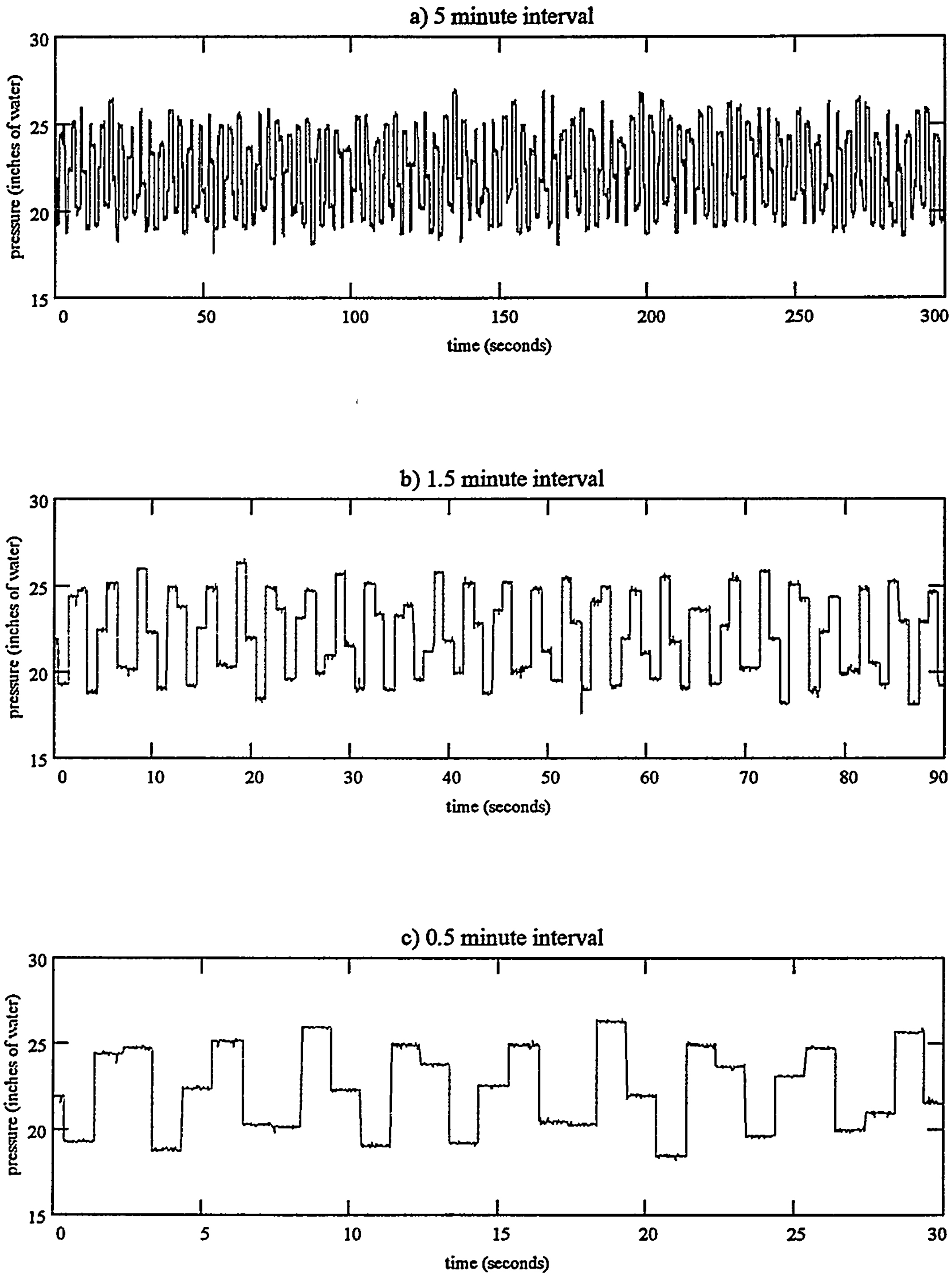


Figure 2: ISU CFB boiler lower bed pressure fluctuations (afternoon load)

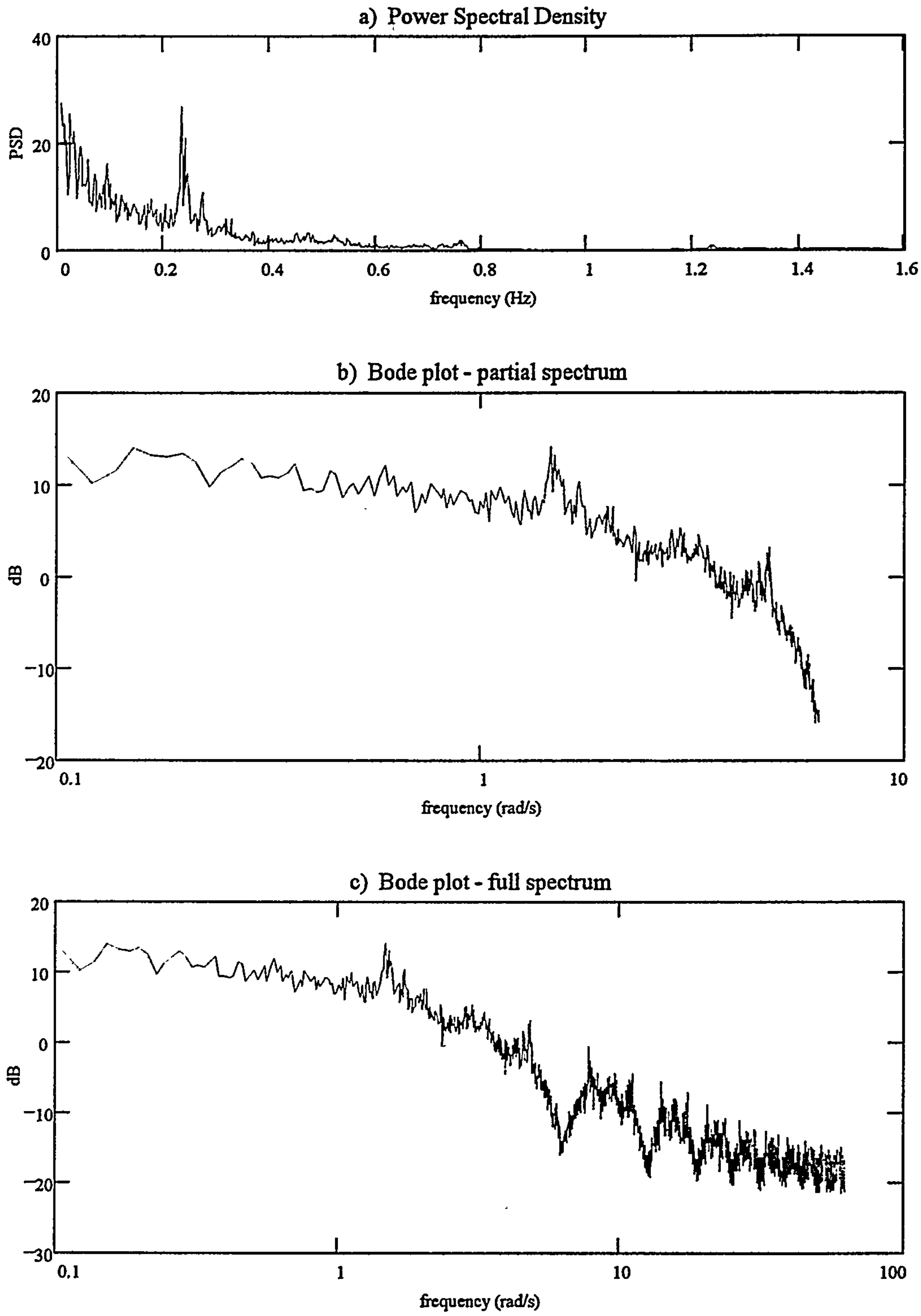


Figure 3: Peak load CFB boiler fluctuations a) PSD b) partial b) full Bode

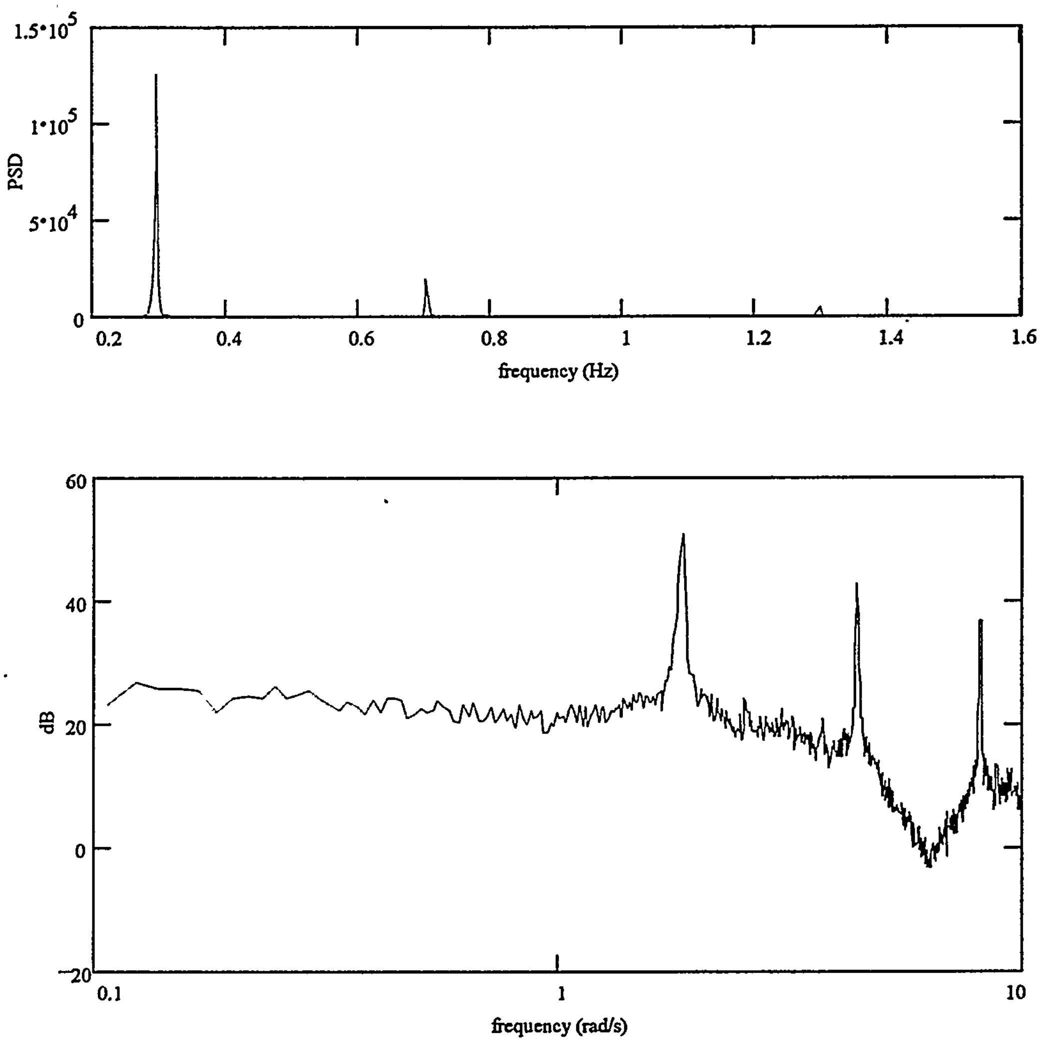
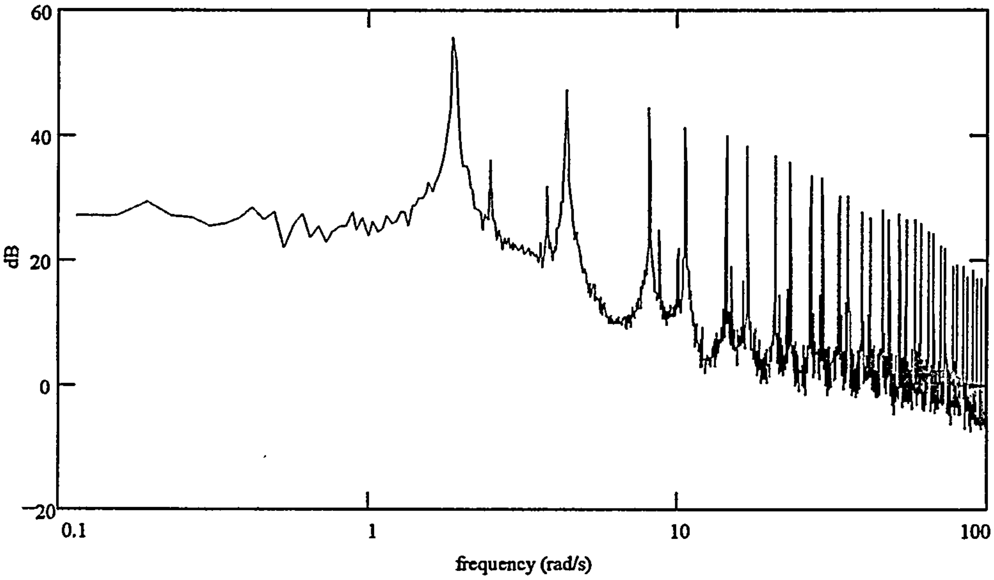


Figure 4: Bode plot & PSD of CFB boiler lower bed fluctuations (afternoon load)

a) CFB Boiler pressure fluctuation Bode plot (filtered)



b) CFB Boiler pressure fluctuation Bode plot (unfiltered)

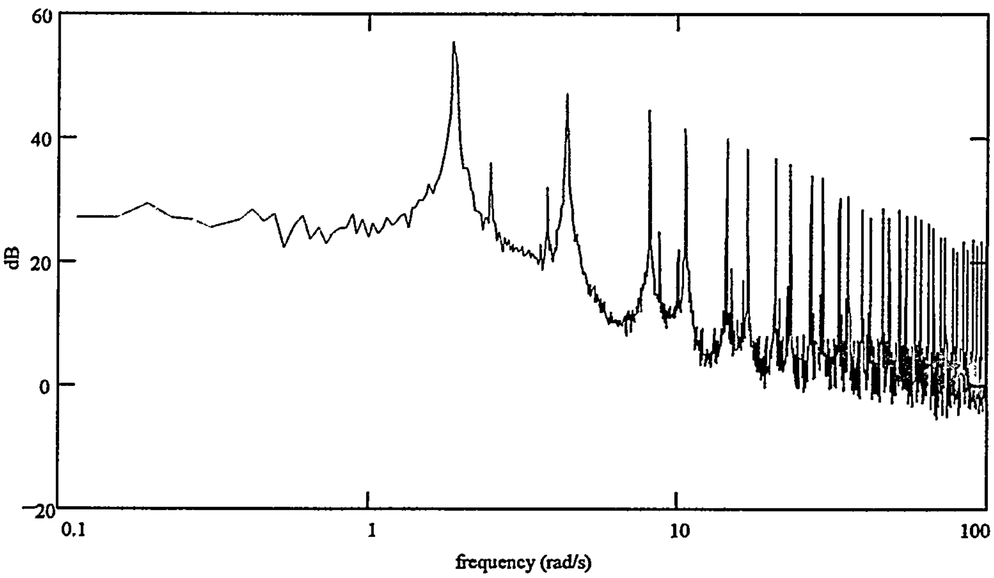


Figure 5: Bode plot of CFB boiler fluctuations a) w/ anti-aliasing filter b) unfiltered

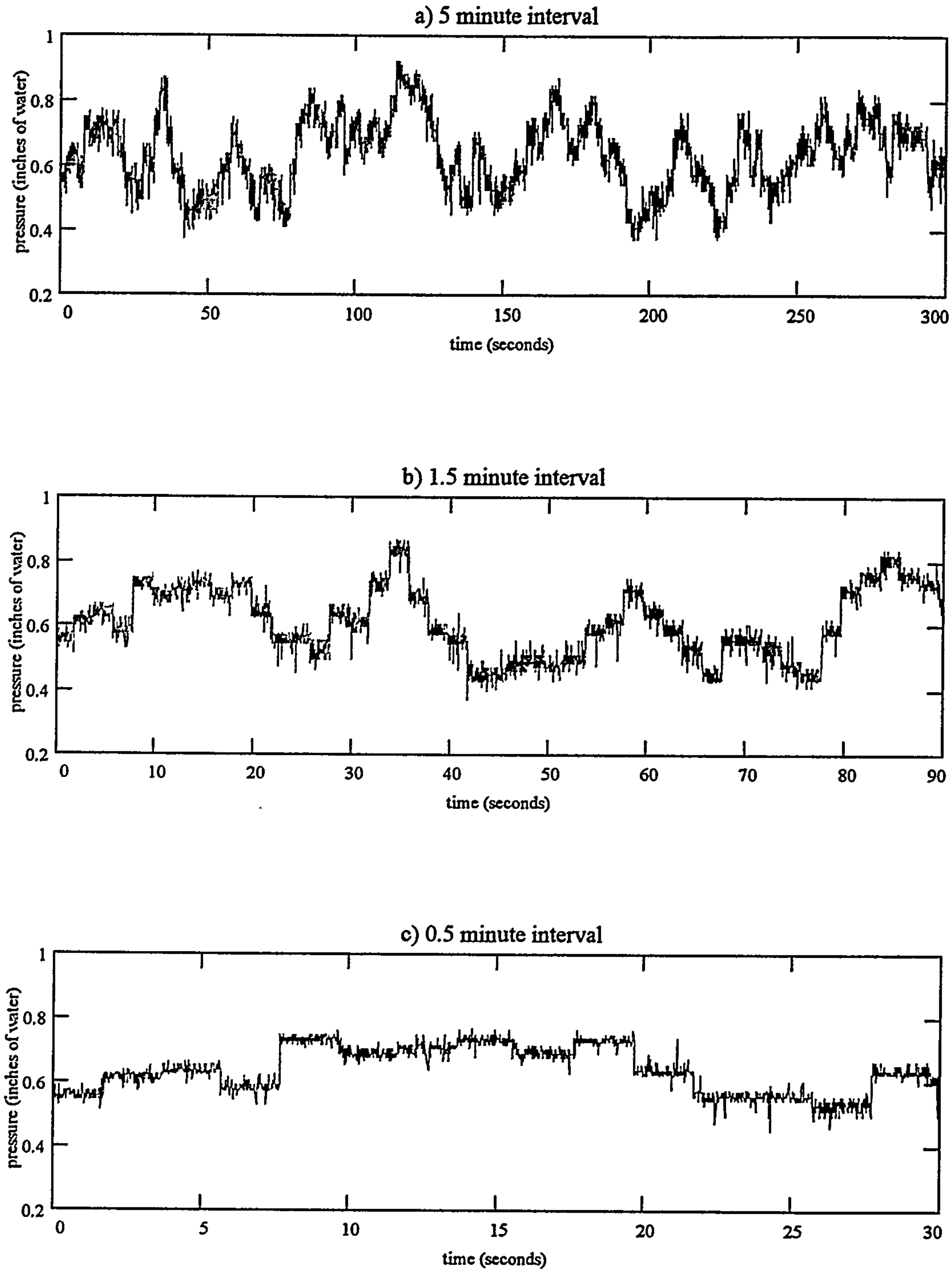


Figure 6: ISU CFB boiler combustion chamber pressure fluctuations

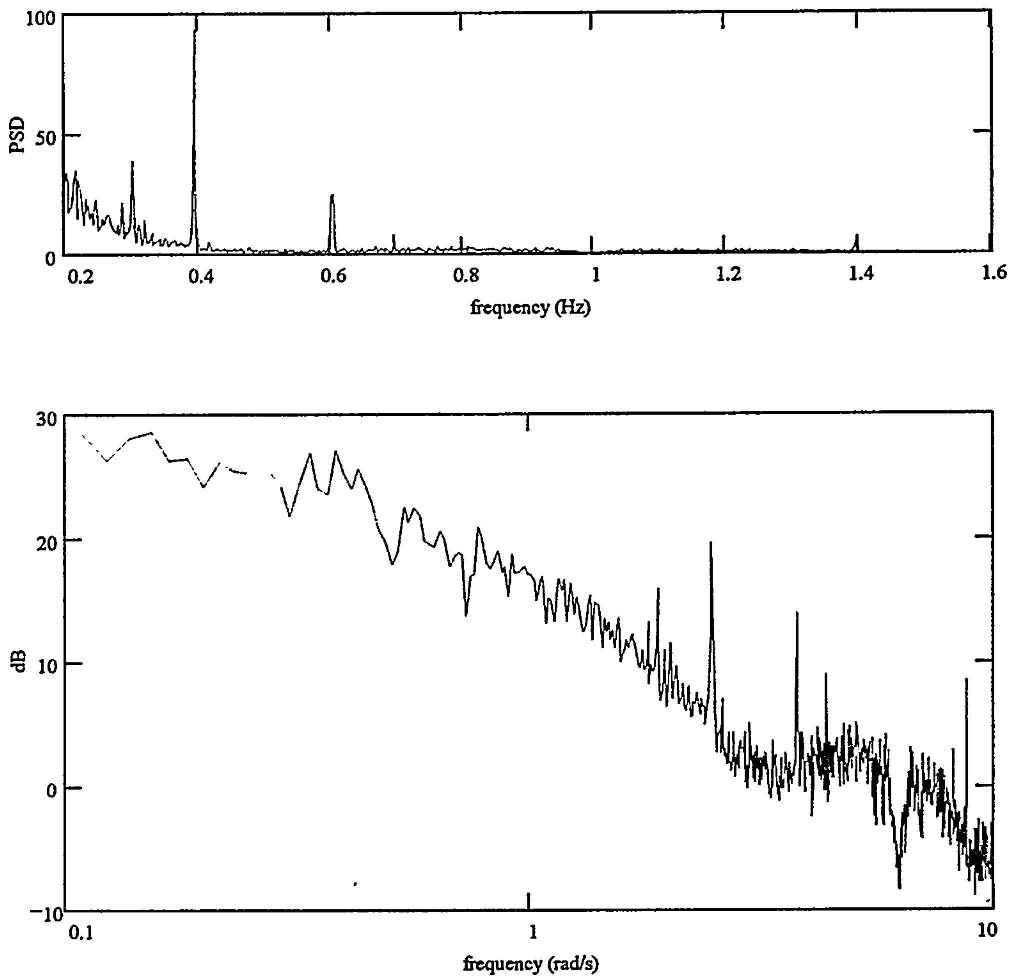


Figure 7: Bode plot & PSD of CFB boiler combustion chamber pressure fluctuations