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"Sensor for Individual Burner Control of Firing Rate, Fuel-Air Ratio, and Coal Fineness Correlation"

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ABSTRACT

To minimize program cost, additional testing was performed in concert with EPRI-funded testing at the Coal Flow Test Facility in late July. The major focus of this effort was noise reduction. As it turned out, the main source of the noise proved to be related to electrical grounding issues and the adjustments needed to address these problems took most of the test period. Once those changes were in place, a very limited quantity of high quality data was obtained and an excellent correlation between the dynamic signature and coal flow was obtained. Additional data were then collected during August. Unfortunately, the sensor signal for the August data collection proved to be extremely weak. Therefore, Airflow Sciences will collect additional laboratory data in October before proceeding with the collection of field data. This will allow the calibration to be expanded to include a wider range of flow conditions and improve the potential applicability to data to be collected at the coal plants.

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EXECUTIVE SUMMARY

The project's overall objective is to develop a commercially viable sensing system to infer the flow rate and fineness of pulverized coal flows using the dynamic signature from a pipe-mounted accelerometer. The preliminary calibration data for this effort are to be obtained using a Coal Flow Test Facility built and operated by our subcontractor, Airflow Sciences Corporation, in support of an EPRI program. Additional operational data are to be collected in field testing at coal-fired power plants to fine-tune the calibration.

Analysis performed on the laboratory data collected during previous reporting periods produced encouraging results, considering the limitations of the available data. However, careful examination of each data file had disclosed that various types of noise were present in many data files. Through extensive analysis of the data sets that appeared to be noise-free, it was discovered that some data sets still suffered from some form of noise that was as yet unidentified. The cases not suffering this noise produced extremely good flow correlations, while the noisy cases are essentially uncorrelated to coal flow. This led us to decide that additional laboratory testing was needed to identify potential sources of noise and to obtain additional data to serve as the basis of the instrument calibration. During the current reporting period, testing was performed at Airflow Sciences in concert with testing for an EPRI-funded program during the latter part of July, significantly reducing the cost to this program. Foster-Miller sent a project engineer to Airflow Sciences in order to assist with this effort. It was found that the primary noise sources were related to grounding issues, which took the majority of the test effort to be resolved. At the conclusion of this test period, ten excellent cases of noise-free data were collected for which the dynamic signature could easily be correlated with coal flow. Due to the small quantity of data available, Airflow Sciences agreed to collect more data during August 2005. Unfortunately, the sensor signal for this additional data was extremely weak, for reasons as yet undetermined. Airflow Sciences has agreed to collect more laboratory data in October 2005, prior to proceeding with the field tests.

EXPERIMENTAL

Additional laboratory testing was performed in the Coal Flow Test Facility during the week of July 25, 2005. The testing was performed in concert with testing by EPRI, providing a significant cost reduction for this program. Foster-Miller sent Bruce Barck, a project engineer, to the Coal Flow Test Facility to observe the testing and assist with the data collection. The key point of focus for Mr. Barck was to identify possible sources for the noise that has been evident in the laboratory data collected previously and, if possible, to find ways to reduce or eliminate that noise.

Prior to this round of testing, we had Krohn-Hite build us a filter module that would function identically to the general purpose Krohn-Hite laboratory filter box used previously. The benefit of using such a module was that installation was accomplished by simply plugging the module into the system, which would facilitate field testing and ensure uniform results.

During the testing it became clear that the system still had many grounding issues that needed to be resolved. In order to ensure safe operation of the system, the coal pipes must be grounded throughout, mandating the use of insulated mounting studs. Unfortunately, the mounting studs are easily damaged when they are repeatedly installed and removed, as was necessary in moving the transducer to enable data collection at multiple elbows. Once mounting studs become damaged they are no longer non-grounding and collecting data with an acceptable level of noise is no longer possible. After several days of adjustments, it became clear that continued use of the stud mounts was likely to remain problematic. While these issues might be resolved with the permanent installation of an instrument, it was not practical to continue further testing with the stud mounts for the balance of the program. Additionally, the analysis to date had produced far more encouraging results for data collected with a magnetic mount of the transducer. Therefore, we decided it would be best to concentrate our efforts on obtaining a reliable instrument calibration using a magnetic mount. The previous test effort had clearly demonstrated that the sensor location one diameter downstream from the elbow generated an optimal signal as compared to the other locations that had previously been considered. Data collected at this location had greater harmonic power and, as a result, had a higher signal-to-noise ratio. Given the delays that had resulted from time spent resolving noise issues, the decision was reached to focus exclusively, for the remainder of the program, on data collected from a sensor at this position.

In sum, numerous adaptations were made to ensure uniformity of the data collection. After several days of modifications, a small quantity of high quality data was collected using the magnetic mounts. In all, a total of ten usable data files were obtained using a vertical-down-to-horizontal pipe configuration. The air flow was approximately constant for this collection of case runs and there were essentially three different coal flow conditions. The flow conditions for this data are summarized in Table 1 below.

Table 1. Conditions Visited in Downflow-to-Horizontal Configuration using a Magnetic Mount

Air Flow (lb/hr, kg/sec)		Coal Flow (lb/hr, kg/sec)		Air/Fuel Ratio	Number of Files
14837	1.8695	7003	0.8824	2.12	1
14845	1.8705	6970	0.8782	2.13	3
14785	1.8629	8192	1.0322	1.80	3
14629	1.8433	11896	1.4989	1.23	1
14640	1.8446	11764	1.4823	1.24	2

Though the noise issues had been thought to be resolved during the July test efforts, the process of identifying the various noise sources had been ongoing through most of the test period. Therefore, the quantity of data collected was insufficient to develop the calibration, particularly as only three flow conditions were visited. Airflow Sciences agreed to collect more data for use in our analysis efforts.

In August 2005, Airflow Sciences collected and sent 60 data files to Foster-Miller. All data were collected with a sensor located one diameter downstream from the elbow and all with a magnetic mount. The set-up was reported to be unchanged from the final set-up in July. However, when the data were compared to the ten cases collected during July 2005, it was found that the signal in this latest collection had been extremely weak. In fact, the harmonic power of the signal had dropped 30-35 dB. Figure 1 below compares both the raw data and the power spectrum of one of the files collected in August with a file collected in July.

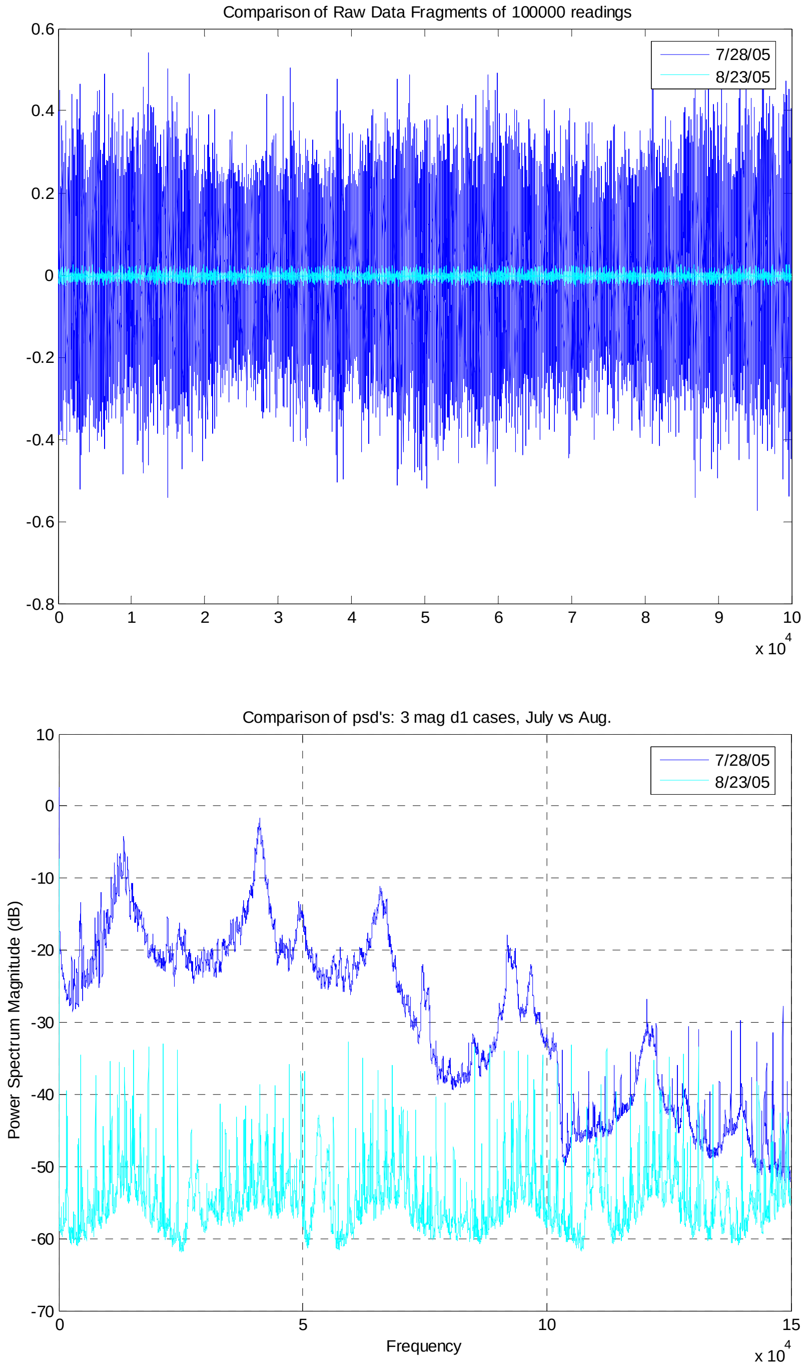

Figure 1. A comparison of two data files, one collected in July 2005 and one collected in August 2005

While there is some evidence of peaks at similar frequencies in both data sets, clearly the harmonic power was very low for the data collected in August, which resulted in a signal that was dominated by noise. As a result of these problems, Airflow Sciences has agreed to collect additional laboratory data during October 2005.

RESULTS AND DISCUSSION

As discussed above, major efforts were directed towards noise reduction during the July 2005 test round. While this effort occupied most of the test period, once the modifications were put into effect, ten files of remarkably consistent data were obtained. This quantity of data is not sufficient to produce a useful instrument calibration, because the Dynamical Instruments technique requires a larger numbers of cases for information-theoretical reasons.

Both the raw data and power spectral density were examined for each individual case, as had been done with the earlier data sets. The aberrant behaviors evident in the earlier raw data sets had vanished. Further, the power spectral density displayed a level of consistency far beyond what had been observed earlier, particularly in the 50-70 kHz frequency range that we had previously chosen for band-pass filtering. Figure 2 below illustrates the power spectral densities of all ten cases simultaneously.

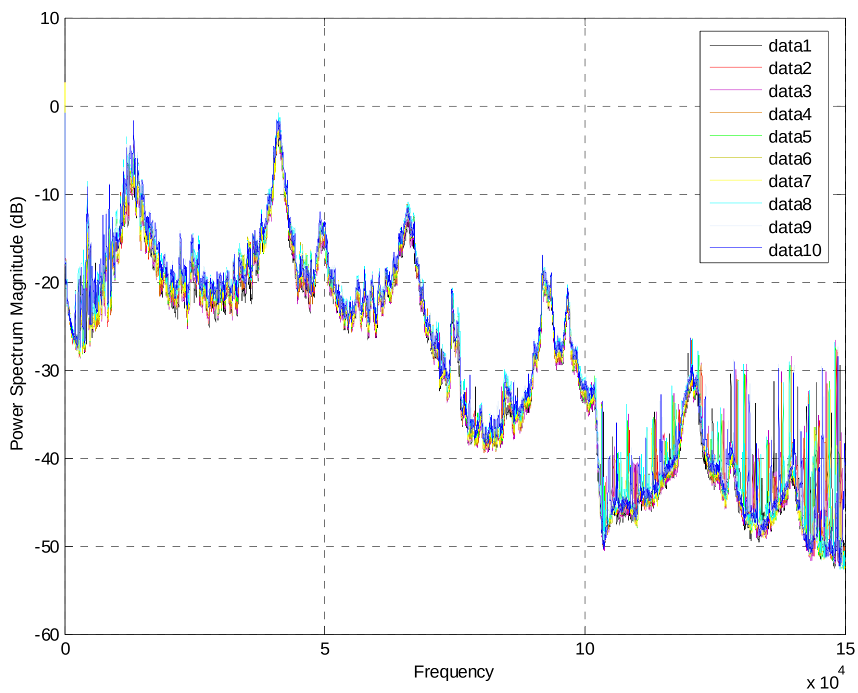

Figure 2. Comparison of power spectral densities for the 10 cases of July 2005

In examining these ten magnetic-mount flow cases, we addressed several questions:

- How do the dynamic signatures of the old "good" magnetic-mount cases compare to the new?
- How well does the previous "best" neural network perform on the new data?
- What is the best correlation that can be achieved between the dynamic signatures and coal flow when training on the new data?

Any comparison of the dynamic signatures between old and new cases is limited by the reduced set of flow conditions covered by the ten cases of July 2005. A comparison of the flow conditions covered is displayed in Figure 3 below.

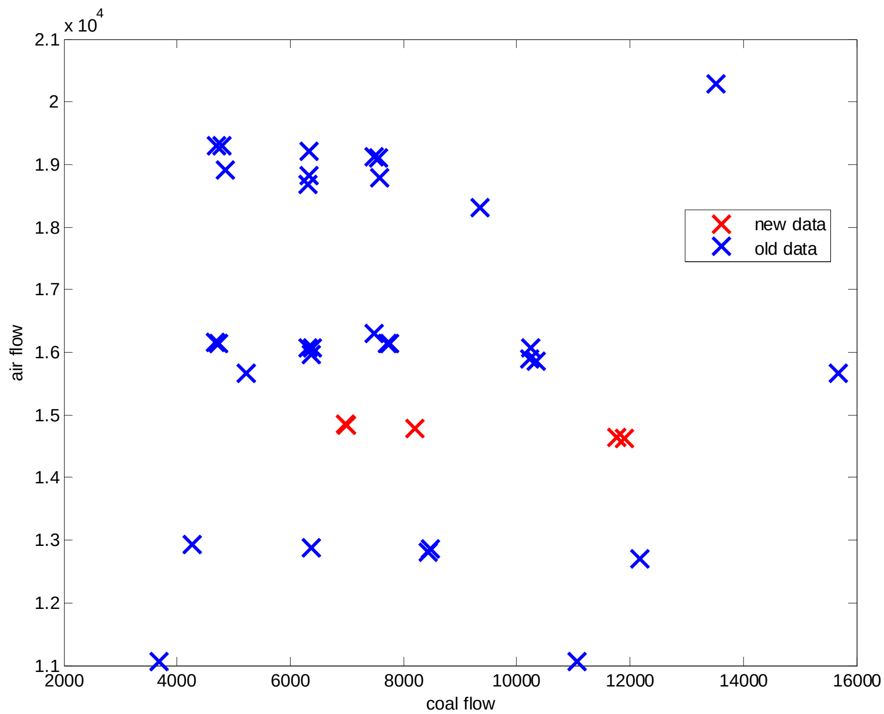

Figure 3. Comparison of Flow Conditions between data of October 2004 and July 2005

The most dramatic differences between Dynamical Instruments signature quantities in the two sets of data occur for the quantities that characterize signal amplitude (which we call size measures). As an example, Figure 4 below shows the standard deviation as a function of coal flow. The behavior illustrated is representative of the behavior exhibited for all size measures. Namely, the standard deviation is larger but more consistent for July data when compared to the data collected earlier. If this increased magnitude were solely due to a difference in amplifier gain, there would be more variation, for the July data, in the standard deviation for any fixed coal flow level. In other words, there would be less consistency in the July data rather than more. The ten cases of July suggest that standard deviation may increase with increasing coal flow when airflow is held constant. However, ten cases are not sufficient to confirm this behavior.

Two sets of cases from the original data, each corresponding to approximately constant airflow levels, are circled, one in green and the other in cyan. These cases demonstrate that the original data did not exhibit a similar pattern to the new data.

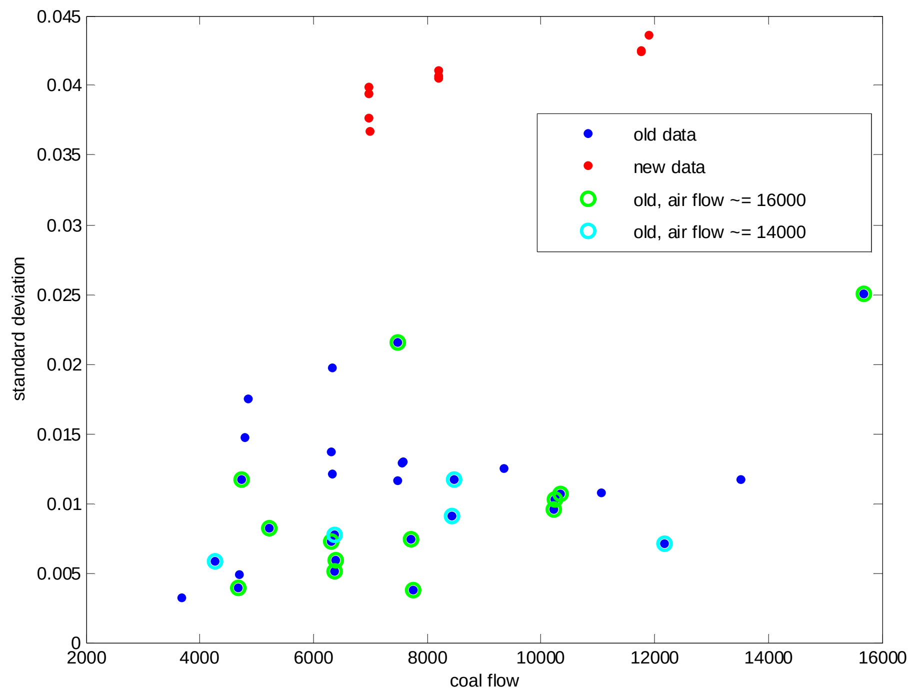

Figure 4. Comparison of Standard Deviation for Original Data and Data of October 2004 and July 2005

Figure 5 below shows a comparison of a signature quantity that characterizes the dynamic variation of amplitude, without reflecting actual signal amplitude (which we call a normalized size measure) between the two sets of data. Although the two sets exhibit a similar order of magnitude for a given signature quantity, the July data tends to be more consistent. The legend for Figure 4 is valid for Figure 5 as well.

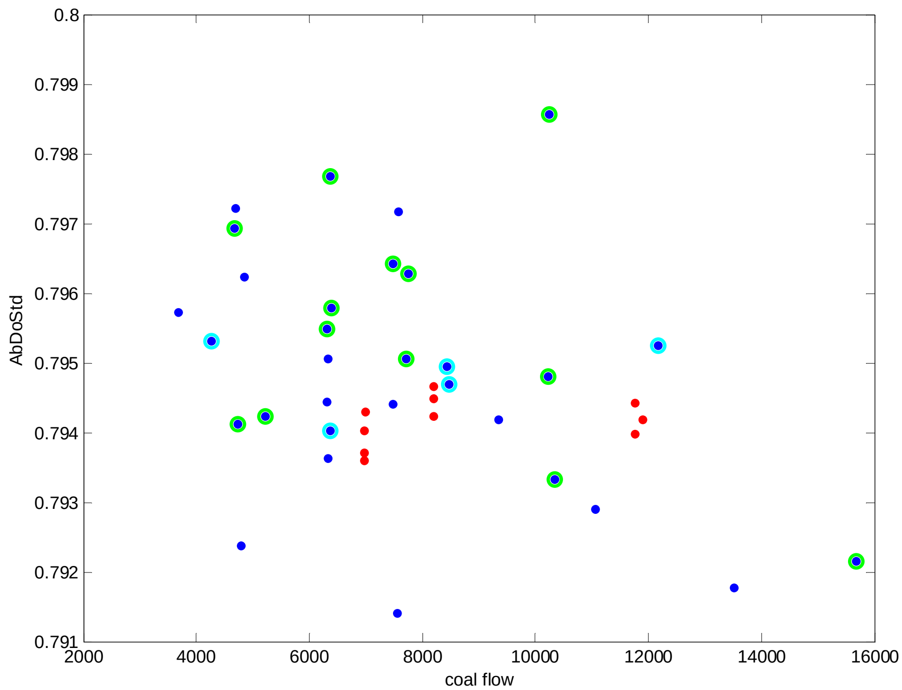

Figure 5. Comparison of AbDoStd for original data and data of October 2004 and July 2005

The dynamic signature that had exhibited highest correlation with coal flow to date had been based on the difference between the signatures calculated for 5-second windows and those calculated for 1-second windows. The signature quantities employed for this signature were of the same order of magnitude for the old and new data. However, when the "best" neural net previously developed was applied to the new data set, the prediction results were essentially uncorrelated with actual coal flow, with a correlation coefficient of only 9.71%. The results are displayed in Figure 6 below. This outcome was not really surprising, considering all the adjustments that had been made to the instrumentation over the test period. A number of these adjustments would ensure uniformity of future data collections, whether in the lab or the field. However, the implications of such a poor prediction are that consistency in the installation of the mounts is critical to the success of a coal-flow prediction instrument.

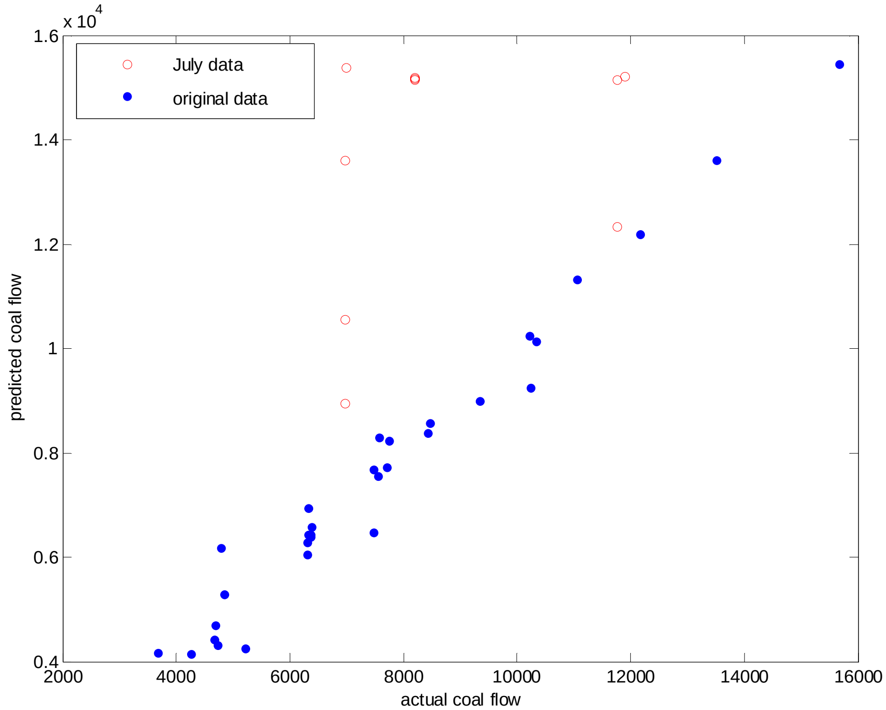

Figure 6. Comparison of coal flow predictions for original data and data of July 2005

When neural nets were trained using only the ten cases of July 2005, the result was quite different. Correlation coefficients above 99% were easily obtained, regardless of whether the original median signatures for the 1-second windows were used, or the median signatures for the 5-second windows, or the difference between the signatures of the 5-second windows and the 1-second windows, or the standard deviation of the signatures of the 1-second windows. In fact, using either the median signatures of the 1-second windows or those of the 5-second windows, correlation coefficients above 99% could be achieved with just one input and one hidden node (the simplest possible neural network). While it is important to remember that this data was limited in quantity and visited only three flow conditions, reducing coal-flow prediction to a sorting problem, these results were highly encouraging. Although any predictions based on such limited data could not achieve statistical significance, this data did display a variation in individual signature-quantity values that appeared to depend on the flow conditions. The flow predictions for the single-input, single-hidden-node network are displayed below in Figure 7.

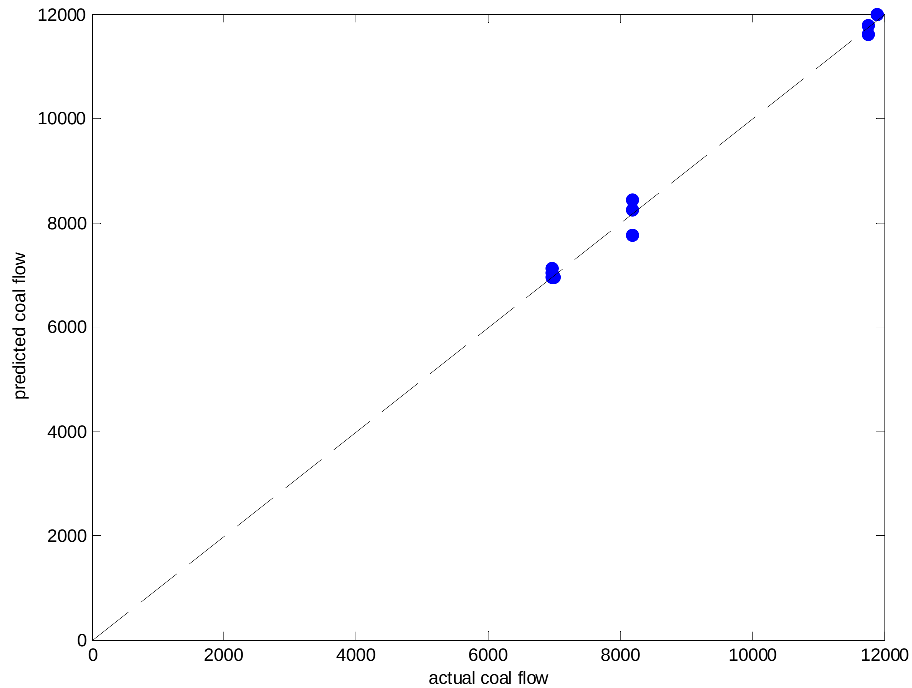

Figure 7. Prediction of coal flow with 1 input and 1 hidden node

CONCLUSIONS

The majority of the July test period had been devoted to pinpointing the noise sources in laboratory data. As a result, only ten clean files of data covering just three flow conditions were collected during the test effort. However, the quality of this data was remarkably good in comparison to the data from previous test efforts. The power spectra were extremely consistent and displayed the expected characteristic peaks. The analysis effort easily produced a neural net with a correlation coefficient between actual and predicted coal flow of greater than 99% using just one input and one hidden node. While ten cases covering such a limited range of flow conditions can not be considered statistically significant, the evidence now indicates that the noise problems that have plagued the program can be resolved. Based both on past experience and the analysis of this small data set, there is every reason to believe that with enough data an instrument-level calibration can be achieved.

At this time, it is not clear what caused the weak signal during the August test effort. However, given that this particular problem has not been present during the earlier test efforts of this program, we are confident that the problem can be resolved.