GAINING CONTROL OF ESP FLY ASH HOPPERS USING 3D ACOUSTICS

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Abstract

Managing the fly ash inside ESP hoppers presents significant challenges. While avoiding the risk of pollution is extremely important, operation and maintenance costs must also be managed. The lack of decision support information is one of the reasons making this situation so hard. This paper will highlight the source of the problem, review available solutions with their strengths and shortcomings and then present a breakthrough development that offers a significant improvement for day to day management of these hoppers.

Figure 1: ESP Fly Ash Hoppers

ESP[1] and its importance in Power/ Process Industries

In recent years the particle emissions from process industries have been attracting more attention because of the anticipation of upcoming strict U.S. Environmental Protection Agency (EPA) regulations. Although electrostatic precipitators generally capture 99.5% of the particles from the flue gas in terms of mass volumes, the anticipated regulations on PM2.5 (particulate matter with particle sizes of 2.5 microns and less) have led power stations to explore improvement options to control the emissions of the fine particulate at a minimal cost.

Electrostatic precipitators (ESPs) are the most commonly used, effective, and reliable particulate control devices (System); they are employed mostly in (coal based) power plants and other process industries. The particle-laden flue gas from the boiler flows through the ESP before it enters the environment (thru stack). The ESP works as a cleaning device, using electrical forces to separate the dust particles from the flue gas.

A set of discharge electrodes is suspended vertically between two collection electrodes in a typical wire-plate ESP channel. While the flue gas flows through the collection area, electrostatic precipitators accomplish particle separation through the use of an electric field in the following three steps. The electrical field does the following:

- Imparts a positive or negative charge to the particles by means of discharge electrodes
- Attracts the charged particles to oppositely charged or grounded collection electrodes
- Removes the collected particles by vibrating or rapping the collection electrodes or spraying them with liquid (applicable only in wet ESP)

That large portion of the Fly-ash (dust) particles (which could not be trapped in the Economizer) are collected in the ESP Hoppers below the Electrostatic Precipitators (ESP) having high peak voltage of 71 KV on the collecting plates to polarize the Fly-Ash (dust) Particles.

To prevent over-spilling of Fly-ash (dust) from these hoppers, de-ashing (de-dusting) is performed after a fixed time interval (even if the hopper is not filled completely with Fly-ash (dust)). This results in:

- High power consumption as many times as the de-ashing (de-dusting) operation takes place.
- A lot of wear & tear due to moving parts of the de-ashing (de-dusting) system.
- Build-up of the ash particles in the portion of the High Voltage Plates could cause a short-circuit between the collecting plate and the electrode (especially under Humid conditions) thus destroying the plate arrangement and the electrical equipment.

This calls for an Automatic Level Detection System to control the High and Low Level of Fly-ash in the ESP Hoppers and start the emptying process only when the pre-set maximum level is reached.

The Problems and Main Challenges of Fly Ash Detection in ESP hoppers[2]

Fly ash detection in ESP Hoppers presents the following main challenges due to following :

- Has very low density, hard to sense (false alarms)
- Tends to stick to everything particularly when moist. (creates rat holing)
- Has a very low dielectric constant.
- Carries static charge.
- Is at high temperature (Approx. 200 deg. C.).
- Is abrasive in nature.

Due to the above mentioned difficulties, current solutions (such as high and low level alarm switches and other technologies) present lots of operational issues.

Users are looking for a non contact solution that will profile the material and measure the volume continuously and therefore save energy (money), maintenance (wear and tear). Once user gets material profile he can easily:

- Detect **rat holes** at a very early stage
- Detect buildups so user can clean the hoppers in time
- Prevent false alarms due to build ups
- Prevent damage to the plates due to absence of alarms and eventually:
- Reduce pollution and allow compliance with the strict EPA regulations.

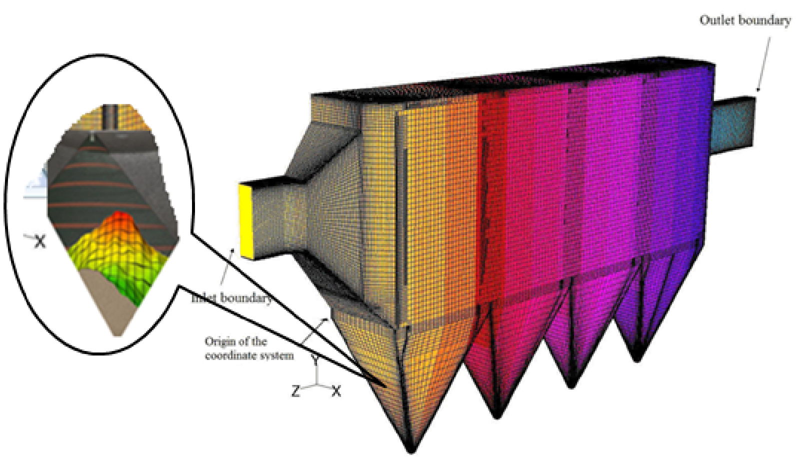

Figure 2: ESP Fly Ash Hoppers, a 3 Dimensional Representation

Current Solutions

Nuclear gauges use a radioactive source mounted outside one side of the hopper transmitting to a receiver on the other side. The fly ash present inside the hopper blocks the radiation from the source to the receiver, thus the level is determined. Since these nuclear switches are mounted outside the hopper they are protected from the harsh environment created by the fly ash. These gauges have several shortcomings including the fact they only measure the high point of the material, leaving managers with insufficient information about the material inside the hopper. For example, there is no information available to determine if a buildup or rat hole is forming. The buildup and / or rat holes can throw off the reading giving a false high level indication. On top of this the operation and maintenance of the nuclear switch are cumbersome and expensive, including specially trained personnel and disposal restrictions. Safety is also an issue.

Paddle switches signal when the fly ash has reached a predefined level. The paddle is continuously rotating, when the fly ash reaches the paddle it stalls the rotation, activating the switch. These switches are very affordable and do not need calibration. Yet they require extensive maintenance due to mechanic failures and motor break down as a result of coming to contact with the harsh environment, with some failing in as little as six months.

Turning forks and vibrating rods, like the paddle switch, signal when the fly ash reaches a predefined level. These technologies utilize a rod or fork to vibrate at a fixed frequency. When the fly ash covers the rod or fork it shifts the frequency and triggers the switch. These switches are very affordable, require little maintenance and do not need calibration. Still, since the fly ash environment is very harsh the switches are susceptible to damage from abrasion and weight loading. False reading can occur since fly ash is too light to dampen vibrations. In addition, the rod or fork can rat hole in the fly ash, tunneling out the material and thus stop registering actual changes. The fly ash also tends to coat the turning fork or rod and create false level conditions.

Capacitance technology uses a sensor and the hoper wall to create a capacitor that is calibrated to the air capacitance in the vessel. As fly ash levels build up the capacitance increases and beyond a certain threshold the switch is activated to show the predefined level has been reached. Capacitance switches are a bad fit for the fly ash environment. When fly ash coats the sensor, due to its sticky nature, the switch stays in alarm mode even when the level has fallen, as the coating conducts current to the ground. This can only be fixed by cleaning the sensor, meaning the maintenance load increases. The capacitor is also very sensitive to the initial calibration, since capacitance changes as temperature changes. If the initial calibration was done on a cold hopper and the measurements are done at temperature the switch may not register the ash level.

RF switches are basically capacitance switches with an added driven shield element that has the same potential as the active sensor. This isolates the active sensor from the ground and eliminates the problems caused by changes in temperature and by fly ash coating on the sensor. Therefore the RF admittance switch is more stable than the capacitance switch. The sensors still need to be protected from the harsh environment and the high temperatures

These switches are mainly used to alert operators that the highest allowable level has been reached and that the bin must be emptied, as they supply very limited information for decision makers. The information they do supply is not detailed enough to improve the facility's performance. Additional information is needed for operators to correctly utilize tools such as hopper wall heating to reduce buildup or differential hopper empting based on actual material level.

3D Acoustic Solution for all ESP Level problems

Continuous volume measurement using the 3D Acoustic technology with real time visualization of the material inside the hopper solves all the operation problems regarding the ash level inside the hopper

The ability to visualize material surface on line, will provide better monitoring and will **reduce the number of failures**.

The ability to empty the hopper on time result in **less pollution** (conformity with EPA regulations) and less **short circuiting, hence longer** plates life (less expenses and higher efficiency).

Methodology/ Summary of the Innovative Technology – Volume Measurement and 3D Profiling

The technology employs a 2-dimensional array beam-former to send low frequency pulses and receive echoes of the pulses from the contents of the silo, bin or other container. The device's Digital Signal Processor samples and analyzes the received signals. From the estimated times of arrival and directions of received echoes, the processor generates a 3-dimensional image of the surface that can be displayed on a remote screen.

The 3D Acoustics is unaffected by the type of materials being stored, avoiding the need for special calibration, or by environmental conditions, such as dust, filling “noise”, humidity, or temperature.

Three factors combine to make the technology an innovative one and the best of-class solution for accurate measurement of bulk solids, particularly those in dusty environments:

1. Low frequency of transmitted signals (under 4 kHz)
2. A 3-antenna system that measures not only elapsed time between transmission and receipt of acoustic echoes but also the phase between the echoes
3. Proprietary algorithms enabling precise 3-D mapping of the contents inside the silo or storage bin

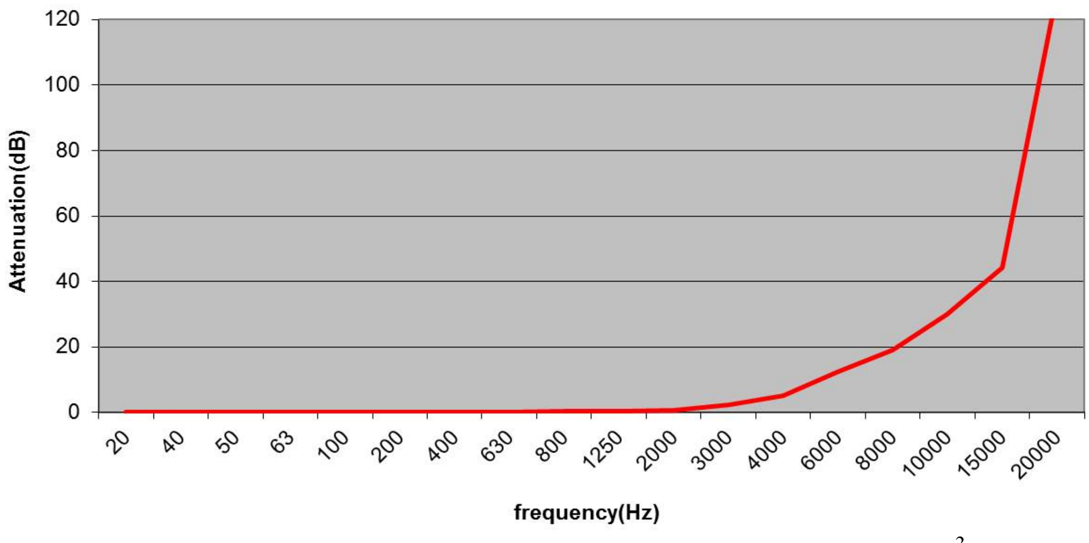

Figure 3: Signal attenuation due to Dust/ Moisture Concentration in air[3]

3D Acoustics technology actually takes advantage of the large 70-degree beam angle (that results from working at a very low frequency), by using a three antenna system with proprietary algorithms to add another important dimension, **direction**. The result is that every 5 seconds the device receives a matrix of x-y-z position coordinates that represent the echoes from the surface of the contents in the silo. Connecting these points together generates a highly accurate profile of the surface area, which in turn yields more precise measurement of the amount of materials being stored.

Method of Algorithm: How to find and detect the direction from which the echoes are coming from:

Step1: Every echo reflected back goes through classification algorithm.

The MUSIC[4] (MUltiple SIgnal Clasification) algorithm: is a linear subspace algorithm that achieves performance close to Shanon limit with relatively low complexity cost. MUSIC estimates the frequency content of a signal or autocorrelation matrix using an Eigen space method. This method assumes that a signal, x(n), consists of p complex exponentials in the presence of Gaussian white noise. Given an, M x M autocorrelation matrix, Rx , if the Eigen values are sorted in decreasing order, the eigenvectors corresponding to the p largest Eigen values spanning the signal subspace. Note that for M = p + 1, MUSIC is identical to Pisarenko's method. The general idea is to use averaging to improve the performance of the Pisarenko's estimator. The frequency estimation function for MUSIC is

$$\hat{P}_{MU}(e^{j\omega}) = \frac{1}{\sum_{i=p+1}^{M} |\mathbf{e}^H \mathbf{v}_i|^2},$$

Where $\mathbf{v}_i$ are the noise eigenvectors and

$$e = \begin{bmatrix} 1 & e^{j\omega} & e^{j2\omega} & \cdots & e^{j(M-1)\omega} \end{bmatrix}^T.$$

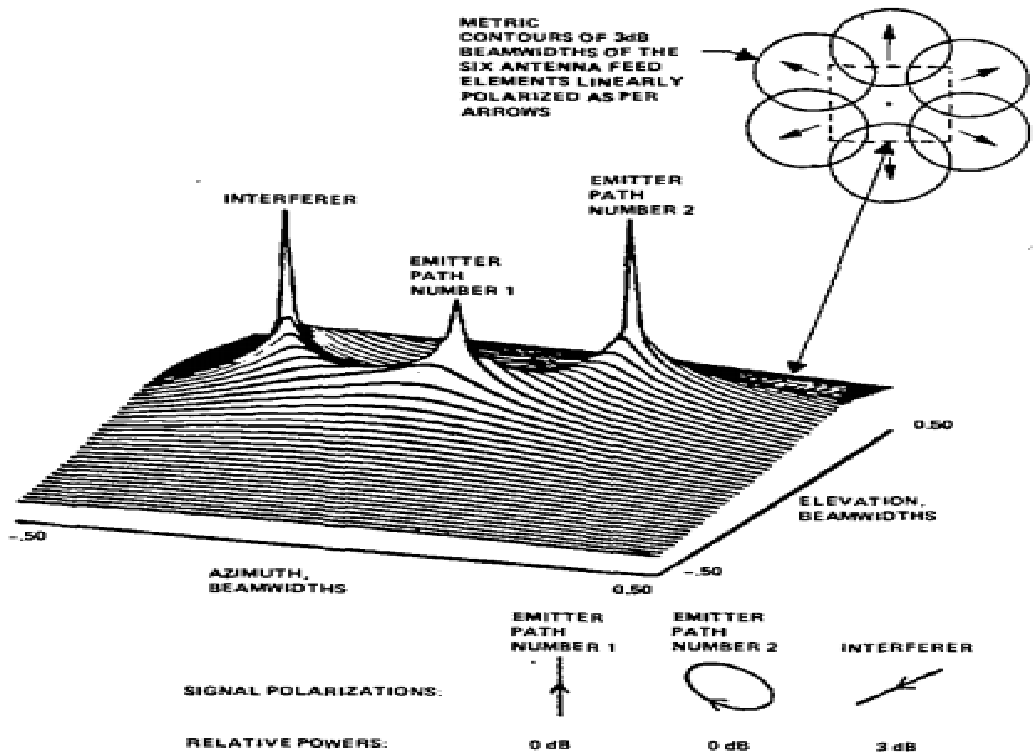

Figure 4: Example of Music algorithm result with 2- dimensional array[5]

The algorithm records the exact time that every pulse is transmitted and the exact time every adjacent echo is received. The difference between these times is the time of flight of signal. The distance is the time of flight multiplayer by half the propagation speed (half because the signal travels forth and back).

The Speed of sound is given by

$$331.3\sqrt{1+\frac{T^{\circ}}{273.15}}$$

T is the measured temperature in Celsius.

For every direction of echo there is a specific set of relative phases induced on the scanner array. However there are some directions that create the same phases on the array even though the directions are not the same.[7]

That effect can be avoided if the spacing between array elements is not more than half wavelength.

Step 2: Angle Calculation

When the spacing between array elements is larger than half wave length there are some different pairs of angles (θ1,φ1) and (θ2,φ2) that cannot be distinguished physically by the array. The smallest angle θ0, such that for every pair of spherical angles that fulfill θ1<= θ0 and Θ2<= θ0, the directions (θ1,φ1) and (θ2,φ2) induce different relative phases on the array (thus every two directions with smaller θ can be distinguished) is the maximal angle at which the array can figure direction without aliasing mistake. In triangular array this angle is given by:

$$\theta_0 = a\sin\left(\frac{C}{\sqrt{3}\cdot f\cdot D}\right)$$

Where:
D is the spacing between antenna elements.
C the propagation speed
F pulse carrier frequency

3D Acoustic Technology Justification for ESP

3D Acoustics[10,11,12] for ESP’s is based on the 3D Acoustic Technology which is extensively researched for dusty applications with high electrostatic charge in the environment, offering managers real answers to their ESP's fly ash needs. The 3D Acoustics was designed specifically for installations inside ESP hoppers, above the fly ash. Using a 3 horn array the scanner maps the entire surface of the material, not just one point, to collect necessary data. This means that managers can now literally see in real time what is going on inside the hopper.

Figure 5: 3D Level Scanner Installation Assembly for ESP Hopper

The 3D Acoustics is dust penetrating, precise even with low dielectric constant material and its inherent self cleaning technology is very effective. These features qualify it as a highly suitable solution for the harsh fly ash environment.

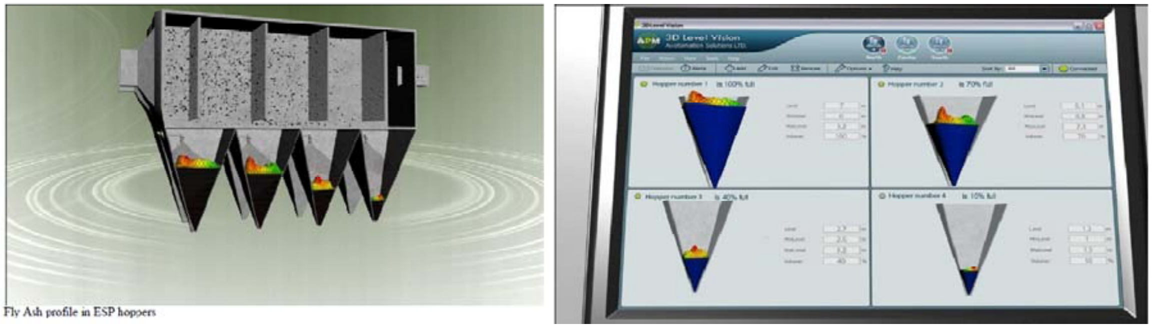

Figure 6 :3D Level Scanner Working in the field and easy access of Output in the Control room

Knowing the actual situation within the hopper allows managers to make informed decisions and control the process better. This could mean taking preventive measures such as turning hopper wall heating on where buildup seems to be starting. It could also mean less frequent hopper emptying and early detection of system malfunctions.

As the only solution on the market to give continuous real time volumetric readings of the fly ash, the 3D Acoustics truly allows managers to do more with less and control their ESPs' fly ash. One point level switch is simply not enough.

Conclusion

ESP hoppers present managers with unique challenges. Making the right decisions in order to optimize the tradeoff between risks and costs is a challenge and without the correct information it becomes even more problematic. The new 3D Acoustics tracking solution offers managers the full set of data needed for making informed decisions, allowing them to maintain low costs and low risk levels concurrently.

References

1. American Coal Ash Association www.acaa-usa.org
2. British Electricity International (1991). Modern Power Station Practice: incorporating modern power system practice (3rd Edition (12 volume set) ed.). Pergamon. ISBN 0-08-040510-X.
3. Aboufadel, E.F., Goldberg, J.L., Potter, M.C. (2005).Advanced Engineering Mathematics (3rd ed.).New York, New York: Oxford University Press
4. Fannjiang, Albert C. The MUSIC algorithm for sparse objects: a compressed sensing analysis Inverse Problems, Volume 27, Issue 3, article id. 035013, 32 pp. (2011).
5. Schmidt, R.O, "Multiple Emitter Location and Signal Parameter Estimation," IEEE Trans. Antennas Propagation, Vol. AP-34 (March 1986), pp.276-280.
6. Hayes, Monson H., Statistical Digital Signal Processing and Modeling, John Wiley & Sons, Inc., 1996.
7. Novák, V., Perfilieva, I. and Močkoř, J. (1999) Mathematical principles of fuzzy logic Dodrecht: Kluwer Academic. ISBN 0-7923-8595-0
8. Francis Jeffry Pelletier, Review of Metamathematics of fuzzy logics in The Bulletin of Symbolic Logic, Vol. 6, No.3, (Sep. 2000), 342-346, JSTOR 421060

9. "Fuzzy Logic". Stanford Encyclopedia of Philosophy. Stanford University. 2006-07-23. Retrieved 2008-09-30
10. M. Crocker (editor), 1994. Encyclopedia of Acoustics (Interscience).
11. D. R. Raichel, 2006. The Science and Applications of Acoustics, second edition (Springer). eISBN 0-387-30089-9
12. L. E. Kinsler, A. R. Frey, A. B. Coppens, and J. V. Sanders, 1999. Fundamentals of Acoustics, fourth edition (Wiley).
13. Stout, K. J.; Blunt, Liam (2000). Three-Dimensional Surface Topograhy (2nd ed.). Penton Press. p. 22. ISBN 978-1-85718-026-8.