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MEASURING AND MODELING SOLIDS MOVEMENT IN A LARGE, COLD FLUIDIZED BED TEST FACILITY

Sixth Quarterly Report for the Period January 1—March 31, 1981

By
Thomas J. Fitzgerald
Robert V. Mrazek
Stephen D. Crane

March 1981

Work Performed Under Contract No. AC01-79ET13152

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U. S. DEPARTMENT OF ENERGY

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COIL DESIGN

In the last quarterly (December, 1980) a new coil arrangement (H-Coil) was discussed. This coil was then built and tested. The results, however, were not as expected. A very much lower signal to noise ratio was obtained than was expected. The reason for this low signal was attributed to a less intense magnetic field in the vicinity of the coils than needed.

A different coil arrangement, which increases the magnetic field intensity, has been designed, built and tested. In this new design the coils (write and read) are still located inside one of the in-bed tubes, but with a different arrangement as shown in Figure 1.

This new coil arrangement is very similar to the anti-parallel coil arrangement described in previous reports, but with the added advantage of compactness similar to that of the H-Coil. This coil arrangement and a new pick-up coil amplifier design has indeed increased and improved the output signal which results from a flow of magnetic solid particles in the vicinity of the coils.

A guide to the design and tests of this new coil arrangement have been provided by the use of a computer program¹ which is capable of simulating the physical characteristics of a two-dimensional magnet and finding the magnetic field and its gradients in these two dimensions. A brief description of this program follows.

The program is divided into two separately executable programs: the mesh generator, MESH; and the magnetostatic program, FIELD. The purpose of MESH is to construct an irregular triangle mesh by interpolating specified (by input)

¹ This computer program has been obtained from Lawrence Berkeley Laboratory of the University of California in Berkeley. For a detailed description of the program and its use, see: John S. Colonias (Particle Accelerator Design: Computer Programs); Academic Press, 1974.

Read Coil placed in the mid-plane
of the write coil.

Anti-Parallel Write Coil

in-bed Tube

Figure 1: The arrangement of the Anti-Parallel write coil within the in-bed tube.

boundary points, and locating the internal mesh points of each region by a pseudo-equipotential method by assigning regional properties to each triangle. The purpose of FIELD is to solve the non-linear Poisson's equation

$$\nabla \cdot (\lambda \nabla \psi) + S = 0, \quad (1)$$

where ψ or its normal derivative is specified on the boundary; λ is a function of ψ or its derivatives and S is a function of position. For magnetostatic problems the manner in which FIELD solves Eq. (1) is arrived at in the following fashion

$$\mathbf{B} = \mu \mathbf{H} = \nabla \times \mathbf{A}, \quad (2)$$

where μ is the permeability of the material.

The curl of the magnetic field intensity $\mathbf{H}$ is given by

$$\nabla \times \mathbf{H} = 4\pi \mathbf{J}, \quad (3)$$

where $\mathbf{J}$ is the current density. Substituting $\mathbf{H}$ from Eq. (2) to Eq. (3) we obtain

$$\nabla \times (1/\mu \nabla \times \mathbf{A}) = 4\pi \mathbf{J}. \quad (4)$$

Since $\mathbf{A}$ and $\mathbf{J}$ have only one nonzero component, for two-dimensional problems, Eq. (4) reduces to

$$\nabla \cdot (\gamma \nabla A) = -4\pi J, \quad (5)$$

where $\gamma = 1/\mu$.

The gradient of A , namely ∇A , is

$$\nabla A = i(\partial A / \partial x) + j(\partial A / \partial y), \quad (6)$$

and since γ depends on $|\nabla A|$, it is convenient to consider γ as a function of B^2 or

$$\gamma = F(B)^2 = F(|\nabla A|^2) = F[(\partial A/\partial x)^2 + (\partial A/\partial y)^2]. \quad (7)$$

The finite difference approximation in a triangular mesh is derived as

$$\sum_{i=1}^6 W_i (A_i - A) + 4\pi J = 0,$$

where A (see Figure 2) is the vector potential at point C , A_i the vector potential at point C_i and the W_i 's are geometric factors called couplings, which depend also on γ .

This computer program, as mentioned before, works only for a two-dimensional magnet. To use it for a three-dimensional magnet, a plane of symmetry must exist in this magnet. Fortunately, such a plane does exist in our magnetic flow meter; this plane is the (x-y) plane shown in Figure 1. A cross section of the magnet flow meter at this plane is shown in Figure 3. The dotted portion of the circular cross section of the tube indicates a groove in the tube. This figure also shows the square geometry that the coil arrangement assumes in the tube. When the tube is totally surrounded by iron powder, the magnetic flow meter can then (for magnetic field calculation) be divided into three different regions as follows:

1. The iron region which is outside the protective shield and can extend as far out as the boundaries of the fluidized bed allow.
2. The write coils region.
3. The nonmagnetic region inside the protective shield other than the write coils region.

Figure 2: One element of the triangular mesh generated by the computer program.

Figure 3: A cross section of an in-bed tube with the write and read coils.

Figure 4 shows the mesh generated by the computer program for the coil arrangement and the regions described above. Figure 5 shows a plot of the magnetic field generated by the program in the nonmagnetic region and in the surrounding magnetic iron powder. The figure shows a high magnetic-field intensity in the immediate vicinity of the write coils, while it shows a less intense field further away from the coils. In fact, the magnetic field drops down by two orders of magnitude just 1.2 cm away from the write coils. The reason for this rapid drop in the magnetic field intensity is the relatively lower permeability of iron powder caused by the presence of air gaps between the iron particles.

One of the important features of this computer program is its flexibility and ability to accept any conceivable arrangements and combination of exciting coils and magnetic and nonmagnetic medias around them. This feature allowed us to simulate different coil arrangements and the effect of the presence of air bubbles in different parts of the iron region surrounding the coils. Figure 6 shows a plot of a magnetic field similar to that in Figure 5, but with the iron region extending only 1.0 cm in each side of the coils in the x-direction. The plot shows that the magnetic field in the immediate vicinity of the coils is not affected by this change. Such simulation allowed us to estimate the effective region of the exciting coils and hence the pickup region of the read coil.

CALIBRATION

A new method has now been considered to calibrate the magnetic solid flow meter. An "L-valve" such as has been studied by Knowlton and Hirsan² to feed

² T.M. Knowlton and T. Hirsan, Wet and Dry Limestone Feeding Using an L-Valve; the proceedings of the Sixth International Conference on Fluidized Bed Combustion; Vol. II, April 9-11, 1980.

Figure 4: Generated mesh for the magnetic solids flow meter.

Figure 5: Flux line distribution for the solids flow meter.

Figure 6: Flux line distribution for the magnetic solids flow meter with the iron region reduced in the X-direction.

limestone to atmospheric fluidized bed combustors has been designed and is being built for calibration purposes.

OPERATION OF THE L-VALVE

The apparatus consists (Figure 7) of a solids feed hopper at the top of the unit connecting to a long stand pipe through which the iron powder passes in a gravity flow to the L-valve. Control aeration is added to the L-valve at a point just above the 90-degree elbow. The aeration gas causes the iron powder to flow through the 90-degree elbow into the horizontal section of the L-valve.

Knowlton has shown that the operation of the nonmechanical L-valve is dependent upon system pressure drop and geometry. Thus, a pressure balance must be maintained in the system such that the pressure drop in the horizontal section of the L-valve must equal the downcomer and hopper pressure drops.

$$\Delta P_{\text{downcomer}} + \Delta P_{\text{hopper}} = \Delta P_{\text{L-valve}}$$

The downcomer is the dependent part of the pressure drop loop; its pressure drop will adjust to exactly balance the pressure drop produced by the independent part of the loop, in this case the L-valve. However, there is a maximum pressure drop per unit length ($\Delta P/L$) that the downcomer can develop. This value is the fluidized bed pressure drop per unit length $(\Delta P/L)_{mf}$ for the material being used.

The independent pressure drop in the L-valve can be increased by increasing the solid flow rate. The downcomer pressure drop adjusts to balance this increase. If the solids flow rate continues to increase, the downcomer pressure will also keep increasing to balance the pressure drop in the L-valve. This will occur until the $\Delta P/L$ in the downcomer reaches $(\Delta P/L)_{mf}$.

Figure 7: Schematic of L-Valve.

The pressure drop in a downcomer is generated by the relative velocity, V_r , between the gas and solids in the downcomer. When V_r reaches the value necessary for minimum fluidization of the solids, a transition from a packed bed to a fluidized bed occurs. Any further increase in V_r results in the formation of bubbles in the downcomer. These bubbles hinder the flow of solids through the downcomer and thus decrease the solids flow rate.

To determine the minimum downcomer length necessary for an L-valve, it is necessary to know the pressure drop on the independent side of the loop at the solid flow rate desired. The minimum length of downcomer necessary, L_{min} , is

$$L_{min} = \Delta P_{L\text{-valve}} / (\Delta P/L)_{mf}.$$

The actual length of downcomer selected for the L-valve design should be greater than L_{min} to allow for the possibility of a required increase in the in solid flow rate and to act as a safety factor. Typical downcomer lengths might be 1.5 to 2 times L_{min} .

Unfortunately, at this time there are no published correlations to predict L-valve pressure drop and aeration requirements. The best way to determine these parameters is to estimate them from basic data from a small L-valve test unit or to extrapolate them (as is done in our case) from the data given by Knowlton.

The magnetic solid flow meter will be placed horizontally inside the downcomer. Calibration measurements can be made by measuring the output signal from the read coil of the magnetic probe at different solid flow rates which can be varied by changing the aeration gas flow rate.

Different size cross sections of the downcomer have been designed and are being built, to study the effective pickup region of the magnetic flow meter.