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Two-Phase Fluid Density Measurement with a Two-Beam Radiation Densitometer

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ABSTRACT

A densitometer consisting of two beams of radiation passing through a pipe is very useful for measuring the average density and the density distribution of inhomogeneous two-phase fluids in the pipe. The general technique is illustrated by an example.

SUMMARY

Radiation densitometers are gaining acceptance as tools to determine the average density and the density distribution of two-phase fluids in pipes. The primary application of this technique is to inhomogeneous steam-water mixtures encountered in nuclear reactor testing.

In its simplest form, a radiation densitometer consists of a radiation source and a radiation detector on opposite sides of a pipe, with shielding arranged to define a narrow beam of radiation passing through the pipe, as in figure 1. The logarithm of the detector output is proportional to the average of the fluid density in the radiation beam.

The single-beam densitometer of figure 1 obviously gives rather limited information about the fluid density. A single radiation beam wide enough to cover the entire pipe cross section gives a little better information about the average density, but this can give large errors depending on the density distribution. A densitometer using a large number of parallel, narrow radiation beams, each with its own detector, can give a good indication of the average density and considerable information about the density distribution. However, space and cost limitations make such a system impractical.

A good compromise can be obtained with a well-designed two-beam system, if we make some assumptions or have some prior knowledge about the general form of the density distribution. This can be illustrated with an example.

The geometry of the example system is indicated in figure 2. The inside diameter of the pipe was about 0.63 times the mean free path of the radiation in liquid water at standard temperature and pressure.

Since the fluid flow was horizontal, it was expected that the density would be generally stratified, with liquid water at the bottom of the pipe and steam at the top. The actual model chosen to represent the fluid assumed that there was liquid in the bottom of the pipe with depth D, and that above the horizontal surface of the liquid there was foam with void fraction V.

A second model, which is unrealistic except for vertical pipes, was simultaneously considered. In the second model, there was a liquid annulus of thickness D next to the pipe wall, and foam of void fraction V filled the space inside the liquid annulus.

The expected normalized reading for each of the two detectors of figure 2 was calculated, for each of many combinations of values of D and V. These calculations were used to construct the interpretation chart of figure 3. In this chart, curves of constant D and curves of constant V were drawn with the calculated normalized detector readings as coordinate axes. All of the points above the diagonal dashed line represent the stratified fluid model; those below the dashed line represent the annular model; and those points on the dashed line represent a uniform density distribution.

To interpret densitometer data from an experiment, we used the two normalized detector readings as coordinates to locate a point on the interpretation chart, and we read (or interpolated) the values of D and V at that point. Knowing D and V, it was easy to calculate such quantities as the average fluid density.

Tests with plastic models have shown this technique to be quite accurate, with the actual densitometer readings generally within 1% of the calculated readings.

The primary limitation of this method is that the actual density distribution may not conform to the assumed model, and erroneous interpretations may result. However, this problem is much less severe with the two-beam system than with a single-beam densitometer. A few lucite tests have indicated that the average density determination is still quite good, even when the density distribution does not conform to the assumed model.

We conclude that a well-designed two-beam densitometer gives much more information than a single-beam system, and that the extra cost of the second detector is well justified. Automated data interpretation procedures for multiple-beam densitometers are being developed.

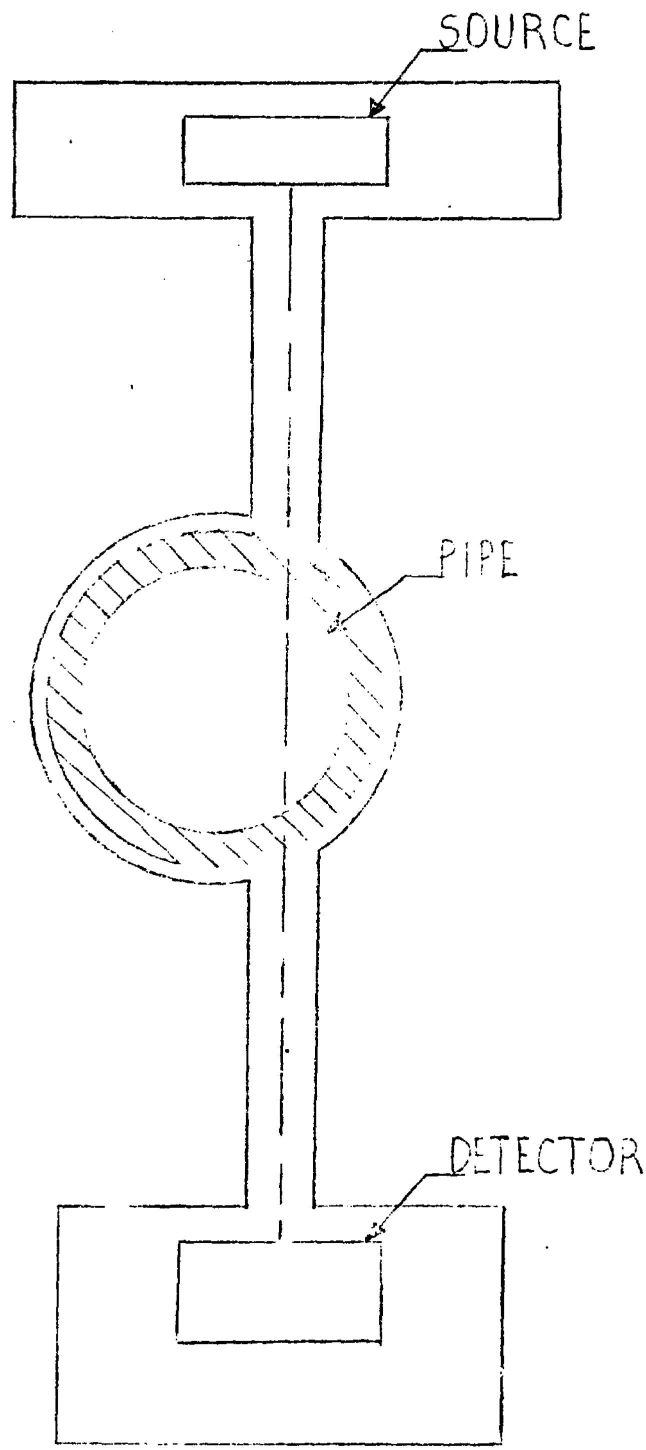

FIG. 1

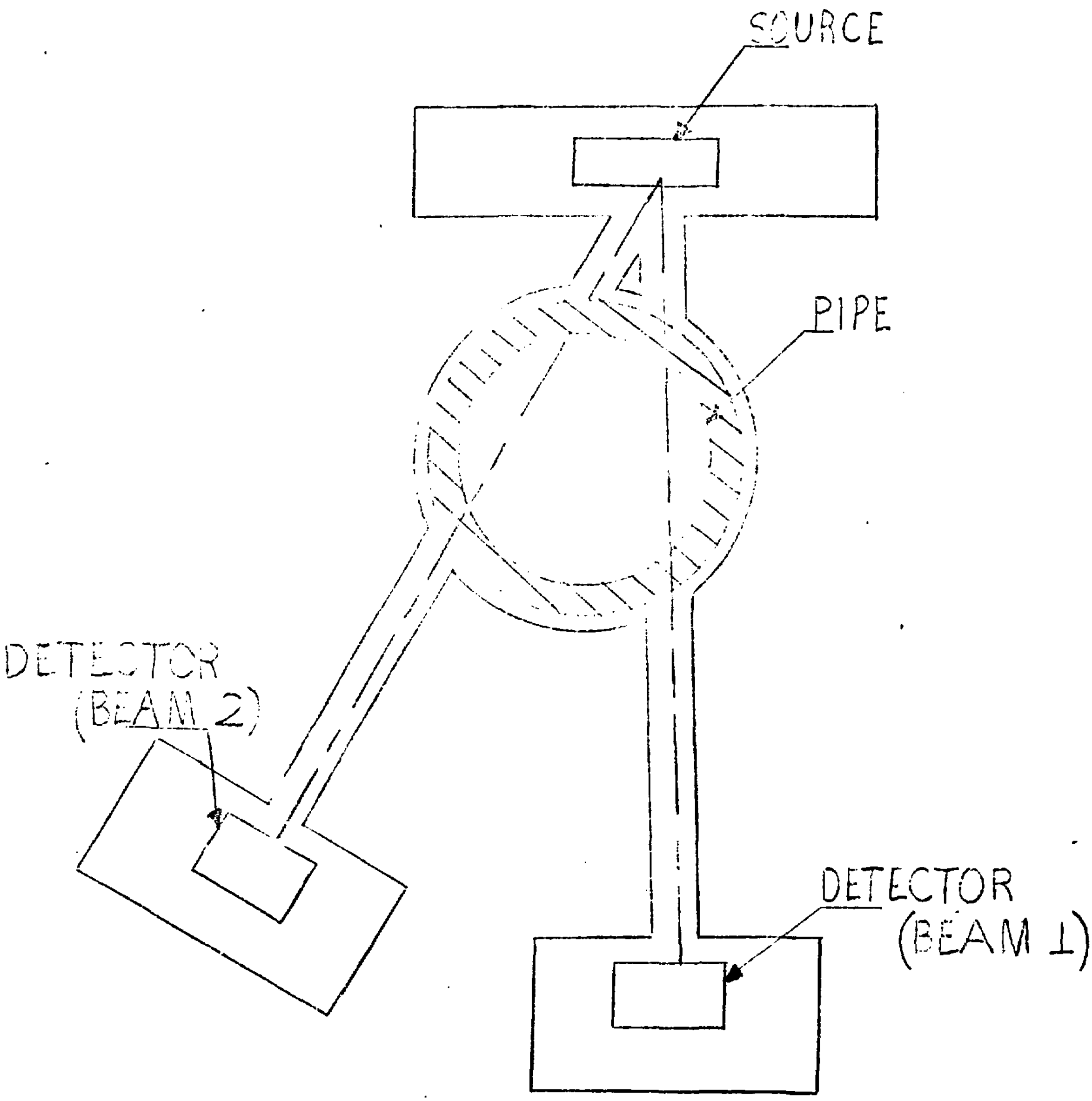

FIG. 2

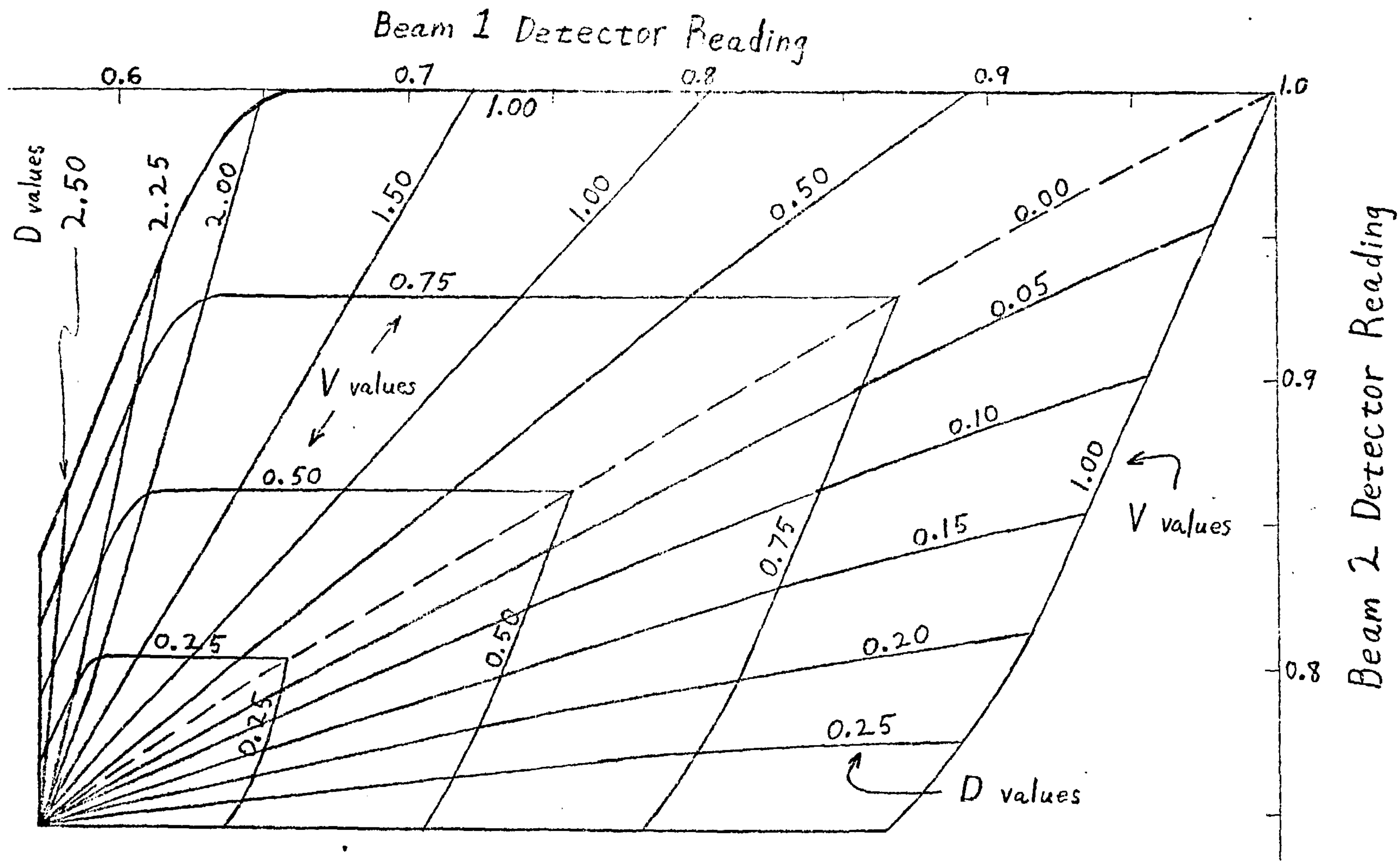

Figure 3. Interpretation Chart.