Harshal B. Nemade, Measurement of single-phase fluid flow by pulsed ultrasound technique using cross-correlation, Ph.D. Thesis, Department of Electrical Engineering, Indian Institute of Technology Bombay, 1999.

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***Abstract* -** In a cross-correlation flowmeter, disturbances in the flow are sensed at two locations separated by a known distance along a pipe. The transit time of the disturbances between the two locations is measured as the delay corresponding to the peak in the cross-correlation function of the two signals. Thus, the flow velocity is equal to the distance divided by the transit time. The measurement is unaffected by variations in the fluid properties and environmental factors.

The present work is aimed at applying cross-correlation principle for non-invasive flow measurement of single-phase fluid, like clean water, using ultrasonic sensing. The turbulent eddies in single-phase fluid flow cause phase modulation of a continuous wave ultrasonic beam sent across the pipe diameter. The problems of variations in the standing waves formed inside the pipe, the acoustic short circuit noise through the pipe wall, and multiple reflections within the pipe have been studied. In order to avoid the problems faced in the use of continuous wave ultrasound, the use of pulsed ultrasound has been investigated and a new technique for sensing naturally available turbulence in the flow has been developed. The turbulence patterns sensed at two locations on the pipe can be cross-correlated and flow velocity can be obtained from the position of the peak in the cross-correlation function.

The technique facilitates sensing variations in the time of flight of ultrasonic pulses, caused by the turbulent velocity components. The velocity component of turbulence perpendicular to the flow axis is sensed by two ultrasonic transducers mounted diametrically opposite on the pipe. The transducers transmit ultrasonic pulses at the same instant and in opposite directions. The pulse after passing through the fluid in the pipe are received by the same pair of transducers and are fed to a differential amplifier. In the presence of turbulence, the instants of arrival of the two pulses are different and the magnitude of differential amplifier output is a function of the turbulent velocity component. The repetition rate of pulse transmission is set higher than twice the maximum frequency component of the turbulence signal, and a sample-and-hold circuit is used after the differential amplifier to reconstruct the turbulence signal.

The technique has been supported by developing a theoretical model of the process and carrying out a numerical simulation of the flowmeter based on the theoretical model. The effect of dispersion in the turbulence pattern and quantization on the peak in the cross-correlation function has been studied. The applicability of the technique has been verified experimentally by building the hardware, and employing it for the measurement of water flow non-intrusively on a PVC pipe, in a water circulation system for various sensor spacing.