01 Apr 1991

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## Recommended Citation

Burget, J. L., "Establishment of a Phase/Doppler Particle Analyzer for Two-Phase Flow Experiments" (1991). *Opportunities for Undergraduate Research Experience Program (OURE)*. 130.
https://scholarsmine.mst.edu/oure/130

# ESTABLISHMENT OF A PHASE/DOPPLER PARTICLE ANALYZER FOR TWO PHASE FLOW EXPERIMENTS

*J. L. Burget*

## Introduction

The accurate measurement of liquid spray drop size and velocity is important in a variety of applications. These applications include agricultural sprays, furnaces, spark ignition and compression ignition engines, gas turbines, and a variety of industrial processes. Because of the need to improve combustion efficiency and minimize soot and other harmful emissions, one of the most active areas of research is fuel spray combustion. Quantitative measurements of the vapor phase in fuel sprays is vital to the understanding of spray dynamics and the operation of combustion devices.

There are various measurement techniques available to measure vapor phase characteristics in a fuel spray including schlieren photography, vapor fluorescence using exiplex emission, and mechanical isokinetic probes. Schlieren photography and vapor flux fluorescence using exiplex emission are nonintrusive techniques which provide only a qualitative picture of the vapor phase. Mechanical isokinetic probes have provided a quantitative picture of the vapor phase, but have the disadvantage of disrupting the flow field.

The Aerometrics Phase Doppler Particle Analyzer (P/DPA) is a laser based instrument that provides a quantitative, nonintrusive method to obtain simultaneous size and velocity measurements. This instrument incorporates the Laser Doppler Velocimeter for flow measurements with particle sizing methods.

My role in this project consists of setup and validation of the P/DPA. This includes developing an appropriate spray set up and making measurements in a variety of spray environments for the validation of drop size, velocity, and liquid volume flux measurements. The instrument will ultimately be used in the investigation of two phase flows, including the measurement of particle size and velocity distributions in fuel sprays.

## Experimental Setup

Spray Setup For validation of the P/DPA a spray apparatus using water was constructed. This apparatus provides the ability to deliver water at a constant pressure to the nozzle. The basic spray apparatus is shown in Figure 1. The spray apparatus functions in the following manner. With the air line valve off, water is introduced into the tank by the T-valve located at the bottom of the tank. When the tank is filled to an appropriate level, the T-valve is shut off and the tank is pressurized by turning on the air line valve and adjusting the pressure regulator. A readout of the pressure in the tank is provided by a pressure gage. To produce spray, the T-valve is opened in the direction of the line flowing to the nozzle. The spray collection bucket functions to collect the spray through the aid of gravity and a vacuum port, which drawls the spray into the bucket. The manually operated pump functions to expel the water from the bucket into a laboratory drain. The pressurized water tank was attached to the side of a moveable cart, and the cart was modified with an additional set of wheels and frame structure to hold the collection bucket. This was done to provide mobility of the spray apparatus.

## P/DPA Background Theory

The optical diagram for the P/DPA is shown in Figure 2. A drop passing through the intersection of the two beams produces a scattered light interference fringe pattern similar to the one shown in Figure 3. The spacing between these projected fringes is proportional to the drop diameter, light wavelength, beam intersection angle, drop refractive index, and the location of the receiver. These fringes move past the detectors at the Doppler difference frequency and produce a Doppler burst signal at each detector which is similar to the one shown in Figure 4. The Doppler burst produced at each detector is shifted in phase from one another. Figure 5 shows the Doppler burst produced at each detector after high pass filtering to remove the low frequency component. The phase shift between detector 1 and 2 is determined by measuring the time difference between zero crossings of each signal and dividing by the measured Doppler frequency.

$$\Phi 12 = \frac{\Gamma 12}{\Gamma D} \times 360^\circ \tag{1}$$

These measurements are averaged over all cycles occurring in the burst signal. This phase shift is related to the drop size by the linear relationship shown in Figure 6. This relationship was computed from a mathematical representation of the scattered light fringe pattern. In this figure, the drop size is made non dimensional by a parameter (DELTA) which is an assumed fringe spacing formed at the intersection of the beams, and which is a function of light wavelength and laser beam intersection angle. Three detectors are used to eliminate the uncertainty in measurement and to provide two sensitivity ranges shown as curves ø1-2 and ø1-3 in Figure 6.

Assuming the drops remain spherical, the method described above provides the ability to measure drop sizes in the range of 0.5 to 3,000 micrometers. Because the drop size and velocity are measured simultaneously, the P/DPA is capable of providing a complete description of the drop distribution within the spray.

## P/DPA System Description

The P/DPA consists of five major components. These components are a transmitter, receiver, signal processor, motor controller, and computer. A very general description of each component follows.

The Aerometrics, model XMT-1100-4S transmitter shown in Figure 7 generates two equal intensity laser beams and focuses them at an intersection point which serves as the measurement region. The transmitter contains a Spectrum-Physics model SP-106, 10 milliwatt, polarized helium-neon laser and optical components which serve to focus, partition, and collimate the laser beam.

The Aerometrics model RCV-2100 receiver shown in Figure 8 collects scattered light and provides the signal phase shift required for determination of drop size. The package consists of a highly efficient lens system for light collection, a spatial filter for exact probe volume definition, a light partitioning prism assembly, and multiple detectors complete with preamplifiers.

The Aerometrics DSA 3000 signal processor, not shown, is a state-of-the-art frequency domain signal processor which analyzes and processes the Doppler burst signals. The proper selection of instrument parameters is necessary in order to obtain reliable data. The selection of instrument parameters is accomplished through software that provides complete control of the processor in all stages of data acquisition, analysis, and presentation. Some of the instrument parameters selected through the software includes various filtering networks, mixer frequency, frequency shifting, sampling frequency, number of samples, signal threshold, and velocity range.

The Aerometrics model MCB-71001-1 motor controller, not shown, monitors both the frequency shift and track select motors located in the transmitter. In addition, the motor controller serves as a multiplexor for other accessories connected to the system.

The data management system consists of a Kapro personal computer, Amdek color monitor, and a Fujitsu DL3300 Printer. The personal computer is enhanced with expanded memory, an 80287 math coprocessor, and an EGA card. The computer contains the system software which allows control of the signal processor, and is used for data handling and reduction. The system produces histograms of the droplet size and velocity on the monitor as the data is accumulated. Sample time and the number of samples recorded is also displayed. When a preset number of samples have been measured, the tabulated results can be printed or stored on disk.

## Results

The original goal of this project was to use operate the Phase Doppler Particle Analyzer to make measurements in a variety of spray environments under controlled conditions for the validation of drop size, velocity and liquid volume flux measurements. This was a new piece of equipment being purchased by the university and was scheduled to be delivered prior to the beginning of the project. Due to a series of delays on the part of the manufacturer, the equipment did not arrive until the middle of the fall semester and validation of the system became unrealistic given the time constraints. Therefore, the sensitivity of the system to variation in a few setup parameters was investigated using the spray apparatus discussed previously.

The setup parameters investigated were the photomultiplier tube (PMT) voltage and the high pass filter settings. The effect of these setting on Sauter mean diameter (SMD) and mean velocity can be seen in Figures 9 through 12. The PMT voltage basically provides a gain to the Doppler burst signal and therefore determines the size of particle data that will be processed. Figures 10 and 12 show a decrease in SMD and mean velocity as the PMT voltage is increased from 300 to 350 Volts and then an increase in both quantities as the voltage is increased to 400 Volts. The low pass filter helps to improve the signal to noise ratio before the signal is sampled. Figures 9 shows a decrease in SMD as the filter setting in increased past 10 MHz, and Figure 11 shows a decrease in mean velocity as the setting is increased from 5 MHz to 20 MHz and then an increase in mean velocity at the 40 MHz setting.

## Conclusions

Due to a series of delays by the manufacturer of the equipment that the major part of this project was dependant upon, the objective of validating the system was not accomplished. Even though this major objective was not accomplished, a spray apparatus was constructed and a small amount of time was spent operating the system and investigating it,s sensitivity to variations in system parameters. The system was found to be sensitive to variations in both of the parameters investigated. A more complete picture of the variation of the system could be obtained if a larger number of data points are obtained with a spray setup that produces a known, constant size particle. Even though the major objectives of the project were not accomplished, this project provided experience in the area of experimental research, and an introduction to fuel spray characterization and basic laser diagnostic principles.

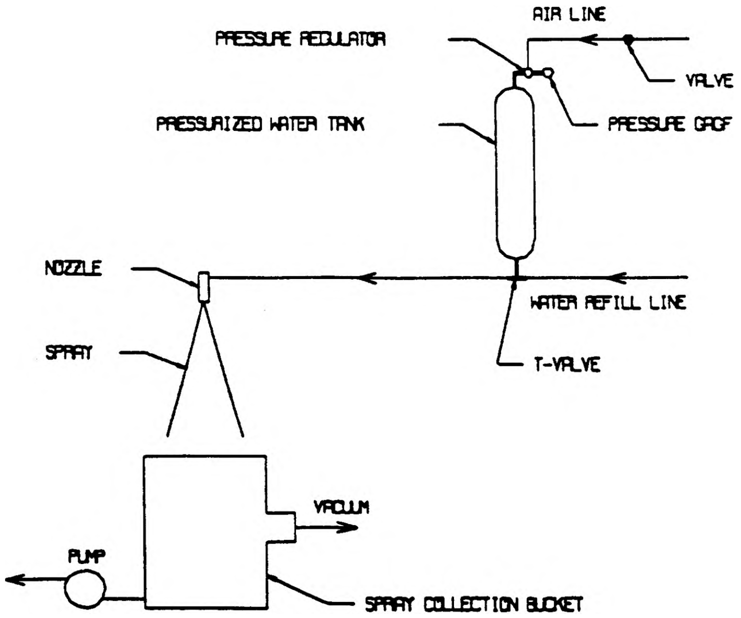

Figure 1 Spray Setup

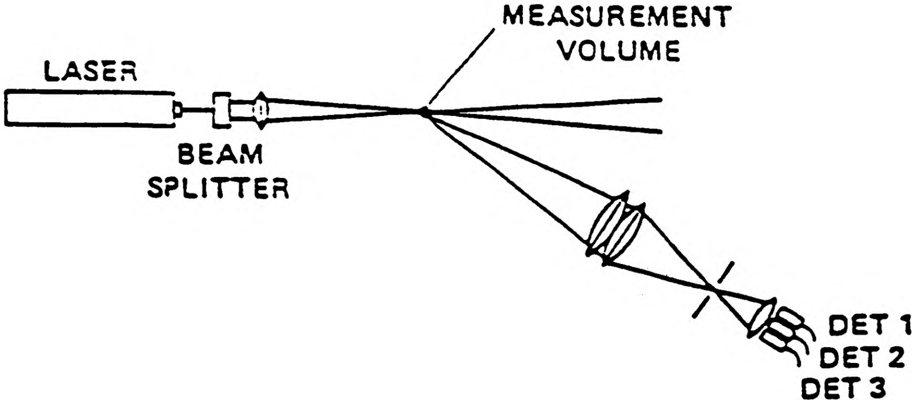

Figure 2 P/DPA Optical Diagram

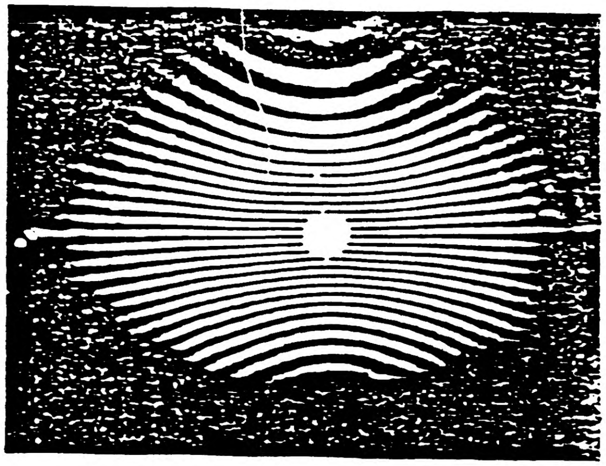

Figure 3 Scattered Light Interference Fringe Pattern

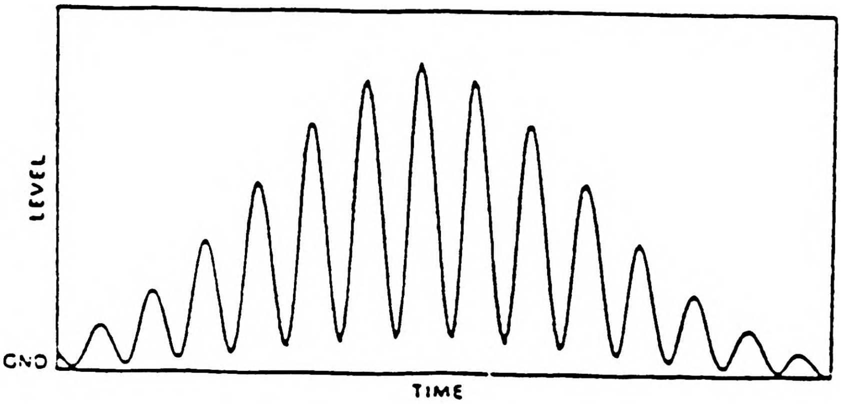

Figure 4 Doppler Burst Signal

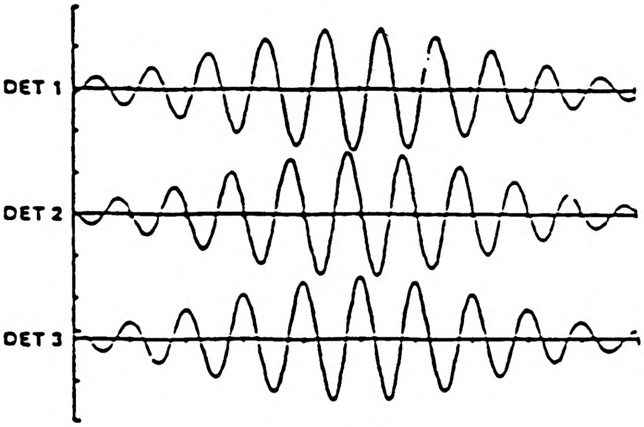

Figure 5 Filtered Signal Produced at each Detector

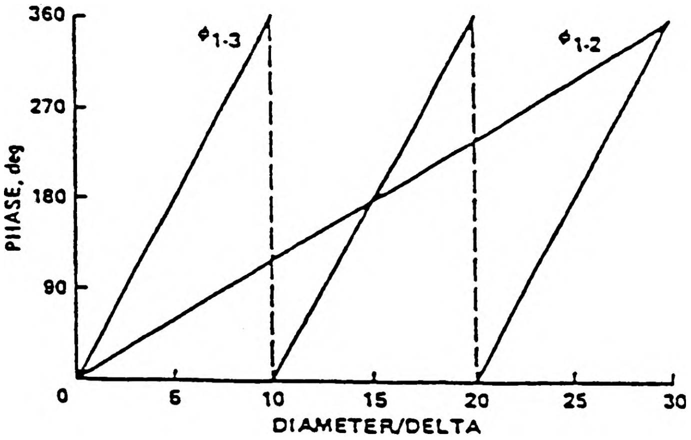

Figure 6 Linear Phase Shift Variation with Drop Size

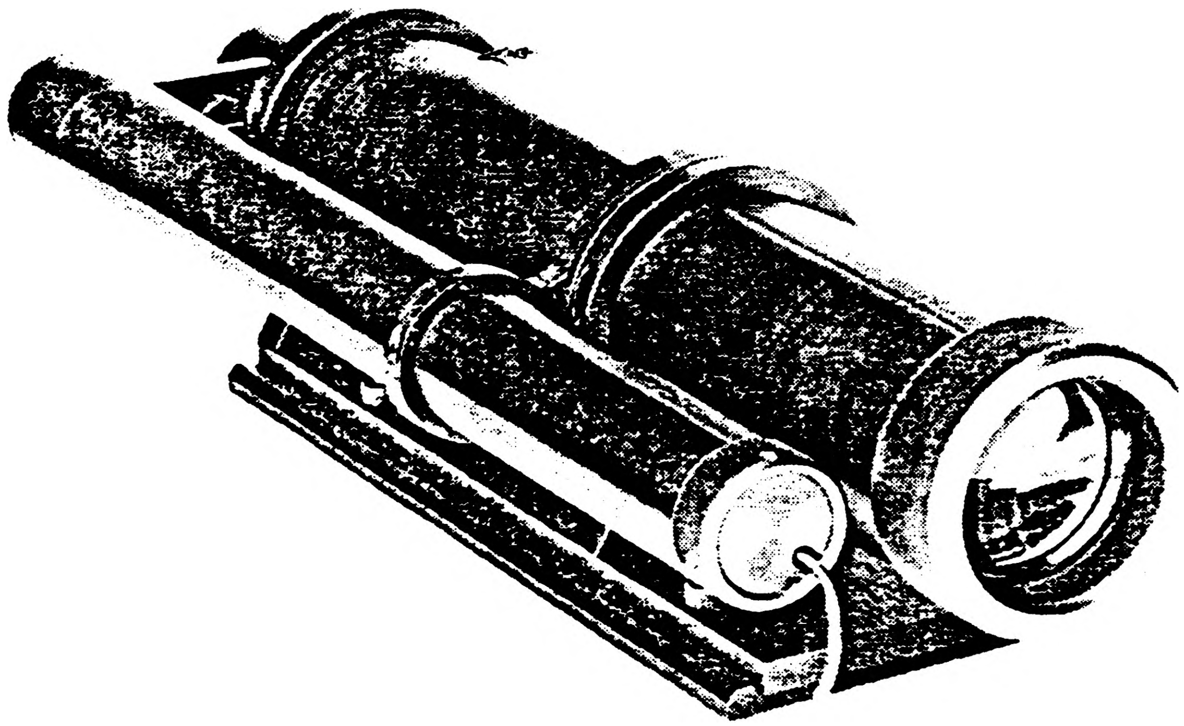

Figure 7 Transmitter Model XMT-1100-4S

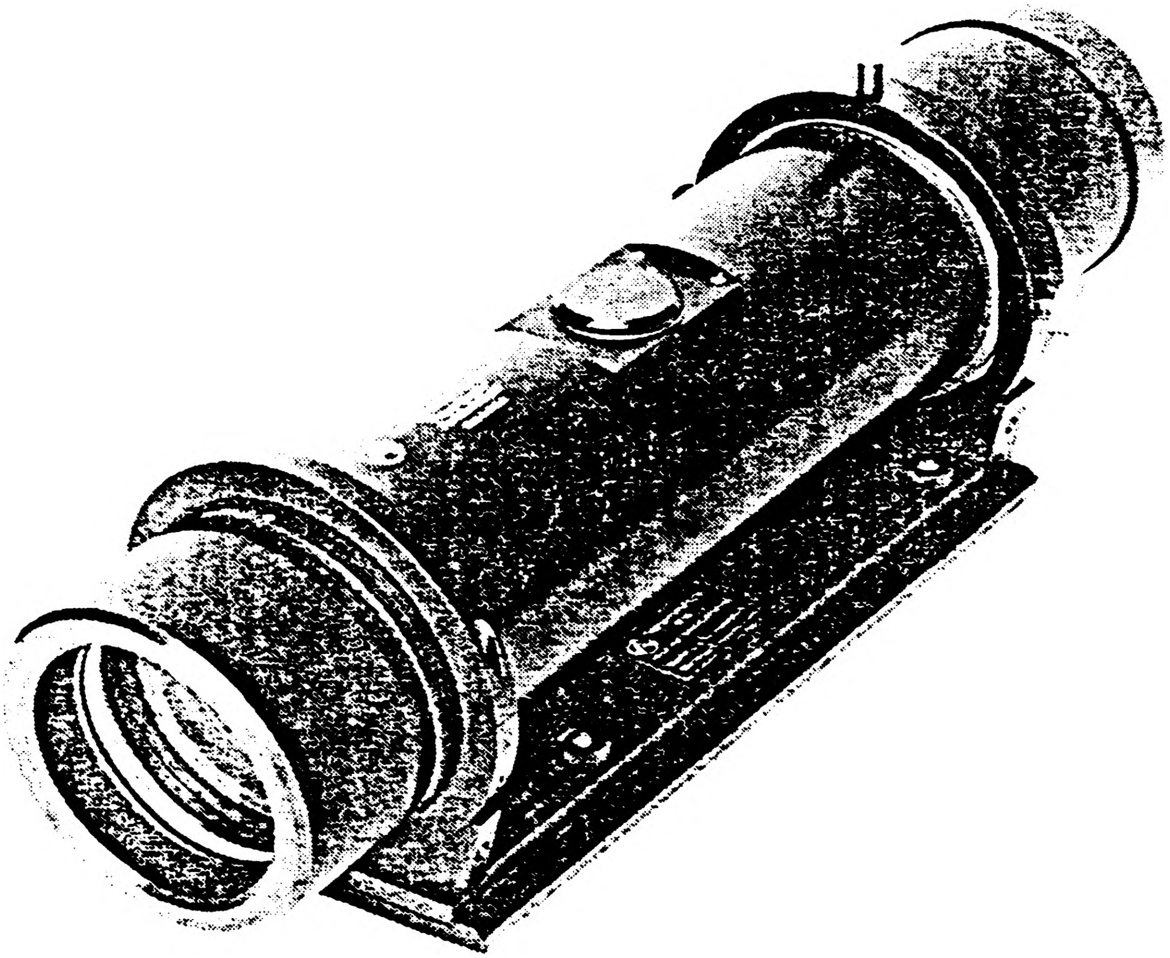

Figure 8 Receiver Model RCV-2100

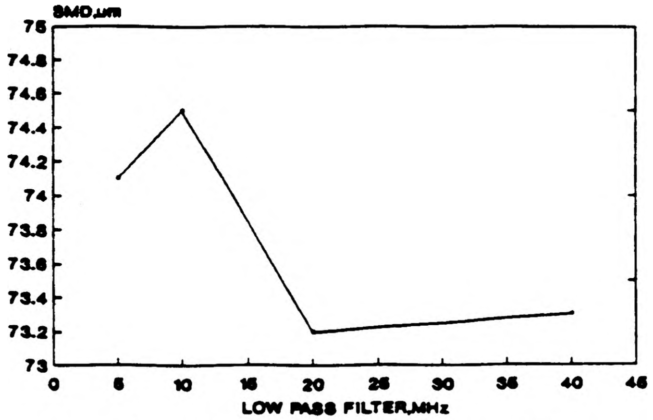

Figure 9 Plot of SMD Vs. Low Pass Filter Setting

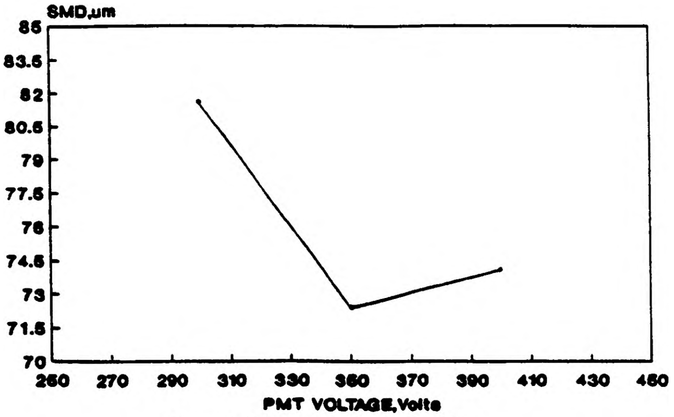

Figure 10 Plot of SMD Vs. PMT Voltage

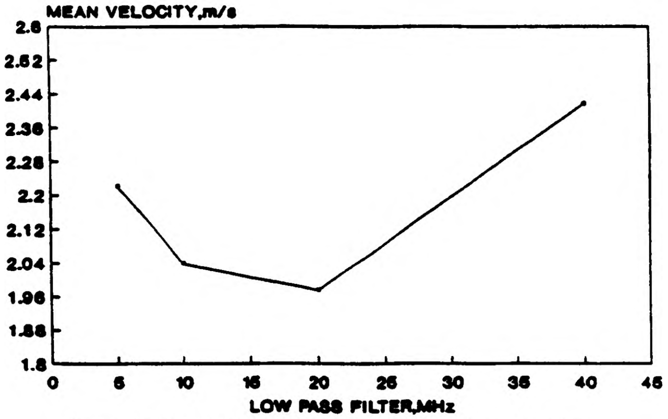

Figure 11 Plot of Mean Velocity Vs. Low Pass Filter Setting

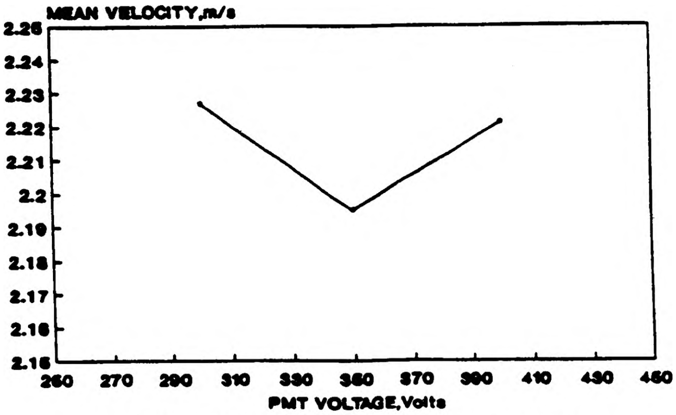

Figure 12 Plot of Mean Velocity Vs. PMT Voltage