PREPRINT UCRL- 79685

Conf-771029--7

Lawrence Livermore Laboratory

MICROCOMPUTER-BASED PELLET TRAJECTORY GUIDANCE SYSTEM
FOR THE BASEBALL II-T EXPERIMENT

W. K. Mortensen

October 15, 1977

MASTER

This paper was prepared for submittal to the Proceedings of the Seventh Symposium on Engineering Problems of Fusion Research, Knoxville, Tennessee, October 25 to 28, 1977.

MICROCOMPUTER-BASED PELLET TRAJECTORY GUIDANCE SYSTEM FOR THE BASEBALL II-T EXPERIMENT*

W. K. Mortensen

Lawrence Livermore Laboratory, University of California
Livermore, California 94550

Summary

In the Baseball II-T experiment a pellet generation and injection system was employed to place frozen ammonia pellets at the focus of a laser beam. The original trajectory guidance system suffered a number of problems that limited its accuracy and complicated the operation of the system. These problems were related to variable charge-to-mass ratios, timing, pellet discrimination, and computer speed. The original system design was improved by changes to the sensing components, microcomputer, and trajectory guidance system.

Introduction

The purpose of the pellet injection system[1-3] in the Baseball II-T experiment was to form a pellet of frozen anhydrous ammonia (NH_3), approximately 150 µm in diameter, and inject it on a horizontal path to the focal point of a 300-J CO_2 laser beam. The target area through which the center of pellet was required to pass was approximately 100 µm in diameter. The nature of the pellet generator required that the liquid ammonia droplet pass through an orifice from a low to a high vacuum system, where the droplet became frozen (see Fig. 1). Air turbulence at the orifice introduced a random perturbation to the velocity and trajectory of the pellets. To guide the pellets into the target area at an acceptable success rate, a system of charge-sensitive amplifiers, peak-holding circuits, and analog and digital arithmetic circuits was used to: sense the pellet's position, trajectory, and charge-to-mass ratio; compute the correction required; and generate the appropriate voltages on the deflection plates to guide the pellet into the laser focal area. The heart of the guidance system was a microcomputer. This computer collected the parameters and solved the appropriate equations for the x and y correction voltages. As a result of a number of deficiencies in the original system, improvements were made in the microcomputer, sensing components, and guidance system.

The original system was able to guide the pellets into a target area only approximately 1 mm in diameter. A number of problems were identified that either limited the accuracy or complicated the operation of the system. These problems were related to variable charge-to-mass ratio of the pellets, timing in the pellet-position-sensing circuits, pellets discrimination, and computer speed.

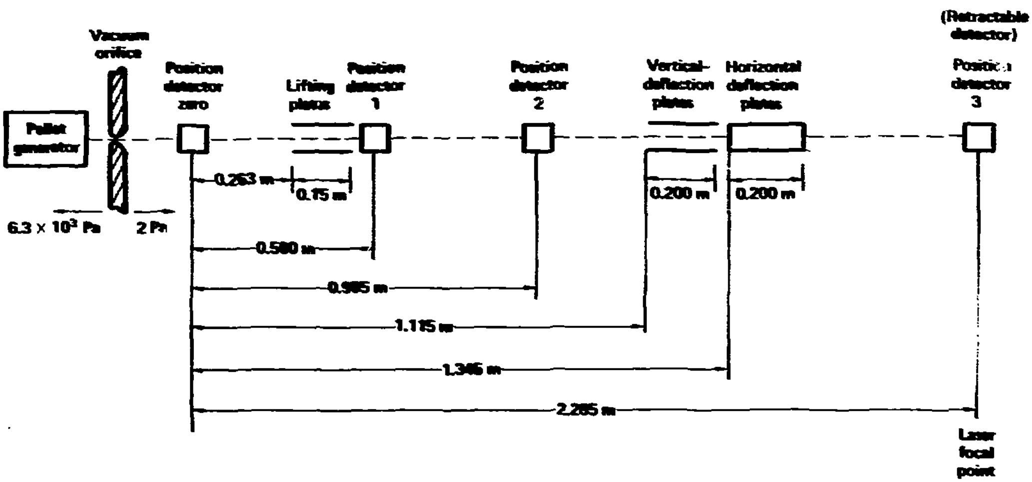

Fig. 1. Placement of system components.

*This work was performed under the auspices of the U. S. Energy Research and Development Administration, under contract No. W-7405-Eng-48.

The Improved System

Correction for Variations in Charge-to-Mass Ratio

The pellet charge-to-mass ratio varied with time and even varied from pellet to pellet. It had been assumed that the charge-to-mass ratio would remain constant (approximately 10^{-4} C/kg). It was decided to measure and account for the charge-to-mass ratio for each pellet guided.

Two position detectors are sufficient to determine the velocity and location of a pellet trajectory. The addition of a third position detector and lifting plates to change the trajectory were required to determine the charge-to-mass ratio. The placement of the components is shown in Fig. 1.

Solution of Timing Problems in the Analog Arithmetic Circuits

Two timing problems existed with the analog arithmetic circuits in the original system. First, the peak signals from the four electrodes in a given detector did not arrive in coincidence at the sum and difference amplifiers (see Fig. 2). This resulted in errors in the analog position information. Second, the sample-and-hold circuits for the analog-to-digital conversion were triggered by the signal from the sum amplifier. Since the duration, as well as the amplitude, of this signal was dependent upon the pellet charge, the time between the trigger threshold and the peak value of the pellet-position pulse also varied in an unpredictable manner. These timing problems seriously affected the reliability of the position information to the computer. Both timing problems were corrected by the incorporation of peak-holding amplifiers that tracked and held the peak values of the signals from the detector electrodes (Fig. 2). The peak-holding amplifiers eliminated the requirement for sample-and-hold circuits. They also produced a status signal useful in the timing and logic circuits described below.

Timing and Logic Circuits to Improve Pellet Discrimination

The system was capable of controlling about 12 pellets per second. This was less than 1% of the pellets that entered the system through the vacuum orifice. The original system lacked controls that could adequately prevent the computer from collecting position data on a different pellet at the second detector. This resulted in frequent meaningless corrections to the pellet trajectories.

Timing and control logic and a multiple-trace oscilloscope (see Fig. 3) incorporated on the second system made it possible for the operator to adjust time delays and time windows to select and track a given pellet through the system. This largely eliminated the problem of confusion of pellets that had existed on the earlier system.

The peak-holding amplifiers on the new system provided two features that proved useful in solving the problem of pellet discrimination. (1) The status output from the amplifier was "true" when tracking and "false" when holding; this signal went false at the instant the pellet passed the plane of the electrodes in the position detector. (2) The peak-holding amplifier had an adjustable threshold; this threshold was set such that pellets too far off center would not be sensed.

Status signals from the peak-holding amplifiers were used by the timing and control logic to determine

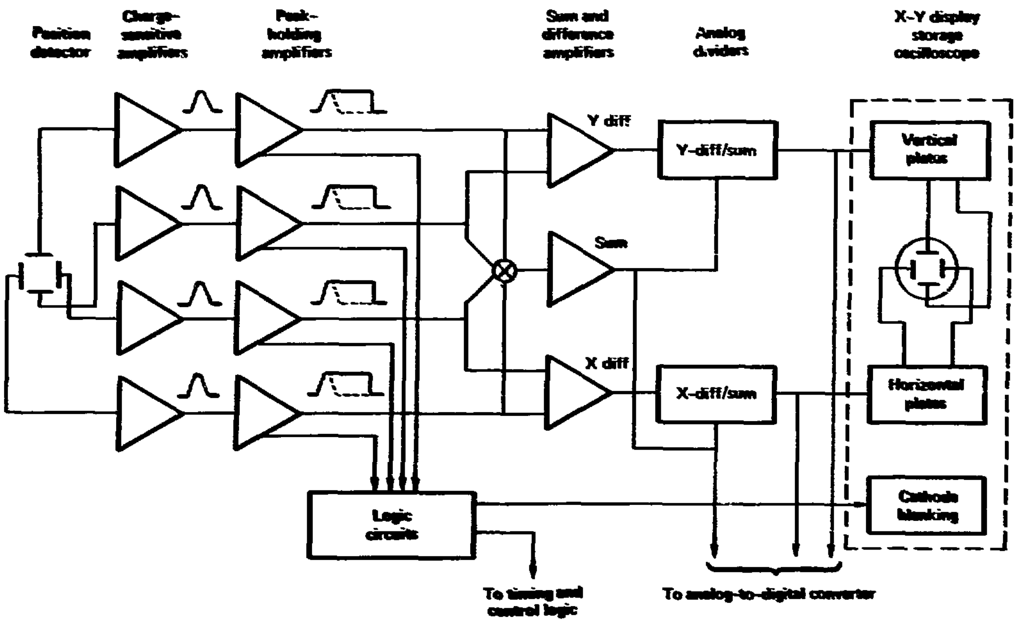

Fig. 2. Position-detector instrumentation channel.

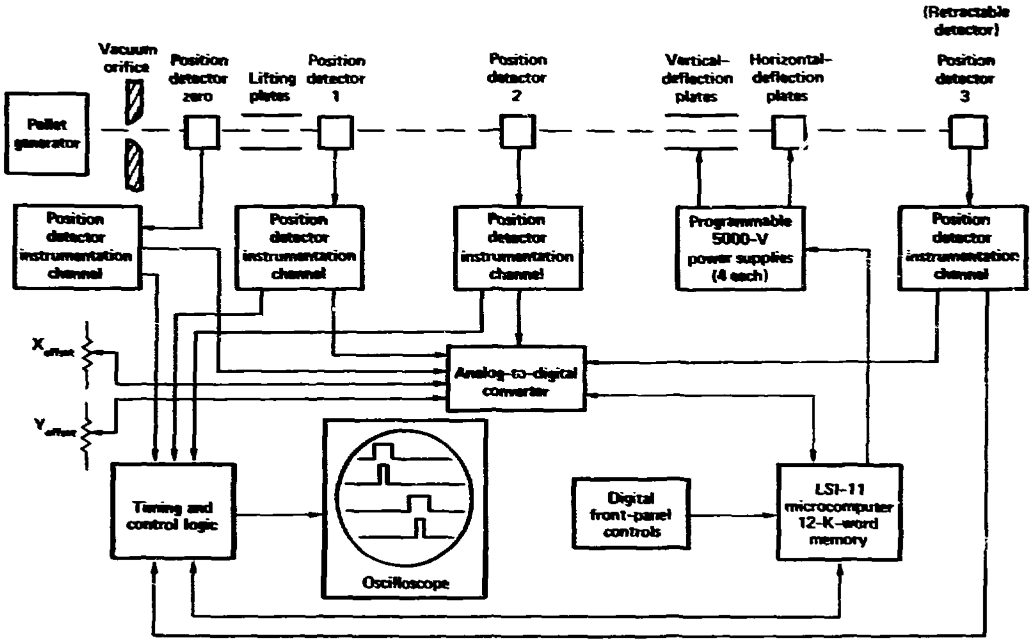

Fig. 3. Pellet-trajectory control system.

either that the position information was ready, or that the selected pellet had not passed through the center of the position detector during the allotted time window. In the former case, the computer collected the position data. In the latter case, the computer abandoned that pellet and looked for another pellet at the first position detector.

Larger and More Powerful Microcomputer

The original computer barely had time to compute the correction voltages before the pellet reached the deflection plates. A faster computer was required to perform the additional required computations to take into account the charge-to-mass ratio.

The new guidance system was designed around an LSI-11 microcomputer, complete with an extended arithmetic element. This computer provided the speed and computational power required to solve the more complex equations.[4] These equations are:

$$E_y = G_y \frac{Y_{os} - Y_2 + k_1 Y_1 + k_2 T^2}{Y_2 + k_0 Y_0 + k_1' Y_1 + k_3 T^3}$$

$$E_x = G_x \frac{X_{os} - X_2 + C_0 X_0}{Y_2 + k_0 Y_0 + k_1' Y_1 + k_3 T^3}$$

where

E = correction voltage at the vertical (y) and horizontal (x) deflection plates.

G = vertical (y) and horizontal (x) gain.

Y_{os} = vertical position voltage.

X_{os} = horizontal position voltage.

Y_0, Y_1, Y_2 = vertical displacements of the pellet at detectors 0, 1, and 2.

X_0, X_2 = horizontal displacements of the pellet at detectors 0 and 2.

T = time of flight from detector 0 to detector 1.

C_0, k_0, k_1, k_1', k_2, and k_3 are constants fixed by the geometry of the system. Y_{os} and X_{os} are controlled by the operator through 10-turn potentiometers on the front panel, and are used to adjust the vertical and horizontal position of the stream of pellets at the laser focal area. G_x is controlled by the operator through digital thumbwheel switches on the front panel to adjust the focus of the stream of pellets at the laser focal area. G_x differs from G_y by a constant multiplier that can be varied in the computer to adjust for pellet-stream astigmatism at the laser focal area.

Implementation

Since the alignment hardware for the third position detector was not ready for operation when the new pellet guidance control system was ready, we decided to initially install the system with only two position detectors. The new system was programmed to solve the old guidance equations for a two-detector system.[1] At the first scheduled shutdown, planned for about 2 mo hence, the third position detector was to be installed to complete the system. The third detector was never installed, because during the initial run it was decided to discontinue the Baseball II-T experiment and devote the space and manpower to the forthcoming TMX experiment.

The portion of the new system that was checked out appeared to meet all its design goals, including easier control by the operator. No significant improvement in the accuracy was achieved, nor had it been anticipated, without the implementation of the third position detector.

Acknowledgement

I wish to acknowledge the contributions of A. Bogdanoff, R. K. Goodman and G. D. Porter.

References

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