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LAWRENCE LIVERMORE LABORATORY
*University of California/Livermore, California*

# PELLET TRAJECTORY CORRECTION

A. Bogdanoff

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A. Bogdanoff
University of California, Lawrence Livermore Laboratory
Livermore, California 94550 USA

## Introduction

The need for pellet trajectory correction at CTR's Baseball II magnetic confinement experiment arose when it was decided to use Laser heating of small pellets for the production of the initial plasma target for trapping energetic neutral beams.

The original pellets were made of frozen ammonia droplets.[1] The process for making these pellets calls for a horizontally aimed nozzle shooting liquid ammonia droplets into a low vacuum chamber, then through a series of small orifices into a high vacuum chamber. It is in this transition from low vaccum to high vacuum that the pellets are frozen and, unfortunately, subjected to wind turbulence, where they acquire random trajectories and varying velocities.

There are two ways to correct this: 1) design non-turbulent orifices, and/or 2) design a trajectory correction system. The end result has to be that the 100 μm diameter pellet traveling at approximately 35 meters/sec has to be struck with a Laser beam 80 μm diameter and 50 ns wide. Thus, the guidance system has to direct the pellet to a target area of at most 100 μm diameter.

## Guidance System

The three things the guidance system has to do is to determine the trajectory and velocity of each pellet, and make mid-course corrections. The equation for calculating mid-course correction is

$$E(X) = \frac{M}{Q}\,\frac{Vz^2\left(X(Z) - X_1\frac{Z}{Z_1} - X_0\left(1 - \frac{Z}{Z_1}\right)\right)}{Z - Z_1 - Z_x - \frac{\Delta X}{2}}$$

where $Vz$ = velocity = 30 to 40 meters/sec

$Z$ = Distance from first position detector to target = 230

$Z_1$ = Distance between first and second detectors = 40

$Z_x$ = Distance to X deflection plate = 40 cm

$\Delta X \approx 10$ cm = Dimension of plate

$X_0$ = X position of pellet at first position detector

$X_1$ = X position of pellet at second position detector

$X(Z) = 0$ if target is exactly on trajectory center-line

$M/Q$ = Mass to charge ratio

Substituting Y's for X's gives the Y direction equation.

The guidance system is shown in Figure One. The first pellet position detector is the start of the guidance system. Here the pellet is traveling horizontally at about 30 to 40 meters/sec. Eight centimeters down stream there is a velocity detector followed by a second position detector and then the X and Y deflection plates.

The block diagram, Figure Two, shows the position detectors which consist of four plates symmetrically positioned about the pellet trajectory center-line. Because the pellets are electrostatically charged, they will induce a charge on the four plates proportional to their actual fly-by position. Charge sensitive amplifiers convert these induced charges to voltages which are combined in three ways: 1) Sum. All four signals summed together to give total charge on the pellet, 2) X Difference. The X axis signals are combined differentially to give the X pellet position and 3) Y Difference. The Y axis signals are combined differentially to give the Y pellet position.

These signals then proceed, by program control, to the sample and hold modules, then through the multiplexer to the A to D converter and then to the memory. Other data that has to be stored in memory is: 1) the time of flight of the pellet over the distance from the first position detector to the steel washer velocity detector, and 2) X(Z) and Y(Z), the amount the target is off-line from the center-line of this pellet trajectory. The time of flight is obtained from an H. P. counter which is started by the sum voltage of the first detector and stopped by the signal from the steel washer velocity detector. To save computer time, hardware conversion is used to convert the H. P. BCD signals to binary. The X(Z) and Y(Z) signals are hand controlled with 10 turn helipot to line the pellets on target. By the time a pellet arrives at the first deflection plates, the microprocessor has already finished and applied the Y axis correction calculations. While the pellet is traveling through the Y deflection plate, the final calculations are done and applied to the X deflection plates.

One final thing the microprocessor does, before it loops back to the start for the next pellet, is to ring the bell on the teletype. When things are running smoothly, the bell rings about 5 times a second.

The software program makes use of floating point arithmetic[2] and was compiled using an assembler[3] and simulator[4] available at the LLL Computer Center. The simulator was most helpful as it has the feature of calculating the time it takes to run a program. This way we were able to determine the time for doing floating point arithmetic (4 1/4 ms for division and 2 1/4 ms for multiplication) and make our first estimates of where to place the detectors.

To calculate the velocity and velocity squared requires one division and one multiplication, which adds up to about 6 1/2 ms. Because the pellets travel at about 32 m/s, then, placing the second detector 32 cm away from the velocity detector would give 10 ms of time, plenty of time for that calculation.

The rest of the calculations has to be done after the second position detector. Here there are two floating point multiplications, two nonfloating point subtractions, two integer to floating point conversions, and one floating point to integer conversions, for each of the two pair of deflection plates. By placing the vertical plate 40 cm away, will given enough time to calculate and apply the correction voltage to the ver-

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tical deflection plate and even start the calculation for the horizontal plates. The additional 20 cm (6ms), the length of the deflection plates, gives plenty of time to do the rest of the calculation.

## Hardware

The system is made up of two chassis: 1) the MCS 80 microprocessor and digital logic control, and 2) the analog portion of the systems.

The MCS 80 microprocessor[5] is a standard chassis here at the lab. It is a chassis of pre-wire-wrapped Control Logic Card Connectors, the basic system consisting of 8 Control Logic Printed Circuit Cards. The cards are 1) the 8080 Microprocessor Board, 2) the 8080 Control Board, 3) the 8080 I/O Device Decoder, 4) Low Speed 8 x 512 PROM, 5) High Speed 1K RAM, 6) Universal Asynchronous Receiver/Transmitter, 7) Electronic Keyboard Interface and 8) High Speed Paper Tape Reader Interface. It is also pre-wired to take up to 20 cards of different types of memory, up to a maximum of 16K. There is also room available for 16 Control Logic cards for user's design hardware. The pellet guidance system uses 15 cards, for triggering multiplexers and sample and hold modules, for setting flags, for tri-state buffers, storage registers and D to A converters. This hardware has to be changed from time to time due to changes in experimental set up, however, this is not difficult as all the wiring is wire-wrap and relatively easy to change.

The analog chassis, also a Control Logic bin, has 11 cards, some are standard Control Logic cards such as the 8 Channel Analog Multiplexer, the 12 Bit A to D Converter and the BCD to Binary Converter, while the others are bread-boards such as the sample and hold, and, sum and difference operational amplifiers. These are wired, more or less, in the general analog multiplexing procedure.

Figure 3 shows a picture of a Position Detector. Each plate is wired to the gate of a FET, to a high meghom resistor and to a 68 pf feedback capacitor. The need for a short wire from the detector plate to the FET precludes this portion of the charge sensitive amplifier to the inside of the vacuum chamber. Each FET is then brought to the outside world, by 3 coaxial cables, to the rest of the charge sensitive amplifiers.

## Experimental Diagnostics

The diagnostics used for physically alligning the position detectors and for setting up the constants and variables in the microprocessor consists mostly of X-Y storage oscilloscopes with Z axis beam modulation. By intensifying the beam at the peak of the position detectors X and Y difference voltages, one gets an end view display of where the pellets actually are. This way, the display will show, if a greater number of the pellets are favoring a non-center position, and thus mechanical adjustments in the pellet generator can be made to center the pellets. The same can be done at the target end, however, even though the pellets are focused, they may be off target; thus, a different type of position detector is needed.

Here the detector is a 4 by 4 matrix of individual 1 cm square detector plates with a 5 mm hole in the center of the whole matrix. Each detector plate has a charge sensitive amplifier which feeds a trace on a multitrace oscilloscope. The 5 mm hole has a smaller version of a position detector behind it. If the guidance is way off, the pellets will strike somewhere on the detector matrix. By watching the scope traces and adjusting the X(Z) and Y(Z) 10 turn potentiometers, the trajectory can be guided to the 5 mm hold. Here, again, a storage scope is used to simulate the end view of the pellet position.

As of this date the pellets have been guided to a target area of 1 mm. The goal is .1 mm. Improvements, such as taking into account variations in pellet charge, and, quicker ways, other than teletype, of changing fixed program parameters, are now being made. Also, improvements in the pellet generator are being made to eliminate varying pellet charge. With these and perhaps other improvements, I'm sure we will be able to reach our goal and even better it.

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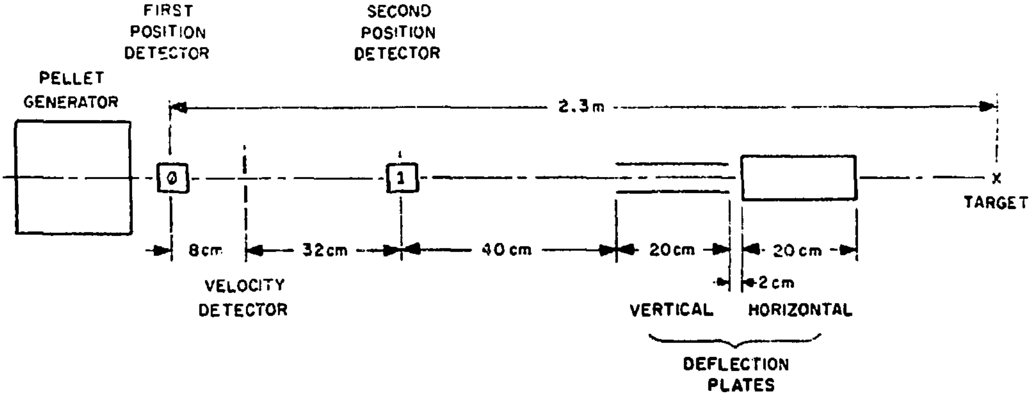
FIRST
POSITION
DETECTOR
SECOND
POSITION
DETECTOR
PELLET
GENERATOR
2.3 m
0
1
X
TARGET
8 cm
32 cm
40 cm
20 cm
20 cm
2 cm
VELOCITY
DETECTOR
VERTICAL
HORIZONTAL
DEFLECTION
PLATES

FIGURE 1.

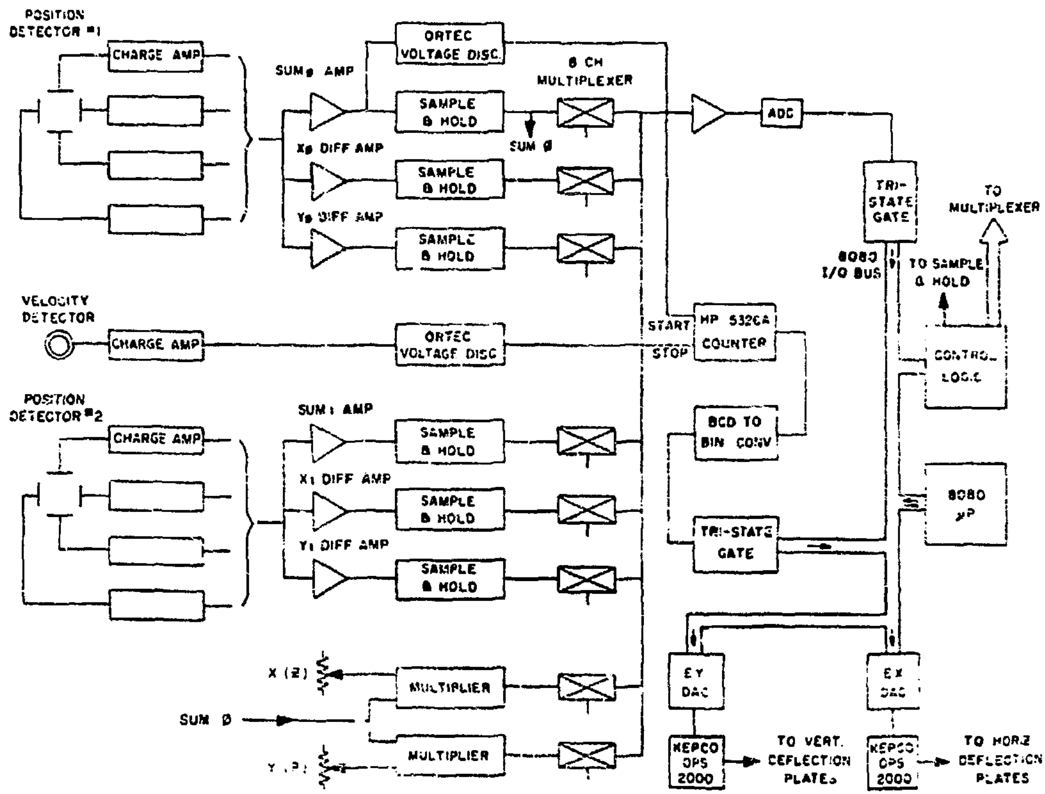
POSITION DETECTOR #1
CHARGE AMP
SUM∅ AMP
X∅ DIFF AMP
Y∅ DIFF AMP
ORTEC VOLTAGE DISC.
SAMPLE & HOLD
SAMPLE & HOLD
SAMPLE & HOLD
8 CH MULTIPLEXER
SUM ∅
ADC
TRI-STATE GATE
TO MULTIPLEXER
8080 I/O BUS
TO SAMPLE & HOLD
VELOCITY DETECTOR
CHARGE AMP
ORTEC VOLTAGE DISC
START
STOP
HP 5326A COUNTER
CONTROL LOGIC
POSITION DETECTOR #2
CHARGE AMP
SUM1 AMP
X1 DIFF AMP
Y1 DIFF AMP
SAMPLE & HOLD
SAMPLE & HOLD
SAMPLE & HOLD
BCD TO BIN CONV
8080 µP
TRI-STATE GATE
X (2)
SUM ∅
Y (2)
MULTIPLIER
MULTIPLIER
ΣY DAC
ΣX DAC
KEPCO OPS 2000
TO VERT. DEFLECTION PLATES
KEPCO OPS 2000
TO HORIZ DEFLECTION PLATES

FIGURE 2.