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INFORMAL PROGRESS REPORT NO. 1

Advanced Control and Informations Systems

ERDA Contract No. E(11-1)-2572

Task 1 - Neutral Injection Beams

Reporting Period: 1 March to 30 June 1975

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Neutral Injection Beam Studies

This study as proposed had four main objectives, as follow:

a. Operational Issues

A review of current and proposed I&C system to determine how operational constraints of the injector systems and the experimental systems interact.

b. Present Programs

A review of beam-line control systems and the integration of multiple beams into experimental devices, specifically the 2xIIB beam line control system will be examined.

c. Beam-line Instrumentation and Interfacing

Instrumentation for a beam-line will be designed for integration into a MIMICS architecture. The impact of this design on beam line components and on the system cost will be determined.

d. Beam-line Instrumentation and Control Tests

Automatic or Semi-Automatic beam-line control loops will be proposed for possible field trial inclusion on existing neutral beam test stands.

Subsequent to contract approval trips were made to LBL and LLL to go over the statement of work and to establish working relationships and appropriate contacts at the two facilities. Individuals identified for contact were

LBL — Bill Cooper
Ken Ehlers

LLL — Art Molvik
George Pollock

It was verified in discussion with the above mentioned personnel, that the conditioning phase of neutral beam operation should be the first target of the CSDL effort.

The conditioning phase encompasses most of the beam operational problems and consumes the greatest portion of time. Because of the difficulty and extended duration most operator errors and beam faults occur in this phase.

At a meeting on March 19th with Fred Coensgen arrangements were made to have a CSDL engineer, R. Metzinger, work at LLL during the next conditioning phase of beam operations. As a participant, not an observer, he would obtain the greatest educational benefit and impose a minimal load on the LLL staff.

The beam conditioning work took place the week of April 28 - May 2, 1975. Much technical and operational information was obtained. A summary of this information was documented in reference 1. This information provided the basis for CSDL subsequent work.

This work centered on four areas: (1) attempts to model the physical mechanisms that lead to faults (interrupts); (2) development of techniques for estimating varying device coefficients in the control structure; (3) development of a control strategy and (4) a heuristic source model for testing the controls. Work on item (2), estimation, is essentially complete and a description of the estimator is given in Appendix A. Work on items (1), (3), and (4) is still in progress.

The present operational technique for conditioning involves stepwise x-y motion in the I-V plane shown in Figure 1. It is suggested that this technique is used because it is convenient for manual operations and because it works. The proposed automatic system utilizes the processors ability to coordinate control of the accel regulated voltage and the arc pulse line (APL) voltage using the device specific estimated coefficients to affect straight line motion in the I-V plane (figure 2). This simplifies the control problem to that of a single dimension. The present control system design is based on this simplification and is described in Reference (2). The primary control input is the interrupt frequency, while outputs are V_{APL} and the extraction potential.

For fault detection we have identified the need for a hardware spotting detector. Other fault conditions can be identified by the estimators as rapid changes in source characteristics.

A meeting is planned for early August with both Berkeley and LLL to discuss a test bed development system. This system would serve both as a test bed of the proposed controller and estimator and as a device for improving the present models of the system.

Figure 1

Figure 2

REFERENCES

1. R. Metzinger, "Operation of 2XIIB Neutral Sources, CSDL Internal Memo No. ES-19, May 20, 1975.
2. D. Keene, "Automatic Electrostatic Polishing of the LBL Neutral Beam Sources, CSDL Internal Memo No. ES-21, June 26, 1975.

APPENDIX A

Calibration of the Accel Current Control for LBL Neutral Beam Sources

ES-22

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ES MEMO #22

TO: Distribution

FROM: D. Keene

DATE: 7 July 1975

SUBJECT: Calibration of the Accel Current Control
for LBL Neutral Beam Sources

For the LBL sources the arc pulse line voltage (V_{apl}) is used to control the beam current (I_{accel}) i. e.,

$$I_{accel} = f(V_{apl})$$

Data for three such sources is plotted in Figures 1, 2 and 3. As can be seen from these curves the relationship between I_{accel} and V_{apl} is approximately linear over the operating range of interest. That is,

$$I_{accel} = a V_{apl} + b$$

The parameters a and b depend on the source characteristics and may also change with time. If it is desirable to control the operating point of the extractor in terms of I_{accel} and V_T (extraction potential) then it will be necessary to estimate a and b . There are several ways of estimating these parameters from measurements of V_{apl} and I_{accel} :

- 1) Least square fit
- 2) Weighted least square fit
- 3) Minimized maximum error fit
- 4) Filtering, etc.

Fig. 1 No. 2 Source Data

Fig. 3 No. 10 Source Data

For the purposes of this discussion filtering can be considered a form of weighted least square estimation where the most recent measurements receive the highest weighting. Filtering has the advantage that if the source characteristics change with time the filtered estimates will track such changes more accurately and rapidly.

For this memo we will consider only the least square approximations and linear filtering. As it turns out both solutions can be cast into the same general mathematical framework developed by R. E. Kalman⁽¹⁾. We begin by defining the measurement, I_{accel} .

$$I_{\text{accel}} = a V_{\text{apl}} + b + \nu$$

where ν is a random number which corresponds to the measurement noise. For the least square solution we also assume that

$$\dot{a} = 0$$

$$\dot{b} = 0$$

i.e., a, b are constants (to be estimated).

For the filter solution we assume

$$\dot{a} = n_a$$

$$\dot{b} = n_b$$

where n_a and n_b are white noise processes, i.e., a, b will be slowly varying random variables.

Measurements are made and processed after each shot to yield estimates of a and b which will be denoted by $\hat{a}$ and $\hat{b}$. For the n^{th} shot the variables will be written as $I_{\text{accel}}(n)$, $V_{\text{apl}}(n)$, $\hat{a}(n)$, $\hat{b}(n)$, etc. The solution to this estimation problem can be written in the form of recursive algorithms as:

$$\hat{a}(n) = \hat{a}(n-1) + K_a(n) [I_{\text{accel}}(n) - \hat{a}(n-1)V_{\text{ap}_\ell}(n) - \hat{b}(n-1)]$$

$$\hat{b}(n) = \hat{b}(n-1) + K_b(n) [I_{\text{accel}}(n) - \hat{a}(n-1)V_{\text{ap}_\ell}(n) - \hat{b}(n-1)]$$

starting with assume initial conditions, $\hat{a}(0)$, $\hat{b}(0)$. For the results given here the initial conditions were arbitrarily set to zero; in practice one would set them equal to some average source values. The computations of the gains $K_a(n)$, $K_b(n)$ depend on the assumed statistics for the problem and since the computation of these quantities is somewhat involved it will not be discussed here. We note, however, that for the least square solution

$$K_a(n) \rightarrow 0 \text{ as } n \rightarrow \infty$$

$$K_b(n) \rightarrow 0 \text{ as } n \rightarrow \infty$$

These equations were programmed on a computer and simulated responses were obtained using data from the #2 source (see Fig. 1). These data are tabulated in Table 1. The results for the least square solution are shown in Fig. 4. The results for the filter solution are shown in Fig. 5.

Referring back to Figures 1, 2, and 3 we see that the slope, a , does not vary much from source to source. This fact suggests that it would be advisable to dispense with the estimation of a and use a constant value (≈ 0.42 amps/volt). Results were obtained for this situation using data for the No. 2 source. Fig. 6 shows the least square solution for b ; Fig. 7 shows the filtered solution for b . Note that the filter solution is a bit noisier as to be expected. For this simple case the filter gain, K_b , approaches a constant value which in this case is

$$K_b \approx 0.48 \text{ for } n \geq 4$$

i.e., the estimator reduces to a simple first order constant coefficient filter.

Table 1 No. 2 Source Data

n	V _{apl} (volts)	I _{accel} (amps)
1	160	20
2	169	22
3	212	40
4	230	45
5	240	50
6	250	58
7	224	48
8	227	45
9	238	52
10	244	52
11	264	60
12	269	64
13	263	63
14	260	62

Fig. 4 Least Square Estimates of a, b for #2 Source

X FOR VAR 01 = AHAT

• FOR VAR 02 = BHAT

$$I(\text{ACCEL}) = A * V(\text{APL}) + B$$

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Fig. 5 Filtered Estimates of a, b for #2 Source

Fig. 6 Least Square Estimate of b for #2 Source

Fig. 7 Filtered Estimate of b for #2 Source

These same filtering algorithms can be used not only for control purposes but also for detecting system faults. For example, if one leg of the arc pulse line supply fails to charge then the slope, a , will be reduced by a factor of 2. The filter will detect this situation fairly rapidly. The estimation techniques can also be to other problems such as estimating the conditions for best focus, for source alignment, and for estimating the polishing parameters discussed in Ref. 2.

References

- (1) Bryson, A. E., and Ho, Y. C., "Applied Optimal Control", Blaisdel Publishing Co., Waltham, Mass., 1969.
- (2) CSDL Memo ES-21.