A MICROPROCESSOR-CONTROLLED BEAD PULLER FOR RF CAVITY MEASUREMENTS

J.D. Hepburn and W.L. Michel
Accelerator Physics Branch
Atomic Energy of Canada Limited
Research Company
Chalk River Nuclear Laboratories
Chalk River, Ontario K0J 1J0

Summary

A microprocessor-controlled bead puller is being developed to provide a sophisticated, self-contained bead pull facility with local data analysis. The following features are incorporated: 1) continuous bead travel to minimize lateral vibrations, 2) 0.1 mm (or better) bead position resolution, 3) up to 5 m total pull length, with steps as small as 0.5 mm, 4) local cassette storage of data, 5) all operations controlled by software via a keyboard, 6) provision of a link to the main CRNL computer, and 7) local programs for bead pull control and data analysis. The facility is described and impressions of its operation given.

Introduction

Successful creation of a working accelerator requires, at some stage, measurement of rf fields in the accelerator cavities. Bead pulls are the standard method for determining these fields. The process is based on the fact that insertion of a small object into an rf cavity perturbs the cavity resonant frequency by an amount related to the squares of the local electric and magnetic fields[1], hence field distributions can be found. Bead pull measurements consist of recording cavity frequency shift versus bead position, as a perturbing bead (supported on a thread) traverses the cavity. The resulting field distribution is used to check the accelerating properties of the cavity.

In its simplest form, a bead pull system consists of a voltage-controlled rf oscillator, an automatic frequency controller to tune the oscillator to the cavity frequency and give an analog frequency output, a chart recorder to plot frequency, and a motor to pull the bead. Digital frequency measurements can only be made using a system capable of reading and storing large amounts of data, quickly.

At the Chalk River Nuclear Laboratories (CRNL), the Accelerator Physics Branch is carrying out a study of the problems associated with designing and building ZEBRA (Zero Energy BReeder Accelerator[2]), a 300 mA, H^+, 100% duty factor, 10 MeV linac facility. At the moment, several experimental structures are being studied with bead pull techniques, so a highly automated bead pull facility satisfying the criteria in Table 1 would be extremely useful to reduce measurement time, improve data handling, and provide immediate data analysis. A microprocessor-controlled instrument can easily satisfy these criteria.

Development of the microprocessor-controlled bead puller suits another area of the ZEBRA study: evaluation of computer control and "smart" instruments. For the bead puller, hardware was bought ready-to-use, with all editing, assembling and emulation performed on an available, well-equipped development station.

Table 1: Criteria for the Bead Puller

- smallest measurement interval	0.5 mm
- largest measurement interval	several mm
- shortest cell	6 mm (50 kV RFQ)
- bead position resolution	0.1 mm
- longest tank to be pulled	5 m
- fast enough to be convenient	1 min/m
- chart output	-
- mass storage of data	-
- local data analysis	-
- connection to main computer	-
- easy to use, by many different users	-
- portable	-

System Layout and Hardware

Figure 1 is a schematic layout of the system hardware. The rf section consists of a voltage-controlled oscillator feeding the rf cavity via a drive loop, while the oscillator is controlled by an automatic frequency controller fed from a sampling loop. The AFC voltage is read by a 10-bit ADC to provide frequency data. The AFC voltage is fed directly to the chart recorder for bead pulls; the chart can also be driven via an 8-bit DAC from data in memory. The chart is turned on and off by the microprocessor.

The chart recorder response rate ($\sim$ 1 Hz) and the length of the shortest cell in a tank combine to limit the bead pull speed; for this system a range of 3 to 15 mm/s was selected. The data recording process takes $\leq$ 300 μs, hence the bead can be moved continuously by a dc motor and readings taken "on-the-fly". This minimizes transverse bead vibrations inherent in stepping-motor driven systems. The bead is held on a continuous loop of monofilament nylon line, and is automatically repositioned to "travel limit 1" between runs.

Bead position information is provided by an incremental optical shaft encoder having 1000 encoder pulses and one marker pulse per revolution. The encoder pulses drive the microprocessor non-maskable interrupt, whose service routine increments the previously stored total pulse count, then periodically initiates an AFC voltage reading and stores both the frequency-related voltage and total pulse count. The Z80 CPU uses interrupt mode 1, for which the shaft encoder marker pulse and the two travel limit switches are "OR"-ed together to drive the interrupt request. These three interrupt signals are also fed to optically-isolated inputs that are polled by the interrupt service routine to identify the interrupt source. Marker interrupts complement the chart recorder marker state to give a position reference on the chart output; travel limit interrupts control bead movement. The keyboard/printer is a Texas Instruments Silent-700 unit. Bulk data storage is on dual ADPI model-1 cassette tape units. Communication with the CRNL main computer is possible via the modem.

The microprocessor system selected for the bead puller uses the STD bus developed by Pro-Log; Table 2 summarizes the boards installed. One board was made locally to interface interrupt and reset signals to and from the bus. All inputs are optically isolated and outputs relay driven.

Table 2: Boards used in the Microprocessor System

Manufacturer	Model	Number Used	Function
Pro-Log	7803	1	Z-80 CPU with 8K ROM, 4K RAM
	7304	2	dual UART
	7502	1	eight SPST relay outputs
	7503	1	eight opto-isolated inputs
	7701	2	16K static RAM
Analog Devices	RTI-1225	1	16 channel ADC and dual DAC
Mostek	MK 77976	1	real-time clock
(in-house)	-	1	interrupts, reset

Data Storage and Software

Use of an incremental, rather than absolute, shaft encoder means that the length of a continuous pull is limited only by the pulse count storage available. Two bytes (16 bits) gives a maximum of 65,536 counts, or 65.5 encoder revolutions. Table 3 shows possible bead-motor pulley configurations, subject to the two-byte count limit. Any one of the three choices given in Table 3 is suitable for meeting the specifications of Table 1. In actual operation, the encoder pulses force a nonmaskable interrupt on the microprocessor. The service routine increments the pulse counter, and after a predetermined number of counts stores the two-byte total pulse count as position information. The count interval and pulley diameter determine the bead distance per reading. When the distance count is stored, the ADC reading the analog frequency is triggered and its 10-bit result stored in a further two bytes.

Table 3: Bead Pull Specifications resulting from a Two Byte Count Limit

Pulley Diameter (mm)	Maximum Pull Length (m)	Resolution (mm/count)	Feasible Minimum Counts per Reading (counts)	Feasible Minimum Step Size (mm)
50.0/π=15.9	3.28	0.050	10	0.500
76.3/π=24.3	5.00	0.076	6	0.458
100/π=31.8	6.55	0.100	5	0.500

The 36K bytes of RAM allow data from all but the longest, highest resolution pulls to be stored directly in RAM, without tape storage.

The only switch-selectable functions in the bead pull part of the system are chart speed, chart amplifier range, and a microprocessor reset; all other controls are entered via the keyboard following prompts from the programs. Because all program and system development and emulation were done on a development station, the main program (called MNITOR) only needs to perform some initializing tasks, read and print the system clock reading, and prompt the user for the code number identifying the subprogram he requires. Figure 2 shows the programs planned, together with their main tasks.

In the chart mode, the data display program MEMOUT complements the marker at the same rate as did the shaft encoder on the original chart display, thus the position scale reference appears on all charts.

Obviously, the data analysis package could take many forms, depending on the actual experiments. For initial experience, PEAKFIND has been configured to suit an experiment measuring field tilts in an Alvarez tank model for various post coupler configurations. For each run it locates each peak, levels the peak baseline relative to that of the first peak, and finds the peak height. Then it normalizes the run by forcing the average of the first four peaks to be a predetermined value, and prints the position, peak height and normalized peak height. The treated data can then be printed or plotted, using MEMOUT.

To date, all programming has been done in Z80 assembly language, but PASCAL may be used in the more complex data analysis routines.

Status and Conclusions

Hardware installation and development is complete and virtually all aspects of actual bead pulls have been operated and tested.

A large amount of software is required, and programs are being written with the goal of getting a working system quickly, with embellishments to be added later. The following programs are functional (refer to Fig. 2) MNITOR, TERMIN, PLBEAD, MEMOUT, and PEAKFIND. Work on the others is continuing now. Note that with the large amount (36K) of RAM available, mass storage on tape is not immediately required.

The direct purchase of boards and a card cage meant that system tests could begin immediately. Installation in a chassis, connection of peripherals, and production of the special board took considerable time, but the overall effort was much less than for a system built completely in-house.

The availability of a development station greatly reduced commissioning time, for several reasons: short programs or code sections to investigate specific system functions could be easily written and operated; software could be edited, assembled and emulated in minutes; and the features of the station greatly surpassed anything that could reasonably have been installed in the microprocessor itself. Developing programs on the emulator means that all programs can be stored in EPROM's, which in turn removes the necessity of loading programs off tape and saves RAM space. This is a convenient feature for occasional system users.

The method of calling sub-programs and the use of prompts works very well. It also allows, with some foresight in writing the monitor, addition of sub-programs with little or no change to existing ones.

The analog voltage range of the frequency difference signal must be chosen to be a substantial fraction of the range of DAC's and ADC's in the system, otherwise the ± 1 bit noise adds significantly to the data noise (particularly for the 8 bit DAC used to drive the chart recorder when data is plotted from memory).

The capability of plotting and/or printing data from memory (subprogram MEMOUT) at various stages in data analysis allows checks on the necessity for and appropriateness of the data treatment.

The sub-program PEAKFIND was written to facilitate a certain experiment, and illustrates the power and time savings of on-line data analysis.

The general approach to selection of the microprocessor hardware, and hardware and software development, was very suitable in this application. While the microprocessor-controlled bead puller is just beginning to be used for experiments, it is already clear that it will provide accurate data quickly, and that the additional powerful feature of local data analysis greatly facilitates data interpretation.

References

1. S. Ramo, J.R. Whinnery, and T. Van Duzer, Fields and Waves in Communications Electronics (J. Wiley and Sons, New York, 1965) p. 568.
2. S.O. Schriber, "The ZEBRA (Zero Energy Breeder Accelerator) Program at CRNL - a 300 mA, 10 MeV Linac" (Proceedings of this conference).

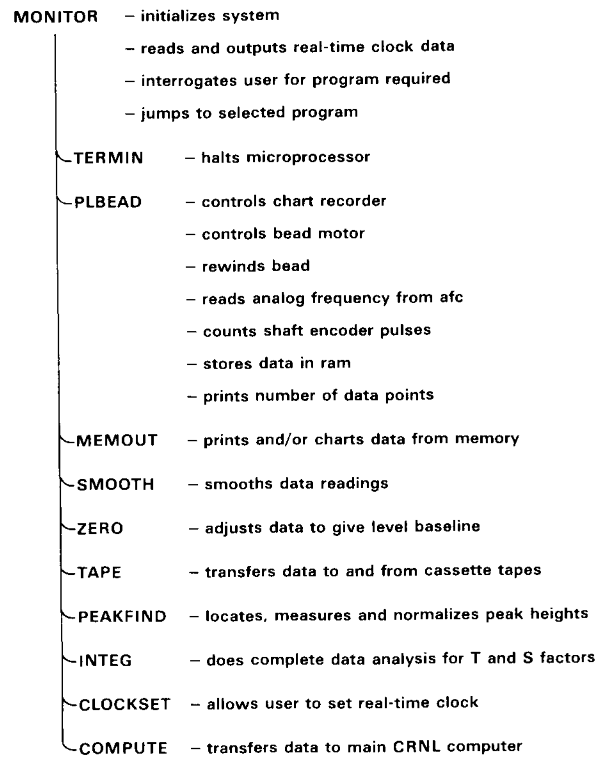

Fig. 2 Software Organization.

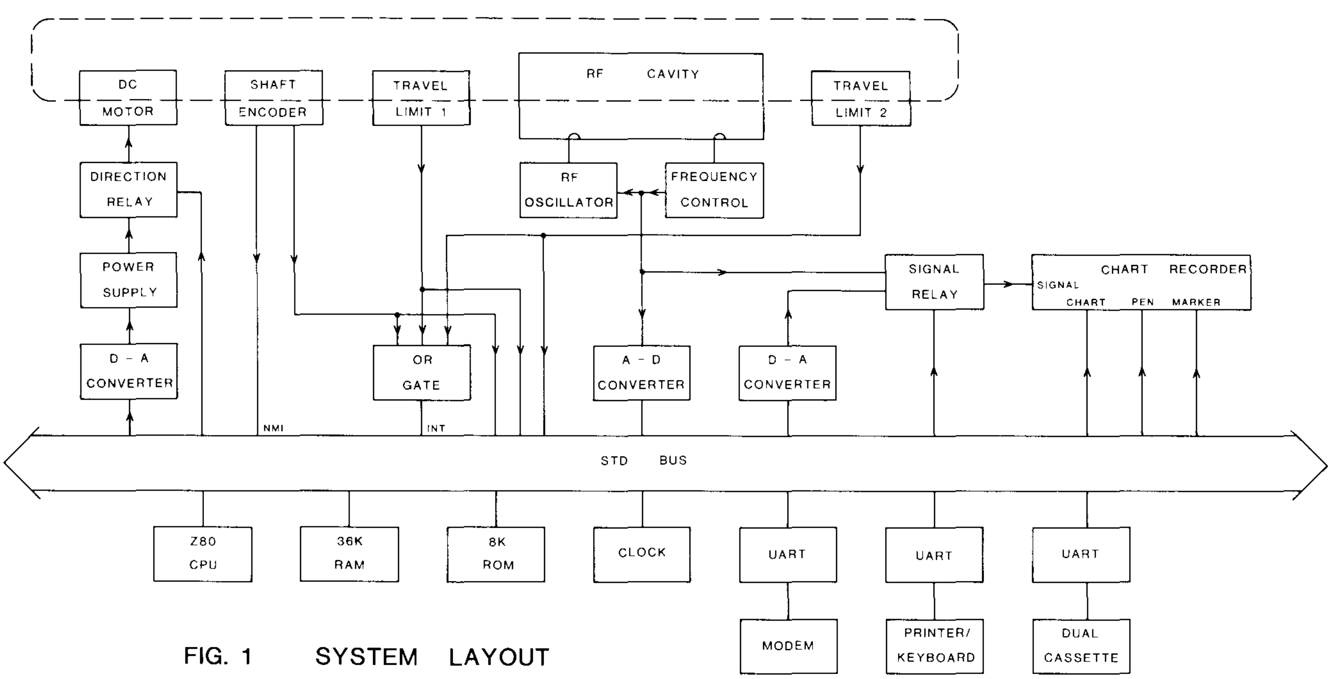

FIG. 1 SYSTEM LAYOUT