Title
THE RAPID MAPPER: A DMA-ACQUISITION SYSTEM FOR LARGE-SCALE MAGNETIC FIELD MEASUREMENTS

Author
Macondray, Frederick W.

Publication Date
1967-07-05

University of California

Ernest O. Lawrence Radiation Laboratory

THE RAPID MAPPER: A DATA-ACQUISITION SYSTEM FOR LARGE-SCALE MAGNETIC FIELD MEASUREMENTS

Frederick W. Macondray

July 5, 1967

Berkeley, California

DISCLAIMER

For the Second International Conference
on Magnet Technology, Oxford
July 11-14, 1967

UCRL-17642
Preprint

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

THE RAPID MAPPER: A DATA-ACQUISITION SYSTEM FOR LARGE-SCALE MAGNETIC FIELD MEASUREMENTS

Frederick W. Macondray

July 5, 1967

THE RAPID MAPPER: A DATA-ACQUISITION SYSTEM FOR LARGE-SCALE MAGNETIC FIELD MEASUREMENTS

Frederick W. Macondray

Lawrence Radiation Laboratory
University of California
Berkeley, California

July 5, 1967

ABSTRACT

Large-scale digital magnetic-field mapping is extensively used at the Lawrence Radiation Laboratory. An automated measuring system, called the "Rapid Mapper," was built in 1962 and rebuilt in 1964. This machine is designed to perform a variety of automatic and semi-manual dc measurements. In the automatic modes the machine positions a probe, sequences the measurements, and records the data for later computer analysis. The semi-manual modes are used when computer analysis of manual data is desired.

A third-generation Rapid Mapper, which is now in the planning stage, will be controlled by a small digital computer. It will contain all the capabilities of the preceding machines. In addition it will make digital pulsed-field measurements and do error checking at the time of measurement. The use of a computer will greatly facilitate modification of test programs. One of the first projects for this machine will be model magnet studies for the 200-GeV accelerator.

The paper discusses

(a) organization of the system,
(b) probe positioning, and
(c) flow diagrams of the control logic.

INTRODUCTION

Large-scale digital field maps of analyzing and bending magnets are an accepted part of high energy physics experiments at the Lawrence Radiation Laboratory. Among the uses for field maps are orbit plotting in beam transport systems and momentum determination in analyzing magnets.

A semiautomatic digital data-acquisition system, called the Rapid Mapper, was built at LRL–Berkeley to meet the needs of our physics program. The complete Rapid Mapper system includes (a) a variety of probes and positioning equipment, (b) the data-acquisition and control unit, and (c) data-processing programs and procedures.

This system was very briefly described in a survey paper.[1] The present paper gives a more complete description of the mechanical equipment and of the logical operation of the system. The data format and data-processing procedures are described in another paper.[2]

HISTORICAL BACKGROUND

The original Rapid Mapper was designed and constructed at the Lawrence Radiation Laboratory during 1961 and 1962. In 1964 the author rebuilt it, retaining the basic design but making improvements in reliability, versatility, and portability. This discussion presents the system as it was in June 1967.

SYSTEM ORGANIZATION

The Rapid Mapper is required to (a) position a probe, (b) sense, digitize, and record data, (c) respond to operator commands, and (d) display information on system operation.

The general layout of the system, shown in Fig. 1, is comprised of five logical groups:

1. Probe positioning
2. Analog data acquisition
3. Data buffer and output
4. Control panel
5. Digital control unit

(Items 2–5: Located in a three-bay portable rack.)

Figure 2 shows some internal components of these logical groups.

Probe Positioning

Accurate magnetic field measurements require accurate positioning of the probe for measurement of high-gradient fields. In the Rapid Mapper system precise positioning is achieved in stepping-motor-driven assemblies such as the one in Fig. 3.

In this assembly a search coil is positioned inside a 2-in.-square "guide tube" (Y direction). The guide tube is supported by two cross drives which translate it in the X direction. The Z elevation is determined by hand-cranked lead screws in the stands which support the guide tube.

The X cross drives are of the lead-screw and split-nut type. Four hundred steps (two revolutions) of the motor are required for 1 in. of travel. The position resolution, which depends on the quality of this lead screw and nut, is about 0.001 in. Both motors are driven from the same logic elements to insure simultaneous stepping. Snap-action switches, operated by cams on the lead screws, are used for position checks.

For simplicity, we use open-loop drive of the stepping motors (i.e., no position feedback). However, we do use an audible alarm to warn the operator of false positioning in certain cases. The alarm signal is derived from the coincidence of a cam-actuated snap-action switch closure and a phase signal from the motor drive unit. This "stopping phase" signal is derived from one of

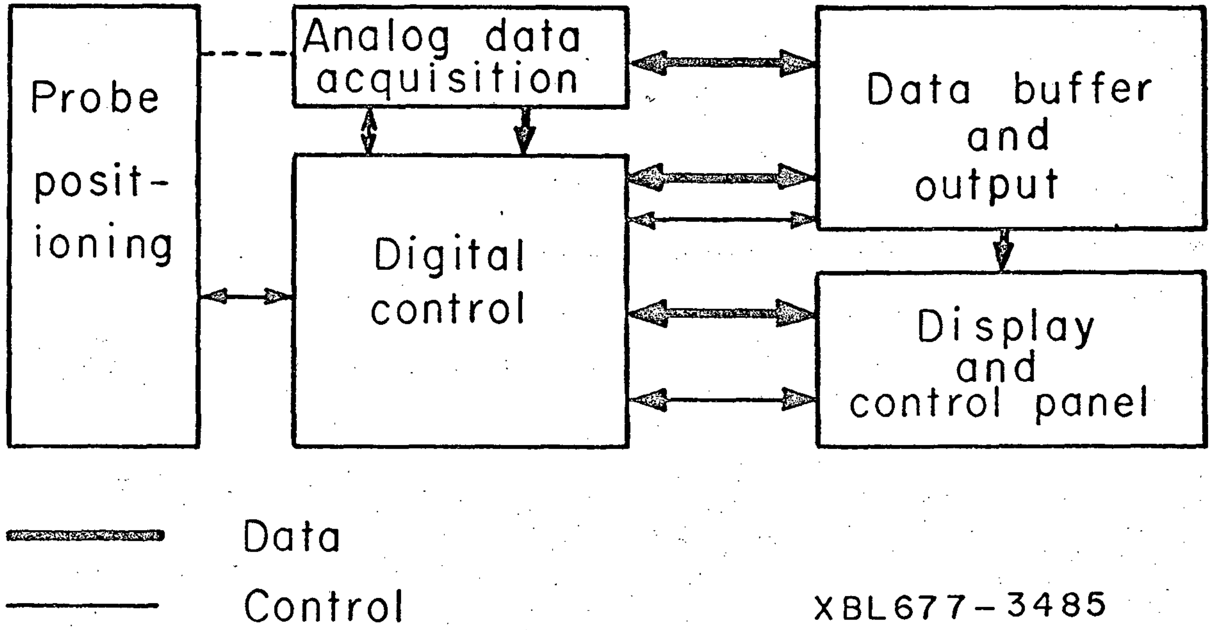


Fig. 1. Simplified block diagram of the Rapid Mapper.

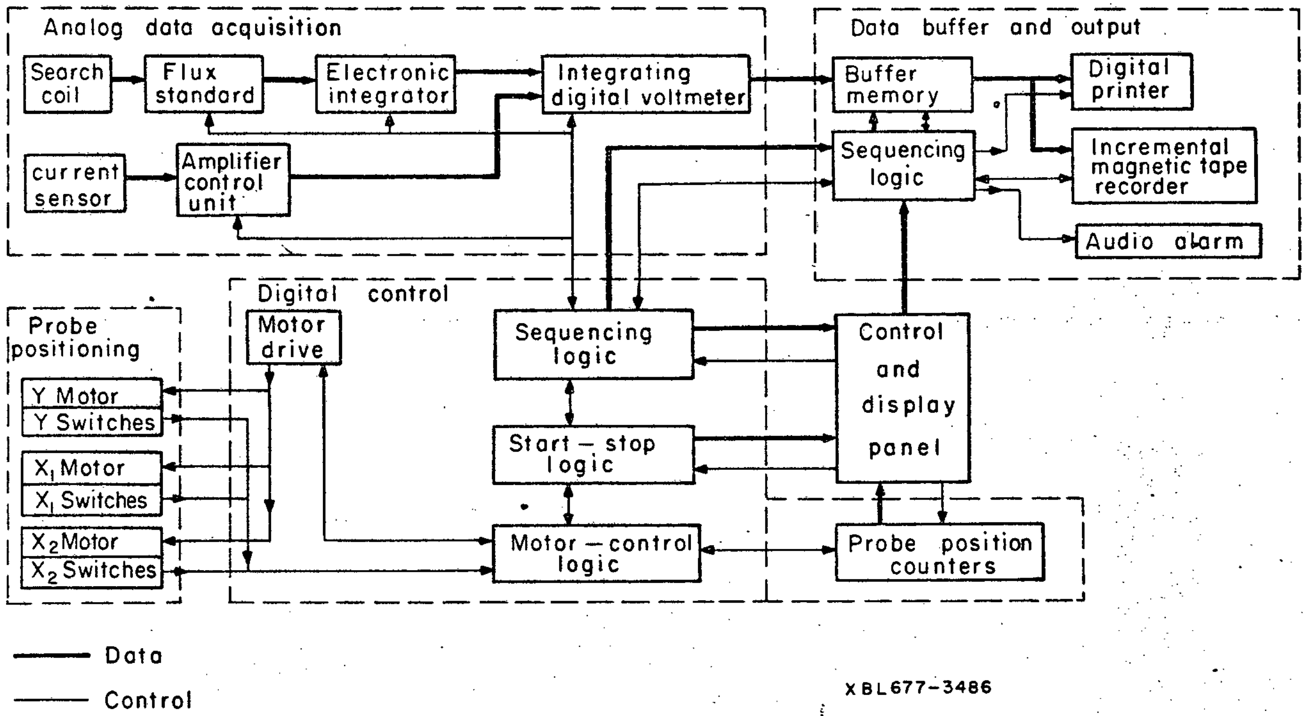
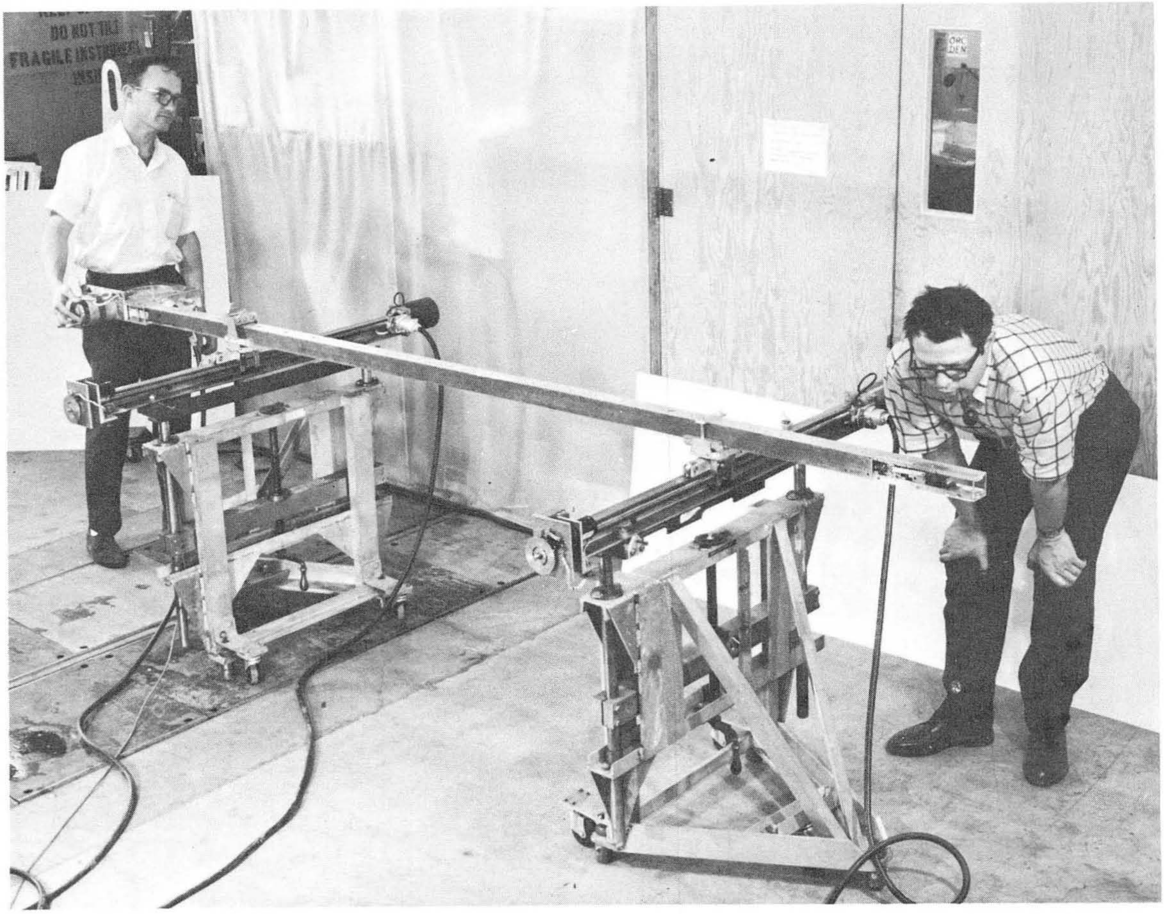


Fig. 2. Block diagram of the Rapid Mapper.



XBB676-3539

Fig. 3. X-Y positioning system.

the four possible states (selected as a permitted stopping condition) of the stepping-motor drive flip-flops.

A drum-and-cable drive (Figs. 4 and 5) was selected for the Y drive in order to obtain higher speeds (>10 in./sec) than are practical with lead screws. Speed is necessary in order to reduce the effects of integrator drift during the measurements. In a period of 45 sec we measure the field twice at each of 110 locations (220 measurements), once while the probe travels down the tube and again as it comes back. The redundancy in the data is used to eliminate the effect of linear drift and to check for errors.

From the beginning we realized that it is difficult to achieve precise positioning with a drum-and-cable drive. Therefore, we made some additions to the guide tube and carriage to produce what we call the "Rabbit" (Figs. 6 and 7).

In the rabbit, precise positioning, relative to a precision rack extending the full length of the guide tube, is achieved in fixed increments of 1.0032 in. Carriage #1 (pinion gear carriage) is driven by the cable and translates a pinion gear and pair of cranks down the guide tube. Carriage #2 (probe carriage) is attached by two connecting rods to pivot points on the crank. The pivot points lie on the pitch circle of the pinion gear and therefore have a cycloidal motion as the pinion rolls along the rack. The pivot points have virtually no motion along the rack when the crank is nearly vertical, and precise positioning is achieved if the drive motor is stopped when the crank is nearly vertical (a snap-action switch and cam sense this condition).

Analog Data Acquisition

Our normal analog field-sensing system[1] consists of a search coil, a flux standard, an integrator, a voltage divider, and a digital voltmeter. This system was chosen because it is extremely easy to use[1] and to calibrate.[3] Change in flux linking the search coil induces a voltage which is integrated, multiplied by a constant (by the voltage divider), and digitized (by the digital voltmeter). The flux standard is used to calibrate the system by introducing known positive and negative pulses into the integrator input circuit. An additional input to the digital voltmeter is provided for a current-sensing device such as a current transductor and power supply. The digitized data are presented to the data buffer (memory).

Data Buffer and Output

The Data Buffer and Output section contains a flip-flop buffer which receives data from the digital voltmeter, the control panel switches, or the probe position counters. The sequencer, on command, clears the buffer, loads the data, writes data on magnetic tape, and prints certain selected data. The printer output is used by the operator to spot-check the system operation.

Control Panel

A control and display panel centrally locates the switches and push buttons used by the operator. See Figs. 8 and 9. Starting at the top of the panel we have the following items (with their uses):

(a) Digit switches provide map constants and control such functions as X increment and X and Y ranges. These are arranged in groups of six characters to form computer words. Digit switches in the lower right-hand set are used to write special records, one word each time the special-word push button is pressed.

(b) The record counter is an electromechanical counter that displays the number of the present record being written on magnetic tape. The number is used in the operator's log and is recorded on the magnetic tape.

(c) The register lights display the contents of the buffer as the sign plus six BCD-coded digits (1248 code).

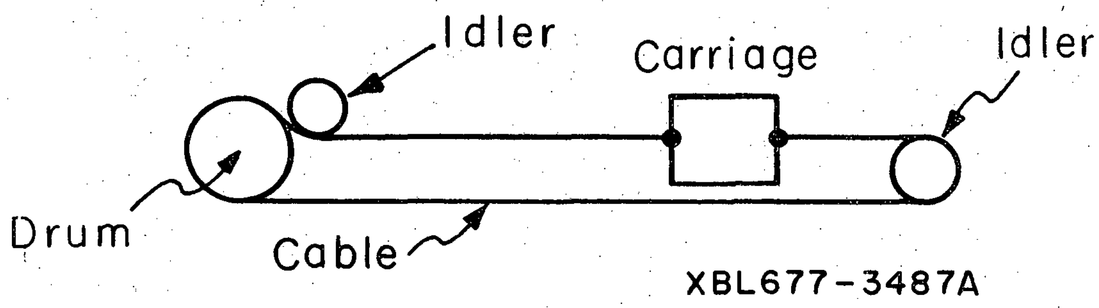
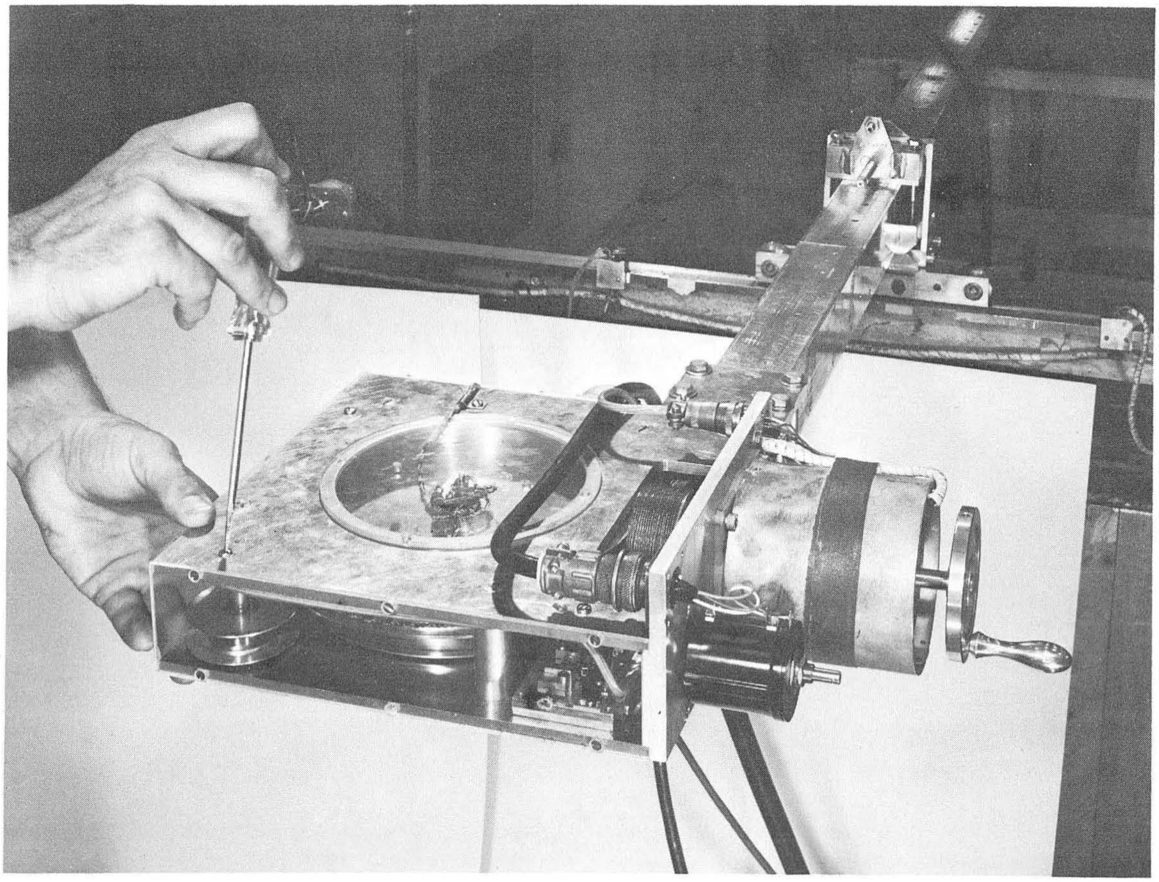
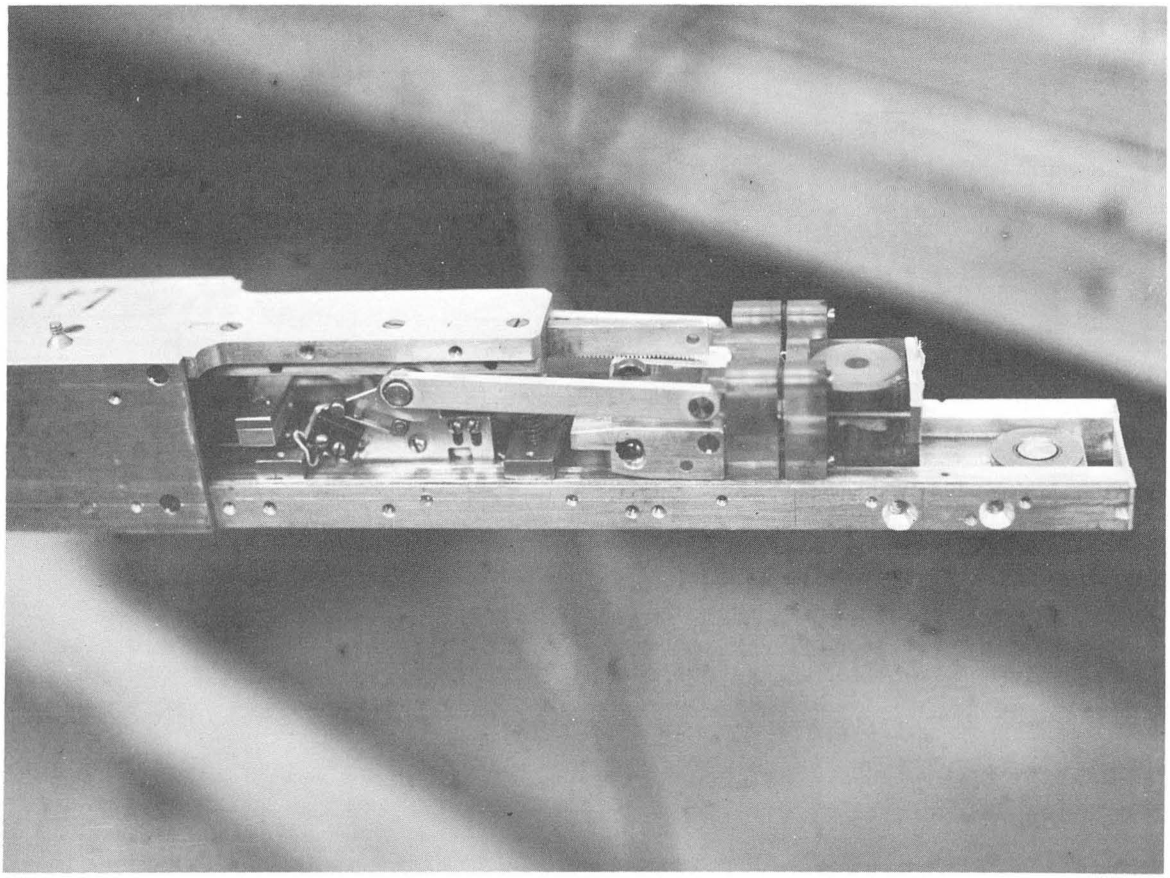


Fig. 4. Basic drum-and-cable drive.



XBB 676-3540

Fig. 5. Y-direction drive.



XBB 676-3518

Fig. 6. Rapid Mapper rabbit.

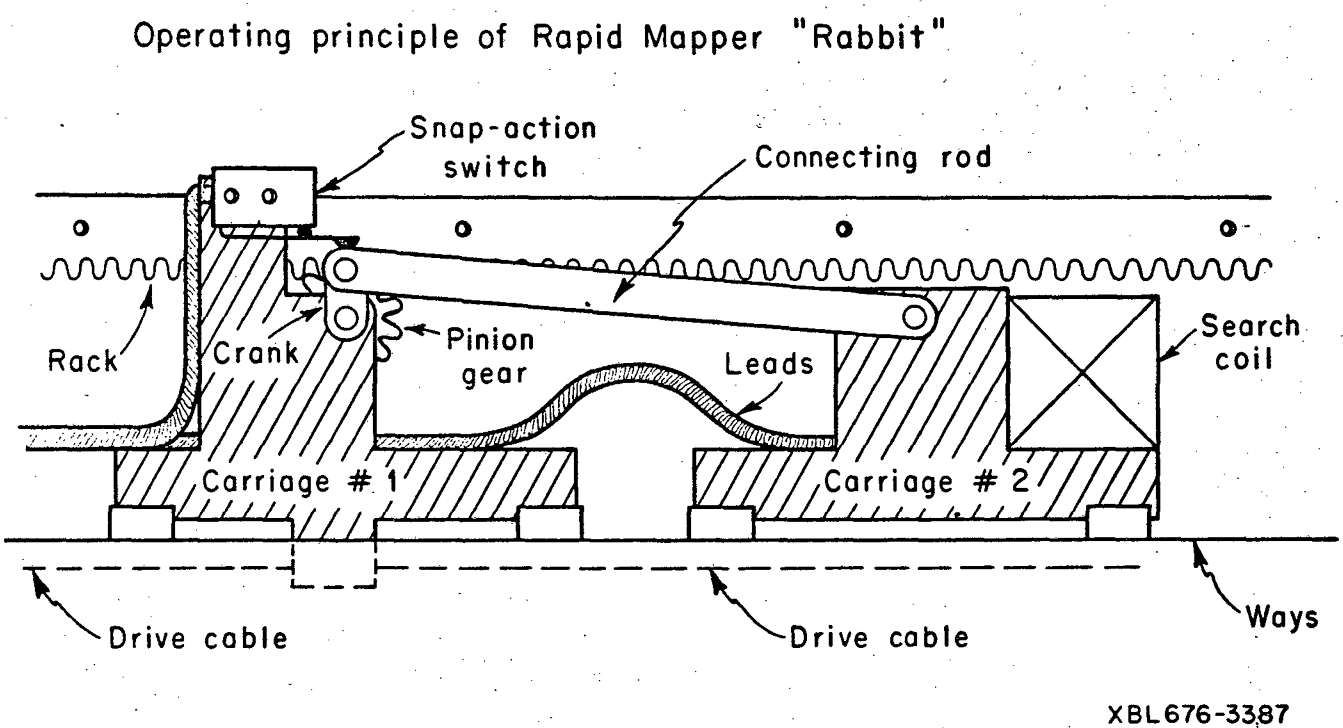
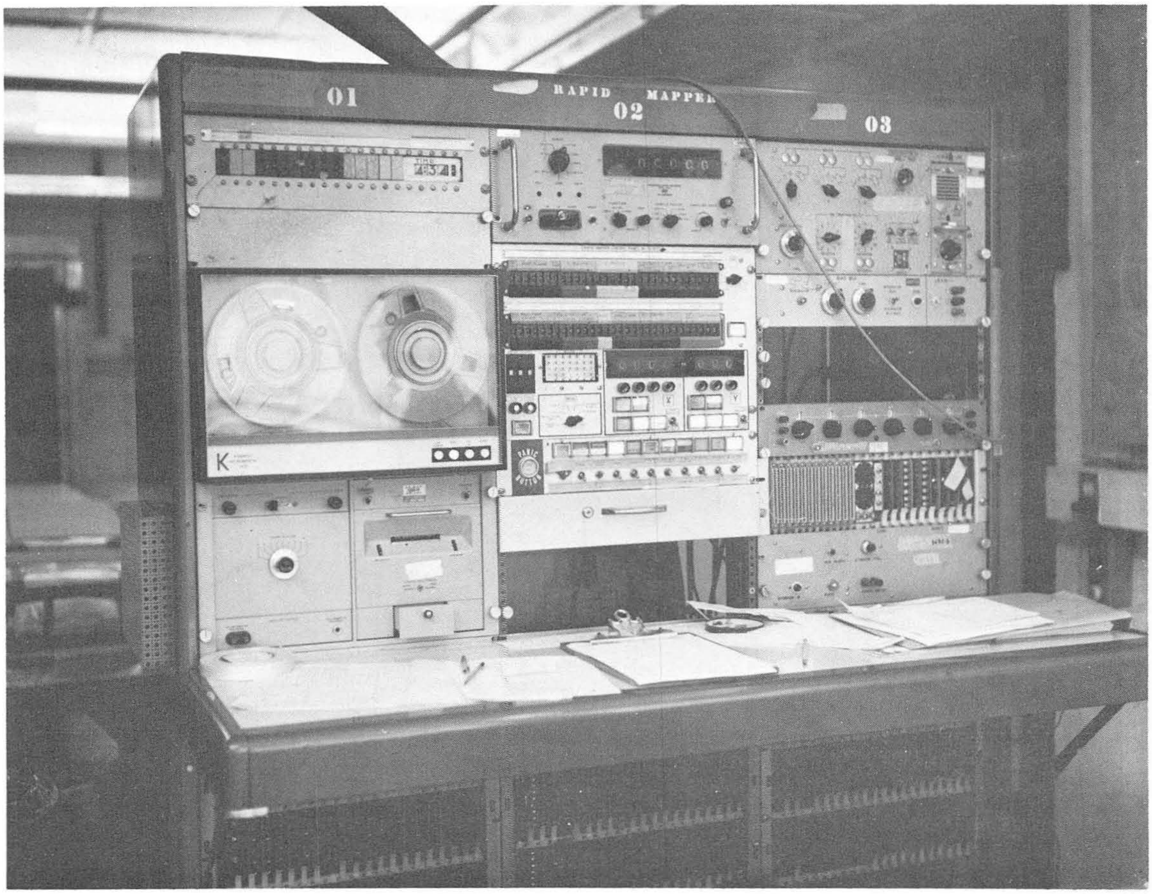


Fig. 7. Functional diagram of Rapid Mapper rabbit.



XBB 676-3515

Fig. 8. Control console.

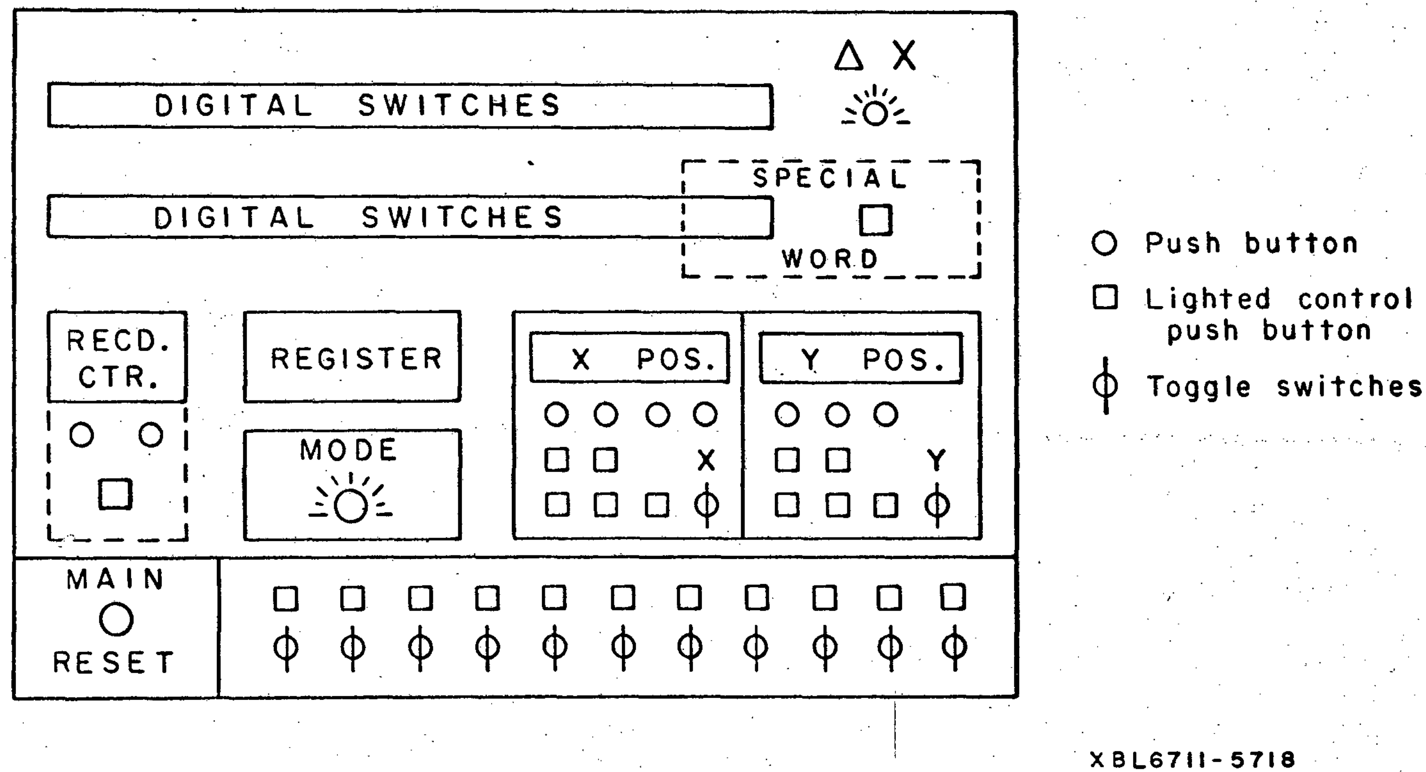


Fig. 9. Layout of control panel.

(d) The X and Y probe positions are displayed by projection display units. The push buttons below the displays are used to manually set the contents of the counters. Next are the counter reset and the forward and reverse push buttons. The last row of push buttons is for manual control of the probe. The single-step button steps the probe one increment each time it is pressed. The multi-step button increments the probe position as long as the button is held down. The continuous-step button steps the probe to the extreme end of its range. When the probe reaches the extreme end of the range the direction of the motor is automatically reversed. If the adjacent toggle switch is up, the probe does not stop at the limit but oscillates between limits.

(e) The mode switch selects the type of run to be made (X, Y, or Z direction).

(f) The bottom panel contains the main sequence control push buttons and switches. Among the functions are:

Push buttons

1. Start indicative data
2. Start calibration
3. Start run
4. Write end of record
5. Write end of file
6. Manual cycle DVM (digital voltmeter)
7. Manual cycle and record DVM

Toggle switches

- Automatic or manual map
- DVM cycle time
- Various probe-control options

Digital Control Unit

The control unit contains the necessary digital logic circuitry to control and sequence the system. This unit can be considered in six parts:

(a) motor drive,
(b) position counters,
(c) motor control logic,
(d) cycle initiate and terminate logic,
(e) equipment control and sequencing logic,
(f) sequencing clock.

The motor drive receives direction and step commands, produces the drive pulses to the motors, and sends stopping-phase signals to the motor control logic.

The position counters determine where the probe is located by counting stopping-phase pulses, and display the location on the control panel. This unit also decodes the counters, compares them with the limit and the increment digit switches, and tells the motor control when to stop the motors.

The motor control section accepts manual and automatic motor start or stop commands, stops the motors if the probe limit switches are actuated, routes signals to the probe position counter, and issues read commands to the DVM after each probe increment of the data portion of the run cycle.

The DVM, together with some logic circuitry, acts as a timing clock. After each cycle of the DVM, three pulses may be generated. These pulses time all commands from the equipment control and sequencing logic sections. All timing is based on either a 1.0-sec or a 0.1-sec cycle of the digital voltmeter. This cycle time is set as needed.

LOGICAL OPERATION OF THE RAPID MAPPER

Basic Data Format

Data are collected in the form of logical files called maps. Each map contains at least one of each of the following logical records:

1. Identification cycle--records "map constants" (setup instructions to the data-processing computer).
2. Calibration cycle--provides calibration data for succeeding runs up to another calibration record.
3. Run (data) cycle-- records run-identifying data and magnetic field data.

Logical records are separated by end-of-record gaps, and logical files (maps) are separated by end-of-file gaps.

Each of these cycles operates in basically the same way, following a sequence in which it

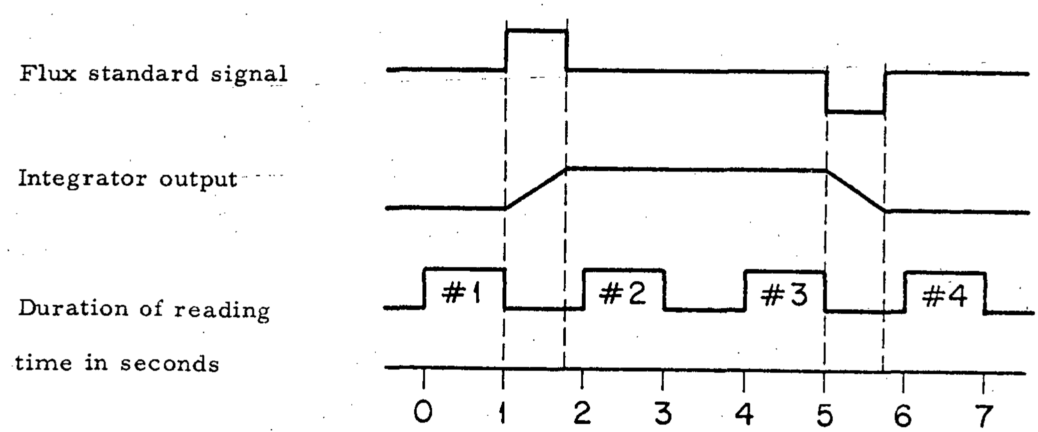
(a) Checks to see if another cycle or operation is in progress. If one is, action is deferred.
(b) Checks to see if the last thing written on the magnetic tape was an end-of-record gap. If not, one is written.
(c) Writes the first word of the record which contains the record number and three identifying characters, clears the cycle-demand flip-flops and the end-of-record flip-flops.
(d) Writes additional setup words which are instructions to the data-processing computer.
(e) Collects and records the data.
(f) Writes an end-of-record gap on the tape, sets the end-of-record flip-flop, and increments the record counter.

Identification Cycle

This cycle records the "map constants" from the digit-switches on the control panels. The flow diagram is shown in Fig. 10.*

Calibration Cycle

Four calibration measurements are made as shown below. The flow diagram is shown in Fig. 11.*



Run (Data) Cycle

The run cycle is divided into three parts: prerun, main run (data), and postrun.

*This figure is in LRL report UCRL-17642, July 1967, available from author at Lawrence Radiation Laboratory, Berkeley, California 94720.

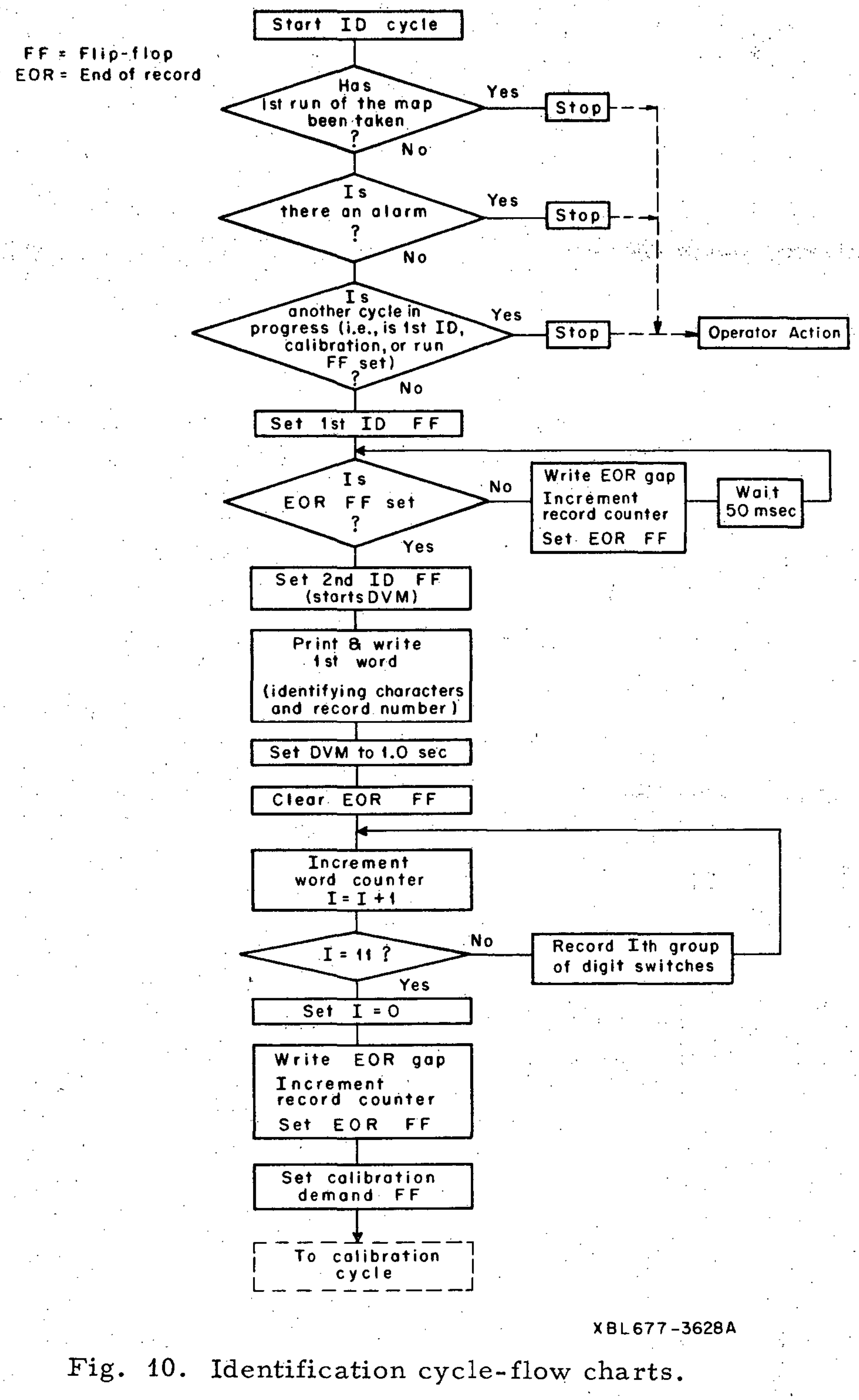


Fig. 10. Identification cycle-flow charts.

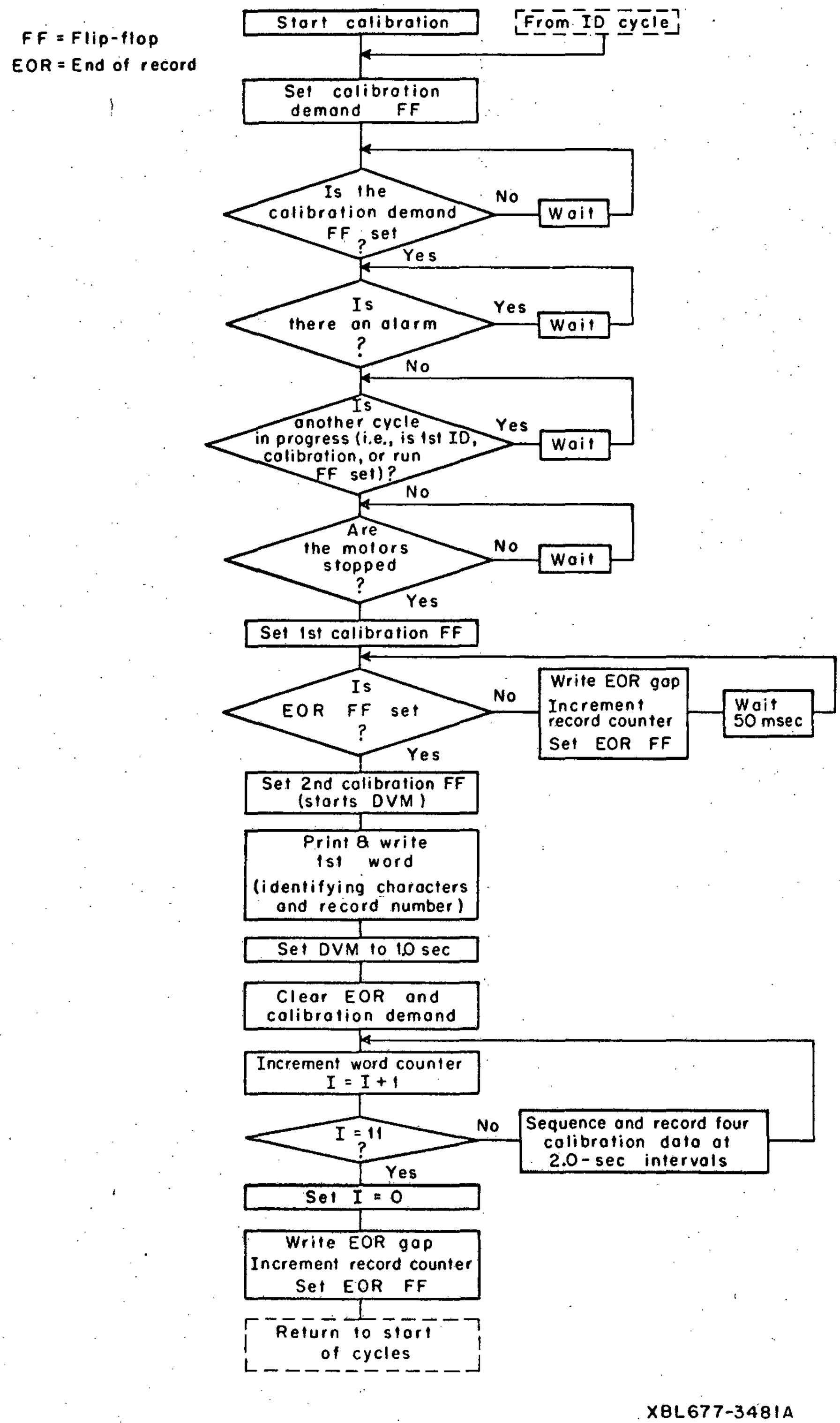


Fig. 11. Calibration cycle-flow chart.

Prerun (Fig. 12*) resembles the ID cycle in that it provides setup information (run location, magnet current, etc.). For convenience the first data point ($Y = 0$ or $X = X_{min}$) is part of this cycle. Main run (Fig. 13*) records data in the sequence move, measure and record. The postrun cycle (Fig. 14*) contains the last field reading ($Y = 0$ or $X = X_{min}$) and a final check of the magnet current.

PERFORMANCE AND RECOMMENDATIONS

Since the Rapid Mapper was constructed in 1962 it has made more than 6 000 000 measurements of individual data points in approximately 1000 maps.

The final version of the system (after the 1964 modification) has been highly successful and reliable. Recently the system was air-freighted to Texas A & M University for a cyclotron measuring job;[4] it arrived in excellent condition except for a minimum of trouble with feed-through eyelets on a few logic boards.

Data have been collected from a variety of positioning devices, including manually positioned data. The manual data were put into the Rapid Mapper for convenience in data recording and because the data could then be analyzed easily and manipulated with our data-processing programs.

Although our system has been very successful, it does have two major drawbacks. First, it is a special-purpose system, which means high costs for design engineering and construction. Second, since it is a "hard-wired" system, maintenance and modification of the operating sequences are difficult.

Because of these problems, future systems similar to the Rapid Mapper should be based on a small digital computer. Computers are relatively inexpensive, highly versatile, and easily interfaced to stepping motors, analog-to-digital (A/D) converters, incremental magnetic tape recorders, etc.; the use of a computer shifts the complexity of the system from the hardware to a software program. This means less expensive construction and easier modifications of operating sequences.

One further advantage of the computer is automatic validity checking of the data as they are collected.

We are now building a new measuring system based on a PDP-5 computer. This system will have all the capabilities of the present Rapid Mapper plus the ability to make field measurements and automatic error checks of the data. In addition, fabrication is under way on a new guide tube positioner in which the rabbit mechanism is replaced by a single carriage with a photodetector to accurately determine position. This device will be capable of faster and more versatile operation than the rabbit. We expect to have this system operating in October and to report on its design and performance at that time.

ACKNOWLEDGMENTS

The author is indebted to Peter G. Watson, who wrote the original specifications for the system, and to Frank Neu, who designed the original version. He is also grateful to Peter G. Watson and Donald H. Nelson for their comments on this paper.

This work was done under auspices of the U. S. Atomic Energy Commission.

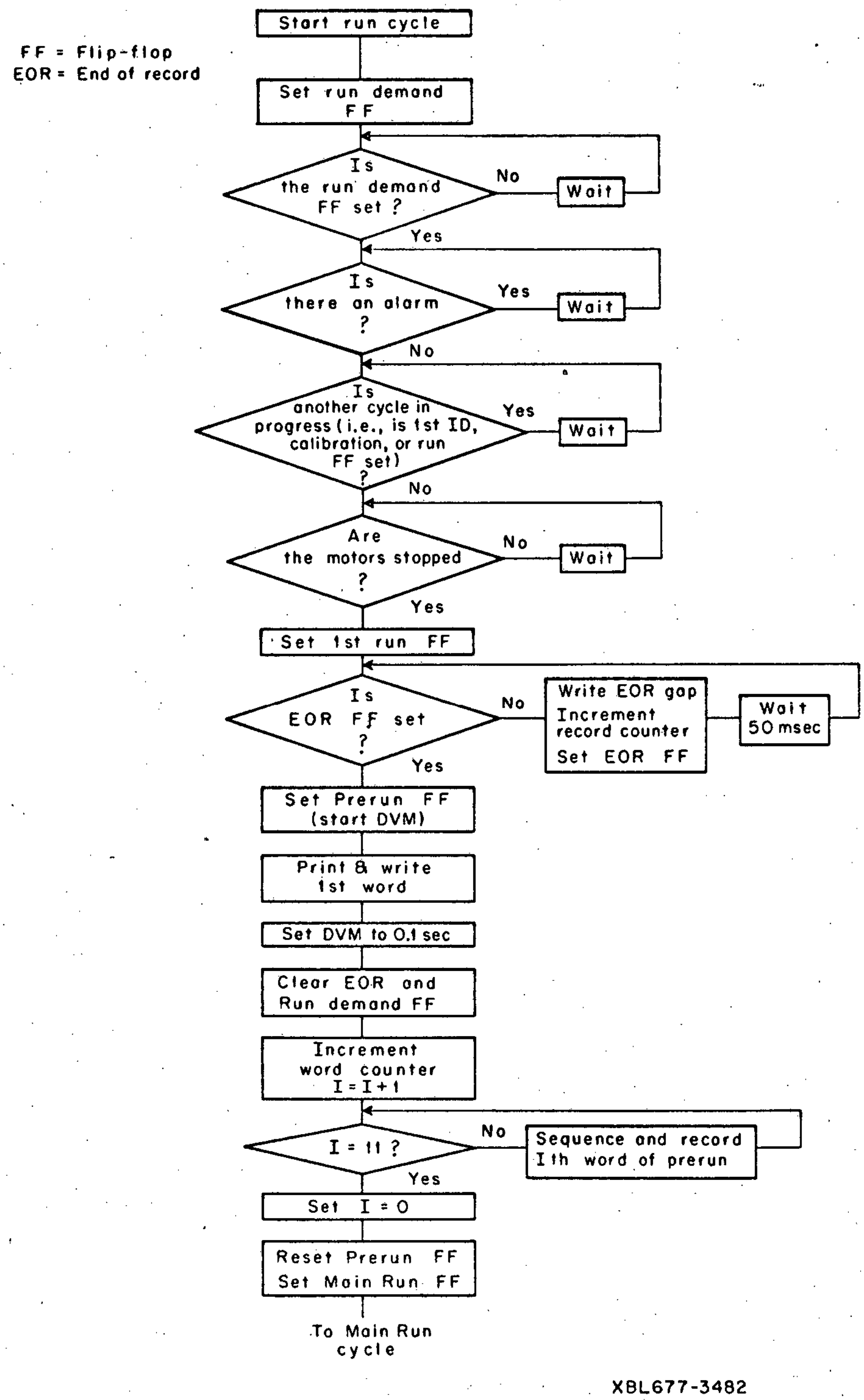


Fig. 12. Pre-run portion of the run cycle-flow chart.

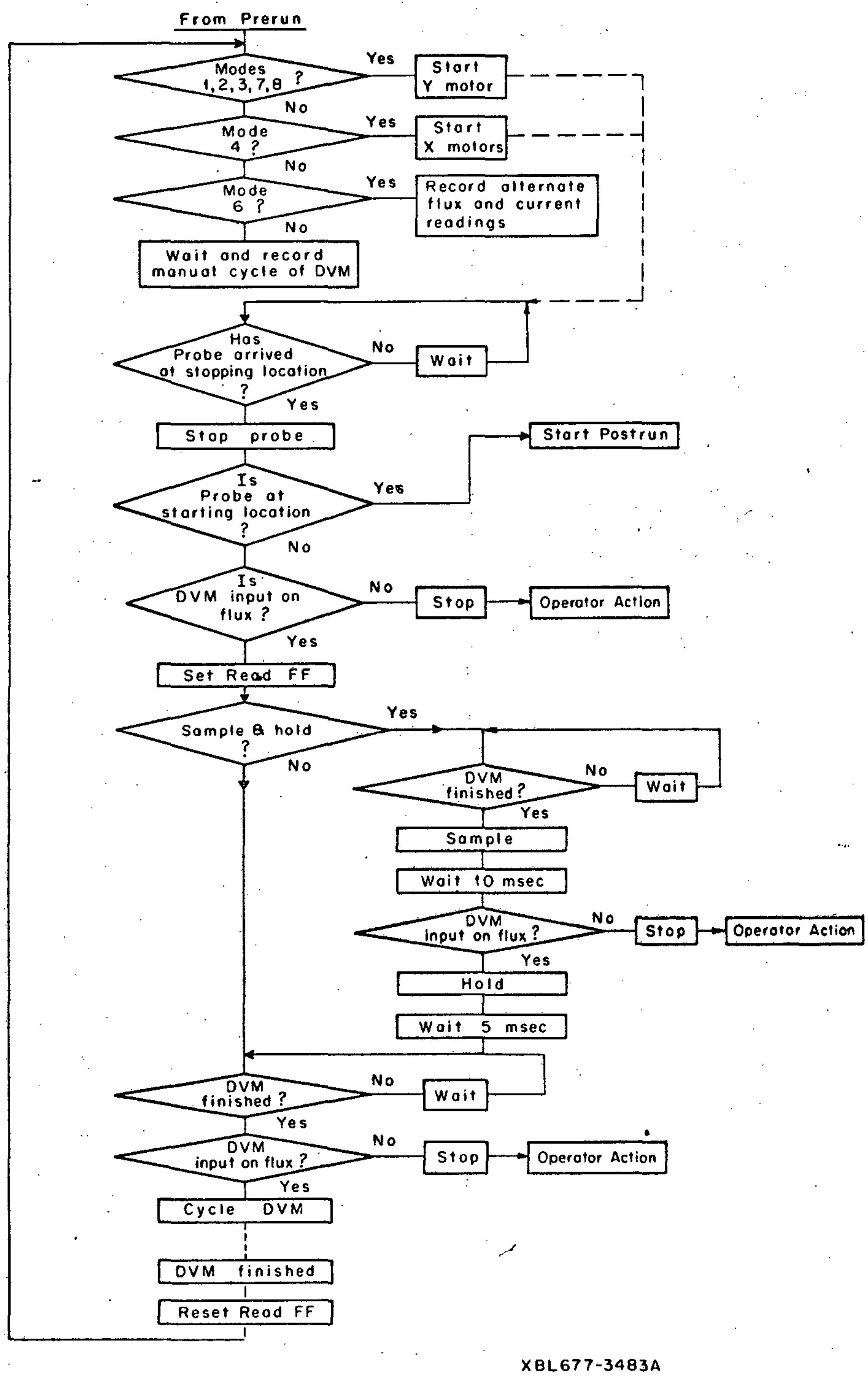


Fig. 13. Main run portion of the run cycle-flow chart.

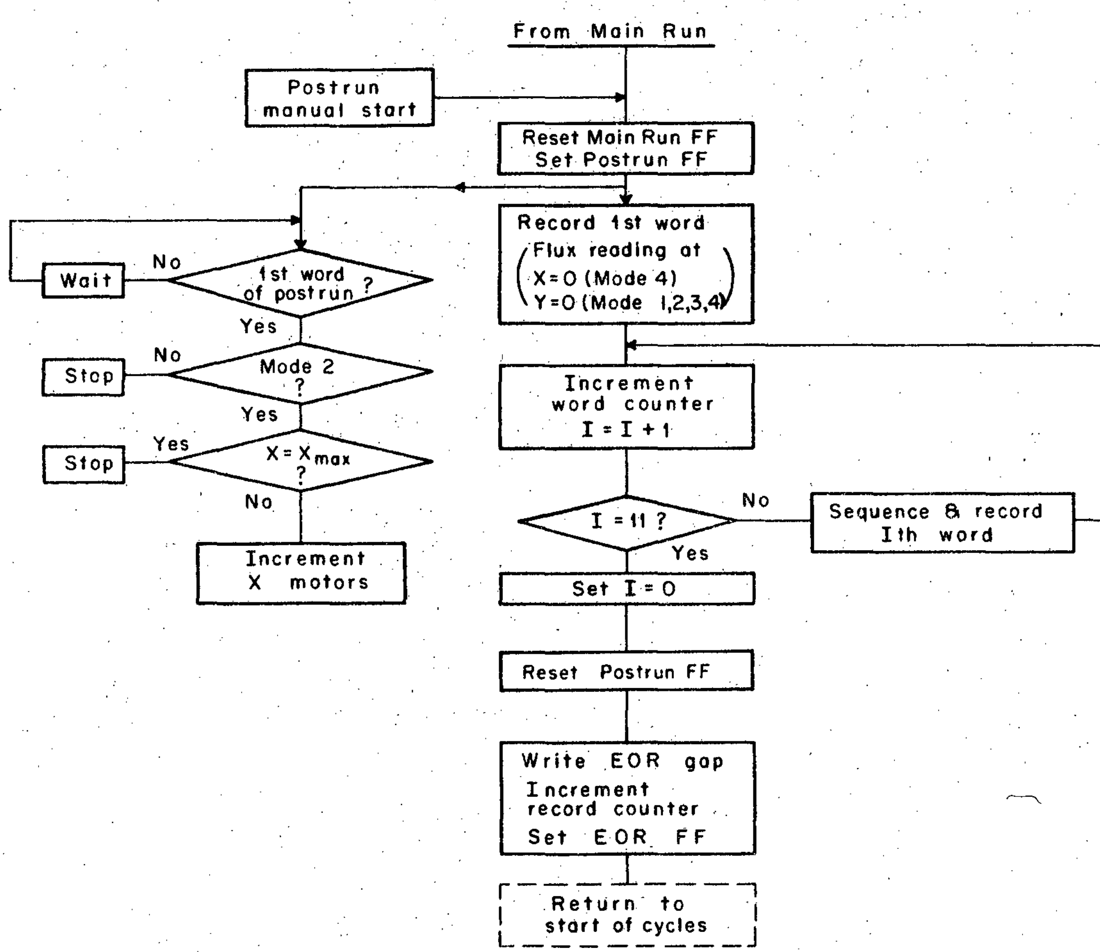


Fig. 14. Post-run portion of the "run" cycle-flow chart.

REFERENCES

1. Peter G. Watson and Ronald F. DiGregorio, Techniques of Magnetic-Field Measurement, in Proceedings of the International Symposium on Magnet Technology, 1965 (National Bureau of Standards, U. S. Department of Commerce, Springfield, Virginia, 1965), p. 393 (UCRL-16357, Aug. 1965).

2. Frederick W. Macondray, The "Square-Loop" Flux Standard - A Precision Pulse Generator, this conference (Lawrence Radiation Laboratory Report UCRL-17639, June 1967).

3. Donald H. Nelson, Recording, Analyzing, and Repressing Large-Scale Digital Measurements of Magnetic Fields, this conference (Lawrence Radiation Laboratory Report UCRL-17641, July 1967).

4. Alfred Kirst, Frederick W. Macondray, Donald H. Nelson, and Peter G. Watson, Magnetic Measurements of TAMVEC, The Texas A & M University 88-Inch Sector-Focused Cyclotron, this conference (Lawrence Radiation Laboratory Report UCRL-17640, June 1967).