Computer Control of the Vacuum Solar Telescope

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I. *DESCRIPTION OF TELESCOPE*

The Vacuum Solar Telescope has been described elsewhere by Dunn (1964, 1969). A brief summary of its characteristics is included here as background for discussing the computer control of this instrument.

This telescope is altazimuth in design. Image rotation is accomplished by rotating the inner tube structure together with all the auxiliary instruments. Azimuth and elevation torque motors drive the two mirrors at the top of the tower to track the sun automatically. The input to the servo is derived from a photoelectric guider. When clouds intervene, the servos are switched from the photoelectric guider to an electromechanical coordinate converter that also generates the signal for the rotation of the table. An elaborate 25 : 1 synchro system connects the mirror servos to the coordinate converter.

Light from the mirrors at the top of the tower passes downward 136 feet to the observing level at ground level and then downward another 180 feet to a concave mirror of 64-inch diameter and 180-foot focal length. The light is reflected back upwards to ground level by this mirror. Tilting of the mirror sends the light to one of several auxiliary instruments clustered around the central tube. At the present time, two spectrographs are installed in the vertical tubes. Several birefringent filters and cameras are placed about the vertical and horizontal optical benches.

II. *CONTROL CONCEPTS*

The design for the telescope was completed in 1964. At that time there was no discussion of a computer for operation of the telescope and for data collection. After considerable delay the construction of the telescope was contracted in 1966. A few months later it seemed clear that computer operation would greatly enhance the flexibility of the data collection system for the photoelectric spectrograph and automatic programming of the photographic spectrograph The computer would replace a number of programming devices and control sub-systems that had limited flexibility.

In changing to the computer, a number of design compromises are made. These are outlined as follows:

(*a*) *Servos*: No wide-band servo loops are closed through the computer so that it is free for its primary task of data collection. All the synchro system is retained because changing to encoders that would encode the position of the turret, for instance, with an accuracy of a few tenths of a second of arc, is very expensive and complicates the existing plans for the slip ring and wiring system. Approximately twenty-five wires are required for each encoder, whereas only six are used for the synchros. The coordinate converter is retained to generate the error signal for the relatively low accuracy tracking requirements of the table servo. Thus the coordinate converter provides a limited backup for the turret photoelectric guiding system.

(*b*) *Logical Decisions*: The computer makes all logical decisions. Each control relay or logic level input in the system is controlled solely by the computer. Each actuator is powered by a relay connected to a relay driver on the computer. Where appropriate, auxiliary electrical contacts on the relay turn on lights indicating the status of each device. Thus all logical decisions are under computer control.

(*c*) *Handbox Intervention*: There are three manual inputs to the system; the typewriter, the data switches on the computer, and the manually operated handboxes. The handboxes consist of a 16-position digital thumbwheel switch, four push button switches (X forward and reverse,

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and Y forward and reverse), and a single toggle switch for selecting a high or low speed. A computer interrupt is generated each time the push button switches are actuated or released. The computer then interrogates the handbox inputs, selects the one that has changed, and turns on or off the relay associated with that particular handbox, digital switch and push button combination. The handbox program can be set up to turn on motors, operate stepping motors, open shutters, or branch to programs. In all cases, the output must be tailored to the handbox configuration. For instance, a gradual change in a speed is not an appropriate input from the handbox since only push buttons and a toggle switch are provided. The handbox is shown in Figure 1.

(*d*) *Condition and Status*: In addition to lights that indicate the status or condition of some portions of the instrument, a visual display is provided by means of a character generator connected to television monitors. This display unit allows 20 lines of information, each 40 characters long, to be displayed. The control unit has its own memory so that the computer is used only during the time it updates the external memory. Thus messages are generated in response to condition changes in the telescope. Focus, solar coordinates, universal time, grating angles, active programs, and so forth, are displayed.

(*e*) *Backup*: No backup electronics are provided for the computer. If something fails the telescope is largely inoperable. It is possible to make the telescope guide and to take pictures without the computer. Backup electronics to replace the computer seemed uneconomical because of the complexity of the control system.

III. *COMPUTER CONCEPTS*

(*a*) *High Speed Disk*: The principal requirement for the computer, in addition to high-speed memory, is a fast auxiliary disk memory. Only those programs required at a given moment need be in memory. For instance, each time a button is pushed on the handbox a new program is brought into memory from the disk. The transfer time must be on the order of the reaction time of a human—about 0.1 sec. The disk chosen has an access time of 17 millisec and a transfer rate of 90 000 words per sec. With this disk the operator is not aware of any delays as he jogs a motor, for instance.

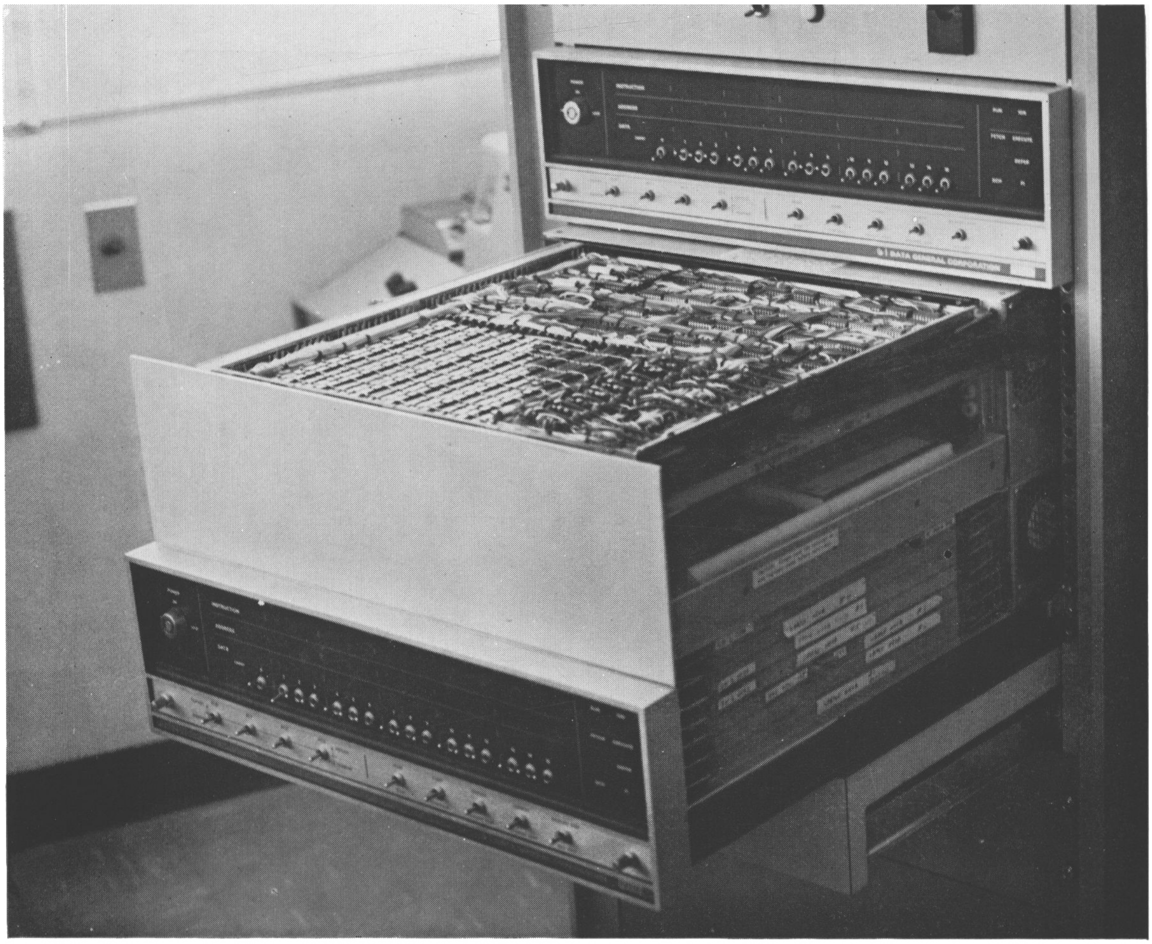
In addition, the disk makes possible fast swapping of large sections of core so that it is possible to list programs or to run Fortran programs while the telescope is collecting data.

(*b*) *Direct Input-Output System* (*DIO*): All the telescope and auxiliary spectrograph encoders, relays, and input and output functions are wired to, and addressed by, a Direct Input-Output System. The functions are grouped on 8-bit logic cards. For instance, a card might contain eight relay drivers or eight logic outputs. A particular card is selected as part of the address of the computer command. Two 8-bit cards may be selected simultaneously. Each of the eight drivers on each logic card is triggered by a different bit in the accumulator register of the computer command. Thus a "high" bit in the accumulator turns on a particular relay driver. For data input the digital number on the input card ends up in the accumulator. Thus the DIO allows the programmer to change individual control lines going out of the computer. This is ideal for a handbox routine. However, since the computer has to address each bit of information, the DIO is inefficient for transferring large blocks of data. For this the Input-Output Processor is desirable.

(*c*) *Input-Output Processor* (*IOP*): The Input-Output Processor is initiated by the computer and then operates by itself. As part of the initialization, a word count and starting address is loaded into the IOP. The IOP then transfers the words, with no additional computer intervention. The disk, typewriter, plotter, data link and card reader are all attached to the IOP. All these devices operate with blocks of data.

IV. DIO *ASSIGNMENTS*

The particular computer chosen contains a DIO that could control 480 cards. The present configuration in the Vacuum Telescope requires only 60 cards. Each card can contain either 8 relay devices,



LASKER Fig. 2

LASKER Fig. 3

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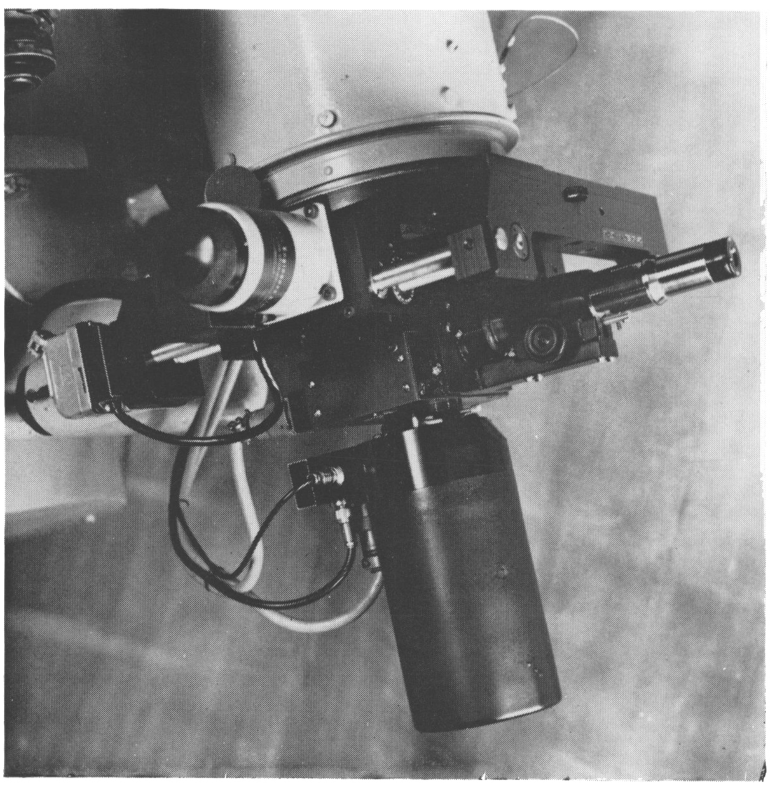
DUNN Fig. 1
Photograph of handbox input to computer.



ADAM Fig. 3

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Adam Fig. 5(a)

Adam Fig. 5(b)

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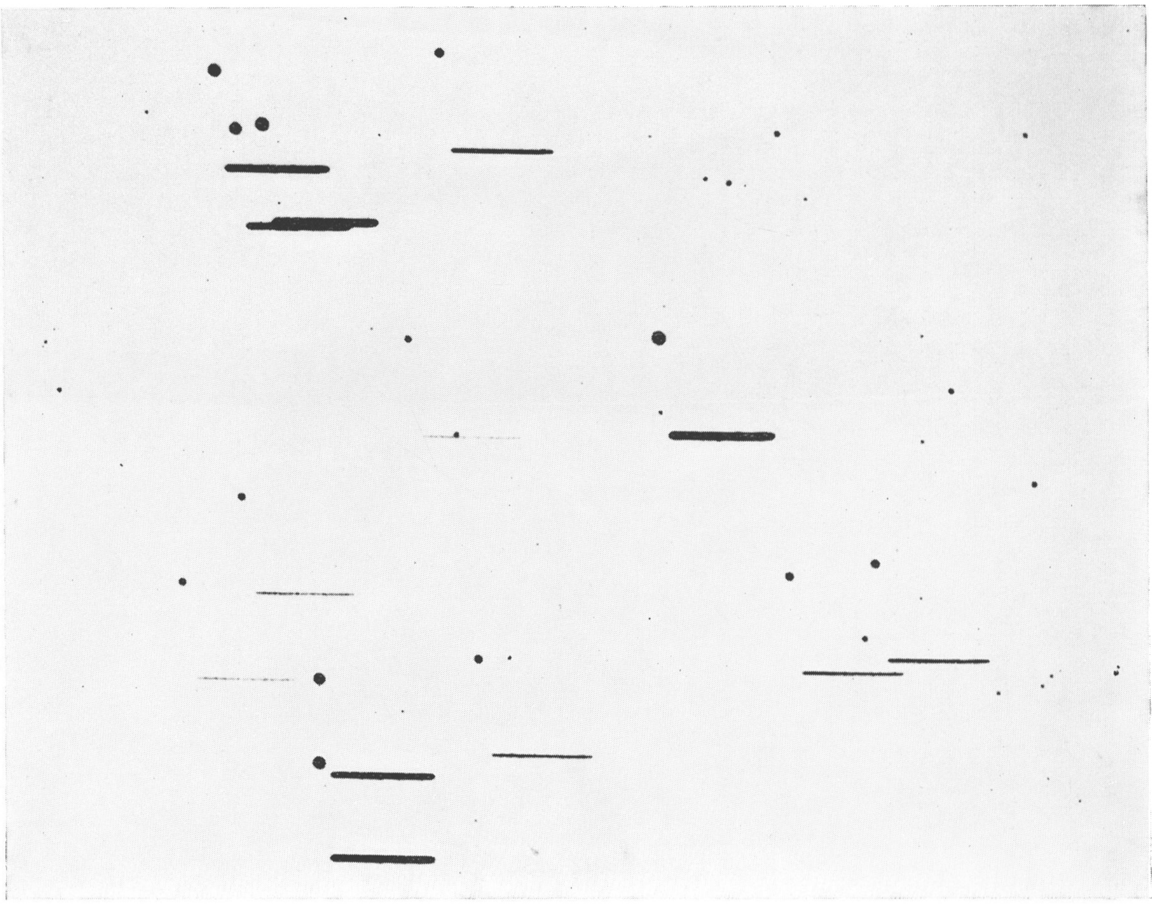
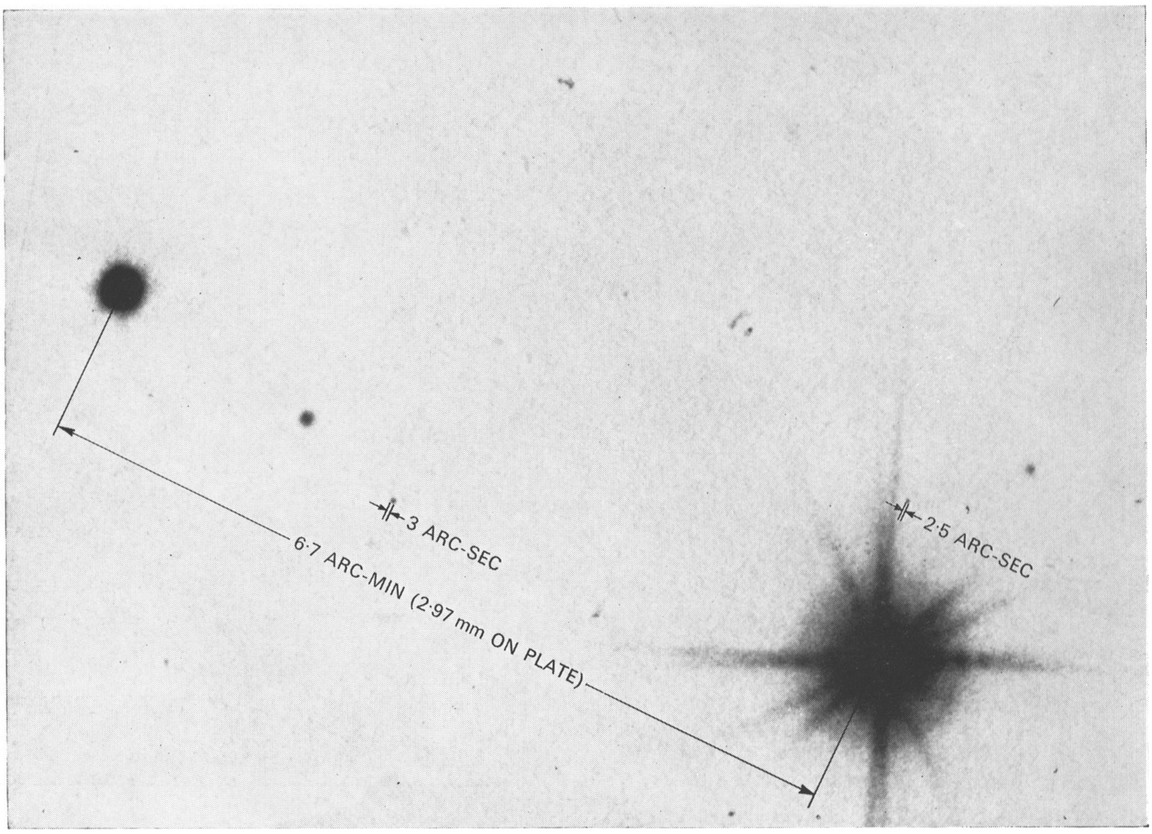


ADAM Fig. 4



ADAM Fig. 6

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8 logic outputs, 8 pulsed logic outputs, or 16 logic inputs. Table 1 shows the assignments of the associated lines.

TABLE 1

DIO ASSIGNMENTS

	Logic In	Relay Out	Logic Out
TELESCOPE			
Control	10	31	25
Encoders	24		
Stepping Motors	8		
Television			8
Storage Scope			32
Clock	40		
Position Angle	16		
Tape	32		16
Handboxes			80
Multiplexer	16		
SPECTROGRAPH 1			
Control		60	
Encoders	29		
Steppers	6		
SPECTROGRAPH 2			
Control	8	4	10
Encoders	21		
Stepper	4		
Pulse Counters	32		
	246	95	171 = 512

In addition to the DIO assignments there are 26 separate interrupts in the system. One of these has 16 inputs arranged so that a change in any of the 16 generates the same interrupt. The computer then queries the input locations in the DIO associated with the interrupts and decides which ones have changed and acts accordingly. Triggering an interrupt either externally or by program control is the preferred method of initiating a program. All but nine of the interrupts are assigned.

An analog-to-digital converter (A-D) allows measurement of potentiometer signals and voltages. There are 48 A-D Channels in the system, but only 14 are presently assigned.

V. *COMPUTER CONFIGURATION*

The configuration of the Computer is shown in Figure 2. The computer is a Xerox Data System (XDS) Sigma 2, with 24 000 16-bit words for memory, and the DIO and IOP described previously. The "peripherals" include the disk, teletype, card reader, data link to a larger computer, clock, TV display, A-D converter, plotter, and cathode-ray storage scope. The data link permits use of the tape decks, card punch and printer attached to the larger computer.

VI. *MONITOR*

The monitor is a computer program furnished by XDS that does the book-keeping in the system. It sets up all the peripherals so that they can be accessed by other routines. It keeps all the interrupts, and hence the programs associated with the interrupts, in order. It contains a library of subroutines and constants that can be accessed by any of the other programs and takes care of all the core "swapping" that occurs when the different interrupt programs are returned momentarily to the disk. This monitor accounts for 7000 words of core. Programs that must be left in core accounts for another 5000 words. Four thousand words are reserved for bringing in programs from the disk leaving 8000 words for compiling Fortran, compiling machine language programs, editing, plotting and so on. The interrupt system allows these programs to continue while the telescope and its spectrographs operate and collect data.

VII. *PROGRAMS*

In addition to a large number of utility programs that handle the peripherals, handbox, plotter and clocks, we have begun to accumulate the programs for data collection. Raster scans of the sun can be made with the stepping motors on the photoelectric guider. All the grating angles are calculated by the computer so that one can simply request a particular wavelength. A program lists the wavelengths in overlapping orders so that the spectograph can photograph several spectral lines simultaneously. All the exposures on the spectrograph and cameras are made under computer control. The motor for rotating the large table is torque limited. Under computer control the table is slowed down automatically so that it does not overshoot in stopping. As the photoelectric spectrograph nears completion, programs will be written for the fast scanning of spectral lines. A magnetometer data collection program will be written. Real-time maps of magnetic fields will be computed by the larger computer and sent back to the Sigma 2 by the interconnecting data link to be displayed on the cathode ray storage scope.

VIII. *SUMMARY*

This computer installation represents a trend in the control of telescopes in the United States. For many applications where the set-up does not need to be changed, for instance in a solar magneto-

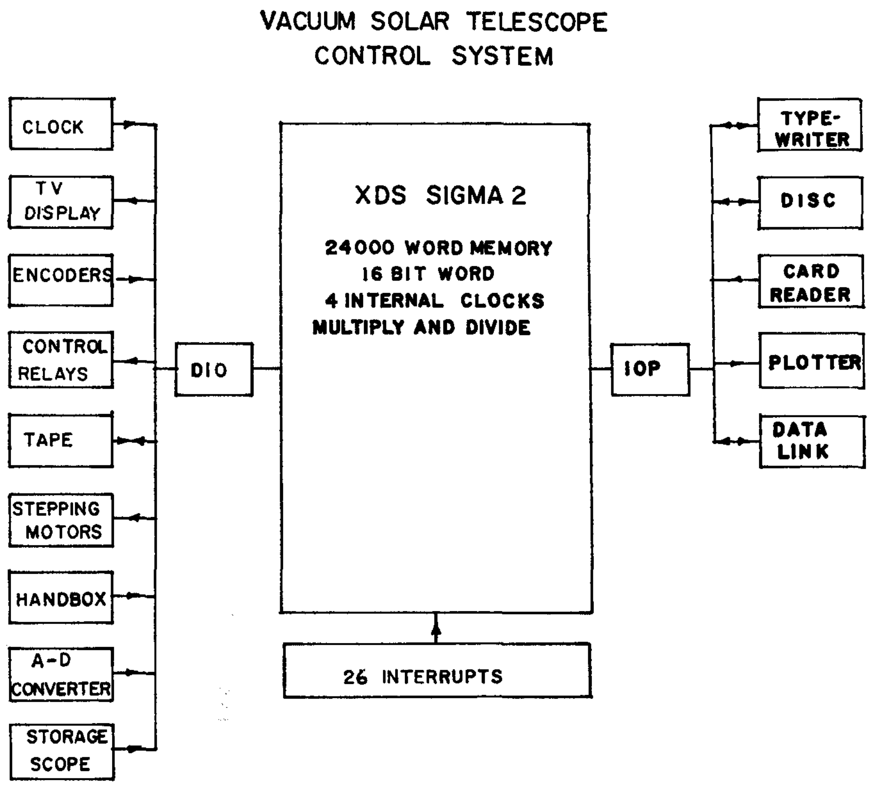

Fig. 2
Vacuum Solar Telescope Control System.

meter, the larger computer with its monitor is not needed and a small computer with a small core can be used. However, if the set-ups are constantly changing, the approach used on the Solar Vacuum Telescope is attractive and is quite easy to program because of the support given by the monitor. It makes possible the execution of a large number of programs that operate concurrently and are not related in any way except by priority. At the same time, the user can compile Fortran programs and execute them. He is usually unaware that the telescope is making scans and collecting data.

REFERENCES

Dunn, Richard B., 1964. *Applied Optics*, **3,** 1353.
Dunn, Richard B., 1969. *Sky and Telescope*, **38,** 368.

DISCUSSION

C. N. W. Reece: I am basically interested in your servo control stage. It would appear to be a very slack servo, and do I presume that the time lost in the start or overrun in this servo is unimportant?

R. B. Dunn: No, we do not lose any time. The drive is called a torque-limited bang-bang servo. To avoid overshoot, the computer starts stopping the table before it comes to null.

C. N. W. Reece: I gather, then, that you are generating a velocity ramp in the computer?

R. B. Dunn: No, the velocity ramp is just given by the torque constant of the motor. The computer continually checks the tachometer on the table and also the distance from null. It then knows when to "bang" the motor into full reverse so that the table will stop at null with no overshoot.

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