THE WEIZMANN INSTITUTE SPIRAL READER SYSTEM

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1. INTRODUCTION

The high energy group of the Weizmann Institute decided to build a Spiral Reader in March 1968, in order to increase the event processing capability of the group to about 500,000 events per year. The mechanical and optical part of our Spiral Reader is identical to the Berkeley SR II, and the on-line computer is a PDP-9. The control electronics and the PDP-9 software were designed and built by our group at the Weizmann Institute. The Spiral Reader is undergoing test production running since February 1970 and has measured to date about 5000 events.

2. THE MECHANICAL-OPTICAL HARDWARE

The mechanical-optical hardware, consisting of the periscope and rotating cone assembly, the x-y stage, the film transport and the projection system has been built for us by the Lawrence Radiation Laboratory and is identical to the Berkeley Spiral Reader II. Thus it has a scanning radius of 80 cm in space (or 5 cm in the film plane), and its film transport is for 46 mm single strip format.

We have designed ourselves a film cage for 35 mm 3 strip film format. This new cage mounts simply on the present stage assembly, and the conversion from one film format to the other should take only a few hours. The 35 mm film cage is presently being built in our shop and will be tested in a few months.

3. COMPUTER

The on-line computer is a Digital Equipment Corp PDP-9. The computer configuration includes 2 DECtape transports, and 1 IBM compatible magnetic tape transport, Automatic Priority Interrupt (API), and a memoscope.

The reason for getting the 2 DECtape transports was to give us the option of making use of the DEC provided Keyboard Monitor system for the PDP-9. This turned out to be of very great help in the writing, debugging and testing of the on-line programs. It will be described in more detail in section 5. During production running, one DECtape holds the system and the program, the second DECtape contains the input information while the output is written on the IBM compatible magnetic tape. In order to facilitate fast listing of programs on the line printer of our computation center, service routines were written to convert ASCII code on DECtape to BCD on magnetic tape in appropriate formats; similarly another program did conversions from card images onto DECtape.

In order to help on the debugging of the Spiral Reader and the filtering programs, a direct data link was constructed between the PDP-9 and our off line computer (a home built GOLEM, roughly equivalent to an IBM 7094).

4. THE CONTROL ELECTRONICS

The control electronics was completely designed and built at the Weizmann Institute. We made our own cards, based upon TTL type integrated circuits and thus achieved a high amount of compactness. The whole electronics only partially fills one standard cabinet, while all the power supplies are in a second cabinet.

The control electronics operates through the use of a command-and-status register (CSR) for each active device. These registers have a uniform general structure for the x and y stage drive, the periscope drive, the film drive and the Q channel (data input). The structure of these command-and-status registers is as follows:

Bits 0 - 5 :	Velocity register	COMMAND-AND-STATUS REGISTER
Bits 6 - 11:	Command register	
Bits 12 - 17:	Status register	

While the general structure is similar for all active devices the specific function of the various bits is somewhat different for the different devices.

As an example we shall describe in somewhat more detail the stage drive register.

The velocity registers contain the sign (bit 0) and magnitude (bits 1-5) of the velocity with which it is desired to drive the stage. The command register controls the mode of operation of the device. Thus bit 6 specifies whether operation is automatic (under computer control) or manual (via the speed ball); bit 7 specifies whether counting is enabled or not; bit 8 specifies whether the reference signal is enabled or not; and bit 9 controls whether the raising of certain flags causes an interrupt in the PDP-9 API device. The status register (bits 12-17) consists of a number of flags that are raised when certain operating conditions occur. In particular, flags are raised when the inner or outer limit switch is hit, a reference mark is crossed or the scaling register overflows. When some of these flags are raised, an interrupt signal is also sent to the computer which subsequently suspends its normal processing sequence and handles the interrupting condition.

The scaling registers are internal in-memory locations in the PDP-9. They are incremented or decremented by the Add-to-Memory capability of the PDP-9 computer via the data channel facility. In order to avoid loss of counts due to timing conflicts, an external scaler of 3 bits is incorporated in the electronics. When the internal scaler overflows (or underflows) an Add-Overflow flag is raised, which is also connected to the interrupt line. Thus by presetting the internal scalers a specified number of counts away from overflow, the stage can be driven that distance while the computer handles other work; when the overflow interrupt occurs the computer can either stop the stage or preset it to move another specified distance before interrupting again.

The Heidenhain grating system which provides the digitizations of the xy stage contains a reference mark. This reference mark causes the raising of a flag whenever this mark is being crossed, if the appropriate bit of the command registered is enabled. The reference mark is used for the original setting of the scalers as well as for periodic checks that no counts were lost.

The Spiral Reader I/O instructions control the devices by writing into the Command-and-Status register (CSR) from corresponding AC positions in the computer. Both jam transfer, as well as ANDing and ORing from the AC into the CSR can be executed. Thus single command bits or any desirable combinations thereof can be changed without modifying the rest. The velocity register can be written independently of the command register. The CSR can be read into the AC, and skip instructions are provided to test the status of the different flags.

The CSR of the other active devices have a similar structure to the stage drive described above, but are different in some of the details. The periscope drive has an additional homing command (in the Command register). This homing command drives the periscope at top speed to a home position, specified by a helipot mounted on the periscope lead screw. (This command is used to return the periscope to its "zero-position" after the completion of a scan). In the film drive there is a leader flag instead of limit switches, and there is a flag that is raised when the film gate is down and vacuum is on. The Q channel (data input) is connected to 2 Data channels, corresponding to 2 buffers in the computer memory being used. When one buffer has been filled, the electronics automatically switches the data input to the other channel, a flag is raised and an interrupt occurs. At this time appropriate action is taken to write the filled buffer on the magnetic tape. Furthermore, in the Q channel the velocity register is replaced by the discriminator level which specifies the acceptance criteria of a pulse.

The output of the Spiral Reader comprises of 5 pieces of data, packed into 4 PDP-9 words, for each hit. They include the radius, pulse height, leading angle (θ_L), trailing angle (θ_T) - where from the hit angle is $\theta = 0.5\,(\theta_T + \theta_L)$. In addition we output the angle $\theta_{1/2}$ at which the pulse reaches half its maximum height. We expect this additional piece of data to be of help in an improved calculation of the track ionization.

A more complete description of our SR Instruction List and Command Register Structure, and details of our electronics is found in several Weizmann Institute Internal Reports[1-2] .

5. ON-LINE SOFTWARE

A new on-line program (ZOO) was written for the PDP-9 to control the Spiral Reader through our new electronics. The program initializes the SR operation, reads the ID information from DECtape, positions the film, controls the fiducial measurement, handles the data input in a vertex scan and outputs it on magnetic tape, allows for crutch point measurements, and performs view changing. In addition it has branches for treating cases where unexpected things occur such as hitting of limit switches, and it allows for operator intervention to remeasure an event, reject it, etc. The program performs simultaneous parallel operations whenever a reasonable saving of time can be achieved.

Our PDP-9 configuration included 2 DECtapes and 1 standard magnetic tape unit. Thus before beginning the measurements the SR input tape (containing the ID information of the events to be measured) - is copied from a magnetic tape onto one of the DECtapes (it takes about 2-3 minutes to copy 500 events). Then during the measurement proper the input is read from the DECtape and output data is written on the magnetic tape. As the DECtape is inherently slow a buffering scheme is used to avoid loss of time. When a new ID is to be read, it is already found in a 40-word buffer in the PDP-9 memory. Thus it takes only the time to transfer it from the buffer to the regular location in memory. Subsequently the next record is read into the buffer and the DECtape is repositioned; obviously this operation is done simultaneously with the measuring of the Spiral Reader and thus no time is lost.

During the collection of data at the time of the periscope scan, the data input (Q channel) is alternately connected to 2 PDP-9 data channels corresponding to 2 buffers. While the Q channel fills one buffer, the other buffer is being written on tape; in addition the data is being displayed on the scope at the same time and various checks are also performed on the input data as it comes in to ascertain that no malfunction of the equipment occurred. When the buffer is filled the Q channel is automatically switched via hardware to the second buffer and an interrupt occurs. As the tape writing is considerably faster than the data input, by the time this switch occurs the contents of the buffer were always already written on tape, and the new buffer is ready to accept data.

As was mentioned already, it was decided to make use of the DEC supplied PDP-9 Keyboard Monitor System, in writing the on-line programs. Thus the programs were written on the PDP-9 teletype using the Editor-9, assembled by the MACRO-9 assembler and loaded by the Linking Loader. The binary programs produced by the assembler were stored, of course, on DECtape. Changes in the program could be effected in a few minutes by going through the sequence Editor-9, MACRO-9, and Linking Loader. It should be emphasized that the Monitor system was used only in the pre-execution phases of the program, as described above. Once execution started the on-line program was completely stand-alone. Thus we wrote our own special purpose and compact handlers for DECtape, Magnetic tape and teletype. Furthermore during execution the resident monitor area (about 900 locations) could be overlaid by storage space, e.g. the data buffers, and thus no serious loss of storage resulted from use of the monitor system.

A new routine which is being written at present will perform a semi-automatic measurement of the fiducials with the periscope scan.

According to this scheme the first fiducial is measured manually. Then one can accurately calculate the correction factor due to film stopping uncertainty. Subsequently the stage is driven to the second fiducial, and it is found that we can stop it well within a third of a leg from the center of the fiducial. At this point about 5 revolutions of the cone are performed at slowly increasing radii of the periscope, thus obtaining about 5 hits on each of the 4 legs of each fiducial. Then the procedure is repeated on the other fiducials. The total time it takes is the time to drive the stage to all fiducials plus about 300 msec per fiducial. Actually, this method significantly decreases the strain on the operators and potentially increases the accuracy of measurement of the fiducials. The data from the periscope scan is being subsequently analyzed in the filter program POOH by a method very similar to that employed in the calibration program. Thus a best straight line is passed through each combination of legs in a local xy coordinate system and the intersection determines the fiducial location.

6. CHECKOUT AND PERFORMANCE

The separate components of the electronic system were tested operationally as they were completed, by specially written PDP-9 programs.

The complete Spiral Reader System entered into a shake-down production run during February 1970. As of now about 5000 events were already measured on it of $\pi^{+}p$ interaction at 5.0 GeV/c (46 mm single strip film of the 82" SLAC Bubble Chamber).

The present measurement rate on our Spiral Reader is typically about 50 events/hour averaged over a two hour shift. This includes the measurement of 4 fiducials manually, and the printing on the Teletype of some ID information to which the measurer must react.

The measurement rate of the Spiral Reader will be increased in coming few months by the following means.

(1) The fiducial measurement procedure will be modified in two ways:

(a) Only 2 fiducials will be measured on each view, while several times on each roll 4 fiducials will be measured for checking purposes. This procedure will be fully implemented only after performing extensive testing to ascertain that no loss of accuracy results.

(b) Semi-automatic fiducial mode will be introduced where one fiducial is measured manually and the others are measured by making spirals around them as described in section 5. This mode is obviously equally applicable to the measurement of 2 fiducials or 4 fiducials, and is also independent of the location of the pertinent fiducials.

(2) The ID information will be displayed on the scope instead of on the Teletype, thus speeding up the response of the measuerer.

(3) The improvement of the mechanics of communication between the operator and the computer, such as in verification of events, rejects or remeasurements.

The measurements already made on our Spiral Reader have gone through the analysis programs of filtering (POOH), geometry (TVGP) and kinematics (SQUAW). The success rate through POOH is at present about 70% and the least squares deviation of tracks in TVGP is of the same general magnitude as the results of our manual measuring machines.

Our main effort now is concentrated in improving the filtering to get a higher success rate, and in the determination of the best calibration procedures in order to reduce the track deviations.

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REFERENCES

1. E.E. Ronat, R. Yaari and H. Brafman - S.R. Instruction List and Command Register Structure (W.I. Internal Report SRWP-2 (Ver. 4); June 25, 1969).

2. H. Brafman - A General Description of the Weizmann Institute Spiral Reader (W.I. Internal Report SRWP-3; December 1, 1969).