PROJECT WHIRLWIND

(Device 24-x-3)

SUMMARY REPORT NO. 25

FOURTH QUARTER, 1950
and
FIRST QUARTER, 1951

Submitted to the

OFFICE OF NAVAL RESEARCH

Under Contract N5ori60

Project NR-048-097

SERVOMECHANISMS LABORATORY

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Cambridge 39, Massachusetts

Project D I C 6345

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FOREWORD

Project Whirlwind

Project Whirlwind at the Massachusetts Institute of Technology Servomechanisms Laboratory is sponsored by the Office of Naval Research and the Air Materiel Command under Navy contract N5ori60. The objectives of the Project are the development of an electronic digital computer of large capacity and very high speed, and its application to problems in mathematics, science, engineering, simulation, and control. At the present time Project resources are about equally divided between (1) operation of the computer and improvement of its reliability; (2) applications of the computer to engineering and scientific problems; (3) storage-tube research and development; and (4) design of additional terminal facilities.

The Whirlwind Computers

The Whirlwind computer is of the high-speed electronic digital type, in which quantities are represented as discrete numbers, and complex problems are solved by the repeated use of fundamental arithmetic and logical (i.e., control or selection) operations. Computations are executed by fractional-microsecond pulses in electronic circuits, of which the principal ones are (1) the flip-flop, a circuit containing two vacuum tubes so connected that one tube or the other is conducting, but not both; (2) the gate or coincidence circuit; (3) the electrostatic storage tube, which uses an electron beam for storing digits as positive or negative charges on a storage surface.

Whirlwind I (WWI) may be regarded as a prototype from which other computers will be evolved. It is being used both for a study of circuit techniques and for the study of digital computer applications and problems.

Whirlwind I uses numbers of 16 binary digits (equivalent to about 5 decimal digits). This length was selected to limit the machine to a practical size, but it permits the computation of many simulation problems. Calculations requiring greater number length are handled by the use of multiple-length numbers. Rapid-access electrostatic storage now has a capacity of 4096 binary digits, sufficient for some actual problems and for preliminary investigations in most fields of interest. Present speed of the computer is 20,000 single-address operations per second, equivalent to about 6000 multiplications per second. This speed, which is expected to be doubled by improvements now under way, is higher than general scientific computation demands at the present state of the art, but is needed for control and simulation studies.

Reports

Quarterly reports are issued to maintain a supply of up-to-date information on the status of the Project. Detailed information on technical aspects of the Whirlwind program may be found in the R-, E-, and M-series reports and memorandums that are issued to cover the work as it progresses. Of these, the R-series are the most formal, the M-series the least. A list of the publications issued during the period covered by this Summary, together with instructions for obtaining copies of them, appears in the Appendix.

I. SIX MONTHS' REVIEW (AND ABSTRACT)

During the latter part of the period covered by this report, the Whirlwind computer became a reliable operating system, with 256 registers of electrostatic storage. At the end of the period, the members of the applications group were operating the computer about 35 hours per week on a prearranged schedule. Of this time 90 percent has been useful. The computer has several times run for 7 hours without error, performing a complicated program that uses all 256 registers of electrostatic storage. No effort has been made to obtain continuous error-free operation for longer than 7 hours.

With a reliable computer available, the expanded applications group has been writing additional programs and developing efficient methods for using a large-scale high-speed computer. Among the problems attacked have been the writing of a complete input program and the development of methods for preparing and handling the Flexowriter input tapes. Members of the group are getting actual experience operating the computer while at the same time checking the success of the programs they have written.

Improvements in procedure have reduced the routine daily marginal-checking period to about 20 minutes, with an average of only one or two marginal circuits discovered each day. The procedure is being further improved by storing the program in electrostatic storage.

Unreliable operation of electrostatic storage during the last quarter of 1950 was traced to fluctuations of the high-velocity beam caused by changes in charge on the glass windows in the storage tubes. A revised design, with the entire inside of the envelope coated with aquadag (the 300-series tube), was developed to alleviate this difficulty. The 300-series tubes are not subject to glass charging. After 16 of them had been made and installed in the computer, it became a reliable working system. Development work on electrostatic storage is now aimed toward increasing storage capacity by using more of the storage surface, increasing the density of spots, and installing a second bank of storage tubes.

The computer is currently operating with an interim input-output system that uses Flexowriter typewriter and punched-tape equipment. Plans are under way for a flexible system that will accommodate various kinds of terminal equipment. This system will include (1) a crystal-matrix switch for choice of a particular unit of terminal equipment; (2) an in-out register to serve as the communicating link between the computer and the terminal equipment; (3) an in-out control; and (4) terminal units of the following types. (a) magnetic tape, (b) paper tape, (c) oscilloscopes, (d) scope camera, and (e) control for programmed marginal checking.

Continued investigation of the life of vacuum tubes in pulsed circuits bears out information in earlier reports. Our experience indicates that it would not be wise to make wholesale replacements of tubes after arbitrary periods, at least not within 20,000 hours. This report contains summaries of tube experience for the year 1950. Further investigations of cathode interface deterioration indicate that the type of service is a very important factor in this problem.

2. SYSTEM ENGINEERING

2.1 OPERATION OF THE COMPUTER

2.11 Reliability and Marginal Checking

During the six months covered by this report, electrostatic storage was successfully integrated with the computer, and reliable operation of the whole system was attained. Troubles with electrostatic storage impaired reliability of the computer during the last quarter of 1950. But by the end of March 1951, the computer was running on a definite applications schedule with about 35 hours scheduled each week. Of this time 90 percent was useful. The computer has several times run for 7 hours without error, performing a complicated program that uses all 256 registers of electrostatic storage. No effort has been made to obtain continuous error-free operation for longer than 7 hours.

Much of the increase in reliability is due to improvements in operation of electrostatic storage, but increased efficiency of marginal checking has also helped substantially in reducing computer errors. The marginal-checking program now in use confirms that all orders operate correctly and makes a complete check of the arithmetic element. This marginal-checking program is operated once each day.

In addition, new programs have been written for a special checking of different sections of the computer. For example, a special program, with its orders in electrostatic storage, has been very successfully used for tracing troubles in test storage. Automatic voltage excursions on all the marginal checking lines are set a few volts lower than the excursion that will cause an error when nothing is wrong.

By the end of March 1951, the marginal-checking programs each morning would result in only one or two errors. This has reduced the marginal-checking time from an hour and a half to about 20 minutes, and has resulted in more reliable operation of the computer.

A special flip-flop-storage marginal-checking program with orders in electrostatic storage revealed some poor margins in the flip-flop-storage output panels. These poor margins showed up only under certain repetition rates. The cause of the low margins was found to be an error in the basic design of the output panels. The flip-flop-storage circuits are now being modified to eliminate this difficulty. Several difficulties in the arithmetic element and control have been found and eliminated.

Now that electrostatic storage is available for marginal-checking programs, it is expected that marginal checking can be made much more useful and efficient. The marginal-checking equipment is being changed so that test programs stored in electrostatic storage can specify which marginal-checking line will be selected and which marginal-checking program will be used with this particular line. This system has become known as programmed marginal checking. The increased reliability of WW has overcome the major problem associated with program-controlled marginal checking, the possible loss of stored information in electrostatic storage during an operational error caused by the marginal checking itself. If these losses of information are at all frequent, the necessity for continued reinsertion of the program into electrostatic storage means that so much manual operation of the marginal-checked equipment will be required that the whole system will be cumbersome. There has recently, however, been an average of only one error per day, and this average will probably not increase significantly after electrostatic storage itself has been incorporated into the automatic marginal-checking system.

To facilitate marginal checking of the electrostatic-storage system, an electrostatic-storage-control alarm panel has been installed. This panel indicates trouble whenever electrostatic control does not supply a completion pulse at the correct time. Thus, this single alarm panel can be used to indicate trouble in most of the sections of electrostatic-storage control.

Test control has been completely revised so that it is not only easier to use but is also much more flexible and has many additional modes of operation.

2.12 Applications

The increase in reliability during the first month of 1951 resulted in a demand from the applications groups for increased computer time. Schedules have been issued during most of the first quarter specifying to the hour which groups will have the use of the computer and in some cases what type of operation will be used. In general, these schedules have been followed very closely, and the schedule for one week has usually been available about the middle of the previous week.

To facilitate trouble-shooting of programs, provision has been made for printing out the contents of several of the more important computer registers. This allows an applications engineer to trouble-shoot a program by printing out the contents of a specific computer register after each step in the problem and thereby to follow the course of the program to the point where the trouble occurs. Furthermore, the printing facility means that the programmer does not actually have to be present in the computer room while his program is being operated, because a written record of the progress of the program can be supplied him for study at his leisure.

2.2 INTEGRATION OF ELECTROSTATIC STORAGE SYSTEM

2.21 Increased Reliability

As described in Section 4.11, unreliable operation of electrostatic storage during the last quarter of 1950 was traced to changes in charge on the glass windows in the storage tubes. The new 300-series all-dag storage tubes are not subject to this trouble. As fast as these tubes were available they were installed in the computer, and as each tube was added, the reliability of the computer increased substantially. A complete set of all-dag tubes is now operating in the computer, and the present small number of computer errors are about evenly divided between storage and the rest of the Whirlwind system. However, electrostatic storage requires about twice as much maintenance as the rest of the system.

Because of the rapid replacement of storage tubes in the computer, no tubes have accumulated any large number of hours. Therefore it is still not possible to predict with any degree of certainty what the eventual life of the tubes will be under actual computer operation.

2.22 Future Plans

Work is now progressing toward obtaining an increased capacity of storage. It is hoped that changes in the operating conditions of the present storage tubes will result in an increase in the number of total storage registers by a factor of about two. This increase is expected to result from two changes. First, the deflection circuits will be reconnected to allow use of the storage surface outside of the normal square area. For a description of one possible deflection connection, see Summary Report 20. Second, it is hoped to decrease the spacing between spots by decreasing spot size and by increasing accelerating voltage in the high-velocity gun. These changes can probably be made to yield a substantial increase in the number of storage registers without reducing the reliability of computer operation.

Another substantial increase in the number of available storage registers will result when a second bank of storage tubes is installed. This increase in available storage registers is a longer-term project than that discussed in the previous paragraph. Plans for the installation of the second bank, including all the required block diagrams and circuit designs, have been completed. Construction on circuits for the second bank of tubes will probably start soon. The present schedule calls for complete installation of the second bank by the end of 1951. This means that by the end of 1951 there will probably be available 1000 registers of high-speed electrostatic storage.

During the months of February and March, storage reliability has been uniformly good. The storage access time during this period has been steadily decreasing. Starting at about 150 microseconds, the reliable access time has been reduced to about 28 microseconds. This consists of a weighted average (18 microseconds) between the read time of 12 microseconds and the write time of 31 microseconds, plus 5 microseconds for bias restoration and about 5 microseconds of holding-gun time. Work is now in progress to remove the necessity for the extra holding-gun time and to reduce the other figures. The goal is an access time of 6 to 8 microseconds.

2.3 INTEGRATION OF INPUT-OUTPUT SYSTEM

2.31 Interim System

The final input-output system, including a new in-out register and in-out control, are still in the development stage (see Section 5). The computer is now operating with an interim system which ties the in-out units to the computer through the flip-flop registers. This system is somewhat slower than the final in-out system, in that an in-out interlock is not used. Thus the computer is idle while it waits for completion of the functions of the in-out equipment. The computer itself is used instead of an in-out control, and flip-flop storage registers are used instead of an in-out register. In addition, with the interim system, there has been much less attention paid to methods of marginal checking than there will be in the final system.

The interim system with input tape reader and output tape punch and printer was installed by the middle of October, and operation was satisfactory.

2.32 Flexowriter Reliability

By the end of 1950, it became evident that the Flexowriter units were not operating in an entirely satisfactory manner. Every few read-in tapes would be in error, and the computer would therefore not perform the correct program. Before the end of 1950, storage errors were so frequent that reliable operating figures on the Flexowriter equipment were difficult to obtain. By the end of 1950, the number of errors caused by the Flexowriter equipment was comparable to the number caused by electrostatic storage. A program was therefore started for obtaining Flexowriter reliability. Several faults were uncovered: (1) The method of synchronizing the completion pulse from the Flexowriter units with the computer pulses was logically at fault; an additional flip-flop was put in to correct this. (2) The spring-loaded mechanism in the reader used to insure that a piece of Flexowriter tape was actually in the read-in unit was not functioning perfectly and would cause occasional skipping of a character; the skipping was eliminated by readjustment of the mechanism. (3) Several faulty gas tubes were found in the synchronizer; these tubes were replaced.

The correction of the above difficulties combined with a general cleaning and overhauling of the equipment resulted in very good reliability. A routine maintenance procedure designed to replace faulty units and keep the equipment in good operating order was started. So far, this procedure has been quite effective. Few Flexowriter troubles have been encountered during the latter part of the first quarter of 1951.

2.33 Decoders and Scopes

The present combination of decoders and scopes used with the computer for output display of different curves is definitely a breadboard system. A new decoder design and a new 16-inch scope are being developed by the in-out group. Until these units are available, the computer is operating with temporary equipment. This equipment is maintained to a reasonable degree of reliability, but the new units are expected to be very much more satisfactory from the standpoint of excellence of display and ease of maintenance.

3. CIRCUITS AND COMPONENTS

3.1 FIVE-DIGIT MULTIPLIER

Since April, 1949, the five-digit multiplier (a prototype of the Whirlwind arithmetic element) has been operating on an extended life test in which studies of system reliability are being made. The system repeatedly performs a multiplication of two five-binary-digit numbers and checks for a correct result at the end of each multiplication. When errors occur they are recorded on electromechanical counters to give a measure of system reliability. The multiplications require about eight microseconds each, and they are repeated at the rate of 15,000 times a second.

Marginal checking facilities were built into the system to provide a means for detecting deteriorating components before they cause operational failures, and such checking has been carried out on a routine basis since the start of the run. For the first 18 months this checking was performed each working day. Since records indicated that only relatively gradual changes in margins occurred, for the past six months the routine checking has been done only twice a week.

As described in Summary Reports 19 to 24, the multiplier has on several occasions been subject to random unexplainable errors whose frequency has seemed to decrease following the discovery and repair of poor electrical contacts. Apparently all, or most, of these faults have now been eliminated, because during the past two quarters much longer error-free runs have been obtained than ever before. On October 17, 1950, following single errors on October 9, 15, and 17, a tube was found which appeared to have an intermittent fault when tapped. Since that time the only errors that have been recorded were on December 8, 1950, when the system failed for about five minutes for some unexplained reason. Immediately preceding this failure the system had an error-free run of 51 days, and since that time it has been operating for 113 days without error (see chart). Previously the longest error-free run was 45 days, and over a one-year period the average time between errors was about 12 days.

A summary of the servicing work performed on the system is given on the chart on page 10. Component replacements during the fourth quarter of 1950 totaled 9 tubes and 16 crystal rectifiers, and for the first quarter of 1951 they totaled 19 tubes, 3 crystal rectifiers, and 1 condenser.

3.2 VACUUM-TUBE LIFE

Information on vacuum-tube life is being gathered principally from three sources: (1) operation of the five-digit multiplier, (2) operation of the Whirlwind computer, and (3) controlled life tests on tubes. The computer, which uses about 4200 tubes, has now operated more than 6000 hours. We believe that with this much operating experience, detailed analyses of the tube failures in the computer are meaningful. The results of analyses carried out to date on both the multiplier tubes and the computer tubes are described below. Some of this work was done in the preparation of a paper that was delivered at the IRE - AIEE - RDB Conference on Electron Tubes for Computers at Atlantic City in December, 1950. This paper was published as Project report R-194.

A question sometimes raised in discussions of tube life is whether tubes tend to have a definite period of usefulness and therefore should be replaced as a group after a certain length of time, or whether the failures occur at a fixed rate so that nothing would be gained by wholesale tube replacement. Our experience with the multiplier seems to point to the latter type of behavior and certainly indicates that wholesale replacement is not warranted within at least 20,000 hours.

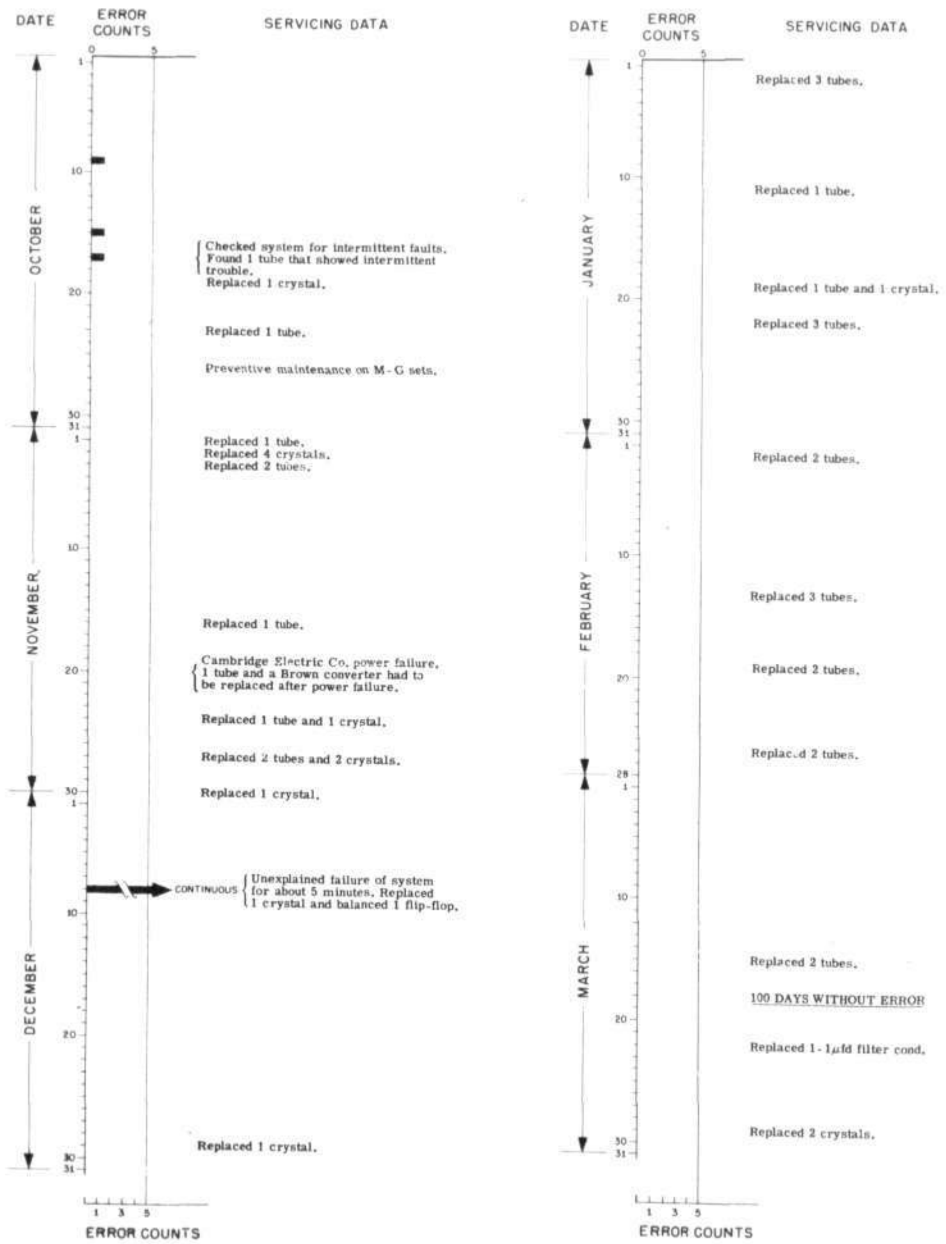
3.21 Five-Digit Multiplier

Summary Reports 22 and 23 have shown curves of the life characteristics of three types of vacuum tubes used in the five-digit multiplier. Of these types -- 7AD7, 7AK7, and 6AS6 -- the 7AD7 and 7AK7 are extensively used in the Whirlwind computer. The present report contains similar curves extended out to 20,000 hours.

The method used to obtain plotted points on the curves was chosen in order to include information from both the original and the replacement tubes in one graph. The test data are similar to those which would be available from many different lots started on test at different calendar dates. The method of analysis must properly combine the data at corresponding ages for the different lots. As for a single test lot, the results from such an analysis can be plotted as a curve of survival percentages versus length of service. The early section of the curve is based on a larger sample of tubes than the later sections, which do not include data from so many replacement tubes.

The data are analyzed as follows to obtain the values for plotting the curve. For each thousand-hour interval of tube life, the total number of tubes whose life reached beyond the end of the interval is noted. To this are added failures during the

FIVE-DIGIT MULTIPLIER PERFORMANCE



interval, to obtain a number of tubes at the beginning of the interval. (This procedure properly excludes from the calculation those tubes which are still alive and have reached the start of the interval but have not been in service long enough to reach the end of the interval.) The number of tubes at the end of the interval is divided by the number at the beginning of the interval to give the survival ratio, S_n, for the nth interval. A survival ratio is thereby established for each time interval of tube life. Beginning with 100 percent tubes in service at zero hours, successive points on the curve are obtained by multiplying the preceding point by the survival ratio of the next interval. Each point on the final curve may be expressed mathematically as the finite product:

$$A_n = 100\ (S_1)\ (S_2)\ \ldots\ (S_n),$$

where A_n is the percent of tubes remaining after the nth time interval and S_n is the survival ratio for the nth interval.

The curves of Fig. 3-1 show the life characteristics of the 7AK7, 7AD7, and 6AS6 tubes used in the multiplier. The figures in parentheses give the total number of tubes on which experience has been obtained. In these curves the life of a tube is considered to be ended when it fails to perform satisfactorily in its circuit. One reason for the relatively poor performance of the 6AS6 is that it is used in circuits which have smaller operating margins than those of the 7AK7 and 7AD7 tubes.

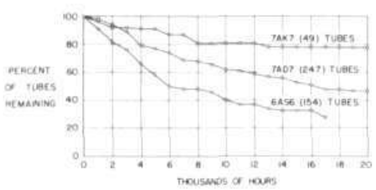


Fig. 3-1 Tube-Life Experience in Multiplier

In Fig. 3-2 these same data are shown on a semi-log plot with smooth curves (the solid lines) drawn through the points. Here the slope of a curve is a measure of the rate of tube failure. For all three types the rate of failure decreases for increasing length of service, as indicated by the flattening out of the curves. However, the samples are probably too small for this to be taken as a significant fact. To get a conservative measure of tube life in this equipment, points have been determined where 50 percent of the tubes would have remained if failures had continued at their initial rates as shown by the broken lines. These figures are 6000 hours for the 6AS6, 14,000 hours for the 7AD7, and 28,000 hours for the 7AK7.

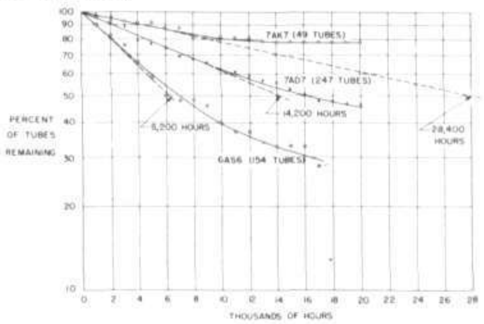


Fig. 3-2 Tube-Life Experience in Multiplier

3.22 WWI Computer

Two types of analysis of tube failures in the computer have been made. First, all those which occurred during the calendar year 1950 were compiled to show the relative numbers of failures among the 7AK7, the 7AD7, and all the other types combined (see Fig. 3-3). Also indicated on the chart are the numbers and percentages of these failures which were located by marginal checking. These data are further broken down in the charts of Figures 3-4, 3-5, and 3-6. They show the causes of tube failure, and indicate the number which caused interruption of computer operation during actual problems as compared with those which were found by routine maintenance checks. The principal cause of failure in all tube types except the 7AK7 has been deterioration in plate current. Other reasons for

TYPE TUBE	NUMBER IN USE	FAILURES		LOCATED BY MARG. CHECK	
		NUMBER	PERCENT	NUMBER	PERCENT
7AK7	1412	18	1	2	11
7AD7	1622	243	15	168	70
OTHERS	1187	92	8	20	22
TOTAL	4221	353	8	190	54

Fig. 3-3 Tube Failures in WWI During 1950
3034 Filament Hours

failure in order of frequency of occurrence are shorts, gas or leakage, heater burnout, and opens. It is significant that a relatively high proportion of the total tube replacements were made during scheduled maintenance periods, so that they did not cause operational failure of the computer.

Survival curves of the type plotted for the multiplier tubes were computed for computer tubes only

TYPE FAILURE		INTERRUPTING	NON-INTERRUPTING		TOTAL
			MARG CHECK	OTHER CHECK	
CHANGE IN CUTOFF				1	1
SHORTS	COMPLETE	3			3
	TAP		1	5	6
OPEN		1			1
GAS OR LEAKS			1	4	5
ACCIDENTAL DAMAGE		1		1	2
TOTALS		5	2	11	18

Fig. 3-4 7AK7 Failures
3034 Filament Hours During 1950

TYPE FAILURE		INTERRUPTING	NON-INTERRUPTING		TOTAL
			MARG CHECK	OTHER CHECK	
LOW PLATE CURRENT		2	127	36	165
CHANGE IN CUTOFF			1		1
SHORTS	COMPLETE	6	21		27
	TAP		7	5	12
GAS OR LEAKS			12	2	14
ACCIDENTAL DAMAGE				24	24
TOTALS		8	168	67	243

Fig. 3-5 7AD7 Failures
3034 Filament Hours During 1950

TYPE FAILURE		INTERRUPTING	NON-INTERRUPTING		TOTAL
			MARG CHECK	OTHER CHECK	
FILAMENT		10			10
CHANGE IN CHAR	LOW PLATE CURRENT	1	17	22	40
	OTHER	1		4	5
SHORTS	COMPLETE	6			6
	TAP			8	8
OPEN		3			3
GAS OR LEAKS		2	3	8	13
ACCIDENTAL DAMAGE		7			7
TOTALS		30	20	42	92

Fig. 3-6 Miscellaneous Type Tube Failures
3034 Filament Hours During 1950

in the case of the 7AD7. Since the number of failures among 7AK7 tubes is so small and since relatively small quantities of other individual types are used, analyses of the life characteristics of these types have not been made yet.

The data on the 7AD7 tubes were broken down to show a comparison between those used in flip-flops, the most critical application, and those used in other types of circuits. Figure 3-7 shows plots of the percentage of 7AD7 tubes remaining versus thousands of hours of service. The curve for tubes used in flip-flop circuits lies below that for tubes used in other types of circuits; this indicates that our flip-flop is a severe application for these tubes. The experience with 7AD7 tubes in the computer shows good correlation with that obtained in the multiplier. At the end of 5000 hours, 77 percent of the tubes remained in service in the multiplier as compared with the 74-percent average for the two curves of Fig. 3-7 at 5000 hours.

Figure 3-8 shows the failure rates for 7AD7 tubes for three classifications of failures: (1) low plate current, (2) mechanical faults (shorts and opens), and (3) other causes. The curves show the mechanical faults to be second to low-plate-current failures. There can be considerable doubt whether this is actually the case, since our checking methods periodically test all tubes for plate current deterioration but only a small number are ever re-examined for mechanical faults. Probably there are many tubes still in service which would be rejected if they were tested for tap shorts.

Perhaps an even more important aspect of this point is that mechanical faults are a source of random errors in computer circuits and are most dif-

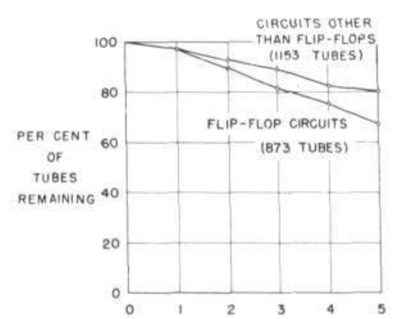


Fig. 3-7 Life Experience of 7AD7 Tubes in Whirlwind Computer

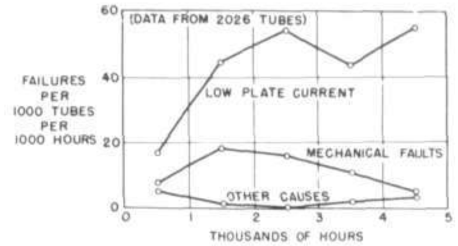


Fig. 3-8 Failure Rates for 7AD7 Tubes in Whirlwind Computer

ficult to find. Since known trouble-shooting techniques are not effective in localizing the sources of such errors, a few tubes with intermittent shorts or opens produce a much more troublesome condition than do many tubes with plate-current deterioration. Until a system test is available that will check for mechanical faults, these should be more heavily weighted than low-plate-current failures.

Tube failures which occurred during the last quarter of 1950 and the first quarter of 1951 are listed in Fig. 3-9.

Type	Total in Service	Hours at Failure	Reason for Failure; Number Failed: Change in Characteristics	Mechanical	Burn-Out	Gassy
7AK7	1450	3000 - 4000	1	1		
		4000 - 5000		2		
		5000 - 5200	1	1		
7AD7	1700	0 - 100		1		
		100 - 500		1		
		500 - 1000	7	3		
		1000 - 2000	30	8		
		2000 - 3000	24	7		
		3000 - 4000	19	8		
		4000 - 5000	38	14		4
		5000 - 6000	10	18		2
2C51	29	1000 - 2000			1	
2D21	30	1566		1		
3E29	140	2466		1		
		4000 - 5000	8	3		
		5187	1			
6V6GT	21	3000 - 4000	2			
6AG7	120	100 - 500	1			
		3000 - 4000	4	1		
		4000 - 5000	4			
6L6G	70	2798			1	
		4000 - 5000	1			
6SN7GT	400	1000 - 2000			1	
		4000 - 5000		1		
		5000 - 6000		1		1
6Y6G	263	3000 - 4000		4		
		4000 - 5000	5	1		

Fig. 3-9 Tube Failures in WWI
October 1, 1950 — March 31, 1951

Component	Type	Total in Service	No. of Failures	Hours of Operation	Comments
Capacitor	20 × 20 mfd	32	1	1000 - 2000	Shorted.
	0.01 mfd	12,000	1	5153	Shorted.
Crystal Rectifiers	D-357	7700	4	1000 - 2000	3 reset crystals: 2 low back resistance, 1 excessive drift. 1 clipping crystal: low back resistance.
			5	2000 - 3000	4 grid crystals: 3 drift, 1 low back resistance. 1 clamp crystal: low back resistance.
			9	3000 - 4000	6 grid crystals: 4 low back resistance, 1 excessive drift, 1 shorted.
			17	4000 - 5000	12 grid crystals: low back resistance. 3 reset crystals: low back resistance. 2 plate clamp crystals: excessive drift.
			10	5000 - 6000	9 grid crystals: 6 low back resistance, 1 high forward resistance, 2 shorted. 1 clamp crystal: drift.
	D-358	3529			All D-358 failures were clamping crystals; all failed because of excessive drift unless otherwise noted.
			2	0 - 500	
			2	500 - 1000	2 reset crystals: low back resistance.
			27	1000 - 2000	2 low back resistance.
			37	2000 - 3000	6 low back resistance. 3 grid crystals: low back resistance.
			47	3000 - 4000	22 low back resistance.
			61	4000 - 5000	20 low back resistance. 5 reset crystals: low back resistance. 11 isolating crystals: drift.
			8	5000 - 6000	5 low back resistance. 1 grid crystal: drift.
Pulse Transformer	1.1	556	1	4000 - 5000	Intermittent.
	3.1	1500	1	5249	Intermittent.
Resistors (fixed)	220 ohms 1 watt	9000	1	4000 - 5000	Open.
(variable)	10,000 ohms 2 watts	24	1	500 - 1000	Burn out.
Toggle Switch	SPST	512	1	4930	Intermittent.

Fig. 3-10. Failures of Components in WWI
October 1, 1950 - March 31, 1951

3.23 Life Tests

Recent results of life tests on 6AG7 tubes specially constructed with different types of cathode-sleeve materials have contributed further information toward the understanding of cathode interface deterioration. The tubes of this group which contained active cathode sleeves were life tested for 7900 hours under both high-duty-factor (94 percent) and low-duty-factor (10 percent) operating conditions. Interface resistance of the tubes operating at low duty factor increased steadily to a relatively high value, while those operating at high duty factor showed only a slight interface resistance. After 7900 hours, the test conditions were changed so that the tubes which had been operating at high duty factor were cut off and those which had been operating at low duty factor were made to draw continuous current. When the tubes were retested after 800 additional hours, it was found that extreme changes in interface resistance had taken place. Those tubes which had shown high interface resistance as a result of operation at low duty factor showed only slight resistance after drawing continuous current, and those which were cut off following a long period of operation at high duty factor showed moderately high interface resistance.

The above data supports the theory that interface deterioration involves two factors: first, the formation of an interface compound; second, the degree of activation of this interface layer by excess barium. The formation of the interface layer appears to depend on the cathode temperature, the amount of silicon in the cathode, and the length of time the cathode is heated. Activation of this layer depends on the amount of cathode current which flows. Thus in Class A operation, the growth of an interface layer may not be objectionable because the flow of cathode current maintains a high activation energy in the layer, which reduces its effective resistance. For low-duty-factor operation, however, the formation of the interface layer must be prevented in order to avoid the interface-resistance type of deterioration.

For the past quarter, life test studies have been interrupted in order to carry out the design and construction of a pulse tester which can be used in the tube shop for routine pulse tests on tubes. This tester (described in E-400) will permit rapid measurements both of interface resistance and of cathode emission, so that these data can be included in the historical records of the tubes used on the project.

3.3 COMPONENT REPLACEMENTS IN WWI

Figure 3-10 lists the replacements of components other than tubes during the last quarter of 1950 and the first quarter of 1951. A summary of failures of these components for the year 1950 appears in Figures 3-11 and 3-12.

TYPE CRYSTAL	NUMBER IN USE	FAILURES		LOCATED BY MARG. CHECK	
		NUMBER	PERCENT	NUMBER	PERCENT
D-357	7,500	64	0.09	32	50
D-358	3,500	278	8	197	70
D-359	400	2	0.05	0	
TOTAL	11,400	344	3	229	64

Fig. 3-11 Crystal Failures in WWI During 1950
3034 Operating Hours

The failure rate of crystal rectifiers was approximately 3 percent for the 3000-hour year (see Fig. 3-11). This rate should be lower for 1951, because the original crystals were not tested for drift, but replacements now undergo this test. The largest contribution to the overall rate is the failure of 8 percent of the D358-type crystals (similar to the 1N38 crystal). In particular, 259 of the total 278 failures occurred in flip-flop clamping circuits, where the back resistance of the crystals must be greater than 0.5 megohm. These 259 failures represent about a 42 percent failure rate on all flip-flop clamping circuits. An investigation of the number of replacements made in any given circuit reveals that 34 originals have been replaced twice and 3 originals have been replaced 3 times. This small number of repeaters would indicate that no circuit trouble exists locally and that improved performance must come from: (1) avoiding the use of clamping circuits when possible; (2) obtaining better crystals by more stringent selection or improved manufacture; or (3) relaxing required crystal characteristics by circuit modifications.

COMPONENT	AVERAGE NO IN USE	NO OF FAILURES
CAPACITORS	21,107	4
CHOKES	3,989	0
RESISTORS	26,210	16
PULSE TRANSFORMERS	3,425	7
DELAY LINES	143	2
POWER CONNECTORS	991	3
TOTAL	55,865	32

Fig. 3-12 Other Component Failures in WWI
During 1950 — 3034 Operating Hours

The reliability of WWI components other than tubes and crystals has been very good. Figure 3-12 shows the low failure rates of these components.

3.4 THREE-DIMENSIONAL INFORMATION STORAGE USING MAGNETIC CORES

A scheme for storing digital information in a three-dimensional array of magnetic cores, and the results of research work on the individual cores, were discussed in Summary Report 24. Developments since that report include preliminary operation of a 4-core, two-dimensional array, and an arrangement for the development and testing of special materials of the types desired for this work.

3.41 The 4-Core Two-Dimensional Array

A test setup which operates a $2 \times 2 \times 1$ memory array has been in partial operation. Information patterns have been cycled around the array with no interruptions except those from external causes. One mode of operation which has been tried emphasizes the disturbing effects on one core of activity in neighboring cores. Also tried has been the alternation of sensing-coil polarities from one core to the next. This alternation is expected to result in the cancellation of most of those noise signals from the array which are inherent in the three-dimensional selection scheme.

The results have all been qualitatively successful. More exact data-taking will follow an attempt to increase the stability and operating margins of the setup.

3.42 Materials Development

By the terms of a temporary arrangement, the Glenco Corp. of Metuchen, N.J., will supply us and the MIT Laboratory for Insulation Research with magnetic-ferrite cores and ferroelectric slabs. Specifications and technical direction are to come from the Insulation Lab and ourselves; testing will be divided up so that the best facilities of each Laboratory can be utilized.

Interest in metal cores is being renewed in view of indications on the part of steel producers that they may be able to supply cores wound of extra-thin tape that have sufficiently rectangular hysteresis loops. Our best metallic core is made of 1-mil tape and has a response time of somewhat over 20 microseconds; a $\frac{1}{4}$-mil tape might reduce this to the order of 5 microseconds or so, a response time suitable to the requirements of high-speed computers.

4. ELECTROSTATIC STORAGE

4.1 TUBE PROGRAM

During the last six months a complete bank of 16 new storage tubes (300-series) was put into reliable operation in WWI.

Tube lineup of the preceding bank (100-series) was completed early in the period. However, operation of the entire bank led to the discovery of intermittent small shifts of the read-write beam in some of the tubes. This phenomenon was found to result from the charging of exposed glass areas within the tube. It has been corrected by replacing the entire bank with new tubes having no internal exposed glass. These tubes were designated the 300-series.

The 300-series storage tubes are operating reliably in the WWI computer at a density of 256 spots, a read access time of 12 microseconds (including rewrite), and a write access time of 50 microseconds. Development continues toward increased density, decreased access time, and longer cathode life.

4.11 The 300-Series All-Dag Tube

On 11 October 1950, a complete bank of 16 individually tested and adjusted 100-series storage tubes were operating in the Whirlwind computer. At this time, additional tests were started on a row-wise basis to determine the margins for the tubes operating as a group and to set up marginal-checking routines. During these tests, it was discovered that several of the tubes would not operate in a consistent manner. Specifically, after 15 to 20 minutes of satisfactory operation, when an array of positive spots was being read out, they suddenly exhibited a number of read-out failures (1 to 100 error points). Upon successive trials, different points would be at fault, and errors at these points would appear intermittently and even shift around in a random manner to neighboring points.

Some correlation existed between the behavior of read-out errors and the following observations. First, the errors were somewhat localized to a certain section of the storage surface; second, a longer run without errors was possible if the television scan read-out was not used for some time before writing on the array of positive spots. By writing another array of positive spots when read-out errors were present, it was definitely ascertained that the failure to read positive spots was caused by a shift in the deflection pattern over a portion of the array. An exhaustive check of all electrode and deflection voltages was made; however, this failed to uncover any significant fluctuations.

The trouble was eventually found to be caused by glass charging, which was investigated while the tubes were operating in WWI. This was done by darkening the computer room and removing the protective tape from the undagged portion of a tube. When read-out errors developed, an intermittent blue glow was noted on the glass wall inside the tube. A possible explanation is that the glass area between A_2 and A_3 was receiving holding-gun electrons and was charging down to holding-gun cathode potential. The leakage currents due to the difference in potential between A_2 and A_3 as well as that between each electrode and the holding-gun cathode would then try to draw the glass area positive. Interaction between holding-beam current and leakage currents would produce intermittent shift in potential of the glass area, thus deflecting the high-velocity beam.

Assuming this explanation to be valid, there are three possible reasons why the effect was not discovered earlier. First, and probably most important, is the fact that changes in the secondary emission characteristics of the glass take place with life under electron bombardment. These changes could conceivably affect the potential to which the glass would charge when struck with holding-beam electrons. Supporting this possibility are the facts that all the tubes exhibiting this phenomenon had been in operation at least 250 hours and that some discoloration of the glass was noted which was not found on new tubes.

Second, several storage-tube electrode voltages had been changed in the WW installation: that of the holding-gun cathode for convenience, that of the holding-gun A'_2 dag to obtain the maximum possible restoring current to the surface, and that of A_3 to reduce spot interaction during negative writing around a positive spot.

Third, the specific type of operation in which errors appeared to be due to glass charging was not re-examined completely after the above changes in electrode voltages. The effects of glass charging had not been previously observed when full tests of this nature were carried out on relatively new tubes with the electrode voltages formerly in use.

Two alternative courses seemed possible for correction of the glass-charging difficulties. The first of these was to try to improve the operation by setting the A_2 and A_3 dags at the same potential, so as to eliminate the fluctuation of the high-velocity beam. This was tried initially in the computer, and it gave a definite improvement in operation. However, the trouble was of such an intermittent nature that we could not feel certain that it was solved.

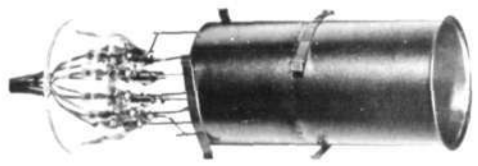


Fig. 4-1 300-Series Holding Gun

The second alternative was to go to a revised tube design. As soon as the trouble was noted in the computer, a group of research tubes were constructed and special tests were undertaken to investigate the type of failure caused by glass charging. The first of these research tubes included a metallic shield ring approximately one inch long covering the gap between the A_2 and A_3 dags. However, restoring-current tests showed that secondary electrons from the shield ring were being collected at the surface. This considerably reduced the available charging currents. Although the shield ring could have been coated with aquadag, it was felt desirable to go to an all-dagged construction.

When the 100-series holding gun was first tried in an all-dag storage tube, it was found that the restoring currents were considerably lower than with the 100-series dag configuration. It was felt that the holding gun had to be redesigned to provide an element serving the function of the A_2' dag in the 100-series tubes. Such a gun was designed using a metallic cylinder with insulated snubbers to the holding-gun neck (see Fig. 4-1). Exhaustive restoring-current tests were carried out on an all-dag tube with this type of gun. The tube was found to operate at least as well as the former 100-series tubes. Since 24 November 1950, no more 100-series tubes have been constructed. The tubes currently being made are designated 300-series; they include the new holding-gun design as well as a complete coating of aquadag over the entire inside of the envelope. The 300-series tube is shown in Fig. 4-2.

4.12 WW Acceptance Tests

In addition to the static and dynamic tests carried out on storage tubes before installation in the computer, holding-beam charging current (restoring current) tests are now being run on all tubes. The restoring current gives a good index of the overall holding ability of the tube, since the combined effects of holding-beam primary current and secondary emission from the surface are measured.

Since 8 January 1951, when the first 300-series tube was installed, one new tube of that series was rejected at installation. The holding-gun emission had decreased to approximately 10 percent of its value at the static testing, and the holding beam would no longer cover the entire surface.

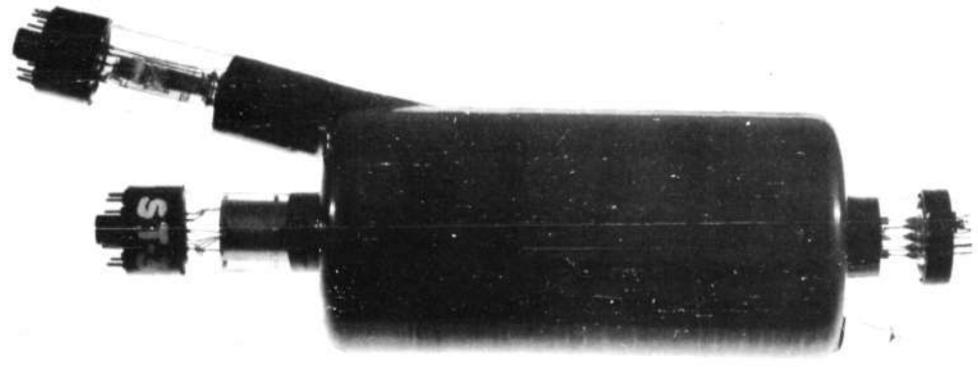


Fig. 4-2 The 300-Series Storage Tube

4.13 Tube Production

During the six months from 1 October 1950 to 31 March 1951, 40 storage tubes were constructed for the computer (see Fig. 4-3). Ten of the 40 tubes were of the 100-series which were later abandoned because of the glass-charging phenomenon. Thirty of the 40 tubes were of the new 300-series type. Shrinkage of 20 percent for the 100-series tubes was caused by storage surface defects. Shrinkage of 30 percent for the new 300-series tubes was due almost entirely to poor emission in the electron guns.

The 300-series tubes have not had any of the storage-surface troubles which plagued the 100-series tubes. However, we did have gun problems which became so serious that the tube construction facilities were shut down during the second week of March to re-evaluate our procedures. Construction was resumed at the end of the month; no conclusions have been reached yet.

Three storage tubes with paralyzed cathodes were reprocessed. Two of the three reprocessed tubes were satisfactory.

Fifteen research tubes were constructed during this period. Six of these tubes were developmental tubes to minimize the glass-charging phenomenon; they resulted in the 300-series tubes. Three tubes were designed to study improved operation of the read-write gun, and two tubes were used to study the holding-beam current density. One tube was constructed to investigate the effects of a second screen in front of the collector screen. One tube was used to determine the restoring currents and crossover voltage of plain mica. Two tubes were used to test techniques for reprocessing storage tubes with paralyzed cathodes.

4.14 The 100-Series Tubes in WWI

Before the entire bank of 100-series tubes was replaced by 300-series tubes, four 100-series tubes were giving marginal operation in the computer and another was rejected for reasons other than glass charging. Two of these tubes had small surface imperfections which made these areas difficult to switch negative. These defects were present when the tubes were initially installed, but since they did not seem to seriously impair tube operation under cyclic tests, it was decided to use them in the computer. Several random errors occurring during computer operation, together with non-uniform spot interaction, were traced to one of these areas, how-

WEEK OF	NUMBER OF STORAGE TUBES 0–1	1–2	2–3	3–4	CAUSE OF FAILURE
10-1	ST-192	ST-189	ST-190		
10-8	ST-191	ST-193	ST-194		LEAKAGE HIGH, BAD SPOT OUT OF ARRAY.
10-15	ST-195	ST-196	ST-197		
10-22	ST-198				SURFACE LEAKAGE, AIR INCLUSIONS.
10-29	RT-187	RT-185	RT-188		
11-5					
11-12	RT-190				
11-19	ST-300				TARGET LOOSE, LEAKAGE HIGH.
11-26	RT-191				
12-3	RT-193	RT-194			
12-10					
12-17	RT-195	ST-305			
12-24	ST-306	RT-196			A_2'-A_3 SHORT; POOR HV GUN.
12-31	RT-198-1				
1-7	ST-307-1	RT-199	ST-308-1	ST-309-1	SPOTS ON SURFACE.
1-14	ST-310	RT-200-1	ST-311	ST-312	(1) SPOTS ON SURFACE. (2) A_3 DAG-COLLECTOR SCREEN SHORT; POOR SURFACE.
1-21	ST-313	ST-314-1	ST-316		
1-28	ST-315-2	ST-318	ST-317-1	ST-319	LOW GUN EMISSION.
2-4	ST-320	ST-321	ST-322		(1) LOW GUN EMISSION. (2) INTERMITTENT A_3 DAG CONTACT. (3) LOW HG EMISSION.
2-11	ST-323	ST-318-R1	ST-324	ST-323-R1	(1) HG EMISSION GONE. (2) SPOTS ON SURFACE.
2-18	ST-325	RT-153-2	RT-197-1		
2-25	ST-326-1	ST-327-1	ST-328		
3-4	ST-320-R1	ST-329	ST-330	ST-331	LOW GUN EMISSION.
3-11					
3-18					
3-25	RT-204				

ST- GOOD STORAGE TUBE; RT- GOOD RESEARCH TUBE; -R REPROCESSED TUBE; BAD TUBE

Fig. 4-3 Storage-Tube Production Record

ever, and the tube had to be replaced. A third tube was removed from the computer because of a fluctuation of 20 to 25 volts in the signal-plate gate amplitude required to write negative spots. Such a variation could be accounted for by a change in the position of the collector screen relative to the surface; the trouble was quickly located, since it caused the tube to make continuous errors. Operation was possible if the write-minus signal-plate gate was raised to an abnormally high value; however, the resulting change in spot size and susceptibility to spot interaction effects made replacement desirable.

The fourth tube suffered a loss of positive-spot holding action at a normal holding-gun voltage of 100 volts. This tube had been in operation only 700 hours, while three other tubes with more than 1200 hours of use had shown no deterioration of positive holding. Operation was possible at a V_{HG} of 120 volts until the tube was replaced.

The fifth tube was kept in operation, until it was replaced, by raising the heater voltage on the high-velocity gun. The beam current from that gun had fallen off to the extent that the writing operations were decidedly critical. Maintaining the high-velocity-gun beam currents of all tubes reasonably constant at a value of at least 20 microamperes is still a prominent feature of the routine checking schedule for the storage tubes in WW. Pulsed transfer characteristics are taken on each of the tubes at frequent intervals, and high-velocity grid gates reset whenever necessary. On 22 December 1950, the currents in the 16 tubes had dropped from 30 percent to 90 percent of their values on 11 October 1950. This period covered approximately 675 hours of operating time. All tubes were still operable, however, with one of the tubes requiring an increased heater voltage.

4.2 STORAGE-TUBE DEVELOPMENT

Development work has been directed mainly toward eliminating the drift of the high-velocity beam, but it has also included considerable efforts toward the design of a tube for storing 1024 spots. Since the construction facilities for this period were devoted largely to the production of all-dagged tubes, few research tubes have been made, except those for developing the 300-series tube. However, more exhaustive tests have been carried out on the available research tubes. These tests included restoring-current tests as a function of electrode voltages, dynamic tests in the storage-tube reliability tester, and life tests of the emission of high-velocity guns.

4.21 Storage Density Research

The restoring-current tester, which measures the net holding-beam charging current versus surface potential and displays this current directly on an oscilloscope, has turned out to be highly useful in evaluating new holding-gun designs and in observing the storage stability characteristics of the surfaces. This tester is described functionally in Fig. 4-4. In operation the holding gun is normally at zero bias. At the instant t_0 a 15,000-microsecond negative gate is applied to the holding-gun grid, which cuts off the holding gun. Simultaneously, a triangular rise of voltage is applied to the signal plate. The storage surface has previously been stabilized at the holding-gun cathode potential.

With the holding gun cut off, the mosaic surface follows the signal-plate voltage to a good approximation. At the instant t_1, the holding gun is pulsed on with a $\frac{1}{2}$-microsecond pulse. The signal plate is connected to a video amplifier through the RC differentiating circuit, which has a time constant of approximately one microsecond. As indicated in Fig. 4-4, the output is a differentiated signal-plate waveform with a current pulse representing the total restoring current superimposed. With t_1 continuously variable between t_0 and t_2, the holding gun may be pulsed on with the surface at any arbitrary potential as determined by the linearly rising signal-plate waveform. The output current pulse then varies in amplitude and traces out the dotted restoring-current curve.

With a single signal plate, only the total restoring current over the entire surface may be obtained. A further refinement uses a research tube having several concentric rings to make up the signal plate, with a separate connection brought out from each ring. In this manner, the restoring-current distribution over the surface may be easily measured.

A research tube has also been constructed to investigate the holding-beam current density at points representative of the entire storage surface without pulsing or deflecting the beam. This tube is similar to a 300-series storage tube except that the storage surface and signal plate are replaced by a plate containing 13 current-sampling apertures, each backed by an electron collector. Separate leads are provided for each collector electrode with adequate precautions to shield the leads and electron collectors from stray electrons and to reduce leakage current to a negligible amount.

4.22 High-Velocity Gun

As might be expected, all parameters of the tube become more critical at an increased storage density. The beam current of the high-velocity gun

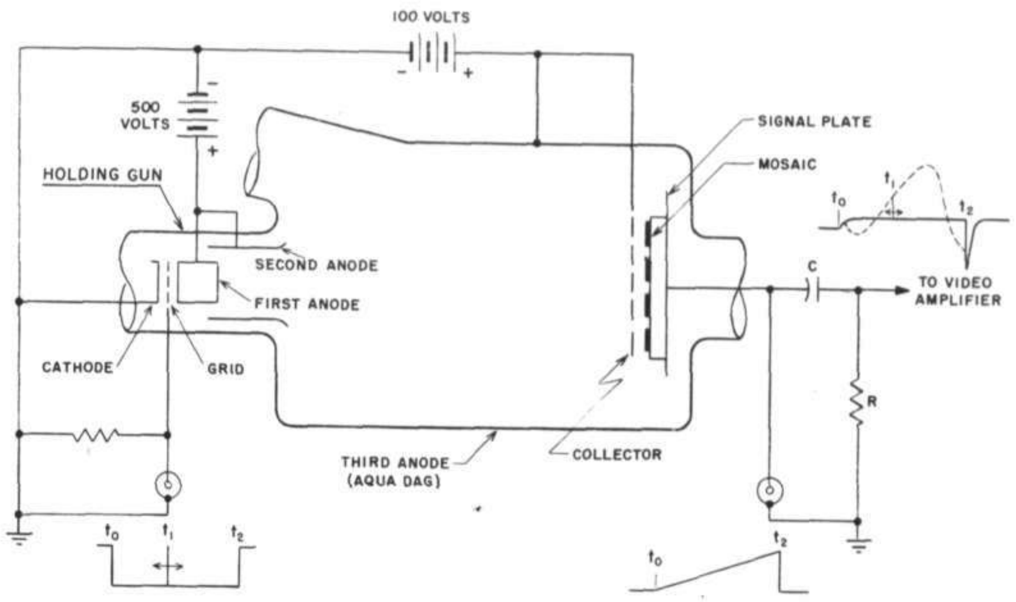


Fig. 4-4 Storage-Tube Restoring-Current Tester

is one of the more important factors in that it affects both spot size and spot interaction. If possible, it should be maintained at a constant value even as the duty factor varies with changes in the computer program. The oxide-coated cathode presently used in the high-velocity gun does not give a truly constant current at the desired level of emission and also has a relatively short life. For these reasons one phase of the research program will investigate the Phillips type "L" cathode, which may satisfy the requirements placed upon the cathode of our high-velocity gun better than the oxide-coated type.

4.23 Target Structure

Tests have indicated that a uniform collector-to-surface spacing of the order of 5 mils instead of the present 12 mils is desirable to control the redistribution of secondary electrons during writing negative. A definite mechanical problem exists in mounting the fine collector mesh. The collector must be under tension to give a uniform spacing, but this tension must be obtained without exerting sufficient pressure to cause the mica surface to buckle. A new type collector spacer is under investigation which will consist of a circular piece of mica with an inscribed square removed. This square will then be the only usable portion of the storage-tube surface.

An attempt has been made to obtain a very close and uniform spacing by transferring the storage surface directly from an evaporation tube into a storage tube (RT-147, Summary Report 23); however, this procedure turned out to be unsatisfactory. Many mosaic squares were shorted to the collector screen, probably because of the small amount of vibration that occurred in transferring the surface to the storage tube and the subsequent glass work in processing.

Work is also being done on sintering powdered glass directly onto a Kovar backing plate. This technique would allow uniform and thin dielectrics to be made with no danger of buckling, since the backing plate is 0.1 inch thick. It remains to be seen from testing whether or not the glass surfaces will be suitable for the storage tubes.

5. INPUT - OUTPUT

5.1 INPUT-OUTPUT PLANNING

In order to operate many units of terminal equipment under control of the computer, some means of programmed selection among the various units is necessary. In the interim input-output system this has been provided, for the few units involved, by temporarily assigning some of the spare computer orders to these units. For a larger number of units, some of them having more than one mode of operation, the use of separate control orders is not practical. Therefore we have undertaken the design of an integrated input-output system that requires a minimum of control orders and is yet flexible enough to accommodate all units of terminal equipment now envisioned.

The basic elements of the planned input-output system are shown in the simplified block diagram of Fig. 5-1. These include: (1) an in-out switch of the crystal-matrix type by which the computer can select a particular unit of terminal equipment and specify its mode of operation; (2) an in-out register which serves as the communicating link between the computer and the various units of terminal equipment for both input and output transfers; (3) an in-out control which provides interlock and synchronization features between terminal equipments and the computer; and (4) various units of input and output equipment each with sufficient control circuits to match its own characteristics with those of the common elements of the system.

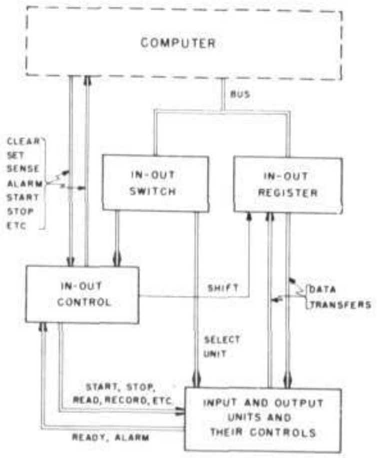


Fig. 5-1 Proposed Input-Output System

In planning the integrated input-output system many types of units have been considered. Those units whose incorporation into the WWI system has been accomplished on a temporary basis or is being actively undertaken are the following:

1) Magnetic-tape units. Recording or reading functions can be selected automatically.
2) Paper-tape units, including
   a) punches
   b) printers
   c) mechanical readers
   d) photoelectric readers
3) Oscilloscopes
4) Control for programmed marginal-checking
5) Scope camera.

Other units which have been considered in the design of the input-output system but whose incorporation will not be undertaken until future needs dictate are:

1) Eastman Kodak film units
2) Punched-card equipment
3) Manual-intervention registers
4) Analog units
5) Asynchronous inputs and outputs requiring buffer storage
6) Magnetic drums
7) Teletype line
8) Bells and lights for special indication.

In order to simplify the system design and minimize the amount of circuitry which would have to be designed, constructed, and tested, several basic characteristics for the system were decided upon. The more important ones are:

1) Only one terminal unit can be used at a time. An interlock stops the computer if a new in-out unit is called for before the previously selected unit has completed its operation.
2) Checking of transfers between in-out units and the in-out register will be done by programmed subroutines. This eliminates the need for a comparison register as a part of the in-out system.
3) A new in-out register will be constructed using d-c coupled flip-flops. This will avoid the restoration problems that exist in the present a-c coupled in-out register. The new register will also have provision for parallel as well as serial transfers to and from external units.
4) As far as is practical, the steps involved in the transfer of data between the computer and an external unit are accomplished by computer subprograms. This simplifies the control circuits needed for the external units. An example is a paper-tape reader which can supply a maximum of only 6 digits for a single reading operation. A computer subprogram rather than in-out-register shifting is used to combine such groups of digits into a single 16-digit word to fill one Whirlwind storage register.

A discussion of some of the details of the proposed orders needed to control the input-output system are given in Memorandum M-1167. The orders are si, select in-out unit; rc, record; and rd, read. The si order sets up the in-out switch to a position specified by the address section of this order. It thereby selects a particular in-out unit in a particular mode of operation. Basically the rc order transfers a word from computer storage to the in-out register preparatory to the word being recorded on an output unit. The rd order transfers a word from the in-out register to computer storage following an input-unit reading operation. The rc and rd orders proposed in M-1167 are essentially the same as those presently in use.

Two features in the proposed in-out control design are significant from the engineering and maintenance point of view: (1) Operations which involve video pulses and which are initiated by asynchronous signals from terminal equipment will be synchronized with the computer control pulses. This will make it more convenient to study circuit performance of the terminal equipment in relation to that of the computer during trouble shooting. (2) A flexible flip-flop counter will measure any delays that are required in operation of the terminal equipment. The counter can be reset on the si, rc, or rd orders as required, and the desired delay count will be selected by the in-out switch. Delays from one microsecond to several milliseconds will be available. The use of such a counter should result in a more reliable system, since it eliminates the necessity for delay multivibrators, which are not readily subject to marginal checking.

5.2 IN-OUT SWITCH

An electronic switch for controlling the various types of input-output devices is being constructed. The switch is quite different from other switches in the computer in that a selection will energize more than one output.

As shown in the block diagram of Fig. 5-2, the switch may be thought of as divided into two parts. The first part consists of a standard 8-position switch, employing a rectangular crystal matrix of the type used in the control switch, driven by 3 flip-flops. The 8 outputs of this first section will be used to select the type of input-output device desired; i.e. scope, magnetic-tape unit, Flexowriter unit, film unit, analog unit, or some other device up to a total of 8. The second part of the switch consists of 8 crystal whiffletree matrixes that are driven by the outputs of the first part and by the remaining 5 flip-flops of the switch. Each of the 8 crystal circuits in this part will be tailored to meet the requirements of the input-output units that it will control. These circuits will be separately constructed and mounted as they become needed The outputs of these units will vary in number and type depending upon requirements. Some outputs will be used to operate gate tubes directly, and others will control relay driver tubes. Where signals from various output circuits are mixed to drive control elements (such as delay counters) that are common to the control of several input-output devices, some of the whiffletree outputs will control the grids of cathode followers.

All of the circuits are d-c coupled to eliminate the difficulties involved in restoring a-c coupled circuits in asynchronous circuits of widely varying pulse-repetition frequencies.

The 8 flip-flop circuits, with associated read-in gate tubes, have been constructed on two separate identical panels. The 9 crystal circuits will be constructed on separate 3-inch panels, with the possible exception that a couple of the very simple circuits may be combined on one such panel. The 8-position matrix and the output matrix for controlling the Flexowriter units have been constructed, but the physical layout is not quite satisfactory, and a few modifications will have to be made on these two panels.

The units have not been tested yet, but as soon as the circuits have passed the shop inspection they will be mounted, together with the required driving elements, and given thorough testing. These first tests will operate with only the completed crystal circuits, since the design of the other input-output devices has not reached the stage where the switch design can be completed.

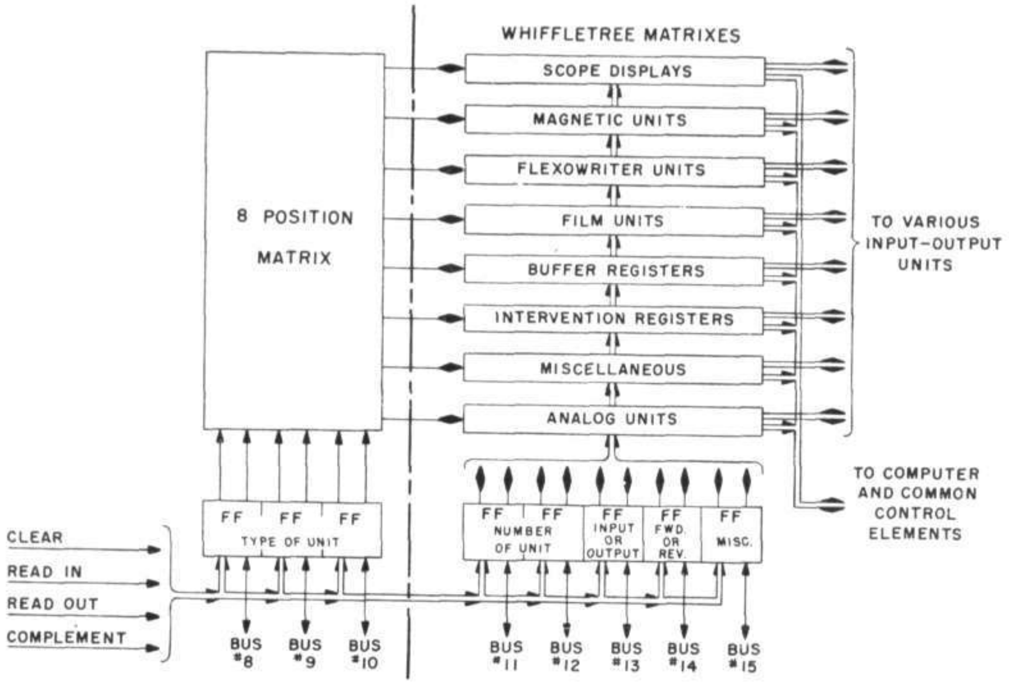


Fig. 5-2 In-Out Switch

5.3 IN-OUT REGISTER

A completely new input-output register panel has been designed to replace the existing input-output register. A prototype panel was built and tested, and by the end of March, production of 16 panels for use in the Whirlwind digits and 12 more for in-out control and general-purpose use was well under way. Completion of the 28 panels is expected in early summer.

The decision to replace the existing equipment with a new register was based on several considerations. The original equipment was specifically designed to operate with the Eastman film reader-recorders. Since present plans call for a variety of input-output equipment operating at widely varying speeds, serious changes would be required in the existing register to adapt it to a more flexible usage. Furthermore, the flip-flops in the present registers are all a-c coupled to their gate tubes, requiring the use of restorer pulses. These introduce annoying problems of synchronization, for terminal equipment outputs occur at random times with respect to the fixed 62.5-kc restorer pulses. Since under the new plan the computer itself will check input-output transfers, the existing comparison register becomes unnecessary. It was therefore decided that greater simplicity and higher reliability would be realized by starting over and designing a new d-c in-out register. An additional advantage was realized from this decision, for the addition of a minimum of extra input and output connections to the new panel permits the same design to be used wherever a d-c flip-flop is required. Thus the new register panel becomes a general-purpose register panel.

This panel, identified by its block diagram number as "403 D-C In-Out Register", contains a flip-flop with two 7AD7 tubes d-c coupled to 4 gate tubes. The gate tubes can be connected all to one side or divided between both sides of the flip-flop. To provide remote high-speed gate voltages, the flip-flop plate signals are coupled to 93-ohm cable (RG-62/U) by the two halves of a 5687 twin-triode cathode follower. To provide slower-rising gate voltages at higher impedance levels for operating remote thyratron relays, the flip-flop signals are fed through isolating resistors to "slow-gate" outputs,

two on each side of the flip-flop. Multiple inputs, with and without 0.1-microsecond delays, mix into the set, reset, and complement terminals of the flip-flop. The complement input is to a 7AD7 trigger tube. Local neon-light indicators are provided on the panel, and provisions for remote indicators are included. As the d-c coupled gates are now connected, the panel can shift left the contents of the flip-flop (either ones or zeros), read to bus, and read to check bus.

The physical layout of the panel (see Fig. 5-3) differs a little from the previous WWI standard. The component board and tube layout are conventional, but each side of the chassis has been folded up 4 inches to provide mounting space for the pulse transformers and their associated networks. This reduces to 7½ inches the width of a panel which, conventionally laid out, would have required at least 13½ inches. No attempt was made to miniaturize any of the components, and the space saving was accomplished entirely by using the available depth. This has not seriously impaired accessibility of the circuitry, either for maintenance or for test.

5.4 PUNCHED-PAPER-TAPE EQUIPMENT

Since the writing of Summary Report 24 (Sections 5.12 and 5.13), the interim punched-paper-tape equipment has been completed, tested, and integrated with the WWI system, and has seen many hours of useful work. It has been remarkably trouble free since certain obscure synchronization troubles were identified and corrected. Engineering Note E-402 contains detailed descriptions of circuitry and timing for the interim tape output equipment. Engineering Note E-380 covers the same ground for the interim input tape reader.

Some planning and preliminary design work has been done on the control system necessary to permit the typewriter and tape punch equipment to be used with the in-out switch. The final form that this control will take remains to be decided.

A photoelectric paper tape reader (see Fig. 5-4) was delivered from the Engineering Research Associates, Inc., St. Paul, in February 1951, and work is under way on the design of circuits to adapt this unit to the computer system. The reader is designed to scan standard 7-hole tape (such as is prepared by Flexowriter punching equipment) at a speed of 14 inches (140 coded characters) per second. A simple friction drive rather than a sprocket drive is used, so that single characters cannot be read unless sufficient blank tape (approximately 3 inches) is provided between the characters to allow for acceleration of the drive mechanism and for acceleration and deceleration of the tape. The unit contains pick-up phototubes for each of the 7 information holes as well as one for the sprocket-feed hole. The phototube signals are individually amplified, so that the output from the unit consists of parallel pulses a few milliseconds long appearing on 8 lines.

For the interim installation of the photoelectric reader, it is planned that information will be read into one of the test-storage flip-flop registers as is presently done with the Flexowriter reader. The reader output pulses corresponding to the information holes will be used to control gate tubes which are sensed at the proper time by a 0.1-microsecond pulse timed by the sprocket-feed-hole pulse. The 0.1-microsecond pulse outputs from these gate tubes, then, accomplish the actual parallel transfer into the flip-flop register.

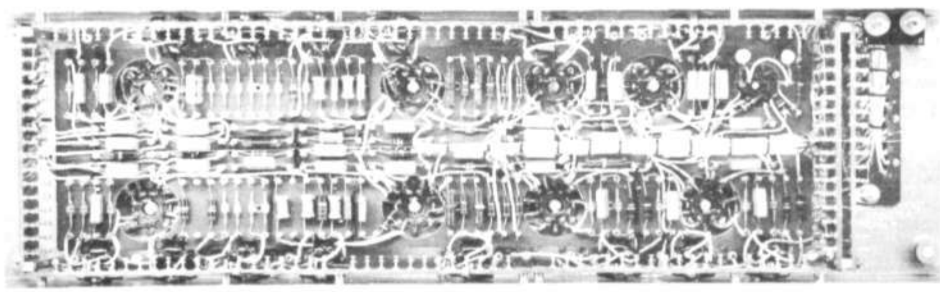


Fig. 5-3 In-Out Register Panel

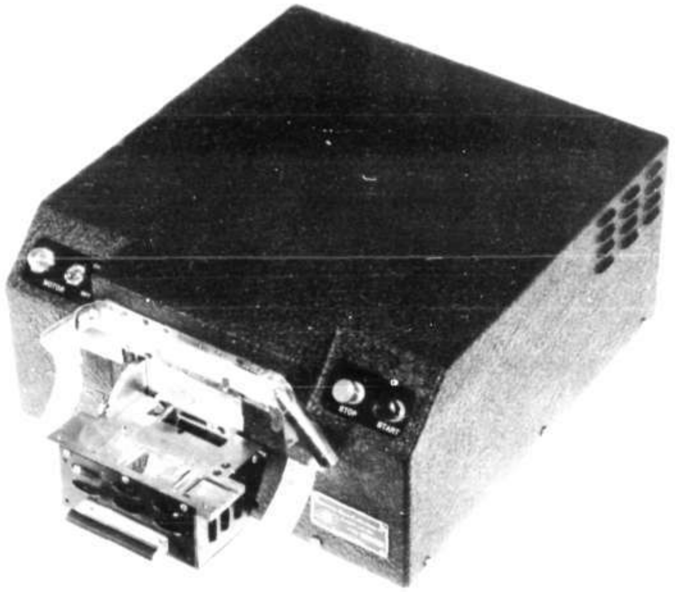


Fig. 5-4 Photoelectric Paper-Tape Reader (Light Box Lowered)

5.5 MAGNETIC TAPE

The first of five magnetic-tape handling mechanisms that were ordered from the Raytheon Manufacturing Company was delivered to the Laboratory on March 8 (see Fig. 5-5). These units are designed to handle 800-foot reels of $\frac{1}{2}$-inch tape and to move the tape in either direction at speeds of 30 inches per second in response to pulse signals from an external control. The magnetic head provided permits recording on or reading from 6 parallel channels simultaneously. The electronic circuitry necessary for accomplishing the recording and reading functions is not included in the unit.

An investigation has been started on the design of the necessary amplifiers and control circuits to permit these tape units to operate under control of the computer. Two phases of this work will require particular emphasis. One of these is the design of satisfactory switching circuits to switch the magnetic head between the reading and recording functions and also to switch among several similar tape-handling units which will use a common set of recording and reading circuits. The other is the study of methods for using magnetic tape that is known to have minute blemishes in its coating. Such blemishes result in loss of one or more digits of a recorded word. To date only incomplete information (obtained from Raytheon Manufacturing Company and others) is available on the nature of the defects, but it appears that blemish-free tape will not be available in the near future. A proposed method for avoiding these areas on the tape is to use one recording channel for index marker signals to indicate where data can be reliably recorded on the other channels. It will be necessary to construct special equipment to scan each new roll of tape for blemishes and to prepare the index marker channel before the tape can be used with the computer system.

5.6 EASTMAN READER-RECORDER

Efforts to get successful operation of the Eastman reader - recorder with the computer system were continued through December, 1950. These efforts were concentrated on the reading operation, since fairly satisfactory recording had been accomplished previously. The principal weaknesses in reading were in obtaining adequate signals out of the phototubes. In the reference-marker channel

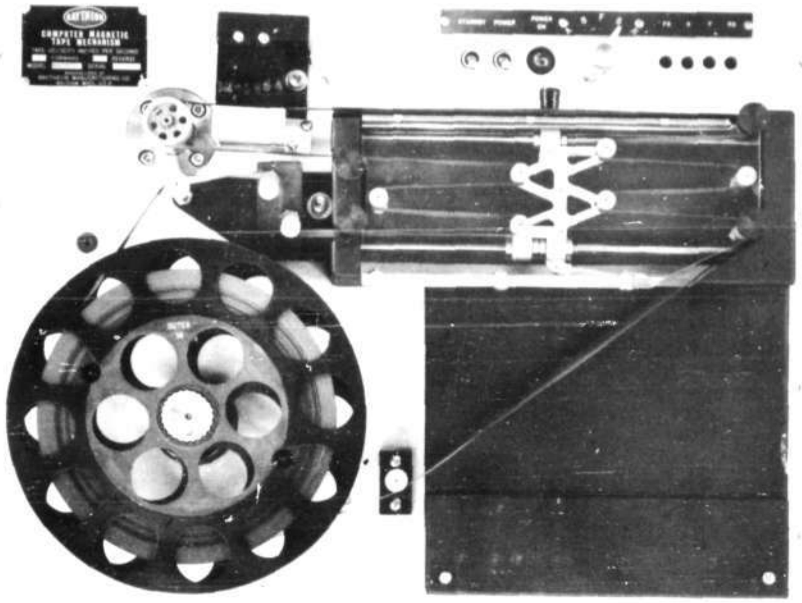


Fig. 5-5 Magnetic-Tape Mechanism

there was insufficient signal amplitude, while in the digit-phototube channels, pulse amplitude was dependent on the number of pulses that occurred in a group. In the worst case, that of 16 pulses in a group (corresponding to a 16-digit word of all ones or all zeros), the amplitude of successive pulses decreased sufficiently so that the smallest pulse was only slightly greater in amplitude than the largest noise pulses which occurred in words that did not have 16 pulses in a group.

To improve the signal amplitude in the reference-marker circuit, the Eastman Kodak Company designed a new light source for scanning the reference-marker lines on the film (see Summary Report 24). A production model of this light source was received and installed the last of November, 1950. Considerable improvement in the performance of the reference-marker channel resulted.

Studies of the digit-phototube channels showed that the cause of the undesirable sensitivity to pulse-repetition frequency was too slow a decay of light in the phosphor of the cathode-ray-tube screen. No satisfactory way could be found to compensate for this by altering the design of the pick-up circuits. The solution decided upon was to slow up the sweep of the cathode-ray tube to lengthen the time between pulses. It was found that about 50-percent increase in the period between pulses was sufficient to overcome the difficulty. Although operation of the film unit in this manner required that the in-out and comparison registers in the computer be deprived of restorer pulses for a longer period than is considered desirable, tests with the system showed that with this change reliable reading from film could be accomplished. The unit was operated in this manner for a period of a few hours with no errors occurring. In the new input-output system being planned, the increase in time between digit pulses will not be harmful, since a d-c coupled in-out register will be used.

Work on the Eastman film units was halted at the end of December, 1950, even though the first successful operation of the units had just been achieved. The reason for this was that the computer applications which are envisioned for the near future will not require these units and additional manpower was needed on other phases of the input-output development. The principal problem remaining in testing the reader-recorders is a study of their line-by-line mode of operation.

6. MATHEMATICS, CODING, AND APPLICATIONS

The successful operation of electrostatic storage and interim punched-tape input and output equipment, attained gradually during the last three months of 1950, brought about a considerable change in the activities of the applications group. With the computer available for use, programming took on a new meaning, for now the programs were to be actually tried and not simply filed away for future use. First, of course, it was necessary to learn to use the machine and to learn to cope with its then frequent infirmities. The applications people spent much of their time waiting for auspicious moments at which to try their programs and then trying to determine whether they or the machine was at fault when a program failed to work as expected.

More recently, Whirlwind has grown extremely reliable and has become available for general applications work on a regular weekly schedule with a very good chance that no failures will occur. With this new turn of events, the applications group, now considerably expanded in size, is able to concentrate on writing more different programs and on developing efficient methods for using the computer. Since one of the primary aims of the group is to show the feasibility of using a large, fast, general-purpose computer to solve many relatively small-scale scientific and engineering problems (where a single problem may require only a minute or two of machine time once a day or once a month), efficient methods of using the machine and efficient methods of locating troubles in programs without tying up the computer unduly are essential to ultimate success. The remainder of Section 6 describes the procedures so far developed toward achieving this aim.

6.1 THE INPUT PROGRAM

One of the first problems to be dealt with in using the computer was getting a program and other pertinent data into the machine with its electrostatic storage and its slow and rather inflexible interim tape input and output equipment. Information on the tape consists of no more than six binary digits on each line of tape, and the tape can be read only one line at a time under the direct control of the computer. Each 16-binary-digit word (instruction or number) must occupy at least 3 lines on the tape, and the digits on these 3 lines must be read in separately and assembled into a single word by an input program. This input program is stored permanently (as far as the applications people are concerned) in the test storage of the machine (27 hand-set non-erasable toggle-switch storage registers and 5 presetable erasable flip-flop storage registers).

The input program must not only direct the reading and assembling of groups of digits from tape into 16-digit words; it must also provide some constant check on the reliability of the input reader, and it must arrange to receive from the tape (and not from manually-set switches) information as to where to store each word as it is assembled, when to stop reading in, and where to transfer control after the read-in is complete. The input program finally adopted does these things satisfactorily. Normally, the address at which the first word is to be stored is specified, and all succeeding words are stored consecutively thereafter. Special indications are used to mark a break in this consecutive process, together with the new address at which the next word is to be stored, or to mark the end of the whole reading process, together with the address to which control is to be transferred.

The transfer in from tape is checked at present by accumulating the arithmetic sum of all the words read in, neglecting overflows (by means of the sa operation), and then checking this sum against a previously-computed sum which is punched at the end of the input tape. In an earlier version of the input program, complete duplicate checking was used by having each character on the tape followed immediately by its complement and then having the input program check each character against its complement. After some initial difficulties had been ironed out, the tape input equipment became reliable enough so that this rather awkward and lengthy checking procedure could be abandoned in favor of the present one.

6.2 THE PREPARATION AND HANDLING OF PAPER TAPES

The present input program requires tapes which have been prepared in a pure binary form, with each 16-digit binary word being punched in 3 parts, 5 digits on each of two lines of tape and the remaining 6 on a third line of tape. The checking feature of the input program requires further that a special sum of all the words be computed and punched at the end of the tape. To convert every word of every program to binary form by hand before punching it on tape would be almost impossibly cumbersome. Instead, the computer itself is used to perform the conversion. Programs are prepared in a simple, standard form, the usual two letters representing the different operations and decimal or octal digits representing numbers and addresses. When such programs are typed out on unmodified Flexowriter

typewriters, a punched tape is formed which contains the desired program in a binary-coded form. A special conversion program has been written and put onto tape in binary form once and for all. This program, which is some 200 registers long and consequently cannot possibly be stored in test storage, can be read into electrostatic storage using the input program. The conversion program then directs the computer to read in successive characters from a tape prepared in the standard way (using alphabetical and numerical characters binary-coded by the Flexowriter equipment) just outlined. The conversion program then properly converts these characters, forms 16-digit binary words, and punches each of the words out on 3 lines of tape. The conversion program also accumulates the special sum and punches this at the end of tape, and it also takes care of punching the special indications which are needed to start and stop the input program.

A procedure has been set up for preparing tapes by which a person who has written a program simply submits a written copy of the program to the person in charge of tape preparation. The program is typed once in the prescribed standard form on a Flexowriter typewriter. A second typist types the program again on a second typewriter connected to a special verifying circuit which checks the second typing against the tape resulting from the first typing (see page 18 of Summary Report 23). The resulting verified or "checked" tape is then duplicated onto a long tape containing all the programs prepared during the day. The tape containing all the programs prepared during each day is fed into the computer just before the computer is shut down for the night, and each program is converted and punched in the proper binary (5-5-6) form. The following morning, the converted tapes are duplicated, marked, and filed. Master copies of both the standard and the converted tapes are filed under lock and key; copies of the converted tape and of the program manuscripts are filed accessibly.

Provisions have been made to allow changes in tapes to be made readily. Again, the originator simply submits a copy of the changes and a request that they be made. A new tape, containing only the modifications, is made up in the manner described above for a new program, except that now the "program" may be only a single order or number. This modification, after being converted in the routine way, is then appended to the original tape with provision being made for the input program to read the modifications into storage after the original incorrect program has been read in. New sets of trial parameters are treated similarly. The need for quick and convenient methods of changing programs and adding new sets of parameters arises from the "operation" techniques described below.

All of the tape preparation is being handled by MIT undergraduates working part-time. They spend part of their time also in learning to code for the computer, leading to possible full-time work in the Laboratory. The tape preparation is done under the supervision of a college graduate who is also experienced in clerical and stenographic work.

6.3 OPERATION OF THE COMPUTER

All of the people who are at present working full-time on programming for the Whirlwind computer have had the opportunity of actually operating the machine. During the early stages, much work was done on manually controlling the computer. Mistakes originating electronically as well as in programs were found and corrected by making the computer operate one step at a time. The computer time and staff involved in such manual operation appears to be quite prohibitive. Consequently, the Whirlwind computer is no longer being operated at manual rates when it is being used for general applications programs. One of the full-time programmers has been assigned to operate the machine during all of the 10 to 15 hours a week assigned to general applications work. He will continue in this duty until the process can be well enough mechanized to be passed on to a technician.

Whenever a person has written a program and wishes it tried on the computer, he submits the manuscript for tape preparation and requests that the program be run on the computer. The general applications time has been intentionally scheduled in one-hour pieces approximately twice daily throughout the week. Several programs are run during each of these hours, except in the event of a program which has been found to be satisfactory and from which a large number of results are needed. One or two 3-hour sessions have been scheduled to provide for long runs when they are needed.

The person who wrote the program is not expected to be at the computer when his program is run, although he may be if he wishes. The operator simply reads the program in from tape, lets it run until it stops, and takes the results to the person who requested the performance. If, as is frequently the case, the program fails to run as predicted, records are made of what happened and these are sent to the originator. It is possible for a person to write a program one day, have the results of the first run on his desk the next morning, make corrections at his leisure, and have the results of the corrections on his desk the following morning.

In the hope of providing complete information of what happened when a program fails to work, some special wiring has been supplied in the interim output punch so that it can be used to punch special information. This situation is not intended to become permanent. It is being used on a trial basis and has been done by wiring rather than by special programmed routines largely because of the present very limited storage capacity. The information which can be punched includes:

1) The address of the register containing each of the sp and cp (transfer of control) orders as they are obeyed by the program.
2) The contents of the control switch as each order is carried out.
3) The contents of the accumulator as each order is carried out, or as each ts (transfer to storage) order is carried out, etc.
4) The contents, in binary form, of every storage register at the time the computer stopped itself or was stopped (by means of a special very short program).

With all or even part of this information, plus the knowledge of what the machine was doing when it stopped, the person who wrote the program can follow through his program and see where the error was. The location of errors is not made automatic or even necessarily easy, but it is made as painless as seems possible at present. Further, it requires the time of only one man, working under no abnormal pressure, rather than using the time of several men (technicians, engineers, etc.) and an expensive computer during the trouble-location process.

The procedure outlined above, by which the programmer need not necessarily ever see the machine, is modelled after the procedures developed and described by M.V. Wilkes and his group on the EDSAC at Cambridge, England. The procedure has been in use, with some exceptions, during the month of March and has shown great promise.

7. ACADEMIC PROGRAM IN AUTOMATIC COMPUTATION AND NUMERICAL ANALYSIS

An expanded graduate-school academic program in Automatic Computation and Numerical Analysis being offered in 1950-51 by the MIT Electrical Engineering Department was described in the Second Quarter Summary Report, SR-23, and the individual subjects are described in the 1950-51 MIT catalogue. Since these publications were issued, another subject, 6.68, Practice in Use of Digital Computers, has been added to the program for the spring term of 1951. This subject is being taught by Mr. Charles Adams, of the Whirlwind staff, and the Whirlwind computer is used as laboratory equipment. The official description of the subject is as follows:

"Practice in Use of Digital Computers, Subject 6.68, taught by Mr. Charles Adams: General principles of the logical design of large-scale, general-purpose digital computers will be discussed with a detailed comparison of the logical designs and the order codes (and the resultant potentialities) of many of the computers now operating or nearing completion in the U.S. and elsewhere. Emphasis will be placed on the techniques being developed for programming and operating such computers, including the use of various forms of storage and terminal equipment and the detection of errors in the programs and in the machines. A considerable portion of the semester will be devoted to the solution of individual computational problems of moderate size selected by each student. Each student will be given the opportunity to program, prepare on punched paper tape, and carry out on the Whirlwind computer at least one problem of his own choosing."

Of the 20 people registered in the first-term Subject 6.535, Introduction to Digital-Computer Coding and Logic, 6 have become members of the Whirlwind staff (two full-time staff members, three part-time, and one research assistant). One other member of the class will start work on the Project later.

Registration of students for the spring term is shown in the table below. Numbers refer to the MIT catalogue, where descriptions of the subjects may be found, as well as in SR-23.

Subject and Number	Students Registered
Numerical Analysis, 6.532	9
Laboratory in Numerical Analysis, 6.534	7
Machine Computation, 6.536	15
Electronic Computer Laboratory, 6.538	10
Practice in Use of Digital Computer, 6.68 (See above)	7

8. APPENDIX

8.1 REPORTS AND PUBLICATIONS

Project Whirlwind technical reports and memorandums are routinely distributed to only a restricted group who are known to have a particular interest in the Project. Other people who need information on specific phases of the work may obtain copies of individual reports by making requests to John C. Proctor, Servomechanisms Laboratory, 211 Massachusetts Avenue, Cambridge 39, Massachusetts.

The following reports and memorandums were among those issued during the last quarter of 1950 and the first quarter of 1951.

No.	Title	No. of Pages	Date	Author
SR-23	Summary Report No. 23, Second Quarter, 1950	31		
R-192	A Coincident-Current Magnetic Memory Unit (M.S. Thesis; Abstract in E-379)	83	9-8-50	W. N. Papian
R-193	Selected Descriptive Material Whirlwind I Computer. Vol. 1: General. Vol. 2: Introduction to Coding		11-10-50	C. W. Adams, ed.
R-194	Experience with Receiving-Type Vacuum Tubes on the Whirlwind Computer (Talk given at Conference on Electron Tubes for Computers December 11 & 12, 1950)	11	12-20-50	E. S. Rich
E-359	ES Test Program	15	9-25-50	G. Cooper
E-366	The Project Whirlwind High-Vacuum Systems	9	3-2-51	T. F. Clough
E-392	Crystal Diode Initial Investigation - Initial Results	6	11-2-50	F. Irish
E-393	Marginal Checking System, WWI	49	12-6-50	R. E. Hunt
E-395	Cathode Interface Impedance and Its Effects in Aged Vacuum Tubes (Paper delivered at Conference on Electron Tubes for Computers at Atlantic City)	5	1-2-51	H. B. Frost
E-396	Crystal Diode Life Experience in WWI Computer Circuits (Atlantic City Paper)	3	1-2-51	H. B. Frost
E-397	Some Basic Relay Pulse Circuits of General Interest	11	1-18-51	C. W. Watt
E-399	Comparison Between 1N56A and D-359 Crystals	2	2-21-51	E. S. Rich
E-400	The Vacuum Tube Pulse Current Tester	8	3-15-51	H. B. Frost
E-401	Arc Suppression for Small Electrical Contacts	16	3-19-51	R. E. Hunt
M-1067	Temporary Operation of qr: Read/Shift Right	3	7-17-50	C. W. Adams
M-1085	Orders sl and sr: Provisions for Selective Round-off	3	11-14-50	R. P. Mayer
M-1108	Special Display	2	10-4-50	D. A. Buck
M-1117	Preliminary Outline and Reference Material for Computer Demonstration, October 25, 1950	10	10-23-50	C. W. Adams
M-1128	A Proposal for Power and Video Cabling in the New Control Room	4	11-15-50	C. W. Watt
M-1130	Preparation and Filing of Punched Paper Tapes for WWI	8	11-20-50	C. W. Adams

No.	Title	No. of Pages	Date	Author
M-1156	Special Add Memory Clearing on Certain Orders	2	1-25-51	R. P. Mayer
M-1166	Proposed Adaptation of Fairchild Recording Camera to WWI Oscilloscope Display System	2	2-13-51	E. S. Rich
M-1167	New Plan for In-Out Orders and In-Out Subroutines	20	2-16-51	E. S. Rich J. M. Salzer B. E. Morriss
M-1171	Marginal Checking Controlled by Program: Preliminary Proposal	7	2-6-51	R. P. Mayer
M-1177	Interim Paper Tape Conversion and Input Programs	6	3-9-51	J.E. Gilmore, Jr.

8.2 PROFESSIONAL SOCIETY PAPERS

Three members of the Project staff delivered four papers at the Conference on Electron Tubes for Computers held by the AIEE and the IRE in collaboration with the Panel on Electron Tubes of the Research and Development Board in Atlantic City on December 11 and 12. The subjects of the papers are given below.

Subject	Author
Experience with Receiving-Type Vacuum Tubes on the Whirlwind Computer Project	E. S. Rich
Cathode Interface Impedance and Its Effects in Aged Vacuum Tubes	H. B. Frost
The MIT Storage Tube	P. Youtz
Crystal Diode Life Experience in the Whirlwind Computer Circuits	H. B. Frost

On February 21, 1951, P. Youtz talked to the Buffalo-Niagara Section of the IRE on "The Digital Computer as an Information Processing System."

At the IRE National Convention held in New York from March 19 through March 22, Jay W. Forrester presented a paper on "Digital Computers in Simulated Control Systems." Mr. Forrester acted as chairman of a session on Analogue Computers, and he organized a session on Digital Computers at which W. N. Papian read a paper entitled "Ferromagnetic Cores for Three-Dimensional Digital Storage Arrays."

Two members of the Project staff delivered papers at the Wayne Conference on Computing Machinery and Applications held at Wayne University, Detroit, on March 27 and 28. The Conference was sponsored by the Advisory Committee for Wayne Computation Laboratory, the Industrial Mathematics Society, and the Association for Computing Machinery. W. K. Linvill presented a paper written in collaboration with J. M. Salzer on "Analysis of Digital Computers in Control Systems". R. R. Everett presented a paper on "Digital Computer Research at MIT."

The November 1950 issue of Electrical Engineering contained a paper by S. H. Dodd, H. Klemperer, and P. Youtz entitled "Electrostatic Storage Tube." This paper was delivered at the North Eastern District Meeting of the AIEE held in Providence in April.

"Marginal Checking as an Aid to Computer Reliability", by N. H. Taylor, originally presented at the IRE National Convention in March, 1950, was published in the Proceedings of the IRE for December.

"Digital Information Storage in Three Dimensions Using Magnetic Cores", by Jay W. Forrester, was published in the Journal of Applied Physics for January, 1951.

8.3 VISITORS

During the past two quarters the Laboratory has had among its visitors the following:

Gen. J. H. Doolittle, Lt. Col. T. F. Walkowicz, Maj. Vincent T. Ford, and Mr. W. A. M. Burden, Special Assistant to the Secretary of the Air Force.

Mr. D. H. Ring and W. D. Lewis, of Bell Telephone Laboratories, to discuss electronic memory tubes and other storage devices.

Dr. Irven Travis and Mr. John H. Howard of Burroughs Adding Machine Co.

Dr. A. L. Samuel, Mr. J. C. McPherson, and Mr. R. L. Palmer of IBM.

Mr. Jay L. Upham of Glenco Corporation and Mr. Martin Littmann of Armco Steel Corporation, who discussed the development of materials for three-dimensional storage.

Mr. G. Glinski of Computing Devices of Canada, Ltd.

Mr. John L. Hill and Mr. S. H. Bruder, of RCA, who were interested in marginal checking.

Dr. H. S. Osborne, Chief Engineer of A. T. & T.

Mr. B. V. Bowden of Ferranti Electric, Ltd., who discussed his work on a Williams computer in England.

Dr. G. C. Comstock, Mr. W. D. White, and Mr. R. N. Close, of Airborne Instruments Laboratory.

Dr. E. P. Little, Mr. R. Hofheimer, Mr. M. S. McDowell, and Mr. M. Kincaid, of the Harvard Computation Laboratory.

Dr. Paul J. Selquin and Mr. James H. Muney, of the National Bureau of Standards, interested in marginal checking of electronic equipment.

Dr. J. R. Bowman, Mr. F. A. Schwert, and Mr. R. T. Steinback, of the Mellon Institute.

Mr. W. A. MacNair of Bell Telephone Laboratories.

Commander Lyle B. Ramsey and Mr. Charles L. Wright, Jr., of the Bureau of Ships.

Mr. R. B. Killingsworth of Socony-Vacuum Oil Company, who was interested in possibilities of using computers in the oil industry.

Mr. R. Mirsky, Mr. R. H. Shatz, and Mr. E. J. Isaac, of Cornell Aeronautical Laboratory.

Mr. H. Kaufman and Mr. W. E. N. Doty, of Continental Oil Company.

Dr. Jan Rajchman of RCA.

Mr. Norman B. Sanders and E. P. Carter, of Transducer Corporation, discussing magnetic-core storage.

Col. Joseph G. Perry and Maj. R. Hopkins, of the Office of Air Research.

Mr. T. H. Briggs of Burroughs Adding Machine Company and Mr. C. D. Richard of Superior Tube Company, who discussed vacuum-tube construction.

Mr. Richard E. Sprague and Mr. Richard W. Dabney, of Computer Research Corporation, who were interested in computer design and reliability.

Mr. Robert E. Miller and Mr. William A. Wheatley, of Willow Run Research Center, University of Michigan.

Dr. S. N. Alexander, Mr. Glenn F. Rouse, and Mr. Ralph J. Slutz, of the National Bureau of Standards, to discuss vacuum-tube life experience.

Dr. K. Zuse and Mr. H. Stacken, of Zuse and Company, Germany, who discussed machine logic.

Mr. Herbert Herz and Mr. H. A. Goldsmith, of Magnetic Amplifiers, Inc.

Mr. W. O. Osborne, Mr. M. G. Myers, and Mr. S. C. Palmer, of Westinghouse Corporation.

Mr. L. H. Cherry and Mr. C. M. Sorvaag, of NAMTC, Pt. Mugu, California.

A group from European Documentation Specialists who were interested in terminal equipment and the use of a computer for scanning library data.

Mr. D. R. Young, Mr. W. E. Mutter, and Prof. L. Brillouin, of IBM.

Mr. C. S. Woodside and Mr. L. D. Whitelock, of the Electronic Division of the Bureau of Ships, who discussed storage tubes.

Mr. W. W. McDowell, Director of Engineering, Mr. E. W. Gardinor, and Mr. A. Malmros, of IBM.

Mr. David Lippitt and Mr. R. Thorensen, of G.E., investigating electrostatic storage.

Mr. A. S. Eisenstein of the University of Missouri, who discussed vacuum-tube techniques.

Mr. R. B. James of RCA.

Mr. C. A. Laws of Elliott Brothers, England, and Mr. R. Benjamin of A.J.R.E., England.