MARGINAL CHECKING: PREVENTIVE MAINTENANCE FOR ELECTRONIC EQUIPMENT

by

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ABSTRACT

A high degree of reliability must be obtained from modern electronic equipment if its use is to be extended in the future. Because of their size and because of the presence of a memory which remembers incorrect as well as correct information, reliability of electronic digital computers is an even more difficult problem than for more common equipment.

Since most component failures in conservatively designed circuits result from gradual deterioration, checks of performance margins permit removal of failing components before operation failure occurs. By submitting circuits to strained operating conditions such as decreasing screen-grid voltage for amplifiers, the condition of vacuum tubes and other components are checked in place. This preventive maintenance is called marginal checking. The amount of additional equipment needed for detection and signal source switching depends upon the degree of reliability required. In electronic computers detection and source switching can be done with the proper test program of computer instructions; so that the procedure may be highly automatized without excessive additional equipment.

Simply varying power supply voltages is inadequate because particular deteriorated components are not isolated. However, grouping of circuits into sections not used simultaneously gives good isolation.

Preventive maintenance in the form of marginal checking applied to a 400 tube system improved reliability over 50 to 1. Preliminary results indicate that equally good results can be obtained with larger systems.

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A high degree of reliability must be obtained from modern electronic systems for two obvious reasons. The investment in the equipment itself may be quite high so that the user justifiably expects dependable operation over a long period. On the other hand, large sums of money or even human life may be staked upon proper operation at specific times. An example of the latter may occur in the future when an electronic computer directs an aircraft as it approaches an airport for landing. The computer in this case receives location, speed, and altitude information perhaps from a radar set, checks this information against that of all other planes in the vicinity, and directs the pilot how to proceed all in a small fraction of a second. Reliability is of utmost importance in such a system. It is not sufficient to keep errors below a certain minimum. It is necessary to prevent their occurrence.

In considering the problem of reliability for electronic equipment, this paper will describe a technique called marginal checking. As a specific example of this technique, methods and results obtained in electronic digital computer research at the Servomechanisms Laboratory, Massachusetts Institute of Technology will be given.

Reliability in computers is an even greater problem than in more common electronic systems. One wrong letter does not void a teletype message, ignition noise does not completely void television, nor does an arcing magnetron nullify the plot on a radar screen. Performance is still considered satisfactory if these occur only infrequently. With digital computers, however, a single disturbance can invalidate the whole effort. This is due to the high concentration of information and to the presence of a memory within the computer. The memory remembers incorrect information as well as the correct, and once an error finds its way into the memory, it can propagate itself into all subsequent operation.

Also the size of digital computers adds to the reliability problem. Most of the large scale digital machines under development use many thousands of vacuum tubes, crystal rectifiers, resistors, capacitors, and inductors. Vacuum tubes and crystal rectifiers are the most unreliable of these, but operation failures due to other components may be expected because there are so many. A typical computer may have 5000 vacuum tube cathodes and 10,000 crystal rectifiers. Assuming an average life of tubes of 5000 hours and for crystal rectifiers 10,000 hours, a failure may be statistically expected every 30 minutes from these aging components. Even if trouble-location is well developed, so that repair time is short, operating efficiency would be very low. A natural question is if periodic replacements of certain components would improve efficiency. Unfortunately, early failure in groups of new tubes is quite high; so that wholesale replacement on a time basis might even increase the failure rate.

The picture is indeed dark, unless a very important fact is recognized. That is that most component failures in conservatively designed circuits result from a gradual change in their characteristics. This is the basis of marginal checking. If a circuit containing a component whose deterioration is not sufficient to cause trouble in normal operation is subjected to an abnormal strain, faulty operation will result. The amount of strain necessary to cause failure is called the operating margin. Marginal checking applies this strain and observes the result in a routine maintenance period. Removal of components causing low margins, insures a predictable life expectancy of all other components. This procedure is somewhat analogous to the common insulation-breakdown tests. However, marginal checking produces no damage to components and is applied by built-in facilities.

In designing a marginal checking system, each circuit must be examined to see how a strain may be applied. Imminent failures must be converted to real failures during the maintenance period by action from outside the circuit. Many possibilities exist such as changing the character of the input signal, changing a supply voltage, or changing of output loading. Some examples of how marginal checking is applied to computer circuits are given below.

Figure 1 gives a typical basic block diagram often encountered in computers and other pulse systems. Gate tube A, when open, allows pulses to pass along a channel to a flip-flop. If the pulses are large enough and the flip-flop in proper condition, each pulse will cause a reversal of the flip-flop from a 1 to 0 or vice versa.

Two sorts of trouble may develop: first, a component of the gate circuit may deteriorate causing the pulse amplitude to reduce to a point where the flip-flop will not switch or, second, the flip-flop may refuse to switch because one of its components has deteriorated.

Gate tube B is controlled by the flip-flop. The application of a sensing pulse at B permits checking to see if the flip-flop has received and properly acted upon pulses from A. The operating margins of these circuits may be measured by voltage variation as shown in the following paragraph.

The gate circuit shown in Figure 2 is a video amplifier which can be switched on and off by its #3 grid. The margin of performance in the gate tube can be checked by lowering the voltage on the screen of the tube. As shown in the figure this is done by inserting a negative voltage in series with the screen grid lead. Under these conditions the pulses emerging from the tube will be lower than they were before the deviation. This effect makes the tube look weaker.

Figure 3 is a simplified schematic of a flip-flop. A flip-flop is a circuit having two stable states, each state being determined by which of its two tubes is conducting. The circuit is symetrical.

One tube must have the ability, when conducting, to hold the other tube in a non-conducting state. Tube deterioration shows up as a reduction in plate current in one tube with a consequent reduction of bias available to the opposite tube. The use of a cathode resistor allows considerable aging before the condition becomes intolerable but eventually tube deterioration will become so extreme that instability will occur and the flip-flop will favor one side. Then, whenever it is ordered to change sides by an incoming pulse the circuit will either fail to hold its new position after switching takes place.

This unfavorable condition can be detected before it leads to failure by feeding the two screen circuits of the flip-flop separately, as shown, and selectively raising the screen voltage of the normally off tube. Raising its screen voltage also raises its no. 1 grid cut-off voltage. The normally on tube must have a safe margin of plate current available if it is able to hold the tube being checked off under these extreme conditions. If the on tube is weak it will fail to hold off the opposite tube and a spurious switching operation will result. The detection of this condition can be automatic by applying sensing pulses to a gate tube attached to the flip-flop as in Figure 1.

Time limits discussion to these two conversion methods. Others are equally effective. Clamping crystals have been checked by changing the timing sequence. Transformers and line terminations have been checked by varying the frequency of pulse sequences.

In applying voltage variation as a means of marginal checking, it is uneconomical to provide separate variation facilities for each circuit. Moreover, simply varying power supply voltages is not enough. This would allow checking overall operating margins but would be of small value because little information as to what components cause low margins is obtained thereby. An economical compromise may be obtained by grouping similar circuits of separate channels into sections. If checking of the channels is then done in time sequence, effective isolation of deteriorated components is obtained.

Figure 4 shows how a computer may be sectioned for marginal checking. Three of many channels are shown. The vertical lines indicate the sections into which are grouped similar circuits of different channels.

As voltage variation is applied to each section, the pulse source sends signals through each channel in time sequence and at the same times, through the checking channel to the checking section or detector. Failure to receive the proper signal at the detector causes the whole sequence to stop and an alarm to sound. The channel and section coordinates of the faulty stage are indicated by the stopping point of the sequence. Thus a high degree of isolation is obtained. Marginal checking of the pulse source, the detector, and the checking channel must be done separate from the other channels, but the same philosophy of grouping can be applied.

In electronic computers the marginal checking routine can be automatized to a great extent. Switching of the pulse source and the detector from channel to channel is accomplished by a set of computer instructions in the form of a specially prepared test program. The only extra equipment needed is for switching voltage variation facilities from section to section.

In the Whirlwind computer system some 200 sections are used. With the proper computer program, pulses are sent through each channel in a fraction of a second. The marginal checking control panel is shown in Figure 5. A register of indicator lights on the left shows the section under test. The telephone dial in the center is used for manually selecting a given section. The voltmeter at the right indicates the voltage excursion applied. In manual operation, the dial beneath the voltmeter controls an amplidyne generator which provides the voltage excursion. In automatic operation, telephone-type stepping switches shown in Figure 6 select the various sections in sequence. The checking time for each section is 5 seconds; so that the whole system may be checked in about 15 minutes.

The potentiality of marginal checking is shown from its performance record. Consider the record of a 5-binary-digit prototype arithmetic element, containing about 400 vacuum tubes. It is set up to solve a test problem and checks the result continuously 24 hours a day. Marginal checking is performed daily during a 1/2 hour preventive maintenance period and deteriorated components replaced. Several runs of three weeks without computational error have been made. A recent period of 45 days contained no errors. This represents over 5 billion correct solutions, and about 10^{13} correct flip-flop reversals in 25 flip-flop circuits. During this time, 16 tubes, 7 crystals, and 4 resistors were replaced during marginal checking periods because of low margins.

It is expected that for larger systems equipped with marginal checking, errors will not increase in proportion to the extra equipment involved. In the equipment just described, a high percentage of errors are caused by power failure, thunderstorms, and other external disturbances independent of the number of vacuum tubes used. This conclusion is verified by experience with the Whirlwind Computer now under test during its installation. The following table shows tube and crystal rectifier failures.

TUBE AND CRYSTAL FAILURES
(2750* Hours of Operation)

	Tube	Crystals
Number in Use	3500	9500
Total Failures From all Causes	128	176
Located by Marginal Checking	78	148

Note: 2750* Hours for majority-minority of tubes were installed later.
Figures to March 31, 1950.

Even though adequate marginal checking facilities were not available for some of the period, of 128 tube failures, 78 or 61% were detected by marginal checking before they caused operational failure. Many of the remaining failures were from obvious causes such as mechanical failure or extreme gassiness causing blown fuses. Of 176 crystal rectifier failures, 84% or 148 were removed during preventive maintenance.

Marginal checking as described does not eliminate the inevitable intermittent faults as such. However, many so-called intermittents are actually caused by deterioration just to the point where obscure and minute external disturbances cause failure sometimes and sometimes not. These faults are uncovered by marginal checking. Moreover, actual intermittent faults such as broken welds in vacuum tubes and poorly soldered joints can be attached more directly and with more assurance if the condition of other components has been established by marginal checking.

In summary, marginal checking is aimed at the detection of aging components before they cause operational failure. Results have already shown that the concept of built-in preventive maintenance equipment is sound. The method of application to specific electronic devices depends upon the case at hand. The degree of elaborateness of the additional equipment is determined by the degree of reliability required.

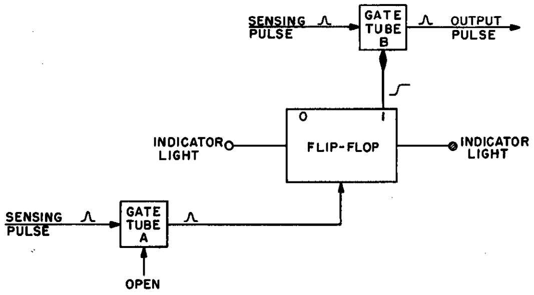

Fig. 1.

Typical pulse circuit

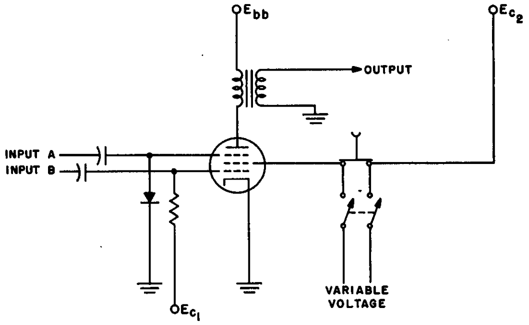

Fig. 2.

Marginal checking of gate circuit

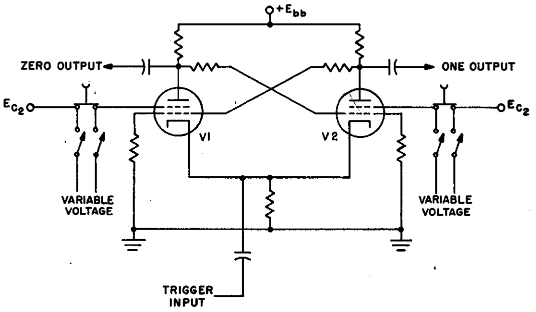

Fig. 3.

Marginal checking of flip-flop circuit

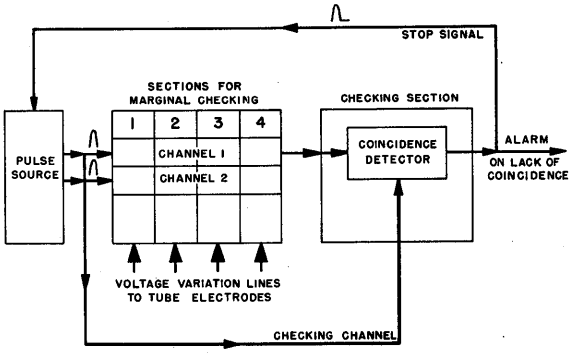

Fig. 4.

Computer marginal checking

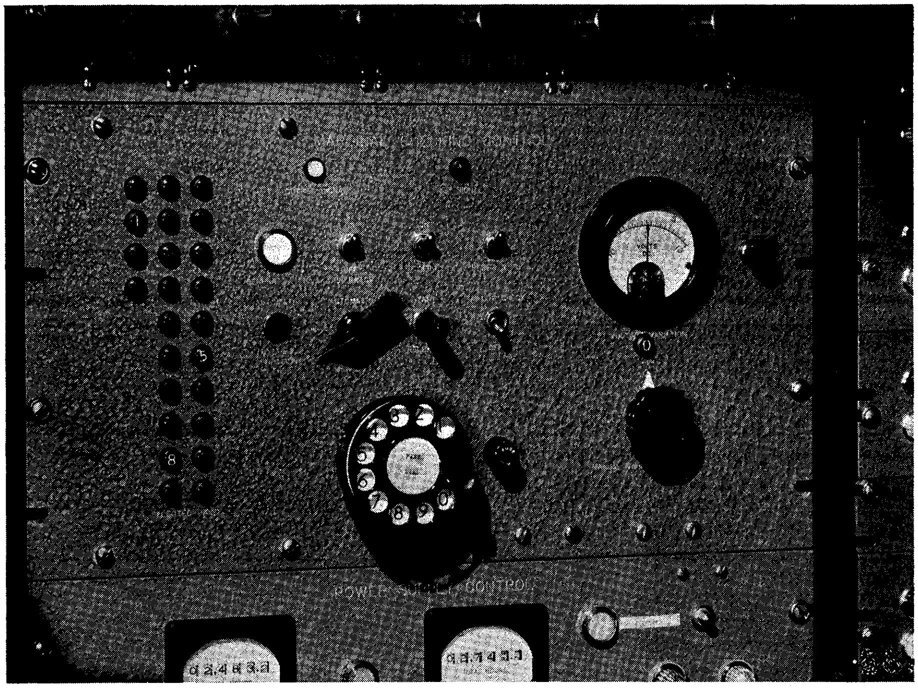

Fig. 5. Marginal checking control panel

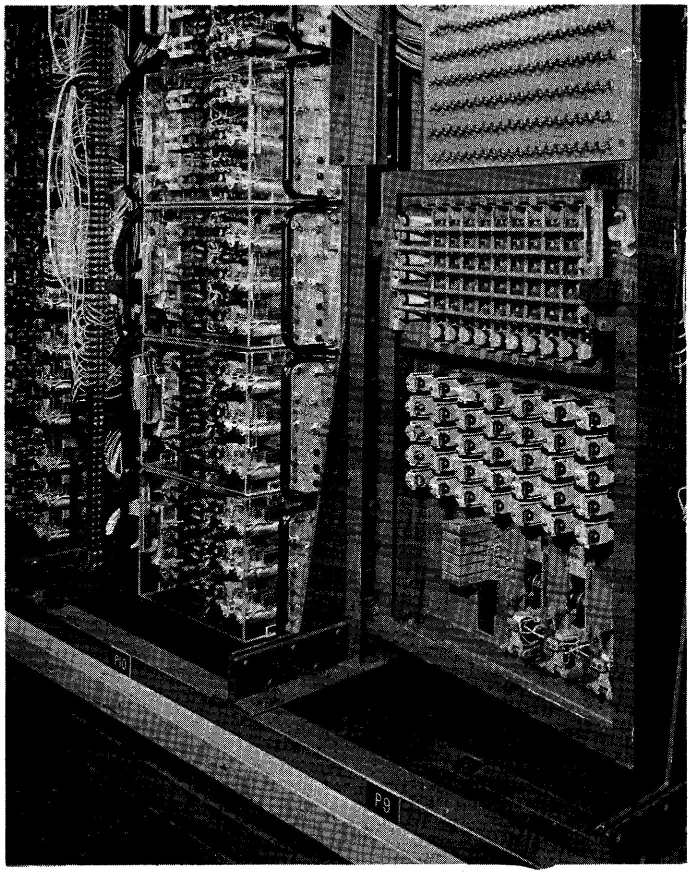

Fig. 6. Marginal checking relays