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"Relay Moe" Plays Tick-Tack-Toe

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relay moe plays TICK TACK TOE

By EDMUND C. BERKELEY*

ON the front cover of this issue of RADIO-ELECTRONICS appears a picture of an automatic relay machine which can play tick-tack-toe—or tit-tat-toe, as many prefer to call it—with a human opponent. This machine—which we call Relay Moe—is one of the more recent of twenty-odd small robots we have made in the last six years as a part of a scientific program of exploring the behavior of intelligent machines, with the help of part-time college students studying electronics or electrical engineering. (Two of them—"Simon," a miniature automatic digital computer made of relays, and "Squee," an electronic robot "squirrel"—appeared on the front covers of RADIO-ELECTRONICS in October, 1950, and December, 1951, respectively.)

Playing with Relay Moe

You can play tick-tack-toe with Relay Moe, if you want to, in our laboratory in New York City. (But please write us beforehand to request a date.)

If you wish the machine to play first, press the MACHINE-MOVE-FIRST button (see Fig. 1). Then the machine will choose a square and light a red light in it.

If you wish to play first, press the green button under the square that you choose. Then the square right above your button lights with a green light. The machine then starts its program of thinking, turning a plastic cylindrical drum (the timing drum) with associated cams which control the successive timing of the circuits; decides on its move and turns on a red light in some other square.

Then you can make another move. And so on.

If the machine wins, a red light is turned on in the top row of the board, red again indicating the machine. If the game is a draw, a white light is turned on in the second row at the top of the board. If you win the game against the machine, a green light is turned on in the third row, green again indicating the human player.

If you are disgusted with the way the game is going (or has gone) and want to start a new one, press the NEXT-GAME button at the bottom of the board, which cancels whatever is on the board and leaves the equipment ready to start a new game.

General layout

The general layout of the machine is shown in Fig. 1. It has been made in two sections, the display board and the main chassis (or "brain"). At the top of each one is a long handle, so that it can be moved around. The two sections are connected by two multi-wire cables and two large Jones plugs. The main chassis contains at its bottom a transformer and rectifier which convert 117-volt ac into 24-volt dc to operate some 90 relays, a motor, a stepper and other apparatus inside the main chassis.

Two groups, each including 9 of the 90 relays, correspond with the 9 squares of the board. One group records the machine's moves into any particular square of the board: the MM or Machine-Move relays. Another group of 9 relays corresponds with the human player moving into any particular square of the board: the PM or Player-Move relays. In parallel with the coil of each of these relays is a small red or green light, respectively. So, as each square on the display board lights up red or green, light of the same color goes on in the main chassis.

This is a rather striking parallel to results reported by a brain surgeon operating on a rabbit. As various parts of a rabbit's retina were stimulated with light, so various parts of its brain showed electrical excitation, reported in neon tubes, and the pattern of vision was roughly repeated in the neons.

The machine's strategy

Several different kinds of strategy are built into Relay Moe. One is *variable intelligence*. In the back of the main chassis are three horizontal cams, called the Machine Intelligence Cams, affecting three snap-action switches. These cams are plastic discs mounted eccentrically so that from time to time they close their switches and disable certain circuits to give the machine less than perfect intelligence. On such occasions the human player may win.

Some more details are shown in Fig. 2. As the cams revolve, four conditions—known as cases A, B, C or D—may prevail. In case A, which is the condition 52% of the time, the machine plays to win at all times; the human player can only lose or draw. In case B, 16% of the time the player can win every game. In case C the human player has a chance to win every time and in case D he may win under certain situations. Cases C and D each occupy 16% of the playing time.

Also in the main chassis are a set of Board Rotation relays. To make the machine strategy harder for a human player to guess, after every game the machine in its "computing mind" turns the board a random multiple of 90°. Of course, the board does not actually turn, but the machine thinks of it as turned. This prevents a human being from guessing quickly what is the machine's strategy or what sequence of moves it plays, because after each game the machine plays a randomly rotated strategy.

Thus the strategy of the machine is hard to guess and is different from game to game, and sometimes the human player has a chance of winning (see Fig. 2). This makes Relay Moe more fun to play a game with than if it were unvarying and always perfect.

Intelligence control does not affect the offensive and defensive machine moves. Thus the machine when playing defensively will always block a human player having only one set of two squares in a row by occupying an empty third square in the same row, and when playing offensively will always occupy an empty third square in a row if it already has taken two squares in that row. Diminution of intelligence only affects the machine when it has a choice of making a move not involving a decisive offensive or defensive play, *except* that in cases B and C, the machine will never choose to take the center square.

A full rotation of the intelligence control cams takes place once for every 60 games if the Board Rotating relays are switched to act.

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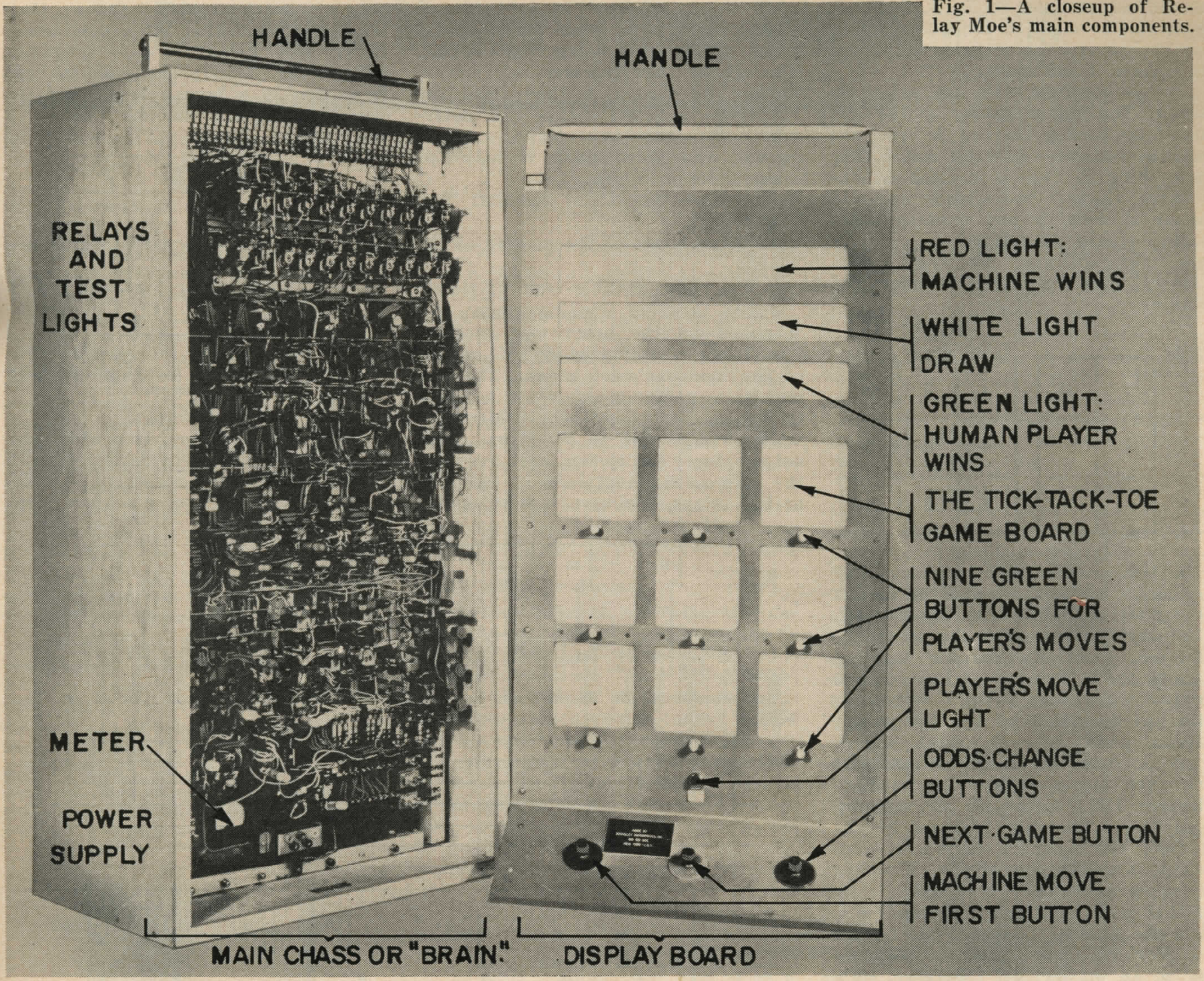
Fig. 1—A closeup of Relay Moe's main components.



The basic organization of the behavior of the machine is controlled by a Timing Drum, a large plastic cylinder with protuberances here and there which act as cams and close snap-action switches so that in a full cycle of the machine about 13 timed sources of current are used. These are identified as times A, B, C, D, E, (two each), and X, Y and Z (one each). Making use of these times, various circuits carry out their functions during every single machine cycle (see Fig. 3). The timing drum and the motor which turns it are located in the middle of the back of the main chassis (not visible in Fig. 1).

For example, the first thing that may happen is that a player may push a button under a square. This will happen at Resting Point time. If a moderately low resistance path from the button to ground exists and if the square selected is unoccupied, a sensitive relay is energized. This energizes another relay which then disconnects the sensitive relay and allows further steps in the operation of the machine to continue. After the player's move, the machine first searches for an offensive (winning) move, using the first set of times A, B, C, D, E of Fig. 3. Failing to win, the machine checks for a defensive (blocking) move, using the

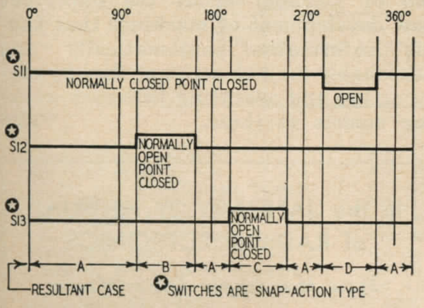


Fig. 2—The intelligence circuits. Rotation of the cams assures the machine's winning half the time; gives the player a chance the other half.

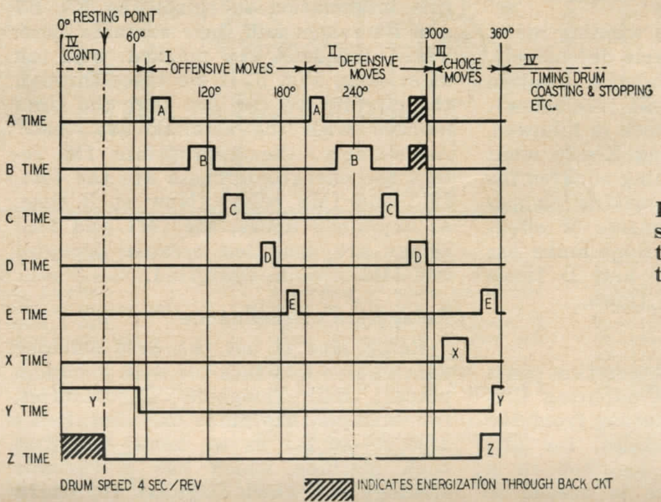


Fig. 3—Timing circuits set sequence of operations. These are controlled by switches on a drum.

second set of times A, B, C, D, E. If none can be made, a decision is made at X time and the machine plays the best move it can make.

Let us continue with the same example. The player having moved and the drum having reached A time, the machine considers effective moves. The first thing it does is to look at the squares which it has already occupied to see if there is any winning unoccupied square (the third square in a row, not occupied by the human player). For example, consider the position:

THE SITUATION

O		O
O	X	
X		X

KEY TO BOARD

1	2	3
4	5	6
7	8	9

In this position the machine (X) has played three times and the human player (O) has also played three times. The machine considers the situation, observing that its possible winning squares are 1, 3 and 8 as shown by the figures on the board at right. (The situation is examined by the Computing Circuit, which we will explain later.)

At A time, the machine considers and then stores in the Intermediate Memory (IM) relays all the winning squares (in this case, 1, 3 and 8). At B time the machine considers occupancy, cancelling out of the IM relays the squares already occupied (1, 3) so that only square 8 remains. At C time the machine selects a line (called the Machine Choice line), corresponding to an uncancelled IM relay, in a succession of choices in numerical sequence. Since there is only one square (8) not cancelled, the machine chooses that square and actuates Machine-Move (MM) relay 8. At D time, the machine checks to see if it has picked up any MM relay at C time. If so, it decides that it has won. Then the rest of the cycle is cancelled and the machine turns on the "Machine Won" light.

If the machine has no winning move, it uses the rest of the cycle defensively, putting the human player's position into the Computing Circuit (see below). The same strategy as above is followed, with the machine putting X's in what would otherwise be winning squares for the human player and making choices in the event of no defensive or offensive answer. These functions make use of the second A, B, C and D times and the E, X, Y and Z times.

Computing circuit

Perhaps the most interesting part of the machine is the Computing Circuit. It receives information from the MM relays and determines, for any two occupied squares together in a line, what third square is needed to make three in a row. If, as indicated above, there is no such move, the E pulse clears the computing circuit. The circuit then receives information during the second A time from the Player-Move (PM) relays and determines for any two player-occupied squares what third square is needed to make three in a row.

How does the circuit operate? Fig. 4 shows:

a The numbers of the squares of the board;

b The eight possible rows of three;

c The third or winning square determined by the other two squares. This is the situation which this circuit of the machine must handle. The circuit which performs this work is shown in Fig. 5. Here the B (branching-network) relays (B1 to B9), for which only contacts are shown, have received the information contained in the MM or PM relays, whichever are being examined. IM relays record the possible winning squares to be played in (or to be blocked) if possible.

Now let us look at Fig. 5 again. How is the position computed by the computing circuit? The machine (X) has played in squares 5, 7 and 9. Therefore this information energizes the B5, B7 and B9 relays and their contacts close. These contacts are marked with an asterisk in Fig. 5. If we trace through the circuit, we can see that the lines marked with the asterisk are "hot." Accordingly, the appropriate IM relays are energized. These are the IM1, IM3 and IM8 relays. Now at B time, as explained above, the IM1 and IM3 relays are concelled because occupied and IM8 remains energized.

Relay Moe's significance

Relay Moe is not the first machine which plays tick-tack-toe with a human player; Bell Telephone Laboratories, for example, has made one. But Relay Moe is—so far as we know—the first such machine which has a variable strategy and which disguises (by board rotation) what strategy it follows. Contrary to the very brief report about Relay Moe given in *Life* magazine (March 19, 1956), the machine can be beaten by a human being, and the percentage of the time he does so on the average can be varied widely by changing the cam settings.

THE EIGHT ROWS OF THREE	WINNING SQUARE	DETERMINED BY
1 2 3	1	2,3;5,9;4,7
1 5 9	2	1,3;5,8
1 4 7	3	1,2;5,7;6,9
2 5 8	4	1,7;5,6
3 5 7	6	3,9;4,5
3 6 9	7	1,4;3,5;8,9
4 5 6	8	2,5;7,9
7 8 9	9	1,5;3.6;7,8

Fig. 4—Information the machine uses in selecting winning moves or blocking the player.

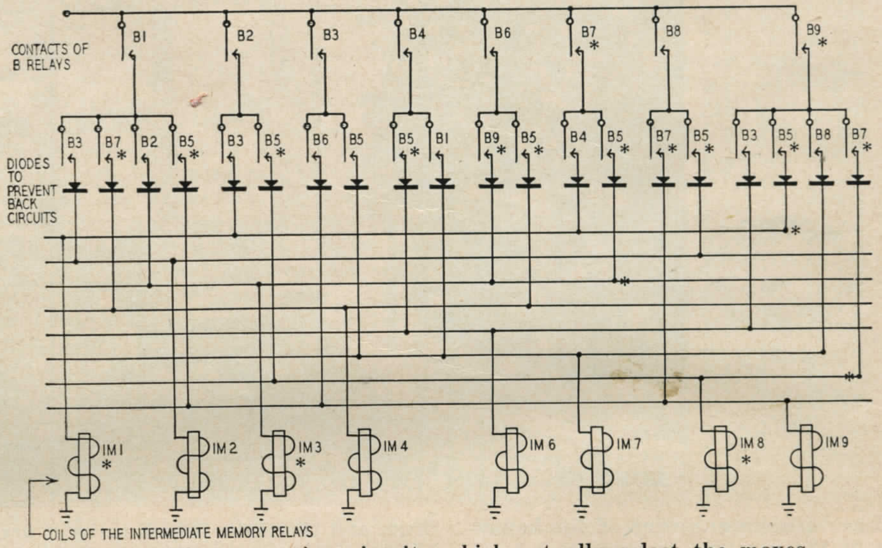


Fig. 5—The computing circuits which actually select the moves.

Relay Moe however has a wider significance, as one of our series of small robots (computing, reasoning, puzzle-solving, game-playing machines, etc) of different types and capacities. We plan to make (and are making) many kinds of small machines and robots that display intelligent behavior. They range from the Geniac and Tyniac (two "tiny genius") electric brain construction kits (finished) up to a simple automatic electronic digital computer using transistors called Simplac (not finished).

We think that a good part of the job of learning about the important new development of machines that handle information automatically and reasonably may be accomplished by constructing and operating just such working models as these. END