AN ELECTRO-MECHANICAL FLIP-FLOP WITH APPLICATIONS TO COUNTING, TIMING AND RANDOMIZATION¹

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The flip-flop described is functionally similar to one described by Hendry and Perry (1962) but uses fewer relays. Relays A and B, shown in Fig. 1, will be in one state after an odd number of operations of input relay (relay I) and in a second state after an even number of operations of relay I. Beginning with a situation in which none of the relays are in operation, the system works as follows: (a) Operation of relay I operates relay A through NO of relay I and NC of relay B. (b) Release of relay I holds relay A through its own NO contacts and NC of relay I. It also operates relay B through the same contacts; the diodes isolate relays A and B in all phases except for the present one. The net result is that a single operation of relay I (both activation and release) leaves both relays A and B in an operated condition. (c) A second operation of relay I removes ground from relay A and releases it, but relay B remains in operation because it receives ground through NO of relay I and NO of relay B. (d) Release of relay I returns relays A and B to an unoperated condition by removing ground from NO of relay B. Thus, a second operation of relay I returns the system to its original state. The system can be made to reset almost instantaneously, regardless of the stage it is in, simply by removal of ground from common of relay I.

Form D contacts (make before break) are used in relay I of Fig. 1 because they ensure that the flip-flop will function properly as long as its component relays function properly in ordinary applications. If the more usual form C contacts (break before make) are used, the properties of the component relays must be such that the following two types of conceivable malfunction do not occur. In stage

(b) of the flip-flop operation as described above, a malfunction will occur if the NO contact of relay A releases before the NC contact of relay I makes: both relays A and B will be released at the end of this stage instead of in operation. A similar malfunction will occur if, in stage (c), NO of relay B releases before NO of relay I makes: in this case, stage (c) will end with relay A in operation instead of relay B. These considerations imply that form C contacts may be used in relay I if, and only if, the time required for relay A or B to release is greater than the switchover time for the contacts of relay I. For the contacts shown

Fig. 1. A flip-flop circuit. The contacts of relay I are form D (make before break); for those unfamiliar with this symbol, common is connected to ground, NO is connected to common of relay B, and NC is connected to common of relay A. Spark suppression is not shown, although it is desirable.

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on relays A and B in Fig. 1, either form C or form D may be used.

The system shown in Fig. 1 has been tested using Clare type J relays with a 500 ohm coil and two form C contacts. When the power was between 1.0 w (22 v) and 2.4 w (35 v), the highest failure rate was one per thousand operations of the input relay. When new relays were used, there were usually no failures in 100,000 operations. The spark suppression used was 1.0 mfd in series with 220 ohms connected from the ground terminal of each coil to ground itself. Release time of the coil was thus not delayed and in view of the possible malfunctions described above, test conditions were as unfavorable as could be obtained. Reliability is bound to be greater with a method of spark suppression which delays the release of relays A and B. If the 1.0 mfd-220 ohm spark suppression system described is connected in parallel with the coil instead of as described, it will delay release of a 500 ohm type J relay by 3 msec when the relay is operated at 1.4 w (27 v). Spark suppression by means of a diode will produce a still greater delay. Placing an indicator light in parallel with the coil will produce a delay of from 10 to 25 msec; this is a risky procedure because the indicator light may burn out. It appears, therefore, that Clare type J relays will be satisfactory unless a high speed flip-flop system (over 15 operations of the input relay per sec) is desired. The search for a relay which will not work well in the system shown in Fig. 1 has been unsuccessful, although perfunctory, and reed relays have not been tested.

A Binary Counter

Consider an additional set of contacts on relay A in Fig. 1. From the logic of the flip-flop, these contacts will switch from NC to NO and return to NC once for every two such cycles made by the input relay. Therefore, if these contacts on relay A are used to operate a second flip-flop, that flip-flop will go through a complete cycle once for every two cycles made by the first flip-flop. Thus, a second binary digit can be added to the system. The second binary digit can, in turn, operate a third flip-flop and so on. A binary counter can thus be constructed. It can be reset nearly instantaneously by removal of ground from the common of each set of contacts used as an input to operate a flip-flop.

Timing

Figure 2 shows how an input relay, much like relay I of Fig. 1, can be made to operate 60 times per sec by rectification of 110-120 v ac, 60 cycles. By means of successive flip-flops as described above, this pulse rate can be successively halved to produce 30, 15, 7.5, etc., operations per sec. If this system is to be accurate, both the input relay and the first two flip-flops must consist of extremely fast-acting relays, and contacts used to supply inputs must be form D. An extremely long operating life is necessary since a relay operated 60 times per sec will be operated 216,000 times per hr. The mercury wetted contact relays manufactured by C. P. Clare (HG series) and by Potter and Bromfield (JM series) fit these requirements; experience supports C. P. Clare's claim that these relays have a life expectancy of over a billion operations. In Fig. 2, Potter and Bromfield JM 1-119-11, which has a 4000 ohm coil, is shown in series with a 4000 ohm resistor. A relay of this resistance costs less in small quantities than a 17,000 ohm relay, which could be used in this circuit without a series resistor, provided the value of the capacitor shown in Fig. 2 was reduced to .1 mfd. The capacitor and resistor are designed both to suppress sparks and to insure that any operation of the input relay will be of sufficient duration to change the state of the first flip-flop even if the ac current is interrupted just as the input relay makes.

The advantage of such a system for digital recording of latencies on read-out or print-out counters is that its accuracy, based on the accuracy of 60 cycles line power, is probably greater than can be obtained with the cheaper

Fig. 2. A control relay supplies rectified ac so that a 4000 ohm input relay with mercury wetted contacts will operate 60 times per sec.

lines of electronic timers. Calibration is unnecessary and the aging of components should not change the timing characteristics unless a mercury wetted contact relay fails. A failure should be obvious rather than gradual.

Randomization

Consider a flip-flop operating rapidly in the absence of a response. Suppose the operations stop when the response is emitted and that the response is random with respect to the parity of the number of operations of the flip-flop during the inter-response interval. If so, the flip-flop is equally likely to be in one of its two states during any response, which produces a simple randomization device. Such a device, which operates at 60 cycles per sec, is described.

NC of a response relay operates an input relay at 60 operations per sec in the same way in which NO of a control relay operates an input relay in Fig. 2. The input relay operates a flip-flop as shown in Fig. 1. Thus, whenever the response relay is operated, the flip-flop will be in one of its two states. All that is needed, then, is a method by which to detect which state the flip-flop is in while the response relay is operating. If the response relay has two NO contacts in addition to its NC contact, one set of contacts can be connected to NO of relay A and the second pair can be connected to NC of relay A as shown in Fig. 1. Thus, with each operation of the response relay, exactly one of its NO contacts will transmit ground. If the time intervals between operations of the response relay are random with respect to the parity of the number of operations of the input relay (pulsing at 60 operations per sec), the result will be a true probability generator.

Two such units have been operated by rats and no significant deviation from random equiprobability was apparent over about 16,000 trials; the obtained values were .497 and .502. A later test over about 60,000 trials after the units were in operation 22 hr a day for about six months yielded probabilities of .506 and .502; the former probability inexplicably differs from chance at the .001 level. If such a small deviation is likely to affect results, reversing the roles of the outputs of the systems every second operation of the response relay by means of a stepping switch or two stage flip-flop system should eliminate this problem. The advantage of this system over

one described by Harley (1961) is that resistors and capacitors are not parameters of the system to create both calibration and aging problems. The all-or-none nature of the system ensures relatively exact probabilities without any extended empirical test. By means of a two-stage flip-flop, the system can yield four equally probable outcomes, although it has not been tested in this form.

Another Type of Flip-Flop

The flip-flop shown in Fig. 1 requires form D contacts on its input relay. As explained above, form C contacts may be substituted under certain conditions; empirical evidence was supplied that the conditions permitting form C contacts are present in many relays frequently used in operant conditioning laboratories. However, some experimenters may desire a flip-flop which will operate reliably with form C contacts whether or not these conditions are present. Such a flip-flop is described below. Its disadvantage is that it requires more materials than the flip-flop shown in Fig. 1 and the component relays must be mounted in a fashion unusual in operant conditioning laboratories.

Figure 3 shows the basic principles governing the function of each relay in the flip-flop. Between the positive terminal of the relay coil and the positive end of the power supply is a diode and a resistor; resistance of the resistor must be low enough to permit the relay to operate reliably at the supply voltage if switch O (operate) is closed and switch I (inhibit) is open; its wattage must be great enough to permit extended closure of switch I. This is how the relay shown in Fig. 3 works. If switch O is closed, the relay will operate unless switch I is closed. If switch I is closed, the relay cannot possibly operate because there can be no voltage drop across it, regardless of the condition of switch O. Thus, if the relay is in operation, closure of switch I will release it regardless of the state of switch O. For these reasons, closure of switch I may be said to "inhibit" the relay.

Fig. 3. A relay mounted so that closure of Switch I prevents it from operating.

Fig. 4. Another type of flip-flop. The relays shown are Clare type J, 500 ohms, DPDT. Spark suppression of the relay coils, although not shown, is desirable. The resistors used should be relatively noninductive.

Figure 4 shows a flip-flop based on the principle shown in Fig. 3. It works as follows, beginning with a situation in which neither relay is in operation and the input switch is open. (a) Closure of the input switch sends ground through NC of relay B; this ground operates relay A and "inhibits" relay B by application of ground to its series resistor. When relay A operates, it transmits ground through its NO both to its own coil and to the coil of relay B, but relay B does not operate because it is simultaneously "inhibited". Thus, only relay A is in operation. (b) Opening the input switch removes the "inhibition" from relay B. Thus, both relay A and relay B are operated through NO of relay A. (c) A second closure of the input switch sends ground through NO of relay B. This ground "inhibits" relay A by

application of ground to its series resistor and holds relay B. Thus, only relay B is in operation. (d) Opening the input switch returns the system to a state in which neither relay is in operation by removing ground from relay B.

This flip-flop has not been tested as extensively as the flip-flop shown in Fig. 1, but it did not fail in 200,000 operations at 27 v. A Clare type J relay with a 300 ohm coil could be expected to operate better in the circuit shown in Fig. 4 because it would receive about 1.3 w of power rather than the 1.0 w which the 500 ohm coil receives.

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