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Comprehensive Measurement System for Electromechanical Relay

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ABSTRACT

The use of electromechanical relays in automatic testing equipment to switch signals to specified connections experience stress and electrical arcing. In order to verify that these components are the cause of hardware failure, it is necessary to properly validate their performance and mechanical life. However, measuring the coil resistance and contacts continuity will be insufficient. In this paper, a comprehensive measurement system for electromechanical relays is presented that could measure the coil resistance, contact resistance, and set/reset time when energized using designed auxiliary circuits. In addition, the bouncing of switch was investigated as another parameter for the performance and mechanical life of electromechanical relays.

Key words: coil resistance, contact bounce, contact resistance, edge interrupt, electromechanical relay, multiplexer

1. INTRODUCTION

Most of the Integrated Circuit (IC) manufacturers use Automatic Testing Equipment (ATE) to measure voltage, current, and other signals to and fro from the device under test (DUT). ATE has three major parts, namely, the tester, the handler, and the Device Interface Board (DIB). Between the testers and handlers is an interface called the final test printed circuit board (PCB), which is a multilayered construction composed of copper as conductors and substrate materials as insulators for all interconnections. It also houses electronic parts such as resistors, capacitors, conductors, diodes, ICs, electromechanical relays and etc.

There are thousands of ATE boards being used in a semiconductor testing facility. Most of the semiconductor companies has ATE-PCBs in which 81.25% of it is composed of electromechanical relays as in the case of Analog Devices Inc. (ADI) and other companies. The tests are halted when one of these relays malfunction. The test equipment is withdrawn for circuit analysis and verification. This becomes a downtime for the test processes. A case study was conducted and results presents 28,526 incidents of repair due to failure in a year. About 11 % of these incidents are from faulty or defective relays.

This study aims to provide a compact solution for a quick relay system for repairing PCB assembly on the manufacturing line. Knowing that relays cannot be tested when installed on PCBs and are connected to other circuits, one cannot pull them out just to test them. ATE PCBs are put back into the test head and run a component diagnostic or board checker, which requires loading of the whole test program. Aside from contact and coil test, this study presents tests for reaction time for energizing coils with consideration of the bouncing effect of switching. A compact prototype is developed to validate the application of such principles. As a benefit, the developed measurement system will help technicians on maintaining the ATE PCBs on the production line and is expected to resolve the problem on electromechanical relay switching stress and electrical arcing.

1.1 High Speed Testing of Electromechanical Relays

Electromechanical relays play major roles in the control system of different application of electrical and electronic products. Products becomes more competitive, therefore, there should be continuous innovation for this technology. High quality demands for these devices should be assured to decrease downtime and to be more efficient in the production [1].

The electromechanical relays are made up of coils of wires, magnet, and contacts. These parts are checked, for which, the lifespan and the performance of the device can be predicted or easily identified. High speed testing systems were also developed in which additional time parameters are considered and automated using virtual instrumentation technology. This technology is called four-terminal current and voltage method [2-3].

The performance of the relays in relation to the low current and high voltage requirements can be analyzed through the use integrated systems. These systems use computers with developed software specifically for these types of tests [4]. Today's technology gears toward mobility, therefore convenience in work areas are needed for efficiency and productivity. ATE PCBs can be designed with microcontroller unit which controls and maintains the important digital features of such devices [5].

1.2 Four-terminal Method

The four-terminal method is an effective and stable way of measuring contact resistance. This method uses simple equations, as in Eq. (1-2), to calculate the voltage drop on a sample circuit presented in Figure 1, where R_s is the known resistance, R_x, the contact resistance, I_m, the circuit current, and V_s, as the voltage drop across the known resistance.

$$R_x = \frac{V_x}{V_s} R_s \tag{1}$$

$$I_m = \frac{V_s}{R_s} \tag{2}$$

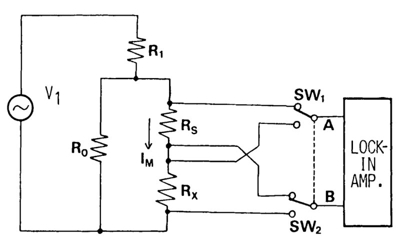


Figure 1: Measurement circuit for contact resistance [2]

1.3 Resolving bouncing and arcing between contacts

Bouncing and arcing between contacts are being studied because it highly degrades the performance of relays and has become one of the common causes of its failure [6]. These things can also be measured and used in order to predict or analyze the behavior of the electromechanical relays [7-8]. Diversion from the common characteristics of bounce and arcing can be a source of intelligence for assuring good quality performance of such devices.

2. METHODOLOGY

2.1 Relay Testing Process

The relay testing system developed in this study is broken down into three procedures: (1) Coil Resistance Test; (2) Contact Resistance Test; (3) Operating Test (or the Set and Reset Time) with analysis of bouncing characteristics. The working system flow diagram is presented in Figure 2. During the coil resistance test, the coil is energized in order to measure the time parameters or the set and reset time. The contact resistance is verified whether it meets the required range of resistance values based on the data sheet specifications. The measurement system uses lithium ion batteries as the source for the instrumentation amplifier reference sourcing for relay tests. A multiplexer is used to lay down the connections of the relay terminals for the resistance test. The difference between the reference and the signal form the DUT is amplified and processed by a 16-bit ADC to digitize to a resolution and accuracy of about 65535.

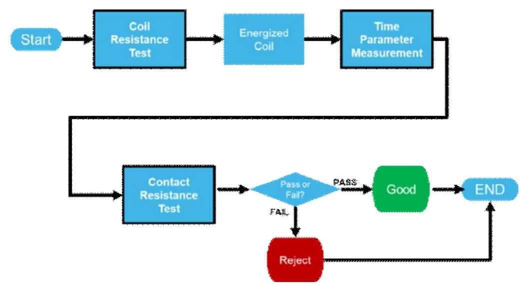


Figure 2: Relay Test System Flow Diagram

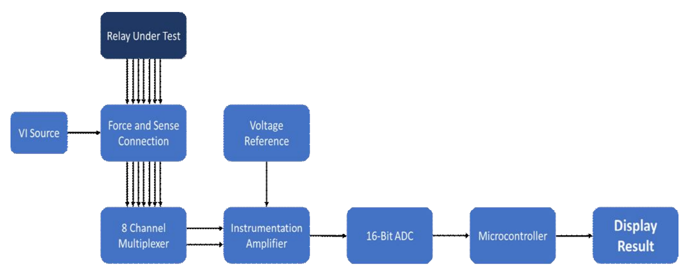


Figure 3: Relay Test System Configuration

The measurement system uses lithium ion batteries as the source for the instrumentation amplifier reference sourcing for relay tests. A multiplexer is used to lay down the connections of the relay terminals for the resistance test. The difference between the reference and the signal form the DUT is amplified and processed by a 16-bit ADC to digitize to a resolution and accuracy of about 65535.

2.2 Coil Resistance Test

The coil has a known resistance R_s which is connected in series with an unknown contact resistance, K_s. The current that is measured in terms of voltage drop across R_s is the circuit current I_m. (See Figure 4). The working equations in this circuit can be derived as follows:

$$V_{RS} = Voltage\ Across\ R_s$$

$$I_s = \frac{V_{RS}}{R_S} \quad (3)$$

$$I_X = \frac{V_X}{R_X} \quad (4)$$

$$\frac{V_{RS}}{R_S} = \frac{V_X}{R_X} \quad (5)$$

$$R_X = \frac{V_X R_S}{V_{RS}} \quad (6)$$

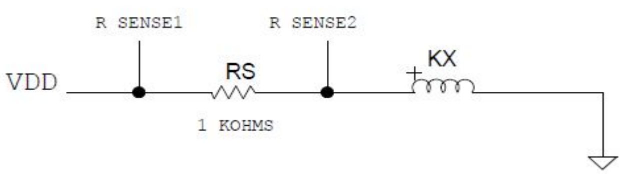


Figure 4: Relay coil resistance measurement configuration

2.3 Contact Resistance Test

Every relay contact has allowable maximum contact resistance. The manufacturers of electromagnetic relays specify these resistances. (See Figure 5). The relays used as an example in this study have contact resistance at about 100 mΩ. It is intuitive to use precise measurement system in order to correctly verify the condition and performance of the relay. It is also important to note that most of the multi-meters has its own internal resistance that needs to be considered in measuring resistances. To address this, a force-sense connection is done using additional sense resistor (RS) 2, of 1kΩ. The 15Ω RS1 is established as reference for the known resistance. The corresponding equivalent voltage drop and current passing across this resistor can also be calculated in this series configuration. In this setup, the measurement can be precisely done. (See Figure 4b).

■Characteristics

Relay Function / Item	Single-side stable models		Single-winding latching models
	G6K-2F, G6K-2G, G6K-2P	G6K-2F-Y, G6K-2G-Y, G6K-2P-Y	G6KU-2F-Y, G6KU-2G-Y, G6KU-2P-Y
Contact resistance *1	100 mΩ max.		
Operating (set) time	3 ms max.		
Release (reset) time	3 ms max.		

Figure 5: Contact Resistance (OMRON relays data sheet)

2.4 Response Time Measurement Test

The response time is an important characteristic of the relay which is influenced by timing structure which refers to the elapsed time during the open and close of the contacts upon energizing and de-energizing of the relay coil. There are two classification of response time; the operating time, which is the time interval from energizing the coil until the contacts switches states; and the release time, in which is goes back to its normal position when de-energized. This is illustrated in Figure 6 (Note that this figure does not include the bounce).

The intermittent switching of the relays upon energizing the coil results is called bouncing which is a result of the mechanical movement of the system. This has been illustrated in Figure 8.

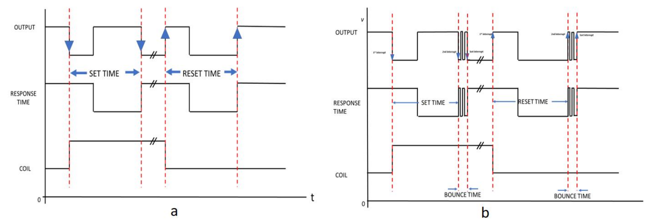


Figure 6: (a) Ideal relay traces during measurement. (b) Traces of time measurement with interrupt

2.5 Interrupt Method

The quick response time of the switching of the relay can be measured using the interrupt method with synchronized time to the CPU clock. In this setup, 2MHz frequency is used based on controller specifications. As an example, the measurement of the response time based on edge interrupts are presented in Figure 6. The small duration of the presence of these bounces are measured starting from its rising edge to its falling edge. About 32 milliseconds timeout for each switching open and close contacts was observed.

To illustrate further, the whole process of response time measurement is presented in Figure 7. The timer is initially set to zero. When run, the maximum switching count that could be reached by the system is 65535 which is approximately 32ms measurement duration.

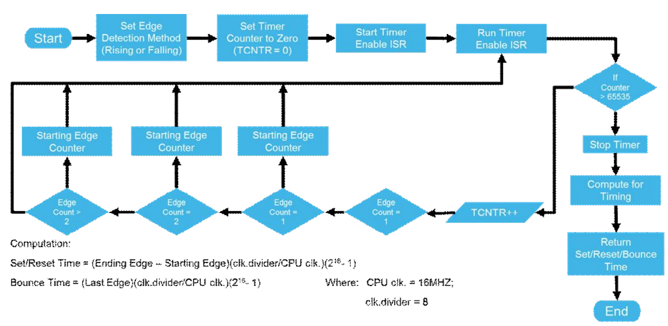


Figure 7: Edge interrupt process flow

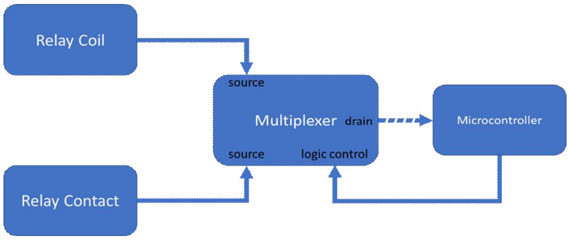


Figure 8: Multiplexer Configuration

2.6 System Configuration

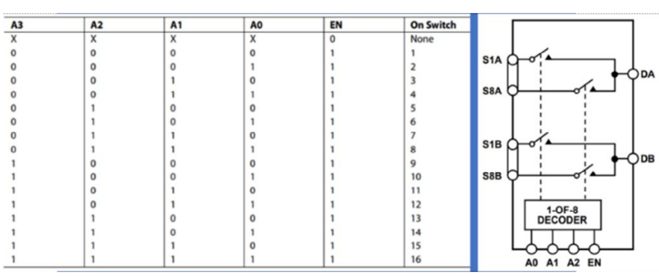
The system for measurement is composed of the force and sense circuit, the multiplexer, instrumentation amplifiers, 16-bit ADC and microcontroller unit (MCU). Each part is discussed as follows:

A. Force and Sense Configuration

It is a four-terminal current and voltage method which is used to ensure an accurate measurement for the coil and contact with the use of small value RS1.

B. Multiplexer

The Multiplexer in this research is used for isolation of multiple switches to separately test the relay coil and the contacts. Coil resistance test is conducted first before the contact test. These are programmed in the MCU to be sequentially and repeatedly done, ensuring that the relay is in functional mode. (See Figure 8). It is setup in an eight-differential type to allow two source signals to be switched simultaneously. Four logic input pins (A0-A3) and a digital input enable (EN) pin is used to control the differential switch. The different combinations of these logic input pins and EN pin are presented in a truth table in Figure 9. A minimum input voltage of 2V is required to enable the logic and digital pins. The source used for the high voltage input is the built-in MCU supply.



A3	A2	A1	A0	EN	On Switch
X	X	X	X	0	None
0	0	0	0	1	1
0	0	0	1	1	2
0	0	1	0	1	3
0	0	1	1	1	4
0	1	0	0	1	5
0	1	0	1	1	6
0	1	1	0	1	7
0	1	1	1	1	8
1	0	0	0	1	9
1	0	0	1	1	10
1	0	1	0	1	11
1	0	1	1	1	12
1	1	0	0	1	13
1	1	0	1	1	14
1	1	1	0	1	15
1	1	1	1	1	16

Figure 9: Logic combination and switching schematic diagram (Analog Device ADG409 Datasheet)

C. Instrumentation amplifier and voltage reference

The instrumentation amplifier used in this project is composed of 3 operational amplifiers in differential configuration method. (See Figure 10). This is designed and tuned based on the calculated gains to achieve optimum conversion of signals. (See Table 1 for reference). Eq. 7 is used to compute the gain based on the given resistance R_G. A stable voltage source is supplied to the REF pin where the instrumentation amplifier offsets the voltage to ensure accuracy.

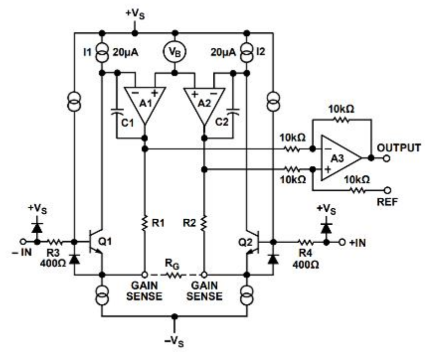


Figure 10: Instrumentation amplifier architecture (Analog Device ADG7680 Datasheet)

Table 1: R_G values of calculated gain

1% Std Table Value of R_G(Ω)	Calculated Gain	0.1% Std Table Value of R_G(Ω)	Calculated Gain
49.9 k	1.990	49.3 k	2.002
12.4 k	4.984	12.4 k	4.984
5.49 k	9.998	5.49 k	9.998
2.61 k	19.93	2.61 k	19.93
1.00 k	50.40	1.01 k	49.91
499	100.0	499	100.0
249	199.4	249	199.4
100	495.0	98.8	501.0
49.9	991.0	49.3	1003.0

$$R_G = \frac{49.4k\Omega}{G-1} \quad (7)$$

D. 16-bit Analog-to-Digital Converter (ADC)

The measurement system used a 16-bit ADC for greater accuracy rather than the built-in 10-bit MCU ADC.

E. Control circuit

The signals passed on ADC is sent to the controller for the computation of the coil and contact resistance of the DUT. (See Figure 11). Equations 3-6 are used and programmed in the MCU. This can also be monitored in a serial display.

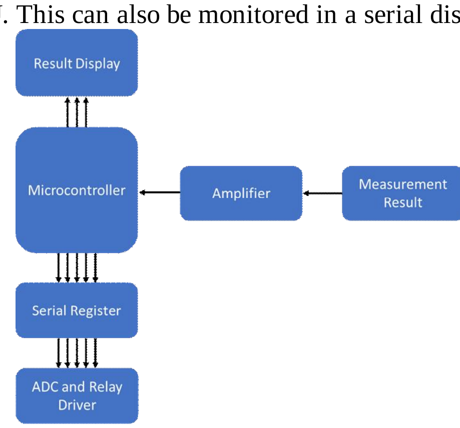


Figure 11: Control Diagram

2.7 Validation Parameters

A series of test points are located to manually verify the circuit when the relay coil is energized. These test points are presented in Table 2.

Table 2: Troubleshooting test points

Test Point	*Remarks*	*Parameters*
1	Vref IC Output	Output must be 3V
2	Inverted Voltage Reference	Output must be -3V
3	Booster Converted Module	Output must be +12V
4	Drain Pin A of Multiplexer	When Energized, the TP4, TP5, and TP6 must be equal
5	Drain Pin B of Multiplexer	
6	Sense Pin Common	

3. RESULTS

3.1 Coil Resistance Test

The actual coil resistance measured using the designed measurement system was compared to the datasheet provided. Diversion from the specifications imply possible malfunction on the DUT. Figure 12 presents the result of the readings from the measurement system while being compared to the datasheet specified parameters. A difference of 5Ω or 2.1% error was observed which means that the DUT is in tolerance and in good working condition because this resistance value does not exceed to the maximum operating voltage, as shown in the data sheet, 80% maximum. The same maximum percentage applies to the resistances because of its direct proportion to voltage.

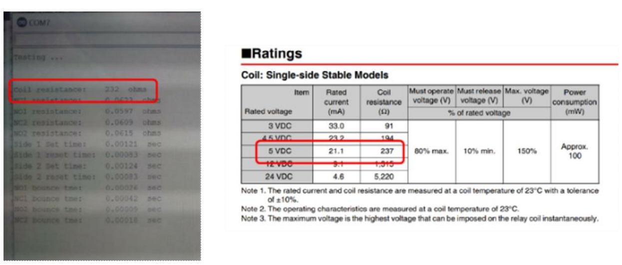


Figure 12: Actual output reading from the measurement system for relay coil resistance test compared to parameters based on specifications.

3.2 Contact Resistance Test

The results show small changes which are crucial for contact resistance test at 34 ±2% error in milliohms measurement. However, at these ranges of error, this does not affect the performance of the electromechanical relay since this comparison is based on the maximum value only as specified on the data sheet. (See Figure 13).

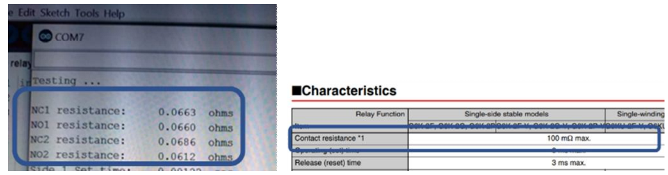


Figure 13: Actual output reading from the measurement system for relay contact resistance test compared to parameters based on specifications

3.3 Response Time Measurement

The measurement of the response time is best validated through the use of digital oscilloscope. A maximum allowable set and reset time of 3ms according to the specifications given are used as reference. A lot-testing for 50 units of a particular relay specified has an average of about 1.5ms for both set and reset time. (See Figure 14). Surprisingly, the response time performance is better in the actual measured relay response time. For 30 good samples, the results show that there is a range of set time about 1.2 to 1.4 ms. and a reset time of 0.79 to 0.84 ms. (See Figure 15) which were verified using an oscilloscope. (See Figure 16). It is similar to the sample shown in Figure 14.

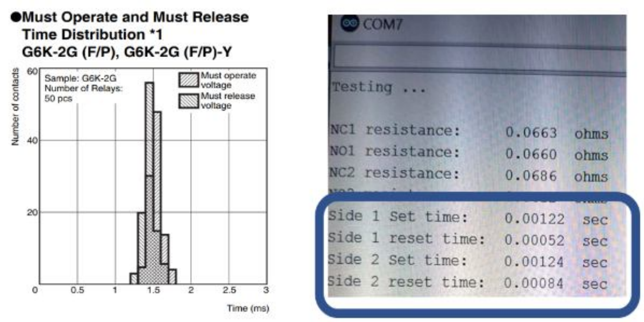


Figure 14: Distribution graph showing the set and reset time of relay compared with the actual response for a single relay.

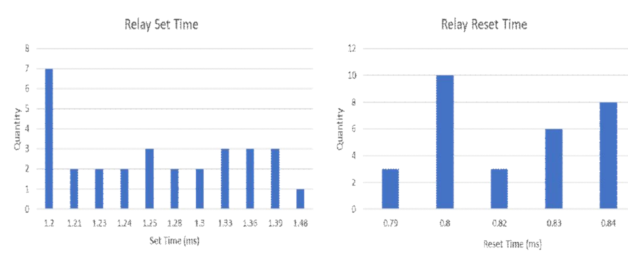


Figure 15: Set and reset time detected using the measurement system for 30 samples

Figure 16: (a) signal verification on oscilloscope (b) bounce time detection

The bounce effect was also considered on the measurement although there is no bounce time specified in the datasheet. The bounce time was measured by the system, running at 260 to 271µs at normally open state in the rising edge for a single contact in the relay, as presented in Figure 16. The bounce can be sought as one potential parameter for the test and measurement of electromechanical relays.

5. CONCLUSION

The comprehensive measurement system for testing electromechanical relays presented in this study used the method of coil resistance test, contact resistance test, and response time test with bounce analysis, which are parameters for determining the condition of the electromechanical relays. The specifications provided on the data sheet were achieved and verified through the measurement of contact and coil resistance even when the DUT is in the PCB considering that the coil resistance changes resistance when energized. For different electromechanical relay models, parameters may vary, and therefore, the system settings should also be changed. Verifications for the response time were done using digital oscilloscope. The measurement system designed can be used to repair and verify hardware components without pulling it out from the board in the production line. This measurement system can be used as a classification system for good and bad units. The bounce characteristics can also be further studied as a parameter for in the classification system. This classification system with these parameters can then be thought intuitively to be incorporated in a single system of measurement and detection.

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