Improving the Reliability of Dry-Reed Relays

Abstract

Two unique tests are examined that can improve the reliability of dry-reed relays used in ATE equipment. These tests examine the quality of the contact surface to predict early life failures, and results are demonstrated through life testing.

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Magnetostrictive Twist and RDEL

The reliability of dry-reed relays can approach or exceed that of electronic components in many applications. Two parametric tests have shown considerable accuracy in predicting early life failures. These tests are called the magnetostrictive twist test (Twist) and the contact resistance stability test (RDEL).[i] These tests examine the contact quality to make life expectancy predictions. Contacts that are smooth, clean, and well aligned will provide superior long-term reliability.[ii]

What is Magnetostrictive Twist?

Dry-reed relays are constructed using a cantilevered beam switch enclosed in a hermetically-sealed glass ampule. The ampule is placed inside a coil, attachments are made to the lead frame, and the entire unit is potted in plastic. The reed switch is built using a ferromagnetic material, usually a nickel/iron alloy. The cantilevered switch is designed to come together in the presence of a magnetic field of a specified magnetic force.

The Twist test is designed to allow contact resistance measurements to be made over various portions of the contact surface. In qualitative terms, the switch is held loosely closed by reducing the coil current to just above the dropout point. While the switch is held lightly closed, the current through the contact is varied in both magnitude and direction. The countering forces from the magnetic field produced by the coil and the magnetic field from the current passing through the reed contacts cause the reed blades to slightly rotate. A series of contact resistance measurements are made, and these numbers are compared to the contact resistance measurements that are taken with nominal coil current (value that tightly holds the contacts together).

A Quantitative Look at Twist

The internal magnetic forces are calculated for a standard Form A reed switch in a SIP package. The physical dimensions are 1 inch in length and 0.3 inch in width. The coil that surrounds the switch has two thousand turns and is 0.8 inches in length. The field strength at the center of this coil can be calculated in Amps/meter by the following simple formula:

$$H = NI / L$$

where
- H = magnetic force in Amps/meter
- N = number of turns
- I = current in Amps
- L = coil length in meters

The dropout current (point where the contacts open) is measured for each relay under test. The magnetic force produced at this point is equal to the mechanical spring tension of the contacts. For the device in this study, the dropout current was approximately 9 mA. After this value was measured, the Twist range was determined by adding a fixed current to the dropout current. This value is typically determined by experimentation and varies for each type of reed relay. In this example, the value was determined to be 3 mA. The incremental force from this Twist current is calculated by the following formula:

$$\Delta H = \frac{N}{L}(Itwist - IDO)$$

The magnetic field strength from the coil is calculated as follows:

$$\Delta H = \frac{(2000 turns)(0.003 Amp)}{(0.019 meter)} = 316 A/m$$

The second factor in the Twist measurement is the magnetic field produced from the current flowing through the closed contacts. A typical value for the current used in this measurement is 100 mA. The equation for calculating the magnetic field at a point distance r from the center of a wire is given by the following formula:

$$H = \frac{I}{2\pi r}$$

where

H = magnetic force in Amps/meter
I = current in Amps
r = distance from center of wire

For a contact beam diameter of 0.56 mm, the magnetic force for r = 0.28 mm is calculated as follows:

$$Hw = \frac{0.1Amp}{(0.28x10^{-3}\ meters)2\pi} = 56.8A/m$$

From these calculations it can be seen that the magnetic force from the Twist current in the coil is 316 Amps/meter, and the magnetic force for the current flowing through the contacts is 56.8 Amps/meter. The magnetic force from the contacts is approximately 18% of the force holding the contacts closed. Contact resistance measurements are made at incremental points while the twist current is varied by +/-30%. The ratio of magnetic force between the contact and the coil is modulated from approximately 13% to 23%. Contact resistance measurements are obtained from different areas of the contact surface as the reed blades are twisted.

Why Does the Twist Measurement Work?

The Twist measurement is performed at low contact forces and looks for contact surface irregularities and particle contamination. These conditions result in non-uniform contact resistance readings across the contact surface. Life test studies have demonstrated that contacts with high Twist readings have a reduced life. The Twist measurement will pick out potential problem relays, even when all other electrical parameters are well within the specification ranges.

For the parts in this study, the mean for the contact Twist measurement was 70 milliohms, with a standard deviation of 21 milliohms. Typically, 1% of a tested lot is rejected for the Twist test, with a limit set at 155 milliohms (4 sigma over the mean).

What is RDEL, and Why Does It Work?

The RDEL test looks at the stability of the contact resistance measurement. A single measurement of contact resistance will provide a resistance value, but it will not tell you if it will change with repeated closures due to contact self-heating or contamination. The RDEL test takes repeated contact resistance measurements with multiple cycling of the contacts between each measurement. Typically, the contacts are cycled five times prior to a measurement. This is repeated ten times, so that the contacts are cycled a total of fifty times, and ten contact resistance measurements are recorded. The maximum and minimum readings are compared, and the difference is RDEL. High-quality contacts will show very repeatable measurements, typically around 1 to 2 milliohms for a nominal contact resistance of 50 milliohms. For the parts in this study, the mean was 1.5 milliohms, with a standard deviation of 1.0 milliohm. Typically, 0.1% of a tested lot is rejected for the RDEL test with a limit set at 6 milliohms (5 sigma over the mean).

Life Test Studies

Life test studies were performed with populations of Twist and RDEL rejects, along with a population that passed all RTS tests.[iii] All parts in this study passed the manufacturer tests (contact resistance, coil resistance, operate and release times, dielectric withstanding, and insulation resistance).[iv] Each sample population had 14 relays. The life test was run switching a 10 Volt and 10 mA resistive load at a 250 Hz operating frequency. The test was run to 200 million cycles, and 23 parts failed out of the total population of 42 relays. The Twist population had 9 total failures, with 8 occurring before 100 million cycles. The RDEL population had 10 failures, with 9 occurring before 100 million cycles. The RTS Accept population (parts with nominal Twist and RDEL values) had no failures by 100 million cycles and 4 failures from 100 to 200 million cycles.

The initial parametric data is shown in tables 1, 2, and 3 for the three populations of relays. All failed parts were removed from the test at the point of failure, and the CR and RDEL readings for these parts were recorded at that time. All failures were due to high contact resistance resulting in the test system recording the failure as a missed closure. From the data it can be seen that the contact resistance for failing parts ranged from 0.3 Ohm to as high as 10 Ohms. All failing devices also show a high degree of contact instability in the RDEL readings, with readings ranging from 37 milliohms to several Ohms. Both the RDEL and the Twists tests were able to predict which contacts would degrade and result in early life failures with better than 50% accuracy (8 out of 14 for the Twist test and 9 out of 14 for the RDEL test).

The life test results are shown in the Weibull plot in figure 1. From this plot, a dramatic difference can be observed for the B1 and B10 failure rates [1] between the RTS Accept population and the Twist and RDEL reject populations. The B1 for the Accept population was 60 million cycles, versus 100 cycles for the Twist population and approximately 1 cycle for the RDEL population. The B10 for the Accept population was 140 million cycles, versus 200K cycles for the Twist population and 7K cycles for the RDEL population. In an application requiring 100-million cycles, over 50% of the Twist and RDEL populations would fail, versus only 4% for the Accept population.

What Do These Tests Mean to Field Returns?

From the life test study, early life failures (before 100 million cycles) would occur for half of the Twist and RDEL rejects. Since the reject rate for these two tests is typically 1.1%, approximately 0.55% of a given random population would be expected to fail.

Let's assume that the annual usage is 100K parts and that the parts will reach 100 million cycles within two years. The AFR (Annual Failure Rate) equals 0.275%, and 275 parts would fail each year. A system that uses 10K relays would experience 27 failures per year.

More conservatively, if we assume that it will take 10 years to reach 100 million cycles, the AFR would equal 0.055%. Again, assuming an annual usage of 100K relays, a total of 55 devices would fail per year, and a system using 10K relays would experience 5 relay failures per year. The failure rate with either cycle rate is too high and would result in costly down time and repair time in the field.

Conclusion

Two very simple parametric tests called Twist and RDEL can predict parts that will fail prematurely, with good accuracy. These tests are able to find reed-relay contacts that are poorly aligned, contaminated, or have rough surfaces. The Twist test is performed at low contact forces and looks for contact surface irregularities and the presence of particle contamination. This test will generally reject 1% of a population, and half of these can be expected to experience early failures. The RDEL test is performed at nominal coil voltage and looks for instabilities that are related to chemical contamination, in addition to poor alignment and rough contact surfaces. The RDEL test will typically reject 0.1% of a population, and over half of these can be expected to experience early failures. When combined, the Twist and RDEL tests provide a very effective measure of contact quality. The life tests performed in this study clearly show strong early-life failures for the Twist and RDEL rejects. A significant improvement in the operating life can be achieved by the simple use of these tests.

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[1] B1 and B10 equal the number of cycles for a 1% and 10% failure rate respectively

Figure 1: Weibull Plot

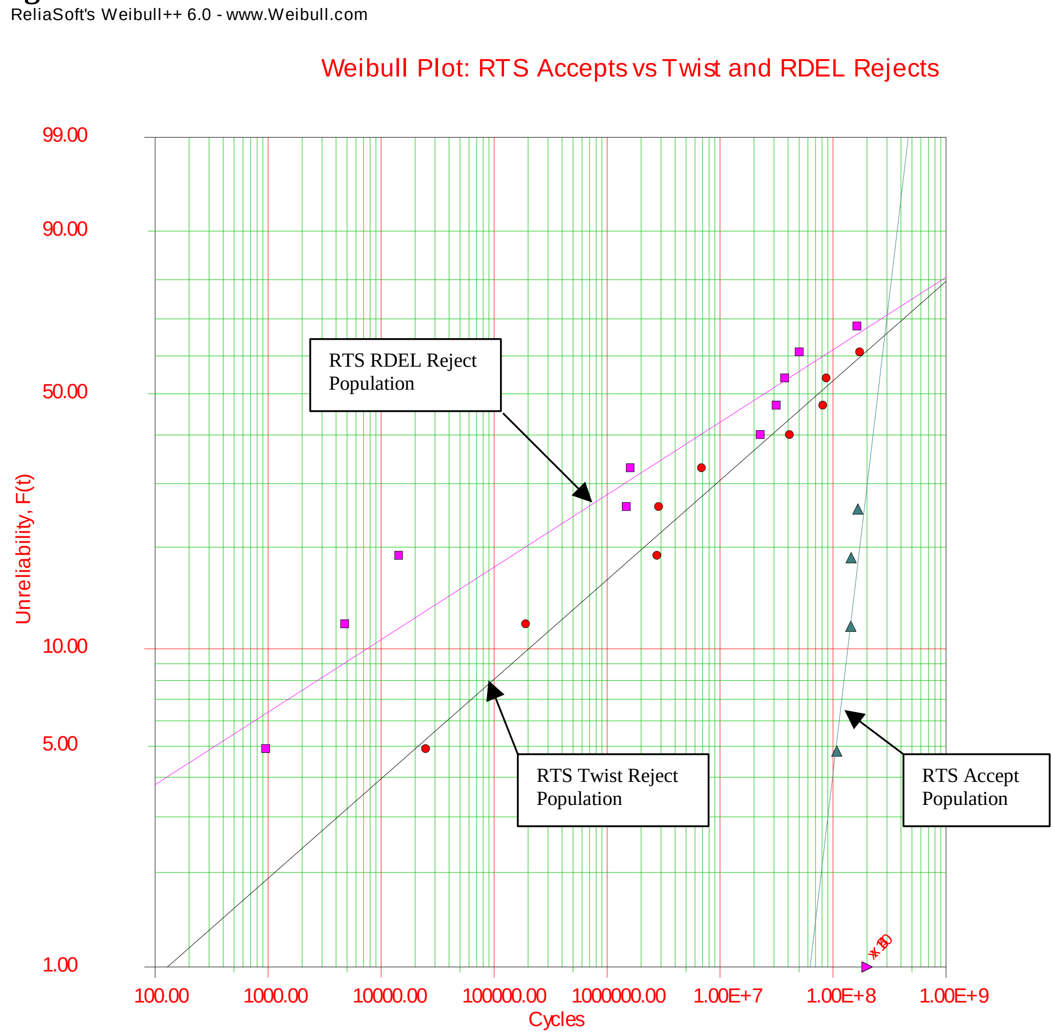

Table 1: Parametric Summary for RTS Accepts

Device #	Initial Data								Data at end of test	
	Coil R	PU	DO	CR	RDEL	Rtwist	Op time	Rel time	CR	RDEL
Spec	Ohms	Volts		Milliohms			usec		Milliohms	
	220	3.8	0.5	150	6	155	750	500	150	6
1	184	2.9	1.7	50	0.3	68	320	135	70	0.7
2	184	3.0	1.7	50	0	86	397	124	67	0.6
3	184	3.0	1.7	47	0	60	382	123	169	18.7
4	184	3.0	1.7	49	1.6	69	349	125	54	1.5
5	184	2.5	1.4	47	0.1	56	300	144	71	4.4
6	184	2.9	1.8	49	2.0	67	316	124	1586	715
7	184	2.7	1.4	50	1.0	62	292	154	58	2.5
8	184	2.8	1.5	50	0.6	66	299	134	69	1.1
9	184	2.5	1.4	44	0	54	344	147	65	1.6
10	184	2.5	1.7	53	0	76	366	120	76	2.5
11	184	3.0	1.8	50	2.9	61	387	113	705	202
12	184	2.5	1.5	47	0	64	335	137	322	97
13	184	2.5	1.6	53	0.7	63	413	121	2003	247
14	184	2.5	1.7	82	3.1	96	281	139	72	3.0

Note: Shaded rows indicate failures during life test.

Table 2: Parametric Summary For Twist Rejects

Device #	Initial Data								Data at end of test	
	Coil R	PU	DO	CR	RDEL	Rtwist	Op time	Rel time	CR	RDEL
Spec	Ohms	Volts		Milliohms			usec		Milliohms	
	220	3.8	0.5	150	6	155	750	500	150	6
1	184	2.7	1.4	43	2.0	134	286	166	10514	8071
2	184	2.7	1.7	75	0.9	248	354	125	77	2.3
3	184	2.8	1.8	90	11.9	188	469	101	455	67
4	184	2.8	1.7	52	2.3	384	312	138	287	37
5	184	2.0	1.5	59	0.8	245	244	152	106	2.9
6	184	3.0	1.5	88	1.1	223	390	134	551	65
7	184	2.3	1.4	60	0.6	137	328	137	1007	434
8	184	2.8	1.8	75	3.1	220	427	116	140	12.6
9	184	3.0	1.5	60	0.5	182	330	136	308	82
10	184	2.8	1.8	85	2.9	176	368	115	60	1.5
11	184	2.4	1.5	49	2.1	139	281	136	445	117
12	184	2.8	1.5	69	0.8	153	379	135	121	6.3
13	184	2.7	1.5	62	2.0	188	270	150	1405	543
14	184	2.6	1.5	62	1.1	210	290	135	936	250

Table 3: Parametric Summary for RDEL Rejects

Device #	Initial Data								Data at end of test	
	Coil R	PU	DO	CR	RDEL	Rtwist	Op time	Rel time	CR	RDEL
Spec	Ohms	Volts		Milliohms			usec		Milliohms	
	220	3.8	0.5	150	6	155	750	500	150	6
1	176	2.7	1.8	73	6.3	92	467	110	1123	322
2	173	2.5	1.5	79	11.0	110	398	130	113	11
3	172	2.8	1.8	68	13.7	128	463	114	300	133
4	175	2.9	1.6	74	13.4	115	377	128	2498	1506
5	173	2.6	1.5	78	24.0	114	332	143	2675	2234
6	179	2.7	1.7	74	11.3	99	583	108	1157	384
7	175	2.4	1.6	74	11.2	88	515	117	116	10
8	172	3.0	1.4	103	6.9	246	356	151	61	1
9	173	2.7	1.7	95	25.5	157	521	112	1870	564
10	173	2.7	1.8	118	5.9	223	404	122	413	123
11	173	2.4	1.7	98	29.0	78	309	129	704	321
12	173	2.4	1.7	85	7.1	162	471	116	704	321
13	174	2.7	2.0	198	118.4	193	469	97	3546	3389
14	172	2.8	1.5	104	7.9	350	457	136	90	3

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