

TESTING REED SWITCHES AND RELAYS FOR RELIABILITY

A White Paper by Coto Technology

BACKGROUND

For many switching applications reed relays remain the best solution, particularly when small size, high electrical off-isolation, very low on-resistance and ability to withstand electrostatic discharge (ESD) are required features. Reed relays can also be the best answer to applications needing excellent radio-frequency performance, since their low electrical capacitance and tunable impedance enables devices capable of switching signals in the GHz range. However, reed relays are inevitably perceived as mechanical devices in an increasingly solid state world, and it is critically important to understand their reliability under field conditions. Knowing how many switching cycles they will last under different electrical load conditions is an important issue when deciding if a reed relay is the best application choice. A rigorous reliability testing program is therefore a vital tool for providing our customers with technical support, and also for continuously improving the quality of Coto's products.

What is reliability?

Reliability can be defined as the probability that a device or system will meet its product specification when called upon to do so. It can only be estimated, never determined exactly, and it can only be estimated by examining the failure rates of individual products taken from a representative sample. Obtaining these estimates requires the use of statistical analysis.

The reliability of a relay is best defined in terms of the number of cycles it can operate while meeting its specifications before it fails. Measures such as MTBF (mean time between failures) or MTTF (mean time to failure) are less useful, since the life of a relay is heavily dependent on how many switching cycles it has been subjected to, not simply how long it has been in service. The MCBF (mean cycles before failure) is a useful measure of reliability for relays, and that is one of the measures Coto Technology uses to estimate relay reliability.

However, estimating and publishing the MCBF for a relay does not show the full picture. How many samples were used to make the estimate? What were the electrical load conditions? What are the confidence limits for the MCBF? A more searching question from a relay user might be: "I don't have the luxury of running my relays until half of them fail so I can see how accurate your MCBF estimate was. How many cycles can I expect my relays to run until one in a thousand has failed, and what confidence do you have in this estimate?"

Properly designed and implemented, reliability testing can answer these kinds of questions, and many more. Is one type of relay significantly more reliable than another? Does this relay get more reliable

as it gets older, or does it show wearout characteristics like people do? What failure rate can I expect for new relays just removed from the box? If a relay fails on a board that has 15 more, is it more cost effective to replace just the failed relay or all of them at the same time? Accurate estimates of reliability statistics allow those types of questions to be answered objectively rather than by the "seat of the pants."

What is a failure?

Reed switches or relays eventually fail in one of three ways. They do not open when they should (usually called "sticking"), they fail to close when they should ("missing"), or their static contact resistance gradually drifts up to an unacceptable level. At light loads, failure may not occur until several billion closure cycles have occurred. The first two listed mechanisms can be further subdivided into "soft" and "hard" failures. A soft failure is recorded when a switch is found to have missed or stuck a few milliseconds after coil activation or de-activation, but it is then found to have recovered from the problem when checked a short time (typically half a second) later. If recovery from the initial soft failure has not occurred by the time the second check is made, the failure is classified as permanent or "hard".

Miss and stick failures need to be defined in terms of the resistance recorded a certain time after causing the switch to close by activating the drive coil, or to open by de-activating the coil. A miss failure is called when the resistance is greater than a defined threshold when the switch is closed. Conversely, a stick failure occurs when the resistance is less than a defined threshold when the switch is opened. These threshold resistances and the measurement timing depend on the application. Coto typically uses one ohm for soft miss failures and half the contact load resistance for soft stick failures, measured one millisecond after drive coil activation and deactivation. These parameters are measured for each switch test cycle.

Since even one soft failure can be problematic in critical applications such as Automated Test Equipment (ATE), Coto records failures for "expected life" estimation as the **first, soft** failure due to sticking, missing or excessive contact resistance. This is a deliberately conservative criterion. Comparison with the reliability data published by other relay manufacturers is difficult, because they may have less stringent failure criteria or different ways of presenting statistical reliability data.

How can reliability be estimated?

The raw data for estimating the reliability of a reed relay is obtained by taking a representative set of samples and cycling them to failure, counting the number of cycles before they fail. Once this basic raw data has been obtained, it must be analyzed so that appropri-

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ate reliability statistics can be determined. The objective is to find a modeling function that closely fits the available data, and can be used for interpolation or judicious extrapolation to find estimates of the MCBF and other reliability statistics.

Like many statistical estimates, the accuracy of the reliability prediction increases in proportion to the square of the number of samples; a reasonable and practical quantity of tested relays is 16 or 32 for routine testing. To get a reliability prediction, it is not necessary to test the relays until they all fail. The life test can be suspended after a certain proportion of relays have failed – generally the test should be run until at least 50% have failed. This type of data set is called “right-censored,” and the information about the relays that survived after the test was suspended is useful and therefore not discarded. This can be understood intuitively; if 32 relays were tested to 100 million cycles and half survived, it’s likely that the MCBF is at least 100 million. Estimating the MCBF from just the 16 failed relays would give a much lower estimate.

A widely accepted statistical distribution for modeling reliability data is the Weibull distribution.⁽¹⁾ Reference (2) is a useful guide to the application of Weibull analysis. Given a set of number of cycles to failure for a series of tested relays, the parameters of this distribution can be fitted to the failure data using least squares regression techniques. Generally (but not always) the predicted fit using the Weibull distribution is better than that obtained with other statistical distributions, leading to better estimates of reliability parameters. Two parameters are obtained - one is the Weibull scale parameter, from which the MCBF can easily be derived. This parameter is sometimes referred to by the Greek letter Eta (η) The second parameter is the Weibull slope, sometimes called the shape parameter or Weibull Beta (β). Once the Weibull regression parameters have been determined, the fitted equation can be used to predict parameters such as MCBF, expected life before 1% part failure, estimation of expected infant mortality and wearout characteristics, and other pertinent reliability data.

Though it might appear that running a 100 million cycle life test might take a very long time, accelerated life testing can be used. The rapid switching time of reed relays allows them to be cycled up to about 200Hz – thus, a 100 million cycle test would take 4.8 days to complete, and probably less if the test was suspended before all relays had failed.

Methods for deriving the Weibull parameters η and β are described in Appendix I. Subsequent estimation of the MCBF is also described.

Relationship between reliability testing and parametric testing

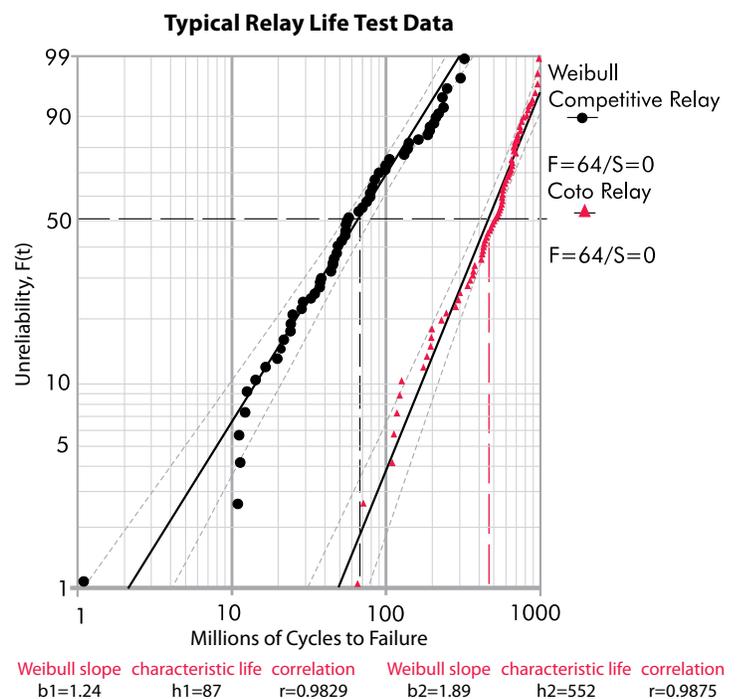
Coto Technology runs up to twelve electrical tests on every relay and switch product that leave its factories. These non-destructive tests

are referred to as “parametric” testing, since the measurement results are product parameters such as pull-in and drop-out voltage, static and dynamic contact resistance, opening and closure times etc. In contrast, reliability testing is generally destructive and takes a long time, and therefore can only be applied to representative samples of products. Products are tested at various current and voltage loads, including inrush current profiles where necessary. We frequently tailor these loads to our customers’ special technical requirements. The sample sizes and the number of test cycles are chosen to allow an accurate assessment of MCBF and other reliability statistics – often involving sample sizes of 64 or 128 test parts and several billion test cycles over many weeks.

Typical example of life data analysis and interpretation

The Weibull regression plots shown in Figure 1 were generated from a life test of 64 Coto ATE-grade relays compared to an equal number of commercially available competitive parts. The test was run at 200 Hz, using a 5V, 10mA resistive load. It was continued until all 128 parts had failed at about one billion cycles and 55 days of continuous testing. The MCBF for each relay type can be approximately estimated from the intercept of each fitted reliability plot with the 50% unreliability ordinate, or more accurately determined by numerical methods described in Appendix I. The estimated MCBF for the competitive relay is 66 million cycles, compared to 450 million for the Coto relay. The dotted lines indicate the 90% confidence limits for each plot – since these do not overlap at any point, the parts clearly have significantly different reliability levels with a 90% confidence level. Another useful reliability statistic is the

Figure 1: Weibull Plots of Relay Life Test Data



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expected life before 1% failure; the plots show that estimated 1% life is between 1 and 4 million cycles for the competitive relay, compared to 30 to 70 million for the Coto relay. The explanation of this bigger reliability differential is the steeper slope of the Weibull plot for the Coto part, indicating a more pronounced wearout characteristic than the random failures exhibited by the competitor.

Since the cost to locate, remove and replace a failed relay can greatly exceed the actual purchase price of the part, steeper Weibull slopes and higher MCBF's mean lower maintenance and replacement costs, and fewer expensive "infant mortality" failures.

How not to lie with statistics – Publishing valid, useful life expectancy data

Misapplied statistics led to the English Prime Minister Benjamin Disraeli's famous quote: "There are three kinds of lies; lies, damned lies, and statistics." Certainly misapplied statistics can inadvertently lead to inflated estimates of reliability. Coto attempts to provide reliability data in an unbiased and accurate manner using industry-standard software tools.

In the Coto catalog, the "Expected Life" is synonymous with MCBF or mean cycles before failure. Since the confidence limits associated with MCBF estimates are usually quite broad, the life estimates are rounded to an appropriate number of significant figures to avoid implied over-accuracy. Relay reliability data are only given for 1V, 10mA or 1V, 1mA resistive loads. Switch life data is given at several different loads, depending on the application. Contact Coto Technology for life data at other loads. We have an extensive database of life test data, and may be able to predict reliability under other load conditions or set up a special life test meeting your requirements.

Demonstrating product reliability for a specific number of switching cycles

A different testing approach is possible if it is only necessary to estimate a relay's reliability after a certain number of switching cycles, rather than determining its MCBF. For example, let's assume we want to be able to say with 90% confidence that the reliability of a certain relay is at least 99% after 100 million cycles. In other words, we want reasonable assurance that less than 1% of relays will have failed by that number of cycles. It can be shown by re-arrangement of the Weibull equation that in this case, if 44 relays are put on test for 300 million cycles and they all survive, the 99% reliability requirement has been demonstrated with 90% confidence¹. That test would take about 17 days at 200 Hz. Test time can be traded off against the number of tested relays; if the test was extended to 370 million cycles (22 days) and the number of test relays was reduced to 32, the required reliability would have been demonstrated if all 32 relays survived. This number of DUT's is convenient since it is the maximum number of relays a single Coto relay life test system can

accommodate.

Failure rates and FIT rates

The MCBF can also be expressed as a failure rate; one is simply the reciprocal of the other. Thus, a relay with an MCBF of 250 million cycles has an average failure rate of 4.0E-09 failures per cycle. In other words, if the failure rate is constant, there's a chance of four in a billion that the relay will fail in any given switching cycle. However, relay failure rates are rarely constant; a mature product will have $\beta > 1$, and an increasing failure rate as it nears the end of its service life.

Since relay failure rates are usually very low, it is convenient to define a Failure-In-Time (FIT) rate as the number of failures that can be expected in one billion (10^9) cycles of operation. Note that FIT rates make the assumption that the failure rate is constant in time (i.e. Beta = 1). This is rarely the case, and the combination of Weibull η and β is a much more useful reliability metric.

THE RELIABILITY OF RELAY SYSTEMS

Estimating system reliability for equipment using multiple relays

Consider a system containing 2000 identical relays. The system fails if any one of the 2000 relays fails. There is no redundancy or backup in the system design. If the reliability of an individual relay is known, is it possible to estimate the most likely number of cycles before the system fails? The answer is yes, but the result may be surprising, especially for relays with low MCBF or shallow Beta slopes. This is a case where using an extremely high reliability relay is vital.

One approach to estimating the system reliability is to use Monte Carlo simulation. Referring to Appendix I, it can be seen that the unreliability of an individual relay is given by

$$F(t) = 1 - e^{-(t/\eta)^\beta} \quad (1)$$

If t_r is the expected number of cycles to failure and η, β estimates are already available from life testing, random values of t_r can be generated from the expression

$$t_r = \eta (-\ln(\text{RND}))^{1/\beta} \quad (2)$$

where RND is a random number uniformly distributed on the interval 0 - 1.

For a system with 2000 relays, computing t_r 2000 times and sorting to find the lowest value provides an estimate of when the system is

¹An assumption of the Weibull Beta has to be made to use this testing method. In this example, a Beta value of 1.5 was assumed. Had the Beta value been higher, the number of tested relays would have been lower. For example, at Beta = 2, only 14 test relays would be needed.

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most likely to fail (since we assume it fails when the first relay fails.) Repeating this simulation a large number of times allows a distribution of cycles to failure for multiple systems to be developed. The following table (Table 1) shows the results of such a simulation, for various values of η and β .

Number of System Cycles Before 1% of Systems Fail

ETA (Millions)	Beta				
	0.5	1	1.5	2	3.44
1000	0	4,335	295,883	2,299,897	31,781,920
500	0	2,717	232,301	1,171,054	14,759,612
250	0	1,117	70,223	620,461	6,868,718
100	0	619	28,872	225,721	2,578,993
50	0	253	19,092	98,634	1,435,337

Table 1. Estimated number of system cycles before 1% of systems fail, for various values of Weibull characteristic life (Eta) and shape parameter (Beta). Numbers are based on the simulation of one thousand systems, each containing 2000 relays, where one relay failure is assumed to cause a system failure.

A premium grade Coto reed relay can be expected to have a characteristic life of at least a billion cycles when switching low level electrical loads. It will also have a Weibull Beta between 1.5 and 4.0. It can be seen that for relays with a characteristic life of 1000 million (one billion) cycles, the estimated number of system cycles before 1% of systems fail is between about four thousand cycles for $\beta = 1.0$, to almost 300 thousand cycles for $\beta = 1.5$ and over two million cycles for Beta = 2.0. Clearly, a small increase in β makes a very big difference to the expected system reliability. And since MCBF is highly correlated with the characteristic life η , the table also shows that specifying relay reliability based on MCBF alone is insufficient; it is important to specify both the MCBF (or characteristic life) AND the Weibull shape parameter β if meaningful estimates of system reliability are to be made.

Obviously not all systems are designed so that any one of a very large number of relays fail, the system goes down. Various strategies such as redundant design can reduce the potential problem. It's worth noting that redundancy based on parallel use of relays in critical locations may improve system reliability under some conditions. However, running relays in parallel in an attempt to increase load switching capacity is NOT a good strategy, since one relay always closes before the other, and the contacts of that relay bear the full switching load.

Simulating systems that have redundancy strategies or components (including relays) that have different levels of reliability is beyond the scope of this White Paper. Commercially available software such as BlockSim (from Reliasoft Inc.) is of great help in predicting the reliability of complex systems.

What Weibull Beta means

The astute reader may be wondering why a Beta value of 3.44 heads the last column of Table 1. It turns out that the Weibull distribution with Beta = 3.44 closely approximates the normal distribution with its familiar, symmetrical bell-shaped curve. The normal distribution can accurately model the failure rates of consumable items such as printer cartridges and incandescent light bulbs that wear out rapidly after a certain number of cycles. However, reed relays have more complex failure mechanisms than printer cartridges, and their Beta values are generally lower, in the range of 1.5 to 2. In other words, they exhibit wearout characteristics after a long period of stable life.

PREVENTIVE MAINTENANCE STRATEGIES

Is it best to replace relays individually when they fail, or replace them in groups on a preventive maintenance schedule whether they have failed or not? Reliability statistics allow an analytical approach to solving this problem, based on a concept called Cost Per Unit Time (CPUT) Minimization. This method takes into account both the costs of preventive maintenance (PM) and the cost of unplanned (unscheduled) maintenance, UM. It is widely accepted in the ATE industry that the cost of finding and repairing a failed relay in the field is between ten and one hundred times the cost of repairing it during line installation. Replacing a \$5 relay when the failure is discovered during manufacturing test might cost \$500 in the field. If that failed relay is mounted on a board with (say) 15 others, is it cost-effective to change all of them at the same time during a field repair, even though 15 out of 16 may have not failed? Perhaps surprisingly, the answer is often "yes".

In this example, let's set the PM cost as 16 relays * \$5/relay = \$80. Let us also assume that the cost of the UM to find and replace the one failed relay is \$500. First, let's figure the reliability of the 16-unit board, regarding it as a system which is to be replaced when one or more individual relays fail. For a system that fails if one relay fails, it can be shown by manipulation of the Weibull distribution equation that the reliability after t cycles of a system containing n relays is:

$$R_s(t) = R_r(t)^n \quad (3)$$

where $R_s(t)$ = system reliability at t cycles

$R_r(t)$ = individual relay reliability at t cycles

n = number of relays in system

The scale parameter (Eta) for the system can be determined from the scale parameter of the individual relays using the expression:

$$\eta_{system} = \frac{\eta_{relay}}{\beta \sqrt[n]{n}} \quad (4)$$

Testing Reed Switches and Relays for Reliability (cont.)

From Equation (4), a 16-relay system using relays with a characteristic life (Eta) of 1000 million cycles and a Weibull Beta of 1.5 will have a characteristic life of 157 million cycles and a MCBF of 142 million cycles. The system Beta remains the same at 1.5.

Given these estimates for the Weibull parameters of the 16-relay system, we are almost ready to calculate the preventive maintenance period that minimizes the CPUT. To take an extreme example, let's first assume PM is performed every million system cycles and all the relays are replaced; in this case, the PM cost in that million cycles would be \$80, plus an additional expectation for the small probability of an unscheduled failure costing \$500. It turns out that CPUT would be \$80.15 per million cycles. Clearly this would be an over-aggressive and uneconomical PM policy, though UM events would almost never occur. It would be equivalent to trading in a new Rolls-Royce when the ashtray was full. However, by calculating the CPUT for this example using increasing periods between PM, it can be shown that a distinct minimum CPUT of \$2.89 occurs when the number of cycles between PM is set at 81 million. In other words, this PM strategy costs \$2.89 per million system cycles.

If it ain't broke, fix it

Now let's look at the expected maintenance costs if no PM is performed, and any individual relay is simply replaced when it fails. We know that the system MCBF is 142 million cycles, and we've estimated that the cost of unscheduled maintenance is \$500 per event. The expected cost per million system cycles is therefore $\$500 / 142 = \3.52 per million cycles. In comparison, running the 81 million cycle PM strategy will save almost 25% in maintenance costs! Actually, the savings will be even higher, since every 81 million cycles a new system board with all-new relays is started, all of which have a period of stable life before they begin to wear out. On the other hand, when a UM replacement strategy is followed, a significant fraction of the un-replaced relays will be in the wear-out phase, and more likely to fail prematurely than the fresh relays replaced under the "replace them all" PM strategy.

Now consider a system board with 64 relays of the same type and cost. Assume that Weibull Beta is 2. The system characteristic life at Beta = 2 is 125 million cycles. Changing all the relays on a PM schedule costs $\$5 * 64 = \320 . Assume the UM cost is \$500 as before. In this case the optimum PM interval is 201 million cycles, with a CPUT of \$4.42/million cycles. On the other hand, the CPUT for a UM strategy is $\$500/125 = \4.00 /million cycles. In this case, it's less expensive just to repair individual relays when they fail. The Weibull Beta would need to be significantly higher before a PM strategy could show a cost benefit.

Effects of Weibull Beta on the PM strategy

Modest Beta values between 1.5 and 2.0 were used in the previous examples. The savings with a PM strategy can increase significantly for relays with a higher Beta. For the 16-relay system at a Beta of 2

for example, the minimum CPUT of \$1.47/million cycles occurs for a PM interval of 112 million cycles. This represents a savings of $(\$1.47 - \$3.52)/\$3.52 = 58\%$ over the UM ("fix 'em when they break") strategy. In this case, "if it ain't broke, don't fix it" is not a good idea. The CPUT is lower because the MCBF of the system is now about 250 million cycles, and the wearout curve is steeper, allowing a bigger interval between PM. This further illustrates the vital need for both the MCBF and the Weibull Beta to be reviewed when considering relay reliability. If a manufacturer does not publish both factors or make them available, a potential relay user should request them before selecting a product. A quality supplier will either have them on file, or be prepared to run a life test to demonstrate them.

Note that a PM strategy is not effective if the relay's Weibull Beta value is one or less. In this case failures are random or decreasing with time and there is no wearout characteristic. In this case the CPUT never shows a minimum, and there are no savings to be had by adopting a PM strategy. Fortunately, good quality relays never have Beta ≤ 1 .

Preventive maintenance strategies – a summary

Sometimes, "if it ain't broke, don't fix it" is not a good strategy. For systems containing relatively small numbers of relays with Weibull Beta > 1 , replacing ALL the relays on a preventative maintenance schedule can reduce costs compared to simply fixing individual relays when they fail. The breakeven point depends on the number of relays in the system, the Weibull Beta of the relays used, the estimated cost for relay replacement, and the estimated cost of fixing individual failed relays on an unscheduled basis. Coto is working on a comprehensive model that will allow relay users to carry out these calculations and devise an optimum PM strategy. The model will be the subject of a future White Paper.

A PRIORI PREDICTION OF RELAY RELIABILITY

The methods for predicting relay reliability that have been described so far are purely empirical, and rely on statistical estimates using representative samples of relays. But relays are relatively simple devices; is it possible to predict how long a relay will last in service, knowing how it is constructed and what electrical load it will be switching, based solely on the physics of the device? No-one has succeeded in doing this so far, despite the simplicity of a reed relay. As an example, consider the relationship between the life of a relay and the electrical load it switches. If an arc occurs on each switching cycle, one might expect that each arc might ablate a small amount of contact material from the contacts, until the contact eventually burns through and the switch fails. In fact, there is some evidence for this phenomenon occurring in reed relays switching relatively high voltages and currents, since the measured Weibull Beta values are usually high for this kind of load, approaching the 3.44 value typical of consumable items. Furthermore, testing at Coto has shown the MCBF of switches operating under high voltage, high current loads

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is roughly proportional to the thickness of the precious metal laid down on the contacts – supporting the consumable material model. However, extrapolation of life estimates to lower loads is very difficult. For example, the relationship between switch life and electrical load is not a simple monotonic function, even for switches in the same size class, with the same blade design, contact coating and amp-turn sensitivity. For example, the life of a reed relay switching a load of 5V, 10mA may be 100 times greater than the life at 12V 4mA, though the wattage switched is almost identical². Such anomalies make prediction of life based on electrical load very difficult.

There is some evidence that parametric measurements made after a reed relay is manufactured can be used as predictors of relay life. For example, the amp-turn sensitivity of the reed switch is very strongly correlated with life – doubling the AT can triple the life, and tripling the AT can cause a twenty-times increase in life at certain loads. The reasons for these large improvements in life at higher AT are the larger switch gap, giving less probability of bridging, and the higher spring forces at higher AT, which tend to pull the switch blades apart when the coil current is released and the magnetic field decays. Pull-in to drop-out ratio is a related parameter; a high ratio indicates good “snap action”, which also leads to enhanced contact life.

Other parametric measurements such as dynamic contact resistance (DCR, contact resistance measurements made while the relay contacts have just closed but are still vibrating) are predictors of ultimate relay reliability, but little has been published that establishes the degree of correlation. However Coto routinely measures the DCR of all relays it ships, since DCR is a valuable indicator of relay quality parameters such as contact cleanliness, hermetic seal integrity, the presence of internal stresses and the soundness of internal connections.

It has also been claimed that magnetostrictive twist measurements on new relays can predict eventual relay life. (3) Measurements of contact resistance are made close to the drop-out point, where interaction between the magnetic flux generated by the coil interacts with the flux generated by the contact load current. Proponents of this method claim that this interaction causes blade twisting, and that contact resistance measurements made in this manner are correlated with eventual contact failure. The relative value of this method compared to other dynamic measurement methods was subsequently disputed by Gusciora(4).

RELIABILITY AND REED CONTACT DESIGN

No subject in reed switch engineering is more controversial than switch contact design. What contact coating should be used? Ruthenium, rhodium, or iridium? Should it be electroplated or sputtered?

²It is believed that the 12V load causes molten precious metal “whiskers” to form by electrostatic pulling forces. These eventually bridge the switch gap and cause sticking, since the 4mA current is too weak to burn away the whiskers. However at 5V, 10mA, the electrostatic forces are lower (causing less whiskering), and the higher current can burn away any whiskers that do form.

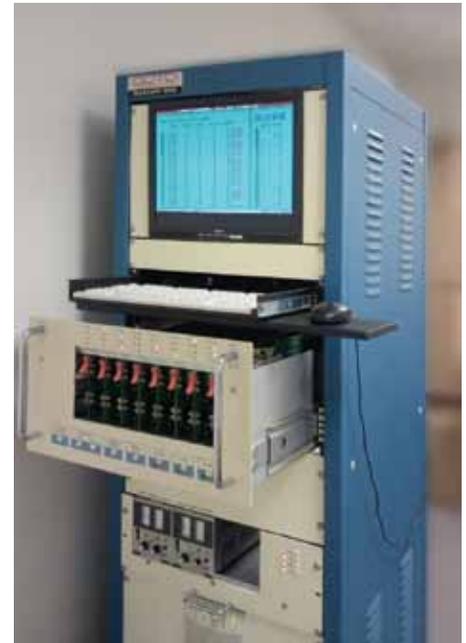
What is the right coating thickness? How will the chosen coating handle inrush currents and other abusive loads? What layer structure should be used? Coto Technology has had many years experience in evaluating such issues. We are convinced that sputtered ruthenium coating is the best choice for most ATE applications. The hardness and high boiling point of ruthenium compared to other platinum group metals provides superb contact wear characteristics and resistance to sticking. Applying ruthenium by sputtering is a slower and more expensive process than the electrolytic plating commonly used by other reed switch manufacturers, but provides superior contact reliability by eliminating impurity inclusions.

These qualities have been demonstrated by controlled side-by-side testing of Coto reed switches against those manufactured by our competitors. A recent independent study supports these conclusions. Oshiyama et. al.(5) found that metal transfer under hot switching conditions was the principal cause of sticking failures, and that switches with ruthenium contacts were seven times less prone to this effect than switches having rhodium contacts.

RELAY TESTING SYSTEMS

Relay life testing systems have unique requirements, including the need to be more reliable than the devices they are testing. Because of the unique requirements of reed relay life testing systems, Coto Technology designed and built its first custom designed life tester in the 1980's and has since upgraded the system several times. Coto now has six testers, designated the Coto System 300, installed at its corporate HQ in Rhode Island USA, and at its production facility in Mexicali, Mexico. (Fig 2)

Fig 2. Coto Technology System 300 Relay Life Test System



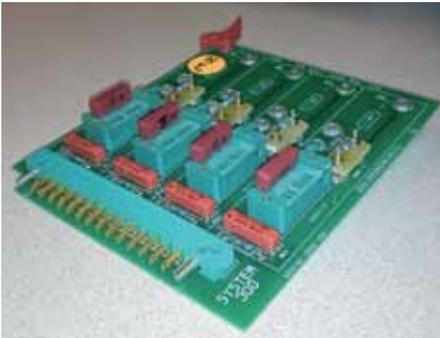
Each system has 32 test channels capable of testing reed switches at loads that can be varied from 0.03V, 1mA (30 microwatts) to 60V, 1A (60 watts). Auxiliary driver modules allow loads up to 150V, 10A

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(1500 watts) or 1000V, 10mA (10 watts) to be used. Modular plug-in load cards enable resistive, capacitive, inductive or hybrid loads to be set up. (Fig 3)

The test cycle frequency is typically set at 200 Hz or an optional sweep over a 10 Hz to 255 Hz range. Soft sticks and misses are

Fig 3. System 300 Life Test System Load Card.



tested on every switching cycle – if either is detected, the system waits for 0.5s and checks if a failure is still present, and registers a hard stick or miss if it is. In addition, parametric measurements of contact resistance are made at programmed intervals; these can be

plotted later for evaluation of contact resistance degradation during the completed life test.

The recorded life data is exported in Microsoft Excel format for subsequent processing of the reliability statistics using a commercial reliability software program.

Coto also has specialized life test equipment that can test individual relays with HF loads over a 20KHz to 1 MHz frequency range, at loads up to 300V, 6A. Such relays are typically used in broadcasting and medical equipment. Coto's environmental test chamber also allows life tests to be run between -40 and +150 degrees C in either static or cyclic temperature modes.

GETTING THE HIGHEST RELIABILITY FROM YOUR REED RELAYS

You've decided on a reed relay solution for your next switching project, and selected what appears to be a suitable Coto product. The Applications Engineer at Coto has reviewed your proposed use and confirmed you have made the most appropriate choice. What can you do during the design-in process to ensure you get the maximum reliability? Here are a few tips.

1. Cold switch if possible

It's not always practical, but if you can design your system so the relays only switch when the current is off, the relay life will be greatly extended.

2. Avoid reactive loads

Reed relays are most reliable when switching resistive loads. Heavy inrush currents from capacitive circuits can cause premature contact failure or even contact welding, and inductive loads can cause excessive arcing on break. Contact Coto for technical advice if you expect to be switching a reactive load.

3. Maintain Overdrive

A relay with a nominal coil voltage of 5V will typically have a listed "must operate by" operate voltage of 3.8V. Try to ensure that the voltage applied to the coil is at least 25% higher, i.e. 4.75V. This overdrive of 25% will ensure that the relay contacts are firmly closed, enhancing the relay's life.

4. Magnetic interaction

If relays are to be stacked closely together on a PCB, ensure that they are oriented to minimize magnetic interaction that can increase the effective operate voltage of the relay, reducing the effective overdrive. Typically this means orienting the relays with opposing polarity. Consult the Coto catalog for optimum layout patterns.

5. Use a relay with a ferrous metal shell

Many Coto relays are offered with a ferrous metal shell that minimizes magnetic interaction and maintains maximum overdrive. Select a relay with a shell if possible.

6. Keep the operating temperature low

The coil resistance of a reed relay increases by 0.39% for every degree Celsius increase. Assuming you are using a constant voltage coil supply, a 50 degree C increase causes a 20% increase in coil resistance, and a corresponding 15% reduction in the power supplied to the coil. This reduces the overdrive, and could reduce the relay's life.

7. Maintain coil voltage after relay closure

Avoid using relay driver IC's that allow the coil voltage to be lowered after the relay closes to save power (or simply turn the programmed reduction off.). Most small reed relays don't have enough differential between pull-in and drop-out voltages to maintain adequate overdrive this way, and relay life may suffer.

8. Use an independent power supply for the relay coils

Relay coils are inductive, and may send potentially damaging spikes down power lines. It's good design practice to provide an independent PSU for the relay coils. Consider external diode inductive spike suppression for all relays that do not have built-in diodes.

9. Program an occasional exercise cycle (Form C relays)

Form C reed relays that are only activated occasionally spend a lot of time with the normally-closed contact shut. This can sometimes lead to contact sluggishness when the relay is first activated, or on

Testing Reed Switches and Relays for Reliability (cont.)

rare occasions the relay may remain stuck in the normally-closed position. Programming an occasional burst of relay operations can greatly alleviate this problem.

APPENDIX I

The Weibull Distribution and Methods For Calculating Its Parameters

This distribution is widely described in the reliability literature. The number of cycles to failure for a sample of relays or switches is fitted by least-squares techniques using the two-parameter Weibull distribution function $F(t)$, where

$$F(t) = 1 - e^{-(t/\eta)^\beta} \quad (A1)$$

Here, $F(t)$ is the unreliability function, t = time or cycles to failure, η and β are the Weibull distribution parameters.

This equation can be linearized using the transformations:

$$y = \log_e(\log_e(1/(1-F(t)))) \quad (A2)$$

$$x = \log_e(t) \quad (A3)$$

After linear regression of x on y , the slope of the regression line = β and the intercept = $\beta \log_e(\eta)$.¹

Given a set of cycles to failure for a particular sample of relays, $F(t)$ values can be calculated with Benard's approximation for median ranks:

$$F(t) = (j - 0.3) / (N + 0.4) \quad (A4)$$

where j = the rank order number for the failure and N = total number of failures. Special precautions are taken to deal with censored data from parts that survive the test without failure.

The product's MCBF and its confidence limits are then calculated from the fitted Weibull parameters η and β . The parameter η (eta) is the characteristic life, or life for 63.2% failure. The Weibull slope parameter β is particularly useful, since its magnitude relates to the wearout characteristics of the product being tested. A value of $\beta < 1$ indicates "infant mortality" failures, that can potentially be reduced by manufacturing improvements, or screened out by burn-in testing. Values of $\beta > 1$ are more desirable, since they indicate a normal mechanism of wearout after a stable period of reliable operation. Typical values of β for reed relays are usually in the range of 1.5 to 4.0

The regression equation described above can be fitted with general purpose spreadsheet software such as Microsoft Excel. However, treatment of data sets with censored data is not straightforward. Commercially available software packages such as Reliasoft Weibull++ (6) or Minitab (7) greatly simplify the calculations, and also have built in capability for calculating supplementary parameters such as confidence limits.

Fig. A1: Computation of the Gamma Function (From Abramowitz & Stegun, Handbook of Mathematical Functions (8))

Series Expansion ² for 1/r(z)			
6.1.34	$\frac{1}{\Gamma(z)} = \sum_{k=1}^{\infty} c_k z^k \quad (z < \infty)$		
k	C _k		
1	1.	00000	000000
2	0.	57721	56649 015329
3	-0.	65587	80715 202538
4	-0.	04200	26350 340952
5	0.	16653	86113 822915
6	-0.	04219	77345 555443
7	-0.	00962	19715 278770
8	0.	00721	89432 466630
9	-0.	00116	51675 918591
10	-0.	00021	52416 741149
11	0.	00012	80502 823882
12	-0.	00002	01348 547807
13	-0.	00000	12504 934821
14	0.	00000	11330 272320
15	-0.	00000	02056 338417
16	0.	00000	00061 160950
17	0.	00000	00050 020075
18	-0.	00000	00011 812746
19	0.	00000	00001 043427
20	0.	00000	00000 077823
21	-0.	00000	00000 036968
22	0.	00000	00000 005100
23	-0.	00000	00000 000206
24	-0.	00000	00000 000054
25	0.	00000	00000 000014
26	0.	00000	00000 000001

Figure A1: Computation of the gamma function (From Abramowitz and Stegun, Handbook of Mathematical Functions (8)).

¹Since the errors on time-to-failure are greater than those of the unreliability estimates, it is common practice to assign the log transform of time-to-failure as the dependent variable, and regress x on y rather than the more familiar y -on- x . Other methods such as Maximum Likelihood Estimation (MLE) can also be used to estimate the Weibull regression parameters. Details are covered in the Reliasoft Weibull++ software documentation (6) and the Minitab documentation (7)

Testing Reed Switches and Relays for Reliability (cont.)

Calculation of MCBF from the Weibull Scale

Parameter η and slope β

The MCBF can be calculated (Ref. 2, page 4) from the expression:

$$\text{MCBF} = \eta \Gamma(1 + 1/\beta) \quad (\text{A5})$$

Where $\Gamma(z)$ is the gamma function. This function is available in tables or can easily be calculated in a spreadsheet using the series expansion shown in Figure A1.² The Reliasoft Weibull++ software has a MCBF calculator that simplifies this operation.

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- (8) Abramowitz, Milton; Stegun, Irene A., eds. (1972), *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables*, New York: Dover Publications, ISBN 978-0-486-61272-0

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²The numerical method described by Dodson (Ref. 2 page 185) is incorrect. Instead, the series expansion shown in Abramowitz and Stegun (Fig. A1) may be used to estimate Γ .