Evaluating relay test equipment solutions for features, benefits and costs

***Abstract* – Understanding the cost and performance benefits of Relay Test Equipment has a direct impact on the "Cost per Part"**

This paper provides a valuable insight into the theory and practice of how the architecture of relay test systems influences their performance and cost, all the way from the simplest equipment, through to the most complex and sophisticated high-end automated production line systems.

It derives some fundamental characteristics which if properly understood, helps the selection of test equipment for a specific application and shows how you can achieve the best test system for your needs.

I. FUNDAMENTALS

A. Defining the need for electrical test.

Before embarking on a paper about the cost of testing, it is entirely appropriate to ask ourselves just why we are testing and what we need to test. This somewhat rhetorical question may seem rather pointless but it does focus our definition when we come to specify our test needs.

"Testing is necessary to ensure that faulty components do not get shipped to customers, by verifying that the product conforms to the manufacturers published product specification".

This is a simple and rather obvious declaration but enshrined within it is the implication that any test philosophy is valid as long as shipped product can be reasonably expected to comply with its specification. The most obvious and usual way of ensuring this is to apply a full electrical test at the very end of the production process. This 'final test' ensures that no further production processes are likely to render a working device faulty or change its characteristics and that numerical feedback from the test results provides very useful product performance statistics.

Constructing a test philosophy.

There are questions that we can ask ourselves concerning the validity of any test station along a production line up to and including final test. These are:

- Must we test all product parameters?
- How extensive does each test need to be?
- Do our test results give us control over the prior or subsequent production process for improved yield?
- Can we obtain the datalog test results we need for traceability, analysis and process improvement?

Answers to these questions are directly related to the costs and the benefits of our testing, so even if we plan to do nothing about changing our test scenario we should at least understand the implications of the choices that we have made.

Must we test all product parameters? In a final test scenario the ideal answer to this question is 'yes' but the real world is less ideal. It takes time and test sophistication to test all device parameters, some of which we can consider to be 'guaranteed by design'. For example high-voltage breakdown testing can be difficult and time consuming and a manufacturing may choose to apply this test on a sample basis if he considers that the product construction and/or the results of other testing virtually guarantees that untested devices will be ok.

How extensive does each test need to be? To comply with the product specification we merely need to know whether the device passed or failed, so the simple answer to this question is 'not very extensive'. We can 'get away' with test results that convince us that the actual operate voltage is within the allowed range for example. Go-No-go testing does this and is the simplest and lowest cost of all test methods but it does not provide any useful feedback on the spread of device parameters or the proximity of the device results to the actual data sheet or production process specification.

Do our test results give us control over the prior or subsequent production process for improved yield? This question is linked to the previous one about how extensive the tests need to be but it focuses on why we want any more information from the test process than only that required by the product data sheet. The customer requires only to know that the product conforms to its specification but we as manufacturers have to be in control of the manufacturing process. As many readers will be only too well aware, achieving manufacturing process control with eletromechanical relays is something between an art and a science and blind yes-no answers to electrical tests are very unhelpful when it comes to achieving process control. Good control over the manufacturing process virtually dictates that test results are actual numerical measurements (not go-no-go flags) and that these results are also available statistically, ideally in real-time. It is significant that we used the phrase 'prior or subsequent production process' in the question because of course our test results are useable both for determining their cause from whatever prior manufacturing processes achieved them, but also for determining the suitability of the devices to go forward into their next phase. At final test, this next phase is shipment to the customer, but for test stations located along a production process test results may be highly useful to 'weed out' parts that would not be expected to survive their subsequent processes and to therefore free up certain production stations for higher quality product and improved throughput

Can we obtain the datalog test results we need for traceability and analysis? The ability for the test equipment to have a flexible solution to data-logging is fundamental. We as relay manufacturers strive for 100% product reliability, however we know that in the real world this is unlikely to be achieved for many different reasons and there is a real conflict between allowing the greatest possible process margins between actual and data sheet limits and the need to keep these margins small to increase production yield. The best that we can achieve is to maintain the greatest possible safety margin between actual and stated datasheet performance.

Effective reporting of data-logged results is also a traceability requirement from many customers and is essential in the process of maintaining and improving product quality by closing the feedback loop and allowing small changes, for example in product design to be correlated to device performance.

B. The costs of applying testing.

Costs are incurred in applying a given test scenario, whether as a final test or as in-production test, and these costs can be broadly categorised into visible cost and hidden costs.

Visible costs

- Purchase of test system and its associated fixtures and options.
- Budgeted time and resources to implement the system and its programming.

Hidden costs.

- Overrun costs in creating multiple test programs.
- Unforeseen tasks stemming from having to integrate the output test results with in-house expectations.
- Repair and maintenance.
- Dependency on one "key" employee

How these various expenditures fall within these two categories is hard to predict because various views can be taken of what constitutes 'visible' and 'hidden'. Indeed, there may be political issues at stake here too where perhaps only a certain level of 'visible' costs should be exposed, leaving the remaining cost-of-implementation to be paid for in an on-going hidden manner for example in-house labour costs.

Good planning should put as many of the cost areas into the visible category but it is often the case that the engineering tasks involved in implementing a test solution turn out to be more demanding than originally expected. On the positive side too, it may be that when the full potential of a test system's capability to make more effective tests on a part is discovered, additional hidden costs may be incurred as staff necessarily expand on the original remit.

C. Today's relay marketplace.

Now more than ever it is necessary to drive down costs and push up output. While relays continue to be an important electronic component and have achieved a high level of sophistication, market competition and production evolution ensures that only the most efficient and effective manufacturers will ultimately survive. Relays are increasingly threatened by solid-state technologies which whilst yet unable to displace them in many present-day designs, continue to apply cost and performance pressures and to encourage the emergence of new mechanical designs, for example the micro machined relay [1].

Relay manufacturers typically implement their production in two ways.

- **Automation** – to increase throughput, remove human error, effectively handle small parts and to speed repetitive processes.

- **Manual cell production** – one operator (or collaborating operators) working on a specific production task within the manufacturing process flow.

Both of these solutions have their advantages and disadvantages. Automation can dramatically speed manufacture but it is costly to implement and can be very inflexible to product changes. Manual production is prone to human error, can be slow and yet is highly responsive to the need for change to the product or work-flow and often flags-up process problems as they happen and before faulty product has been finished.

There is no one solution that works for all manufacturers. Indeed, many manufacturers employ a mixture of these two techniques that suits their product needs and production philosophy.

Integrating a test philosophy within these manufacturing structures requires an understanding of the best points at which to apply testing and the likely benefits of revealing device results at various stages of the manufacturing process.

It is clear though that if both the visible and hidden costs of applying a test solution anywhere in the production flow can be minimised, this dramatically increases a manufacturers test options and ability to react to changing demands for device information.

II. PUTTING RELAY TEST SYSTEM TECHNOLOGIES UNDER THE MAGNIFYING GLASS

A. Is there a perfect relay test system?.

It would be great if there was a single relay test system product which cost very little, was simple to use and measured everything in a very short time. As with the myth of the perfect automobile, if this product existed, nobody would have to consider the tradeoffs between various costs and their benefits. In relay testing, though, the reality is that on the one hand we have the equivalent of formula-1 racing cars which provide relay automation lines with their high throughput, and on the other we have the 'utility runabouts' which are attractive for their low cost. Since there is no 'ideal' relay test 'vehicle' we must deliberate over the nature of the test system, it's options and the total cost so that we can obtain a 'devices per dollar' mileage figure for it.

It's true that test equipment is improving all the time, but it is also true that within relay testing the 'do-everything' test system is often the most expensive and slowest option compared to purchasing a test tool that is adapted to the task, simply because you are purchasing capability that you may not require and circuitry that spends most its time in a few of its many possible modes of operation.

B. How do relay test technologies differ?.

Most relays have a relatively simple coil interface, non-latching devices for example, but a much more complex and varied contact configuration. Since every contact must be tested, there are a number of electronic solutions to test this wide variety of contact configurations. When scrutinised more closely though, these solutions fall between only two major measurement methodologies:

- Dedicated resources.
- Multiplexed resources.

Parallel Test (The dedicated resource methodology.)
The most obviously elegant solution is to apply individual electronic measurement to each and every contact as shown in Fig 1.

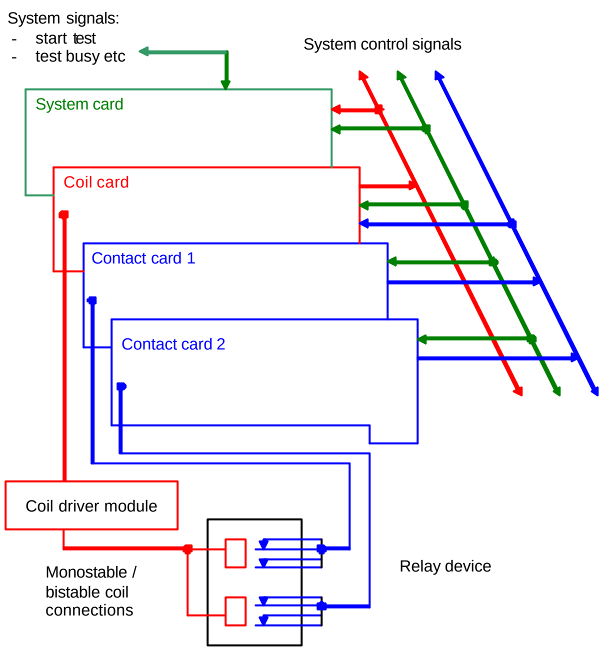

Figure 1 A parallel architecture test system

The benefit of this is that there is an almost direct connection between the measurement circuitry and the relay and that the measurement can actually take place simultaneously on all contacts, improving test time. This general solution is employed in our RT290 high-end test system shown in Fig 2.

Figure 2 The RT290 parallel architecture test system.

Although this architecture is the most expensive to implement, it is ideal for automated lines where it provides the highest throughput (all testing is performed simultaneously). It is also the least affected by device complexity, since a large multi-contact relay tests in the same time as a single contact relay [2].

There is a high cost associated with the design and manufacture of a high speed automatic relay assembly line and there are significant cost benefits to handling and testing devices in parallel. Therefore on many automatic relay production lines more than one device is tested at a time, for example where the indexing time is comparable to the device test time and where this is then the only way to achieve the desired throughput. The dedicated resource architecture adapts to this requirement easily, and Applied Relay Testing's 'ReFlex' architecture [2] has been designed specifically for this need and at a competitive cost. The single relay parametric version is shown in Fig 3.

Figure 3 The Reflex 20 parallel architecture test system.

Sequential test (the multiplexed resource methodology.)

This is the measurement technique used by the lowest cost test systems and those which wish to offer a wide range of test flexibility whilst utilising fixed electronics. A set of standard measurement resources are connected in turn to each parts the relay (coil, contact1, contact2, etc) and measurements are made until the entire device has been covered. The major perceived difference in a relay test system operating in this way is that the contacts are measured sequentially, not together and this philosophy has some impact on the effectiveness of the test system as follows:

- The overall test time per device is longer.
- It may not be relevant to compare associated contact timing results

The increase in the overall test time may not be a problem, especially if there is a significant reduction in cost due to this technique, but the disparity between the contact measurements methods should be borne in mind.

The potential problem of the timing disparity can be minimised (since we do not generally require CR delta between contacts) by allowing sequential contact resistance measurements and by ensuring the contact timing test monitors ALL contacts simultaneously and is not allowed to be sequenced. This raises the cost again, but does now permit correct transfer and simultaneity time reporting.

The multiplexed resource architecture is very popular amongst the lower cost test systems and Applied Relay Testing's new Reflex 10 test system has adopted this test philosophy to offer a price to performance ratio previously not achievable in relay testing.

Figure 4 The Reflex10 multiplex resource tester.

III. CONSIDERATIONS WHEN PLANNING THE PURCHASE OF A RELAY TEST SYSTEM

A. Initial planning, attention to your 'STAFF' details.

When you are faced with choosing a relay test system, as with choosing an automobile the lower you wish to go in cost terms, the more careful you have to be in understanding exactly what you are buying (or rather not buying!)

The laboratory and high volume automated production line test scenarios are technically demanding of the test equipment but the least cost-conscious, the ultimate in test capability and performance, accuracy and flexibility being the major factors. At the other end of the cost scale are the low-cost test systems which are attractive due to their simplicity and low cost-of-test.

Choosing between these two extremes involves some definite compromises, each of which has a direct bearing on the cost of the final test solution. I'd like you to consider these main areas as your 'STAFF details' namely **S**uitability, **T**hroughput, **A**ccuracy, **F**lexibility and **F**ixturing. Let's look at these areas in more detail.

- **Suitability.** The first decision to make is very basic and based on which parameters need to be tested. "Will it test what I need to test?" Does the system include any special test types or meet the need for special tests i.e. MIL Spec can these be added at a later date ?

- **Throughput.** The second decision relates to the throughput that can be achieved with the system. "Fundamentally, will it achieve the throughput I need ?"

- **Accuracy.** The accuracy of the system is a factor since a more accurate measurement system will return a higher yield in allowing testing to limits closer to the actual data sheet limits.

- **Flexibility.** It may be that the system must exhibit a high degree of flexibility either in the device types that it will be testing, in its location or from the capability of its user.

- **Fixturing.** Although often seen a peripheral issue to the test process, a good fixturing solution can improve the cost performance of the test system just as easily as a bad fixture can lower it.

B. How suitable is a test system for my application?

Determining the suitability of a test system starts by confirming that the tests which it will perform cover the test needs of the application. Since high-end equipment will usually perform all possible tests, it is only the low-cost equipment that must be scrutinised to ensure capability in this area. Serious cost-savings can be made here though, because identifying a test system as 'only-just' suitable for a test application will provide the user with the most cost-effective solution, eliminating overkill.

C. Will it achieve the desired throughput?.

Throughput is usually dictated by the test application, i.e. an automatic line or manual production, but there is often scope for considering how best to achieve a specific throughput requirement. Is it possible to benefit by utilising 2 lower-throughput test systems instead of a single faster system? Some production process lend themselves to a 'parallel' style of testing particularly when fixturing times are a significant fraction of the allowed unit time. Throughput is also affected by possible equipment down-time for maintenance or calibration so this must be borne in mind too.

D. Is a test system accurate enough for the measurements that I wish to make?

A test system can only provide test results to a specific degree of accuracy. This accuracy will depend on the performance of the system itself and of the test environment. It will also have a bearing on the cost, both in terms of the initial purchase price (an accurate system costs more) but on device yield (less good product can be correctly identified at final test on a less accurate machine). Fig 5 shows this in action with a typical parameter distribution for a batch of devices. This 'bell curve' is often shaped differently than the symmetrical Gaussian distribution shown here but may be used to represent a typical parameter such as coil resistance or contact resistance. This curve is shown with two sets of limits applied – production limits and data sheet limits. With a highly accurate test environment the production test limits can be made very close to the device specification limits and the yield of good devices is high. With less accurate test, the size of the 'guard bands' (the difference between the two sets of limits) has to be increased to ensure that accuracy errors do not result in out-of-spec devices being shipped, this leads to a consequent reduction in yield.

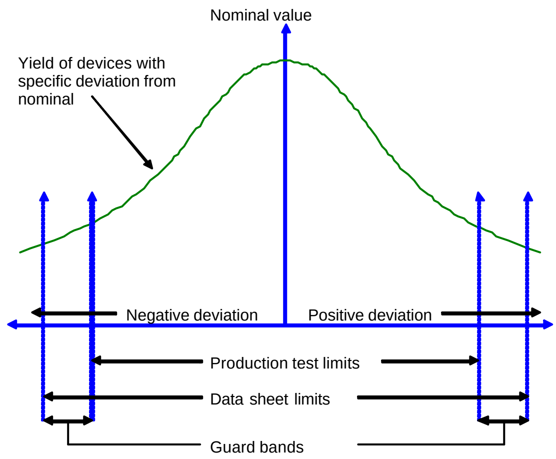

Figure 5 A typical result distribution for a test parameter

It's not all bad news though, because although a high accuracy test system may seem the most desirable solution, the use of a lower cost test system with increased guard bands may result in relatively few devices being rejected. In addition, even a low-cost, less accurate test system can sometimes be kept 'in-check' by appropriate self-test and calibration.

E. How much flexibility should I purchase along with the test system?.

Manufacturing methods vary considerably and it's instructive to look at how the manufacturing costs of various styles of relay are distributed based on the volume of manufactured parts and assembly techniques. Consider the chart in Fig which shows the slice of each cost area by each device sold. Fig 6 shows a cost comparison table between two hypothetical devices, a telecom device (very low lost) and (say) a MIL-spec part (high cost). It assumes that the output of two lines is targeted at the same monetary value ($10M) but that manufacturing methods differ completely – the telecom part is manufactured using an automated production line (low human resource cost / high investment) and the MIL-spec part is assembled predominantly using cell-based manual processes(high human resource cost / low investment).

Category	High cost part, e.g. MIL-spec relay ($)	Low cost part, e.g. telecom ($)
Cost per part	100	1
Line turnover (per year)	10M	10M
Direct human resource cost	60% (6,000k/yr)	20% (2,000k/yr)
Test cost per part	1	0.01
Raw materials	10	0.1
Machine resource cost	10	0.5

Figure 6 Widely differing relay device types - cost comparison

If we look at a pie chart of these two cost breakdowns we see the vast difference in the human resource cost.

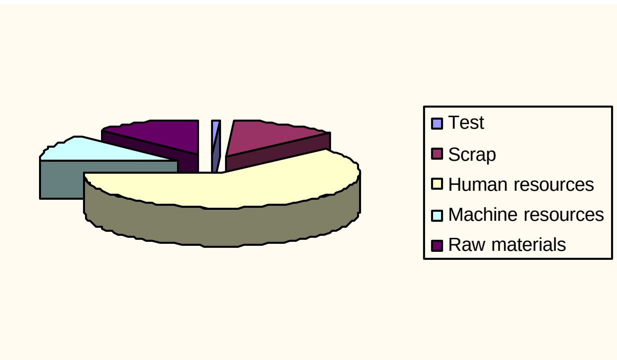

Figure 7 High cost-per-part e.g. MIL-spec relay

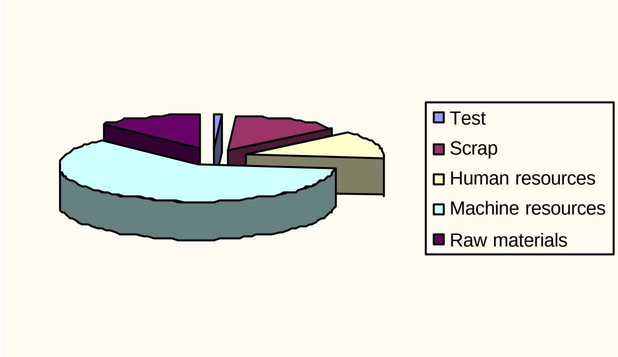

Figure 8 Low cost-per-part e.g. Telecom

You can clearly see that the only major difference between the cost areas is in either machine or human investment – the actual cost of the other areas can often be similar.

So, how does this affect the test environment? Note that we have assumed the same level of test cost ratio for each part type – about 1% of the net cost of the part, however this test is actually 'attached' to the means of manufacture of the part, i.e. either the machine resource or the human resource, so it has to be appropriate for each style of its employment. This implies that:

- **Where there is a high level of human resource cost** the test environment needs to be simple to understand, quick to set up and flexible (it will often be re-assigned or moved between stations). Down-time is not so important here unless costs are to be further minimised.

- **Where there is a high level of machine resource cost** the test environment has to support the dedicated nature of the machine and concentrate on throughput and minimising down-time. Flexibility is not a key requirement here.

This gives us two conclusions.

- Test equipment purchased for manual production should be flexible and easy to use, whilst that purchased for automated production must have a high throughput capability.

- The test equipment purchased for manual production may be required for later function within an automated environment, so consideration should be given to whether this is an issue in the nature of the equipment purchased.

F. Device fixturing considerations.

The other major impact on the "visible" cost of testing is the choice of test fixture. Whether or not to chose a single or multiple test site solution, as shown in Fig 9, is a trade off between a number of factors which include:

- Operator device insertion/extraction time
- Test time.

Figure 9 A multi-way test fixture which can speed operator-based test.

When considering the operator loading and unloading times it is important to consider operator safety - particularly when performing tests requiring high voltages.

G. Is a more expensive test system automatically a better choice?

The Applied Relay Testing RT290 is a relay test system which is both fast (by means of a parallel contact hardware) and comprehensive in its approach to data analysis (using a capture-based architecture). This satisfies those who know they need the most information about the relay that they are testing and the ultimate traceability between laboratory and production output.

However to meet the "lowest cost per part demand" relay test requirements have evolved and a new need is now emerging which is driving the need for both dedicated resources and parallel test. Cost is a major driving factor in these new systems and one which has significantly influenced the design of ART's ReFlex 20 systems.

In manual production lines, at the opposite end of the production spectrum there is now a need more than ever to replace traditional in-house relay test systems with more flexible low cost systems which can provide a good all round capability for the majority of standard relay test requirement. This type of system also addresses the 'in-line production' test requirements of manufacturers and users who need 'casual' or 'roving' test capability.

H. Must you lower your sights when choosing a low cost relay test system?.

The table in Fig 11 illustrates three parametric relay testers from Applied Relay Testing which cover the spectrum of system cost and performance. The RT290 clearly illustrates the performance and resources provided in the high end tester. At the other end of the cost spectrum the lowest cost ReFlex10 offers a good general relay test capability. Interfaced via the PC parallel port this system provides greatly enhanced flexibility both to move between test positions and in not requiring a skilled technician to open the PC case.

Other low cost test systems, such as those based on an internal PC plug-in card offer a very tempting alternative for the low-cost in-house test equipment designer bearing in mind the number of PC's in the marketplace and the low cost of this platform. However, the changing format of PC cards (ISA, PCI etc) and the noisy environment of the PC restrict it's use and make it quite unsuitable for microvolt contact measurements without compromise.

However, the low cost multiplexer based architectures such as that employed in the Reflex 10 do not have to mean that important points have to go unaddressed. What about self-test and calibration?

By retaining internal self-test which needs minimal extra hardware and thus has little impact on price and by removing the functionality of the calibration to a single optional external unit, calibration is fully available without purchasing it as part of the test capability of every system. A typical calibration unit is shown in Fig 10.

Figure 10 A portable ReFlex calibration standard

IV. REAL-WORLD MANUFACTURING TEST SOLUTION CHOICES

A. 'STAFF' choices for a fully automated line.

With a fully automated line, throughput is the most important target and the test system is designed or selected according to the time of each test which needs to be made.

Typical cycle times are in the region of 1.5 to 2s with around 0.5s required for handling, leaving 1-1.5s for actual relay testing, but since automated outputs of around 3k units / hr are rather low it is common practice now to manufacture and test relay pairs, hence doubling the output.

Conventionally, to test a typical relay pair in 1s or less, required two individual high-end test systems are often employed. A typical device test time is around 700 ms for all of the major relay tests which leaves a good margin.

A more recent solution would be to employ a parallel test system architecture incorporating a multiple device capability within a single unit to assemble a dual relay test system. This creates a lower cost and highly flexible synchronous test system that simplifies the triggering and data collection compared to a dedicated dual-high-end system scenario. The Applied Relay Testing ReFlex architecture is designed to create multiple parallel test systems for this purpose.

- **S**uitability. Low-cost test systems are not usually suitable for this application since they compromise test time for simple electronics. The test types to be performed may also dictate a higher 'spec machine.

- **T**hroughput. This is usually required to be high.

- **A**ccuracy. Depends on product quality. If product performance is tight to nominal values, a less accurate system is permitted.

- **F**lexibility. Not important. Once the system is incorporated in the line it is unlikely to be reapplied elsewhere.

- **F**ixturing. Dictated by the production process.

B. 'STAFF' choices for a manual or cell-based line.

Manual relay assembly is often the result of a need for flexibility, difficulty with automating processes or for the production of low volumes of relatively high-cost parts. Indeed most manual production lines incorporate at least partial automation.

The defining characteristic of a manual line is that of individual 'cell' based manufacture within which well-defined processes advance the relay through its production. Reflecting the focussed procedures that are applied within any one cell, the cell equipment is focussed too, for example on adjusting contacts (measuring timing) or for checking contact closure force (CR measure).

For manual test cells, the cost of test is often a major issue in the choice of whether to design in house with it's "hidden" costs and compromises or to buy from a commercial test equipment vendor.

Device test times are less critical in such situations since the set up and adjustment times of many seconds or even minutes are not uncommon. Very low cost multiplexed architectures are ideally suited to this style of manufacture. Easy installation, and roving connection to any PC are real benefits when cost dictates that a limited number of systems are shared across a number of test cells or between production and design workplaces.

- **S**uitability. Low-cost test systems are very suitable for this application since test time is not normally a problem.

- **T**hroughput. This is usually low (one device every 10s or so).

- **A**ccuracy. Depends on product quality. If product performance is tight to nominal values, a less accurate system is permitted.

- **F**lexibility. Not important. Once the system is incorporated in the line it is unlikely to be reapplied elsewhere.

- **F**ixturing. The test system must usually work with a variety of fixture solutions so that it can be quickly adapted to work for with a number of device types.

FIG 11 - COMPARISON OF VARIOUS RELAY TEST SYSTEM ARCHITECUTURES

	HIGH SPEED DEDICATED RESOURCE TESTER	**DEDICATED RESOURCE GENERAL-PURPOSE TESTER**	**FLEXIBLE, LOW-COST MULTIPLEXED RESOURCE TESTER**
OVERVIEW	**RT290**	**ReFlex 20**	**ReFlex 10**
Typical application	Automated/manual production line, laboratory,	Manual production line, laboratory,	Manual production line
Test Time	<500 ms	750 ms – 1 sec	2 – 3 sec
Max throughput, basic tests	>8,000 parts / hr	>3,000 parts / hr	>1,000 parts / hr
System Cost	$40,000	$22,000	$8,000
GENERAL			
Relay types	DC Latching, non-latching, AC optional	DC Latching, non-latching, AC optional	DC Latching, non-latching
Max number of contacts	8 changeover	8 changeover	4 changeover
Contact resistance measure method	Constant current, voltage drop	Resistive, voltage drop	Resistive, voltage drop
Typical accuracy	0.3%+0.3mO	0.5%+0.5mO	0.8%+0.8mO
Graphical output	Full analysis	Graphical timing output	Numeric output only
Calibration	Semi-automatic	Manual	Manual
Handler port	YES	YES	Optional
TEST TYPES			
Fixture check	YES, Kelvin measurement	YES, Kelvin measurement	YES, Kelvin verification
Basic relay tests (Coil, timing, CR, V/I Operate / release)	YES	YES	YES
MIL-spec tests (e.g. Contact stabilisation time, neutral screen etc)	YES	Optional	Optional
Magnetic circuit investigation tests	YES	Not available	Not available

V. CONCLUSION

It has been shown that there is no one single relay test system or methodology that is a solution to all test requirements, but that by matching the test system capability to the application the best cost of test per part can be achieved. This matching process can only be completed by attention to your ‘STAFF details’ – namely “Suitability”, “Throughput”, “Accuracy”, “Flexibility” and “Fixturing”.

VI. ACKNOWLEDGEMENT.

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