Testing Between the Specs:

Spark Testing for Quality Control

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Abstract

Spark testing has long been used on the primary insulation line and at packaging, providing first and final insulation quality checks. These tests are often mandatory under agency specifications.

An increasing number of manufacturers are finding that spark testing provides a valuable tool to check for insulation defects prior to or following interim processes including: twinning, bunching, taping, cabling, jacketing, and marketing.

Spark testers employed at key points of production insure that product damaged by mishandling or faulty prior-processes will not be further processed, which drastically reduces the likelihood that defects will be discovered during final hipot testing or by the customer.

Considerations for spark tester selection and application into interim processes will be discussed.

Keywords

Spark Testing; flaw detection; quality control; proof testing; insulation testing; dielectric testing; interim testing.

1. Introduction

Spark testers provide a clean, reliable, cost-effective in-line method for checking wire and cable insulation quality. The wide range of wire and cable products manufactured requires spark test systems of different voltage types and operating frequencies. Systems are commercially available by a number of manufacturers that can test the majority of wire and cable products. These include power mains frequency, DC, Impulse and High Frequency AC spark testers.

Spark testing has long been used on the primary insulation line as the first measure of insulation quality during the production of insulated wire. It is also traditionally used at the packaging line, providing a final insulation quality check prior to shipment. These tests are mandatory under a variety of specifications. The requirements for the major specification agencies such as Underwriters Laboratories (UL) will be described and information necessary to select the appropriate spark test system will be presented.

Aside from these compulsory tests, quality conscious manufacturers are finding that spark testing provides a valuable tool to check for insulation defects prior to or after processes including twinning, bunching and taping, cabling, jacketing and marking. Spark testers employed at carefully chosen points of production insure that product damaged by mishandling or faulty prior-processes will not find its way into expensive cable assemblies. This can drastically reduce the likelihood that the defects will be discovered during final hipot testing or in the worst-case scenario, discovered by the end user.

These in-process test points are generally not governed by published specifications. The major criteria for the application of a spark test system for these test points are therefore efficacy, reliability and cost-effectiveness. This paper will provide a general overview of the considerations regarding correct selection and application of the various types of spark testing equipment available. These considerations include: selection of test voltage type and level, electrode design and placement, product grounding strategies, process control, maintenance and operator safety.

In many cases, standard spark testing equipment can be integrated into an existing process on the shop floor. In some instances, due to space considerations, modified or custom designed equipment must be developed for specific applications. When new equipment is to be purchased, spark testers can easily be integrated by the equipment manufacturers.

2. Spark Test Operation and Definitions

While spark testers are used in a number of industries to test a wide range of non-conductive products and coatings, spark testers for insulated wire and cable have evolved through the years into a unique and specialized form. They function by continuously applying a high voltage signal through an electrode to all surfaces of the insulated wire during manufacture. The center conductor is at, or near, ground potential acting as the reference ground or grounded electrode. The polymer under test insulates these electrodes from each other. When a defect or a fault in this coating passes through the high voltage electrode, the electrical resistance of the insulation is lowered to the point where an arc will form, which discharges the electrode, allowing current to flow from the high voltage electrode to the grounded electrode. The spark tester detects this current flow and provides various outputs.

2.1 Voltage Type

Spark Testers can be divided into three general types: AC, DC, and Impulse.

- AC testers are the most common type of spark test system. They are widely used to test most types of insulated wire products. These vary by frequency and can be further divided into two groups:

- Power mains frequency spark testers, which operate at 50 or 60 Hz., depending on the Power Mains frequency.
- High frequency spark testers, which operate at frequencies above the power mains frequency. Systems ranging in frequency from 500 Hz to 4.5 kHz have been available. These are the single most common type of spark tester.
- DC or direct current testers are used often to test telecommunication wires and foamed products. Due to the more gentle nature of the DC signal, it is preferred for testing very fine wire with delicate insulation that might be damaged by the more aggressive AC type.
- Impulse spark testers operating at 200-250 ips (impulses per second) were adopted early on by the US military. They are still in wide use by military contractors. In the private sector they have been almost entirely replaced by high frequency spark testers.

2.2 System Configuration

Regardless of the manufacturer and the specific configuration, all spark test systems comprise the following components.

- Electrode. The electrode is the "working end" of the spark tester. Product under test travels through the electrode. In the past, there were as many electrode designs as there were manufacturers of spark testers. Agency acceptance of the bead chain electrode accounts for its wide use. Other designs may offer advantages in specific applications.
- High Voltage Power Supply. This is the high voltage generator, which might be a commercial power supply or a specially designed proprietary transformer. This is typically located within the enclosure that also houses the electrode.
- Control Interface. This provides a means to energize the system, adjust the test voltage and reset the circuitry after a fault has been detected. These controls can be located on the front panel of a separate control unit, operated locally and accessible to the line operator, or it can be interfaced into the centralized, line control system with analog or digital signals.
- Fault Detection Circuitry. This is the heart of the spark tester. The detection circuit analyses the current flow to the electrode. When this current exceeds a predetermined value (that associated with an arc striking ground through faulty insulation) the circuit energizes, providing means to actuate alarms, counters and signals for centralized data collection.

3. Spark Testing to Agency Standards

Agency standards ensure that an effective spark test has been applied to wire and cables made to the standard. UL, NEMA, CSA, BSI and other agencies in their published standards for wire & cable products describe the required spark test apparatus as well as the specific test parameters. These include:

- Electrode Design. As mentioned above, bead chains are the most common type as they are accepted for UL, CSA, NEMA and many other published standards.
- Test Voltage. The voltage is specified in every agency specification. Test voltage varies with the insulation thickness or wire gauge (considerations for test voltage selection in the absence of specified voltages will be discussed later in this paper).
- Electrode Length/Dwell Time. The dwell time is the amount of time that any point on the wire remains under test in the electrode. Electrodes must be long enough to maintain the specified dwell time at the maximum line speed. Often the dwell time (or electrode length) of an AC spark test is linked to the frequency in Hertz of the spark tester. For example, the UL Standard for Electrical Wires, Cables and Flexible Cords, UL-1581, requires an electrode length which will allow nine full cycles.

  To calculate the maximum allowable line speed for a given electrode length to UL-1581 and all UL standards based on it, the following formula is used:

  $$S=(5/9)\ FE$$

  Where S is the maximum allowable line speed in feet per minute, F is the test frequency in Hertz and E is the electrode length in inches.

Agency standards generally specify where in the production line the test is to take place. The two most common test points are immediately following primary extrusion and just prior to final packaging.

While these tests are often mandatory, there are no limitations imposed by these agencies to the number of spark tests that might be conducted to wire and cable products. Manufacturers are, therefore, free to employ additional spark tests to monitor the quality of the insulation elsewhere in the production line, between these compulsory tests.

4. Limitations of Agency Standards Testing

Production line spark testers when properly applied in conjunction with agency standards are effective in detecting insulation defects on primary extrusion of single conductor wire. The final spark test at packaging checks the integrity of the cable jacket only when applied over a metallic shield. When there is no shield, this test is ineffective, detecting faults only when damage to the jacket is severe enough to also expose the underlying conductor, which provides the necessary path to ground. No spark tester is able to find defects in component conductors when covered by a jacket.

Expensive engineered cables typically include multiple insulated wires, twisted pairs, bunched and taped groups, fillers, shields and drain wires. A relatively simple finished cable can represent a dozen or more separate processes, each adding to the cost of manufacture. Defects to individual components, if not detected, can be unknowingly manufactured into expensive cable assemblies. Often these defects will be discovered during final hipot testing, but only after a series of expensive value-added operations have been performed to finished goods. While locating these faults is possible, it is a costly, time-consuming process that often results in less profitable short product lengths and high percentages of scrap. In the worst-case scenario defective cables may pass final testing, only to fail in the field and be discovered by the customer with potentially serious consequences.

With continued attention to product quality and minimizing waste in order to increase profitability, spark testing offers a familiar and valuable tool for manufacturers who must tightly control product quality while keeping manufacturing costs low and reducing scrap. It makes sense therefore, from the point of view of both product quality and profitability, to have the ability to identify defects in cable components following processes that may introduce damage and before they are further processed.

5. Interim Spark Testing

Spark testers offer a reliable means by which defective components can be identified. Often the same type of standard equipment already in use for the agency prescribed tests at either end of the production line can be utilized for this “interim” testing.

5.1 Fault Types

The spark test, when properly applied, will detect a wide range of fault types. Defects that can be detected with a spark tester are referred to as “spark faults” and can be divided into two broad categories: Insulation defects and Subsequent defects.

Insulation defects are those flaws that are associated with the extrusion process and are detected during the primary spark test. Faults of this type are caused by a variety of factors including defective raw materials and improper extruder operation. Insulation defects are outside of the scope of this paper and will not be further discussed. A. Hebert and R. Trinklein have recently written a paper offering a comprehensive discussion of spark fault types associated with the extrusion process in their paper, "Troubleshooting colored wire and cable products." [1]

Subsequent defects are introduced into the product after the primary extrusion of the component conductors. Assuming that an effective spark test has been performed at extrusion and that the product is therefore free of insulation defects, subsequent defects then include anything that compromises the insulation to the point where detection by a spark tester is assured. The causes of these defects are many; careless handling and storage of product, poorly operated or maintained downstream equipment can damage wire. Any process that is out of control can put an insulated wire at risk. The nature of these faults with examples of their causes include:

- Cuts and abrasion. Contact with sharp objects, rough surfaces and impact with objects can cause physical damage to the insulation. Numerous causes have been observed. Among the most common are: collision between fork lift trucks and stored process reels, sharp edges on reels that nick the insulation as wire is being paid off, worn or broken twinning bow ferrules that expose sharp edges, and moving wire falling off of guide sheaves and being skinned by stationary objects.
- Splices. In continuous cabling operations the spark tester detects splices to individual conductors that have not been identified and removed, in the same way as bare wire.

An analysis of product failure modes is often part of a comprehensive Quality Control Program. Careful observation of the processes involved in a particular cable's manufacture will show the cause for faults of any type. When corrective actions are performed, the spark tester's role is then to continuously monitor product quality and alert the operator when control is lost, resulting in damage.

6. Application of Interim Spark Testing

Because interim tests are voluntary and not governed by agency specifications, the sole criterion is efficacy. It is important therefore for persons involved in process engineering and quality control to understand what is required in order to effectively apply a spark test system to a process.

Interim tests on single conductors can be performed using the same type of test system employed for the primary insulation test. This is generally a retest after a period of storage or an incoming inspection for product manufactured elsewhere. For these applications, the same test parameters and electrode design used at extrusion can in most cases be repeated with good results.

Interim tests are often performed on conductor pairs, quads or larger groups of conductors. These applications cannot always be successfully tested with standard test equipment. In some cases, modifications to standard equipment are necessary, in other cases custom-made systems must be configured for specific test points.

6.1 Placement of the Spark Test

In order to assure an effective application it is important to consider the location of the test site. The issue is twofold: finding a location that is both effective and practical.

The spark tester must be positioned far enough into the production line so that all of the potential points of damage precede the test, but before the subject wires, due to some later process, become inaccessible. As an example, when twisted pairs are bunched, the test point is best placed just before the closing die, at a lay plate. Or in the case of a bunch being tested for damage, prior to adding a drain wire or shielding.

Having enough physical space to fit the system can be challenging in an existing cabler, for instance. The control unit (when this is a separate component) can usually be located remotely; the electrode and its enclosure pose the bigger problem. In most cases careful consideration, creative thinking and clever design will uncover an adequate location.

6.2 Voltage Type

Each of the three spark tester types (see 2.1 above) has different properties. No single type of spark tester can reliably test all wire applications.

Multiple conductors place a heavy capacitance load on the spark tester. AC spark testers are sensitive to this loading, which can limit the available AC test voltage. If the test voltage is limited to a level that is below the effective test voltage, an effective test cannot be performed.

DC systems are the usual choices for multi conductor testing. These systems are not prone to current losses resulting from high product capacitance the way that AC and Impulse systems are.

6.3 Test Voltage Level

Determining a safe effective test voltage for testing can be difficult. Too high a test voltage and the spark tester can damage the insulation, particularly on the smaller wire sizes. Too low a test voltage and the test will be ineffective, allowing defects to pass through undetected.

In order for the detection circuit to function, an arc (spark) must occur. The design of the electrode is a significant factor in arc generation along with the voltage potential. The voltage level required to generate an arc between two electrodes (one charged and the other grounded) varies with the amount of air gap between them. This is referred to as the "spark gap voltage." Depending on the shape of the electrodes, this voltage can range between 25 and 100 volts (peak) per mil (.001 inches) of air gap.

In practical terms, the center conductor(s) provide the grounded electrode and the spark tester provides the charged electrode. The air gap is the space between the closest bead or bristle to the wire surface plus the insulation thickness, which for the purpose of spark test potentials is treated as additional air gap.

Spark tester test voltages as mentioned earlier are generally specified by agency standards for the primary extrusion test. These voltage levels provide a good starting point for test voltages when testing singles or twisted pairs during interim testing. When a test voltage is not given, it is necessary to experiment to determine adequate test voltage levels. This testing is to determine two key voltages: dielectric breakdown voltage and minimum effective test voltage.

The dielectric breakdown voltage is the voltage level at which good insulation will fail. This value is a function of the dielectric strength of the insulation polymer and the thickness of the insulating layer.

It is difficult to calculate an accurate breakdown voltage of an insulated wire even when the dielectric strength per mil of the insulating polymer thickness is known. It is more accurate to perform a simple test to a wire sample. Place a sample of wire into the spark test electrode and ground one end. Elevate the test voltage until the insulation fails, noting the voltage at which failure occurred. Repeat this test on fresh samples several times to arrive at an average value. This is the breakdown voltage for the product.

The minimum effective test voltage is the lowest voltage at which the spark tester will reliably detect a typical fault of the type likely to be encountered in the application. This voltage is also easily determined though testing. Manufacture a fault, which will approximate a fault similar in nature to the actual faults encountered. Set this grounded wire into the spark tester and elevate the test potential until the fault will reliably be detected. Again repeat this test to arrive at average values. Use fresh samples each time because the carbonized polymer surrounding a previously detected fault site will artificially reduce the fault resistance and will lower the required voltage, yielding inaccurate results.

Choosing an effective test voltage is a matter of selecting a voltage between the dielectric breakdown and the minimum effective test voltage levels.

H. Clinton has provided a thorough discussion of this method of determining test voltages in his paper entitled, "Selection of 3kHz spark testing potentials for insulating wire." [2]

When a high frequency (AC) tester is used on the primary line for a given wire, but a DC tester is used when testing at twinning or cabling, it is necessary to select the equivalent DC potential to the AC voltage level. To convert an AC potential, which is an RMS (root means squared) measurement, to its DC (Peak) voltage equivalent, multiply the RMS value by 1.414. To convert a Peak voltage to its RMS potential, multiply the Peak Value by .707 (the reciprocal of 1.414).

Testing larger groups after bunching can pose difficulties in the selection of an effective test voltage. It is important to remember that the test voltage for the group cannot exceed the breakdown voltage of any single component conductor. A test voltage that is high enough to find pinhole faults in the middle conductor of the group may well be above the breakdown voltage in each conductor, possibly causing failures.

If detection of anything more than splices and gross physical damage is required, it is preferable to test the individual wires or pairs prior to closing or bunching at safe, effective voltage levels.

6.4 Electrode Type

Although standard electrode designs have been in use for many years, any conductive material that can be electrically connected to the high voltage power supply could conceivably be used as an electrode. The goal in choosing an electrode is to provide good product coverage allowing the test voltage contact with all surfaces of the product under test. Since the electrode is in physical contact with the moving product, it must be made of a material that is both long wearing and not damaging to the insulation. The most common electrode types are: bead chain electrodes, brush electrodes and ring electrodes. Each type has advantages and limitations.

The nearly universal agency acceptance of the bead chain design is an indication of both its effectiveness and its superior wear characteristics, compared with other materials. Bead chain electrodes can be made in different sizes to accommodate different product diameters and to fit different space allocations. Bead chains do not provide perfect coverage on large products, which require higher test voltages. Bead chain electrodes are not suitable for wires running vertically.

Wire Brush Electrodes are widely used to test flat cables, wire running vertically, or very large cables. Brushes typically are spring-loaded and bear directly on the wire surface. This allows for lower effective test voltages, as the air gap between the electrode and the wire surface is essentially eliminated, but wire brushes may abrade more delicate insulation. Brushes wear quickly, and over time will develop a “set” (the bristles bend and lose contact with the product). Bristles may break free from the brush and cling to the product. Due to the rate of wear, brushes must be replaced more frequently than bead chains. Electrodes made of metal rollers are sometimes used in place of brushes; they do not wear quickly, but are suitable only for flat cables.

Ring Electrodes encompass many different types. Wire running through charged pigtails, springs, loops and tubes are all examples. Ring electrodes are simple and long wearing. However, ring electrodes are problematic in that adequate clearance must be provided to allow easy wire insertion when stringing up the line at start-up, and to allow variations in the diameter of the product under test. This clearance distance increases the air gap between the charged electrode and the wire surface, which will necessitate a higher test voltage. If the test wire is not guided concentrically though the ring, excessive electrical stress will be applied to the insulation. When the dielectric strength of the insulation is low, damage may result.

6.5 Fault Indication

As with standard production line spark testers, fault indication for interim testing is by front panel fault lights and counters as well as relay contacts, which can initiate process alarms and controls. The testing of single wires, pairs and bunched groups is identical to testing at extrusion or packaging, in terms of fault indication.

When testing multiple conductors, however, testing is often performed on groups of wires, running in parallel, through a common electrode with a single fault detector. This is referred to as "group detection." When the spark tester indicates a fault, it will not be known which conductor of the group tested contained the defect. Often the spark tester is configured to signal the line to halt and the defective conductor is located through visual inspection. In these cases knowing in which wire the fault occurred may not be important to the manufacturer, as that entire portion of the wire will be marked and discarded.

When testing multiple conductors, pairs or quads it is, of course, possible to detect faults in any wire, identifying the specific conductor in which the defect occurred. This is called "individual detection." In this case separate spark testers with individual electrodes are required. Due to the cost and space requirements of separate spark test systems to accommodate cable testing of up to 200 twisted pairs of wires, multi-channel spark test systems comprising separate fault detection, and fault indication circuitry for each channel, all housed into a common enclosure, have been developed. These units offer differentiation between pinholes and bare wire, with separate control outputs for each fault type.

While these custom designed systems are more complex and expensive, some manufacturers have found that having this information available allows for data collection of defect types, and patterns. Data analysis may point out specific processes or equipment that are out of control, leading to high percentages of failure. Corrective action can then be implemented that will justify the cost of the equipment.

6.6 Control Options

Control requirements for spark testers used in interim testing are similar to standard spark testers. Both local and remote control versions are available.

6.7 Grounding of Conductors

There is much confusion within the industry regarding the grounding of conductors during the spark test. In his paper, "Grounding of Conductors during the Spark Test," H. Clinton discusses the reasons for grounding in terms of compliance with agency standards, efficacy of test and operator safety. [3] This complex issue will not be discussed in detail here, except to reiterate the importance of providing a secure ground connection to each conductor under test, and to provide a brief overview of the methods by which this grounding can be accomplished.

The grounding of wire on a process reel is relatively easy, requiring only minor modifications to equipment and processes. When the wire is wound onto the reel a tail must be left protruding from the side of the reel at the bottom. This "lead" with the insulation must be stripped from the end will later provide the ground connection during the spark test. The payoff spindle on the cabling machine likely rotates with the reel. It is a small matter then to drill and tap a hole into the spindle, insert a stud and provide some means by which a secure connection can be quickly made during changeover, generally a wing nut or a short lead with an alligator clip, or the like. The payoff rack must then be bonded to earth ground.

When wire is paid-off from a stem or barrel pack, it is also necessary to have the wire at the bottom accessible. When this is the case, a ground lead, bonded to a reliable ground connection, can be conveniently made.

Often, prior processes must be altered to ensure that the means for providing the ground will be available. In the case where component wire is purchased off-site, specifying access to both ends of the wire on a reel or barrel as a condition of sale may be necessary. In cases where this is impossible, there is little choice but to respool the wire, or to make the ground connection at the take-up end of the cable line.

It is equally effective to make the ground connection at take up; however, all of the connections must then be made with each finished reel, which may be cumbersome.

Some agency standards require grounding at both ends. While these tests are not governed by agency standards, the rationale for grounding both ends bears mention. Should there be a break in the conductor (open conductor) when only one end is grounded, the other end of the wire is left ungrounded, or floating. If the break has not opened, an intermittent ground may be present. This can cause false indications by the spark tester. Both cases pose safety concerns for the operator.

6.8 Maintenance

Maintenance on spark testers used for interim testing is the same as for production line spark testers.

The electrodes should be inspected regularly for excessive dirt build up, wear and damage. They should be cleaned or replaced when the condition of the electrode may begin to compromise function, i.e., when the beads or brushes are damaged to the point where they no longer make contact with the product.

Cable connections between spark tester components, power and ground should be inspected periodically for damage and looseness.

The equipment should be calibrated regularly, on the same schedule as the other spark testers in the plant. Since calibration generally only checks the high voltage output against the spark tester's voltmeter, some means of checking detector function and detection sensitivity is also advisable (this is true for all spark testers, regardless of application). This can be accomplished by purposely damaging a wire while it is being tested. If this is not practical, it can be checked offline by use of a grounded probe. Having a probe grounded through an impedance to simulate the load placed on the spark tester when wire is in the electrode will give more accurate results.

7. Conclusions

Mandatory spark tests to agency standards provide adequate in process and final quality control measures for single conductors and simple cables. These tests are often inadequate, however, in more complex cable constructions that may comprise dozens (if not hundreds) of separate components. These cables involve many different processes and a considerable amount of handling and storage of component parts. Each added step increases the possibility for damage, caused by many different factors, to individual cable components. This damage, if undetected, can cause failure at final testing, rejected product and lost profit.

Adding spark test systems at logical points of production can identify defects and damage to conductors before they are manufactured into expensive cabled products.

To apply the spark test system to an interim process, an analysis of the process under test, and understanding of spark test function and the elements of a successful spark test are necessary to make certain that product quality is being consistently and accurately monitored.

8. Acknowledgments

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9. References

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