# PROBLEMS WITH IN-LINE HIGH VOLTAGE CONTINUITY (HVC) TESTING

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**ABSTRACT: This is a summary of magnet wire testing equipment, procedures, and its evolutionary role in achieving present day wire excellence. We all benefit from the improved quality of the myriad products we use that incorporate magnet wire.**

Key words: Magnet wire, Testing equipment.

## I. INTRODUCTION

We sometimes forget what tremendous improvements there have been in manufacturing magnet wire. Initially, magnet wire was insulated by being wrapped with one or two layers of cotton thread. It was called SCC or DCC for Single Cotton Covered or Double Cotton Covered. The cotton served as a spacer, keeping the copper wires separated from each other, rather than as an insulator. Equipment using that wire was designed for rather small voltages between adjacent turns of wire. Careful layer winding was necessary with separate sheets of insulation placed between layers. Later, in the early part of this century, the Dudlow's developed film insulated, enameled, wire in Fort Wayne, Indiana. Their wire coating functioned both as a spacer, and as insulation, permitting smaller and less expensive products. Since that time, there have been continual improvements in the coating material and application methods. Present magnet wire is tremendously better than the earlier varieties.

## II. DISCUSSION

In the early 1950's, a magnet wire film coating continuity test was developed to determine if there were holes in the film coating or bare portions of the wire. A sample of the film coated wire was pulled through a pool of mercury with a test voltage of 20, 30, or 60 volts applied between the mercury and the wire. If the resistance between the electrode and wire dropped below 5,000 to 10,000 ohms, a counter was incremented. A mercury to wire contact length of 1 inch was used, largely because of the time necessary to activate the counter. Initially, long portions of bare wire would be counted as one fault. The circuit was modified so that the counter would advance repeatedly as long as the bare wire was in contact with the mercury electrode.

It was soon recognized that there should be an industry standard for such a tester and the National Electrical Manufacturers Association (NEMA) "Committee X" was formed. The committee was composed of representatives from various magnet wire manufacturers. They established a standard.

Later, there was an increasing awareness of the hazards of mercury vapor and a different electrode system was sought. The wire was caused to partially wrap around a v-grooved pulley with a voltage applied between the wire and the pulley. It was recognized that the pulley would not make actual electrical contact with the wire through small diameter faults, so to overcome this problem, the test voltages were greatly increased so they would jump this gap. It was found later that these voltages were not high enough to detect small faults on the side of the wire not in contact with the pulley. A second similar pulley was added a short distance along the wire and on the opposite side of the wire. It counted the previously missed faults, but there was overlap in the coverage of the two pulleys, and faults on the side of the wire were detected by both pulleys and counted twice. With no obvious solution, it was accepted that the wire was better than the test indicated.

In the late 1970's, it was recognized that a film continuity tester operating on wire as it was being manufactured, rather than later in the quality control (Q.C.) lab, would have significant advantages for quality production and marketing. Some manufacturers placed v-grooved pulley electrodes in contact with the wire as it was being produced. The resulting data was used by supervision and management to evaluate the coating process.

The importance of in-line testing, that is testing *all* of the product, became apparent. A number of ways were devised and tried. The results were often disappointing. It was essential that the testing be valid, but in no way deteriorate the quality of the wire.

A major advantage of in-line testing is that a process that produces wire with less than optimum quality may be discovered immediately, permitting immediate correction, resulting in premium quality wire. This is far better than scrapping wire that has been found to be inferior, obviously. Q.C. Lab tests did not provide timely oven operator information.

Even when a satisfactory in-line test method appeared to be found, it often turned out to produce different results that the long accepted NEMA specified sampling tests. There was a question of which to believe. The wire user may have become quite familiar with the NEMA standard sampling tests and may have acquired equipment to perform those tests. How do you argue with a good customer who believes he has discovered that the quality of your wire is less than he expected? Exchanging returned wire does not entirely solve the problem.

What is needed is in-line testing that produces the same results as the well-established NEMA sampling tests. A worthy endeavor, but not easily accomplished.

A problem with the V-grooved sheaves that were used in sample testing was that they could produce work hardening in the wire when it passed over the four small diameter pulleys that the NEMA standards specified. While this was not a problem in sample testing where the test samples were discarded, it was a concern with 100% in-line testing.

One solution was to use larger diameter sheaves, but this produced a wire to sheave contact length of more than the one inch specified by the NEMA standard, which also required that defects substantially longer than one inch are to produce more than one fault count. A large sheave that contacts several inches of wire would either produce more than one count for a very tiny fault or it would disregard the NEMA requirement and count a long bare area the same as the single tiny fault. The large sheave could not produce in-line test results compatible with the NEMA specified sampling tests. Compatibility with the NEMA standard was of undoubted importance, so this became quite a disappointment.

An electrode using a conductive carbon foam sponge was tried. It appeared to have great promise. It eliminated double counting and contacted the wire for only the desired one-inch. Unfortunately, an uncorrectable deficiency was soon found. The material had a plastic memory. The presence of the wire could form a groove in the sponge so that there was no longer electrical contact with the entire periphery of the wire. Some of the wire faults were not detected and counted. Again, it proved to be not compatible with the NEMA specified sampling tests.

Recognizing the problem, we developed an electrode using single crystal, carbon fiber brush electrodes to contact the wire. The fibers were very flexible, being of a diameter about one fifth that of a human hair. Surrounding brushes provided contact with the entire surface of a one-inch length of wire without bending it from its normal straight-line path. The work hardening problem, and the problem of incomplete surface coverage by v-grooved pulleys or v-shaped scrapers, and the problem of a larger diameter v-grooved pulley contacting more than a one-inch length of wire, were simultaneously eliminated.

A demonstrator was built that passed wire through several successive test electrodes of different types. There were defect counters for each of the electrodes. In addition, there was a computer display of the test results for each of the detector heads.

The close and predictable spacing of the double counts from the two v-grooved sheaves became glaringly apparent. Defects missed by the carbon foam electrode also became obvious. It became immediately apparent that the carbon fiber brush electrodes did not double count any of the faults. Two carbon fiber brush electrodes were placed sequentially along the wire. It was reasoned that any difference in their counts would become immediately apparent. There was none. They did not miss faults.

The NEMA committee soon learned of the carbon fiber brush test results and adopted them as a replacement for the dual v-grooved sheaves.

We think it is very important to attain full compatibility between the sampling tests, which have been used for decades and in-line testing of all of the wire. But even beyond the benefits from such compatibility, potentially the greatest benefit to accrue from in-line testing is that it can immediately reveal any process deficiencies in time to correct them and eliminate making wire that must later be scrapped. The result should be better wire at lower cost, an unbeatable combination.

The NEMA standard Q.C. sampling test for benchtop testers is performed at a wire speed of 60 feet per minute. We discovered that at the higher wire speeds encountered when testing wire as it was being produced, there were new problems.

The NEMA standard specifies a count rate of 450 counts per minute for bare wire in Q.C. testing at a wire speed of 60 feet per minute, causing lengths of bare wire to be counted at a rate of one fault for each 1.6 inches of bare wire. At the higher wire speeds of in-line testing, this specification would result in counting considerable lengths of bare wire as single faults. For example, at a wire speed of 600 feet per minute, a 16-inch length of bare wire would be counted as one fault. We increased the count rate for the in-line system to be in proportion to actual wire speed.

At the high production wire speeds, pulses less than 6 milliseconds wide might be caused by valid faults. However, the NEMA specification says they should not be counted (since they were considered to be noise pulses). After some investigation, we found that typical noise pulses were much shorter than 6 milliseconds, actually only a few microseconds long. We modified the shortpulse rejection circuit accordingly. The result was the ability to handle high wire speeds and still reject actual noise pulses.

We have discovered another problem at high wire speeds. There is a capacitance between the wire and the test electrode. This capacitance must be charged to the specified test voltage in order to produce a valid test. To cause this charging, a current is necessary. This current can appear to the test system as a fault current. It can also cause a voltage drop in the NEMA specified series resistance causing the test voltage to be considerably lower than that specified by NEMA.

At the NEMA specified test speeds; these phenomena do not seriously affect the test conditions. However, at the wire manufacturing speeds, they produce test results that are not compatible with NEMA specified Q.C. tests. Since this compatibility was, for us, a major objective with in-line testing, this was a serious problem.

Fortunately, after considerable development effort, we have overcome this problem so our equipment meets the NEMA specified test voltage, current, and series resistor conditions at all wire test speeds. There can now be complete compatibility between the Q.C. Laboratory tests and in-line production test results at much higher production wire speeds.

The wire capacitance causes still another problem. As wire leaves the test electrode, its capacitance remains charged to the test voltage. The stored charge on the wire spool can result in a disagreeable electric shock for anyone handling the spool. In addition, the long-term application of the high voltages to the wire insulation can cause dielectric breakdowns. The solution is to place another carbon fiber brush electrode "downstream" from the test electrode. Connecting this electrode to ground through a low resistance will discharge the wire and prevent such shocks or potential wire deterioration.

We believe there is one more important requirement for an in-line system. It must have a continual self-test feature to provide immediate notification if it ceases to function properly. Without self-testing, the apparent absence of defects might be interpreted by the manufacturer to indicate that perfect wire is being produced. Later rejection of that wire by the user, with accompanying displeasure and distrust, would be highly undesirable.

In-line testing could provide a "map" of any defects that were located. Such a "map" would permit the wire user to avoid incorporating that portion of the wire into a product. While rejection of selected portions of wire might be inconvenient, it would not be as inconvenient as rejecting the product incorporating that portion of the wire if the product failed in testing because of those wire flaws. It would certainly be much more convenient than replacing a product that experienced failure in the ultimate users hands.

## III. CONCLUSIONS

As these benefits of in-line testing become widely recognized and accepted we believe there will be increasing interest in in-line testing for other wire parameters such as in-line Surface Defect Detection (SDD) and, in-line Dissipation Factor (DF) measurement to provide continuous indication of the degree of cure of the film coating so the cure can be automatically controlled to maintain it at its optimum value. We are also considering in-line non-destructive dielectric breakdown strength testing. We realize that this statement appears to be contradicting. How can you have breakdown testing that is non-destructive? It turns out it is achievable.

**John A. Whitney** earned a B.S. in electrical engineering from the Indiana Institute of Technology and an M.S. in electrical engineering from Purdue University. He taught electrical engineering classes for 17 years, while developing test equipment in Indiana Tech's Research and Development Laboratories. John also served as Manager, Engineering, Advanced Development, for 25 years at the Franklin Electric Company, Bluffton, Indiana. He is now serving as a consultant for A/Z-Tech, Inc.