Evaluating Motor Condition With Advanced Diagnostics (Part 2)

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In the first part of this two-part series, we discussed the components of low voltage testing and how ALL-TEST Pro, LLC and PdMA Corp utilize these methods in order to identify and trend faults in motor windings. In this article, we will discuss surge comparison testing as a high voltage testing method used to detect weakened insulation between conductors. We will then compare the application for each of the testing methodologies.

Surge Comparison Testing

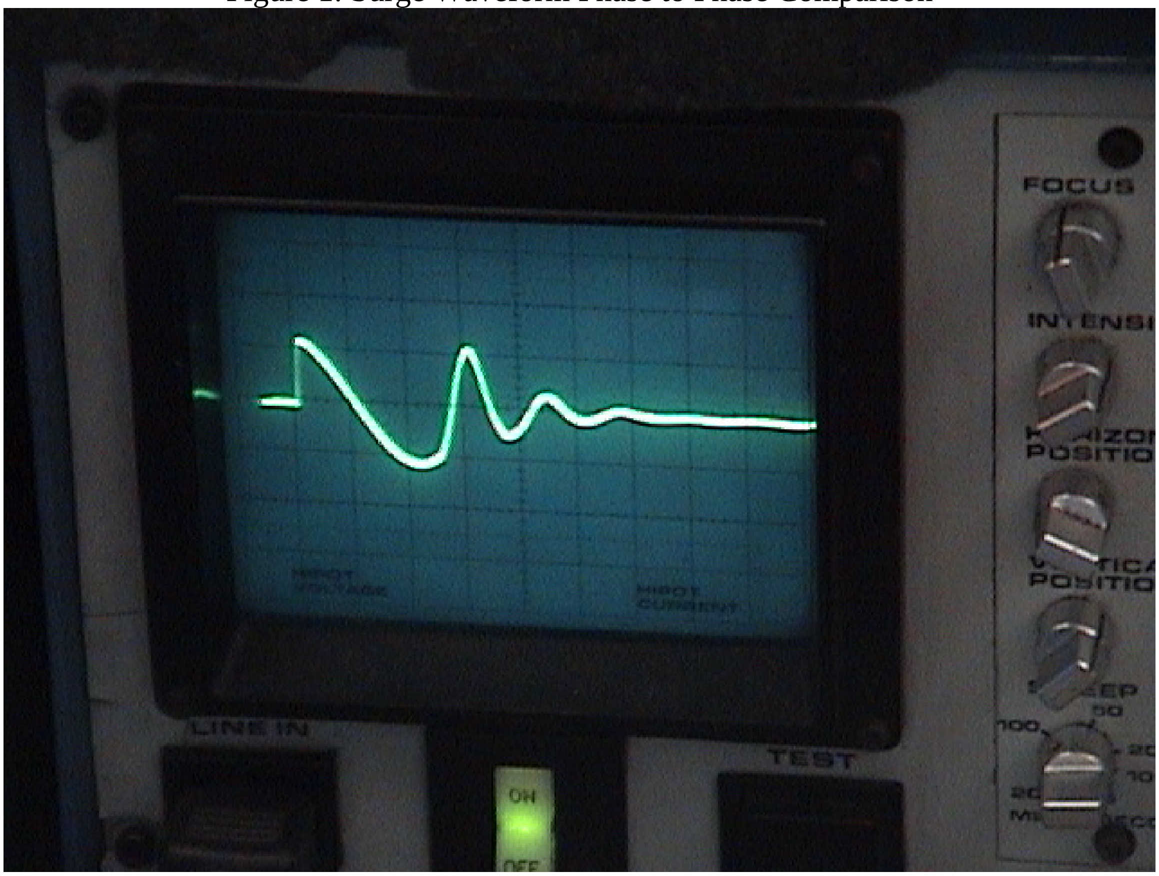
The concept of high voltage testing for turn insulation faults have been around for over 80 years but only put into practical application over the past fifty plus. In modern times, if a motor repair shop or motor manufacturer is not using surge comparison technology to confirm the quality of their turn insulation system, they cannot meet modern motor repair or manufacturing standards or specifications. These include the ANSI/EASA AR-100 motor repair standard by the Electrical Apparatus and Service Association, Inc., NEMA MG-1 standard by the National Electrical Manufacturers Association and Institute of Electrical and Electronics Engineers, Inc. (IEEE) standards.

Surge comparison test instruments operate by sending out a high voltage, fast rise-time impulse. When the impulse is introduced to a coil, the peak of the impulse resonates based upon the impedance of the coil and a 'ringing' effect will appear at the peak of the impulse. If impulses are applied to two or more identical coils, and the peaks are viewed on an oscilloscope, the ringing should be exactly the same. If any of them deviate, it represents a difference between coils.

This technology operates via Paschen's Law. The basic definition is that this guides the voltage required to ionize the space (gas or material) and then draw an electrical arc between two conductive surfaces. Jacob's ladder is an example of Paschen's Law at work and was often used in old horror and science fiction movies to show an arc forming between two antennae then climb to the top and repeat. When breakdown occurs between two conductors, how the energy reacts will depend on the type of breakdown or failure. When dealing with two points in atmosphere (air), a point of partial discharge will occur at a voltage below the point where an arc would be drawn. If there is weakness between two points in insulation the fault may react with some level of partial discharge, or may not and go directly to an arc. The amount of voltage required depends on the distance across the fault point, the material across the fault and the depth into the coil.

In smaller machines, there are a larger number of turns per coil and per phase. As the high energy impulse is applied to the winding, it dampens quickly across the first two to four turns of up to hundreds of turns per phase. In larger machines, the depth of penetration of the high energy impulse will vary by the design and size of the coil. This means that when the new winding or used winding voltage is applied, the surge may not detect weakness further than a few turns into the winding. Both found conditions or missed faults are frequent enough that those that support the technology and those who object to the technology in field applications can identify numerous examples. The user should understand that both situations are very possible.

Figure 1: Surge Waveform Phase to Phase Comparison



When a breakdown does occur, it will happen at a specific voltage that relates to the severity of the fault. Typically, the minimum voltage to pass can be found in Formulae 1 and 2.

Formula 1: New Winding Surge Voltage

$$Eapp = 2E + 1{,}000V$$

Where Eapp is the Surge Voltage and E is the motor nameplate rating.

Formula 2: Used Winding Surge Voltage

$$Eapp = 0.75(2E + 1{,}000V)$$

When an electric machine has a rotor, the position of the rotor has a direct impact on the shape of the waveform and will be different for each phase. With a standard surge comparison tester, the position of the rotor must be adjusted whenever comparing two coils in an assembled machine. Newer technology surge comparison testers, used in field applications, electronically compensate for rotor position.

Figure 2: Standard Surge Testing With Arc

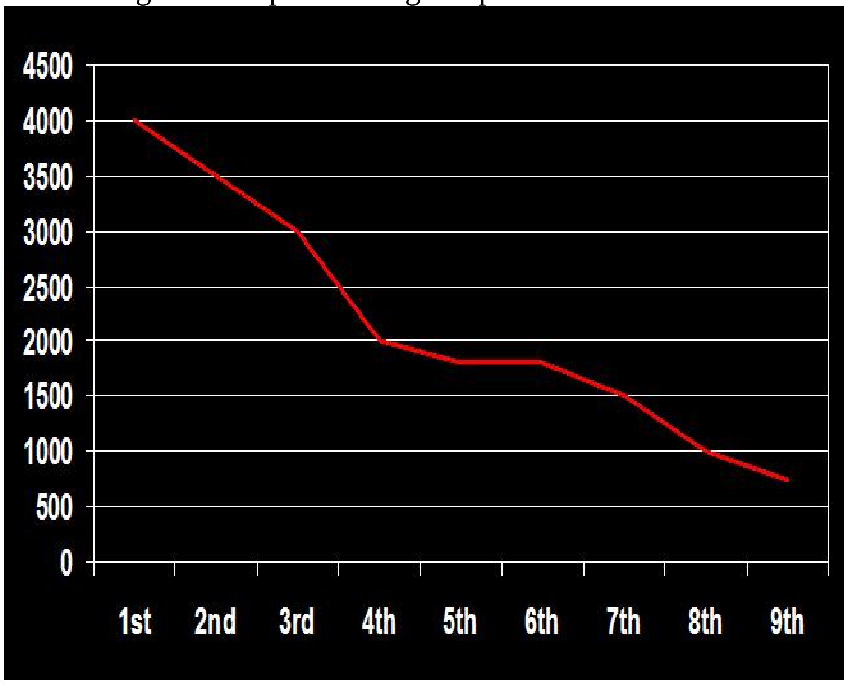
The size and voltage rating of the surge comparison tester will vary based upon the size of machine that is meant to be tested. Commonly if there are a number of medium voltage motors that will be tested, up to 6,000 Vac, a surge tester with a voltage limit of 12,000 V is used. If all of the motors to be tested are rated under 600 Vac, new testers are available with an upper limit of 2,000 V.

Winding Analysis with Surge Comparison Testing

When a winding is evaluated, and is in new and good condition, the waveforms associated with the condition of the machine will be identical between phases when electronically compensated. In fact, a new winding can often have voltages applied many time the maximum values calculated by either formula 1 or 2 without degrading the insulation system. It is not until energy crosses between conductors that any latent damage, or accelerated degradation, may occur.

As a result of the potential damage that may occur when weakness is found, the newer digital surge testers monitor for the point where partial discharge occurs, which, by eyesight, would be an unstable surge waveform. This is very important as previous testers relied upon user operation. As shown in Figure 3, a human operator using a surge comparison tester on a failed insulation system. The fault point is shown in Figure 2 which was a deep-winding phase to phase short that was observable to the operator prior to surge application. The surge was applied repeatedly to the winding and stopped as soon as there was any deviation to the waveform which only occurred, to the human eye, when the arc was drawn.

Figure 3: Repeated Surge Impact Human Control



The newer digital technology surge testers are designed to avoid this type of situation by identifying the variation in the waveform prior to the arc being drawn. This reduces the instances where the detection of insulation weakness causing immediate faults.

Baker AWA Tester

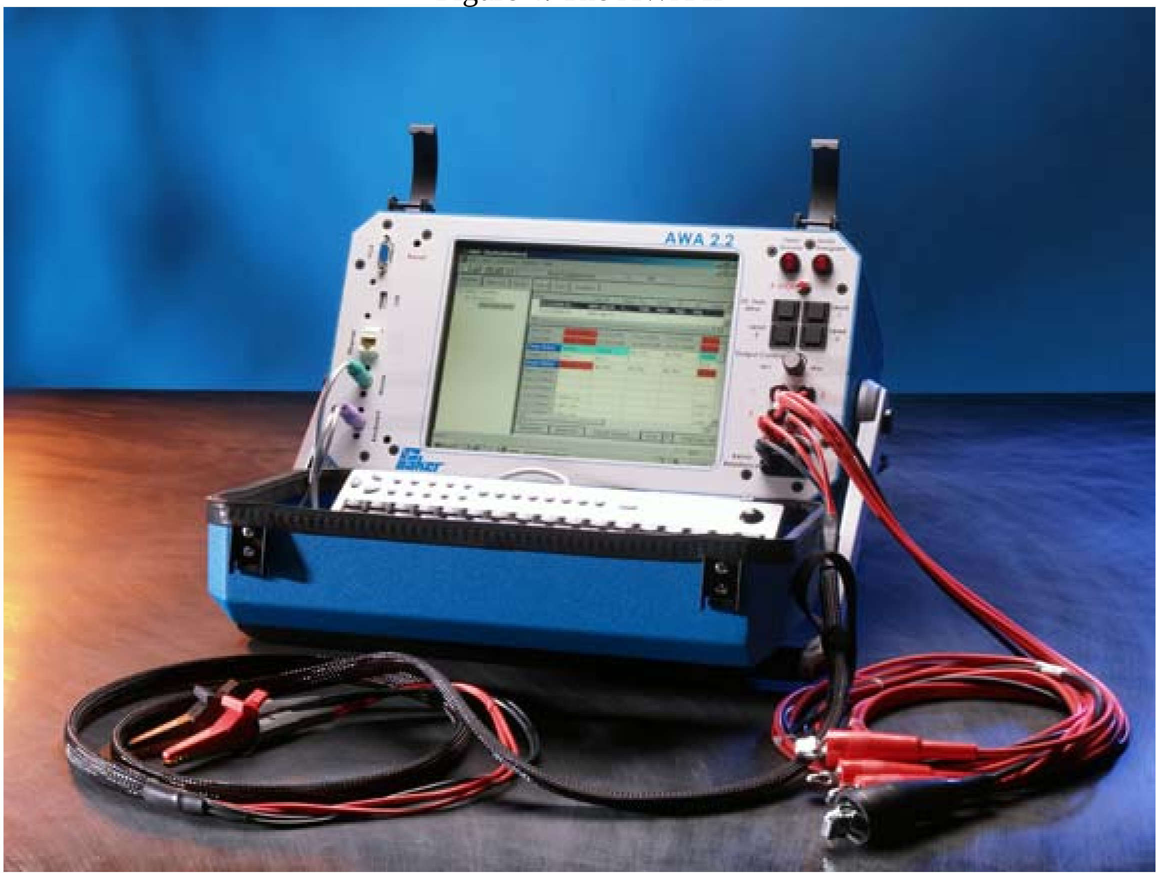
Two of the primary digital surge comparison instruments are the Electrom TIG instruments and the Baker Instruments Advanced Winding Analyzer (AWA). With the AWA providing a trendable phase to phase value, we will cover that instrument in this article.

There are two primary models, the AWA IV which has a 12,000 Volt limit and includes a built-in surge comparison tester, polarization index, DC Hi-Pot, insulation resistance and winding resistance testing. This unit weighs 42 pounds and requires a power outlet. The AWA II is a solution for users of smaller electric motors and includes the same tests with a 2150 Volt limit. This one weighs 18 pounds and also requires a power outlet. Both contain a software for trending, recordkeeping and troubleshooting.

Table 1: AWA 2.2 and AWA IV

Test	**AWA II**	**AWA IV**
Surge	0 - 2150 V, 200 Amp	0 – 12,000 V, 400 Amps
DC HiPot	0 - 2150 Volts,	0 – 12,000 V
Insulation Resistance	Up to 50 Gig-Ohms	Up to 50 Gig-Ohms
Resistance	0.001 to 50 Ohms	0.001 to 50 Ohms

Figure 4: The AWA II



Comparison of Technologies

There has been a long battle of articles and papers by the manufacturers of both low and high voltage winding analyzers. To be quite blunt, the verbiage is presented in such a way as to claim one or the other are not effective, or unable, for some reason, to meet their claims. These discussions are, quite simply, market speak as the users of each of the technologies will attest to.

Following is a short summary of the strengths of each of the primary technologies' capabilities (in alphabetical order):

☑ ALL-TEST Pro, LLC: Manufacture the ALL-TEST IV PRO 2000 and ALL-TEST PRO 31 analyzers. Both are hand-held instruments that are focused on evaluating insulation degradation, contamination, insulation troubleshooting and rotor testing. While they each include an insulation to ground tester, this is not their primary focus. The ALL-TEST IV PRO 2000 instrument saves data in memory that can be uploaded and downloaded to software that provides data analysis and trending. Requires a minimal level of training for successful use.

☑ Baker Instruments: Manufacture of surge comparison test instruments including the AWA II and AWA IV. The built-in software provides trending capabilities with a focus on insulation weakness due to insulation defects and wear. The insulation resistance test capabilities also test for insulation to ground weakness and built in limits provide an increased level of automatic protection which are designed to reduce the chance of damage and will stop testing if a fault is detected early enough.
☑ PdMA Corp: Manufacture the MCE instrument which is portable and includes a laptop. The focus of this instrument includes insulation to ground testing, winding contamination and rotor testing with the ability to detect later stage turn insulation faults. This instrument requires a medium level of training and experience for successful use.

All have the capability of testing AC induction motors from the motor control center, disconnect or right at the motor. Each will detect cable faults as well as motor winding faults and each will detect insulation faults in advance of failure.

Conclusion

Advanced winding analysis troubleshooting and trending techniques for electrical machine insulation testing are extremely important for improved reliability of industrial, commercial, utility and manufacturing firms. At the present time, there are three primary off-line motor diagnostic technologies including: ALL-TEST Pro, LLC, Baker Instruments and PdMA. Each of the technologies has specific strengths and capabilities which should be selected based upon the particular site's needs.

The purpose of these last two articles has been to outline the basic concepts of each technology and their specific strengths and concerns.

About the Author

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