Electronic Systems of Wisconsin, Inc.

# Production Testing of Low Resistance Stators & Armatures

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ESW has developed a testing process specifically for Low Resistance parts. These parts are typically used in applications like starters, alternators, and DC motors. Basically, all parts use standard testing techniques, however, due to the uniqueness of the process and properties of these parts, special methods are necessary.

## Low Resistance Challenges

Before discussing the specifics of testing low resistance products, we need to consider the unique problems that can arise during the manufacturing processes. In general, the basic construction of these products is similar to those components found in smaller AC & DC motors used in consumer grade appliances and hand tools. However, there are also some specific material properties and process steps that we see only in low resistance products.

Usually, low resistance armatures and stators are wound with much heavier gauge wire. Many of these parts are wound with 14 gauge or lower magnet wire. Typically the number of turns within a given coil structure is limited to six. Forming of the heavier gauge magnet wire is a difficult task. Nicks in the insulation and wire are very common due to the process necessary for forming. Nicks create electrical “hotspots” in the coil. In addition, more effort is needed to insert the wound coil into the lamination slot. This in turn places additional stress on the wire and slot insulators. Likewise, the coil-to-coil winding consistency is subject to greater variability. The heavier gauge wire does not lend itself to consistent layering, as does the smaller gauge wire.

Single element (hair-pin) coils in armature windings are often used on the low resistance armatures. The forming of these windings is highly consistent in most cases. However, the large cross-section of the wire used creates significant stresses in the wire and insulation at every bend.

## Tang Vs. Staked Terminations

Typical small motor armatures employ “tang” type terminations to connect the coil windings to the commutator. Terminations are normally “staked” in low resistance armatures to accommodate the heavy gauge wire. The “tang” method usually terminates a continuous wire loop at the point of one coil finish lead and the start lead of the next coil. The start and finish leads occur at the first and last coil termination points in "tang" type armature windings. "Staked” terminations create individual start and finish termination points at each commutator bar. This significantly increases the chances of flaws that can occur during the fusing process. For example, leads may satisfactorily fuse to each other but not to the commutator bar. It is common for the “staked” or “tang” terminations to be subsequently machined immediately after the fusing process. In this step, the commutator is finished or turned. During the machining process, burrs or chips are created. These burrs and chips can become lodged in between the commutator bars creating the possibility of shorts between the adjacent bars. If parts are not tested at this point, these machining defects can become “hermetically sealed in” by the varnish impregnation process.

## ESW Test Methods

Most "turnkey" production test systems utilize the same basic tests. Resistance testing checks the winding continuities, overall coil resistance, and the quality of fused terminations. Surge or impulse tests verify the integrity of the insulation within the windings themselves and near bar to bar short conditions. Hipot or dielectric tests check the insulation system between the coil windings and the “dead” metal laminations/shaft of the part. We have optimized each of these basic test methods in our application to test low resistance parts.

### Resistance Test

The resistance testing can be broken down into two sub-categories. Coil resistances and continuities make up one category that applies to both armatures and stators. The other category, which applies specifically to armatures, is the resistance measurement of the fused coil termination at the commutator bars.

Accurate low resistance measurements can only be achieved using the four lead Kelvin technique. A programmable constant current source is applied across the unknown resistance through one pair of leads. Simultaneously the other pair measures the voltage drop developed across the unknown resistance by the constant current source. In extremely low resistance measurements (less than 10 milliohms) it is important to maintain precise control of the constant current. At the same time, it must maintain a high signal to noise ratio within the measurement system itself. Without this, inaccuracies can develop in the resistance measurements. ESW uses a precise thermally compensated constant current source controlled by the systems software. Power levels are constantly monitored to maintain a minimum of 0.1% of the set point. The software controls maximize the voltage drop across the unknown resistance without producing undesirable heating effects within the coil. This method allows for the production of the best possible signal to noise ratio. The voltage measurement system has extremely high input impedance, greater than ten giga-ohms. This allows the measurement of the entire voltage drop signal without losses by the data acquisition system. Eighteen-bit ADC resolution guarantees better than 5½-digit measurement. Since ESW resolves voltage measurements to a microvolt level, thermoelectric phenomena (Seebeck effect) can become a factor of error. ESW eliminates this error by utilizing a special reverse polarity measurement technique called Thermocouple Cancellation. This is unique to ESW.

With this technique ESW is able to achieve a consistent, repeatable and accurate resistance measurement reading, while maintaining a one micro-ohm resolution.

### Armatures And Resistance Testing

Armatures present a unique opportunity to quantify and derive several different resistance characteristics, the most important being the quality of the fused termination. All armature-winding patterns can be normalized into one or more sets of series-parallel combinations of resistive elements. Usually this consists of two parallel branches of coils. In even bar parts, each branch has an equal number of elements. In odd bar parts, one branch has one extra element. ESW provides custom-made test sockets that configure the presentation of the armature winding to the tester in this consistent normalized fashion. Thus, variables such as wave vs. lap windings, number of poles, polarity, and multiplicity do not have to be accounted for in the test system. All armatures with the exception of odd-bar vs. even-bar utilize the same test methods and setup parameters.

There are four types of resistance tests performed on armatures: end/end resistance, bar/bar resistance, end/end weld, and bar/bar weld.

### End/End Resistance

This measurement looks at the lump sum value of the series-parallel coil combination. The four-lead Kelvin measurement system is applied to each possible combination in a given part. For example, a 24 bar part will have twelve END/END resistance measurements. A 23 bar part will also have twelve measurements, with one of the nodes measured twice. Special compensation techniques are present in software to account for the unequal current division in odd-bar parts. After all of the measurements are made, they are sorted for highest and lowest values. The measurements are compared to the high and low-test limits specified by the customer.

### Bar/Bar Resistance

Measurements are taken across each individual coil. The constant current connection is at the same points as for the END/END resistance measurement. However, the voltage measurement is taken across the individual coils directly adjacent to the feed point. Thus, for each END/END measurement there will be two corresponding BAR/BAR measurements. After every node is measured each reading is compared to high/low test limits specified by the customer.

Low Resistance armatures typically consist of single element "hair-pin" coils each terminated by a "staking" process to the commutator bars. Each element is an identical unit. The BAR/BAR resistance measurements should all be the same. Variations here will indicate either a damaged coil (hair-pin) or a defective fusing at the commutator.

### End/End Weld

This is a measurement derived from the END/END resistance readings. A part having perfectly fused terminations (no resistance at all) reads the same at every END/END node. The difference found between the highest and lowest END/END reading is used to represent the END/END WELD measurement. It is then compared to a high limit specified by the user. Differences in these readings are an indication of a possible defect in the fused termination and/or commutator bar itself.

### Bar/Bar Weld

This is a derived measurement from the BAR/BAR resistance readings. The basic concept behind it is similar to the END/END weld except that the difference in the two BAR/BAR readings taken at a given END/END node are used to represent this value After all of the BAR/BAR differences are found the highest one is compared to a high limit specified by the user.

## Surge Testing On Low Resistance Parts

Checking for insulation defects within the coil windings using a surge (pulse) test is very demanding in low resistance parts. This is due to the very nature of the test itself. The typical surge test employs a pulse detection circuit that acquires the signature of a decaying sinusoidal waveform. This signal is a result of the natural series resonance that occurs between the discharge capacitance and the inductance of the coil under test. The decaying amplitude is the result of the series resistance and distributed capacitance within the coil winding.

The frequency of this resonant circuit is given by:

Resonant Frequency, $f_o$ = ( 2p * (L * C)0.5 )-1, where
L = the coil-under-test inductance
C = the surge capacitance

When the coil under test is "excited" by the surge pulse, it will oscillate at this resonant frequency. The observed pulse waveform is often referred to as the "reflected" pulse and/or "ringing" waveform in ESW literature. As seen in the formula above, the resonant frequency is inversely proportional to the square root of the inductance and capacitance product. Thus, as the inductance of the coil under test is reduced the ringing frequency will increase. In most cases, parts having low DC resistance will also have extremely low inductance values; therefore, the resonance frequency will be extremely high.

ESW has developed the high speed sensing circuits to successfully acquire and analyze these fast waveforms. The test system is also equipped to vary the discharge capacitance to obtain the best possible ringing waveform from the part under test. While testing a given part, the system can optimize the discharge capacitance and acquisition parameters "on-the-fly" for each coil. This part can have several different coil inductances.

There are three types of surge sensing available on ESW test systems: End/End Surge, Bar/Bar Surge (Differential Surge), and Low Z Surge.

## End/End Surge

This is the standard method used to acquire the damped oscillation of the discharge current. A high frequency current transformer couples this signal to a high-speed analog to digital converter in the computer's data acquisition system. Pulse ringing with frequencies as high as 100Mhz are measured with this sense system with accuracy.

## Bar/Bar or Differential Surge

This optional method uses a comparison method of analyzing matched coils within a part. The surge potential is applied simultaneously to two coils and the resultant ringing signals are "beat" against each other through a differential summing circuit. Any differences in the signal because of defect losses will show up as an error signal that is quantified by the data acquisition system. This differential sensing occurs simultaneously while the End/End testing is taking place. On armatures, this sense method is much more sensitive to detecting small errors in the part. The Bar/Bar sense method is comparing only two single coils against each other while the End/End method is looking at the overall part.

## Low Z Surge

This option is used for extremely low impedance coils with resultant ringing frequencies in excess of 100Mhz. High frequencies of this type are common in single-turn (hair-pin) type of windings. Like the Bar/Bar sense, this sensing takes place concurrent to the primary End/End method. This option will also detect arcing conditions that can occur because of chips or burrs between the conductive elements of the part.

Insulation defects in turn-to-turn, coil-to-coil, and phase-to-phase windings are detected using the proprietary sensing systems listed above. In addition, opens, some grounds, and chips/burrs are often detected by the surge test.

## Hipot

Low resistance parts often exhibit very low levels of dielectric leakage while subjected to the AC Hipot test. The measured leakage is directly related to the applied test potential and the capacitive reactance formed between the live (coil) and dead metal (lamination/frame) of the part. The insulation system between these two elements is the dielectric medium of this capacitance. Because capacitance is directly proportional to the area of the elements adjacent to the dielectric, very small values are seen in low resistance parts. By their very nature having low turn counts and very coarse compaction in the lamination slots yields a low physical surface area common to the lamination.

ESW utilizes a very high-resolution measurement system that can accurately measure low leakage currents with a 1-microampere resolution. In addition to this extremely high resolution, a proprietary sensing method (measurement at the part) guarantees the leakage measurement is a true measure of part leakage in the unit under test. Losses within the test system itself and test fixture cabling are ignored because of this unique method.

High Potential (Hipot) or dielectric withstand testing is of vital interest to all manufacturers of wound coil products. Safety and long-term reliability are closely related to the hipot integrity of the insulation system. Most hand-held products must meet hipot safety standards set by independent agencies. Typically, the applied potential for this test is 1000VAC plus twice the nominal operating voltage of the product. Low resistance products are usually found in low-voltage applications such as automotive starters, motors and alternators. While operator safety may not be a direct concern here, long-term reliability under adverse operating conditions is essential. Automotive products often experience environmental extremes in temperature, humidity and outside contaminants. Therefore, applying the same (or higher) test potentials as used in hipot safety tests will prove that these automotive products will continue to perform as needed under these severe conditions.

## Summary

While testing of low resistance parts uses some conventional methods found in many test equipment manufacturer's products, optimal measurements can only be obtained by using specialized techniques like those developed by ESW. Our broad experience in testing these types of products has lead many to believe that ESW is the true leader in this industry.

For more information on ESW Products and Services, please call Tim Naegeli at 262-554-1211 or email us at sales@eswtesters.com. Or you can visit our website at www.eswtesters.com for additional information on our products and services.

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Brochure No. 139
10/03