Application Guidance Notes: Technical Information from STAMFORD | AvK

AGN 015 – Testing Winding Insulation Systems

INTRODUCTION

Alternator performance depends on good electrical insulation of the windings. Electrical, mechanical and thermal stresses, along with the environmental contaminations, cause the insulation system to degrade. The condition of a winding insulation can be established by conducting an Insulation Resistance (IR) test or a High Voltage Withstand Test (Flash Test). While the latter is a compulsory test during the manufacturing process of every alternator, due considerations must be given for repeated test of the same kind as the insulation system may be degraded and operating life may be reduced. The former (IR test), however, is the less harmful way to determine the condition of the insulation system.

SECTION 1: INSULATION RESISTANCE (IR)

Background

The IR value provides an indication of the condition of the entire electrical insulation system including the impregnation material. The chemical design and formulation of electrical impregnation material requires considerations be given to the following aspects:

- Manufacturing process methods and controlled procedures, including associated Health and Safety issues.
- Excellent adhesion and creeping inclusion into the wound assembly at process stage.
- Material retention between wet application and initiation of cure process.
- Controlled film thickness, linked to ability to cope with thermal cycling.
- Resistance to surface contamination during operational life.
- Ability to cope with the different levels of thermal expansion between copper and steel components within the wound assembly during operational life.
- Provide mechanical bond-strength both Hot and Cold to resist the effects of imposed mechanical vibration and the electrically based forces under nonlinear current conditions, and sudden load step changes.

And lastly but by no means least!

- Maintain a high level of dielectric strength, and so achieve High IR levels.

When the ideal impregnation resin has been formulated, the above requirements are all satisfied. This means the Chemist has cleverly ensured that all the required mechanical and electrical characteristics have been achieved and surpassed by 'safety factor' multiples of the fundamental required levels for each characteristic.

Testing IR Values - Cautions

Note: The full test procedure is detailed in the Installation, Service and Maintenance Manuals (also known as the Owner's Manual) issued with every alternator and can also be found on the website, www.stamford-avk.com

The IR test involves an instrument commonly called a Megger. This instrument will apply a 'test voltage', measure the 'leakage current' and then indicate the value of the winding's IR in [M] Ohms.

A Megger will subject a voltage of some 500V (or more with some megger instruments) to any circuit to which it is connected. If a winding is in a very contaminated condition and then subjected to the typical 500V Megger test the resulting leakage current could promote permanent damage to the winding insulation system. For this reason, care should always be taken to observe the readings indicated at the very moment the megger test begins and if possible, always slowly increase the applied 'test' voltage.

The Megger test voltage could damage electrical / electronic components that are connected to the winding under test and so must be disconnected. The AVR is directly connected to the stator windings to provide the required 'Voltage sense' information. With the SX (Self excited) type AVR, the excitation power supply is also taken directly from the stator terminals. Various wiring loom assemblies connect the stator to the AVR, some incorporate individual 'Voltage sense' and 'power' leads, others interconnect the various AVR inputs by links along the AVR terminals.

Care must be taken to ensure the loom arrangement is understood and that the easiest possible point is chosen for AVR disconnection, so ensuring the megger test will not damage the AVR and that mistakes are not easily made when reconnecting the AVR after the test. Within the terminal box mounted there may well be optional equipment connected to the stator, e.g. Radio Interference Suppression kit. These items must also be disconnected.

Every alternator leaves the STAMFORD | AvK (Cummins Generator Technologies) factory with an Installation, Service & Maintenance Manual (Owner's Manual). Also enclosed in the package supplied with the alternator, will be a full set of electrical connection diagrams specific to the alternator, showing AVR and Stator Connections and also, diagrams for any fitted optional extras. These drawings will provide guidance with regard to the AVR 'Voltage sensing' and 'Power supply' circuits. This will help with lead and component identification and so help identify the easiest point for AVR disconnection before doing the megger test. These documents are also available by email at applications@cummins.com.

The following table offers basic guidance regarding AVR connections, but always confirm the individual alternator connection details before disconnecting any leads and so risk, loosing individual lead identity.

AVR Type	If Sensing T/ F	Sensing Lead No's		AVR Sensing	AVR Power
	is Used :	At Stator	At AVR	Term. No's.	Term No's.
SX 460	NO	7, 8	7, 8	7, 8	7, 8
SX 440	NO	7, 8	7, 8	3, 2	P2, P3, [P4]
SA 465	NO	7, 8	7, 8	3, 2	7, Z2
MX 341	NO	7, 8	7, 8	3, 2	P2, P3, P4
MX 321	YES, as a				
	PCB assembly	6, 7, 8	6, 7, 8	6, 7, 8	P2, P3, P4
MX 321	YES as a				
	Chassis assembly.	U, V, W	6, 7, 8	6, 7, 8	P2, P3, P4

The AVR output is connected to the Exciter Field via terminals marked X – XX or F1 – F2. So should the Exciter field be megger tested it would be these two leads that must be disconnected.

A remote 'Volts–Trim' adjustment 'Pot' is connected across Terminals 1 – 2, if this option is not being used, then 1 must be linked to 2. A Quadrature Droop CT secondary winding will be connected to terminals S1 – S2. Terminals A1 – A2 may be connected to a separate excitation adjustment module, most commonly this second module is a PFC3 [Power Factor Controller, used when operating in parallel with a Utility / Grid]. If a PFC3 module is being used then this will be connected to the alternator stator and must be disconnected prior to the megger test.

It may be that Generating Set instrumentation and monitoring equipment is connected directly to the alternator's stator output terminals. Care should be taken to check for such connected equipment and ensure this is disconnected before conducting a megger test. It may be possible to simply remove fuses to isolate some of these items.

Expected IR Values

The alternator's Insulation Resistance, along with many other critical factors, will have been measured during the CGT Factory processes of manufacture, assembly and test. The alternator will have been transported with a packaging appropriate for the journey to the Generating Set assembler's works, where it is expected it will be stored within a weather protective building.

However, absolute assurance that the alternator will arrive at the Generating Set builder’s production line with IR values still at the factory test levels of above 100 Mega-Ohms cannot be guaranteed. The alternator should arrive at the Generating Set assemblers works in a clean and dry condition. If held in appropriate storage conditions the alternator IR value should be typically 25 Mega-Ohms.

If the unused / new alternators IR values fall below 10 Mega-Ohms, then a drying out procedure should be implemented by one of the processes outlined in the next sections before being despatched to the Customers site and some investigation undertaken into the storage conditions the alternator had been subjected to.

It must be noted that an observed change can be detected with the level of the measured IR value between the cold and the hot winding assembly condition. It is quite normal to observe that the ‘hot’ IR value may well be much lower than the unnecessarily, excessively high Ohmic value measured on the ‘cold’ wound assembly.

When a value of several Mega-Ohms are recorded for the ‘hot’ condition of the winding assembly, which is several times higher than the minimum value of 1 Mega-Ohm stipulated by some Marine Classifying Societies, this indicates that the dielectric performance of the insulation system is still in excellent ‘health’.

What Causes Low IR Values

This cold-to-hot change of the IR value is associated with the impregnation resin’s internal molecular stress associated with the wound assembly’s thermal expansion, and the need for the impregnation seal not to be broken. The chemist played off one characteristic against another in order to maintain an excellent hot bond strength to assist mechanical rigidity of the wound assembly in order to combat imposed vibration and forces from external sources such as; the prime mover, the characteristics of the connected electrical load, and the challenges of the local operating environment. The chemist has achieved all his objectives, including ensuring more than adequate dielectric strength is still being provided.

When the alternator is in service, various mechanisms will contribute to factors that will affect the IR value and site measurements of just a few Mega-Ohms become more typical. Major factors that affect and reduce the IR value start with the winding outhang. Surface moisture, often present in conjunction with surface contamination, are both the result of prevailing site conditions. Either will seriously reduce measured IR values and if the root cause that allows these contaminants to be present is not addressed, then the expected mean time before failure (MTBF) will be considerably reduced. The CGT manual - Installation, Service & Maintenance Manual (Owner’s Manual) - issued with every alternator, in the Service and Maintenance Section, offers guidance about measuring the IR value and expected typical values.

Ways to Increase IR

Any temporarily reduced IR values can be restored to expected values by adhering to the following explained drying out procedures. Then a further operation on load will complete a thorough heating of the winding assembly and will completely dry-off the IR reducing moisture.

Consider a known good condition alternator that has not been run for some time, but during which it has been standing in conditions of high Relative Humidity (RH). It is possible that simply running the Generating Set unexcited for a period of say 10 minutes will sufficiently dry the surface of the windings and so raise the IR sufficiently – to above ONE Mega-Ohm – and so allow the unit to be put into service.

If the above unexcited ‘blow-drying’ does not raise the IR value sufficiently then consider separately exciting the alternator with its output terminals connected by appropriately rated short circuit links. By separately-exciting at a level such that some 80% of rated current flows through the short circuit link the alternator stator winding will start to heat up. This will drive off the embedded moisture, during a run period dependent upon the size of the alternator but consider:

1 hour for a S0/S1 and P0/P1
2 hours for a UC22/S2 and UC27/S3
3 hours for an HC4/S4, HC5/S5, HC6/S6, P7/S7, and P80/S9

If the IR value remains below 1 Mega-Ohm, even after the above drying methods have been properly conducted, then a Polarization Index test (PI) should be carried out (see next section). This will offer some guidance about the characteristics and so reason, for the ‘leakage current’ that is causing the low IR.

If surface contamination is the cause, therefore promoting surface tracking, then the alternator must be removed from the engine and stripped down to enable the stator winding to be thoroughly, but carefully, pressure washed, then baked in an oven to completely dry out.

If now the value of IR is acceptable, then the stator should be treated with an over-coating resin that is compatible with the original factory impregnation, before the generator is reassembled onto the engine.

Polarisation Index (PI) Testing

This test involves using a Megger type instrument that can be set to apply the test voltage to the winding twice in a period of ten minutes. Usually, a motorised Megger is used. The value of the windings IR is recorded after 1 minute of the motorised Megger test and then again after 10 minutes. The two values are compared, the 10 minute reading is divided by the 1 minute reading and hopefully, the result is in the order of 3.

A very basic explanation of a PI test is that it enables an observation of the separation of the three basic elements that sum together to give the total leakage current identified by a normal quick Megger test and the correspondingly indicated IR value.

1. Capacitive Current……is the element of total inter-winding or winding to lamination pack capacitive charge current, which at the start of the test, is high but decays very quickly and by the end of the 10 minute test will have virtually reduced to zero.

2. Polarisation Current……..caused by charges in the insulation materials under the effects an electric field or by molecular di-poles lining themselves up with the applied field - therefore orientation polarisation. This current is greatly affected by moisture or contamination in the insulation. This polarisation process takes longer to settle out than capacitive current.

3. Leakage Current……….Steady resistive current through the insulation material the product of surface tracking aided by general winding contamination in the form of embedded dirt and surface moisture.

If the molecular structure of the materials in an insulation system are subjected to an electrical voltage achieved by energisation (using a Megger) of the electrical windings on either side of the electrical insulation barrier (insulation system of aramid materials and impregnation resins, etc.), then the insulation material's molecules will gradually all align with their +ve end facing in one direction and so their -ve end facing towards the other side of the barrier. When this situation is complete, Polarisation has been achieved.

Making these molecules align is the result of a capacitance effect across the insulation material 'barrier' region. This capacitance 'charging' current will cause a Megger instrument to detect current flow and so indicate a correspondingly low(ish) IR reading.

When a PI test is conducted, the one minute reading is after the Capacitive Current (item 1 above) has occurred, but item 2 and 3 are still 'leaking' and so the IR value is (relatively) low. When the 10 minute reading is finally taken the Polarisation Current (item 2) is complete and so now only leakage current (item 3) is present.

The two measured IR values offer guidance about the overall condition of the winding assembly's insulation system. If both readings are low, but the ten minute reading is only a little higher than the one minute reading and a visual inspection confirms a very dirty, surface contaminated winding, then this assembly could benefit from a thorough washing and drying process.

Normally a PI test would be conducted on a winding assembly that has been in service, which visually appears to be clean and dry. But whilst in service, inevitably, the insulation materials will have been subjected to working dielectric stress, some coil flexing in the out-hang resulting in minor relative movement between adjacent conductors and the presence of some surface contamination on out-hangs and through the stator bore.

A PI test on a healthy winding assembly will result in the ratio of the 10 minute reading to the one minute reading in the order of 3 (or greater) : 1. But an experienced tester will take great interest in the actual IR values of both readings.

If a PI test is conducted on a new, perfectly clean and virtually unstressed stator winding assembly, then the one minute reading is usually of such a high IR value, that when the ten minute reading is taken there is little increase in this IR value over the one minute reading. Now, when the two readings are ratio'ed, the PI value is often only around 2:1.

Obviously, this does not mean that the new stator assembly is unserviceable, simply that the PI test has not been a justifiable test to establish the condition of a new stator assembly. Under such conditions the IR values provide proof of the real condition of the stator assembly.

Ways to Maintain High IR Values

Basically, keep the wound component clean and dry and good values of IR are assured. But achieving the 'clean and dry' condition has to be engineered into the original Generating Set design and then maintained by an effective On Site 'Care regime'.

Considerations at the Engineering stage must include a way to combat moisture and contaminants carried airborne with the cooling air especially when the Generating Set is operating in Rain, Fog, or Sea Mist, etc.

Then also carefully consider the microclimate conditions that occur inside a typical Generating Set canopy, especially just after the hot unit is taken out of surface and is stopped. Within the canopy the cooling down of the Generating Set promotes high humidity levels, which result in surfaces become wet, and this includes the alternator windings. It is necessary to find a way to combat this and basically, it requires engineered natural convection of airflow through the canopy, to counteract the dew point situation and so keep the levels of Relative Humidity [RH] low.

These are the ways to maintain high IR value:

- **Anti-Condensation Heater.** Fit the alternator with an anti-condensation heater and ensure that this is automatically switched on when the Generating Set is at rest. This will maintain a high value of IR for windings that are already in a clean and dry condition.

- **Generating Set Canopy Space Heater.** Of a power rating capable of maintaining low Relative Humidity values within the Generating Set enclosure at the site environmental conditions.

- **Regular Use as part of Planned Maintenance.** Planned routine operation of the Generating Set at a rating that elevates the stator temperature to some 110degC T-total for a period of, say one hour, will drive out any moisture that might otherwise begin a degradation process to the Insulation system.

SECTION 2: VOLTAGE WITHSTAND TEST

Basic Impulse Insulation Level (BIL)

The reference document for the BIL situation is the ANSI / IEEE Std 141 Red Book that is titled "IEEE recommended practice for Electrical Power Distribution for Industrial Plants". In summary the BIL situation sets out to establish the withstand characteristics of the insulation system when this system is subjected to a temporary excess-voltage stress over and beyond the normal operating voltage.

The idea of the BIL test is that the insulation should be capable of withstanding a short, sharp impulse voltage, and sets out to subject the insulation system to a steep fronted, hi-voltage stress of very short duration. However as the IEEE book points out; “Rotating machines have a relatively low impulse strength and no established, standardised BIL’s”. In a further section in the IEEE Red Book it restates that Rotating Machines have a low BIL, and that maybe in certain troublesome applications, or locations, a Surge Arrester will be required to be fitted at the terminals of the machine.

Typically, the applied BIL voltage should have a peak [crest] value that is 25% higher than the standard ‘flash test’ voltage –but remember that the ‘flash test’ voltage is always identified as V.rms. This BIL [impulse or surge] test voltage is applied from zero to peak in 1.2micro seconds and then allowed to decay over 50micro seconds.

Whilst STAMFORD | AvK do not subject their alternators to an actual BIL test, they do subject them to a ‘Flash Test’, which has characteristics of both a standard ‘flash test’ and satisfies the intent of the BIL test. The applicable standard for rotating elect-machines BS 4999, has guidance about ‘flash testing’ that allows a higher than the standard 2.2kV voltage to be applied for a shorter period than the standard 1 minute.

The Voltage Withstand Test

Voltage Withstand, High-Pot, Flash Test are all terms applied to the test that involves subjecting a winding to a test, which applies a mains frequency (ac) high voltage to the winding groups in turn phase to phase and phase to earth. This test is maintained for a period of typically one minute, during which no breakdown of the EIS must be detected. This is a test which should only be undertaken after due technical consideration following other less stressful test procedures.

Note……. It should be accepted that to undertake a Hi-pot test on an alternator that is in service is likely to take several hours (4<6) typically.

This time is based on the restricted access and time taken to gain access to the ancillary electrical equipment, which must be very carefully disconnected before the Hi-pot test can begin. The hi-pot test must be undertaken in a restricted access area and prevailing local legislative health and safety requirements regarding electrical testing ***must*** *be applied.*

One the Hi-pot test is complete the alternator ancillary circuits must be very carefully reconnected, and the initial run-up of the Generating Set should be undertaken with care and attention that all is functioning correctly.

The applied test voltage is of a magnitude which is typically three to four times the winding assembly’s normal operating level and so will severely test the integrity of the winding’s EIS.

If this test is not carefully conducted with due consideration of the damage which can result from recklessly subjecting electrical systems to inappropriate test voltage levels then EIS breakdown and associate tracking paths will occur and so permanent damage will be present within that assembly which will render life expectancy very short.

During the manufacturing process of the alternator, each wound assembly is subjected to a Hi-Pot test as part of the final inspection function of the QA process.

The test voltage at this QA process, is at the voltage level stipulated within the test method and prescribed levels contained within IEC60034-1. Typically the test method is advised as being: (2 x V.rated) + 1kV. However for reasons of standardization STAMFORD | AvK test at 2.4kV for 1 minute for Low Voltage alternators.

IEC 60034-1 then advises that following a successful test at the manufacturing QA test point, the wound assembly should NEVER again be subjected to a Hi-Pot test at that level.

If it is necessary to repeat a hi-pot test on that winding assembly, it should be conducted at no more that 80% of the original advised IEC 60034-1 test value.

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