

Application Guidance Notes: Technical Information from Cummins Generator Technologies

AGN 102 - Markon Alternators

ANNOUNCEMENT

Markon alternators are no longer manufactured. This Applications Guidance Note provides information for customers who are still operating the 2-pole single-phase alternators.

DESCRIPTION

The small Markon 2-pole alternators are designed for simple applications and, as such, have quite basic excitation systems - although not always simple to understand - which are designed to be rugged and reliable rather than sophisticated. The remit during the design / development stage was 'keep it simple and reliable' yet able to cope as well as any other alternator sold into this small machine sector.

MARKON ALTERNATOR TYPES

Marcon has a long history of alternator manufacturing and many models and variations have been produced over the years. This AGN concentrates on the final alternator Markon Range that was manufactured before production ceased – the BL105 and the SL105. For information on any other Marcon Ranges, please contact applications@cummins.com.

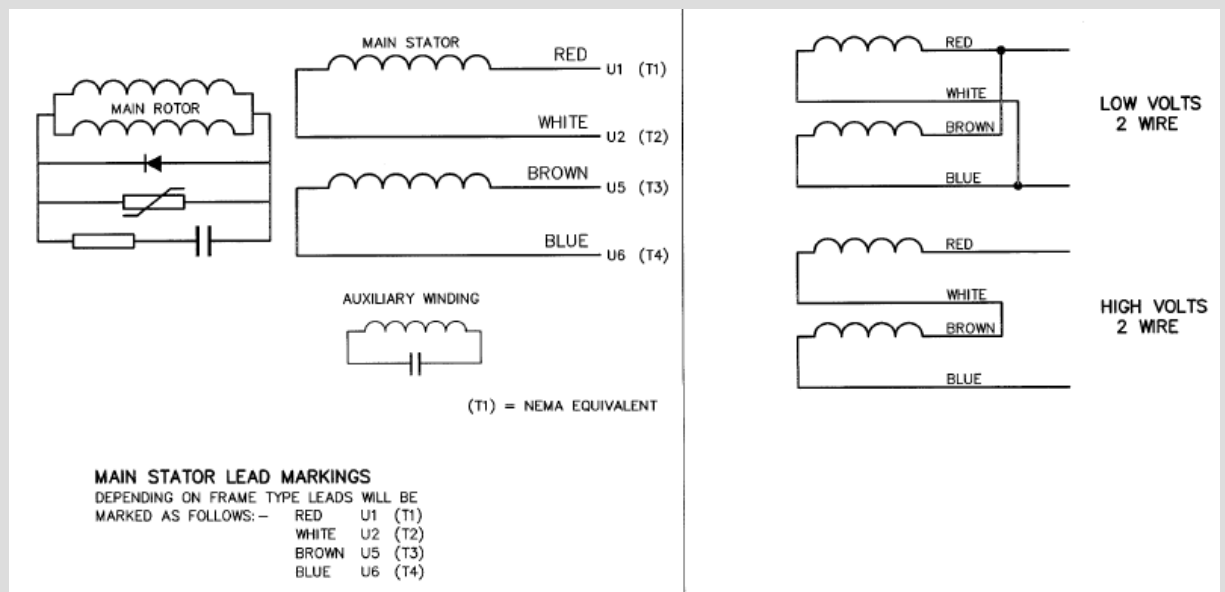
The BL105

The Markon Capacitor Brushless **BL 105** family of alternators actually operate with a system based on a leading power factor, 'self-excitation' principle. Within the alternator's stator there are two isolated windings, a Main winding to power the connected load and an auxiliary winding connected to a capacitor. The sole purpose of the auxiliary winding is to "self excite" the alternator, by inducing a voltage, therefore current, into the rotor winding; which is simply connected to a diode to make the resulting current dc, therefore creating a polarised rotating magnetic field. With this excited rotor spinning within the stator, the resulting magnetic flux not

only supports and maintains the capacitor and auxiliary winding with its needs to excite the alternator, but it is also magnetising / exciting the Main winding, which is now available to power any connected electrical load.



The Main winding's output voltage is regulated by the effects of mutual inductance between the stator windings and the rotor winding. The above describes a simple a.c. generator (alternator), which is able to inherently maintain the output voltage within some +/- 5% and is therefore, quite acceptable to the types of loads typically powered by small Generating Sets.



BL 105 Wiring Diagram

Repairing BL 105 Capacitor excited Alternators

Main Rotor Diode. To test the rotor diode, at least one side of the diode must be completely disconnected from both the rotor windings and the Varistor. Preferably, to do the following test more effectively, it is better to remove the diode completely, from rotor assembly.

WARNING: Danger of electrocution. Ensure the mains supply is disconnected when making connections and ensure all connections are insulated.

- The only way to correctly test that the diode 'is good', is to connect the diode in series with a 40W to 100W, 240V filament bulb (ordinary house light) and connect this circuit to a 240V single phase mains supply. For example; The Neutral cable to one side of diode, the other side of diode to one side of lamp and the other side of lamp to the Live cable. A 5A fuse should be used in the plug.
- If the diode is good, then the lamp will be flickering at 25Hz and half normal brilliance. If the diode is unserviceable with a short circuit, the lamp will be at full brilliance. If the diode is unserviceable with an open circuit, then lamp will be off.
- Diode Type. 16A, 1200V, stud mounted diode.

Varistor or Voltage Dependant Resistor (VDR). The Varistor will have a very high resistance and then, providing it does not look as though it has been subjected to excessive heat, it should be OK to re-use.

Insulation Resistance. Megger test all windings at 500V, to confirm they are insulated from core packs and from each winding. A minimum of 0.5MegOhm should be measured.

Restoring Residual Magnetism. Re-flash the residual magnetism into the alternator whilst it is stationary. 'Flash' a 12V battery across the capacitor terminals, in a sequence of one second on, then one second off. Repeat three times. The battery polarity is not important.

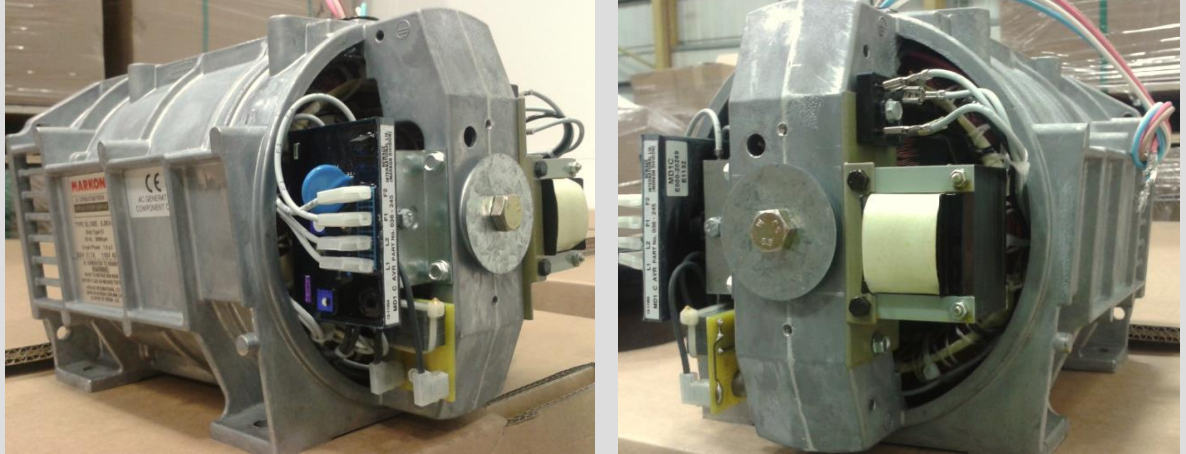
Testing. The alternator will not give an output voltage if it is running too slowly. The correct No-Load running speed for 50Hz is 3150 rev/min. and the correct running speed for 60Hz is 3750rev/min.

If the alternator does not build-up to the typical voltage (240V), then with the Generating Set running, try momentarily flashing with 12V battery across the capacitor. To do this safely, it is important to 'flash' the battery to the capacitor for only one tenth of a second.

The SL105

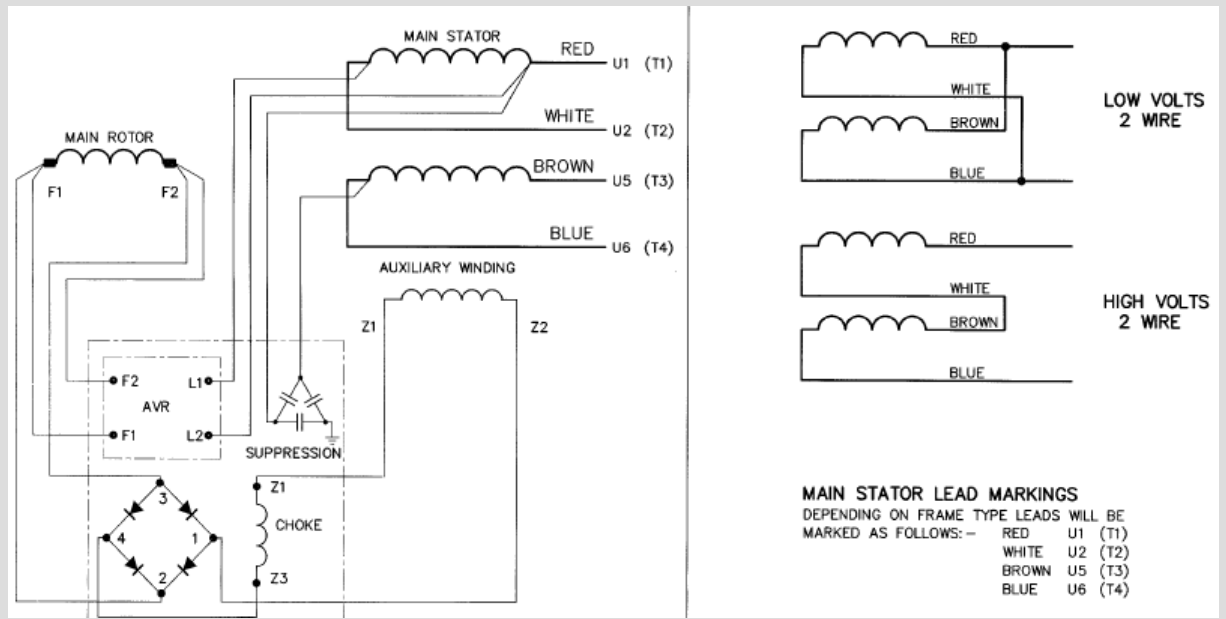
The Markon Slip-ring **SL 105** also has two stator windings, a Main winding to power the connected load, and an auxiliary winding connected to a choke and then a bridge rectifier; the dc output of which is connected to the rotor windings via the slip-rings. This excitation system is designed to generate slightly more excitation than is really needed for any condition between No-load and Full-load, and then the excess excitation is diverted away from the rotor [field] windings by the AVR, which is designed to momentarily short-out the generated excitation voltage at the slip-rings, and so reduce the actual excitation to just the required amount to allow the alternator to operate at the 'set' nominal output voltage. However, all small alternators have a tendency to generate quite high level of harmonic content within the fundamental output voltage of the stator main winding. Therefore, connect these types of alternators to a load that

includes any frequency sensitive elements, such as transformers, chokes and motors with inductive frequency sensitive loads. These are examples of inductive (lagging power factor) loads, whereas frequency sensitive loads with capacitors have leading power factor characteristics.



The following information is directly associated with the SL105 excitation system:

- The choke DC resistance is 7Ω.
- The factory set airgap is in the order of 2mm (0.08”).
- The gap and the inserted packer pieces are factory set to give the choke an a.c. impedance of 80Ω, when tested on a 50Hz supply.
- The choke must be fitted in the alternator air inlet air stream to control its operating temperature.
- Typically, the choke will have a surface temperature of some 140°C, (285°F) if the air inlet temperature is around 30°C (85°F).
- The choke current is typically 1.8A.
- The actual level of choke current is dependant on the alternator’s loading level and therefore, the amount of excess excitation being diverted by the AVR.
- If the alternator is run at speeds higher than the designed speed, then the choke and AVR will have to work harder. At no-load and 50Hz, the maximum speed is 3150rpm and at 60Hz, the maximum speed is 3750rpm.
- Under a no-Load condition, the AVR should be diverting 750 to 850mA. Any more than 1A and the choke’s life expectancy is short!!
- The choke is supported by two fixing screws. If the prime mover creates high levels of vibration and these are imposed on the alternator assembly, the choke may become a loose item.



SL 105 Wiring Diagram

MARKON ALTERNATORS FOR DIFFERENT LOAD TYPES

When we determine the type and size of Markon alternator required for a particular load application, we must always be aware of the fact that all small alternators – from any manufacturer – have a tendency to generate quite high level of harmonic content within the fundamental output voltage of the stator main winding. This means that when these small alternators are connected to any load that is sensitive to supplied frequency – read harmonic distortion – there is a tendency for higher than expected current to flow.

Single Phase Motors

The Markon range of 2-pole alternators operate on a principle of induced compounding initiated by the stator Main winding load current and then mutual inductance with the stator Auxiliary-excitation winding and also the rotor winding. In the case of the SL105, the ‘compounding’ between the windings is designed to be in excess of the required excitation level and then this excess is diverted away by the AVR. When considering the alternator’s ability to accept a step load, or start a motor, the resulting Transient Voltage Dip %, will greatly depend upon the behaviour and characteristics of the Generating Set engine.

Engines

Petrol engines do not have a particularly good speed governing capability and this, combined with their light weight flywheel and so low kinetic energy, will mean that when a load is suddenly applied, there may be a big reduction in speed / frequency (Hz). Some petrol engines are incapable of recovering from this condition and may run for a short time at about half speed before stalling. But during any severe overload, which results in under-speed running, the connected electrical load(s) - and the alternator windings - are in danger of being damaged.

Diesel engines have much better speed governing characteristics and have much greater kinetic energy; but even so, severe overload can force down the running speed and cause them to stall.

Motor Types

The BL and SL are only offered as single phase alternators, therefore only comments regarding the starting and run characteristics of single phase motors follows.

The starting and run-up torque of a single phase motor is usually lower than that of an equivalently rated three phase motor. To make a single phase motor develop a starting torque - and run-up in the correct direction of rotation - requires single phase motors to be fitted with a start winding, which [usually] operates in circuit with a capacitor – sometimes two – and sometimes a centrifugal switch.

There is a type called “Split Phase” which has two windings, a centrifugal switch and no capacitor. There is also the high speed and variable speed universal motor – with commutator – as used in most power tools.

The following table is not offered as being absolute, but just a guide about the commonly encountered single phase motors available today. From the table it can be seen that the starting requirements of single phase varies considerable according to their design type and operating principles. Motor manufacturers are able to offer variations of the below values by design changes and motor control system switching changes, to the values of the run and start capacitance values.

	Capacitor Start	Cap. start and Run	Shaded pole	Split phase	Power tool universal motor	3 phase motor (shown for comparison)
Typical Full Load Efficiency %	<60	<60	<30	<60	<70	<80
Full Load Power Factor	<0.7	<0.9	<0.7	<0.7	<0.9	<0.8
Start Amps x Full Load Current	5	4	2	<10	< 4	7
Start Torque %	190	40	20	180	<150	200
Run-up Torque %	200	34	50	160	<150	200
Pull Out Torque %	200	190	150	200	N/A	250
Comments	High start torque, but not to be used for high inertia load with prolonged run-up time	Low start torque than Capacitor start. Should always be on some load.	Low start torque, and low efficiency.	High start torque and high kVA demand from power supply.	Motor allowed to drive power tool up to speed before motor is loaded.	DoL start causes high start kVA demand from power supply.

Engineering the Generating Set

Trying to offer a simple 'factor' as guidance for the ability of a small single phase Generating Set or to start a single phase motor is difficult. Firstly, it is necessary to identify the characteristics of the engine to be incorporated within the Generating Set. Secondly, it is necessary to identify the characteristics of the motor to be started and run. Thirdly, it is necessary to identify the characteristics of the motor's coupled load, and so the torque required and duration of the run-up time. Failing to consider the above would introduce a high risk of 'getting it wrong'.

Alternator Performance

Once again, the following is offered as typical and should be used as a 'rough' guide for the capability of an alternator's performance under a low lagging power factor impact load, such as a motor start situation.

- **Condition 1.** The following assumes that the Generating Set running speed is maintained at a constant rated frequency during the motor start period.
- **Condition 2.** The following is for both the BL and SL types of alternator:
 - A motor start kVA that **equals** the Generating Set's **rated kW** will result in a **10% TVD**.
 - A motor start kVA of **twice** the Generating Set's **rated kW** will result in a **20% TVD**.
 - A motor start kVA of **three times** the Generating Set's **rated kW** will result in a **30% TVD**.

Small Generating Sets and their ability to start motors.

Because, under a motor start situation, the engine of a typical small Generating Set incorporating a small alternator will lose speed and so, in turn, the alternator's output voltage will 'naturally' be reduced. This natural voltage 'roll-off' with speed 'roll-off' will result in the motor being supplied with a natural 'soft-start'.

The effect of the reduced voltage and frequency will be to reduce the motor's normal inrush kVA and so overall, reduce the load that has just been impacted onto the Generating Set.

The risk is that this reduced motor input voltage and current (kVA) will reduce the motor's ability to develop the necessary starting torque to allow the motor to fully accelerate to rated speed. If the motor becomes 'stalled', then this will subject the motor and the Generating Set to a severe overload condition that could result in something being damaged.

Markon Alternators for Washing Machines etc.

Unfortunately there is a classic problem when trying to use a small Generating Set to operate modern day equipment that makes use of power electronics to control a motor speed or a heating process.

The output waveform of any alternator is never a perfect classic sine wave. The smaller the alternator the more the compromises the electrical designer must use to be able to offer a cost effective product that can be manufactured at reasonable cost and unfortunately the further away the output voltage waveform is from the perfect sine wave. For ordinary loads, incandescent bulbs, resistive heating, fixed speed induction motors, etc., this is not a problem. The problem is that many modern electrical loads use the power electronics, which take only a 'bite' or 'portion' of power from each generated voltage half sine wave. The most common example is a lamp dimmer, which applies only a portion of the voltage [electrical pressure] waveform to pass a variable current through the lamp filament to vary the brilliance.

This 'biting' process grossly distorts the alternator's output voltage sine wave, to the point that the power electronics can't recognise the difference between a positive and a negative going half sine wave. At which point their electronic control module's either get very confused, or 'fail safe' and stop the power electronics from working.

The manufacturers of washing machines, microwave's, etc, all know the problem, but have designed their products to be operated from the mains supply and so their 'biting' effect is negligible - well almost and this is what CE product marking is all about.

What can be done to combat this problem and a small Markon alternator?

Unfortunately, there is no 'off-the-shelf' filter kit for the Markon, or any other manufacturer's alternator, because it's not the alternator that requires filtering. It is the connected load that works with power electronics, which 'bite' into the applied voltage waveform; so it is the connected load that must be filtered.

An 'off-the-shelf' filter may work, and may also initiate resonance that makes the problem even worse. It is a process of experimenting to find out what does and what does not work for an individual load package.

If the only power supply is a Generating Set, then the normal route is to avoid any complicated electrical loads. The alternative is to oversize the alternator by a factor of at least 3 to 4 times the required kVA rating. Note; the engine does not need to be oversized. Engines do not perform well on light load running. Unfortunately, there is no 'quick-fix' to supplying power to modern day equipment that makes use of power electronics.

Leading Power Factor Loads - Lighting

Some simple theory: when a load causes the current to lead the voltage, we say we have a leading power factor load. When the voltage source to such a load is an alternator, the effect of this leading power factor current in the stator winding, is to 'self-induce' a voltage into the rotor winding, which adds to the already present correct level of excitation current. The effect of the combined pair of excitation currents is OVER excitation and so OVER output voltage.

If the level of leading power factor load is a low % when compared with the alternator's rated kVA, then maybe the voltage will be kept within reasonable levels, because the alternator's designed excitation system [AVR] will automatically reduce the excitation current in an attempt to get the voltage down to 'set' nominal voltage. However – here comes the 'watch-out' – if the amount of leading power factor load is too high, then despite the alternator's real excitation

system reducing, the resulting leading power factor self-excitation condition, becomes cumulative, because as the voltage rises, then the effect of this is to force more leading power factor current through the load, and so increase the 'self-excitation' effect, therefore; more induced voltage and current into rotor winding, so more output voltage and so more leading power factor load current....and so on, until something is damaged.

Alternators are tested for this leading power factor capability and graphs called Operating Charts, or Capability diagrams, are available for alternators rated at typically 20kVA and upwards.

When you consider that florescent lighting units and High Pressure discharge lamps – Sodium, Mercury, Metal Halide – all have control circuits [ballast's] that include chokes and capacitors, then it is reasonable to consider the various modes of operation of these lamps and the resulting power factor of the load. A quick 'watch-out' / risk assessment exercise is strongly recommended. It should also be remembered that any lamp involving electron flow within a gas – an ionization process – generates harmonic current distortion and this adds to overall system harmonic voltage distortion.

Assessment exercise

When considering one of the above mentioned lighting loads, the total load will have quite a high proportion of capacitance, but under normal lamp operation the capacitance and inductive choke circuits are all part of the total lamp circuit and the resultant power factor for the load will be lagging, say as low as 0.7. This is until the High Pressure lamps reach full brilliance and then it will operate at typically 0.95 lag with lamp at full brilliance, after some 15 minutes from being switched-on.

If a hot lamp is switched off, then back on again, a High Pressure lamp will not immediately re-strike, unless fitted with an electronic igniter. During this period the only component associated with this lamp that is being supplied by the alternator is the power factor correction capacitor, so this particular load is now Zero power factor.

If the alternator is supplying other loads at the same time and therefore the resultant total load has a power factor very close to unity, then no self-excitation will occur and the alternator will supply close to nominal output voltage. However, if the total load has a distinctly leading power factor, then problems with self-excitation will begin.

Just for a moment consider more closely, frequency sensitive loads and an applied voltage containing a high harmonic content. The current forced through a capacitor by any connected ac voltage supply is very dependent upon the frequency of the applied ac voltage. Capacitors used for power factor correction on lighting units are chosen to operate at a given kVAr, based on the ac voltage waveform having a fundamental frequency of 50Hz (or 60Hz) and designed against a mains supply.

If that fundamental 50Hz is being generated by a small Generating Set, and this is generating the fundamental 50Hz voltage with quite a harmonic content, then the capacitor - because of

its frequency / harmonic sensitive characteristic - will 'draw' more than expected current and so create more than the expected leading power factor (kVAr) of load.

Now consider a typical problem

The **BL105** and a light load of florescent lights resulted in the output voltage rising. We may be a little surprised by this, but must ask the question; what was the actual kVA and power factor of the connected lights and were the measurements taken, the voltage with a true rms Voltmeter?

Maybe with more load, the voltage would have fallen or maybe the Voltmeter was not able to determine the real rms voltage level of the harmonically distorted system voltage waveform. It is intriguing, about what in a standard florescent lamp circuit, would cause the lamps to "cut in and out". A unity power factor resistive load test may prove the alternator to be OK and the problem to be load generated, but what within load was the critical condition?

As for tests with the Generating Set on High Pressure Metal Halide lamps; then again the lighting load apparently causes the alternator to give Over Volts of 270V. At what kVA and power factor? Also, were true rms instruments being used on this harmonically distorted load?

The hot lamps situation may be fully expected, but must be avoided at all times. One way to overcome this is to operate the lamp without the power factor correction capacitor. The lamp doesn't need the capacitor, but the lamp manufacturer fit's it to achieve an acceptable operating power factor and so peak efficiency.

It is quite common practice on lighting tower applications, where there is a dedicated alternator to dedicated lighting load for say half the lamp units to have their capacitors disconnected so that the loads leading kVAr load will not promote self-excitation if a lamp fails, leaving too much overall capacitance in circuit.

As for the **SL 105**. This design of alternator is the safe-bet for these types of lighting loads. It offers closer voltage regulation and adjustable output voltage control, which can be set to voltage low enough to give long lamp life, yet high enough to give required brilliance.

Test results that indicate; having successfully operated the High Pressure lamps until they were hot, then after the Off / On switching, the voltage collapses to 48V until the lamp was cool enough to re-strike, would be surprising. The values of the alternator's excitation volts and amps and AVR divert current would need to be measured to find out what was going on.

Conclusion to this typical problem: The easiest method to determine the correct type of alternator required, is to take both the BL and SL to site, study the load characteristics and then make a decision about which type is best suited. Normally, the SL will offer best compatibility with an odd collection of loads that seem to be harmonic sensitive.

However, maybe disconnecting some power factor capacitors from the lights will help with any self-excitation problem, but a record of the effect on overall load kVA/kW/pf should be made.

FAULT FINDING GUIDANCE FOR MARKON BL105 AND SL105 ALTERNATORS

The following guidance is offered for fault finding and the repair of the Markon 2-pole single phase alternators. It is expected that the person conducting this work will have suitable experience with electro-mechanical components and electrical equipment; and will ensure all work is conducted in a safe working environment.

Brief description and identification codes

Markon manufacture two distinct types of rotating field 2-pole alternators, which are explained in detail previously in this AGN. The BL type is a capacitor excited brushless design. The SL type has a rotor winding connected to an excitation circuit via a pair of slip-rings. Both above codes – BL 105 and SL 105 – will be followed by the core pack length identifying alphabetic letter. Both types of alternator are designed for basic applications and therefore incorporate a rugged and reliable, rather than a sophisticated, excitation system.

Older Markon nomenclature. The earliest types of rotating field 2-pole alternators were identified as SC21 followed by alphabetic letter. These very early designs have an electronic AVR – of a SERIES principle of operation identified as an MS type – which was fixed to the non-drive end of the frame, located on the right hand side of the bearing, and their mode of operation has not been included in this document. Contact applications@cummins.com for further information on older types of Markon alternators:

- The earliest version of the Brushless types were identified as: B21, B112, B105, followed by a letter.
- The earliest version of the Slipring with Diverter type AVR: SCD 21, SC105, followed by a letter.
- There are also some without an AVR, identified as SCN21 [N = No AVR]

The BL105

The BL 105 range have an excitation system based on a controlled level of 'self-excitation' generated by the effect of a leading power factor condition created within the stator winding assembly. Within the alternator's stator, there are two isolated windings, identified as a Main and an Auxiliary winding. The Main winding is used to provide the alternator's output power, therefore will be connected to the load. It typically consists of two 120V windings, brought out to terminals by four leads identified as: U1 [red] – U2 [white] & U5 [brown] – U6 [blue].

Connecting these windings in series (link U2 [white] to U5 [brown]) will provide the most commonly required 240V output between terminals U1 [red] & U6 [blue]. The Auxiliary winding is connected to a capacitor (40 μ F), its sole purpose being to "self-excite" the alternator by generating a leading power factor current, which in turn induces excitation into the rotor coils.

The rotor windings are connected to a diode(s) mounted within the rotor construction assembly. The diode(s) effectively short(s) out the rotor winding and this results in dc current 'flowing' through each rotor coil, thereby creating a polarised rotating electro-magnetic field.

Various versions of the rotor assembly have been manufactured, with either one or two diodes, and these have been variously located within a plastic moulding located at the bearing end of the shaft, or located within the boss of the plastic fan at the engine end of the shaft. The diode(s) have always been connected to an adjacently mounted surge suppression device identified as a Voltage Dependant Resistor [VDR] and some have also included a surge arresting resistor and capacitor assembly.

Under normal and healthy operating conditions, the excited rotor, spinning within the stator, generates a magnetic flux which acts upon the stator windings, thereby generating a voltage within the stator windings which, not only supports and maintains the auxiliary winding and capacitor with the ability to continuously excite the alternator, it is also magnetising the main winding, thereby generating output power at the correct voltage and so an output available to power the connected load.

The alternator's output voltage is automatically regulated at close to the required output voltage level by the effects of mutual inductance between both the main and the auxiliary stator windings and the rotor winding.

This capacitor brushless excitation system provides a cost effective and simple alternator with voltage regulation quite acceptable to the loads typically powered by small Generating Sets. This type of excitation system is very sensitive to operating speed, and so the BL105 type alternators will not initiate any electro-magnetic activity if operated below 90% of rated speed.

The following values refer to a 50Hz / 3000rpm unit. These alternators will not self-excite below 2800rpm and the output voltage regulation will be compromised by an engine, which is operating outside the normal 3150>3000 rpm, No-Load < Full Load, speed regulation 'droop'. For guidance regarding speed range for a 60Hz/3600rpm unit, multiply above values by 1.2.

The SL105

The SL 105 range have two stator windings. The main winding is used to provide the alternator's output power and therefore, will be connected to the load. It typically consists of two 120V windings, brought out to terminals by four leads identified as U1 – U2 and U5 – U6. Connecting these windings in series [link U2 to U5] will provide the most commonly required 240V output between terminals U1 and U6. The output leads of the auxiliary winding are marked Z1 and Z2 and this winding provides power for the excitation system. The output of this winding is connected, via a series connected choke, to the ac input terminals of a single phase full wave bridge rectifier, which is the 4-terminal solid state device mounted near the choke. The dc output of the bridge rectifier is connected to the rotor windings via the slip-rings. The positive (+ve) lead is identified by the marking F1 [X on old alternators] and this is connected to the slip-ring closest to the alternator bearing. The negative (-ve) lead being marked F2 [XX on old alternators].

This excitation system is designed to generate slightly more excitation than is really needed for any condition between No-load and Full-load. Excess excitation is diverted away from the rotor [field] windings by a solid state Automatic Voltage Regulator [AVR]. The AVR is designed to momentarily short-out the excitation voltage being supplied to the slip-rings and by so doing, it reduces the effective level of excitation available to 'flow' through the rotor winding. The alternator's output voltage is controlled by the level of excitation current flowing through the rotor winding. The AVR senses the voltage of the main winding and compares this voltage level with the 'set' voltage level and maintains a constant output voltage under load conditions by constantly adjusting the level of the excitation being applied to rotor winding.

As explained above, the alternator actually generates more than required excitation and this is reduced by the action of the diverter type AVR. This means that the alternator will operate without an AVR, but will generate higher than nominal output voltage.

Without the AVR being connected, the output voltage will be some 300V under a No-Load condition. If load is applied to the alternator, then this 300V will reduce in proportion to the level of load applied such that at rated load the output voltage will be some 250V. In emergency conditions, where the alternator must be operated without an AVR, the output voltage can be reduced to acceptable levels if the engine speed is reduced.

Fault Finding Guidance, applicable to both BL 105 and SL105

Safe working practices must be followed at all times. It is further expected that electrical instruments will be available to measure winding resistances and test for insulation resistance values to ensure that wound assemblies are serviceable. Furthermore, to ensure that a re-assembled alternator is functioning correctly, a good quality multimeter will be required to identify output voltage and check that the alternator is running at the correct speed, by accurately identifying the operating frequency [Hz].

Fault finding will involve the use of a 12V battery, which at all times should be used with due care, always being handled in a safe manner and placed in a safe location.

The fundamental method of testing an alternator begins with a visual inspection of all components for obvious damage, surface contamination of all electrical windings and terminations and loose, or broken, connections.

The Markon Installation, Operation and Maintenance Manual contains a great deal of useful information, including data for all winding resistance values, basic connection diagrams, and a Fault Finding Guide.

After completing a visual inspection of all components and establishing no obvious reasons for the alternator failing to operate correctly, then the following specific areas of investigation should be considered.

Insulation Resistance (IR) Testing. This test is typically conducted using a 'Megger'. It is most important that during IR testing, the test voltage is only applied to the winding under test. This will require all components normally connected to the winding under test, to be

disconnected. This is particularly important with regard to any electronic components. Care must be taken to identify the original location of each connection, to ensure correct reconnection. Megger all windings at 500V, to confirm they are adequately insulated from core packs, the metal frame and also from each different winding within the wound assembly. A value greater than 0.5Meg Ω should be measured for all IR winding tests.

Winding Resistance Testing. The resistance values of all wound assemblies should be measured and compared with the values listed in the Installation, Operation and Maintenance Manual. If this manual is not readily available, then establish that the both sections of the main stator winding are the same value at approximately $0.5 < 1.0\Omega$. The stator auxiliary winding should be some $1.5 < 2.0$ times the resistance of the main stator winding. The resistance value of the rotor winding coils varies with the type of rotating diode assembly being used. If two diodes are incorporated within the rotating diode assembly, then each rotor winding coil should be approximately 5Ω ; the important factor being that both coils should be the same resistance. If only one diode is incorporated within the rotating diode assembly, then the two rotor winding coils will have been connected in parallel and the resistance of this parallel coil circuit will be approximately 3Ω .

Restoring Residual Magnetism. Long term storage or a rough and bumpy journey to site, can result in a perfectly healthy alternator not self-exciting once the engine is started and the Generating Set is being driven at rated No-Load speed. It is most important that the Generating Set is being driven at the correct speed, 3150rpm for 50Hz generators and 3750rpm for 60 Hz. Failure to run at the correct speed will severely handicap the alternator's ability to 'self excite'.

After inspecting the alternator's output scheme for any incorrectly set switch, or obvious reason for the alternator not giving an output, it may be necessary to 'flash' the excitation system with a 12V battery. Because of the damage that can result from 'flashing' an alternator that is working, although a problem is not allowing the alternator output to be available, the voltage across the terminals that are to be flashed should be measured. If this test confirms the excitation system is not working, then 'flashing' can be carried out.

WARNING. It is dangerous practice to make 'splash' connections directly at the terminals of a battery because of the risk of hydrogen gas being present in the atmosphere just above the battery cells. Therefore, short leads should be connected to the terminals of the battery, so that the 'flashing' connection takes place and an electrical arc occurs on disconnection, this activity will be at least 1 metre away from the top of the battery.

Restoring the Residual Magnetism - BL105. There are two methods, as follows:

- Method 1. To Re-Flash the residual magnetism into the alternator, the Generating Set should be at rest. 'Flash' a 12V battery across the capacitor terminals, in a sequence of One second on and one second off. Repeat three times. Battery polarity is not important.
- Method 2. If the alternator does not build-up to a typical voltage (240V) with the Generating Set running at the correct No-Load speed, check the ac voltage across the capacitor. If measured at less than 10Vac, then the alternator may be coerced to excite

by momentarily flashing across the capacitor with a 12Vdc supply from a battery with the Generating Set running at rated no-load speed. 'Flash' the battery to capacitor for no more than one tenth of a second.

- Note. When the alternator is working, the ac voltage across the battery is some 250<300V. If this voltage is applied for longer than 1 second to a 12V battery it could result in serious damage to the alternator components, or the battery.

Restoring the Residual Magnetism - SL105. There are two methods, as follows:

- Method 1. To Re-Flash the residual magnetism into the alternator, the Generating Set should be at rest. The F1 and F2 leads connected to the brush gear should be disconnected. Temporary leads should be connected to the brush-gear connections, taking care to ensure that the brush/slip-ring [F1 or X] connection nearest to the bearing will be connected to the positive terminal of the battery. The lead from the brush/slipring [F2 or XX] connection nearest the engine can be connected directly to the negative terminal of the battery. 'Flash' the 12V battery across the brush-gear and so rotor winding, in a sequence of one second on, one second off. Repeat three times. Remove all battery connections to the alternator, reconnect the pair of F1[X] and F2 [XX] connections. Start the engine and ensure the Generating Set is being run at the correct No-load speed, and then confirm with a voltmeter that the alternator has self-excited and is providing the required output voltage.
- Method 2. If the static 'flashing' has not worked, then the following procedure can be used. Run the Generating Set at the correct No-Load speed, check the voltage across the brush gear F1 [X] and F2 [XX] connections. If measured at less than 5Vdc, then the alternator may be coerced to excite by following the method outlined below.
 - During the following procedure the AVR leads F1 and F2 should be disconnected to ensure the AVR will not be damaged. A voltmeter should be connected across the alternators output terminals to provide indication that the alternator has excited – because it is very dangerous to 'flash' across the brush gear connections of an alternator that is already excited.
 - Note. With the AVR disconnected the alternator will operate at 300V across output connections, where the normal 220<240V would be expected. Follow the safe working practice regarding battery test leads outlined in Method 1, above, and consider connecting temporary extension leads to the brush-gear to reduce the risk of shorting the battery or connecting to the wrong place. Momentarily 'flash' 12Vdc from a battery across the brush gear connections with the Generating Set running at rated no-load speed. 'Flash' the battery to the brush-gear – and so the rotor winding – for no more than one tenth of a second. This procedure may be necessary more than once. However, allow a delay of at least three seconds between each 'flash', during which time the voltmeter connected across the alternator's output terminals should be observed to check for signs of excitation building.

- Note. When the alternator is working, the voltage across the brush-gear is much higher than that of the 12V battery and so there is a risk of serious damage to the alternator components and the battery.
- Once the alternator has excited, the engine should be stopped. All temporary connections associated with 'flashing' should be removed from the brush-gear and the AVR connections F1 and F2 should be refitted. With the engine re-started and the Generating Set running at the correct No-load speed, the alternator should now be operating at the AVR's set level of output voltage.

Specific Fault Finding for the BL105

Rotor diodes and their surge suppressors (VDRs). The plastic housings into which the surge suppressor components have been embedded should be checked for signs of cracking and heat damage. If this is evident then there is likelihood that the VDR's have been stressed and are damaged and this suggests the diodes may also be unserviceable.

- Main Rotor Diode. To test the rotor diode, at least one side of the diode must be completely disconnected from both the rotor windings and the Varistor. Preferably, to do the following test more effectively, it is better to remove the diode completely, from rotor assembly.
- **WARNING:** Danger of electrocution. Ensure the mains supply is disconnected when making connections and ensure all connections are insulated.
- The only way to correctly test that the diode 'is good', is to connect the diode in series with a 40W to 100W, 240V filament bulb (ordinary house light) and connect this circuit to a 240V single phase mains supply. For example; The Neutral cable to one side of diode, the other side of diode to one side of lamp and the other side of lamp to the Live cable. A 5A fuse should be used in the plug.
- If the diode is good, then the lamp will be flickering at 25Hz and half normal brilliance. If the diode is unserviceable with a short circuit, the lamp will be at full brilliance. If the diode is unserviceable with an open circuit, then lamp will be off.
- Diode Type. 16A, 1200V, stud mounted diode.
- Diode Connection. The diode(s) must be connected to each rotor winding coil so that each diodes indicating 'arrow' is pointing in a direction which indicates the current flow through each of the coils is in the same direction (coils must work together, not fight each other).
- VDRs. The Varistor will have a very high resistance and then, providing it does not look as though it has been subjected to excessive heat, it should be OK to re-use.

Reassembly. Once it has been established that all alternator components are serviceable then the alternator can be re-assembled onto the engine. Once an alternator has been dismantled and re-assembled, it will almost certainly need to be 'flashed' to re-store residual magnetism within the rotor assembly to enable it to self-excite.

Load Testing. With all alternator components in a serviceable condition, the Generating Set running at the correct No-Load speed and the above method of restoring residual magnetism correctly followed, the alternator should now be providing the expected output voltage under a No-Load condition. The Generating Set should now be connected to various loads to confirm the alternator is regulating the output voltage within acceptable limits and that the engine is able to maintain the speed, and so Hz, also within acceptable limits.

Observations. The following comments assume the output voltage of a alternator is expected to be in the order of 240V:

- If the output voltage, under no-load condition, is only some 180V and then rises slightly - to around 190V - when a 1kW load is applied, then this indicates one of the two rotor diodes is faulty.
- If the output voltage is above 260V under No-load condition, then this indicates the operating speed is too high.
- If the capacitor value is not within the required $40\mu\text{F} \pm 5\%$ tolerance band, then the output voltage under No-load conditions will be proportional to the higher or lower level of capacitance in circuit.

Specific Fault Finding for the SL105

The slip-rings incorporated within this alternator allow a fault finding process of separately exciting the alternator from a 12V battery. This test 'forces' the alternator to work, which then allows a constructive diagnosis of the reason for a malfunction. If the alternator is to be dismantled, then the brush box should be unbolted from the alternator frame to ensure the carbon brushes are not damaged.

In addition to winding resistance values given in the Installation, Operation and Service manual, the following winding resistance values specific to the SL105 should be noted. The rotor winding has a typical resistance of 10Ω and this should be measured directly from the bronze slip-rings, taking care to not unnecessarily mark the surface of the slip-rings. If measured through the brushes, a higher value will be recorded.

The resistance of the wound coil of the choke assembly, which is mounted to the right hand side of the non drive end bearing, is approximately 7Ω . This choke has factory set air-gap in the lamination steel assembly and this gap distance, of typically 2.0mm should not be tampered with. The factory setting involves adjusting the air-gap such that when a 50Hz voltage is applied the choke coil has Impedance $[Z]$ of 85Ω .

The condition and serviceability of the brushes should be checked. Ensure that the remaining length of the carbon brush is sufficient to maintain a good and positive contact area on the slip-ring. Check that the carbon brush is able to slide in and out of the brush holder. When refitting the brush-box take care to align the brush-box such that the end of the protruding section of carbon brush is fully contacting with the slip-ring surface.

Once the visual inspection is complete, the winding resistances have been confirmed as acceptable and the winding Insulation Resistance test has confirmed that all components are healthy, the reassembled alternator can be tested under an engine driven situation. With the AVR being a diverter type, this item should be removed during the initial stage of testing.

In preparation for checking the alternator windings under a separately excited test condition, the stator output leads should be located and positioned to suit safe measurement of the generated voltage in each winding section. This may require the leads to be temporarily extended in a safe manner ensuring no short circuits can occur.

- Main Winding: Leads 1 – 2. Leads 5 – 6. Note. If the alternator is only used to provide 220 < 240V and the 2-5 connection can be seen to be in place. Then consider only Leads 1 – 6.
- Leads L1 – L2, which are the input to the AVR.
- Auxiliary Winding: Leads Z1 – Z2.

When separately exciting the alternator with a 12V battery, care should be taken to ensure that no other leads are connected to the F1 +ve and F2 -ve connections of the brush-gear. F1 [X] +ve positive is nearest the bearing.

The battery should not be connected to the brush-gear until the engine has been started, because there is a risk of burning the slip-rings if current flows across the carbon brush to slip-ring surface if the slip-rings are stationary.

With the engine running at 3000 < 3200rpm, and 12V dc being applied – from a healthy 12V battery, or from a 5Amp variable voltage dc power pack - to separately excite the alternator, the following ac voltages should be present.

- Main Winding:
 - Leads 1 - 2 110V +/- 15%
 - Leads 5 - 6 110V +/- 15%
 - Leads L1 – L2..... 110V +/- 15%
 - Leads 1 – 6 220V +/- 15%
- Auxiliary Winding:
 - Leads Z1 - Z2 220V +/- 15%

With the battery disconnected and the engine stopped and voltages measured are generally in line with the above values, then the next test involves the reconnection of more alternator components. However; if any of the above voltages are very much lower than the above, or the mains winding voltages 1-2 and 5-6 are not very similar, then a winding fault must be suspected.

If the measured voltages of the main winding are balanced, but values are lower than above and also the auxiliary winding voltage is also low, then;

- Re-check the running speed of the engine, as the output voltage is very speed dependant.
- If the alternator makes a 'growling' type noise when the battery is connected and/or the engine can be heard to slow down or make more noise, then this indicates a winding fault, most probably within the stator winding assembly and the faulty winding should be identified by more sophisticated bench testing.
- If the running speed is correct, the applied voltage is 12Vdc, the measured voltages are in-line with the expected values but much lower and then a faulty rotor winding should be suspected.

The Auxiliary winding leads should now be reconnected to the choke and the bridge rectifier. Z1 is connected to one of the choke winding connections. The other choke winding connection has a short Z3 lead, which is connected to one of the ac input terminals of the bridge rectifier. Z2 is connected to the other ac input terminal of the bridge rectifier.

The dc output from the bridge rectifier should be connected to the F1 [X] positive lead and the F2 [XX] negative lead, which both run from the rectifier to the brush-gear.

At this stage, do not reconnect at the brush-gear end.

A modern alternator's bridge rectifier is a square shape with a terminal in each corner. One of the corners has been moulded with a flat and the terminal in this corner is 90° out of orientation with the other three terminals. This is the dc +ve [positive] terminal for lead F1 [X] and the dc -ve [negative] terminal for lead F2 [XX] is diagonally opposite. The remaining two terminals are the ac input, and the polarity of the Z2 and Z3 leads to these terminals is unimportant.

The next test involves running the alternator under a separately excited condition and measuring the DC voltage across the F1 – F2 leads at their brush-gear end. The measured voltage should be 230 Vdc +/- 15%. Measurement of the expected dc voltage confirms a healthy bridge rectifier and continuity of the choke coil.

With the battery disconnected and the engine stopped, the F1[X] and F2 [XX] leads can be reconnected to the brush-gear. F1 is connected to the brush/slip-ring nearest the bearing.

When the engine is now started, the alternator should self-excite and be operating at a no-load voltage of:

- Main winding leads 1 – 2 = 150V, 5 – 6 = 150V and 1 – 6 = 300V.

The dc voltage measured across F1 – F2 will now be in the order of 20Vdc. This is because the choke winding now is acting to reduce (by choking back) the full auxiliary winding voltage and some 200+ Volts is ‘dropped’ across the choke winding. The effectiveness of this choke winding is set by the factory set air-gap of the choke assembly.

From a position of the alternator now generating an output voltage, albeit more than the required level, the next step is to reconnect the AVR.

Modern versions have the AVR mounted to the plastic brush box assembly. Early versions had the AVR mounted above the choke.

The AVR type is: MD1, **Markon Diverter** type and cannot be replaced by any other type of Markon AVR. E.g...MS = **Markon Series** type. The MD1 has undergone various developments, the latest version (Aug 2004) being the MD1C. The MD1C AVR has 4 terminals. With the AVR held such that the terminals are pointing upwards and on the side of the AVR nearest to you, the terminals from left to right are:

- L1 L2 F1 F2

Looking at the AVR component side, with the terminals in a vertical line on the left hand side:

- The **Voltage** adjusting pot is at the top edge, right hand corner.
- The **Stability** adjusting pot is in the centre of the AVR.

AVR Reconnection. The L1 and L2 leads, which have already been tested and a voltage at these terminals was measured during the initial tests, should be connected to the AVR. The short F1 and F2 leads, which form the second set of leads on each of the brush-box connections, should be connected to the AVR.

For absolute thoroughness, an ac ammeter, capable of measuring < 1.5A, can be connected in series with the F1 lead from the AVR to the brush-gear.

When the engine is started and the Generating Set is running at rated no load speed, the output voltage should now be under the control of the AVR. This can be confirmed by adjusting the voltage pot and setting the required level of output voltage. Under this no-load condition, the ammeter should indicate some 0.8A being diverted by the AVR. For reference; under full load conditions, the diversion current will only be in the order of 0.1A. This ammeter should be removed and the short F1 lead reconnected to form the AVR to brush-gear link.

If the output voltage is unstable, although the engine speed is perfectly stable, then adjustment of the AVR’s Stability pot will stabilise the output voltage. But overall stability should be checked under various different loading levels from No-load to Full-load.

If once the AVR is reconnected and the alternator output voltage is not under the control of the AVR, or the output voltage will not build-up as the engine accelerates to speed, then the AVR must be replaced. In emergency conditions, where the alternator must be operated without an AVR, the output voltage can be reduced to acceptable levels by reducing the engine speed.

With the alternator now operating correctly, the main stator winding leads 1, 2, 5 and 6 should be reconnected to the correct connections of the Generating Set's output distribution system of over current protection devices and output sockets.

Hopefully, this distribution system and included circuitry is in good working order and the correct level of output voltage can be measured at each output socket, or terminal array. If not, a logical fault finding procedure must be followed for this equipment.