

Application Guidance Notes: Technical Information from Cummins Generator Technologies

AGN 039 – Marine Shaft Generators

DEFINITION

A shaft generator is a term used by the Marine industry. It means an a.c. generator (alternator) that is to be driven by the Ships main engine. The main ship propulsion shaft from the engine to the propeller passes through a large gearbox, and this gearbox can have more than one auxiliary shaft for driving pieces of equipment such as compressors or hydraulic pumps, or maybe an alternator. This application for an alternator just having the general description, and known to all as: the **shaft generator**.

Before the shaft generator can be used to supply power, the ships main engine and therefore propeller shaft, must be running at a fixed speed appropriate for the shaft generator to supply a useable output of voltage and frequency. Most ships operate at 450V, 60Hz. This means that the only time the shaft generator may be used to supply power, is when the ship is at sea and cruising at a constant speed.

Under cruising conditions, the ships main engine has plenty of power to spare. It therefore makes good economic sense to make use of the main engine and 'stand down' the diesel-engined generators that are used at all the times when the ships main engine is either running too fast or too slow. This happens mostly, when the ship is approaching or leaving port, or in heavy traffic areas, or in difficult navigational areas.

SHAFT GENERATOR DESIGN

Two bearing alternators are always used for shaft generator applications. The shaft generator will be turning – unexcited – on all occasions when the shaft running speed is outside the required speed for the shaft generator to supply power. The generator to gearbox coupling will be quite an elaborate flexible coupling. The ship's design engineers will consider carefully, the

weight of the coupling half that is to be fitted to the generator shaft. If this coupling half is too heavy it could stress the shaft generator's bearings.

With the shaft generator spinning for many hours at many different speeds and for much of this time unexcited, the ships maintenance schedule should include clear guidance about bearing regreasing instructions. It is recommended that the shaft generator is fitted with re-greasable bearings, which should be specified at time of order.

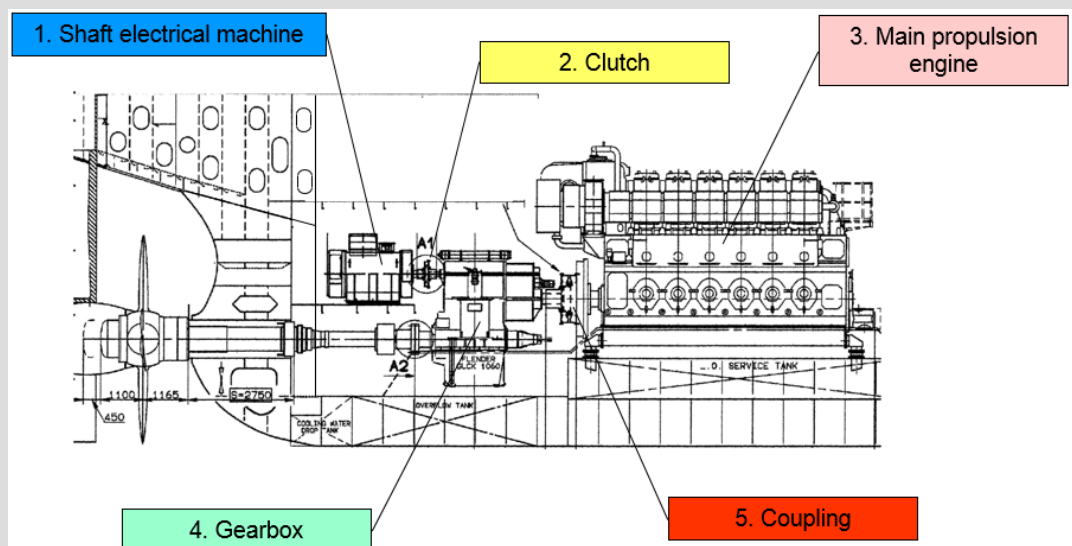
When the shaft generator is aligned with the gearbox drive shaft, the ships design engineer must take great care to allow for the thermal expansion of the hot gearbox, which may well expand and lift the shaft centre line by < 1 mm.

If the alignment is not accurate, then excessive vibration is likely to damage the shaft generator. There can also be lots of generator damaging vibration when the main engine is running at slow speeds and also when the ship is in storm conditions, because the ship's hull flexes and so the gearbox to generator alignment becomes distorted.

An experienced ship design engineer will know of these potential problems and will ensure that the coupling between gearbox and the shaft generator is a high quality, designed for purpose unit, which can absorb misalignment, and also torsional vibrations to help the generator remain reliable.

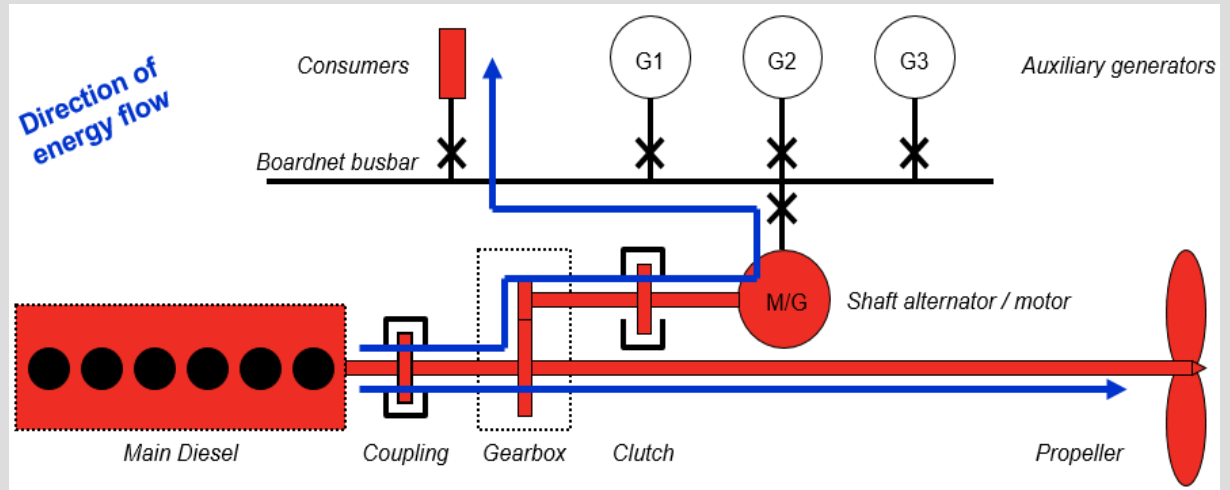
POWER TAKE OUT (PTO) / POWER TAKE IN (PTI) / POWER TAKE HOME (PTH)

Marine shaft generators are often required to operate in a multi-function role. They could operate as an alternator to provide the vessels primary electrical power supply. This is the conventional use of an alternator for Power Take Out (PTO). They could operate as an electric motor to provide a short/medium term power boost alongside the propulsion engine. This is known as Power Take In (PTI). Alternatively, the shaft generator could operate as an independent method of propulsion, when the main engine is out of commission. This is normally a very short term or emergency use known as Power Take Home (PTH). The following drawing shows a typical ship's arrangement and layout of a shaft electrical machine.



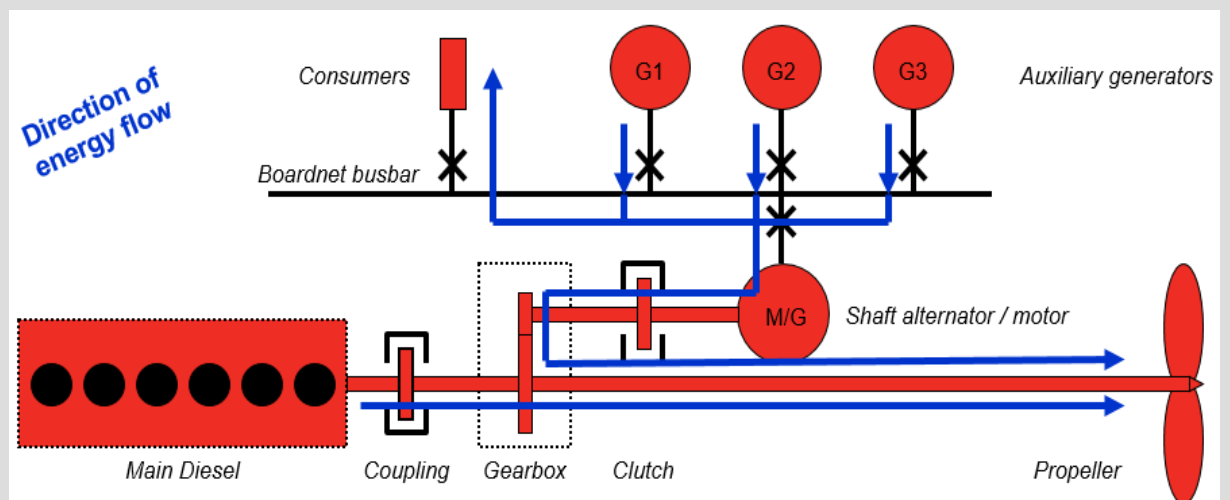
PTO (Power Take Out) mode of operation

The shaft generator is operating as an alternator, driven from the main propulsion engine, providing the primary power supply for the vessel electrical systems. The following drawing shows a typical PTO layout with power flow direction.



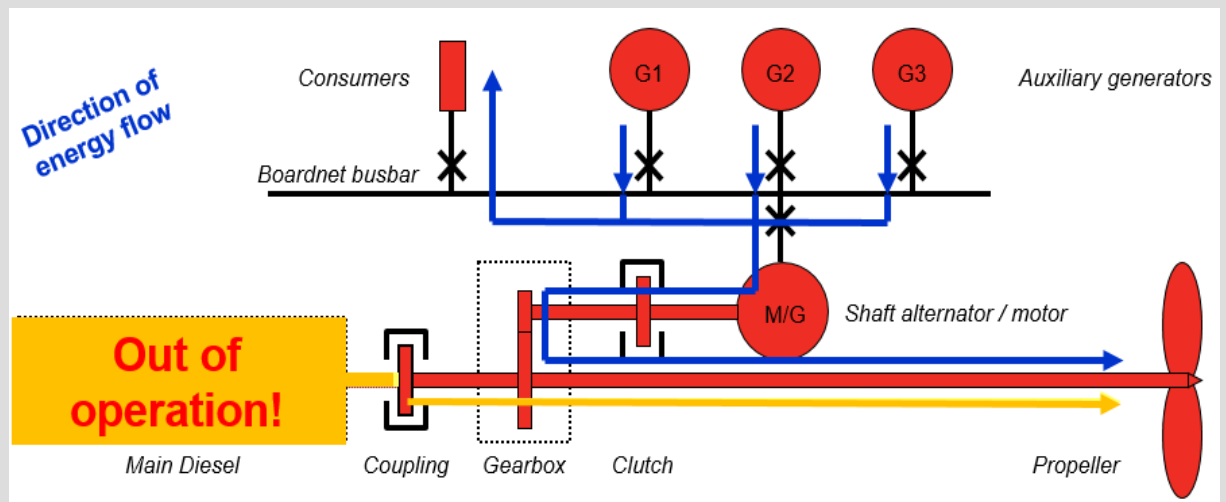
PTI (Power Take In) mode of operation

In this mode of operation, the shaft generator is operating as a synchronous motor (electrical power being supplied by the vessels auxiliary diesel generator sets). It can either provide a boost in power, working alongside the main engine to increase vessel speed, or it allows the main engine to reduce power, thereby lowering fuel consumption and wear on the main engine. In this PTI mode of operation, the shaft generator does not require a self-starting capability, because under normal circumstances, it will already be spinning as an alternator before switching over to motor mode. The following drawing shows a typical PTI layout with power flow direction.



PTH (Power Take Home) mode of operation

As with PTI, the shaft generator is operating as a synchronous motor in this mode of operation. However, this time it is providing 100% of the ship's propulsion power. In emergency situations, this could be due to failure of the main engine or the main engine requiring critical, unplanned maintenance. In other cases, this can be a normal mode of operation. Occurrences such as the main engine requiring routine maintenance or the main engine being stopped when the ship is entering port. Unlike PTI mode, in this mode of operation, the shaft generator needs to have a self-starting capability to run up as a motor from zero speed. The following drawing shows the layout of a typical PTH application with power flow direction.



Self-Starting Methods for PTH

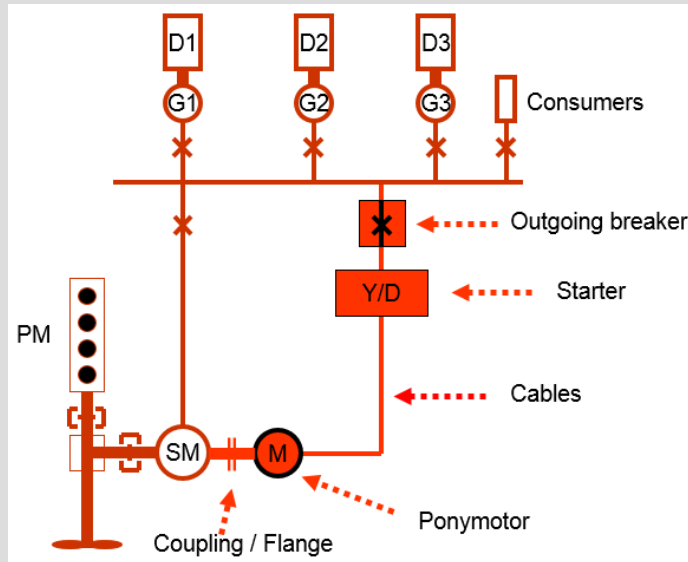
In many cases the PTH mode of operation is required comparatively few times during the lifespan of the shaft generator. Therefore, primarily for reasons of cost, an alternator is adopted for use as a motor and so will not have the inbuilt robust rotor design (particularly the damper cage) and excitation system needed to generate the necessary torque for starting from zero shaft speed, when compared to a designated synchronous motor. Consequently, a method of soft-starting has to be applied to the shaft generator during start up and in the case of AvK products, some modifications to the machine are also necessary.

Due consideration must be afforded by the ship's design engineers to the paralleling of the shaft generators with the ship's electrical system, ensuring voltage, phase and frequency is matching. Once the machine is paralleled and now running as a motor, the excitation system needs to be controlled to enable it to develop sufficient torque and power to drive the gearbox and therefore, the propeller.

There are a number of different methods that can be employed for starting the shaft generator when it is used in PTH mode as a motor. STAMFORD alternators are not suitable for PTH operation. This Application Guidance Note continues to describe five of the most well-known solutions; however, Cummins Generator Technologies do not offer any of these five motor starting methods on AvK alternators.

1. Pony Motor Start

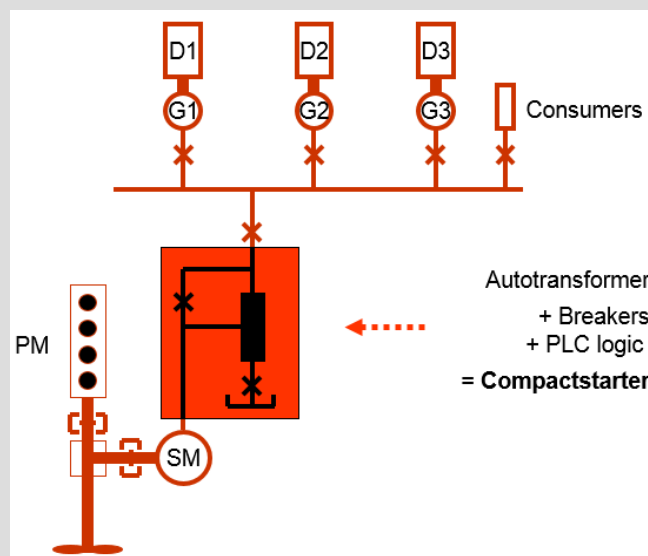
The shaft of the electrical machine (shaft generator) is physically connected and driven up to speed by an additional (smaller) electric motor, which will then disengage once synchronous speed is achieved. The following drawing shows a typical arrangement and the equipment needed.



The starter for the pony motor could be Star/Delta, Electronic Soft Starter, Autotransformer or Inverter/VFD, fed by the auxiliary generators G1, G2, G3 as shown.

2. Auto-Transformer Start

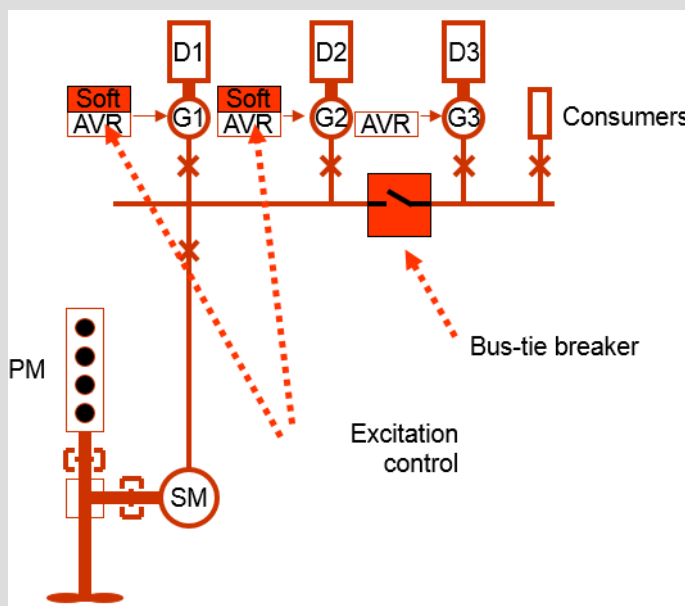
An auto-transformer is used to reduce the voltage level supplied to the shaft generator main terminals, thereby restricting the inrush current to acceptable levels. However, it is important to ensure that sufficient inrush current is provided to produce the necessary breakaway torque to turn the shaft generator's shaft. This current level is best determined during the commissioning process on-board the vessel. The following drawing shows a typical arrangement and the equipment needed.



The shaft generator is started as an asynchronous motor with this method and therefore, requires some modifications to the excitation system of the machine. These modifications are explained later on in this AGN.

3. Excitation controlled start (single propeller)

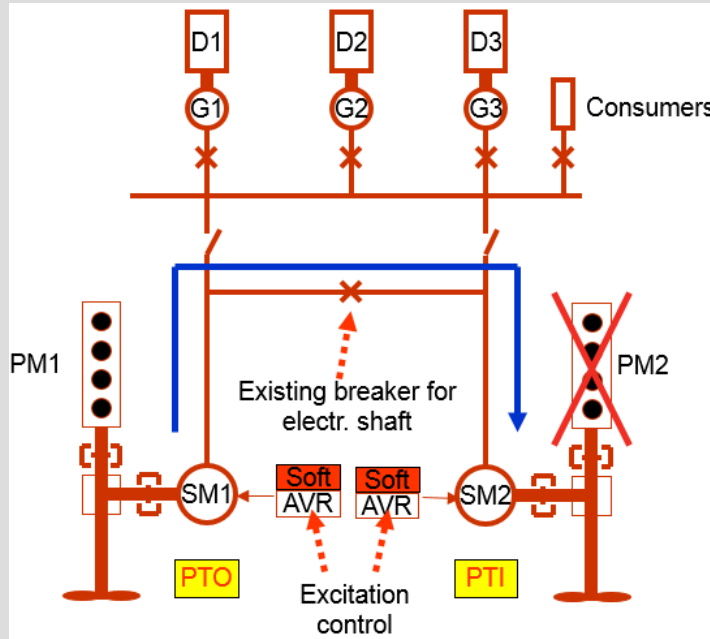
There are two systems to consider with regard to excitation controlled starting; single propeller system and twin propeller system. In this case, the inrush current can be limited by using a Stator Current limiting feature on the AVR's of the auxiliary generators. However, in order to isolate the vessel's consumers during machine start up, the main bus requires a tie breaker to avoid any risk of under voltage interference with consumer equipment. The following drawing shows a typical arrangement and the equipment needed.



As with the Auto-Transformer Start described in Option 2, the machine is started asynchronously and so requires some excitation system modifications.

4. Excitation controlled start (twin propeller)

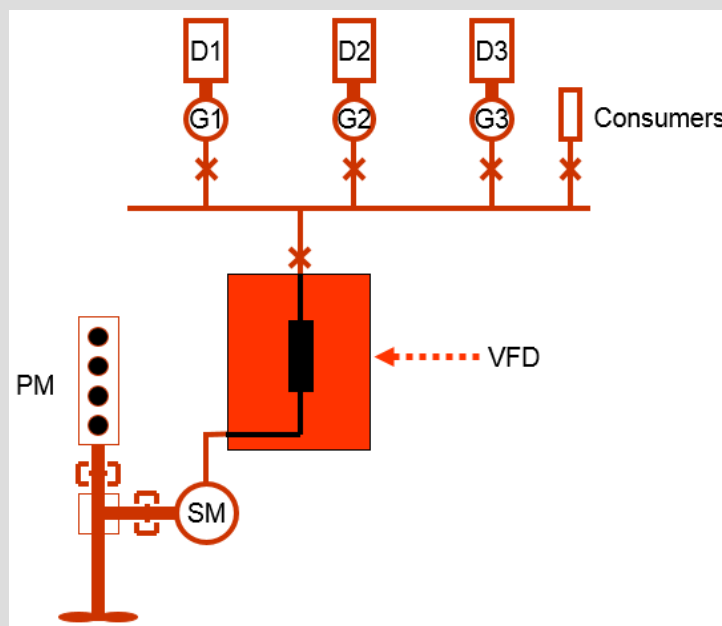
This scenario is very similar to that described in Option 3, above. However, this time the ship has twin propellers, twin main engines and two shaft machines. Instead of the Stator Current limiting capability being performed by the auxiliary generators, this time it is present on each shaft machine, allowing one shaft machine (operating in PTO mode) to start the second machine (operating in PTI/PTH mode). The consumers on board are completely isolated from both shaft machines during start up. The drawing on the next page shows a typical arrangement and the equipment needed.



With two identical shaft generators, it is possible to swap over the PTO and PTI/PTH modes of operation from one side to the other.

5. Variable Frequency Drive (VFD) Start

Here the shaft generator is controlled through a Variable Frequency Drive unit, which gradually rotates the generator shaft, ensuring the current is limited but the correct amount of shaft torque is delivered, until synchronous speed is achieved. The shaft generator can be started as a synchronous motor. The following drawing shows a typical arrangement and the equipment needed.



This system can also be applied to twin propeller vessels.

Excitation System modifications for Self-Starting PTH mode of operation (AvK alternators)

The modifications are applicable only to AvK alternators. The excitation system on an AvK alternator must be modified in a number of ways to enable the alternator to self-start as an asynchronous motor during a PTH mode of operation. These modifications changes to the low voltage AvK DSG alternator include the re-designation of the product to AvK DSU alternator. It should be noted that these modifications are not currently available on STAMFORD alternators or AvK DIG high voltage alternators. The modifications are listed, as follows:

- Rotor Modifications:
 - Enhanced Rotor Damper Winding with bronze alloy is used for DSU applications.
 - An additional switch is introduced in the rotor circuit. During start-up of the shaft generator as a motor, until synchronous speed is achieved, the machine behaves as a squirrel cage induction motor. It is necessary to isolate the Rotating Rectifier and Exciter Rotor from the Main Rotor winding, whilst at the same time shorting out the Main Rotor winding across a resistance, so that it acts like a squirrel cage induction motor. This additional switch does the above function making it safe to start the shaft generator in PTH mode of operation without damaging the exciter and diodes. This additional module can be up fitted to any low voltage marine AvK alternator, to achieve the self-start capability.

- Exciter Stator without magnets:
 - All AvK alternator exciter stators have permanent magnets fitted to ensure positive excitation build up when the alternator is used in its normal PTO mode of operation. When the alternator is used as a shaft generator running in PTI or PTH mode of operation, it is not required to build up the excitation and excitation is open circuited. However, when the shaft generator is started again as an alternator in PTO mode of operation, it may be necessary to apply a 24V d.c. voltage to the exciter stator for a short period to ensure excitation build up.

SHAFT GENERATOR SELECTION

Alternator Selection

It is necessary to understand that not all alternators are suitable for use as Marine shaft generators. The table on the next page indicates the suitability, or otherwise, of STAMFORD and AvK alternators for use as shaft generators in a Marine application:

	Mode of Operation					
	PTO	PTI	PTH			
STAMFORD						
UC22 - 27	■	■	Not suitable for PTH			
S4	■	■	Not suitable for PTH			
HC5 - P7	■	■	Not suitable for PTH			
P80	■	■	Not suitable for PTH			
AvK						
			Pony Motor	Auto Transformer	Excitation Controlled	VFD
DSG 62-114	■	■	■	■	■	■
DSG 114-125	■	■	■		■	■
DIG 110-156	■	■	■			■

AVR selection

Some of the AVRs available for use on STAMFORD and AvK alternators may not be suitable when the alternator is used as a shaft generator. The following table shows a matrix of AVR's with suitability for the PTO / PTI / PTH modes of operations:

	Mode of Operation					
	PTO	PTI	PTH			
STAMFORD						
MX341	■	■	Not suitable for PTH			
MX321	■	■	Not suitable for PTH			
DM110	■	■	Not suitable for PTH			
AvK						
			Pony Motor	Auto Transformer	Excitation Controlled	VFD
DM110	■	■	■			■
DECS100	■	■	■			■
DECS150	■	■	■	TBC	TBC	■
DECS250	■	■	■	TBC	TBC	■
Unitrol 1010	■	■	■	TBC	TBC	■

Information required for product nomination

When a technical request is received for a Marine shaft generator it is important to ascertain critical information with regards to the application and modes of operation. It is also important

to remember that more often than not, each marine project is different, with small variations in specification requirements and as such, each enquiry must be treated individually. There follows, a list of minimum items of information that are required from the customer to enable the correct nomination of an alternator for a Marine shaft generator application:

- Required modes of operation. It is always assumed that PTO is required, but there is a need to know if there is a requirement for PTI and/or PTH [certain countries in the Scandinavian region sometimes refer to the stand alone (PTH) operation as PTI, even though the main engine is not operating].
- The alternator output parameters and specification for power output, voltage, frequency and speed etc. are required for the alternator when operating as a shaft generator in PTO mode of operation.
- If the shaft generator is required for PTI/PTH mode of operation, then the mechanical shaft power output is required. Once an alternator is selected, the mechanical kW output can be determined.
- If the shaft generator is required for PTH mode of operation, the starting method to be employed, is required.
- Information on shaft generator cooling and bearing requirements must be determined.
- Information on the need to comply with a particular Marine Classification Society is required.

Other considerations

When the shaft generator is used in a PTH mode of operation, the shaft generator should be mechanically disconnected from the ship's propeller shaft during start up. A suitable clutch mechanism is normally used for this purpose. This will reduce the level of starting torque required and subsequently, the inrush current will also be minimized.

Application Engineering stand ready to assist in any enquiry regarding the application of Marine alternators. Contact: applications@cummins.com.