SEAFDEC Training Department

SOUTHEAST ASIAN FISHERIES DEVELOPMENT CENTER

TD/TRB/56 September 1990

# DIESEL ENGINE POWERED GENERATOR FOR FISHING BOATS

compiled by
Shinzo Yamamoto



Published by the Training Department, Southeast Asian Fisheries Development Center
P. O. Box 4, Phrapradaeng, Samutprakarn, Thailand.

Text Reference Book No.56
September 1990

# DIESEL ENGINE POWERED GENERATOR FOR FISHING BOATS

Compiled by
Shinzo Yamamoto

Training Department
Southeast Asian Fisheries Development Center

**PREFACE**

This text book has been compiled for students in the SEAFDEC Marine Engine Regular Course as a suplementary manual to the Internal Combustion Engine for fishing boat series, Volumes I-V.

The text provides an elementary introduction to the diesel-engine powered generator, usually referred to as a diesel generator, which today is the most widely used auxiliary power source in fishing boats.

However, at present the chief source of electrical energy in a fishing boat is generally provided directly from the prime mover, such as a diesel or gasoline engine because no alternative source is available. Therefore, the capacity to provide continuous reliable generation of electricity by the using and carefully maintaining these engines is essentail.

With the rapid introduction of technological advances, such as refrigeration plants, navigation aids, radio equipment, auxiliary machinery and mechanized fishing gear, the demand for electrical power on board has increased dramatically. A good practical engineer without a basic knowledge of electronics and electrical engineering therefore cannot hope to satisfactorily fulfill their duties. I hope this text book will be of great benefit to those students who wish to study further in this field.

Shinzo Yamamoto
Instructor
September 1990.

CONTENTS

## 1. Planning of Diesel generator installed in fishing boat

Recently, the amount of electric power used in fishing boats has increased dramatically; it hauls fishing gears, illuminates fishing lights, provides electrical and electronic equipment for navigation and radio signals, and powers deck machinery and refrigerating machines etc. The diesel powered generator; particularly the alternate current (AC) generator i.e. the alternator, is the most widely used power source for such purposes.

When planning the installation of a diesel generator, the following items should be examined carefully:

First

- Kinds or type of load
- Amount of load
- Space allocated for generator installation

Second

- Capacity of generator
- Type of generator
- Voltage, Cycle (HZ)

### 1.1 Capacity estimation

If there are many auxiliary machines in the fishing boat such as fishing gear, deck machinery, various types of pumps, compressor, refrigerator, and electric heaters, most of which are to be driven by induction motors, the most important consideration will be its starting input.

It is common knowledge that, when a large amount of load is applied to a small capacity AC generator, the terminal voltage drops noticeably. This will cause a marked reduction in speed or the motor to stop, the tripping of relays or contactor to disconnect, the lights to flicker, the power sources to shut-off and so on.

1.2 Starting methods for induction motors

In squirrel cage induction motors, the starting current can be five to seven times as large as the rated current and between 70%-80% of the power factors of the motors, as shown in the following Table 1.

Table 1. Starting current of induction motor

Starting current

| Rated output (PS) | Rated current (A) | Number of poles 4 | Number of poles 6 |
|---|---|---|---|
| 1 | 3.7 | 23 | 24 |
| 2 | 6.8 | 42 | 44 |
| 3 | 9.8 | 60 | 65 |
| 5 | 16.0 | 97 | 105 |

Low-voltage Induction motor
(Squirrel cage type)

| Rated output (PS) | Rated current (A) | Starting current, Number of poles: 4 | 6 | 8 |
|---|---|---|---|---|
| 7.5 | 23-26 | 130-150 | 130-150 | 140-160 |
| 10 | 30-33 | 170-190 | 175-185 | 185-210 |
| 15 | 44-48 | 250-280 | 255-290 | 265-300 |
| 20 | 58-63 | 330-370 | 335-380 | 355-405 |
| 25 | 72-77 | 405-455 | 410-470 | 436-485 |
| 30 | 84-92 | 480-540 | 485-555 | 510-575 |
| 40 | 112-121 | 640-710 | 650-730 | 680-760 |
| 50 | 139-149 | 785-875 | 800-900 | 840-940 |

Low-voltage induction motor
(Enclosed open-squirrel type)

(In accordance with
JIS C 4201)

Note 1. These values show the starting current at 200 VAC.
Note 2. When the Voltage is E, the value should be multiplied by 200/E.

Therefore, the capacity of the AC generator should be determined by the total operating output i.e. the sum of the required load (KW) of each machine. But, more importantly, it should also be determined by the value that prevents an instant drop in voltage at a specified level. In general, the desired maximum voltage drop is estimated to be at about 30% of the rated voltage.

1.3 Starting current of Induction motors

It is impossible to reduce the size and weight of the generator capacity (KVA) unless the starting current of each motor is also reduced.

However, it is possible to reduce the starting current required by each motor either by modifying the starting method or the starting sequence.

Starting methods which may applied are as follows;

- Full voltage starting (Direct-on starting)
- Star - delta - starting
- Reactor - starting
- Compensator - starting
- Kondorfer - starting

The approximate values of allowable current are shown in the following table.

Table 2. Starting current (Direct on current : 100)

| Starting methods | | Starting Current | Starting torgue |
|---|---|---|---|
| Full voltage starter | | 100 | 100 |
| Compensator | 80% tap | 64 | 64 |
| starter | 65% tap | 42 | 42 |
| Reactor | 80% tap | 80 | 64 |
| starter | 65% tap | 65 | 42 |
| Y - Δ start | | 33 | 33 |

1.4 Voltage drop in the AC generator.

The amount of voltage drop in an AC generator when the load is applied suddenly, varies according the type and characteristic of AC generator's exciter and the load applied.

The following figure (I) shows the difference in voltage dip between two types of exciting methods.

- Separately excited AC generator

Direct-Axis reactance of generator ; xd

Transient reactance ; xd'

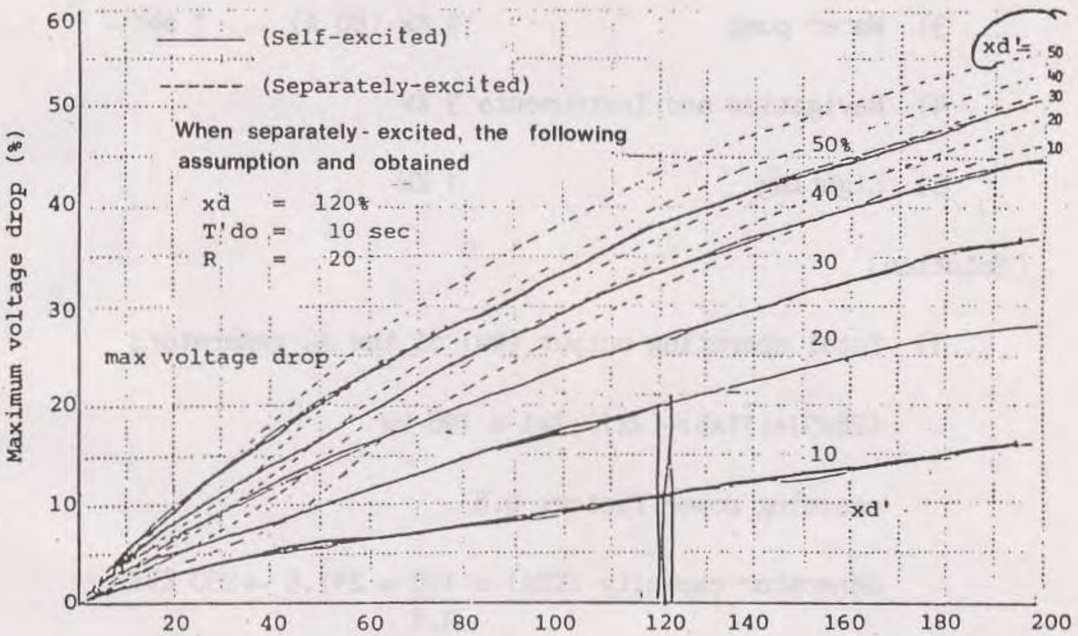
Open-circuit time constant ; Tdo'

Excitor response ratio ; (R)

- A self-excited AC generator

  Transient reactance of generator ; xd'

  Instantaneous voltage drop Fig. (1)




Starting current (%) = $\frac{\text{Instant current}}{\text{Rated current}}$ x 100 Starting KVA(%) = $\frac{\text{Starting KVA}}{\text{Rated KVA}}$ x 100

Fig. 1

The figure shows that the self-exciting AC generator obviously has a much smaller voltage drop than that of the separately excited generator.

1.5 Example of capacity calculation

[Example]

Determine the capacity of the self-excited AC generator (600 HZ 440 VAC) under following load conditions:

1) Fishing gear, pumps,
Deck machinery drive induction motors
(starting current 230 A) ... 5 sets

2) Refrigerating m/c and Air-conditioner
drive I.M 11 KW (starting 100 A) ... 5 sets

3) Water pump 9 KW (80 A) ... 1 set

4) Navigation and Instruments 3 KW

5) Lighting 1 KW

[ Solution ]

1) Total operating output (kw) of the AC generator;

(26x5)+(11x5)+(9x1)+3+1 = 198 kw

assuming power factor; 0.8

Generator capacity (KUA) = $\frac{198}{0.8}$ = 247.5 $\rightarrow$ 250 KVA

(Note) In 3-phase alternating current,

$\sqrt{3}$ E.I = KVA E ; Voltage (Volt)
I ; Current (Ampere)

KVA x $P_F$ = KW $P_F$ ; Power factor

2) The starting sequence of the induction motors may be determined as follows;

a. 2.6 KW I.M. ..... Start the I.M. one by one

b. 11 KW I.M. ...... Start the I.M. one by one

c. 9 KW I.M. ....... Start

Assuming that, the terminal voltage drop is 22% and the xd' value of generator is 20%, a corresponding starting current (%) of 122% is obtained from calculations in Fig. 1.

The maximum starting current (rush current) of 26 KW I.M. is given by 230 Ampere.

$$\frac{230}{1.22} = 188.6 \text{ (A)}$$

This current should be the prerequisite rated current of the generator.

That is generator KVA $= \sqrt{3}$ E.I $- \sqrt{3}$ x 440 (V)x188.6 = 144 KVA

Then 144 KVA x 0.8 = 115.2 KW → 120 KW

[Conclusion]

The capacity of the above generator, as determined in terms of voltage drop, is smaller than the actual required output 250 KVA. Therefore, to be on the safe side, a 250 KVA motor should be selected if at all possible.

[Example 2]

Examine 60 KVA, 200 VAC self-excited AC generator under the following load conditions:

| | | |
|---|---|---|
| 1) | Lighting; | 10 KW |
| 2) | Water pump | 19 KW (I.M.) |
| 3) | Fire pump | 5.5 KW (I.M.) |
| 4) | Drainage pump | 6.7 KW (I.M.) |
| 5) | Strage pump | 2.2 KW (I.M.) |
| | Total | 43.4 KW |

- If at all possible the motor must be capable of applying each load simultaneously.

[ Solution ]

1) Generator capacity
Total operating out is 43.4 KW, PF ; 0.8 (assumed)

$$\frac{43.4}{0.8} = 54.2 \rightarrow 60 \text{ KVA}$$

2) Total load of I.M. is 33.4 KW
Estimated total starting current of I.M. ; 750 A

Lighting equipment current ; 29 A (Table 1)

Total starting current; Total 779 A (calculate A)

The rated current for 60 KVA generator K $\sqrt{3}$ E I=KW at 20 VAC is about 173 Ampere (calculation) then the starting KVA; $\frac{779A}{173} = 450\%$

This value is too large and cannot be accepted. (the generator will be damaged)

Conclusion

(a) A 60 KVA generator should be installed but using a full voltage starting method is impractical.

(b) Therefore, the sequence of starting of I.M. should be as follows;

(1) Lighting (10 KW)-(2) water pump (19 KW. I.M.)

(2) Others (14.4 KW. I.M.)

In this case, although the voltage drop will be more than 30%, it can be revived within a few seconds and therefore will be of practical use.

1.6 Selection of generator type

AC generators are classified into two types according the exciter used i.e.; the separately excited AC generator, and the self-excited AC generator. Self-excited generators have been more widely developed and with their improved characteristics are most often found in fishing boats. However, the brushless AC generator, a modern type of separately excited AC generator, has recently been introduced.

1.6.1 Separately excited AC generator

The original separately excited AC generators were equipped with a DC generator as its exciter. In this generator an automatic voltage regulator (AVR) is generally used to regulate the terminal voltage. The exciter is usually directly connected to the generator's shaft at the opposite side of the engine where it is either coupled, or over-hung on the generator. As is shown in the Figure 2 in the bracket type of generator the exciter's frame is mounted on the bracket, and in the pedestal type, the exciter is supported on the attached frame.

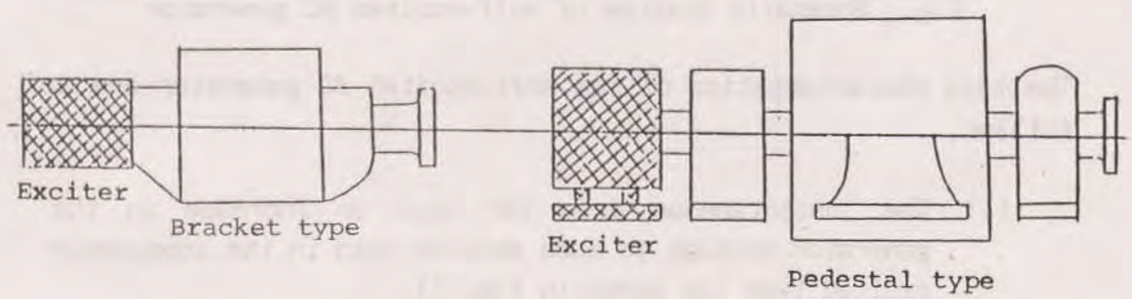
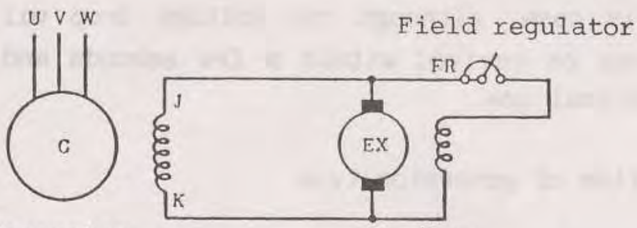


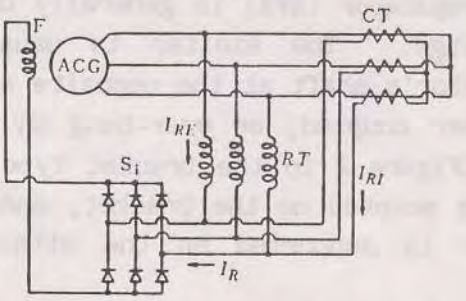

Fig. 2




Schematic diagram of separately excited AC generator

1.6.2 Self-excited AC generator

This type of AC generator has its own self-excited circuit in which part of the generator's output is picked up and rectified by a selenium or silicone rectifier, which it then feeds into the field coil. The outstanding advantage of this type of generator is in the rapid response of the excitation, and with the development of the metal rectifier, has become the most popular to be used in marine engines.




ACG : Armature of AC generator
F : Field winding of ACG
Si : Rectifier
RT : Reactor
CT : Current transformer

Fig. Schematic diagram of self-excited AC generator

The main characteristics of the seft-excited AC generator are as follows;

(I) The instantaneous drop (or dip) or increase in the generator voltage is much smaller than in the separately excited type (as shown in Fig. 1).

(II) During load changes the voltage recovery time is remarkably short.

(III) Fewer moving parts make the maintenance and inspection easy, thus improving its overall reliability.

(IV) Less space is required for the installation of the generator.

(V) There can be no jamming caused by spark between the commutator and brush on the DC exciter because of absence of them.

Automatic Voltage Regulator in self-excited AC generator

The self-excited AC generator has a variety of circuits, however it is classified into two types; those with or those without an automatic voltage regulator (AVR).

**(A) AC generator without AVR**

The characteristics of AC generator without an AVR are;

(1) Less instantaneous voltage changes when the load is suddenly changed.

(2) Rapid recovery of voltage due to the lack of an AVR.

(3) Simple circuit.

(4) Less voltage regulation required (within ± 3%) in setting.

**(B) AC generator with AVR**

The characteristics of AC generator with an AVR are;

(1) Less voltage regulation required (within ± 1%) in setting.

(2) The parallel operation of the AC generators between the non-equal rated power generators or power sources is possible by attaching a cross-current compensator.

Therefore, when selecting a self-excited generator, the above characteristics of both those with or without an AVB should be taken into account.

**(C) Brushless AC generator**

A revolving armature type of AC generator (an AC exciter) and a revolving rectifier have been installed on the same brushless generator shaft. The revolving rectifier changes the AC output into direct current, and supplies the DC current to the main magnetic field.

Unlike the separately-excited or self-excited AC generators previously mentioned, here there is no need for brushes or slip rings and therefore it is called the brushless generator. This type of generator is widely used for marine purposes including fishing boats. Brushless generators also require an automatic voltage regulator. The circuit is shown in Fig. 3 below.

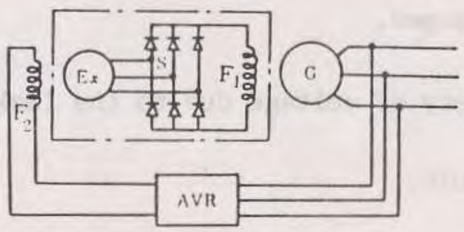



Fig. Schematic diagram of brushless AC generator

G ; Main generator armature windings
$F_1$; Main generator main field winding (on shaft)
Ex; Exciter armature winding (on shaft)
$F_2$; Field winding for exciter
S ; Revolving rectifier (on shaft)
AVR ; Automatic Voltage Regulator

The brushless AC generator has the following characteristics;

(a) With no wearing parts such as commutator, slip rings, and brush, and therefore no problems relating to these parts, it is much more reliable.

(b) Because there are no brushes insulation deterioration due to worn-out carbon dust or powder will take place.

(c) No maintenance is required for brush or slip rings.

(d) The exciting device can be reduced by between 1/10-1/20 the size of the self-exiting generatory, therefore it is more compact and light weight.

However, there is a draw back, the transient response in a brushless AC generator is inferior to that of the self-exciting ones.

1.6.3 Voltage

The generator's voltage is not pre-determined but is usually dictated by the main electric power source on the initial power receiving end.

A distribution voltage of 200 VAC for land use or 3300 VAC for a large capacity receiving end is normally required.

However, more recently 400 VAC has been preferred because, despite the fact that there is a limit to induction motor capacity of up to 40 KW or under, where 400 VAC has been installed, the motor capacity can be developed up to between 150-200 KW. On the other hand, controlling devices for 600 VAC can be used in either 200 VAC or 400 VAC devices and therefore, when there is equal capacity, 400 VAC devices use half the current of that of 200 VAC and can also reduce its rated capacity and price by between 20%-40%.

The insulation properties of amature coils for diesel generators are classified into the following three categories;

600 volt class
3300 volt class
6600 volt class

The windings of insulation materials usually consist of a meica-lapper, glass fiber etc. and, especially in 6600 VAC coils, bonding materials such as unsaturated polyester resin for prevention of corona discharge are used. However, in the smaller generators of under 100 KVA there are some production difficulties due to the many restrictions imposed on construction items. It is recommended that the voltage be adapted according to the following list:

| | |
|---|---|
| 100 KVA or under ........... | 220 volt or 440 volt |
| 101 KVA - 250 KVA ........... | 440 volt or 3300 volt |
| 251 KVA - ........... | 3300 volt |

In the case of 6600 VAC being used, it is first necessary to examine the relationships between the other auxiliary electrical equipment.

1.6.4 Speed

The speed of the AC generator (N) is represented

$$N = \frac{120 \times f}{p}$$

Where N = revolution per minutes (rpm)
f = frequency; cycle/second or HZ
p = the number of poles

The relation is tabulated in the table below.

Table 3.

| P | 50 c/s (HZ) | 60 c/s (HZ) |
|---|---|---|
| 4 | 1500 | 1800 |
| 6 | 1000 | 1200 |
| 8 | 750 | 900 |
| 10 | 600 | 720 |
| 12 | 500 | 600 |

An AC generator which is designated to be used at higher speeds, needs to be reduced in size so as to require less installation space and cost less. However, when being used for driving the prime-mover, or on the engine side, a high speed generator may have a shorter service life, create more vibration and noise, and incur increased maintenance costs. These factors should be taken into account before selecting a generator.

For a land use AC generator, the following speeds are frequently obtained;

(A) 250-300 KVA

50 HZ
- 4 P ..... 1500 rpm
- 6 P ..... 1000 rpm

60 HZ
- 4 P ..... 1800 rpm
- 6 P ..... 1200 rpm

(B) 1000 KVA

$$50\ HZ \begin{cases} 10\ P \ldots\ldots 600\ rpm \\ 12\ P \ldots\ldots 500\ rpm \end{cases}$$

$$60\ HZ \begin{cases} 10\ P \ldots\ldots 720\ rpm \\ 12\ P \ldots\ldots 600\ rpm \\ 14\ P \ldots\ldots 514\ rpm \end{cases}$$

1.6.5 The required horsepower for driving an AC generator

Approximate horsepower (out) is calculated using the following formula. (The actual engine output should be increased to allow for any loss of driving power and increase the safety margin)

DC generator

$$P.S = \frac{KW}{0.736x\eta} \quad - (1)$$

KW ; D.C generator capacity,

$\eta$ ; generator efficiency

AC generator

$$P.S = \frac{KVAxP_F}{0.736x\eta} \quad - (2)$$

KVA ; A.C generator capacity

$\eta$ ; generator efficiency

$P_F$ ; Power factor of the load

Example

Find the required horsepower to drive a D.C generator (10 kw) under the following conditions; 8 poles, 60 HZ, generator efficiency (0.8):

$$\text{Ans} \quad BPS = \frac{KW}{0.7636x\eta} = \frac{10}{0.736x0.8} = 17\ PS$$

[Example]

Find the required horsepower to drive the A.C generator 30 KVA under following conditions:

8 poles, 60 HZ, generator efficiency (0.80) power factor of the load (0.90)

$$P.S = \frac{KVAxP_F}{0.736x\eta} = \frac{30x0.9}{0.736x0.8} = 45.8\ (PS)$$

1.6.6 Power factor

As is shown in formula (2), the amount of AC power varies depending on the value of power factor. The power factor is one of the important items which relates to the output estimation of electrical load, and voltage regulations for the engine drive.

In the power factor, there are load power factors, as in the electrical circuit characteristics and a rated power factor, as in the reactive or wattless power's power factor. These power factors should not be confused with each other.

The following table shows an example of power factor of the electrical equipment which varies according to the circuit and the load factor.

Table 4. Power factor of electrical equipment

| Kinds of load | P.F. (%) | Approx capacity | Kinds of load | P.F (%) | Approx capacity |
|---|---|---|---|---|---|
| Incandescent lamp | 100 | 5 W - 10 KW | 3 Phase induction motor | | Sea Table B |
| Fluorescent lamp | 60 | 15 W - 25 W | " 1/8 PS Motor (split phase-start) | 56 | |
| Arc lamp | 30 - 70 | 1 KW - 3 KW | " 1/4 PS Motor (repulsion-start) | 62 | |
| Neon tube lamp | 40 - 50 | 30 W - 150 W | 1/2 PS Motor | 72 | |
| Mercury lamp (HP) | 50 | 300 W | Portable fan | 65-75 | 40 W |
| Sodium lamp | 70 | 100 W | Ceiling fan | 50-70 | 100 W - 150 W |
| AC Arc welder | 30 - 40 | 5 KW - 20 KW | Electric drill | 90 | 100 W - 800 W |
| AC resistance welding | 65 | 1 KW - 50 KW | Phonic motor (Disc drive motor) | 60 | 20 W |
| Arc furnace | 85 | 100 KW-10000 KW | Electric clock | 50 | 2 W |
| Low frequency Induction furnace | 60 - 80 | 50 KW - 500 KW | Heater | 100 | 20 KW - 10 KW |
| Salt bath | 80 | 5 KW - 100 KW | Induction heater | 85 | 1 KW - 100 KW |
| X-ray unit | 40 - 95 | 1 KW - 10 KW | (Hot air Heater) | 99 | 1 KW |
| Radio | 70 - 98 | 20 W | | | |

Table B Three-phase induction motor (low voltage common squirrel cage) open/enclosed, closed, and totally enclosed fan cooled types

| Rated output | Speed | Full-load performance | | Starting current (mean value of each phase) |
|---|---|---|---|---|
| | | Efficiency | P | |
| KW | r.pm | (%) | (%) | (Ampere) |
| 1.5 | | 78.5 | 77.0 | 42 |
| 2.2 | 1500-1800 | 80.5 | 79.0 | 60 |
| 3.7 | | 82.5 | 80.0 | 97 |
| 1.5 | | 78.0 | 71.5 | 44 |
| 2.2 | 1000-1200 | 79.5 | 73.5 | 65 |
| 3.7 | | 82.0 | 75.5 | 105 |

3-Phase induction motor (low-voltage special squirrel)

| Rated output | Speed | Full-load performance | | Starting current (mean value of each phase) |
|---|---|---|---|---|
| | | Efficiency | P | |
| KW | r.p.m. | (%) | (%) | (Ampere) |
| 5.5 | | 84.0 | 81.5 | 130 |
| 7.5 | 1500-1800 | 84.5 | 82.5 | 170 |
| 11 | | 85.5 | 83.0 | 250 |
| 15 | | 86.0 | 83.5 | 330 |
| (19) | | 87.0 | 84.0 | 405 |
| 22 | | 87.0 | 84.5 | 480 |
| 30 | | 87.5 | 85.0 | 640 |
| 37 | | 88.0 | 85.5 | 785 |
| 5.5 | | 83.0 | 77.0 | 130 |
| 7.5 | | 84.0 | 78.0 | 175 |
| 11 | 1000-1200 | 85.0 | 79.5 | 255 |
| 15 | | 85.5 | 80.5 | 335 |
| (19) | | 86.0 | 81.5 | 410 |
| 22 | | 86.5 | 82.0 | 485 |
| 30 | | 87.0 | 82.5 | 650 |
| 37 | | 87.5 | 83.0 | 800 |

The rated power factor of the generator is 80%, however, in a single phase AC generator, the value is 100%. The rated power factor is as specified in the ship's type and classification as found in registries such as NK, Lloyd's, ABS, BERITAS (France), where the value is regulated as 80%.

1.6.7 Generator efficiency

The generator efficiency is classified into two categories according to the calculation methods; nominal (or conventional) efficiency and efficiency by input-output test.

Generally, when we say efficiency it implies a nominal one, and unless otherwise stated the value shown is the one found under normal rated output conditions. However, in the case of AC generators, the value is regarded as the rated power factor.

$$\text{Nominal efficiency} = \frac{\text{Generator Output (kw)}}{\text{generator output(kw)+Generator loss(kw)}} \times 100\%$$

$$\text{Efficiency by input-output test} = \frac{\text{Generator output(kw)}}{\text{Generator input(kw)}} \times 100$$

**Note:** The generator loss should be estimated by converting the value into the one found at 75°C on the winding wire temperature.

There is no standard value for generator efficiency, therefore, it is customary to determine the value as the guaranteed one agreed between the manufacturer and the customer.

In a diesel generator, especially a small one, the generator efficiency is very important. It is therefore, meaningless to consider the margin of output without first confirming the generator efficiency.

1.6.8 Engine shaft horsepower

The engine shaft horsepower is measured from the driving shaft joints which can drive various types of machinery. The shaft horsepower is measured by several types of dynamometers such as brake, hydraulic, electric, and fan brake.

The shaft horsepower is indicated in a performance curve as shown in Fig. 3 and is stated in the engine specifications or the instruction manual.

Performance curve

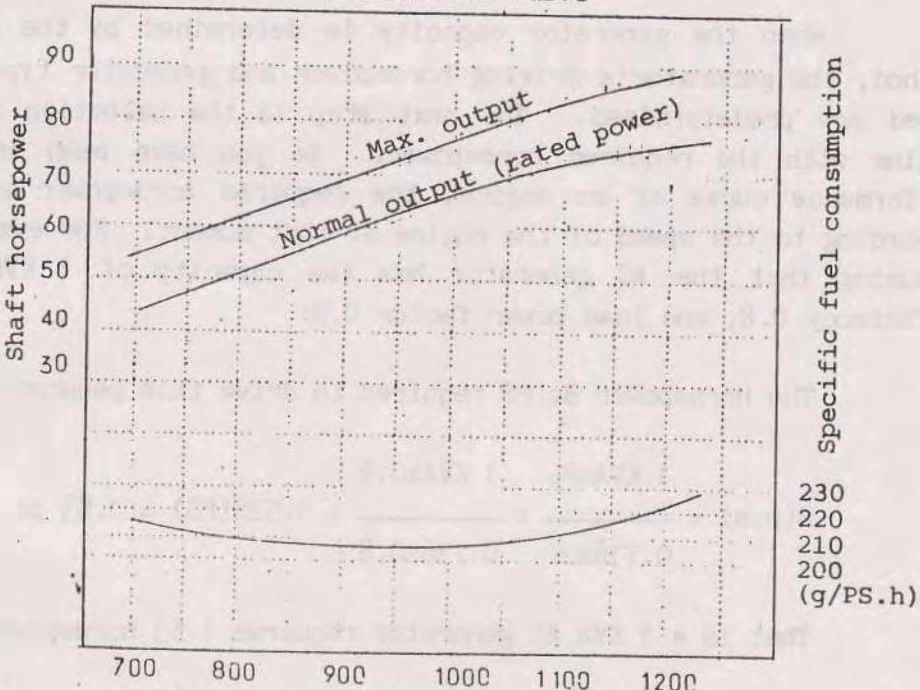



Fig. 3

The performance curve shows the relation between the crankshaft speed (x axis), shaft horsepower (y axis) maximum output, normal output, and specific fuel consumption. Each value can be read from the cross-point of each factor. The normal output can be read as follows:

| | | | |
|---|---|---|---|
| 720 rpm | 45 ps | 1000 rpm | 65 ps |
| 900 rpm | 58 ps | 1200 rpm | 75 ps |

1.7 Selection of engine

When the generator capacity is determined by the above method, the generator's driving horsepower and generator type and speed are predetermined. The next step is the selection of an engine with the required horsepower. As you have seen in the performance curve of an engine, the required horsepower varies according to the speed of the engine at that moment. For example, assuming that the AC generator has the capacity of 1 KVA, an efficiency 0.8, and load power factor 0.9:

The horsepower B. PS required to drive this generator is:

$$B(p.s) = \frac{1\ KVAxP_F}{0.736x\eta} = \frac{1\ KVAx0.9}{0.736x0.8} = 1.528(PS) = 1.53\ ps$$

That is a 1 KVA AC generator requires 1.53 horsepower.

Therefore, without taking into consideration driving mechanical loss, the engine in theory can operate at 720 rpm with 45 PS to drive a 29 KVA AC generator. If the engine speed is changed the resulting AC generator (10 P. 60 HZ) capacity will also be changed as in the following:

900 rpm - 58 ps - 37 KVA (8 P 50 HZ) (58 ÷ 1.53 = 37.9)
1000 rpm - 65 ps - 42 KVA (6 P 60 HZ)
1200 rpm - 75 ps - 49 KVA (6 P 60 HZ)

Caution should be taken here to check the value of generator efficiency as the size of generator that the engine can drive may change according this value.

The normal output (horsepower) or rated power in the performance curve assumes that the engine is to be operated under continuous reliable performance conditions. This horsepower is specified in the instruction manual as the nominal horsepower which provides the most economical performance for both the engine, and overall efficiency and maintenance.

The maximum horsepower is the maximum output which can be maintained safely and continuously, however, the fuel consumption increases and the color of the exhaust gas becomes visible. (Close to the smoke limit).

Therefore, when the engine type is selected, the normal output at specified speed (frequency, HZ) should be checked. In some cases, the specified operating output horsepower, which lies between the maximum horsepower and normal output (rated PS) may be employed after consultation with the manufacturer. However, the engine varies in horsepower within a certain tolerance during production and deteriorates in the course of service time, and may cause problems. Therefore, the regular use of increased rated horsepower is to be avoided.

1.8 Mechanical loss in drive parts.

When power is transmitted some loss occurs in the drive parts between the engine and generator. It is important to be able to estimate these losses so as to calculate the required engine horsepower.

In general, the following losses should be included in the calculation:

| | |
|---|---|
| Gear and Chain drive | 2 - 3% |
| Belt drive | 5 - 10% |

1.9 Speed variation

The speed variation of an engine is explained in the text I.C. engines for fishing boats (V) section 15.2. Speed variations are particularly important in the generator coupled type of engine. A flywheel with a adequate I (Moment of Inertia) value must be selected by first taking into consideration the installation space allocated for the flywheel and engine, especially in cases where the power for driving the generator for the fishing lamps is taken from the main propulsion of the engine. If the driving pulley is determined from the main engine speed at idling or dead-slow position the speed variation of the generator will be affected even by a small change in engine speed, causing the lamps to flicker or a surge brightly and darken. Therefore, if the size of the flywheel cannot be changed to one with a large I value, the rated speed and horsepower of the engine must be increased to match the generator output.

1.10 The power requirements for fishing lights

The rated voltage of fishing lamps is sometimes intentionally disregarded to increase illumination and thereby attract more fishes.

If such is the case extreme care should be taken during the operation of the engine or generator. The generator load varies according to the voltage used and therefore, the rated speed and horsepower of the engine are also required to respond to these conditions. The electric power consumed by the lamp is proportional to between 1.54 - 1.7 power of the increased ratio. For example a lamp of 110 V, requires that the voltage be raised to 150 Volt to provide sufficient power.

$$(Pg) = \left(\frac{150}{110}\right)^{1.54} \text{ x rated power of the lamp} \ldots\ldots\ (1)$$

$$= 1.61 \text{ x rated power of the lamp}$$

The above example shows that both the generator and engine undergo an overload of 61%.

Or by applying the following formular:

$$P_E = \frac{A \times N \times E/100 \times (0.006\ E + 0.4)\ [KW]}{\eta \times 0.01 \times 0.746} \ldots\ldots\ (2)$$

where : $P_E$ = Required horsepower for generator
$E$ = Raised voltage value
$A$ = Rated capacity of lamp
$N$ = Number of lamps
$\eta$ = Generator efficiency (0.85)

Example : Five lamps with 1 KW capacity each and rated voltage of 110 V, are going to increase the voltage up to 150 V. By how much is the required horsepower changed?

From formula (1)

$$\frac{5\ KW \times 1.61}{0.85 \times 0.746} = 12.69$$

From formula (2)

$$P_E = \frac{1 \times 5 \times \frac{150}{110} \times (0.006 \times 150 + 0.4)}{85 \times 0.01 \times 0.746} = 13.97$$

1.11 Facts about Torsional Vibration

When the generator is coupled with the engine, the torsional vibration is an important factor to be taken into consideration. (Detailed information is presented in SEAFDEC Text Series of TRB/49, Elementary torsional vibration of diesel engine, by the same author). Torsional vibration is simply explained as follows:

When a force turns a shaft it creates a stress which, when the force ceases to be applied, starts to bring the shaft back to its original position. However, owing to the mass of the shaft it will be carried past its original position and start to twist in the opposite direction, thereby creating a new restoring stress. These movements will continue back and forth through the equilibrium position until they are absorbed by internal friction. Such movements on one section in relation to another section are called torsional vibration. The force which produces torsional vibration in an I.C. engine shaft comes from the variable gas pressures on the pistons applied on the forces of inertia. Maximum vibration occuring at a critical speed can be destructive to the shaft and gears if its increase was not absorbed by the damping forces.

**Prevention of Resonance**

To widen the gap between the critical speed and the engine speed the natural frequency of torsional vibration of a shaft may be increased by any one or all of the following methods:

1. Increasing the diameter of the shaft
2. Decreasing the length of the shaft
3. Increasing the rigidity of the shaft
4. Decreasing the weight of the flywheel

Unlike the main engine, if the natural frequency of torsional vibration on the generator-engine system is calculated on the rated speed of the generator the out come will be destructive.

Therefore, if the generator and engine are coupled the engine manufacturer should be consulted about the overall specifications of the generator such as, the shaft dimension, materials used, the moment of inertia, and coupling method, dimension etc. before any adaptations are made.

**Appendix**

## Parallel Operation of AC Generators

1. The reason why parallel operation is necessary

1.1 The demand for electrical power on a boat varies according to whether the boat is cruising, at anchor or running at full load. If a large capacity generator is installed in order to meet maximum power requirements the operating efficiency of the generator is lowered when the load is reduced.

1.2 More recently, a large number of pumps and auxiliary machinery requiring electric power are being installed. A separate generator is now needed to meet these extra demands. Therefore, when considerating the installation of a spare generator, it is better to equip the boat with two small capacity generators rather than rely on one large one.

When only a light load is needed, one generator should be able to efficiently supply the necessary power leaving the second one to act as a stand-by or emergency supply.

2. Necessary conditions for parallel operation of generators

2.1 The voltage capacity of the two generators should be equal:

If the voltages are not equal a cross circulating current will flow between the generators and cause a rise in their temperature. This is due largely to the inherent properties of generators and the AVR (Automatic Voltage Regulator).

2.2 Voltage phase should coincide:

If a difference exists in the voltage phase, the synchronous current (effective cross current) will flow between the generators, and act on the phasing to bring them back into synchronization (coinciding with each other). If full synchronization is not resumed because of the large the difference in voltage phase it will lead to an eventual malfunction of the device or change the load distribution.

2.3 Frequency equalization:

If the frequencies do not coincide difference occurs in the voltage phase, which will cause the synchronous current to flow as in figure (2.2). Usually the synchronous force works to keep the frequency equal. Therefore, the engine plays an important role in holding the frequency i.e. its speed as constant as possible, and the performance of the generator plays a large part in this.

2.4 The wave forms of the voltages should be equal:

If the wave forms are not equal, the duration in which the voltage phase passes will not coincide because the high frequency voltage is instantly generated causing a reactive circulating current to flow alternately between the generators.

2.5 Both phases of the revolution direction (Vector) must be same. This condition must be set when the generator is first installed and connected. Each phase of the R.S.T. must correspond with the breaker terminals. A wrong connection will result in short circuit trouble.

3. Necessary pre-requisites for the prime mover (engine)

3.1 Uniform angular velocity of engine should be maintained

A diesel engine generates fluctuations in the torque because of its reciprocating crank mechanism which in turn alters the angular velocity.

The rate of this fluctuation is called cyclic irregularity. Excessive cyclic irregularity will generate a pulsating electromotive force in the generator and consequently make parallel operation impossible. This problem, together with that of torsional vibration, should have been examined and corrected by the engine manufacturers.

3.2 Speed variations of the engines should be equal

This equalization of speeds is related to the load-sharing of both generators after synchronization is completed. If the difference in speed variation is too large, the load-sharing will become unbalanced and a smooth operation will be impossible to attain.

3.3 The sensitivity of the governors

If the governor response is too sensitive against a slight variation in the load causing the load distribution to change quickly, the engines will begin to hunt and become unstable.

**Note:** (1) As previously stated, the parallel operation of the AC generator is largely affected by the performance of the prime mover. Adverse factors such as, irregularity of angular velocity in one revolution of engine, speed variations, and hunting due to excess sensitivity of the governor are induced by the engine rather than the generator. Therefore, it is no exaggeration to say that the successful parallel running can be obtained by simply selecting an engine that has proved itself capable of supporting a generator.

(2) Cyclic irregularity: (See, TRB/52 I.C. Engine for fishing boat) L-15 flywheel and governor

(3) The value of cyclic irregularity (C) is represented by the following formula (Sass formula), if C is given then the $GD^2$ value suitable for the parallel operation is determined as:

$$C = \frac{K \times L}{GD^2 \times N^3}$$

where K = Factor of Sass, depending upon the structure of engine.

L = Engine shaft output

$GD^2$ = Flywheel effect (including the effect of generator rotor)

n = Rated RPM of engine

From previous experience, if the value of C is $\frac{1}{200}$ or $\frac{1}{230}$ there will be no problem.

(4) The speed variation can be determined by the following formula, indicating the governor performance.

$$\delta = \frac{{}^{1}{}_{ni} - n1}{n} \times 100 \ (\%)$$

where $\delta$ = Instantaneous speed change

$N_i$ = Instantaneous Max (Min) RPM

$\eta$ = Rated RPM

Permanent speed variation can be obtained by putting NS in place of $N_i$. Generally speaking, values of $\delta \mp 10\%$, $\delta \leq 5\%$ are necessary for the Diesel engines to run generators.

(5) The ship regulations on parallel operation refers to the incidence of unbalanced load-sharing in parallel operation, which is actually measured in factory tests. Unbalanced load-sharing includes a lack of balance between the effective current compared to the speed characteristics of the engine and lack of balance between the ineffective current and the generator. These tolerances are shown in the following.

| Regulations | Test conditions and defined value |
|---|---|
| JG | The load on any generator should remain within ± 15% of its rated load in a proportionate share in cases where the sum of the loads of all generators are increased or decreased by between 20% - 100%. |
| NK | Same as above |
| AB | Same as above |
| LR | Any lack of balance should remain within 10% of the rated output of the Max generator in a proportionate share or within 25% of the rated output of each generator |