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American National Standard

for Rotating Electrical Machinery –

Hydrogen-Cooled, Combustion-Gas-Turbine-Driven, Cylindrical-Rotor Synchronous Generators – Requirements

ANSI C50.15-1989

ANSI American National Standards Institute
1430 Broadway
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American National Standard

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Secretariat

Institute of Electrical and Electronics Engineers
National Electrical Manufacturers Association

Approved January 23, 1989
American National Standards Institute, Inc

Foreword

(This Foreword is not part of American National Standard C50.15-1989.)

This new standard was originally prepared by a working group of the IEEE Synchronous Machines Subcommittee of the Rotating Machines Committee. It was circulated and approved by the subcommittee in 1988.

It was letter-balloted and approved by Subcommittee C50.1 on Synchronous Machines and the C50 Committee on Rotating Electrical Machinery.

Suggestions for improvement of this standard will be welcome. They should be sent to the National Electrical Manufacturers Association, 2101 L Street, NW, Suite 300, Washington, DC 20037.

This standard was processed and approved for submittal to ANSI by Accredited Standards Committee C50 on Rotating Electric Machinery. Committee approval of the standard does not necessarily imply that all committee members voted for its approval. At the time it approved this standard, Accredited Standards Committee C50 had the following members:

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The Working Group of Subcommittee C50.1, which helped to develop this standard, had the following members:

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A. Hoffman
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Contents

American National Standard for Rotating Electrical Machinery –

Hydrogen-Cooled, Combustion-Gas-Turbine-Driven, Cylindrical-Rotor Synchronous Generators – Requirements

1. Scope

The requirements in this standard apply to the 60-Hz, hydrogen-cooled, cylindrical-rotor synchronous generators, rated 10 000 kVA and above, and driven by combustion gas turbines.

All requirements and definitions, except as specifically covered in this standard, shall be in accordance with American National Standard General Requirements for Synchronous Machines, ANSI C50.10-1977, and American National Standard for Rotating Electrical Machinery – Cylindrical-Rotor Synchronous Generators, ANSI C50.13-1989.

2. Referenced American National Standards

This standard is intended for use with the following American National Standards. When these referenced standards are superseded with a revision approved by the American National Standards Institute, Inc, the revision shall apply:

ANSI C50.10-1977, General Requirements for Synchronous Machines

ANSI C50.13-1989, Rotating Electrical Machinery – Cylindrical-Rotor Synchronous Generators

ANSI/IEEE 115-1983, Test Procedures for Synchronous Machines

3. Classification

A cylindrical-rotor, combustion-gas-turbine-driven synchronous generator is classified by the method used to cool the windings, as shown in 3.1 and 3.2.

3.1 Stator Types. The stator has an indirectly or directly cooled armature winding.

3.2 Rotor Types. The rotor has either an indirectly or directly cooled field winding.

4. Usual Service Conditions

The power output of a combustion gas turbine, for a given combustion temperature, is a function of the density of the ambient air, which, in turn, is a function of temperature and atmospheric pressure. The standard operating condition for combustion gas turbines is 15°C ambient air temperature at sea level.

Combustion gas turbines usually carry two power ratings corresponding to different combustion temperatures. These are designated as base and peak operating modes. The latter mode permits increased output with decreased intervals between turbine inspection and maintenance.

A generator driven by a combustion gas turbine and conforming to this standard shall be suitable for carrying load in accordance with the generator rating and capabilities under usual service conditions, as described in 4.1–4.7.

4.1 Ambient Air Temperature. The temperature of the ambient air does not exceed 49°C (120°F) and is not less than –18°C (0°F).

4.2 Altitude. The altitude is sea level.

NOTE: The power output of the gas turbine decreases at altitudes above sea level. The capability of a hydrogen-cooled generator will not decrease at altitudes above sea level if the liquid coolant temperature and the absolute hydrogen pressure are maintained at the rated values at sea level.

4.3 Number of Starts. The starting frequency to substantial load conditions does not exceed 500 starts per year.

4.4 Application of Load. Load may be applied rapidly, and the rate of generator loading is limited only by the ability of the combustion gas turbine to assume load.

4.5 Variation from Rated Voltage. In addition to the preceding usual service conditions, generators shall operate successfully at rated kilovolt-amperes (kVA), frequency, and power factor at any voltage not more than 5 percent above or below rated voltage, but not necessarily in accordance with the standards of performance established for operation at rated voltage.

4.6 Variation from Rated Hydrogen Pressure. Capabilities at hydrogen pressures other than rated pressure shall be available from the manufacturer. The capabilities at hydrogen pressures other than rated shall be determined such that the hottest-spot temperature of the winding that is limiting at the specified capability is essentially the same as that at rating.

4.7 Variation from Rated Frequency. Capabilities at frequencies other than rated frequency shall be available from the manufacturer.

5. Output Rating and Capabilities

5.1 Output Rating. The continuous output rating of the generator shall be expressed in kilovolt-amperes available at the terminals at a specified speed, frequency, voltage, power factor, and hydrogen pressure at a cold gas temperature not exceeding 46°C at sea level.

The output rating shall be equal to the base capability of the generator (defined in 5.2.1) at these conditions.

5.2 Capabilities. The capability of a generator is defined as the highest acceptable loading at a specified condition. Capability is expressed as a function of cold gas temperature, the average temperature of the gas leaving the generator cooler(s). Typical capability curves are shown in Figure 1.

One method of relating cold gas temperature to ambient air temperature is to use an external liquid to air cooler in combination with the generator liquid to gas cooler. In this closed system, the common liquid is circulated through both coolers in series. A typical combined generator cooler – external cooler characteristic is shown in Figure 2.

The power output – ambient air temperature characteristics of the generator – external cooler system, shown in Figure 3, are obtained by cross-reading Figures 1 and 2, as shown by the dashed lines. In general, the curves of Figure 3 do not have the same slope as the combustion gas turbine power output – ambient air temperature curves.

Another possible method of cooling utilizes liquid from a source whose temperature is not related to the ambient air temperature. For this the relationship of the liquid coolant to cold gas temperature should be provided by a curve similar to Figure 2, but with ambient air temperature replaced by the source cooling water temperature. Because there is no consistent relationship between the air and the source water temperature, a curve such as Figure 3 cannot be developed. The generator capability as shown by Figure 1 shall be compared with the turbine output capability for the appropriate source water and air temperatures.

5.2.1 Base Capability. The manufacturer shall supply a curve showing the continuous (8760 hours per year) base capability of the generator at rated power factor and sea level, similar to Figure 1. The base capability of the generator – external cooler system, Figure 3, should equal or exceed the base rating of the combustion gas turbine over a specified ambient air temperature range within the limits described in 4.1.

5.2.2 Peak Capability. The manufacturer shall supply a curve showing peak capability of the generator at a specified power factor and at sea level, similar to Figure 1. If the peak capability power factor is greater than rated power factor, it shall be determined by agreement between the user and the manufacturer. The peak capability of the generator – external cooler system (Figure 3) should equal or exceed the peak rating of the combustion gas turbine over a specified ambient air temperature range within the limits described in 4.1.

NOTE: Operation at peak capability can result in accelerated loss of life (see 6.2).

5.3 Voltage Ratings

5.3.1 Armature. Armature voltage ratings shall be the following:

6 900*
11 500*
12 500*
13 800
14 400*

NOTES:

(1) Ratings followed by an asterisk (*) are recognized for use on established systems but not preferred for new undertakings.

(2) For very large machines, the voltage may be greater than 14 400, at the mutual choice of the manufacturer and user.

5.3.2 Excitation System Voltage Ratings. The preferred excitation system voltage ratings for field windings are 125, 250, 375, and 500 direct voltage. These excitation system voltages do not apply to generators of the brushless type with direct connected exciters.

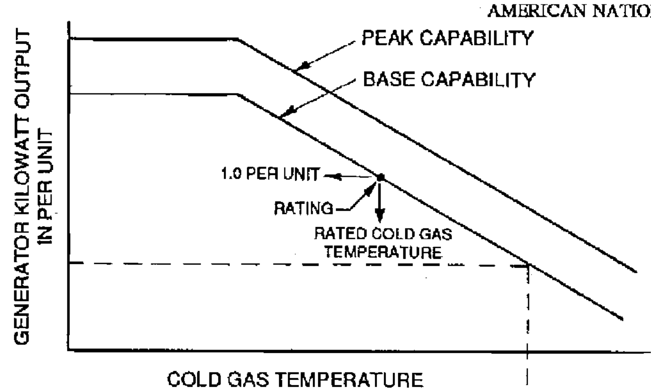
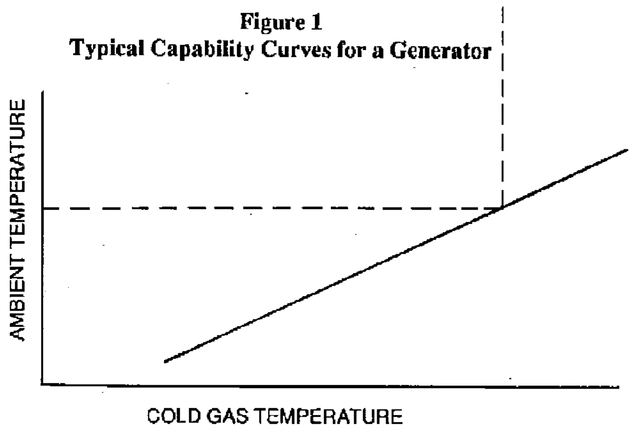


Figure 1
Typical Capability Curves for a Generator

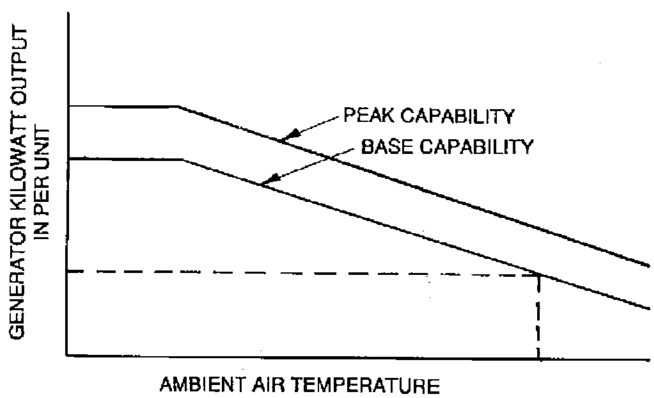


NOTES:

(1) Cold gas temperature is the average temperature of hydrogen at outlet of generator coolers.

(2) Altitude is at sea level.

Figure 2
Typical Characteristics of a Combined Generator Cooler – External Cooler



NOTE: Altitude is at sea level.

Figure 3
Typical Capability Curves for a Generator – External Cooler System

Table 1
Limiting Observable Temperature Rise and Temperature of Hydrogen-Cooled, Combustion-Gas-Turbine-Driven, Cylindrical-Rotor Synchronous Generators

Item	Machine Part	Method of Temperature Determination	Temperature Rise* and Temperature† in Degrees Celsius at Output Rating — Indirectly Cooled Windings, Insulation Class B	Indirectly Cooled Windings, Insulation Class F	Directly Cooled Windings, Insulation Class B	Directly Cooled Windings, Insulation Class F
1	Temperature rise of armature winding	Embedded detector	54	74	—	—
2	Temperature rise of field winding	Resistance				
	(a) Generators below 100 000 kVA		79	99	64	84
	(b) Generators 100 000 kVA and above		74	94	64	84
3	Temperature rise of cores and mechanical parts in contact with or adjacent to insulation	Detector	64	84	—	—
4	Temperature† of collector rings, brushes, and brushholders	Thermometer	125	125	—	—
5	Other metal parts such as shielding devices in the end region, structural members, amortisseur windings, and the rotor surface may be operated at temperatures that are considered safe for the particular metals used, provided these parts do not appreciably influence the temperature of insulating material either by conduction or radiation.					

* Temperature rises are based on a maximum cold gas temperature of 46°C at sea level.

† Total temperature is specified here because these parts are usually cooled by ambient air instead of the generator hydrogen.

6. Temperature

6.1 At Output Rating. Rated cold gas temperature may be less than 46°C, but shall not exceed 46°C.

Based on a cold gas temperature of 46°C, the observable temperature rise of each of the various parts of the generator shall not exceed the values given in Table 1.

If the generator is rated at a cold gas temperature less than 46°C, the observable temperature rises of Table 1 may be increased by the amount 46°C exceeds the rated cold gas temperature.

When designing to meet the temperature rises of Table 1, it is intended that the hottest-spot temperatures should not exceed 130°C for Class B insulation systems and 155°C for Class F insulation systems.

6.2 At Base and Peak Capabilities. It is intended that the hottest-spot temperatures of 130°C for Class B insulation systems and 155°C for Class F insulation systems should not be exceeded at base capability. At peak capability, it is intended that the hottest-spot temperatures of 155°C for Class B insulation systems and 180°C for Class F insulation systems should not be exceeded. This design concept shall be demonstrable by direct measurement or recognized methods of calculation correlated to special factory tests on a basically similar machine.

The hottest-spot temperatures for peak capability are in excess of the usual 130°C value for Class B insulation systems and the 155°C value for Class F insulation systems.

Operation at the peak temperature values causes the generator insulation to age thermally at about 4 to 8 times the rate that occurs at the base capability temperature values; that is, operating 1 hour at the peak temperature values is approximately equivalent to operating 4 to 8 hours at the base capability temperature values.

7. Requirements for Abnormal Conditions

7.1 Armature Winding Short-Time Thermal Requirements. The generator armature shall be capable of operating at 130 percent of rated armature current for at least 1 minute starting from stabilized temperatures at rated conditions.

NOTES:

(1) The permissible armature currents at times up to 120 seconds, based upon the same increment of heat storage as defined in 7.1, will be:

Time (seconds)	10	30	60	120
Armature current (percent)	226	154	130	116

(2) It is recognized that armature temperatures will exceed rated load values under these conditions and, therefore, the machine construction is based upon the assumption that the number of such operations at armature currents to the limits of Note (1) will occur not more than two times per year.

7.2 Field Winding Short-Time Thermal Requirements. The generator field winding shall be capable of operating at a field voltage of 125 percent of rated-load field voltage for at least 1 minute starting from stabilized temperatures at rated conditions.

NOTES:

(1) The permissible field voltages at times up to 120 seconds, based upon the same increment of heat storage as defined in 7.2, will be:

Time (seconds)	10	30	60	120
Field voltage (percent)	208	146	125	112

(2) It is recognized that field winding temperatures under these conditions will exceed rated-load values and, therefore, the machine construction is based upon the assumption that the number of such operations at field voltages to the limits of Note (1) will occur not more than two times per year.

7.3 Rotor Short-Time Thermal Requirements for Unbalanced Faults. The generator rotor shall be capable of withstanding, without injury, unbalanced short circuits or other unbalanced conditions on the system or at the armature terminals resulting in values of I_2^2t, as listed in the following table.

Type of Rotor	Minimum Generator Short-Time Capability Expressed in Terms of I_2^2t*
Indirectly cooled	30
Directly cooled	10

*See note in this subsection.

I_2^2t, in the preceding table, is the integrated product of the square of the negative-phase-sequence current (I_2) of the generator, expressed in per unit stator current at rated kilovolt-amperes and duration of the fault in seconds (t).

The unbalanced fault capability of the generator, expressed in terms of I_2^2t, applies for times up to 120 seconds, based on a constant increment of heat storage and negligible heat dissipation.

In the above criteria, the generator shall be capable of withstanding the thermal effect of unbalanced faults at the machine terminals, including the decaying effects of:

(1) Field current, where protection is provided by causing field current reduction, such as with an exciter field breaker or equivalent

(2) Direct-current component of the stator current

NOTE: Generators subjected to faults between the preceding values I_2^2t and 200 percent of these values may suffer varying degrees of damage. For faults in excess of 200 percent of these limits, serious damage may be expected.

7.4 Mechanical Requirements for Short Circuits. The generator shall be capable of withstanding, without mechanical injury,[1] any type of short circuit at its terminals for times not exceeding short-time thermal requirements, when operating at rated kVA and power factor and 5 percent overvoltage, provided the maximum phase current is limited by external means to a value that does not exceed the maximum phase current obtained from the three-phase fault.

7.5 Continuous Unbalance Requirements. A generator shall be capable of withstanding, without injury, the effects of a continuous current unbalance corresponding to a negative-phase-sequence current of the following values, providing the rated kVA are not exceeded, and the maximum current does not exceed 105 percent of rated in any phase. Negative-phase-sequence current is expressed in percent of rated stator current.

Type of Rotor	Permissible I_2 (percent)
Indirectly cooled	10
Directly cooled	8

These values also express the negative-phase-sequence current capability at reduced generator kilovolt-ampere capabilities in percent of the stator current corresponding to the reduced capability.

8. Efficiency

The following losses shall be included in determining efficiency:[2]

(1) I^2R losses of armature and field winding.

(2) Core loss.

(3) Stray load loss.

(4) Friction and windage loss.

[1] In the case of stator windings, the criterion for no injury is that the winding can satisfactorily withstand a normal-maintenance, high-potential test. There must also be no visible abnormal deformation or damage for the winding coils and connections.

[2] Refer to ANSI C50.10-1977 for definitions of losses.

Table 2
1960 Single-Frequency TIF_f Weighting Factors

Frequency	TIF_f	Frequency	TIF_f
60	0.5	1860	7820
180	30	1980	8330
300	225	2100	8830
360	400	2160	9080
420	650	2220	9330
540	1320	2340	9840
660	2260	2460	10 340
720	2760	2580	10 600
780	3360	2820	10 210
900	4350	2940	9820
1000	5000	3000	9670
1020	5100	3180	8740
1080	5400	3300	8090
1140	5630	3540	6730
1260	6050	3660	6130
1380	6370	3900	4400
1440	6650	4020	3700
1500	6680	4260	2750
1620	6970	4380	2190
1740	7320	5000	840
1800	7570		

(5) Excitation systems losses, if required by specifications, shall include the exciter, voltage regulator, and associated devices comprising the excitation for a particular synchronous machine. Include motor loss if unit motor-generator, exciter set is used. If a unit rectifier is used, include the loss of the rectifier and rectifier transformer.

9. Overspeed

Cylindrical rotor generators shall be so constructed that they will withstand, without injury, an overspeed of 20 percent.

10. Telephone Influence Factor

10.1 Balanced. The balanced telephone influence factor (TIF) of the generator, based on the weighting factors given in Table 2, shall not exceed the following values:

kVA Rating of Generator	Balanced TIF
10 000 to 19 999	100
20 000 to 99 999	70
100 000 and above	40

[3] Later superseded by ANSI/NEMA MG1-1978 and NEMA MG1-1987.

10.2 Residual. The residual component TIF of the generator, based on the weighting factors given in Table 2, shall not exceed the following values:

kVA Rating of Generator	Residual TIF
10 000 to 19 999	75
20 000 to 99 999	50
100 000 and above	30

10.3 Single Frequency. The single frequency telephone influence weighting factors (TIF_f) according to the 1960 single frequency weighting are as shown in Table 2.

Methods of measurement for TIF shall be in accordance with ANSI/IEEE 115-1983.

NOTES:

(1) Although TIF is designed basically as a measure of the influence of current or voltage in a power circuit on parallel telephone circuits, the TIF of open-circuit generator voltage has been used for many years as an approximate index of the influence of generator waveshape. There has been no experience to indicate that generators designed in accordance with ANSI C50.1-1955,[3] Synchronous Generators, Synchronous Motors, and Synchronous Machines in General, have caused inductive coordination problems. However, accumulated measurements by manufacturers indicate that generator open-circuit TIF measured in accordance with the 1960 weighting averaged higher than with the 1935 weighting. Accordingly, in 1965, when the 1960 weighting was adopted, the limiting TIF values of lower-capacity machines were increased. At the same time, the greatly improved waveshape of modern high-capacity generators is recognized in setting a lower limit of balanced TIF for the larger units.

(2) For information on TIF, see Supplement to Engineering Report 33, The Telephone Influence Factor of Supply System Voltages and Currents, Engineering Reports of the Joint Subcommittee on Development and Research, Edison Electric Institute and Bell System, Edison Electric Institute Publication 60-68. For further information on methods of measurement of TIF, see Telephone Influence Factor (TIF) and Its Measurement, W. C. Ball and C. K. Poarch, AIEE Transactions, Part I, vol. 79, January 1961, pp 659 664 (Transactions Paper 60-1195).

10.4 Other Considerations. Special consideration may be necessary where trouble exists or may be anticipated from difficult exposure conditions.

11. Tests

Tests shall be as listed in Table 3. The tests shall be conducted in accordance with ANSI/IEEE 115-1983 and ANSI C50.10-1977. The extent of the tests to be required in multiple unit orders should be mutually agreed upon by purchaser and manufacturer.

12. Direction of Rotation

The direction of rotation of the generator shall suit the prime mover requirements.

Table 3
Tests on Hydrogen-Cooled, Combustion-Gas-Turbine-Driven, Cylindrical-Rotor Synchronous Generators

Tests	Generators Completely Assembled in Factory for Test	Generators Not Completely Assembled in Factory for Test	
	Factory Tests	Factory Tests	Field Tests
Resistance of armature and field windings	X*	X	X
Dielectric tests of armature and field windings	X	X	X
Voltage balance	X	—	X
Phase sequence	X	—	X
Mechanical balance	X†	X†	X†
Open-circuit saturation curve‡	X	—	X
Overspeed	X	X	—
Short-circuit saturation curve‡	—§	—	—§
Harmonic analysis and measurement of TIF	—§	—	—§
Heat runs	—§	—	—§
Short-circuit tests at reduced voltage to determine reactance and time constants	—§	—	—§
Measurement of segregated losses	—§	—	—
Measurement of rotor impedance	X	—	X
Measurement of insulation resistance of armature and field windings	X	—	X
Measurement of bearing insulation resistance	—**	—	X

*An X indicates that the test shall be made on each unit.
†A field check of mechanical balance of all generators is recommended after installation.
‡On brushless generators, readings of exciter field current instead of generator field current may be obtained.
§This test, or copies of a certified test report covering test made on an essentially duplicate generator, may be specified.
**On all generators furnished with one or more insulated bearings, a field measurement of the bearing insulation resistance is recommended.

13. Nameplate Marking

A nameplate showing the manufacturer's name, serial number, or other suitable identification shall be provided.

The following information at rating shall be supplied:

(1) Output kilovolt-amperes
(2) Voltage
(3) Revolutions per minute
(4) Armature amperes
(5) Frequency
(6) Temperature rise of armature
(7) Temperature rise of field
(8) Number of phases
(9) Power factor
(10) Excitation voltage
(11) Field amperes
(12) Cold gas temperature
(13) Hydrogen pressure (psig) at sea level

NOTES:
(1) On generators furnished with brushless excitation systems, the exciter input-rated voltage and current should be supplied for (10) and (11), respectively.
(2) Items 1, 2, 4, 5, 9, 10, 11, and 12 shall be supplied for the peak capability at rated cold gas temperature.

14. Performance Specification Form

Figure 4 shows the form that shall be used for specifying the performance of hydrogen-cooled, combustion-gas-turbine-driven, cylindrical-rotor synchronous generators.

The following data shall be given in accordance with ANSI C50.15-1989.

Date ______________

Output Rating

kVA	Power Factor	kW	Speed, r/min	No of Poles	No of Phases	Volts	Amperes	Type or Frame

Description: ______________

Type of excitation system: ______________

Amortisseur winding is (closed) (open) (not supplied)

Insulation Classes: Armature winding __________ : Armature connections __________ : Field winding __________.

Direction of rotation, viewing the end opposite the drive __________, if of unidirectional design or construction.

	Temperature Rise Guarantees			
		Rise(°C) Not To Exceed		
		Armature Winding		Field Winding
kVA	Power Factor	by Resistance	by Detector	by Resistance
		X		
Exciter (1)			X	

Maximum Excitation Requirements					
Generator Excitation		Exciter Input For Brushless Excitation		Excitation System	
Amperes	Volts	Amperes	Volts	Response Ratio	Nominal Ceiling Volts

(1) At "Maximum Excitation Requirements" operating level.

Temperature rises shall be in accordance with Table 1 of ANSI C50.15-1989 and are based on a temperature of ________°C of the cooling gas at the exit from the coolers, at ________ psig pressure, and at sea level.

Efficiencies: When the generator is sold with the turbine as a set, generator efficiencies will be included in the overall set efficiencies. When sold as a generator only, efficiencies will be given below.

		Minimum Efficiencies						
				Percent Efficiencies				
kVA	Power Factor	kW		Rated Load	3/4 Load	1/2 Load		

In determining efficiencies I^2R losses in the armature and field windings at ________°C, open-circuit core loss, and stray load loss are included. Friction and windage losses (are) (are not) included. Exciter and exciter-field rheostat losses (are) (are not) included. Hydrogen seal losses (are) (are not) included. Generator-field rheostat loss is not included. If the generator is not furnished with a complete set of bearings, the friction and windage losses (if included) are based on the use of shop bearings.

Calculated Reactances (Per Unit At Rated kVA)				
Rated Current Direct Axis Synchronous Reactance, X_{di}	Rated Current Direct Axis Transient Reactance, X'_{di}	Rated Voltage Direct Axis Subtransient Reactance, X''_{dv}	Rotor Wk^2 $(lb\text{-}ft)^2$	Short Circuit Ratio

Approximate Weights in Pounds			
Total Net	Rotor Net	Heaviest Part for Crane	Total Shipping

Approximate Operating Data (at rated load and hydrogen pressure):

(a) Generator coolers

Temperature of inlet liquid to coolers, ________°F

Volume of cooling liquid, ________ gpm

(b) Bearing oil cooler

Temperature of inlet liquid to bearing oil cooler, ________°F, when required

Volume of cooling liquid, ________ gpm, when required

Capabilities: Curve of kilowatt output versus cold gas temperature for base and peak capabilities.

Figure 4
Performance Specification Form for Hydrogen-Cooled, Combustion-Gas-Turbine-Driven, Cylindrical-Rotor Synchronous Generator