AMERICAN NATIONAL STANDARD

Procurement Standard for

Gas Turbine Ratings and Performance

ANSI B133.6 - 1978

SECRETARIAT

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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FOREWORD

The purpose of the B133 standards is to provide criteria for the preparation of gas turbine procurement specifications. These standards will also be useful for response to such specifications.

The B133 standards provide essential information for the procurement of gas turbine power plants. They apply to open cycle, closed cycle, and semi-closed cycle gas turbines with conventional combustion systems for industrial, marine, and electric power applications. Auxiliaries needed for proper operation are covered. Not included are gas turbines applied to earth moving machines, agricultural and industrial-type tractors, automobiles, trucks, buses and aeropropulsion units.

For gas turbines using unconventional or special heat sources (such as: chemical processes, nuclear reactors, or furnaces for supercharged boilers), these standards may be used as a basis; but appropriate modifications may be necessary.

The intent of the B133 standards is to cover the normal requirements of the majority of applications, recognizing that economic trade-offs and reliability implications may differ in some applications. The user may desire to add, delete or modify the requirements in this standard to meet his specific needs, and he has the option of doing so in his own procurement specification.

The B133.6 standard provides a basis for a completely defined set of ratings, such that comparisons made among alternative gas turbines can reflect significant differences in performance. Performance under both standard conditions and site conditions are covered. Standard conditions are established that are compatible with ISO 2314, Gas Turbines-Acceptance Tests and with ISO 3977, Gas Turbines-Procurement.

Suggestions for improvement of this standard will be welcome. They should be sent to the American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, NY 10017.

American National Standard B133.6 was approved by the B133 Standards Committee and final approval by the American National Standards Institute was granted on November 28, 1978.

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Procurement Standards for Gas Turbines

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AMERICAN NATIONAL STANDARD

PROCUREMENT STANDARD FOR GAS TURBINE RATINGS AND PERFORMANCE

1. SCOPE

The ratings and performance of gas turbines are developed by the manufacturer to match site conditions that are supplied by the user. When complete site conditions are unavailable, standard conditions may be used. This standard provides guidance for specifying ratings and performance.

2. RATINGS

2.1 General

2.1.1 The rating of a gas turbine is considered to include the output power and the thermal efficiency and the specified control conditions, at which this power is produced.

2.1.2 The output power of a given gas turbine at a given turbine inlet temperature is in general, proportional to the absolute ambient pressure and is also greatly dependent on compressor inlet air temperature (normally outside dry bulb temperature). Likewise, the output at a given air intake temperature is dependent on turbine inlet temperature. To achieve a rating, it is necessary to adopt a standard condition of ambient temperature and pressure; but gas turbine ratings will nevertheless vary considerably owing to the differing operational modes demanded of them as well as the varying criteria used in the design of the basic elements.

2.1.3 The thermal efficiency of a given gas turbine is affected by the same variables as output power but is generally independent of the absolute ambient pressure.

2.1.4 The ratings of gas turbines shall be established for at least two sets of operating conditions including a site rating and a standard rating. These ratings are to be fully qualified by the operating or reference conditions associated with each rating.

2.2 ANSI Standard Ratings

2.2.1 The manufacturer shall declare standard ratings under the standard reference conditions (Para. 3) associated with the following operational modes:

Standard Mode A: Operation at 1250 hours per annum with 5 hours per start.

Standard Mode B: Operation at 8000 hours per annum with 800 hours per start.

For each standard mode, the manufacturer shall state the type frequency and degree of inspection and/or maintenance required. It is common to refer to Mode A as Peak and Mode B as Base.

2.3 Site Ratings—Output

2.3.1 The site power ratings shall be specified by the manufacturer as follows:

1. *Generating Plant.* The electrical power at the generator terminals. In addition to this rating, the manufacturer shall specify auxiliary loads and losses necessary to produce this power. In the event auxiliary loads and losses are supplied directly by the gas turbine independent of the generator, they shall not be specified by the manufacturer as a part of the site power rating.

2. *Mechanical Drives.* The shaft power at the gas turbine output coupling(s). In addition to this rating, the manufacturer shall specify auxiliary loads and losses necessary to produce this power. In the event auxiliary loads and losses are supplied directly by the gas turbine and not from an external source, they shall not be specified by the manufacturer as a part of the site power rating.

2.3.2 In either case, the site power ratings shall relate to specified site conditions of the installation (such as ambient pressure and temperature, and duct pressure losses) and operating modes and fuels under which the plant is intended to run in service.

2.3.3 Where the gas generator is supplied separately, its site power shall be expressed as the gas power resulting from the reversible adiabatic expansion of the gas generator exhaust flow (using total pressure and total temperature) to the ambient atmospheric pressure when it is operated under the specified site conditions of the installation and operating modes under which the plant is intended to run in service.*

2.3.4 When a specific allowance is to be made in the performance ratings for deterioration of rated power and thermal efficiency, (as might be typical for the contaminants in the fuel and/or air at a particular site), this allowance shall be stated and agreed to by the user and the manufacturer (see ANSI B133.10). Performance ratings not so qualified, as well as standard performance ratings, shall be applied to the new and clean condition of the gas turbine components.

2.4 Site Ratings—Efficiency and Fuel Consumption

2.4.1 Various terms express the rate of fuel consumption and these terms differ, depending upon the application. Thermal efficiency is dependent upon many of the same variables as power output. Thermal efficiency usually changes in the same direction as power and has the advantage of being dimensionless. Alternate forms are related to the inverse of thermal efficiency, that is, the ratio of the rate of heat consumption to the power output. The number of combinations of these terms is increased by the choice of high or low heat value of the fuel and by the choice of units of measure. The following paragraphs describe the preferred standard terms that have become common practice in each of several applications.

* The user is cautioned not to compare quoted values of gas power, gas thermal efficiency or gas heat rate with the corresponding values based on shaft power. In addition to multiplying gas power by an appropriate efficiency factor for the particular power turbine, the gas power itself may be subject to a small adjustment which accounts for compressor air extracted from the gas generator for the purpose of cooling the power turbine and/or its exhaust collector.

2.4.2 Electric Utility Application:

Heat Rate. The ratio of the rate of heat consumption, based on high heat value (HHV), to the output at the generator terminals, Btu/kW h (kJ/kW h). It is necessary to state both the heat rate and the corresponding ratio of fuel heat values (HHV ÷ LHV) for this definition of heat rate to be complete.

2.4.3 Generator Drive Application:

Heat Rate. The ratio of the rate of heat consumption, based on low heat value (LHV) to the power output at the generator terminals, Btu/kW h (kJ/kW h).

2.4.4 Mechanical Drive Application:

Heat Rate. The ratio of the rate of heat consumption, based on low heat value (LHV), to the power output at the gas turbine output shaft coupling, Btu/hp hr (kJ/kW h).

2.4.5 Marine Application:

Specific Fuel Consumption. The ratio of the fuel mass flow to the power output at the gas turbine output shaft coupling, lbm/hp h (kg/kW h). It is necessary to state both the specific fuel consumption and the corresponding fuel low heat value for this definition of specific fuel consumption to be complete. (See also ANSI B133.16 ("Marine Applications")

2.4.6 Universal Application:

Thermal Efficiency. The ratio of the power output to the rate of heat consumption based on the low heat value (LHV) of the fuel (dimensionless).

2.4.7 Conversion Equations.

(1) Heat Rate (Utility)

$$= \frac{3412.14\ (\text{HHV} \div \text{LHV})}{(\text{Thermal Efficiency})}\ \text{Btu/kW h}$$

$$= \frac{3600\ (\text{HHV} \div \text{LHV})}{(\text{Thermal Efficiency})}\ \text{kJ/kW h}$$

(2) Heat Rate (Generator Drive)

$$= \frac{3412.14}{(\text{Thermal Efficiency})}\ \text{Btu/kW h}$$

$$= \frac{3600}{(\text{Thermal Efficiency})}\ \text{kJ/kW h}$$

(3) Heat Rate (Mech. Drive)

$$= \frac{2544.43}{\text{(Thermal Efficiency)}} \text{ Btu/hp h}$$

$$= \frac{3600}{\text{(Thermal Efficiency)}} \text{ kJ/kW h}$$

(4) Specific Fuel Consumption (Marine)

$$= \frac{2544.43}{\text{(Thermal Efficiency)} \times \text{(LHV)}} \text{ lbm/hp h}$$

$$= \frac{1547.72}{\text{(Thermal Efficiency)} \times \text{(LHV)}} \text{ kg/kW h}$$

3. STANDARD REFERENCE CONDITIONS

ANSI B133 Standard Ratings shall be composed using the assumptions listed below. Standard ratings are for zero inlet and exhaust duct pressure loss, except where the gas turbine is described as a complete power plant.

3.1 Standard Atmosphere

A standard atmosphere is represented by air at a temperature of 59°F (15C), a barometric pressure of 14.696 psia (1.01325 Bar), and a relative humidity of 60%.

3.2 Compressor inlet total pressure, total temperature, and humidity same as standard atmosphere (zero duct loss).

3.3 Turbine exhaust flange static pressure same as standard atmosphere (zero duct loss).

3.4 Cooling water temperature (if used for cooling the working fluid) 59°F (15C).

3.5 Standard Gas Fuel

A standard gas fuel is represented by Methane (CH_4) with a H/C ratio of 0.333, a low heat value of 21,500 Btu/lbm (50,000 kJ/kg), a high heat value of 23,800 Btu/lbm (55,545 kJ/kg), and a density at standard atmospheric conditions of 0.04236 lbm/ft^3 (0.6786 kg/m^3).

3.6 Standard Oil Fuel

A standard oil fuel is represented by distillate ($CH_{1.684}$) with a H/C ratio of 0.1417, a low heat value of 18,057 Btu/lbm (42,000 kJ/kg), a high heat value of 19,183 Btu/lbm (44,620 kJ/kg), and a density at standard atmospheric conditions of 56.52 lbm/ft^3 (966 kg/m^3).

3.7 Standard Turbine Temperature

The manufacturer shall declare a standard turbine temperature associated with each type standard fuel and each type standard operating mode (para. 2.2.1), and each standard power output rating. This temperature can be the turbine inlet temperature, the gas generator exhaust temperature or the turbine exhaust temperature, depending upon the manufacturers choice. This choice will, in turn, be selected as that temperature that best relates ratings and performance to inspection and maintenance intervals and to the particular temperature control and protective devices to be supplied.

3.8 New and Clean Condition

Standard ratings shall refer to the new and clean condition of the gas turbine components.

4. DEFINITIONS

Definitions related to ratings and performance are included in this section. A more complete list of definitions is available in ANSI B133.1 Gas Turbine Terminology.

4.1 Heat Value

Total heat liberated by complete combustion of a unit of fuel.

The high heat value is the total heat released per unit mass of fuel burned, expressed in Btu/lbm. (kJ/kg).

The low heat value is the high heat value less the heat absorbed by the vaporized water formed during combustion, expressed in Btu/lbm. (kJ/kg).

The high heat value for constant volume (Q'v) is obtained using a bomb calorimeter. The low heat value for constant pressure (Qp) is used in the steady flow combustion process. [$Q'v \div Qp > 1.04$. $Qv \div Qp < 1.004$.]

4.2 Gas Generator

An assembly of gas turbine components which produces heated pressurized gas to a process or to a power turbine. It consists of one or more rotating compressors, thermal device(s) associated with heating the working fluid, and one or more compressor driving turbines, a control system and essential auxiliary equipment.

4.3 Gas Turbine

A machine which converts thermal energy into mechanical work; it consists of one or several rotating compressors, thermal device(s) which heats the working fluid, one or several turbines, a control system and essential auxiliary equipment. Any heat exchangers (excluding waste exhaust heat recovery exchargers) in the main working fluid circuit shall be considered to be part of the gas turbine.

4.4 Gas Turbine Power Plant

A gas turbine and all essential equipment necessary for the production of power in a useful form.

4.5 Turbine Inlet Temperature

The flow weighted mean total temperature of the working fluid, relative to a stationary plane immediately upstream of the first stage rotor blades.

4.6 Turbine Exhaust Temperature

The average gas temperature of the working fluid at the turbine exhaust flange. Usually this temperature is defined by the particular sensors included with the gas turbine control system.

4.7 Gas Generator Exhaust Temperature

The average gas temperature of the working fluid at the gas generator exhaust flange (load turbine inlet flange). Usually this temperature is defined by the particular sensors supplied with the gas generator control system.

APPENDIX A

SAMPLE PERFORMANCE CURVES

A.1.0 For operating conditions that are different from either the standard reference conditions (Para. 3) or the site rating conditions, (Para. 2.), the manufacturer should supply the user with estimated performance curves and correction factors to cover the intended range of site conditions. This information should cover the expected range of variation of the following:

1.1 Shaft speed (speeds)

1.2 Power output

1.3 Temperature entering the compressor

1.4 Atmospheric pressure

1.5 Inlet and exhaust pressure losses

1.6 Effect of variations in certain fuel properties.

A.2.0 Typical performance curves are included to illustrate the most useful forms of these performance curves depends upon the application under consideration.

A.2.1 Mechanical Drive–Single Shaft. Figure A1 illustrates one form of performance curve useful for mechanical drive applications of a single shaft gas turbine. As shown, this curve applies for one set of values of atmospheric pressure, compressor inlet temperature, inlet and exhaust pressure loss.

A.2.2 Mechanical Drive–Two Shaft. Figure A2 illustrates one form of performance curve useful for mechanical drive application of a two shaft gas turbine. Figure A2a applies to a two shaft gas turbine having some form of variable geometry such as an adjustable load turbine nozzle. This adjustment permits independent selection of a turbine temperature such as exhaust temperature. Figure A2a represents the special case where the turbine nozzle is adjusted to maintain the turbine exhaust temperature constant. Figure A2b applies to a two shaft gas turbine having fixed geometry. In this case, the turbine temperatures change in such a manner as to maintain a power balance between the HP turbine power generated and compressor power absorbed. As shown, these curves apply for one set of values of atmospheric pressure, compressor inlet temperature, inlet and exhaust pressure lost.

A.2.3 Generating Plant. Figure A3 illustrates one form of performance curve useful for electric utility and other generator drive gas turbine power plants. This example applies to a complete electric power generating plant with a single shaft gas turbine and with whatever inlet and exhaust pressure losses are built into the complete plant. Since these site pressure losses are part of the plant, they need not be specified,* as they were for Figure A1 and A2. Figure A3 will apply to a specific site atmospheric pressure however. For this example, Fig. A3 indicates a load limit for each compressor inlet temperature (0, 40, 80, 110F). This load limit is the point where turbine inlet temperature reaches the rated value. The upper portion of Fig. A3 shows how the maximum allowable turbine exhaust temperature varies with compressor inlet temperature.

A.2.4 It is customary to refer site performance to the compressor inlet temperature. The relation between this temperature and ambient temperature is frequently uncertain as there is some ambiguity in ambient temperature. With multi-unit installations at a single site, and to a lesser extent, with single unit installations, the compressor inlet temperature can be higher than the surrounding ambient air temperature as a

*The user frequently refers to the manufacturer's expected values of inlet and exhaust pressure losses when available, to aid in analysis of performance deterioration, therefore such values should be stated by the manufacturer.

result of several relatively large heat rejections to the ambient air. This is especially important for the heat rejected at the turbine exhaust or stack since an unfavorable wind direction could cause reinjection back into the gas turbine compressor inlet. Other sources of heat including lube oil and generator cooling could also cause increases in compressor inlet temperature depending on wind direction and orientation of cooling fan exhaust. The manufacturer and user should examine each installation design and arrange to minimize the adverse effect of compressor inlet temperature elevation above the surrounding ambient temperature.

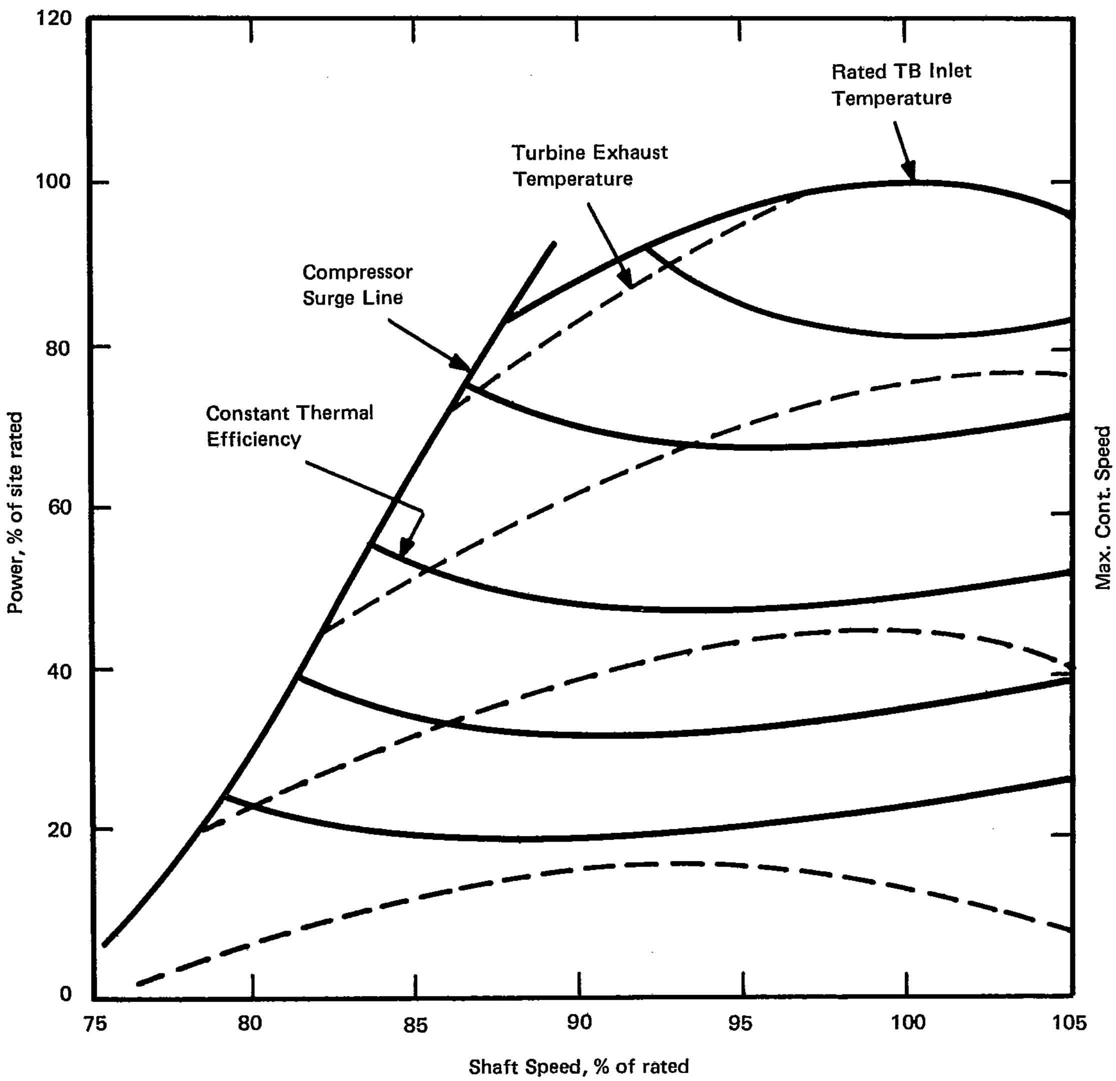
A.2.5 Except for the case where a complete generating plant is supplied, the manufacturer should supply the user with correction factors to go with estimated performance curves. Typically, this can be done by adding simple notations to these performance curves such as:

A.2.5.1 Reduce power output 2 percent for each four inches of water inlet pressure loss.

A.2.5.2 Reduce thermal efficiency one percent for each four inches of water inlet pressure loss.

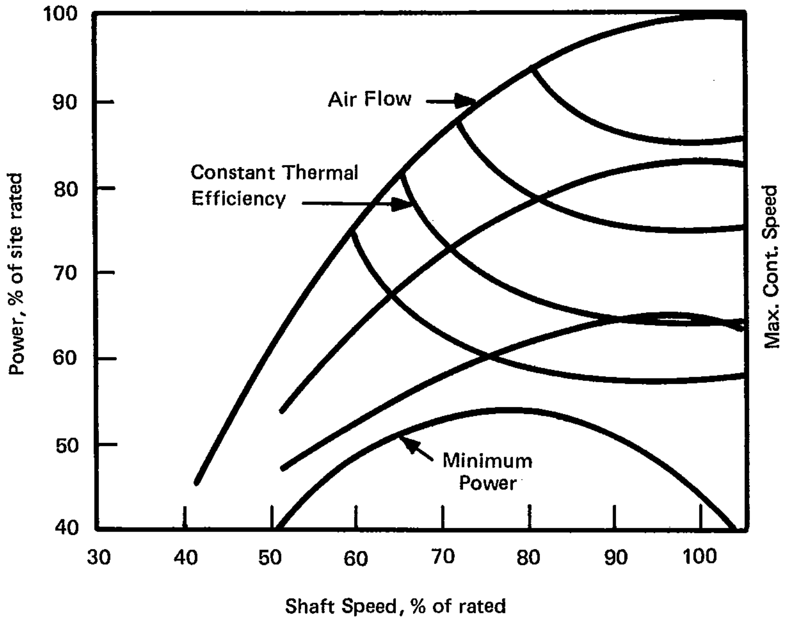
A.2.5.3 Reduce power output and thermal efficiency one percent for each four inches of water exhaust pressure loss.

A.2.5.4 Increase power output one percent for each four inches of water increase in absolute atmospheric pressure.

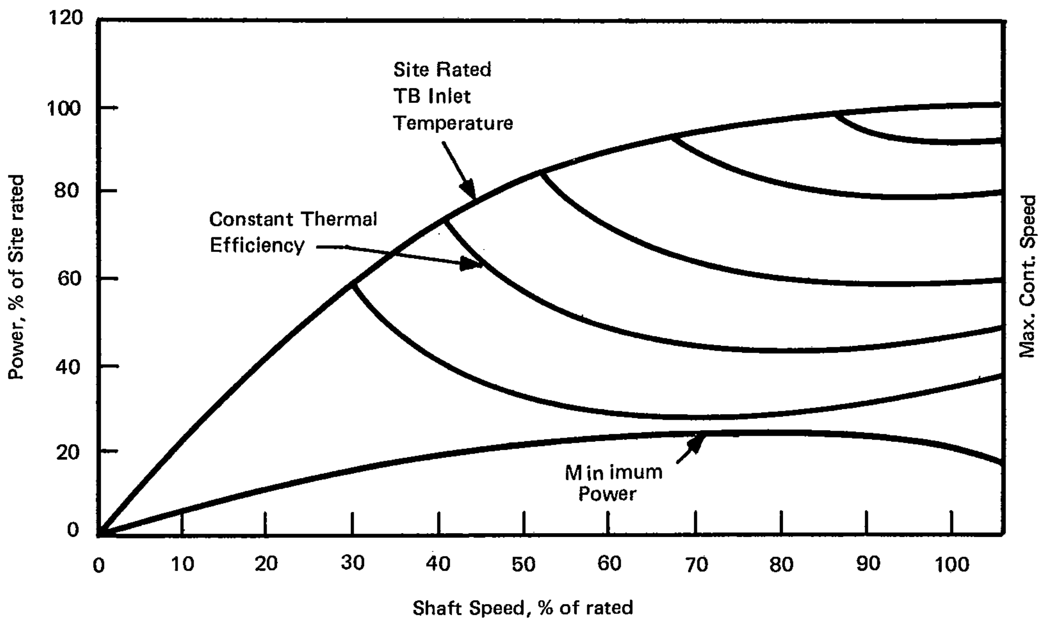


Rated site conditions
Inlet pressure loss (in. H_2O)
Exhaust pressure loss (in. H_2O)
Inlet air temperature (deg. F)
Atmospheric pressure (psia)

FIG. A1 SAMPLE PERFORMANCE CURVES
MECHANICAL DRIVE—SINGLE SHAFT



(a) Constant exhaust temperature turbine



(b) Variable exhaust temperature turbine

Rated site conditions
Inlet pressure loss (in. H_2O)
Exhaust pressure loss (in. H_2O)
Inlet air temperature (deg. F)
Atmospheric pressure (psia)

FIG. A2 SAMPLE PERFORMANCE CURVES
MECHANICAL DRIVE—TWO SHAFT

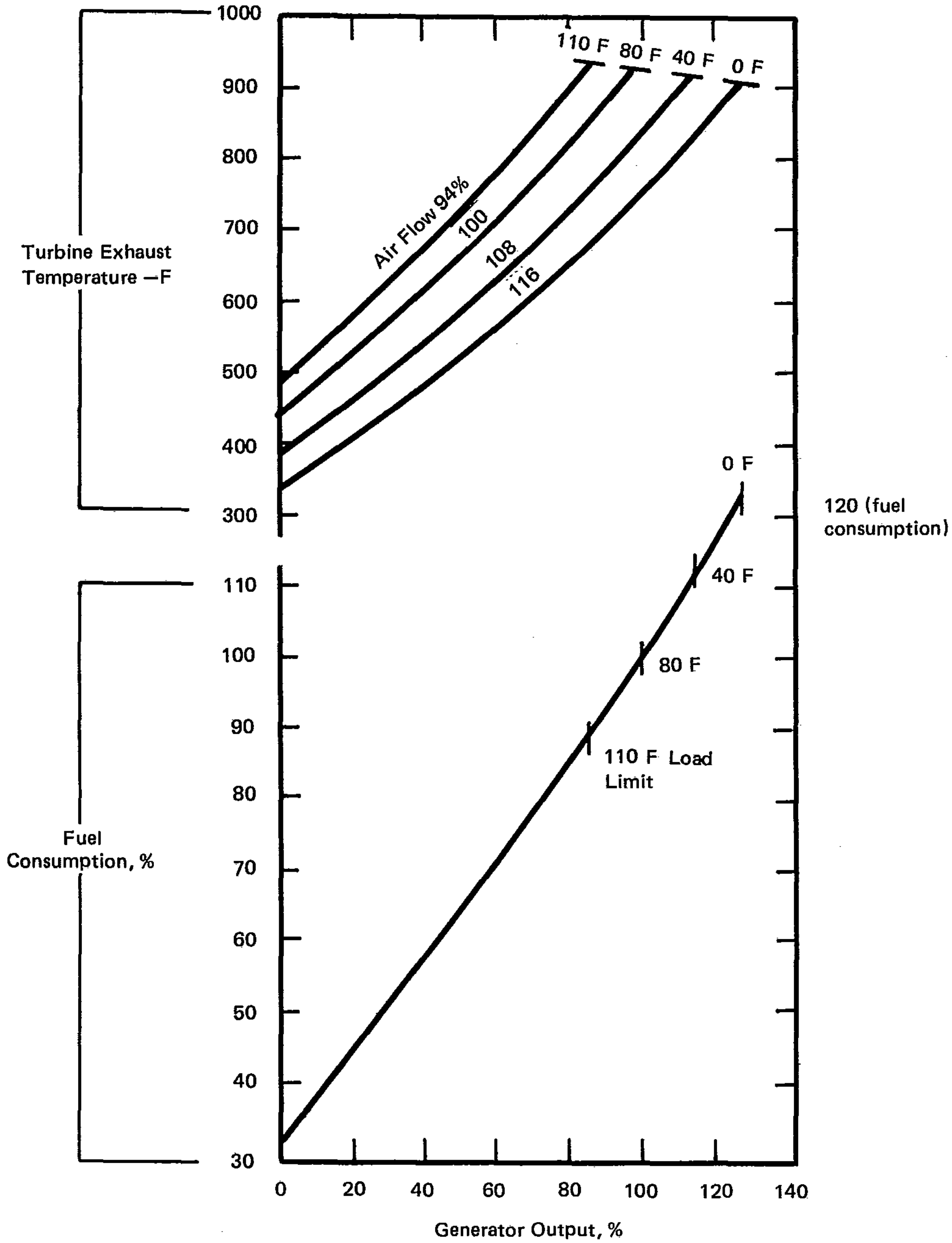


FIG. A3 SAMPLE PERFORMANCE CURVE
GENERATING PLANT—SINGLE SHAFT

APPENDIX B

PROVISIONS FOR MEASUREMENT OF PERFORMANCE

B.1.0 The user and the manufacturer should reach agreement on the specific provisions for, and locations of, pressure taps and temperature measurement points that will be used in conjunction with these estimated site performance curves and correction factors. (See Section B133.10–"Information to be Supplied by the User and Manufacturer".)

B.2.0 The user and the manufacturer should reach agreement on specific plans for performance tests if these are to be included in an Acceptance Testing program. (Refer to ISO 2314 "Acceptance Tests" or ASME PTC-22 "Performance Test Code"). This planning should include agreement on the degree of precision of the measurements to be made and the effect that this degree of precision has on the result. Higher precision in measurement, naturally will result in smaller intervals of uncertainty, smaller testing tolerance, and higher testing cost. Reference: ASME PTC-6-1969 "Guidance for Evaluation of Measurement Uncertainty in performance Tests of Steam Turbines".

B.2.1 Agreement on the testing tolerance or dead band can be patterned after one of the three cases described below:

Zero Testing Tolerance. The manufacturer provides for uncertainty intervals in test results by incorporating appropriate margins in performance guarantees and by developing precision testing techniques.

Negotiated Dead Band. The manufacturer and the user reach agreement, prior to the test, on the size of a specific testing tolerance or dead band to be used in determining performance and rating conformance.

Flexible Tolerance. The manufacturer and user reach agreement, prior to the test, on the method for determining the uncertainty interval to be applied to the results. The method for determining this uncertainty interval will be based on specific rules for measuring test scatter or variations among redundant measurement systems.

AMERICAN NATIONAL STANDARDS FOR GAS TURBINES

TITLE OF STANDARD

The ASME Publications Catalog shows a complete list of all Standards published by the Society.