NEMA SM*24 91 ■ 6470247 0500427 6 ■

STANDARDS PUBLICATION/NO. SM 24

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Land Based Steam Turbine Generator Sets 0 to 33,000 kW

NEMA

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION ■ 2101 L STREET, N.W., WASHINGTON, D.C. 20037

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NEMA SM 24-1991

SM 24

LAND BASED STEAM TURBINE GENERATOR SETS 0 TO 33,000 KW

Published by

National Electrical Manufacturers Association
2101 L Street, N.W., Suite 300
Washington, D.C. 20037

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Foreword

This standard has been developed by the Steam Turbine Section of NEMA. In its preparation and revision, consideration has been given to the work of other organizations, such as the American National Standards Institute, the American Society of Mechanical Engineers, and the American Gear Manufacturers Association, striving toward the development of standards, and credit is hereby given to all whose standards may have been helpful in the preparation of this publication.

The purpose of this standard is to facilitate the application of these turbine generator sets by engineers, users, and contractors, to promote economies of steam power generation equipment, and to assist in the proper selection and application of the differing designs of steam turbine generator sets.

NEMA Standards Publication SM 24-1991 revises and supersedes the NEMA Standards Publication Land Based Steam Turbine Generator Sets 0 to 33,000 kw, SM 24-1985.

User needs have been considered throughout the development of this standard. Proposed or recommended revisions should be submitted to:

Vice President, Engineering Department
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2101 L Street N.W., Suite 300
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Scope

These standards cover single stage and multistage steam turbines, reduction gears, air cooled electric generators, switchgear and auxiliary systems. This standard is also applicable to turbines expanding various gases or compressed air.

In addition, this standard applies to auxiliary equipment associated with the turbine generator such as governors, baseplates, excitation controls, steam piping, and so forth. The standard does not apply to other equipment in the steam cycle or electrical distribution systems.

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Section 1
REFERENCED STANDARDS AND DEFINITIONS

1.1 REFERENCED STANDARDS

In this publication, reference is made to the standards listed below. Copies are available from the indicated sources:

American Boiler Manufacturers Association
1500 Wilson Boulevard
Arlington, VA 22209

Boiler Water Quality and Steam Purity Rates for Water Tube Boilers (1982)

American Gear Manufacturers Association
1901 North Fort Myer Drive
Arlington, VA 22209

421.06 — *Practices for High-Speed Helical and Herringbone Generator Units*

American National Standards Institute
1430 Broadway
New York, NY 10018

C37.06-1989 — *Standard for High Voltage Circuit Breakers Rated on a Symmetrical Current Basis-Preferred Ratings and Related Required Capabilities*

ANSI/IEEE 100-1988 — *Dictionary of Electrical and Electronic Terms*
S1.4-1983 — *Specification for Sound Level Meters*
S1.11-1986 — *Specifications for Octave-Band, Fractional Octave-Band Analog and Digital Filters*

ANSI/ASME
B1.20.1-1983 — *General Purpose Pipe Threads (Inch)*
B16.1-1989 — *Cast Iron Pipe Flanges and Flanged Fittings, Class 25, 125, 250 and 800*
B16.5-1988 — *Pipe Flange and Flanged Fittings*
B31.1-1989 — *Power Piping*

Expansion Joint Manufacturers Association
25 North Broadway
Tarrytown, NY 10591

The Standard of the Expansion Joint Manufacturers Association (1980) (1985 Addendum)

Institute of Electrical & Electronic Engineers
345 East 47 Street
New York, NY 10017

IEEE Standard 1-1986 — *General Principles for Temperature Limits in the Rating of Electrical Equipment*
IEEE Standard 112-1984 — *Test Procedures for Polyphase Induction Motors and Generators*
IEEE Standard 115-1983 — *Test Procedures for Synchronous Machines*
IEEE Standard 200-1975 — *Design Electrical & Electronic Parts & Equipment (Device Numbers and Functions)*

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MG1-1987	*Motors and Generators*
SM 23-1985	*Steam Turbines for Mechanical Drive Service*
AB 1-1986	*Molded Case Circuit Breakers*
250-1985	*Enclosures for Electrical Equipment (1000 Volts Maximum)*

1.2 DEFINITIONS

The terms in Section 1.2 are defined as they apply to land based steam turbine generator sets covered in this standards publication.

AC Power—Power used in an alternating current electrical circuit. (See Appendix.)

Alternating Current (ac)—Current which varies from zero to a positive maximum to zero to a negative maximum to zero, a number of times per second, the number being expressed in cycles per second or Hertz (Hz).

Alternator—A generator which produces alternating current.

Ambient Temperature—The temperature of the surrounding air in which the generating system operates.

Ammeter—An instrument for measuring the magnitude of an electric current.

Amortisseur—A short-circuited winding consisting of conductors embedded in the pole faces of the rotor of a synchronous generator.

Ampere—The unit of electric current flow. One ampere will flow when one volt is applied across a resistance of one ohm.

Apparent Power—The vectorial sum of real power and reactive power. (See Appendix.)

Automatic Transfer Switch—An automatic device for transferring an electrical load from one power source to another.

Brushless Exciter—An ac (rotating armature type) exciter whose output is rectified by a semiconductor device to provide excitation to an electric machine. The semiconductor device would be mounted on and rotate with the ac exciter armature.

Capacitance—The property of a system of conductors and dielectrics that permits the storage of electrically separated charges when potential differences exist between the conductors.

Capacitor—A device, the primary purpose of which is to introduce capacitance into an electric circuit.

Circuit Breaker—A mechanical switching device capable of making, carrying, and breaking circuit conditions and also, making, carrying for a specified time, and breaking currents under specified abnormal circuit conditions, such as short circuit.

Continuous Rating—The load rating of an electrical generating system which it is capable of supplying without exceeding its specified maximum temperature rise limits for continuous operation.

Cooling Steam—A minimum steam flow which must be passed through a turbine stage to absorb the frictional heat input resulting when the turbine rotor is rotated by means other than the normal expansion of steam through that stage.

Core—An element made of magnetic material, serving as a part of a path for magnetic flux.

Critical Speed—A speed at which the amplitude of the vibration of a rotor due to shaft transverse vibration reaches a maximum value.

Cross-current Compensation—One of two systems which permits generators in parallel, to share the reactive component of the power in proportion to their rating while maintaining constant output voltage. See Droop Compensation.

Cross-current Compensation Transformer (CCCT)— A current transformer which controls the division of reactive KVA in proportion to the rating of generators operating in parallel.

Current Transformer (CT)—An instrument transformer used in conjunction with ammeters and control circuits that produces an output proportional to primary current.

Cycle—One complete reversal of an alternating current or voltage, from zero to a positive maximum to zero to a negative maximum back to zero. The number of cycles per second is the frequency, expressed in Hz.

DC Field—The field poles and their winding which, when energized, produce the magnetic flux in a generator.

Delta Connection—A three phase connection in which the start of each phase is connected to the end of the next phase, forming the Greek letter Delta (Δ).

Deviation Factor—The deviation factor of a voltage wave is the ratio of the maximum difference between corresponding ordinates of the wave and of a sine wave of the same root-mean-square value and time base to the peak value of this sine wave when this sine wave is superimposed in such a way as to make this difference as small as possible.

Diode—Solid state semiconductor which allows current to pass in one direction only.

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Direct Current (dc)—A unidirectional current in which the changes in value are either zero or so small that they may be neglected.

Droop—The change in speed when the power output is gradually changed from zero power to rated power output and the turbine generator is not paralleled with other generating units.

Droop Compensation—A system which permits generators in parallel to share the reactive component of the power in proportion to their rating. See also Cross Current Compensation.

Efficiency—The efficiency of a turbine is the ratio (expressed as a percentage) of its useful power output to its net available energy input.

Electrical Runout—An apparent deviation in shaft concentricity indicated by the output of a proximity probe which is due to variations in the electrical conductivity or magnetic properties of the observed shaft surface.

Entrapped Energy—The energy which remains in the volume of steam trapped between the turbine and a trip valve or nonreturn valve.

Excitation—The input of dc power into the rotating field coils of a synchronous generator or the input of ac power into the stator coils of an induction generator.

Exciter—A rotating or static device for supplying excitation to the field of a synchronous generator.

Field—A region of space under magnetic influence resulting in a distribution of magnetic lines of flux in that space.

Field Coil—A suitably insulated winding to be mounted on a field pole to magnetize it.

Field Pole—A structure of magnetic material on which a field coil may be mounted.

Flexible Shaft—A shaft which is intended for operation at speeds greater than the first lateral critical speed.

Frequency—The number of complete cycles of an alternating voltage or current per unit of time, usually per second, expressed in Hz.

Frequency Droop—The change in frequency expressed in Hz between steady state no load and steady state full load.

Frequency Regulation—The percentage change in frequency from steady state full load to steady state no load.

Frequency Recovery Time—The interval of time required for the frequency to return to and remain within a prescribed frequency band following an instantaneous load change.

Frequency Transient—The maximum frequency deviation as a result of a sudden change in load.

Full Load Current—The full load current of a generator is the value of current in root mean square (rms) or dc amperes which it carries when delivering rated output under rated conditions.

Generator—A machine that converts mechanical power into electric power.

Ground—A conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the earth, or to some conducting body of relative large extent that serves in place of the earth.

Grounded Neutral—A point of an electrical system which is intentionally connected to ground.

Hertz (Hz)—The unit of frequency, one cycle per second.

Hunting—The oscillation of voltage, frequency, or other controlled parameter above and below the mean value. An unstable condition.

Hydro Test—A test for leaks and integrity of the pressure containing components of the turbine by pressurizing with water.

Impedance—The total opposition offered by a circuit to the flow of alternating current. It is composed of resistance and reactance (inductive or capacitive, or both), and its symbol "Z" is expressed in ohms.

Inductance—The property of an electric circuit by which a varying current induces an electromotive force in that circuit or in a neighboring circuit.

Induction Generator—An induction machine driven above synchronous speed by an external source of mechanical power for use as a generator.

In-phase—A condition in which the ac voltage waves of two generating systems coincide.

Inrush Current—The inrush current of a machine or apparatus is the maximum value of rms or dc amperes which it carries after being suddenly and fully energized and prior to reaching a stable operating condition.

Insulation—Material or a combination of suitable nonconducting materials that provide electric isolation of two parts at different voltages.

Internal Water Washing—A procedure in which steam having a high percentage of moisture is injected into the turbine for the purpose of removing water soluble deposits from the turbine blades and nozzles.

Kilovolt Ampere—One thousand volt amperes (apparent power), equal to kilowatt divided by the power factor, also equal to (root mean square) current times (root mean square) volts in kilovolts. (See Appendix.)

Kilovolt Ampere Reactive—One thousand volt amperes reactive-reactance power. (See Appendix.)

Kilowatt—One thousand watts (real power). Equal to kilovolt amperes times power factor. (See Appendix.)

Kilowatt Hour (KWH)—One thousand watts times one hour, unit of electric energy or work.

Lateral Critical Speeds—The speeds at which the amplitude of the lateral vibration of a machine rotor due to shaft rotation reach their maximum value.

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Line-to-Line Voltage —The voltage existing between any two conductors in polyphase circuits. Also, the voltage between the phase conductors.

Line-to-Neutral Voltage—The voltage existing between any phase conductor and the neutral conductor.

Manual Transfer Switch—A manually operated device for transferring an electrical load from one power source to another.

Maximum Power—Maximum power is the output power at the generator terminals in kilowatts when operating with maximum inlet conditions, minimum exhaust conditions, specified power factor, minimum extraction, and maximum induction steam flow, when applicable.

Neutral—The point common to all phases of a polyphase circuit—it is the point along an insulated winding where the voltage is the instantaneous average of the line terminal voltage during normal operation.

Non-Salient Pole—A pole structure with its electrical coils wedged in axial slots in a cylindrical body.

Normal Power—Normal power is the power which the turbine generator set will produce when operating at specified normal conditions.

OHM—Unit of electrical resistance. One volt will cause a current of one ampere to flow through a resistance of one ohm.

Overload Power—Overload power is that load in excess of rated load which the turbine generator unit is capable of delivering for a specified period of time. The voltage, frequency, and operating temperature may differ from normal rated values.

Out-of-Phase—A condition in which the ac voltage waves of two generating systems do not coincide.

Parallel Operation—Two or more generators of the same phase, voltage, and frequency characteristics supplying power to the same load.

Paralleling—The procedure used to connect two or more generators to a common load.

Permanent Magnet Generator (Pilot Exciter)—A generator in which the open-circuit magnetic flux field is provided by one or more permanent magnets.

Phase—The number of complete voltage or current sine waves, or both, generated per 360 electrical degrees.

Phase Angle—The amount by which the zero point of the voltage wave differs from the zero point of the current wave in an ac circuit. (See Appendix.)

Phase Rotation—The sequence in which the phases of a generator or network pass through the positive maximum points of their waves. The same sequence must exist when units are paralleled.

Phase Sequence—The order in which the voltages successively reach their positive maximum values between terminals.

Pole—A machine structure which generates and directs lines of magnetic energy.

Potential Transformer (Voltage Transformer)—An instrument transformer that is intended to have its primary winding connected in shunt with a power supply circuit, the voltage of which is to be measured or controlled.

Power Factor—The ratio of real power divided by apparent power. (See Appendix.)

Proximity Probe—A non-contacting device which electronically measures the position or displacement motion of an observed surface relative to the probe position.

Purge Air—A method of sealing in which air (or inert gas) is bled into the seal or housing to maintain a slight positive pressure and thus prevent the entrance of contaminants.

Rated Current—The rated current of a generator is the value of current in rms or dc amperes which is obtainable from a turbine generator set when it is functioning at rated conditions. See Full Load Current.

Reactance —The out-of-phase component of impedance that occurs in circuits containing inductance or capacitance, or both.

Reactive KVA (KVAR)—The reactive component of ac power. (See Appendix.)

Real Power—The real component of ac power. (See Appendix.)

Reduction Gear—A mechanical device used to reduce the turbine speed to the generator speed.

Relay—A device which initiates an output change as a response to a specified input change.

Resistance Temperature Detector (RTD)—A device for measuring temperature in which the electrical resistance of the device changes with temperature.

Response Time—The time required to recover to the steady state operating value after a sudden change in load.

Root Mean Square (rms)—A measurement of alternating current and voltage and representing a proportional value of the true sine wave.

Salient Pole—A pole structure and its electrical coils which project from a hub or yoke.

Service Factor—The factor by which the maximum power capability of a device exceeds its rated power.

Short Circuit Ratio—The ratio of the field current for rated open-circuit armature voltage and rated frequency to the field current for rated armature current on sustained symmetrical short-circuit at rated frequency.

Short Term Rating—The load rating of an electrical generating system which it is capable of carrying for a short specified period of time.

Silicon Controlled Rectifier (SCR)—Solid state device which permits current to flow in one direction only when triggered by a suitable potential applied to the control lead or terminal.

Specified Conditions—Specified conditions are all customer defined power, voltage, frequency, power factor

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and steam conditions at which the turbine generator must operate.

Static Exciter—A non-rotating device which furnishes direct current to the generator field.

Stator—The portion of a generator which includes and supports the stationary active parts.

Stator Winding —A winding on the stator of a machine.

Steady State —The operating point under constant load when no transients are present.

Steam Turbine—A prime mover which converts the thermal energy of steam directly into mechanical energy of rotation.

Stiff Shaft—A shaft which will not be operated during normal circumstances at speeds greater than the first lateral critical speed.

Switchgear—A general term covering switching and interrupting devices and their combination with associated control, instrumentation, metering, protective and regulating devices. It also includes assemblies of these devices, associated interconnections, accessories, and supporting structures used primarily in connection with the generation, transmission, distribution, and conversion of electric power.

Synchronous Generator—A synchronous ac machine which transforms mechanical power into electrical power and operates at synchronous speed at any load. Excitation is supplied by a generator exciter.

Synchronous Speed—The generator speed which is directly proportional to the frequency of the system to which the generator is connected. (See 2.4.2.1.)

Synchronizing—The process whereby a synchronous machine, with its voltage and phase suitably adjusted, is paralleled with another synchronous machine or system.

Telephone Influence Factor (TIF)—The telephone influence factor of a synchronous generator is a measure of the possible effect of harmonics in the generator voltage wave on telephone circuits.

Thermocouple—A device for sensing temperatures in which a pair of dissimilar conductors are joined at two points so that an electromotive force is developed by thermoelectric effects when the junctions are a different temperatures.

Torsional Critical Speed—The speed at which the amplitudes of the angular vibrations of a machine rotor due to shaft torsional vibration reach a maximum.

Transformer—A static electric device that introduces mutual coupling between electric circuits.

Volt—The unit of electromotive force. One volt will cause a current of one ampere to flow through a resistance on one ohm.

Voltage Dip—The maximum reduction in voltage resulting from an increase in load.

Voltage Range—The voltage range of a generator is the band width of voltage through which the generator is capable of adjustment and operation from no load through full load at specified conditions.

Voltage Regulation—The voltage regulation of a generator is the difference between the regulated no load and the regulated full load output voltage expressed as a percentage of the regulated full load voltage.

Voltage Regulator —A device which maintains the voltage output of a generator.

Voltmeter—An instrument for measuring the voltage magnitude.

Wye Connection—A method of interconnecting the phases of a three phase system to form a configuration resembling the letter "Y". A fourth or neutral wire can be connected to the center point.

NEMA Standard 6-12-1985.

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Section 2
CONSTRUCTION

2.0 GENERAL

2.0.1 Introduction

A steam turbine generator set includes a steam turbine, reduction gear (when applicable), and a generator.

The steam turbine converts energy from the available heat drop between two or more steam pressure levels into shaft power. The reduction gear, when applicable, allows the turbine to operate at an efficient speed and matches the output speed to the generator speed.

The generator converts the shaft power into electrical output at the generator terminals.

The turbine generator controls regulate the steam flow and generator excitation to produce stable operation.

Authorized Engineering Information 1-30-91.

2.1 TYPES OF STEAM TURBINES

2.1.1 Classified by Exhaust Conditions

2.1.1.1 NONCONDENSING TURBINE

A noncondensing turbine is a steam turbine designed to operate with an exhaust steam pressure equal to or greater than atmospheric pressure.

NEMA Standard 11-13-1969.

2.1.1.2 CONDENSING TURBINE

A condensing turbine is a steam turbine designed to operate with an exhaust steam pressure below atmospheric pressure.

2.1.2 Classified by Number of Stages and Control Valves

2.1.2.1 SINGLE VALVE SINGLE STAGE TURBINE

A single valve single stage turbine is a steam turbine which has one governor controlled valve and one stage.

NEMA Standard 6-21-1979.

2.1.2.2 SINGLE VALVE MULTISTAGE TURBINE

A single valve multistage turbine is a steam turbine which has one governor controlled valve and two or more stages.

NEMA Standard 6-21-1979.

2.1.2.3 MULTIVALVE SINGLE STAGE TURBINE

A multivalve single stage turbine is a steam turbine which has two or more governor controlled valves and one stage.

NEMA Standard 6-21-1979.

2.1.2.4 MULTIVALVE MULTISTAGE TURBINE

A multivalve multistage turbine is a steam turbine which has two or more governor controlled valves and two or more stages.

NEMA Standard 6-21-1979.

2.1.3 Classified by Process Needs

2.1.3.1 CONTROLLED (AUTOMATIC) EXTRACTION TURBINE

A controlled (automatic) extraction turbine is a steam turbine which has an opening(s) in the turbine casing for the extraction of steam and which is provided with means for directly regulating the flow of steam to the turbine stages following the extraction opening for the purpose of controlling extraction pressure.

NEMA Standard 6-21-1979.

2.1.3.2 NONCONTROLLED EXTRACTION TURBINE

A noncontrolled extraction turbine is a steam turbine which has an opening(s) in the turbine casing for the extraction of steam but which does not have means for controlling the pressure of the extracted steam.

NEMA Standard 6-21-1979.

2.1.3.3 NONCONTROLLED INDUCTION TURBINE

A noncontrolled induction turbine is a steam turbine which has an opening(s) in the turbine casing for induction of steam but which does not have means for controlling the pressure of the inducted steam.

NEMA Standard 11-14-1985.

2.1.3.4 CONTROLLED INDUCTION (MIXED PRESSURE) TURBINE

A controlled induction (mixed pressure) turbine is a steam turbine which is provided with separate inlets for steam at two pressures and has an automatic device for controlling the flow of steam to the turbine stages following the induction opening.

NEMA Standard 6-21-1979.

2.1.3.5 INDUCTION EXTRACTION TURBINE

An induction extraction turbine is one which combines the features of extraction (controlled or noncontrolled) with the features of induction.

NEMA Standard 6-21-1979.

2.2 STEAM TURBINE COMPONENTS

2.2.1 Turbine Casing

A turbine casing is the enclosure which surrounds the rotating element of the turbine and supports the stationary

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steam parts. Casings shall be axially split, radially split, or a combination thereof.

The turbine casing shall be divided into two or more sections as follows:

NEMA Standard 6-21-1979.

2.2.1.1 STEAM INLET END SECTION

The steam inlet end section is that portion of the casing which contains the higher pressure steam.

NEMA Standard 6-21-1979.

2.2.1.2 EXHAUST END SECTION

The exhaust end section is that portion of the casing which contains the exhaust connection and the steam at exhaust conditions. It shall also contain the low pressure stage(s) of a multistage turbine.

NEMA Standard 6-12-1979.

2.2.1.3 INTERMEDIATE SECTION

The intermediate section (multistage turbines only) is that portion of the casing which is between the steam inlet end and the exhaust end sections and which contains the intermediate stage(s).

NEMA Standard 6-21-1979.

2.2.2 Steam Chest (Governor Valve Body)

A steam chest (governor valve body) incorporates the inlet connection, houses the governor controlled valve(s), and is bolted to or integral with the steam ring inlet section.

NEMA Standard 6-21-1979.

2.2.3 Steam Ring

A steam ring incorporates the passage(s) through which the steam flows from the governor valve(s) and steam chest to the first stage nozzles.

NEMA Standard 6-21-1979.

2.2.4 Nozzles

Nozzles are stationary machined or formed openings which expand the steam and direct it against the turbine blades or buckets.

NEMA Standard 11-13-1969.

2.2.5 Stationary Reversing Blades

Stationary reversing blades in a velocity-compounded stage redirect the steam flow from one row of rotating blades or buckets to the following rotating blades or buckets.

NEMA Standard 11-13-1969.

2.2.6 Stationary Reversing Chambers

Stationary reversing chambers in a reentry velocity-compounded stage redirect and return the steam flow to the preceding rotating row of blades or buckets.

2.2.7 Diaphragm

A diaphragm is the stationary element of a stage containing nozzles which expand the steam and direct it against the rotating blades. It is normally used in a multistage turbine.

NEMA Standard 6-21-1979.

2.2.8 Stage, Turbine

A steam turbine stage consists of a "matched set" of stationary nozzles and rotating blades. A pressure drop occurs in a steam turbine stage generating kinetic energy which is converted to mechanical work.

2.2.8.1 IMPULSE STAGE

An impulse stage consists of stationary expansion nozzle(s) discharging the high velocity steam jets on the rotating blades. A pressure drop occurs only in the stationary nozzle(s). Impulse stages consist of three types:

2.2.8.1.1 A pressure impulse or Rateau stage consists of stationary expansion nozzle(s) and one row of rotating blades.

2.2.8.1.2 A velocity-compounded impulse or Curtis stage consists of stationary expansion nozzle(s) and two or more rows of rotating blades.

2.2.8.1.3 A velocity-compounded impulse reentry stage consists of stationary expansion nozzle(s), one row of rotating blades and one or more reversing chambers.

The pressure drop across a Rateau stage is relatively low in comparison to the pressure drop across a Curtis stage.

Authorized Engineering Information 6-21-1979.

2.2.8.2 REACTION STAGE

A reaction stage consists of stationary expansion nozzle(s) discharging high velocity steam jets on the rotating blades. A pressure drop occurs in both the stationary and rotating elements.

NEMA Standard 6-21-1979.

2.2.9 Shaft Seals

2.2.9.1 CASING SHAFT SEALS

Casing shaft seals minimize the leakage of steam out of the casing along the shaft.

For condensing turbines, seals are arranged to prevent the entrance of air into the casing along the shaft. They are arranged for the admission of steam at a constant low pressure and low temperature.

NEMA Standard 6-21-1979.

2.2.9.2 INTERSTAGE SHAFT SEALS

Interstage shaft seals minimize the leakage of steam along the shaft between stages in a multistage turbine.

NEMA Standard 6-21-1979.

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2.2.10 Bearing Housing

A bearing housing contains and supports a bearing(s) and is equipped with seals to prevent leakage of oil and the entrance of moisture, dust, and foreign materials.

NEMA Standard 6-21-1979.

2.2.11 Bearings

2.2.11.1 Radial Bearings

Radial bearings are bearings which support the rotating element in horizontal shaft turbines. They are of the sleeve, tilting pad, or antifriction type. In vertical turbines, these bearings radially position the rotor assembly.

NEMA Standard 6-21-1979.

2.2.11.2 Thrust Bearings

Thrust bearings are bearings which transmit the axial thrust of the rotating element to the bearing housing and maintain the axial position of the rotor assembly in the casing. They are of the antifriction, land, or segmental tilting pad type.

NEMA Standard 6-21-1979.

2.2.11.3 Antifriction Bearings

Antifriction bearings should have a minimum rating life of 3 years or 25,000 hours when operated continuously at maximum thrust and radial loads and at rated speed.

Authorized Engineering Information 6-21-1979.

The rating life is the number of hours at constant speed that 90 percent of a group of identical bearings will operate before the first evidence of fatigue develops.

Authorized Engineering Information 6-21-1979.

2.2.12 Rotor Assembly

The rotor assembly is the rotating element of the turbine which includes all parts attached to the shaft, excluding the coupling(s) unless coupling is integral with the shaft.

NEMA Standard 6-21-1979.

2.2.13 Wheels (Discs)

Wheels are discs which are integral with, or fixed to, the turbine shaft and on which blades are mounted, or in which blades or buckets are machined.

NEMA Standard 6-21-1979.

2.2.14 Blades (Buckets)

Blades (buckets) are curved vane elements proportioned to convert kinetic energy of the steam to mechanical energy.

NEMA Standard 6-21-1979.

2.2.15 Shroud

A shroud is an integral or separately attached rim located at the blade tip. The shroud prevents radial leakage of the steam jet and increases the blade rigidity.

NEMA Standard 6-21-1979.

2.2.16 Hand Valve(s)

A hand valve(s) is the valve which isolates steam flow to a nozzle or a group of nozzles to permit efficient operation at reduced power or with dual steam conditions. Hand valves can be either manually controlled or automated, and are used on single valve turbines only.

NEMA Standard 6-21-1979.

2.2.17 Protective Device

A protective device is one which, alone or as part of a system, responds in some predetermined manner to abnormal conditions attending the operation of the unit or system to which it is connected.

NEMA Standard 6-21-1979.

2.2.18 Controlling Device

A controlling device is one which manually or automatically initiates action of a system which controls normal operation of the turbine.

NEMA Standard 11-13-1969.

2.2.19 External Control Device

An external control device is an element which is responsive to signals other than turbine speed, i.e., flow, pressure, temperature, and so forth, and acts to control the flow of steam to the turbine. It shall be pneumatically, mechanically, hydraulically, or electrically actuated from the signal source to position the governor valve(s). (Reference Section 3.1.6.)

NEMA Standard 6-21-1979.

2.2.20 Warning Device

A warning device is one which, by visible or audible means, or both, indicates that an abnormal operating condition exists.

NEMA Standard 6-21-1979.

2.2.21 Sentinel Warning Valve

A sentinel warning valve is a pressure warning device which opens when the steam pressure rises to a predetermined level. The device shall discharge to the atmosphere and shall be so located as to be plainly visible.

For condensing turbines, it shall be set at 5 psig [35 kPa (gauge)]. For noncondensing turbines the minimum setting shall be either 10 percent or 10 psi (70 kPa) above maximum exhaust steam pressure, whichever is greater.

NEMA Standard 6-21-1979.

A sentinel warning valve is not recommended for the following applications:

- turbines which expand volatile gases
- locations where the discharge of steam to the atmosphere is objectionable, hazardous, or prohibited by law
- turbines which are arranged for automatic and/or unattended start-up

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For these applications, an alternate warning device or optional trip device is recommended.

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2.2.22 Soleplate(s)

A soleplate(s) is a machined flat steel plate(s) or casting(s) for mounting of the equipment supports and for bolting and grouting to the foundation.

NEMA Standard 11-13-1969.

2.2.23 Baseplate

A baseplate is a fabricated or cast continuous structure having machined pads for mounting of the equipment and for bolting and grouting to the foundation.

NEMA Standard 11-13-1969.

The turbine generator set shall be mounted on a baseplate, soleplates, or a combination of both.

2.3 FEATURES AND ACCESSORIES

2.3.1 Basic Features and Accessories

2.3.1.1 STEAM TURBINE ITEMS

Steam turbines shall include at least the following basic features which are deemed necessary for proper functioning and safety of operation.

1. Steam strainer with removable corrosion-resistant element.
2. Control system.
3. Overspeed trip system.
4. Provisions for lubrication.
5. Exhaust casing gland sealing connection (for condensing turbines only).
6. Eyebolts or other provisions for lifting the upper half of the casing on an axially split turbine.

2.3.1.2 GEAR ITEMS

Parallel shaft gears shall include at least the following basic features which are necessary for proper functioning and safety of operation.

1. Casing to enclose the rotating elements of the gear.
2. Rotating elements having gear teeth with surface quality, hardness, and strength to provide long service life.
3. Bearings to support rotating elements.
4. Covered opening to allow for internal inspection.
5. Provisions for lifting the upper half of the gear casing.
6. Provisions for lubrication.
7. Couplings and coupling guards.

NEMA Standard 6-12-1985.

2.3.1.3 GENERATOR ITEMS

The generator shall include at least the following basic features which are deemed necessary for proper functioning and safety of operation:

1. Enclosure to guard against the entrance of moisture, dust and foreign objects into the generator. An open dripproof enclosure shall be the basic enclosure for a generator driven by a steam turbine.
2. Frame which rigidly supports the machine to provide low vibration and long life.
3. Stator composed of a support structure and a core made up of electrical steel lamination and insulated windings (coils). The stator shall be set into the frame in a way which will permit the circulation of cooling air around the core. The insulation system shall maintain its insulating properties at the maximum operating rated temperatures as specified in 2.12.1.2 (Temperature Rise).
4. Rotor consisting of the shaft, field poles, field windings, and one or more fans to circulate cooling air. The rotating element of the exciter shall be mounted on the rotor shaft. The coupling, if integral with the shaft, is also part of the rotor. The insulation system shall maintain its insulating properties at the maximum operating rated temperature as specified in 2.12.1.2 (Temperature Rise).
5. Bearings to support the rotor.
6. Provisions for lubrication.
7. Power terminals.
8. Excitation system for synchronous generators only. The basic excitation system shall be the brushless type with a rotating armature generating a 3 phase ac voltage with full wave rectification to dc for field excitation.

2.3.2 Optional Features and Accessories

2.3.2.1 STEAM TURBINE OPTIONS

In addition to the features listed in par. 2.3.1.1, the following are optional features and accessories which may be selected depending on the application.

1. Control systems with option for pressure control or load sharing.
2. Hand valve(s) for single valve turbines.
3. Combined trip and throttle valve which incorporates into one assembly a means for gradual opening and adjustment of inlet steam flow as well as a means for rapid and complete shutoff of that flow.
4. Solenoid trip which allows an electrical protective device(s) to act through a hydraulic, pneumatic, or mechanical tripping system to shut off steam flow into the turbine.

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5. Trip system which can be tested during operation.
6. Trip or alarm initiating devices which respond to abnormal conditions such as:
   a. low oil pressure
   b. high bearing temperature
   c. high vibration
   d. high axial shaft movement
   e. high steam pressure
   f. high steam temperature
   g. high oil temperature
   h. high or low oil reservoir level
   i. speed pickup failure
   j. governor failure
   k. loss of exhaust vacuum
   l. high exhaust temperature
7. Oil sight flow indicator(s) in drain piping of pressure lubricated systems.
8. Constant level oilers for non-pressure oil lubricated systems.
9. Insulation for the high temperature section of the turbine to limit exposed surface temperature to 165°F (74°C) or other temperature specified by the purchaser.
10. Steam pressure gauges to indicate inlet steam, steam ring, first stage, and exhaust steam pressure.
11. Gland leakage evacuating apparatus when the gland casing design requires its use.
12. Tachometer of the vibrating reed, mechanical, or electrical type; indicating speeds from above the trip speed to below the minimum operating speed. Tachometers shall be suitable for the specified environment.
13. Supervisory instruments to monitor such as vibration, axial shaft movement, temperatures, etc.
14. Shaft grounding device to carry to ground any static charge which might be developed on the turbine rotor and which may otherwise build to levels which could damage turbine bearings.
15. Rotor turning gear together with driving means, engagement and disengagement features, and lube oil pressure interlocks to permit slow turning of the rotor system on start-up and shutdown.
16. Admission trip valve which provides a means for quick and positive shutoff of admission steam for emergency tripping.
17. Nonreturn valve(s) for blocking the reverse flow of steam from process into the turbine through exhaust or extraction openings.
18. Redundant overspeed trip.
19. Exhaust relief valve or rupture disc to prevent overpressuring of the exhaust end section (see Section 8.7).
20. Vacuum breaker to admit air into the exhaust of a condensing turbine in order to reduce coastdown time.

Additional items may be available.

Authorized Engineering Information 1-30-1991.

2.3.2.2 GEAR OPTIONS

The following are accessories which may be selected, depending on rating and application:

1. Bearing temperature indicators.
2. Vibration monitoring devices.

Additional items may be available.

Authorized Engineering Information 1-30-1991.

2.3.2.3 GENERATOR OPTIONS

The following are accessories which may be selected, depending on ratings, voltage, and applications:

1. Enclosure other than drip-proof type where necessitated by environmental conditions.
2. Stator temperature indicators.
3. Bearing temperature indicators.
4. Vibration monitoring devices.
5. Space heaters
6. Terminal box.
7. Surge suppressors/capacitors.
8. Lightning arresters.
9. Current transformer(s)
10. Potential transformer(s)
11. Circuit breaker trip or alarm in response to any of the following functions:
    a. high stator temperature
    b. over/under voltage
    c. over/under frequency
    d. reverse power
    e. differential protection
    f. high coolant temperature (air or water)
    g. ground fault
    h. open phase/phase balance
    i. loss of excitation
    j. turbine trips
12. Other accessories are available.

2.3.3 Controlled Extraction and Controlled Induction Turbines

Controlled extraction, controlled induction, and controlled induction extraction turbines shall include basic features listed in items 1 through 6 of par. 2.3.1.1, together with those listed in 2.3.3.1 through 2.3.3.4.

2.3.3.1 Controlled extraction turbines shall have a pressure regulating system for controlling the pressure of the extracted steam by regulating the flow of steam to the turbine stages following the extraction opening(s). A nonreturn valve for the extraction opening(s), which is also

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actuated by the overspeed trip system, is required for installation in the extraction steam line(s).

2.3.3.2 Controlled induction turbines shall have a pressure regulating system for controlling the pressure of the induction steam to regulate the flow of steam to the turbine stages following the induction opening. A trip valve which is also actuated by the overspeed trip system is required for installation in the induction steam line.

NEMA Standard 1-30-91.

2.3.3.3 Depending on the source of induction steam, the user should consider the need for a steam strainer in this line to protect the lower pressure stages of the turbine.

Authorized Engineering Information 11-14-1985.

2.3.3.4 Controlled extraction turbines and controlled induction turbines shall have a multivariable control system which provides interconnection between the pressure regulating system and the speed governing system.

2.3.3.5 Controlled induction extraction turbines shall include the combination of the foregoing items.

NEMA Standard 11-14-1985.

2.3.4 Noncontrolled Extraction Turbines

Noncontrolled extraction turbines shall include the basic features listed in items 1 through 6 of par. 2.3.1.1, together with nonreturn valve(s) for the extraction opening(s). The quantity and location of nonreturn valves are to be determined by the turbine manufacturer based on entrapped energy and redundancy policy.

NEMA Standard 6-21-1979.

2.3.5 Noncontrolled Induction Turbines

Noncontrolled induction turbines shall include the basic features listed in items 1 through 6 of 2.3.1.1, together with a trip valve(s) for the induction opening(s).

NEMA Standard 11-14-1985.

2.4 TURBINE GENERATOR RATING

2.4.1 Power

The basis of rating of the turbine generator set shall be the power output in kilowatts at the generator terminals when operating at the steam conditions, voltage, and power factor specified by the purchaser.

The rating of the generator shall be the real output power in kilowatts measured at the output terminals when the generator is operating at the design power factor, voltage, and frequency under design environmental conditions. The rating shall include the excitation power requirements. The power absorbed by a separate excitation system, when supplied, shall be deducted from the real output power at the generator terminals.

NEMA Standard 6-12-1985.

The rating may also be the apparent output power in kilovolt-amperes measured at the output terminals at design operating conditions.

Authorized Engineering Information 6-12-1985.

2.4.2 Frequency and Speed

Frequency of power generated shall be 50 or 60 Hz. Other frequencies are available for special applications. Generators will employ one or more pairs of rotating field "poles" to produce the desired frequency of ac power output.

2.4.2.1 RATED SPEED, GENERATOR

Rated speed of a synchronous generator is related to power output frequency by the equation:

$$N = \frac{120F}{P}$$

where F = frequency in Hertz
N = synchronous speed in rpm
P = numbers of poles

Rated speed of an induction generators will be 1-2 percent above synchronous speed, as a positive "slip" is necessary in order to convert mechanical input to electrical output.

2.4.2.1.1 Overspeed Limitations

Generators shall be so constructed that, in an emergency, they will withstand without mechanical injury overspeeds above synchronous speed in accordance with the following:

Synchronous Speed, RPM	Overspeed, Percent of Synchronous Speed
1801 and over	20
1800 and below	25

NEMA Standard 6-12-1985.

2.4.2.2 RATED SPEED, TURBINE

Rated turbine speed will be the same as rated generator speed if directly coupled without a gear. On geared turbine generators the rated turbine speed will exceed the generator speed and will equal the product of rated generator speed and gear ratio.

2.4.3 Voltage

The generator voltage shall be specified by the user.

NEMA Standard 1-30-1991.

Typical voltages are as shown in Table 2-1.

2.4.3.1 VARIATIONS FROM RATED VOLTAGE, SYNCHRONOUS GENERATORS

Synchronous generators shall operate successfully at rated kVA, frequency and power factor at any voltage not

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Table 2-1
TYPICAL VOLTAGES FOR TURBINE DRIVEN GENERATORS

60 Hz Voltage		120	240	208	480	2400	4160	4150Y/2400	7200	12000	12470	13800
50 Hz Voltage		120	240	-	400	1900	3300	3300Y/1900	6600	11000	-	13200
PHASES		1	1	3	3	3	3	3	3	3	3	3
KW Rating	KVA Rating											
100	125	X	X	X	X							
500	625			X	X	X	X	X				
1000	1250				X	X	X	X				
1500	1875				X	X	X	X	X	X	X	X
2000	2500				X	X	X	X	X	X	X	X
2500	3125					X	X	X	X	X	X	X
3000	3750					X	X	X	X	X	X	X
4000	5000					X	X	X	X	X	X	X
5000	6250					X	X	X	X	X	X	X
6000	7500					X	X	X	X	X	X	X
7500	9375						X		X	X	X	X
10000	12500						X		X	X	X	X
12500	15625						X		X	X	X	X
15000	18750								X	X	X	X
20000	25000								X	X	X	X
30000	37500									X	X	X
33000	41250									X	X	X

NOTE: Other voltages such as 600 V and 6900 V may be available at the ratings shown for 480 V and 7200 V respectively.
Authorized Engineering Information 6-12-1985.

more than 5 percent above or below rated voltage but not necessarily in accordance with the standards or performance established for operation at normal rating.
NEMA Standard 1-30-1991.

2.4.3.2 VARIATIONS FOR RATED VOLTAGE AND FREQUENCY, INDUCTION GENERATORS

Induction generators shall operate successfully under running conditions at rated load with a variation in the voltage or the frequency up to the following:

1. Plus or minus 10 percent of rated voltage, with rated frequency.
2. Plus or minus 5 percent of rated frequency, with rated voltage.
3. A combined variation in voltage and frequency of plus or minus 10 percent (sum of absolute values) of the rated values, provided the frequency variation does not exceed plus or minus 5 percent of rated frequency.

NEMA Standard 1-30-1991.

Performance within these voltage and frequency variations will not necessarily be in accordance with the standards established for operation at rated voltage and frequency.
Authorized Engineering Information 1-30-1991.

2.4.3.3 MAXIMUM DEVIATION FACTOR

The deviation factor of the open circuit line-to-line terminal voltage of generators shall not exceed 0.1.
NEMA Standard 1-30-1991.

2.4.4 Steam Conditions

2.4.4.1 MINIMUM STEAM CONDITIONS

Minimum steam conditions are the lowest inlet steam pressure and temperature and lowest exhaust pressure to which the turbine is subjected in continuous operation.
NEMA Standard 6-21-1979.

2.4.4.2 MAXIMUM STEAM CONDITIONS

Maximum steam conditions are the highest inlet steam pressure and temperature and exhaust pressure to which the turbine is subjected in continuous operation.
NEMA Standard 6-21-1979.

2.4.4.3 MINIMUM ENERGY STEAM CONDITIONS

Minimum energy steam conditions are the lowest inlet steam pressure and temperature and the highest exhaust pressure at which the turbine is required to produce a specified power and speed.

2.4.4.4 NORMAL STEAM CONDITIONS

Normal steam conditions are the pressures and temperatures to which the turbine is subjected during specified normal operation.

The steam conditions used for rating the turbine generator set shall be the normal steam conditions unless otherwise specified by the user (purchaser).

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2.4.4.5 INLET STEAM PRESSURE

Inlet steam pressure is the pressure of the steam supplied to the turbine. It is measured at the steam inlet connection of the turbine and is expressed as a gauge pressure.

NEMA Standard 6-21-1979.

2.4.4.6 EXHAUST STEAM PRESSURE

Exhaust steam pressure is the pressure of the steam system to which the turbine exhausts. It is measured at the exhaust connection of the turbine and is expressed as a gauge pressure for noncondensing turbines and as an absolute pressure for condensing turbines.

NEMA Standard 6-21-1979.

2.4.4.7 EXTRACTION STEAM PRESSURE

Extraction steam pressure is the pressure of the steam extracted from the turbine. It is measured at the extraction connection of the turbine, and is expressed as a gauge pressure.

NEMA Standard 6-21-1979.

2.4.4.8 INDUCTION STEAM PRESSURE

Induction steam pressure is the pressure of the secondary steam supplied to the turbine. It is measured at the induction connection of the turbine and is expressed as a gauge pressure.

NEMA Standard 6-21-1979.

2.4.4.9 INLET STEAM TEMPERATURE

Inlet steam temperature is the total temperature of the steam supplied to the turbine. It is measured at the steam inlet connection of the turbine and is expressed in degrees Fahrenheit or in degrees Celsius.

NEMA Standard 6-21-1979.

2.4.4.10 EXHAUST STEAM TEMPERATURE

Exhaust steam temperature is the total temperature of the steam exhausted from the turbine. It is measured at the exhaust connection of the turbine and is expressed in degrees Fahrenheit or in degrees Celsius.

NEMA Standard 6-21-1979.

2.4.4.11 EXTRACTION STEAM TEMPERATURE

Extraction steam temperature is the total temperature of the steam extracted from the turbine. It is measured at the extraction connection of the turbine and is expressed in degrees Fahrenheit or in degrees Celsius.

NEMA Standard 6-21-1979.

2.4.4.12 INDUCTION STEAM TEMPERATURE

Induction steam temperature is the total temperature of the secondary steam supplied to the turbine. It is measured at the induction connection of the turbine and is expressed in degrees Fahrenheit or in degrees Celsius.

NEMA Standard 6-21-1979.

2.4.4.13 MAXIMUM ALLOWABLE WORKING PRESSURES AND TEMPERATURES

Maximum allowable working pressures and temperatures are the maximum continuous conditions for which the manufacturer has designed* the equipment or any part thereof.

They are not normally to be considered as operating conditions.

NEMA Standard 1-30-1991.

2.4.4.14 DUAL STEAM CONDITIONS

Dual steam conditions are two or more combinations of inlet steam pressure, inlet steam temperature, or exhaust steam pressure.

NEMA Standard 6-21-1979.

2.4.4.15 VARIATIONS IN STEAM CONDITIONS

The rating, capability, steam flow, speed regulation, and pressure control shall be based on operation at maximum steam conditions as defined in 2.4.4.2.

Steam turbines shall be capable of operating under the following variations in inlet pressure and temperature, but performance shall not necessarily be in accordance with the standards established for operating at maximum steam conditions. Continuous operation at other than maximum steam conditions shall require review by the turbine manufacturer.

NEMA Standard 6-21-1979.

2.4.4.15.1 Variations from Maximum Inlet Steam Pressure

The turbine shall be capable of operating without damage at less than the guaranteed steam flow to the turbine with average inlet pressure of 105 percent of maximum inlet steam pressure. (This permissible variation recognizes the increase in pressure with decrease in steam flow encountered in operation.)

The inlet steam pressure shall average not more than maximum pressure over any 12 month operating period.

The inlet steam pressure shall not exceed 110 percent of maximum pressure in maintaining these averages, except during abnormal conditions.

During abnormal conditions, the steam pressure at the turbine inlet connection shall be permitted to exceed maximum pressure briefly by as much as 20 percent, but the aggregate duration of such swings beyond 105 percent of

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* The use of the word "design" in any term (such as design pressures or temperature) should be avoided in the purchasers' specifications. Such terminology should be used exclusively by the equipment designer and/or manufacturer.

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maximum pressure shall not exceed 12 hours per 12 month operating period.

NEMA Standard 6-21-1979.

2.4.4.15.2 Variations from Maximum Inlet Steam Temperature

The inlet steam temperature shall average not more than maximum temperature over any 12 month operating period.

In maintaining this average, the temperature shall not exceed maximum temperature by more than 15°F (8°C) except during abnormal conditions. During abnormal conditions, the temperature shall not exceed maximum temperature by more than 25°F (14°C) for operating periods of not more than 400 hours per 12 month operating period nor by more than 50°F (28°C) for swings of 15 minutes duration or less, aggregating not more than 80 hours per 12 month operating period.

NEMA Standard 6-21-1979.

2.4.4.15.3 Variations from Maximum Exhaust Steam Pressure on Noncondensing Turbines

The exhaust steam pressure shall average not more than the maximum exhaust steam pressure over any 12 month operating period.

In maintaining this average, the exhaust steam pressure shall not exceed maximum pressure by more than 10 percent nor drop more than 20 percent below maximum exhaust pressure.

NEMA Standard 6-21-1979.

2.4.4.15.4 Variations in Exhaust Steam Pressure on Condensing Turbines

Any anticipated variations in the exhaust steam pressure should be specified by the user so that it can be taken into consideration in the design of the turbine.

Authorized Engineering Information 6-21-1979.

2.4.4.16 Flow Limits for an Automatic Extraction Turbine

An automatic extraction turbine may be designed so that, when operating with extraction flow and with only cooling steam flowing to the exhaust, it will develop the rated power of the turbine.

Good design practice indicates that the maximum extraction flow ratio should be held to 2.5 or less. (The extraction flow ratio is the ratio of the total extraction flow to the nonextracted rated load flow.)

Authorized Engineering Information 11-13-1969.

2.4.4.17 Flow Limits for an Induction Turbine

An induction turbine may be designed for a steam flow through the low pressure stages equal to the flow of low pressure steam alone that is required to produce the rated power of the turbine.

Authorized Engineering Information 11-13-1969.

2.4.5 Units of Measurement for Absolute Pressure and Gauge Pressure

Steam pressure values should be clearly stated as gauge pressure or absolute pressure. Gauge pressure equals absolute pressure less atmospheric pressure. Gauge pressure is measured in psig (pounds per square inch gauge) or in kPa (gauge) (kilopascals gauge). Absolute pressure is measured in psia (pounds per square inch absolute) or in kPa (absolute) (kilopascals absolute). Unless otherwise stated, atmospheric pressure is assumed to equal 14.696 psi or 101.325 kPa. To convert from psi to kPa, multiply by 6.894757.

2.5 THERMODYNAMIC TERMS

2.5.1 Steam and Heat Rates

2.5.1.1 Theoretical Steam Rate*

Theoretical steam rate is the quantity of steam per unit of power required by an ideal Rankine cycle heat engine. It is expressed in pounds of steam per kilowatt hour or in kilograms of steam per kilowatt hour.

$$\text{Theoretical steam rate in pounds/KWH} = \frac{3413}{h_1 - h_2}$$

$$\text{Theoretical steam rate in Kg/KWH} = \frac{3600}{h_1 - h_2}$$

with h in kilojoule per kilogram

Based on Keenan, Keyes et. al. Steam Tables (International Edition - Metric Units) or other steam tables or Mollier charts, which are in accordance with the International Skeleton Tables of 1963 of the International Conference on the Properties of Steam that are expressed in joules per gram or kilojoules per kilogram, or based on Keenan and Keyes Steam Tables published in 1969 expressed in Btu per pound, where:

h_1 - the enthalpy of steam at inlet steam pressure and temperature.

h_2 -the enthalpy of steam at exhaust steam pressure and initial entropy.

NEMA Standard 6-21-1979.

2.5.1.2 Actual Steam Rates*

Actual steam rate is the quantity of inlet steam required by the turbine generator per unit of power output measured

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* Steam rate does not apply to extraction or induction turbine generators.

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at the generator terminals. It is expressed in pounds of steam per kilowatt hour (or in kilograms of steam per kilowatt hour).

2.5.1.3 GUARANTEED STEAM RATE*

The turbine generator set guaranteed steam rate is the rate which will not be exceeded when the turbine generator set is operated at normal power, speed, and steam conditions. The steam rate shall be stated in pounds per kilowatt hour based on kilowatt output measured at the generator terminals. For separate exciters, the exciter losses shall be deducted from the output kilowatts.

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2.5.1.4 HEAT RATE

Heat rate is the heat supplied in BTU/hr minus heat returned in BTU/hr divided by output in kilowatts. Guaranteed heat rate will not be exceeded when the turbine generator set is operating at normal power, speed, and steam conditions. Heat rate for units with separate exciters shall be based upon generator terminal kilowatts minus exciter losses.

2.6 TURBINE CONNECTIONS

2.6.1 Output Shaft Extensions

2.6.1.1 Output shaft extensions shall be suitable for a cylindrical coupling bore and provided with a keyway(s), tapered coupling bore with a keyway(s), tapered for a hydraulic fit, or fitted with an integral coupling hub.

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2.6.1.2 When a tapered shaft extension with keyway(s) is specified, the taper, coupling hub, and coupling nut shall be in accordance with Figure 2-1. NEMA taper diameters are available for shaft extensions from 2 to 5 inches.

NEMA Standard 11-14-1985.

2.6.1.3 If cylindrical shaft extension is specified, it is recommended that the coupling-to-shaft fit be an interference fit.

2.6.1.4 When a hydraulic fit coupling is specified, the mounting method should be reviewed with the turbine manufacturer.

2.6.1.5 Recommended use of one and two keys and keyways is as shown in Table 2-2.

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2.6.1.6 COUPLINGS

For direct-connected turbine generator sets, a coupling shall be supplied between the turbine and the generator.

For geared turbine generators sets, a coupling shall be supplied between the turbine and the gear input shaft, and between the gear output shaft and the generator.

Table 2-2
RECOMMENDED KEY FITS

Nominal Shaft Diameter(ib)		Maximum Speed for One Key
Inches	Millimeters	ppm
up to & including 1.50	40	16,000
2	50	14,000
2.50	65	12,500
3	75	11,500
3.50	90	10,500
4	100	10,500
4.50	115	9,500
5	125	9,000
5.50	140	8,500
6	150	8,500
6.50	165	7,500
7	180	7,500
7.50	190	7,000
8	200	7,000
9	230	6,500
10	250	5,000

Two keys may be used in any case.

Flexible type couplings shall accommodate the maximum possible relative axial movement of the connected shafts without exceeding the thrust bearing capacities of the connected machines.

A limited-end-float flexible coupling shall be used to transmit power to a generator which has sleeve bearings. When the generator is energized, its rotor shall be free to position itself at the magnetic center of the generator. When the generator is not energized, the coupling shall limit relative axial motion between the generator rotor and the shaft of the machine which drives the generator.

Flexible coupling parts shall be machined to a tolerance of not more than 0.001 inch (0.025 mm) on the diameter and the face-to-face. The bore shall be concentric within 0.001 inch (0.025 mm) with the surface used for dial indicating. Where required by coupling size and speed, coupling parts, including bolts, shall be matchmarked and each hub shall be dynamically balanced. The assembled coupling shall be balanced to a tolerance which will permit satisfactory performance at speeds up to 110 percent of maximum continuous speed of the turbine and without damage at 110 percent of the tripping speed.

Non-flexible type couplings shall be installed in accordance with the manufacturer's instructions.

Couplings shall be mounted on the shaft with either a taper or a cylindrical fit.

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A	B	C	D	E	F	G	H	J	K	L	M	N	P	R	S	T	V	Keyway AA	Keyway AB	Keyway AC	Keyway AD	Keyway AE	Keyway AF	Key	Key AH	Key AK	Key AL	Key AM
Shaft Diameter +0.0000, −0.0005	Taper Diameter +0.0000, −0.0005	Coupling Bore +0.0000, −0.0005	Coupling Taper Bore +0.0000, −0.0005	Coupling Bore Length			+0.0, −1/64								+1/64, −0.0		+0.005, −0.000	+0.000, +0.002	+0.000, −0.002		+0.005, −0.000			Number	±0.001	+1/64, −0.0		
2.0000	1.8770	1.9965	1.8676	2 1/16	3/8	1/4	2 3/4	2 1/4	1 5/8	9/32	2 3/16	1/16	1 31/32	1/2	2 15/16	1 1/4–12	1.193	0.500	0.496	1 31/32	0.312	1/16	1/16	1	0.500	1 31/32	1/4–20	2 1/2
2.5000	2.3438	2.4965	2.3344	2 19/32	1/16	1/4	3 1/2	2 1/4	2	9/32	3 1/32	3/32	2 1/2	9/16	3 9/16	1 1/2–12	1.489	0.625	0.621	2 1/2	0.391	1/16	1/16	1	0.625	2 1/2	1/4–20	3 1/16
3.0000	2.8125	2.9965	2.8031	3 3/32	1/2	1/4	4 1/4	3 1/2	2 1/2	11/32	3 19/32	3/32	3	5/8	4 5/16	2–12	1.786	0.752	0.746	3	0.469	1/8	1/16	1	0.750	3	1/2–13	3 3/4
3.5000	3.2793	3.4965	3.2699	3 5/8	9/16	3/8	4 7/8	3 1/2	2 7/8	11/32	4 3/16	1/8	3 11/32	11/16	4 13/16	2 1/4–12	2.083	0.877	0.871	3 11/32	0.547	1/8	1/16	1	0.875	3 11/32	1/2–13	4 3/8
4.0000	3.7480	3.9965	3.7387	4 1/8	5/8	3/8	6 1/4	4	3 1/4	13/32	4 3/4	1/8	4 1/32	3/4	6 5/16	2 1/2–12	2.380	1.002	0.996	4 1/32	0.625	1/8	1/16	1	1.000	4 1/32	3/4–10	5 1/2
4.5000	4.2168	4.4965	4.2074	4 5/8	11/16	1/2	6 3/4	4	3 5/8	13/32	5 5/16	1/32	4 17/32	13/16	6 13/16	2 3/4–12	2.614	1.002	0.996	4 17/32	0.641	1/8	1/16	1	1.000	4 17/32	3/4–10	6
5.0000	4.6758	4.9965	4.6664	5 5/32	3/4	1/2	7 1/4	4	4	13/32	6 1/32	5/32	5 5/16	7/8	7 5/16	3–12	2.968	1.252	1.246	5 5/16	0.787	1/8	3/32	1	1.250	5 5/16	3/4–10	6 1/2

All dimensions in inches.

NOTE I All diametric tapers are 0.75 inch/foot.

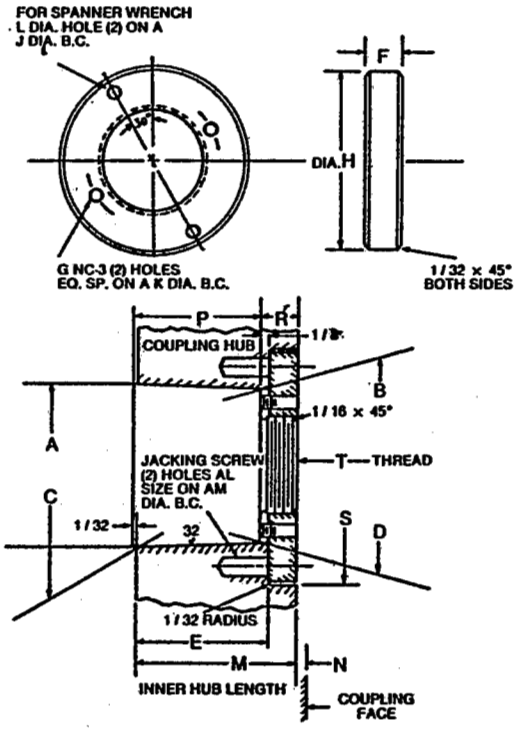
NOTE II Minimum of one key is required.

NOTE III When two keys are used, they shall be located 180 degrees apart.

NOTE IV Three jacking screws are suggested with two keys.*

NOTE V Key to be fitted to shaft and coupling hub at assembly: Fit in shaft to be 0.000 to 0.0015 tight. Corners shall be chamfered to suit.

*Note IV has been approved as Authorized Engineering Information.



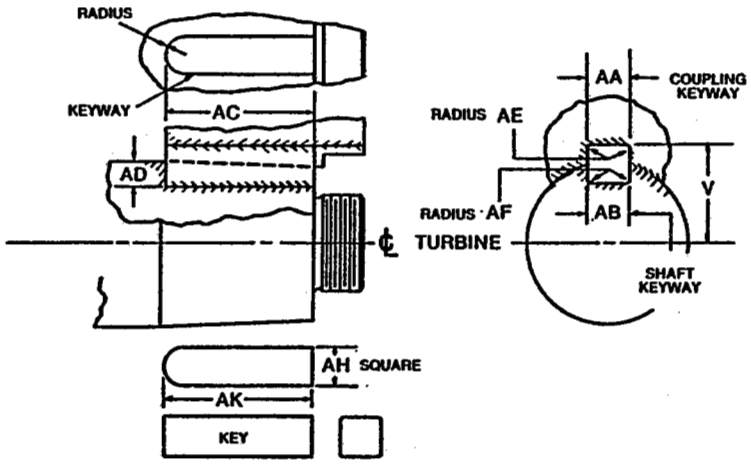


Figure 2-1
OUTPUT SHAFT EXTENSIONS

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2.6.1.7 COUPLING GUARDS

An easily removable coupling guard shall be placed over all exposed couplings. The coupling guard shall be of sufficiently rigid design to withstand deflection and consequent rubbing as a result of bodily contact and shall extend to within 1/2 inch (12.7 mm) of a stationary housing.

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2.6.2 Steam Connections

Turbine flanged steam connections shall be faced and drilled for bolting to flanges which are in accordance with ANSI/ASME B16.1 or B16.5.

Cast iron flange connections shall be flat faced.

The thickness of cast iron exhaust flanged connections under 10 inches (250 mm) in diameter shall be not less than Class 250 of ANSI/ASME B16.1.

Single valve single stage horizontally split casing turbines shall have steam connections in the lower half of the turbine.

Threaded connections for making up to pipe not over 2 inches in diameter (50 mm nominal diameter) shall have internal taper threads conforming to ANSI/ASME B1.20.1.

NEMA Standard 11-14-1985.

2.6.3 Auxiliary Connections

Auxiliary connections that are threaded shall conform to ANSI/ASME Standard B1.20.1. Typically, these are nozzle ring pressure gauge connection, drain connections for casing and steam chest, casing sealing glands and bearing housings, cooling water, valve stem leakoffs, and so forth.

NEMA Standard 11-14-1985.

2.7 LUBRICATION

2.7.1 Nonpressure-Type Lubrication

2.7.1.1 OIL LUBRICATED SLEEVE BEARINGS (HORIZONTAL ROTORS)

a. Lubrication should be provided by oil rings or similar means.
b. Bearing housings should be large enough to permit solids or water to settle to the bottom and should have a drain connection at the lowest point, oil fill fittings, and an oil level indicator.
c. Facilities for cooling should be provided when necessary to assure the proper oil temperature. The cooling water should be supplied at a temperature not exceeding 90°F(32°C).

2.7.1.2 GREASE OR OIL LUBRICATED ANTIFRICTION BEARINGS

a. Grease lubricated antifriction bearings should be regreaseable in the field. Grease fittings should extend to the outside of the machine to permit regreasing during operation.
b. Means should be provided for venting grease- lubricated bearings to prevent the buildup of pressure within the housing.
c. Facilities for cooling should be provided when necessary to assure the proper lubricant temperature. The cooling water should be supplied at a temperature not exceeding 90°F (32°C).

2.7.2 Pressure-Type Lubrication

2.7.2.1 INTRODUCTION

It is recognized that there is a wide variation in turbine sizes and applications which makes it impractical to have one recommended lubrication system design. However, the following should serve as a general design guide to the user for specifying his requirements.

2.7.2.2 OIL PUMPS

2.7.2.2.1 A main oil pump driven from the turbine shaft or gear shaft, or a separately driven pump to provide oil for lubrication and governing should be provided.

2.7.2.2.2 An auxiliary oil pump for use during the start-up or shut-down period should be furnished when required by the design or when specified. This pump should be powered by a different source of energy than the main oil pump. A pressure sensing device should be provided for automatically starting the auxiliary oil pump when the oil pressure in the main system drops below a predetermined value.

For a turbine driven auxiliary oil pump, the turbine should conform to all of the applicable provisions of these standards.

2.7.2.3 OIL RESERVOIR

A separate oil reservoir should have:

a. Sufficient capacity to provide for the defoaming and settling of foreign material and for the contents of the system when drained.
b. Interiors cleaned.
c. Fill connection, level indicator, and breather suitable for outdoor use.
d. Sloped bottom and connection for complete drainage when the design permits.
e. Clean-out opening large enough to permit inspection and cleaning.

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f. Reservoir and fittings applicable for the intended ambient conditions.

2.7.2.4 OIL COOLER(S)

The oil cooler should be capable of maintaining the temperature of the oil supplied to the bearings at a maximum of 120°F (49°C), with a maximum cooling water temperature not exceeding 90°F (32°C). It should have a fouling factor on the water side of 0.001 for cooling tower water and a fouling factor as recommended by the manufacturer for other cooling water sources. The cooler should be suitable for a working pressure of not less than 75 psig [517 kPa(gauge)] on the water side.

Single or twin coolers may be used. Each cooler should be capable of operation at a pressure equal to or greater than the relief valve setting of positive displacement oil pumps or of the maximum shutoff discharge pressure of centrifugal oil pumps. Twin coolers should be piped in parallel with a continuous flow transfer valve to permit the transfer of oil from one cooler to the other without interrupting the oil flow. Each cooler should be sized for the total cooling load, and should be arranged and vented for maintaining either cooler with the turbine in operation.

2.7.2.5 OIL FILTER(S)

Single or twin oil filters may be used. A filter(s) should be capable of removing particles larger than 25 microns. When the filter is clean, the pressure drop should not exceed 5 psi (35 kPa) at design temperature and flow. Twin filters should be piped in parallel with a continuous flow transfer valve to permit the transfer of oil from one filter to the other without interrupting the oil flow. Each filter should be sized for the total oil flow and should be arranged and vented for maintaining either filter with the turbine in operation. A common transfer valve may be used for the oil filters and coolers. The filter cartridge should be corrosion resistant. Filter cases should be suitable for operation at a pressure not less than the relief valve setting of the positive displacement oil pumps or at the maximum shut off discharge pressure of centrifugal oil pumps.

2.7.2.6 PIPING AND INSTRUMENTATION

2.7.2.6.1 Pressure sensitive devices with isolation valves should be provided for each pressure level (for example, oil header to bearings, discharge from oil pumps, before and after filter(s) and control oil).

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2.7.2.6.2 If bearing metal thermocouples or RTDs are not provided, then thermometers should be provided for oil outlet from each bearing housing. Thermometers may be provided before and after oil cooler(s). Thermowells should be provided in the piping for the purpose of thermometer replacement while on line. Thermometers should be gas filled or corrosion-resistant bimetallic type.

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2.7.2.6.3 An oil sight flow indicator when specified should be provided in the oil return from each bearing housing where the design permits.

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2.7.2.6.4 A pressure regulator or relief valve should be provided to maintain the oil pressure level(s).

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2.7.2.6.5 After fabrication, piping should be cleaned and passivated by mechanical and/or chemical means.

Authorized Engineering Information 6-21-1979.

2.7.3 Combination of Systems

A turbine generator set may combine a turbine, reduction gear, and generator using any combination of the lubrication systems described in 2.7.1 and 2.7.2.

Authorized Engineering Information 1-30-1991.

2.8 PROVISIONS FOR THE ENVIRONMENT

2.8.1 Enclosure

Steam turbine generator sets should preferably be installed in enclosed areas. The effects of unusual service conditions may be mitigated by the use of one or more of the measures described in 2.8.2 and 2.8.3.

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2.8.2 Exposure to Natural Elements

In general, all exposed surfaces should be protected against rusting by a protective coating or paint after installation of the unit. Exposed working parts which affect operation of the unit such as governor, governor linkage, fulcrum points, valve stems, and similar elements should be protected against rusting by the use of corrosion-resistant materials.

Generators should incorporate weatherproof construction or a weatherproof enclosure and space heater(s). As an alternate a totally enclosed generator construction may be considered.

Equipment having nonpressure lubricated bearings should be designed to prevent the entrance of moisture, dust, and foreign materials to the governing system and bearing housings.

Equipment having pressure lubrication or hydraulic governing systems, or both, should be protected as follows:

2.8.2.1 The lubrication system or governor system, or both, should be protected against the entrance of water or foreign materials by proper sealing devices. The points to be protected include all connections or openings to the oil reservoir, governor, servomotor, bearing housings, and

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similar elements. The reservoir should be provided with a vent with an air filter and connections to facilitate removal of water.

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2.8.2.2 In addition to the foregoing protective measures, the following should be included when ambient temperatures will be less than 40°F (4°C):

1. For use during down times, drains should be provided where water can collect for all steam, oil, and water lines, the turbine casing and steam chest, and the oil and water side of the oil cooler. Pneumatic "blow down" may be necessary in some instances.
2. A heater for the oil reservoir. If an electric heater is specified it must be of a sufficiently low watt density to prevent coking of the oil. An auxiliary pump may be required to ensure oil circulation for uniform heating.
3. An enclosure or hood with venting to cover the governing system may be provided, and heating should be supplied to prevent icing. The amount and type of enclosure and heating will be governed by local conditions.
4. Protection against freezing for instruments and small piping.
5. Turbine manufacturer should identify those lines that require freeze protection by purchaser.

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2.8.3 Exposure to Abnormal Atmospheric Conditions

If possible, the turbine generator set should be located away from damaging fumes and vapors, or abrasive, magnetic or metallic dust. If this is not practical, the atmospheric conditions should be called to the attention of the manufacturer. Suitable materials or protective coatings may be required to offset the corrosive effects of the fumes. When necessary, purge air connections on bearing housings, gland cases, and governors should be provided. For these conditions a totally enclosed generator is recommended.

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2.9 GENERAL MECHANICAL REQUIREMENTS

2.9.1 Pressure and Temperature Ranges

Steam turbines should be designed and proportioned for operation at maximum steam conditions. General pressure and temperature ranges are shown in Table 2-3. The ranges are general, according to temperature/pressure combinations at which point material or design changes, or both, may be required.

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2.9.2 Vibration

The vibration (double amplitude) of the rotating elements when operating within the specified operating speed range at no-load, as measured on the surface of the shaft adjacent to the radial bearings shall be in accordance with Figure 2-2.

Shaft mechanical and electrical runout shall be determined by slowly rolling the rotor in vee blocks or its bearings while measuring the runout with a proximity probe. If it can be demonstrated that mechanical and electrical runout is present, this shall be added to the allowable vibration level up to a maximum 25 percent of the allowed double amplitude vibration or 0.25 mils, whichever is greater.

NEMA Standard 1-30-1991.

Vibration of the installed turbine generator set may be adversely affected by many factors, such as piping loads, alignment at operating conditions, supporting structures, handling during shipment, handling and assembly at the site, and abnormal electrical conditions.

Authorized Engineering Information 1-30-1991.

2.9.3 Critical Speeds

The turbine generator set shall be designed so that its critical speeds, including the effect of couplings, shall not be detrimental to its satisfactory operation.

The calculated first critical speed of a stiff shaft turbine rotor shall be a minimum of 10 percent over the trip speed.

Torsional critical speed shall not occur within 10% of the operating speed of the turbine generator set.

The actual first critical speed of a flexible shaft turbine rotor shall be determined during the no-load running test when practical and shall be stamped on the nameplate followed by the word "test." Where it is impractical to determine critical speeds during the running test, the calculated critical speed shall be stamped on the nameplate followed by the abbreviation "approx."

The calculated first lateral critical speed of a flexible shaft rotor(s) shall be not more than 80 percent of the rated speed, and the calculated second lateral critical speed shall be a minimum of 10 percent over the trip speed.

NEMA Standard 6-21-1979.

2.9.4 Nameplate Data

2.9.4.1 TURBINE NAMEPLATE

The following minimum data shall be given on the turbine nameplate:

1. Manufacturer's name and location
2. Serial number (also stamped on the turbine casing).
3. Model/type
4. Rated kilowatts
5. Rated speed
6. Maximum inlet steam pressure
7. Maximum inlet steam temperature

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Table 2-3
GENERAL PRESSURE AND TEMPERATURE RANGES

Inlet Steam Pressure psig [kPa (gauge)]	Inlet Steam Temperature, °F (°C)						
	to 500 (1 to 200)	501 to 600 (201 - 315)	601 - 750 (316 - 399)	751 - 825 (400 - 450)	826 - 900 (451 - 482)	901 - 950 (483 - 510)	951 and above (511 and above)
Up to 250 [Up to 1724]							
251 to 600 [1725 to 4137]							
601 to 900 [4150 to 6201]							
901 to 1500 [6201 to 10 343]							
1501 and above [10 344 and above]							

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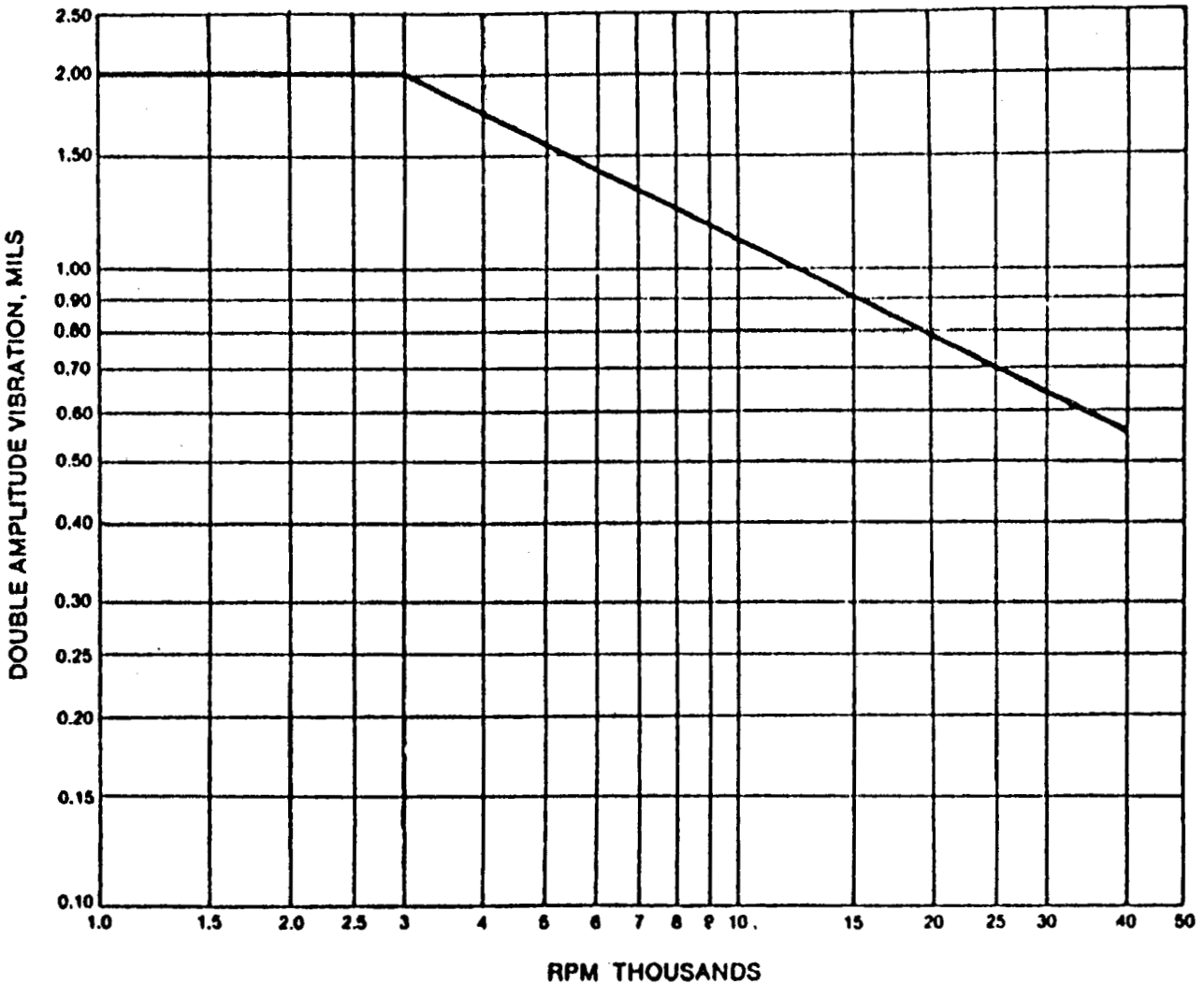


Figure 2-2
MAXIMUM PERMISSIBLE SHAFT VIBRATION

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8. Maximum exhaust steam pressure
9. Maximum extraction/induction pressure (if applicable)
10. Trip speed
11. First lateral critical speed
12. Purchaser's equipment item number (when specified).

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2.9.4.2 GEAR NAMEPLATE

The following minimum data shall be given on the gear nameplate:

1. Manufacturer's name and location
2. Serial number
3. Model/type
4. Rated power
5. Service factor
6. Input speed/output speed
7. Gear ratio

NEMA Standard 6-12-1985.

2.9.4.3 GENERATOR NAMEPLATE

The following minimum data shall be given on the generator nameplate:

1. Manufacturer's name and location
2. Serial number
3. Model/type
4. Kilovolt-ampere rating (synchronous only)
5. Kilowatt rating
6. Power factor
7. Time rating
8. Temperature rise for rated continuous load
9. Rated speed in RPM
10. Voltage
11. Rated current in amperes per terminal
12. Number of phases
13. Frequency
14. Rated field current (separate exciters)
15. Rated excitation voltage (separate exciters)

NEMA Standard 1-30-1991.

2.9.5 Short Circuit

The turbine, gear, generator, and couplings of a turbine generator set shall be capable of withstanding, without injury, a 30 second 3-phase short circuit at the generator terminals when operating at rated kVA and power factor, at 5 percent overvoltage, with fixed excitation. The turbine, gear, generator, and couplings shall be capable of withstanding, without injury, any other short circuit at the generator terminals of 30 seconds or less provided:

1. The generator phase currents under fault conditions are such that the negative phase sequence current, (I_2) expressed in per unit of stator current at rated kVA, and the duration of the fault in seconds, t, are limited to values which give an integrated product, $(I_2)^2t$, equal to or less than 40, and
2. The maximum phase current is limited by external means to a value which does not exceed the maximum phase current obtained from the 3-phase fault. Such external grounding devices are "system" components and not a basic turbine generator component.

NEMA Standard 6-12-1985.

2.10 GEAR CONSTRUCTION

2.10.1 Types

The reduction gears most commonly used in turbine generator sets are of the parallel shaft type. Other types of gears are available which may be used with turbine generator sets.

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2.10.2 Service Factor

The service factor for continuous duty shall be the minimum used in selecting the gear unit, per AGMA Standard 421.06.

NEMA Standard 6-12-1985.

2.11 TYPES OF GENERATORS

2.11.1 Classified by Rotor Construction

2.11.1.1 SALIENT POLE

This type of generator is constructed with projecting pole pieces (salient poles) on the rotor. Each pole piece is wound with conductors to form a magnetic pole when the rotor is energized by the exciter.

Salient pole construction is normally used for generators operated at speeds of 1800 RPM and below.

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2.11.1.2 NON-SALIENT POLE

This type of generator is constructed with a cylindrical rotor (non-salient poles) into which slots are machined. Electrical conductors are inserted into the slots to form the electrical path in the rotor.

Non-salient pole construction is normally used for generators operated above 1800 RPM.

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2.11.2 Classified by Excitation Means

2.11.2.1 SYNCHRONOUS

A synchronous generator is an AC machine driven at synchronous speed and with excitation energy separately supplied and controlled. It may be operated in parallel with or isolated from generation systems employing other generator(s) of the same design frequency.

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2.11.2.2 INDUCTION

An induction generator is an AC machine which is driven above synchronous speed to induce electric power (KW). Excitation is taken from the system to which the generator is connected and it is not self-excited.

NEMA Standard 6-12-1985.

2.11.3 Classified by Enclosure and Cooling Means

2.11.3.1 OPEN GENERATOR ENCLOSURES

An open generator is one having ventilating openings which permit passage of external cooling air over and around the windings of the generator. The term "open generator," when applied to large apparatus without qualification, designates a generator having no restriction to ventilation other than that necessitated by mechanical construction.

NEMA Standard 6-12-1985.

2.11.3.1.1 Dripproof

A dripproof generator is one in which the ventilating openings are so constructed that successful operation is not interfered with when drops of liquid or solid particles strike or enter the enclosure at any angle from 0 to 15 degrees downward from the vertical.

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2.11.3.1.2 Splashproof

A splashproof generator is one in which the ventilating openings are so constructed that successful operation is not interfered with when drops of liquid or solid particles strike or enter the enclosure at any angle not greater than 100 degrees downward from the vertical.

NEMA Standard 6-12-1985.

2.11.3.1.3 Semi-Guarded

A semi-guarded generator is one in which part of the ventilating openings in the machine, usually in the top half, are guarded as in the case of a "guarded machine" but the others are left open.

NEMA Standard 6-12-1985.

2.11.3.1.4 Guarded

A guarded generator is one in which all openings giving direct access to live metal or rotating parts (except smooth rotating surfaces) are limited in size by the structural parts or by screens, baffles, grilles, expanded metal, or other means to prevent accidental contact with hazardous parts.

NEMA Standard 6-12-1985.

2.11.3.1.5 Dripproof Guarded

A dripproof guarded generator is one whose ventilating openings are guarded in accordance with 2.11.3.1.1 and 2.11.3.1.4.

NEMA Standard 6-12-1985.

2.11.3.1.6 Open Pipe-Ventilated

An open pipe-ventilated generator is an open generator except that openings for the admission of the ventilating air are so arranged that inlet ducts or pipes can be connected to them. Open air-ventilated machines may be self-ventilated (air circulated by means integral with the machine) or force-ventilated (air circulated by means external to and not a part of the machine).

NEMA Standard 6-12-1985.

2.11.3.1.7 Weather-Protected

Type I—A weather protected Type I generator is an open generator with ventilating passages so constructed as to minimize the entrance of rain, snow, and air-borne particles to the electric parts and having its ventilated openings so constructed as to prevent the passage of a cylindrical rod 0.75 inch (19 mm) in diameter.

Type II—A weather protected Type II generator shall have, in addition to the enclosure defined for a weather protected Type I generator, ventilating passages at both intake and discharge so arranged that high-velocity air and air-borne particles blown into the generator by storms or high winds can be discharged without entering the internal ventilating passages leading directly to the electric parts of the generator itself. The normal path of the ventilating air which enters the electric parts of the generator shall be so arranged by baffling or separate housings as to provide at least three abrupt changes in direction, none of which shall be less then 90 degrees. In addition, an area of low velocity not exceeding 10 feet (3 meters) per second shall be provided in the intake air path to minimize the possibility of moisture or dirt being carried into the electrical parts of the generator.

NEMA Standard 6-12-1985.

2.11.3.2 TOTALLY-ENCLOSED

A totally-enclosed generator is one enclosed to prevent the free exchange of air between the inside and the outside of the case but not sufficiently enclosed to be termed air-tight.

NEMA Standard 6-12-1985.

2.11.3.2.1 Totally-Enclosed Nonventilated

A totally-enclosed nonventilated generator is a totally-enclosed generator which is not equipped for cooling by means external to the enclosing parts.

NEMA Standard 6-12-1985.

2.11.3.2.2 Totally-Enclosed Fan-Cooled

A totally-enclosed fan-cooled generator is a totally-enclosed generator equipped for exterior cooling by means of a fan or fans integral with the machine but external to the enclosing parts.

NEMA Standard 6-12-1985.

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2.11.3.2.3 Explosion-Proof

An explosion-proof generator is a totally-enclosed generator whose enclosure is designed and constructed to withstand an explosion of a specified gas or vapor which may occur within it and to prevent the ignition of the specified gas or vapor surrounding the machine by sparks, flashes, or explosions of the specified gas or vapor which may occur within the generator casing.

NEMA Standard 6-12-1985.

2.11.3.2.4 Dust Ignition-Proof

A dust ignition-proof generator is a totally-enclosed generator whose enclosure is designed and constructed in a manner which will exclude ignitable amounts of dust or amounts which might affect performance or rating, and which will not permit arcs, sparks, or heat otherwise generated or liberated inside of the enclosure to cause ignition of exterior accumulations or atmospheric suspensions of a specific dust on or in the vicinity of the enclosure.

NEMA Standard 6-12-1985.

2.11.3.2.5 Waterproof

A waterproof generator is a totally-enclosed generator so constructed that it will exclude water applied in the form of a stream from a hose, except that leakage may occur around the shaft provided it is prevented from entering the oil reservoir and provision is made for automatically draining the generator. The means for automatic draining may be a check valve or a tapped hole at the lowest part of the frame which will serve for application of a drain pipe.

NEMA Standard 6-12-1985.

2.11.3.2.6 Totally-Enclosed Pipe-Ventilated

A totally-enclosed pipe-ventilated generator is a generator with openings so arranged that when inlet and outlet ducts or pipes are connected to them there is no free exchange of the internal air and the air outside the case. Totally-enclosed pipe-ventilated generators shall be self-ventilated (air circulated by means integral with the generator) or force-ventilated (air circulated by means external to and not part of the generator).

NEMA Standard 6-12-1985.

2.11.3.2.7 Totally-Enclosed Water-Cooled

A totally-enclosed water-cooled generator is a totally enclosed generator which is cooled by circulating water, the water or water conductors coming in direct contact with the generator parts.

NEMA Standard 6-12-1985.

2.11.3.2.8 Totally-Enclosed Water-Air-Cooled

A totally-enclosed water-air-cooled generator is a totally-enclosed generator which is cooled by circulating air which, in turn, is cooled by circulating water. It is provided with a water-cooled heat exchanger for cooling the internal air and a fan or fans integral with the rotor shaft or separate, for circulating the internal air.

NEMA Standard 6-12-1985.

2.11.3.2.9 Totally-Enclosed Air-to-Air Cooled

A totally-enclosed air-to-air cooled generator is a totally-enclosed generator which is cooled by circulating the internal air through a heat exchanger which, in turn, is cooled by circulating external air. It is provided with an air-to-air heat exchanger for cooling the internal air and a fan or fans, integral with the rotor shaft or separate, for circulating the internal air and a separate fan for circulating the external air.

NEMA Standard 6-12-1985.

2.11.3.2.10 Totally-Enclosed, Fan-Cooled Guarded

A totally-enclosed, fan-cooled guarded generator is a totally-enclosed fan-cooled generator in which all openings giving direct access to the fan are limited in size by the design of the structural parts or by screens, grilles, expanded metal, and so forth, to prevent accidental contact with the fan.

NEMA Standard 6-12-1985.

2.11.3.2.11 Totally-Enclosed Air-Over

A totally-enclosed air-over generator is a totally-enclosed generator intended for exterior cooling by a ventilating means external to the generator.

NEMA Standard 6-12-1985.

2.12 GENERATOR COMPONENTS

2.12.1 Insulation System

An insulation system is an assembly of insulating materials in association with the conductors and the supporting structural parts of a generator. Insulation systems are divided into classes according to the thermal endurance of the system for temperature rating purposes.

2.12.1.1 CLASSES OF INSULATION

Four classes of insulation systems are used in generators, namely, Classes A, B, F and H. These classes have been established in accordance with IEEE Standard 1.

Authorized Engineering Information 6-12-1985.

2.12.1.2 TEMPERATURE RISE IN SERVICE

The observable temperature rise for each of the various parts of the machine above the temperature of the cooling air, referred to as the cold air temperature, shall not exceed the values given in Table 2-4 when the machine is operated at output rating conditions. The temperature rises in the Table are based on a maximum cold air temperature of 40°C.

When designing to meet the temperature rises in Table 2-4 it is intended that the hottest-spot temperature should

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Table 2-4
TEMPERATURE RISE

Item	Machine Part	Temperature Method of Determination	Temperature Rise (°C) Class A	Class B	Class F	Class H
Induction						
(1)	Armature Winding					
	(A) All kilowatt ratings	Resistance	60	80	105	125
	(B) 1119 kilowatt and less	Embedded detector*	70	90	115	140
	(C) Over 1119 kilowatt					
	(1) 7000 volts and less	Embedded detector*	65	85	110	135
	(2) Over 7000 volts	Embedded detector*	60	80	105	125
(2)	Cores, squirrel cage windings, and mechanical parts, such as collector rings and brushes, shall be permitted to attain such temperatures as will not injure the machine in any respect.					
Salient-Pole						
(1)	Armature Winding					
	(A) All KVA ratings	Resistance	60	80	105	125
	(B) 1563 KVA and less	Embedded detector*	70	90	115	140
	(C) Over 1563 KVA					
	(1) 7000 volts and less	Embedded detector*	65	85	110	135
	(2) Over 7000 volts	Embedded detector*	60	80	105	125
(2)	Cores, amortisseur windings, and mechanical parts, such as collector rings, brushholders, and brushes, shall be permitted to attain such temperatures as will not injure the machine in any respect.					
Cylindrical Rotor (Non-Salient Pole)						
(1)	Armature Winding					
	(A) Below 10000 KVA	Resistance		80	105	125
	(B) 1563 KVA and less	Embedded detector*		90	115	140
	(C) 1564 KVA to 10000 KVA					
	(1) 7000 volts and less	Embedded detector		85	110	135
	(2) Over 7000 volts	Embedded detector*		80	105	125
	(D) 10000 KVA and above	Embedded detector*		70	90	110
(2)	Field Winding	Resistance		85	105	125
(3)	Cores and mechanical parts in contact with or adjacent to insulation	Detector or Thermometer		70	90	110
(4)	Collector Rings	Thermometer		85	85	85
(5)	Miscellaneous parts (such as brushholders, brushes, and so forth shall be permitted to attain such temperature as will not injure the machine in any respect.					

* Embedded detectors are located within the slot of the machine and shall be either resistance elements or thermocouples. For generators equipped with embedded detectors, this method shall be used to demonstrate conformity with the standard.

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not exceed 130°C for Class B, 155°C for Class F, and 180°C for Class H insulation systems.

For machines of 10,000 kVA and above, the relationship between hottest-spot temperature and the temperatures specified in the table for the armature and field windings shall be demonstrable by direct measurement or recognized methods of calculation corrected to special factory tests on a basically similar machine.

Temperatures shall be determined in accordance with IEEE Standard 115 or IEEE Standard 112.

For machines that operate under prevailing barometric pressure and are designed not to exceed standard temperature rise at altitudes from 3300 feet (1000 m) to 13,000 feet (4000 m), the temperature rises, as checked by test at low altitude, shall be less than those listed in Table 2-4 by 1 percent of the specified temperature rise for each 330 feet (100 m) of altitude in excess of 3300 feet (1000 m).

2.12.1.2.1 Open Cooling

For open machines and for parts of enclosed machines that are cooled by open ventilation passages, that is, collector rings, the cold air temperature is the average temperature of the external air as it enters the ventilating openings of the machine.

Open machines may be required to operate in an ambient temperature above 40°C. For such operation it is recommended that temperature rises of machine parts be limited to values less than those given in Table 2-4 by the number of degrees that the maximum ambient temperature exceeds 40°C.

2.12.1.2.2 Closed Cooling

For totally enclosed machines, the cold air temperature is the average temperature of the air leaving the cooler or coolers. The cold air temperature at rating, when the cooler(s) is supplied with water of the rated amount and temperature up to 30°C, shall not exceed 40°C.

Totally enclosed machines designed for cooling water temperature above 30°C may utilize a cold air temperature above 40°C provided the temperature rises of machine parts be limited to values less than those given in Table 2-4 by the number of degrees that the maximum cold air temperature exceeds 40°C.

2.12.2 Power Terminals

2.12.2.1 Lead Connection

Synchronous generators should be wye connected unless delta connection is specified by the user. Wye connection with the neutral made up externally permits installation of current transformers in each phase for differential protection. Delta wound connections do not include a neutral lead.

Induction generators may be delta or wye connected.

Delta wound generators may also be available. If the user requires a delta wound generator, the requirement must be included as a part of the job specifications to the manufacturer.

Authorized Engineering Information 6-12-1985.

2.12.2.2 Lead Enclosure

An enclosure should be provided for mounting the current transformers and connecting the generator terminals. The enclosure may contain lightning arresters and surge capacitors when required by the user.

2.12.2.3 Location of Terminals

On horizontal synchronous generators furnished with bracketed or pedestal-type bearings and without a terminal box, the recommended location of the armature winding terminals is at the bottom edge of the stator frame within 30 degrees of the vertical centerline. On all other types of horizontal synchronous generators, the recommended location is on the left-hand side of the generator, viewing the end of the generator opposite the drive.

Authorized Engineering Information 6-12-1985.

2.12.2.4 Numerals on Terminals of Alternating Current Polyphase Generators

2.12.2.4.1 Synchronous

The numerals 1, 2, 3, and so forth, indicate the order in which the voltages at the terminals reach their maximum positive values (phase sequence) with clockwise shaft rotation when facing the connection end of the coil windings; hence for counterclockwise shaft rotation (not standard) when facing the same end, the phase sequence shall be 1, 3, 2.

NEMA Standard 6-12-1985.

2.12.2.4.2 Induction

Terminal markings of polyphase induction generators are not related to the direction of rotation.

Authorized Engineering Information 6-12-1985.

2.13 GENERAL ELECTRICAL REQUIREMENTS

2.13.1 MOTOR STARTING CAPABILITIES

If a synchronous generator provides a substantial amount of the power in an electrical system, it shall be capable of starting the largest motor in the system without allowing an excessive voltage dip. The size of the largest motor and the allowable voltage dip shall be specified by the user.

NEMA Standard 6-12-1985.

In order to meet the motor starting requirements, it may be necessary to increase the size of the generator and increase the capacity of the exciter and the voltage regulator.

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2.13.2 Maximum Momentary Overload

Synchronous generators shall be capable of carrying a 1-minute overload of 50 percent of normal rated capacity with the field set for normal rated load excitation. The voltage, power factor and temperature rise will differ from rated values when generators are subjected to the overload conditions.

NEMA Standard 6-12-1985.

2.13.3 Telephone Influence Factor (TIF)

When specified, the balanced telephone influence factor (TIF) based on the weighting factors given in Table 2-5 shall not exceed the following values:

Table 2-5
TELEPHONE INFLUENCE FACTOR

kVA Rating of Generator	TIF
62.5 to 299	350
300 to 699	250
700 to 4999	150
5000 to 19999	100
20000 and above	70

When specified, the residual component telephone influence factor based on the weighting factors given in Table 2-5 shall not exceed the following values. The residual component applies only to those generators having voltage ratings of 2000 volts and higher.

kVA Rating of Generator	TIF
1000 to 4999	100
5000 to 1999	75
20000 and above	50

The single-frequency telephone influence weighting factors (TIF_f), according to the 1960 single frequency weighting factors are shown in Table 2-6.

The telephone influence factor shall be measured in accordance with IEEE Standard 115. TIF shall be measured at the generator terminals on open circuit at rated voltage and frequency.

NEMA Standard 6-12-1985.

2.13.4 Efficiency

Efficiency and losses shall be determined in accordance with IEEE Standard 115. The efficiency shall be determined at rated output, voltage, frequency, and balanced load conditions.

The following losses shall be included in determining the efficiency:

1. I^2R loss of armature.
2. I^2R loss of field.
3. Core loss
4. Stray load loss.
5. Friction and windage loss.
6. Exciter power requirements.

NEMA Standard 6-12-1985.

2.13.5 Generator Constants

Direct-Axis Synchronous Reactance (X_d). Used to determine current flow at steady state conditions.

Direct-Axis Transient Reactance (X'_d). Used to calculate the short circuit current produced by the generator after the first few cycles following a fault (six cycles to five seconds). Also used to determine voltage dips resulting from load applications.

Direct-Axis Subtransient Reactance (X''_d). This is the apparent reactance of the stator winding at the instant short circuit occurs. It is used to calculate the current flow during the first few cycles after a short circuit. The subtransient reactance is important when determining the required capacity of a circuit breaker to interrupt a fault within a system.

Negative Sequence Reactance (X_2). Used to determine line-to-line short circuit currents.

Zero Sequence Reactance (X_o). Used to determine line-to-neutral short circuit currents.

Potier Reactance (X_p). Used to calculate excitation of the generator at different loads and power factors.

Direct-Axis Transient Short Circuit Time Constant (T'_d). Time (seconds) for the slowly decreasing component of the armature current to reach 36.8 percent of its initial value after application of a short circuit condition to a generator running at rated speed.

Direct-Axis Subtransient Short Circuit Time Constant (T''_d). Time (seconds) for the rapidly decreasing component of the armature current (present during the first cycles after a short circuit) to reach 36.8 percent of its initial value after sudden application of a short circuit condition when the unit is running at rated speed.

Direct-Axis Transient Open Circuit Time Constant (T'_{do}). Time measured in seconds for the open circuit voltage of the armature to drop to 36.8 percent of its initial value after the field winding is short circuited.

NEMA Standard 6-12-1985.

2.13.6 PHASE SEQUENCE

The order of numerals on terminal leads does not necessarily indicate the phase sequence, but the phase sequence

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Table 2-6
1960 SINGLE-FREQUENCY TIF_f WEIGHTING FACTORS

Frequency	TIF_f	Frequency	TIF_f
60	0.5	1,800	7,570
180	30	1,860	7,820
300	225	1,980	8,330
360	400	2,100	8,830
420	650	2,160	9,080
540	1,320	3,220	9,330
660	2,260	2,340	9,840
720	2,760	2,460	10,340
780	3,360	2,580	10,600
900	4,350	2,820	10,210
1,000	5,000	2,940	9,820
1,020	5,100	3,000	9,670
1,030	5,400	3,180	8,740
1,140	5,630	3,300	8,090
1,260	6,050	3,540	6,730
1,380	6,370	3,660	6,130
1,440	6,650	3,900	4,400
1,500	6,680	4,020	3,700
1,620	6,970	4,260	2,750
1,740	7,320	4,380	2,190
		5,000	840

is determined by the direction of shaft rotation relative to the connection end of the coil winding. (See 2.12.2.4.1.)

Vector diagrams shall be shown so that advance in phase of one vector with respect to another is in the counter-clockwise direction. See Figure 2-3 in which vector 1 is 120 degrees in advance of vector 2 and the phase sequence is 1, 2, 3.

NEMA Standard 6-12-1985.

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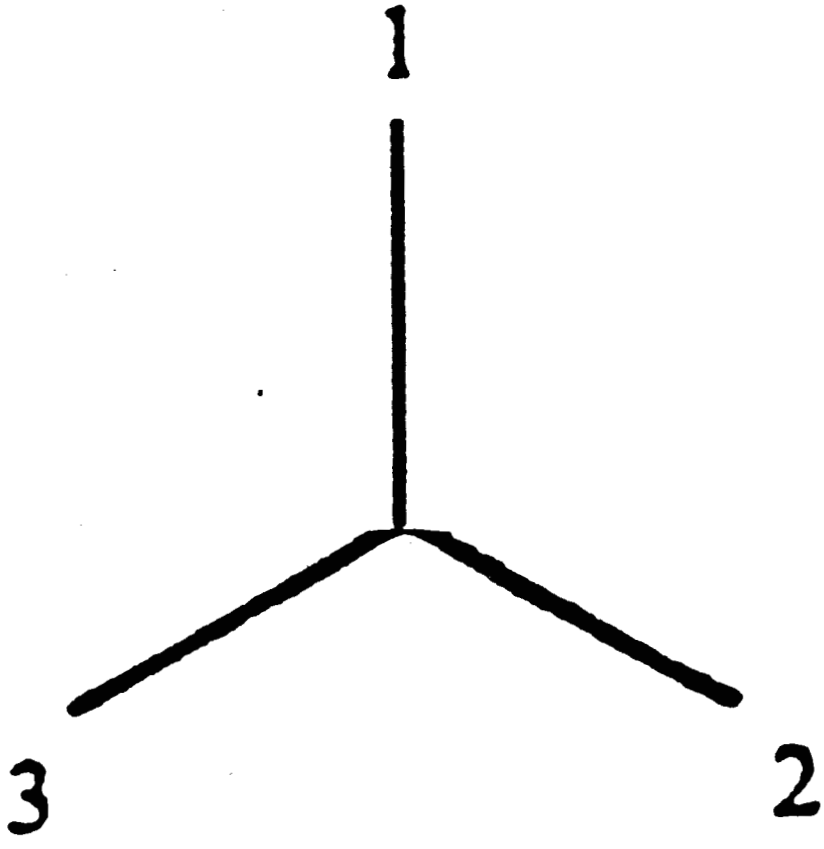


Figure 2-3
PHASE VECTOR DIAGRAM

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Section 3
CONTROLS

3.1 GOVERNING SYSTEM

The governing system includes the speed governor, the control mechanism, the governor controlled valve(s), the speed changer, and external control devices. The governing system is the primary system necessary to match the turbine to the application. Various types of governors are available to meet specific user requirements.

NEMA Standard 6-12-1985.

3.1.1 Speed Governor

The speed governor includes those elements which are directly responsive to speed and which position or influence the action of other elements of the governing system to maintain the operating speed within the limits shown in 3.2.

NEMA Standard 6-12-1985.

3.1.2 Multivariable Governor

The multivariable governor shall have the capability to control two or more parameters simultaneously.

NEMA Standard 11-14-1985.

3.1.3 Control Mechanism

The control mechanism includes all of the equipment between the governor and the governor controlled valve(s) (for example, levers, linkages, relays, servomotors, and pressure or power amplifying devices).

NEMA Standard 6-12-1969.

3.1.4 Governor Controlled Valve(s)

The governor controlled valve(s) controls the flow of steam to the turbine in response to the governor or external controlling device(s).

There are two methods of controlling the admission of steam:

1. By single throttling valve
2. Multiple automatic valves.

NEMA Standard 6-12-1985.

3.1.5 Servomotor System

A servomotor system includes a pilot valve actuated by the governor or control mechanism, and a power cylinder to actuate the governor controlled valve(s) which allows steam to enter the turbine. The pilot valve controls the flow of high pressure fluid to the power cylinder. This flow of high pressure fluid causes the piston in the power cylinder to move in response to the signal from the governor or control mechanism.

NEMA Standard 6-12-1985.

3.1.6 External Control Devices

External control devices shall be one of three types described below:

3.1.6.1 Speed Changer Type

The speed changer type is incorporated directly into the governing system which in turn positions the governor controlled valve(s). The governor shall be selected to provide the specified adjustable speed range.

3.1.6.2 Remote Set Point Type

The remote set point type is incorporated directly into the governing system which in turn positions the governor controlled valve(s). The governor shall be selected to provide the specified adjustable ranges for all controlling parameters.

3.1.6.3 Valve Actuating Type

The valve actuating type is separate from the governor. The external signal acts to position either the governor controlled valve(s) or a separate line mounted valve. In this case, the governor acts only as a speed limiting (preemergency) governor.

NEMA Standard 11-14-1985.

3.1.7 Speed Changer

The speed changer is a device for changing the setting of the governing system within the specified speed range while the turbine is in operation.

NEMA Standard 6-12-1985.

3.2 SPEED GOVERNING SYSTEM CLASSIFICATION

Speed governing systems shall be classified as shown in Table 3-1.

NEMA Standard 6-12-1985.

A governor system in service which meets all the following conditions shall be capable of limiting speed to prevent overspeed trip when load is suddenly reduced from rated to zero:

a. The driven machine is synchronous generator.
b. The governor system is operating in a mode in which it responds to demand for electrical power.
c. The steam turbine has an inlet pressure of at least 150 psig [1035 kPa (gauge)].
d. The steam turbine exhausts to a condenser.

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Table 3-1
SPEED GOVERNING SYSTEM CLASSIFICATION

Class of Governing System	Percent of Maximum Continuous Speed: Maximum Speed Regulation Percent	Maximum Speed Variation Percent	Maximum Speed Rise Percent
A	10	0.75	13*
B	6	0.50	7*
C	4	0.25	7*
D	0.50	0.25	7*

* These Maximum Speed Rise Percent Values can be achieved under the following conditions:

a. Governor system is adjusted for maximum sensitivity.

b. Rotational inertia of the equipment is relatively large for the power rating.

c. Steam conditions produce a relatively low theoretical steam rate.

3.2.1 Speed Range

Speed range, expressed as a percentage of rated speed, is the specified range of operating speeds below or above rated speed, or both, for which the governor shall be adjustable when the turbine is operating under the control of the speed governor.

NEMA Standard 6-12-1985.

Normally a speed range of ±5 percent will allow for adequate frequency control of a turbine generator set.

Authorized Engineering Information 6-12-1985.

3.2.2 Maximum Speed Rise

The maximum speed rise expressed as a percentage of rated speed, is the maximum momentary increase in speed which is obtained when the turbine is developing rated power output at rated speed and the load is suddenly and completely reduced to zero.

$$\text{Maximum speed rise (\%)} = \frac{\left(\frac{\text{maximum speed at}}{\text{zero power output}}\right) - \left(\frac{\text{rated}}{\text{speed}}\right)}{\text{rated speed}} \times 100$$

For non-parallel operation, frequency rise is the same as speed rise. See Figure 3-1 for a graphic representation of speed rise characteristics of a Class D governor.

NEMA Standard 6-12-1985.

3.2.3 Speed Variation

Speed variation, expressed as a percentage of rated speed, is the total magnitude of speed change or fluctuations from the speed setting under the steady state conditions given in 3.2.4. The speed change is defined as the difference in speed variation between the governing system in operation and the governing system blocked to be inoperative, with all other conditions constant. Speed variation includes dead band and sustained oscillations.

$$\text{Speed variation (±\%)} = \frac{\text{change in rpm above set speed} + \text{change in rpm below set speed}}{2 \times \text{rated speed}} \times 100$$

See Figure 3-2 for graphic representation of speed variation characteristics of a Class D governor.

3.2.3.1 DEAD BAND

Dead band is the total magnitude of the change in steady state speed within which there is no resulting measurable change in the position of the governor controlled valve(s). It is a measure of the speed governing system insensitivity and is expressed in percent of rated speed.

3.2.3.2 STABILITY

Stability is the ability of the speed governing system to position the governor controlled valve(s) so that a sustained oscillation of speed or of energy input to the turbine is not produced by the speed governing system during operation under sustained load demand or following a change to a new sustained load demand.

For the purpose of this standard, sustained oscillations produced by the speed-governing system:

(a) of turbine speed, for isolated operation undersustained load demand, or

(b) of energy input, for parallel operation with a constant-frequency alternating current power system, or

(c) of energy input for parallel operation with a constant-voltage direct current power system—are defined as the difference between those existing with the speed-governing system in service and those existing with the speed-governing system blocked or inoperative.

In the case of parallel operation with an alternating current power system of other than constant frequency, energy input which correspond to variations in power-system frequency and to the incremental speed regulation of the speed-governing system covered by this standard are excluded in determining stability. Similarly, in the case of parallel operation with a direct current power system of other than constant voltage, energy input changes which correspond to the voltage regulation of the driven generator and to the variations in voltage of the power system are deducted in determining stability.

3.2.4 Speed Regulation, Steady State

Speed regulation, expressed as a percentage of rated speed, is the change in sustained speed when the power output of the turbine is gradually changed from rated power output to zero power output under the following steady state conditions:

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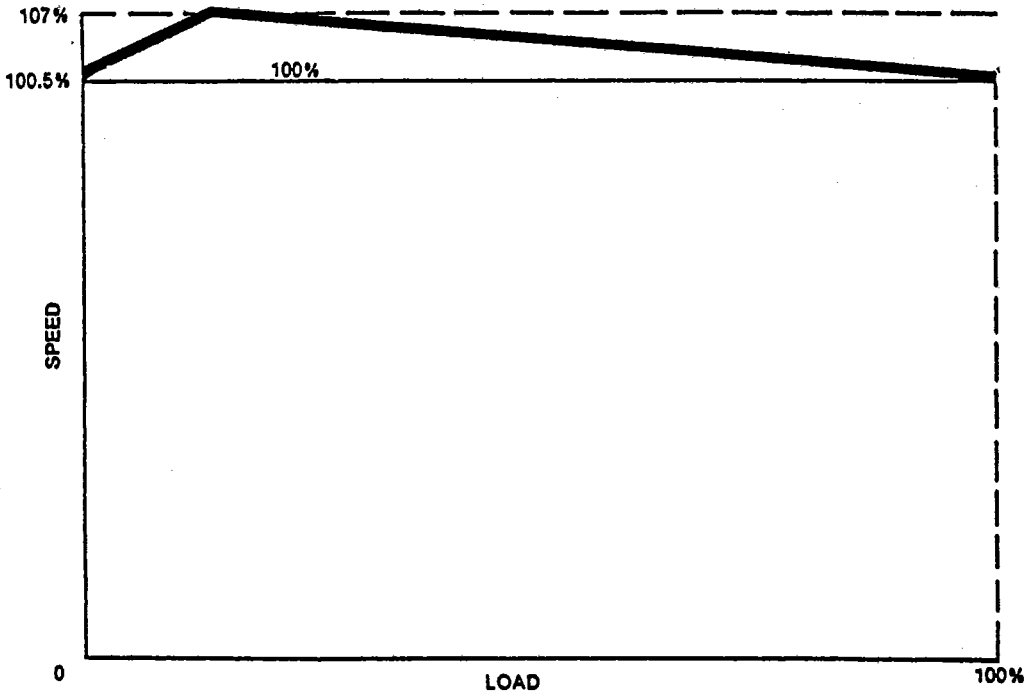


Figure 3-1
SPEED/FREQUENCY RISE FOR NON-PARALLEL SYNCHRONOUS TURBINE GENERATOR SET WITH A CLASS D GOVERNOR

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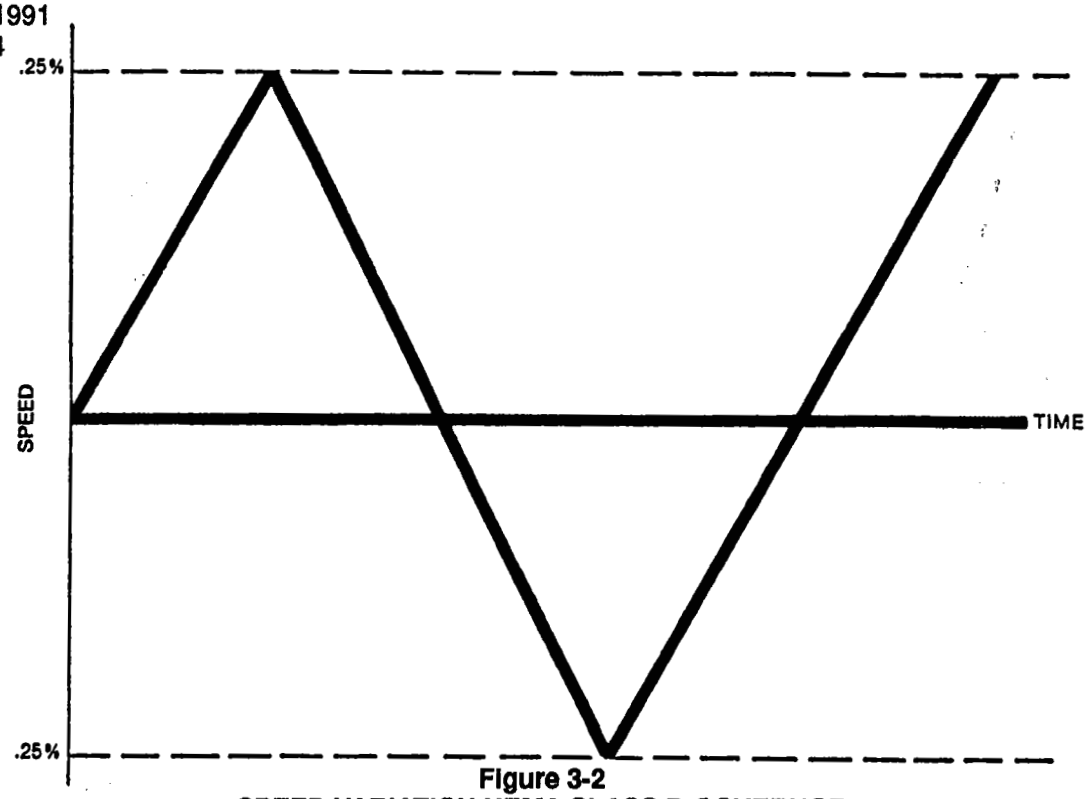


Figure 3-2
SPEED VARIATION NEMA CLASS D GOVERNOR

1. When the steam conditions (inlet pressure, inlet temperature and exhaust pressure) are set at rated values and held constant.
2. When the speed changer is adjusted to give rated speed with rated power output.
3. When any external control device is rendered inoperative and blocked in the open position so as to offer no restrictions to the free flow of steam to the governor controlled valve(s).

$$\text{Speed Regulation (\%)} = \frac{\left(\begin{matrix}\text{speed at zero}\\ \text{power output}\end{matrix}\right) - \left(\begin{matrix}\text{speed at rated}\\ \text{power output}\end{matrix}\right)}{\text{speed at rated power output}} \times 100$$

For non-parallel operation, frequency regulation is the same as speed regulation.

Speed regulation is referred to as droop when the speed change is from no load to full load.

NEMA Standard 6-12-1985.

See Figure 3-3 for a graphic representation of speed/frequency regulation characteristics.

3.3 STEAM PRESSURE CONTROL

3.3.1 Pressure Regulating System

The pressure regulating system includes the pressure regulator(s), the pressure control mechanism(s) and the pressurecontrolled valve(s).

NEMA Standard 6-12-1985.

3.3.2. Pressure Regulator

The pressure regulator includes only those elements that are directly responsive to pressure and which position or influence the action of other elements of the pressure regulating system.

NEMA Standard 6-12-1985.

3.3.3 Control Mechanism

The control mechanism includes all of the equipment, such as relays, servomotors, pressure or power amplifying devices, levers, and linkages between the pressure regulator(s) and the pressure controlled valve(s).

NEMA Standard 6-12-1985.

3.3.4 Pressure Controlled Valves

The pressure controlled valves include those valves which control the flow of steam through the lower pressure stages of the turbine and which are actuated by the pressure regulator(s) through the medium of the control mechanism(s).

NEMA Standard 6-12-1985.

In the case of noncondensing turbines provided with exhaust pressure regulators and also compensated controlled extraction or controlled induction type turbines, the governor controlled valves may serve also as pressure controlled valves.

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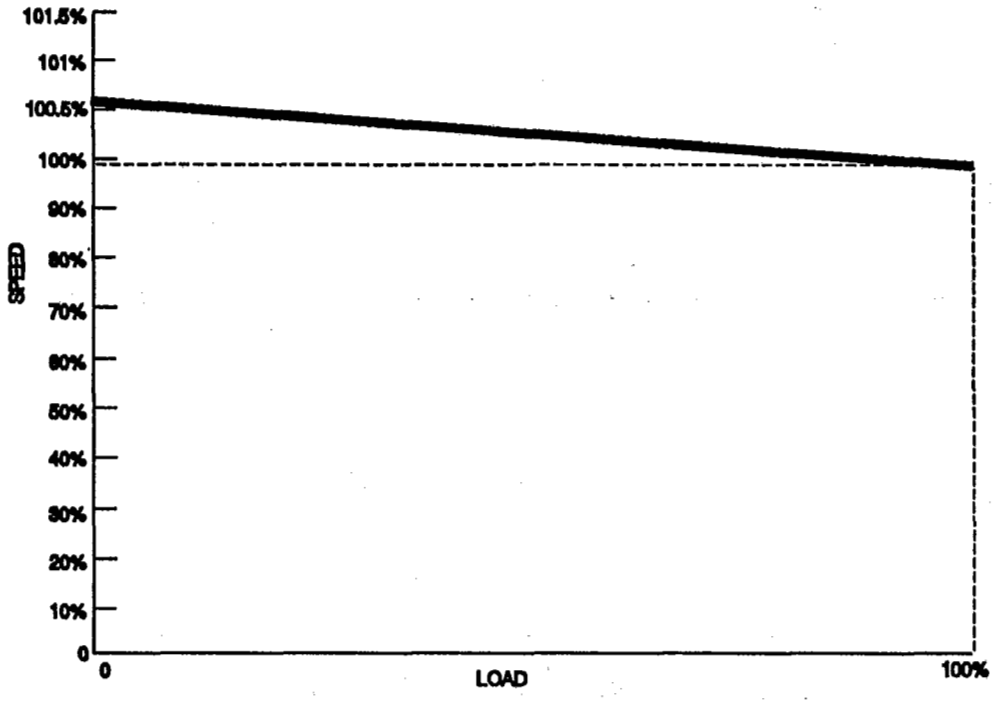


Figure 3-3
STEADY STATE SPEED REGULATION NEMA CLASS D GOVERNOR

3.3.5 Pressure Changer

The pressure changer is a device by means of which the setting of the pressure regulating system may be changed for the purpose of adjusting the pressure of the exhaust steam or of the extraction or induction steam while the turbine is in operation.

NEMA Standard 6-12-1985.

3.3.6 Steady State Pressure Regulation

For controlled extraction or controlled induction type turbines, the steady state pressure regulation is the change in sustained extraction or induction pressure when, with identical settings of all parts of the speed governing system and of the pressure regulating system(s), the extraction or induction flow is gradually changed from rated flow to zero flow.

For noncondensing turbines provided with exhaust pressure regulators, the steady state pressure regulation is the change in sustained exhaust pressure when, with identical settings of all parts of the speed governing system and of the pressure regulating and through the action of the pressure regulator, the power output of the steam turbine is gradually reduced from rated power output to zero power output.

NEMA Standard 6-12-1985.

3.3.6.1 Pressure Regulation Convention

Pressure regulation is considered positive when pressure increases with decrease in steam flow.

NEMA Standard 6-12-1985.

3.3.7 Stability

Stability is the capability of the pressure regulating system(s) to position the pressure controlled valve(s) so that sustained oscillations of the controlled pressure(s) or the energy input to the steam turbine are not produced by the pressure regulating system(s) during operation under sustained flow demands or following a change to another value of sustained flow demand.

For the purpose of this standard, sustained oscillations produced by the pressure regulating system of controlled pressure or of energy input are defined as the difference between those existing with the pressure regulating system in service and those existing with the pressure regulating system blocked or inoperative.

NEMA Standard 6-12-1985.

3.3.8 Pressure Control Performance

A Class D governing system (see Section 3.2) shall exhibit the following characteristics when utilized in a compensated control system:

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3.3.8.1 Change in sustained speed shall be 1 percent maximum for any sustained change in flow within limits of 5 percent and 95 percent of maximum induction or extraction flow guaranteed for that load.

NEMA Standard 11-14-1985.

3.3.8.2 Steady state pressure regulation shall be 0.5 psi (3.5 kPa) maximum or 4 percent of rated exhaust, extraction, or induction pressure expressed in psia or kPa (absolute); whichever is larger.

NEMA Standard 11-14-1985.

3.3.8.3 Sustained oscillations of controlled pressure, when operating at constant flow demand or following a change to another constant flow, shall not exceed 0.25 psi (1.7 kPa) or 2 percent of the controlled pressure expressed in psia or kPa (absolute); whichever is larger.

NEMA Standard 11-14-1985.

3.3.8.4 Sustained oscillations of energy input, when operating at constant flow demand or following a change to another constant flow, shall not exceed 4 percent of rated power.

3.3.8.5 The range of adjustment for pressure change(s) shall permit adjustment of exhaust, extraction, or induction pressure between 5 psi (35 kPa) or 10 percent of the controlled pressure expressed in psia or kPa (absolute); whichever is larger.

NEMA Standard 11-14-1985.

3.4 COMPENSATED CONTROL SYSTEM

A compensated control system is one which is provided with interconnections between its control mechanisms so that the action of the speed governor or of the pressure regulator(s) also directly actuates the other control mechanism.

NEMA Standard 6-12-1985.

3.5 ELECTRONIC GOVERNING SYSTEM

3.5.1 Basic Features

An electronic governing system shall include the following basic components:

1. Sensors which measure an operating parameter of the turbine or system, and produce corresponding electric signals.
2. A governor which compares signal(s) from the sensor(s) with the selected set point(s) and produces a signal(s) for the valve actuator(s) to maintain system parameters.
3. An actuator(s) which positions the valve(s) directly or through a control mechanism in response to the governor signal.

One or more of following parameters shall be controlled by the governing system:

a. Speed
b. Inlet steam pressure
c. Each induction/extraction pressure
d. Exhaust pressure
e. Generator output
f. Others for specific applications.

NEMA Standard 6-12-1985.

3.5.2 Accessories

The following are accessories which may be selected, depending on rating and application:

3.5.2.1 CONTROL PRIORITIES

A signal selector may be incorporated in the governor to allow the governor to receive signals from several sensors and to choose the signal which will result in the proper valve opening.

Any parameter may be primary which the governing system maintains as constant during normal operation. Any parameter could be secondary which is ignored as long as it is below the preset value.

3.5.2.2 CONTROL OF INDUCTION OR EXTRACTION

The governor may be designed to control the low pressure valve(s) of an induction or extraction turbine in conjunction with the high pressure valve(s). In this case, the governor controls the flow to maintain the steam pressure at each controlled extraction or induction opening while simultaneously controlling speed when necessary for the application.

A governor with this capability incorporates features to adjust all the controlled valves in response to a change in any controlled parameters.

3.5.2.3 MISSING SIGNAL DETECTION FEATURE

The missing signal detection feature monitors all input signals and determines if they are in the correct range. Any signal that is out of range should cause immediate action by the electronic governor to ensure safe operation of the turbine, and should cause an alarm indication.

3.5.2.4 SENSOR REDUNDANCY

3.5.2.5 OVERSPEED TRIP

The overspeed trip feature in the governor can be provided in addition to the primary trip.

3.5.2.6 IMPORT/EXPORT CONTROL

Import/export control allows the governor to regulate the exchange of electric power between the utility and the system to which it is connected. Import/export control may be used as a primary parameter or a secondary parameter.

3.5.2.7 ISOCHRONOUS LOAD SHARING

Isochronous load sharing which allows two or more synchronous turbine generator sets operating in parallel to

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maintain constant system frequency from zero system load to maximum system load without the need for any adjustments by operating personnel. This allows each turbine generator set to operate at the same percentage of its full load rating. Therefore, if the load on the system is 60 percent of the maximum system capacity, each turbine generator set in the system will be operating at 60 percent load.

In order for isochronous load sharing to be used, each turbine generator set in the system must have a governor with the isochronous load sharing feature.

3.5.2.8 AUTOMATIC SYNCHRONIZER

The automatic synchronizer adjusts turbine speed to match bus frequency and generator phase to match the bus phase. It can also provide voltage matching by adjusting the voltage regulator reference. The synchronizer will generate a breaker close command when everything is within specified limits.

3.5.2.9 KILOWATT LIMIT CONTROL

3.5.2.10 Other electronic governor accessories may be available.

Authorized Engineering Information 6-12-1985.

3.5.3 General

Care should be taken in each installation to provide for adequate wiring. In addition, electronic governors and their associated wiring should be protected from heat, wear and induced signals. Local codes and area classifications should be considered.

When microprocessor based turbine control systems are provided which interface with plant distributed control systems, there may be some overlap of control loops and confusion regarding inputs/outputs. In these cases the purchaser and the vendor should mutually agree upon scope and responsibility split. External setpoints can come from the plant DCS but the turbine control loop should be supplied by the turbine manufacturer.

A typical electronic governor schematic is shown in Figure 3-4 at the end of this section.

3.6 AUTOMATIC START CONTROLS

Automatic start controls are available for turbine and driven machine. The turbine manufacturer should be consulted for recommended equipment and procedures.

Authorized Engineering Information 6-12-1985.

3.7 TURBINE GENERATOR CONTROLS

Turbine generator controls regulate the output of the turbine generator set in terms of load (KW), voltage and frequency in response to normal operating requirements.

Authorized Engineering Information 6-12-1985.

The type of controls shall be consistent with the application of the turbine generator set and the type of generator.

NEMA Standard 6-12-1985.

3.8 SYNCHRONOUS GENERATOR

3.8.1 Frequency Control

Generator frequency is directly proportional to turbine speed when the turbine generator set is operating independent of utility power. Therefore, the required frequency is maintained by controlling the turbine speed with a governor.

When the turbine generator set is operating in parallel with a large synchronous power system, change in turbine speed setting on the governor results in a change in turbine load because the frequency of the turbine generator set is locked to the frequency of the connected power system.

Authorized Engineering Information 6-12-1985.

3.8.2 Voltage Control

A voltage regulator shall be supplied for synchronous generators to maintain system voltage when (1) operating independently, (2) when in the process of paralleling, or (3) when controlling the reactive KVA loading of the generator.

NEMA Standard 6-12-1985.

3.8.3 Load Control

For nonparallel operation of synchronous generators, the turbine speed control shall maintain the frequency within the required limits while operating from no load to full load.

For parallel operation, the governor shall be supplied with a local or remotely adjustable speed changer to allow the generator frequency and phase to be matched with the connected power system in order to synchronize the turbine generator set on-line.

For parallel operation, the governor shall be supplied with a droop adjustment or isochronous load sharing capability to allow load sharing between the turbine generator set and the connected system.

NEMA Standard 6-12-1985.

3.9 INDUCTION GENERATOR

A turbine induction generator set is not suitable for isolated operation; it must be operated in parallel with a utility. A speed governor is not required for speed and phase matching before an induction generator's breaker is closed to the utility. However, a speed governor should be considered in order to bring the turbine generator set to synchronous speed before closing the circuit breaker.

In the application of a turbine induction generator set as a pressure reducing valve, the output of the turbine generator set is regulated by a pressure control. In this applica-

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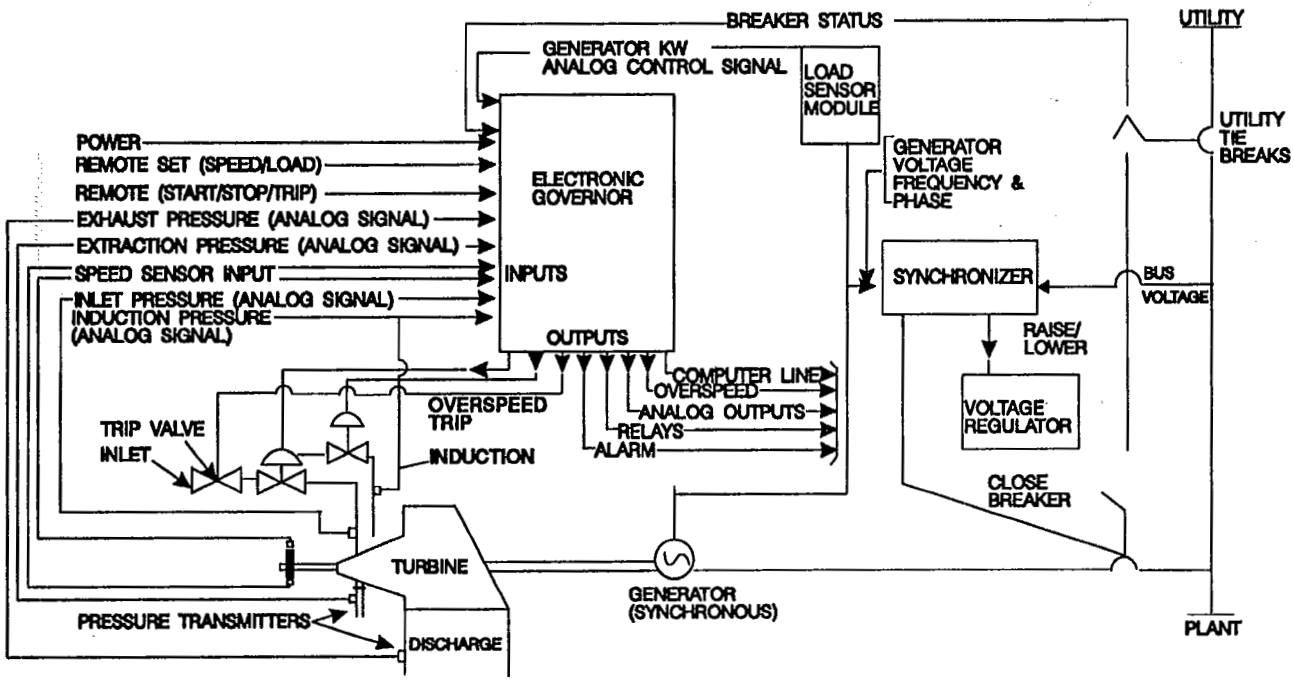


Figure 3-4
ELECTRONIC GOVERNOR FOR SYCHRONOUS GENERATOR CONTROL

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tion, a speed governor can be used as a preemergency governor, with its speed setting just above the full load speed of the generator.

In application of induction generators, such as peak shaving units where load is to be controlled, the governor will be used to set generator load.

Authorized Engineering Information 6-12-1985.

3.10 GENERATION SYSTEM CONTROL

When the steam turbine generator set produces power as a byproduct of an industrial process, an external control such as system pressure, flow or temperature, may be used to control the steam flow through the turbine generator to insure that kilowatts are produced as a function of the system steam demand.

Authorized Engineering Information 6-12-1985.

3.11 GENERATOR VOLTAGE CONTROL

3.11.1 Basic Features

The synchronous generator shall be supplied with an automatic voltage regulator which shall have a means of adjustment. The regulator shall control current in the field of the exciter to maintain generator voltages during changes in load.

The voltage regulator shall hold the generator output voltage within a specified range (from 1/2 to 1 1/2 percent of nominal voltage) for all steady state loads from no load to full load.

When two or more ac generators operate in parallel, the voltage regulator shall have paralleling provisions to permit it to control the reactive load while it is in parallel operation.

The regulator shall have a sufficiently short response time to minimize voltage dips or rises after load transients. In hospitals, where light flicker must not occur and x-ray equipment would be affected by voltage variations, the generator shall be of sufficient size and design capability to minimize the effect of load.

A power isolation transformer for use with the voltage regulator shall be supplied when required by the application.

NEMA Standard 6-12-1985.

3.11.2 Accessories

The following are accessories which the manufacturer may select, depending on rating, voltage, and application:

3.11.2.1 Excitation Support System

Voltage regulation systems can be made sensitive not only to voltage, but also to current output of the generator. Under large load transients, when there is a rush of current through the generator leads, a large current is automatically induced in the exciter field, greatly increasing its output to combat the voltage dip of the generator. This is known as series boost, short circuit boost, or short circuit sustaining. This accessory is used for motor starting or fault-clearing applications.

Alternatively, a small separate shaft mounted permanent magnet generator may be used to supply power to the voltage regulator. It is independent of the line voltage drop and maintains a supply voltage to the regulator regardless of load.

3.11.2.2 Under Frequency/Overvoltage Protection

This accessory automatically protects the generator from the effects of under frequency and overvoltage operation by disconnecting the voltage regulator in the event of severe under frequency or overvoltage conditions.

3.11.2.3 Remote Manual Voltage Control

3.11.2.4 Automatic Power Factor Controller

3.11.2.5 Additional items may be available.

Authorized Engineering Information 6-12-1985.

3.12 GENERATOR CONTROL PANEL AND SWITCHGEAR

Generators for industrial plant or commercial class power system service usually have ratings varying from 480 volts through 13,800 volts.

The generator switchgear is to provide protection for the equipment and its operating personnel. The degree of switchgear protection recommended for generators is based on the cost and service requirements. Additional protection can be justified on the basis that greater fault sensitivity and faster response can minimize fault damage and considerably lessen repair costs and downtime.

When the generator is to be paralleled with the utility system, the protection and metering requirement of the utility should be considered. Prior to installation the purchaser or user should obtain approval from the utility for the equipment being supplied.

When used with steam turbine generator sets, the switchgear and controls covered in this section should perform the following functions:

1. Connect the generator output to and disconnect it from the power bus.
2. Provide instrumentation to monitor the various parameters necessary to operate the equipment.
3. Control the generator voltage.
4. Protect the generator and the associated equipment against faults, detect faults if they occur and provide an alarm or shutdown, or both.

This section covers basic equipment up to and including the generator circuit breaker.

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3.12.1 General Requirements

The equipment described in this section for factory- built alternating current switchgear is considered minimum for typical 3-phase, 3-wire circuits.

For other system requirements, additional equipment should be added, in which case the manufacturer should be consulted.

The following covers metal-enclosed units and the devices associated with them for use on 3-phase circuits.

Adequate surface area and mounting facilities should be provided for all standard panel-mounted items. Space should be provided in auxiliary compartments, when required, in addition to that available in the standard unit assemblies to house buses, connections, operating transformers, instrument transformers, rheostats, field control equipment, and other devices.

Enclosures should be suitable for the site environment. (For 1000 volts maximum, see NEMA Standards Publication 250-1985.)

When the switchgear in intended for outdoor use, the equipment should be located within a weatherproof housing, with each housing having:

1. Suitable weatherproof access door or doors with provisions for locking.
2. Protected openings for ventilation, as required.
3. Interior lighting and utility outlets with protective devices.
4. Heaters with protective devices.

Authorized Engineering Information 6-12-1985.

3.12.2 Low Voltage Switchgear (to 600 Volts)

3.12.2.1 Non-Paralleled Synchronous Units

(See Figure 3-5) Equipment located either in a cabinet on the generator enclosure, or in a separate wall or floor mounted unit, shall include:

1. Voltmeter
2. Ammeter
3. Frequency meter
4. Wattmeter
5. Combination selector switch (voltmeter/ammeter)
6. Current transformers as necessary
7. Potential transformers as necessary
8. Automatic voltage regulator with manual adjustment
9. Power isolation transformer for voltage regulator, if required
10. Low voltage power circuit breaker operated manually or electrically
11. Suitable control wiring and terminal blocks

NEMA Standard 6-12-1985.

3.12.2.2 Manual Paralleled Synchronous Units

(See Figure 3-6) Equipment located either in a cabinet on the generatorenclosureor in a separate wall or floor mounted unit shall include:

1. Voltmeters-bus side and generator side
2. Ammeter
3. Frequency meters-bus side and generator side
4. Wattmeter
5. Combination selector switches (voltmeter/ ammeter)
6. Current transformers as necessary
7. Potential transformers as necessary
8. Automatic voltage regulator with manual adjustment and cross current compensation for paralleling
9. Power isolation transformer for voltage regulator, if required
10. Low voltage power circuit breaker operated manually or electrically
11. Synchronizing switch
12. Two synchronizing lights
13. Synchroscope
14. Reverse power relay
15. Suitable control wiring and terminal blocks
16. Overcurrent time delay relay

NEMA Standard 6-12-1985.

3.12.2.3 Paralleled Induction Units

(See Figure 3-7) The following instrumentation and equipment shall be mounted in a wall mounted or free-standing enclosure:

1. Ammeter with switch
2. Wattmeter
3. Voltmeter with switch
4. Manually or electrically-operated power circuit breaker with shunt trip or a contactor with fuses
5. Reverse power relay
6. Panel lights for indicating motoring or generating
7. Current transformers as necessary
8. Potential transformers as necessary
9. Suitable control wiring and terminal blocks

NEMA Standard 6-12-1985.

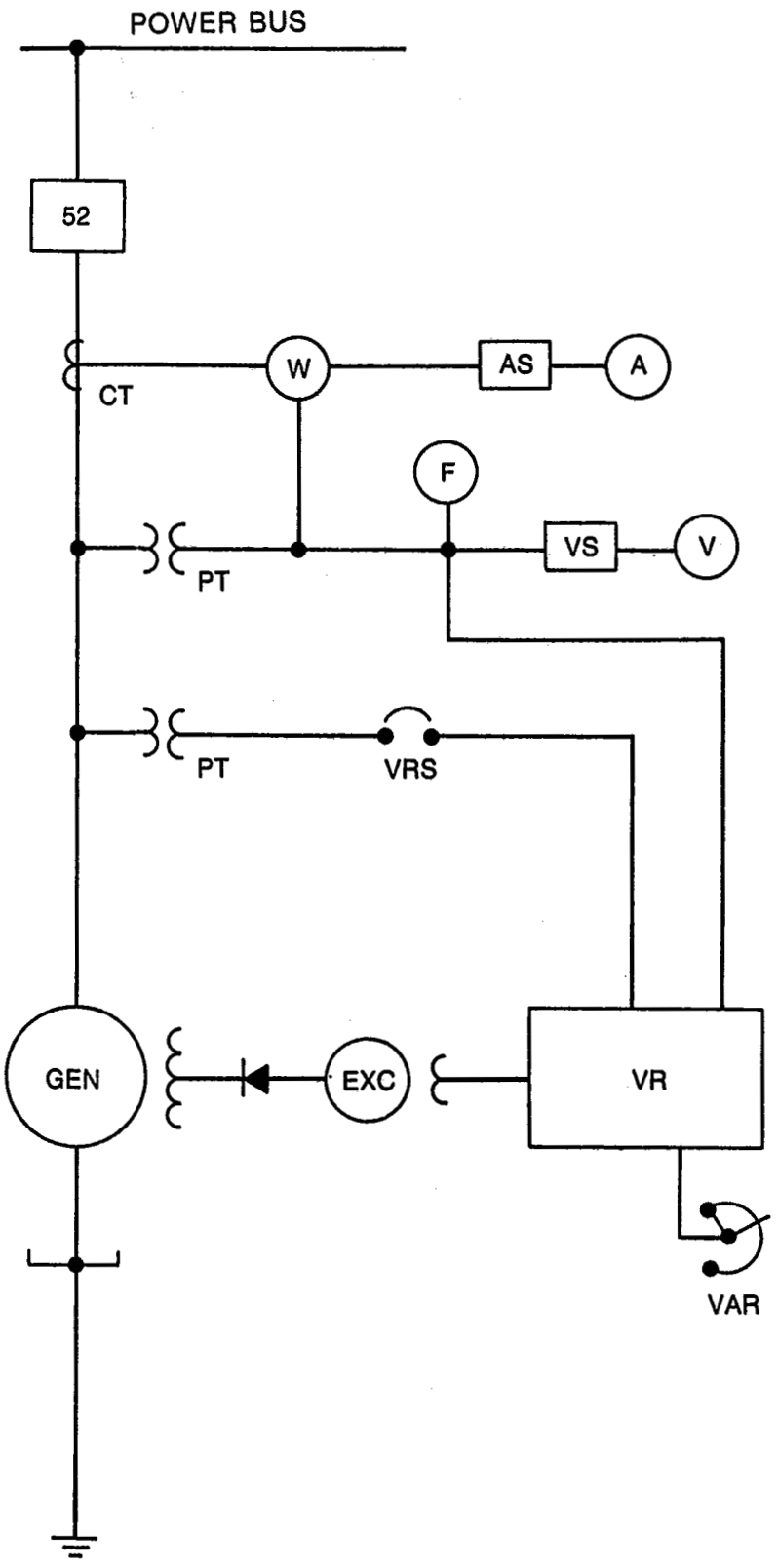
3.12.3 High Voltage Switchgear (601 to 13,800 Volts)

3.12.3.1 Non-Paralleled Synchronous Unit

(See Figure 3-8) The following instrumentation and equipment shall be mounted in one or more free-standing enclosures:

1. Voltmeter with switch
2. Ammeter with switch

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52	Circuit Breaker
A	Ammeter
F	Frequency Meter
V	Voltage Meter
AS	Ammeter Switch
CT	Current Transformer
EXC	Exciter
GEN	Generator
PT	Potential Transformer
VAR	Voltage Adjusting Rheostat
VR	Voltage Regulator
VRS	Voltage Regulator Cutout Switch
VS	Voltmeter Switch
W	Wattmeter

Figure 3-5
NON-PARALLELED LOW VOLTAGE SNYCHRONOUS UNITS (3.12.2.1)

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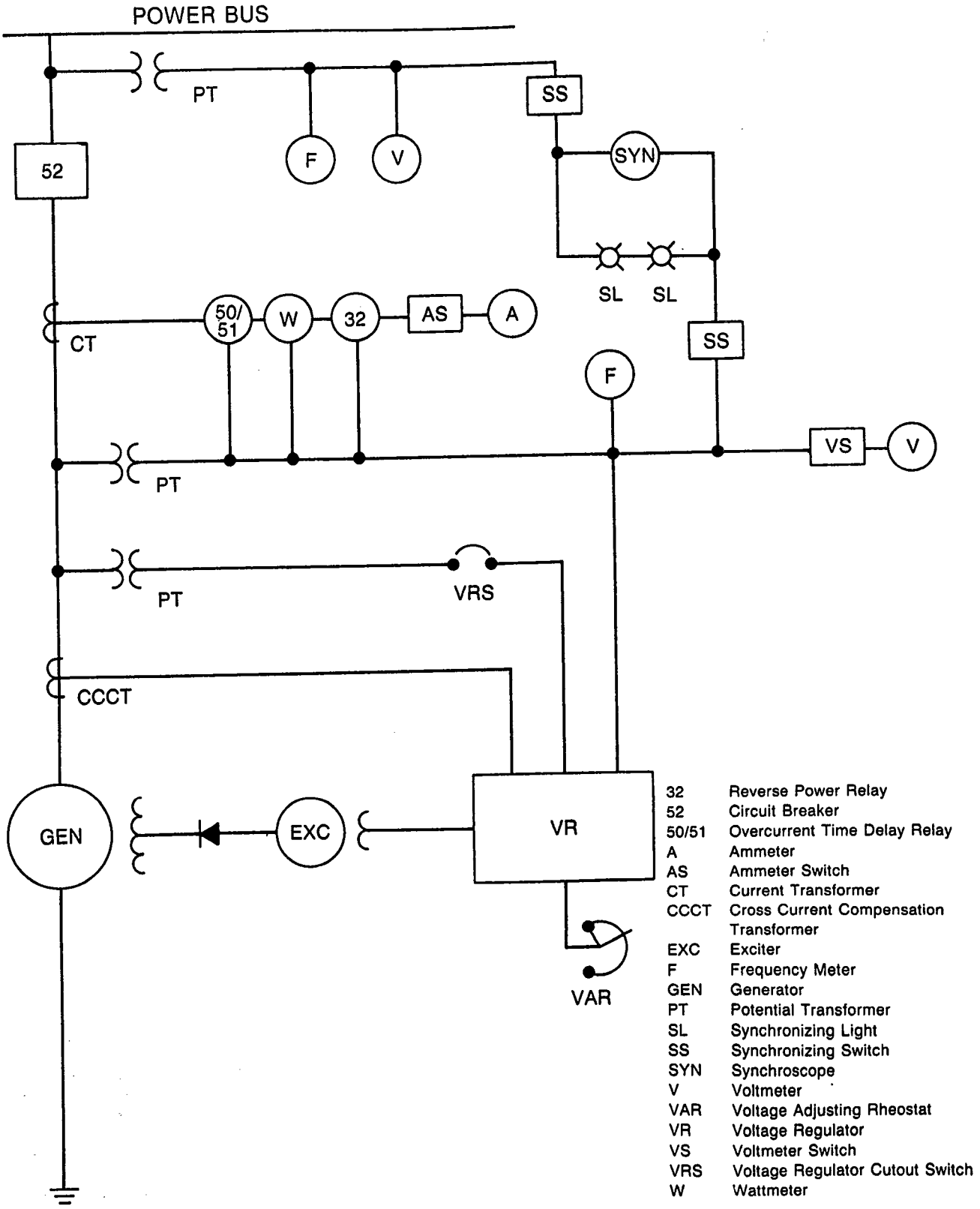
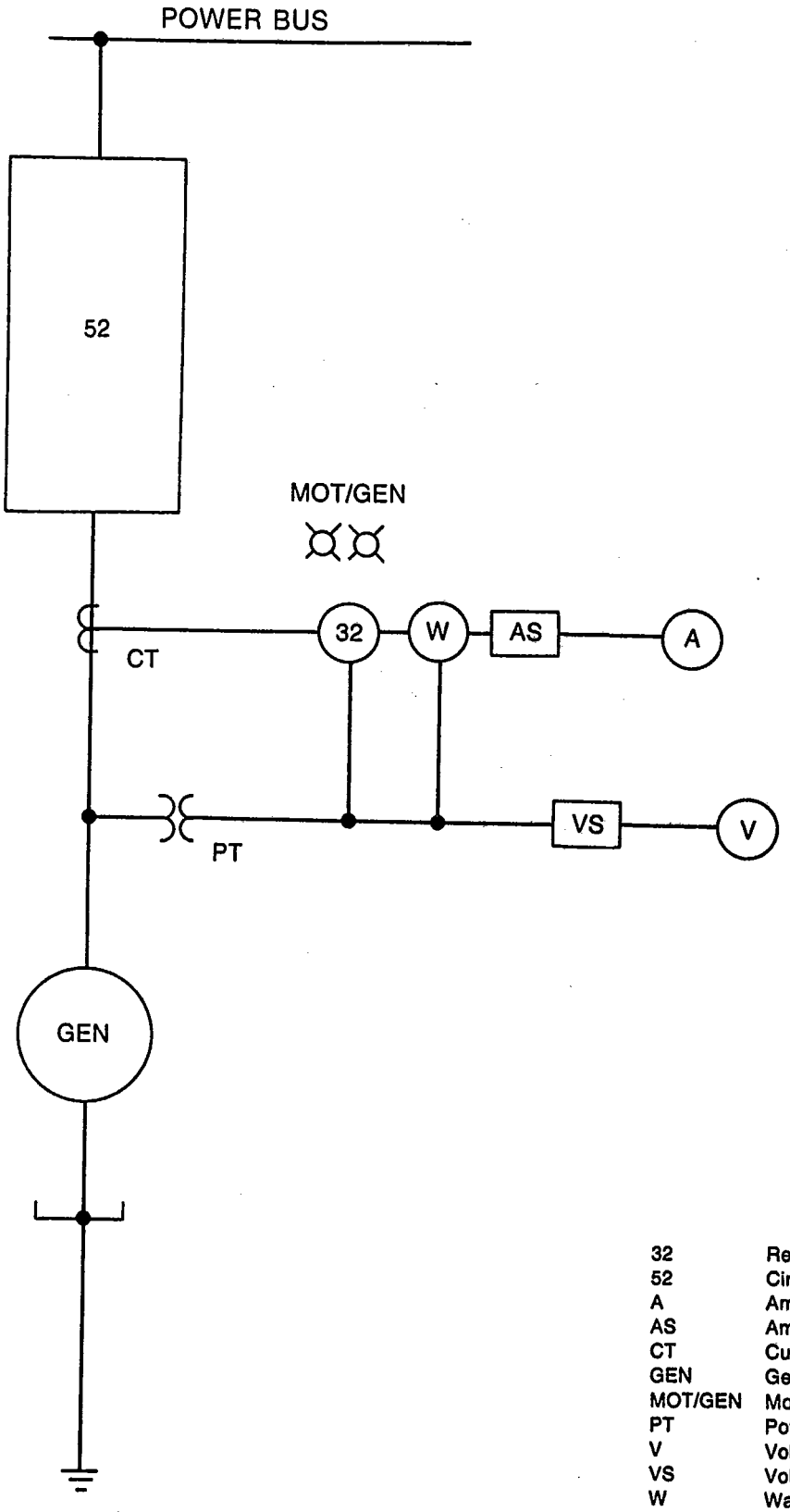


Figure 3-6
MANUAL PARALLELED LOW VOLTAGE SYNCHRONOUS UNITS (3.12.2.2)

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32	Reverse Power Relay
52	Circuit Breaker
A	Ammeter
AS	Ammeter Switch
CT	Current Transformer
GEN	Generator
MOT/GEN	Motor Generating Lights
PT	Potential Transformer
V	Voltmeter
VS	Voltmeter Switch
W	Wattmeter

Figure 3-7
INDUCTION GENERATOR UNITS (3.12.2.3)

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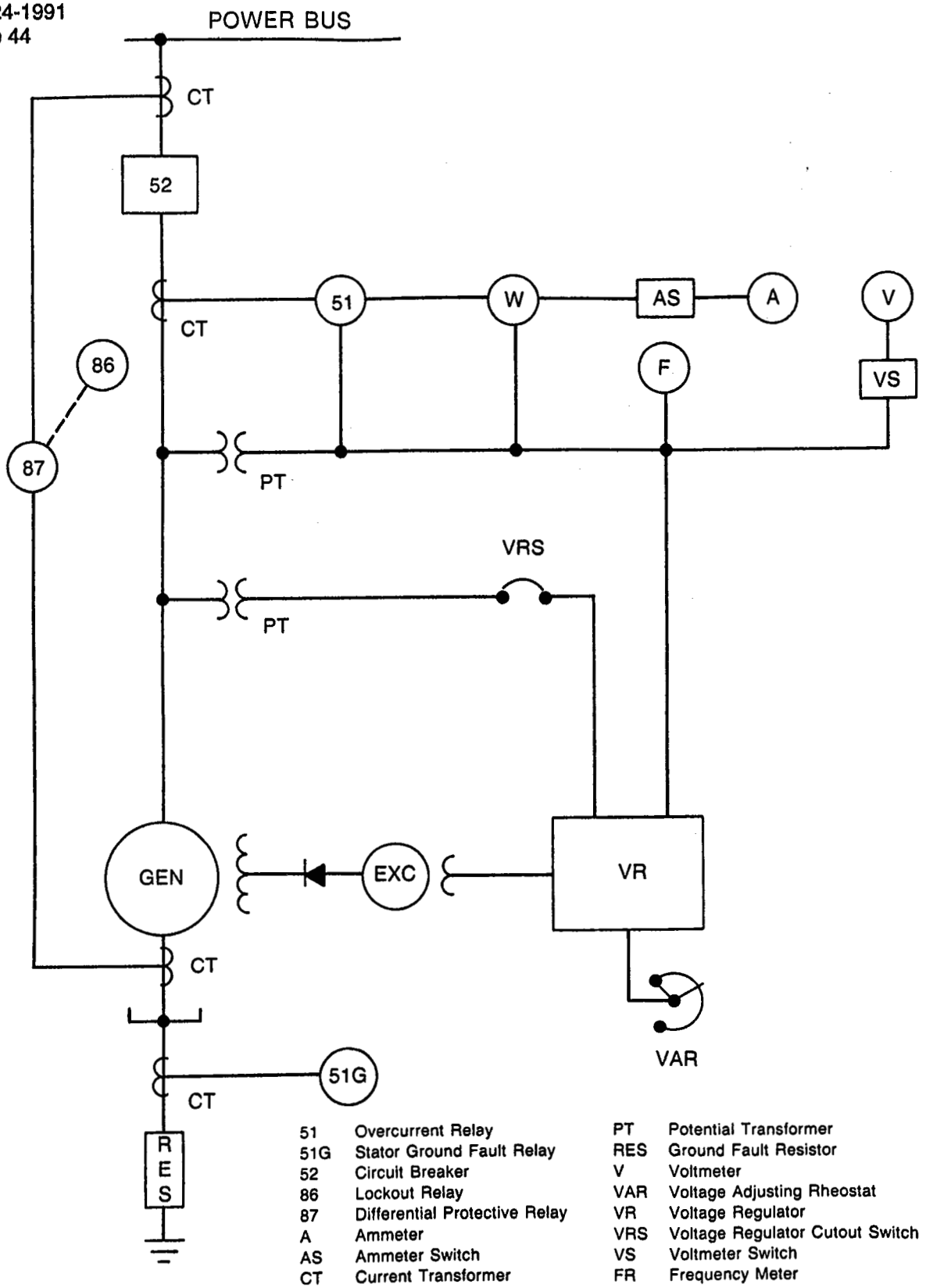


Figure 3-8
NON-PARALLEL HIGH VOLTAGE SYNCHRONOUS UNITS (3.12.3.1)

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3. Frequency meter
4. Wattmeter
5. Current transformers as necessary
6. Potential transformers as necessary
7. Automatic voltage regulator with manual adjustment
8. Power isolation transformer for voltage regulator, if required
9. Power circuit breaker of suitable rating and interrupting capacity, electrically operated with closing relays and shunt trip
10. Control switch for circuit breaker with indicating lights for open/close positions
11. Overcurrent relays for phase protection
12. Governor control switch
13. Differential protection with lockout relay
14. Ground fault relay
15. Suitable control wiring and terminal block

NEMA Standard 6-12-1985.

3.12.3.2 MANUAL PARALLELED SYNCHRONOUS UNITS

(See Figure 3-9) The following instrumentation and equipment shall be mounted in one or more free-standing enclosures:

1. Voltmeter with switch on generator side
2. Voltmeter on bus side
3. Ammeter with switch
4. Frequency meters on generator and bus sides
5. Wattmeter
6. Current transformers as necessary
7. Potential transformers as necessary
8. Automatic voltage regulator with manual adjustment and cross current compensation
9. Power isolation transformer for voltage regulator, if required
10. Power circuit breaker of suitable rating and interrupting capacity, electrically operated with closing relays and shunt trip
11. Control switch for circuit breaker with indicating lights for open/close positions
12. Overcurrent relays for phase protection
13. Governor control switch
14. Differential protection with lockout relay
15. Stator ground fault relay
16. Synchronizing switch
17. Synchroscope
18. Two synchronizing lights
19. Reverse power relay
20. Suitable control wiring and terminal blocks

NEMA Standard 6-12-1985.

3.12.4 Generator and Switchgear Accessories

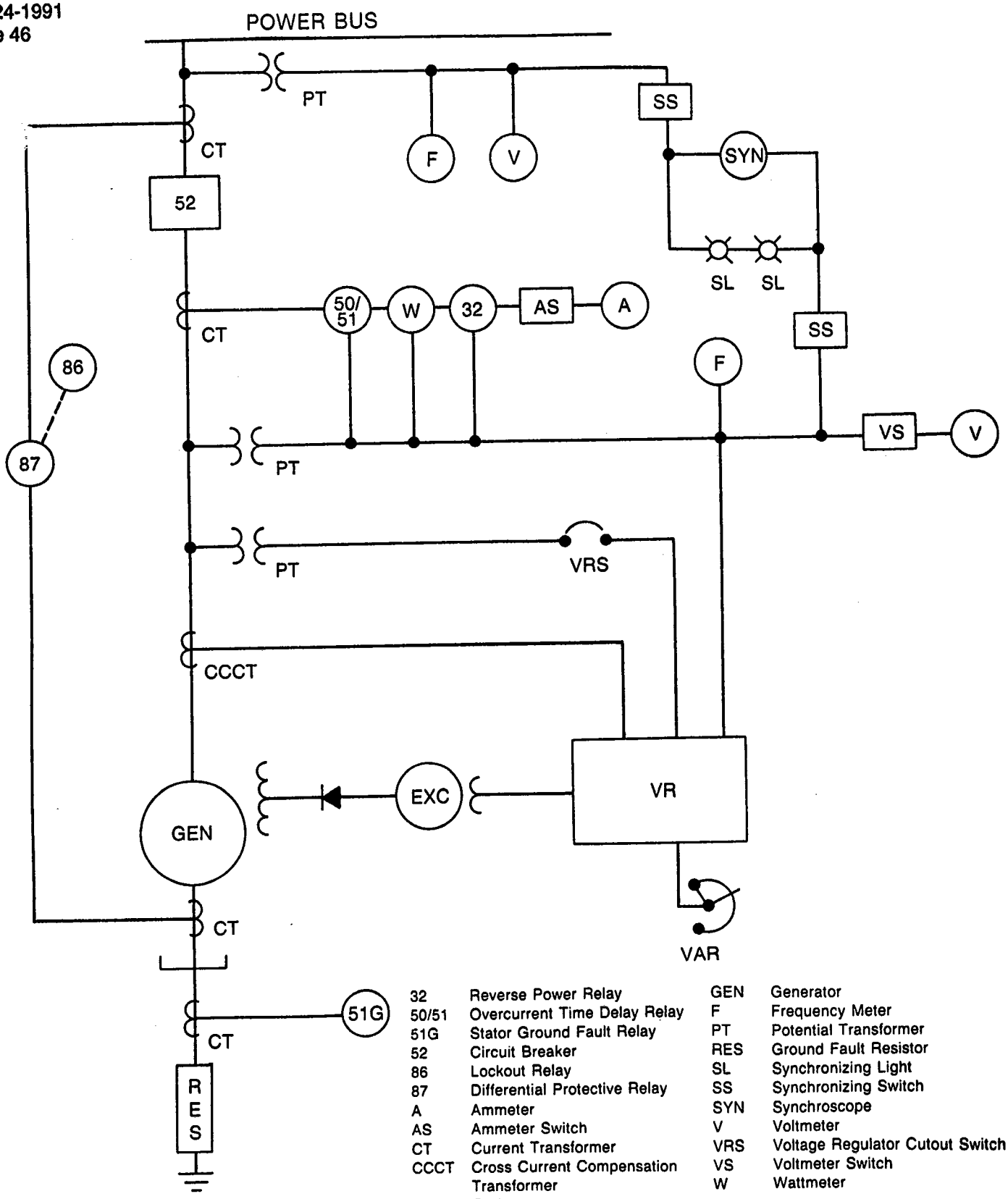
The following are accessories which the manufacturer may select, depending on ratings, voltage and application:

1. Power Factor Meter
2. Varmeter
3. Under/Over Frequency Protection
4. Under/Over Voltage Protection
5. Short Circuit Sustaining Protection
6. Ground Fault Protection
7. Differential Protection
8. Surge Protection
9. Lightning Arrester
10. Synchronizing Check Relay
11. Other options as required for the particular application.

Additional items may be available.

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32	Reverse Power Relay	GEN	Generator
50/51	Overcurrent Time Delay Relay	F	Frequency Meter
51G	Stator Ground Fault Relay	PT	Potential Transformer
52	Circuit Breaker	RES	Ground Fault Resistor
86	Lockout Relay	SL	Synchronizing Light
87	Differential Protective Relay	SS	Synchronizing Switch
A	Ammeter	SYN	Synchroscope
AS	Ammeter Switch	V	Voltmeter
CT	Current Transformer	VRS	Voltage Regulator Cutout Switch
CCCT	Cross Current Compensation Transformer	VS	Voltmeter Switch
EXC	Exciter	W	Wattmeter

Figure 3-9
MANUAL PARALLELING HIGH VOLTAGE SYNCHRONOUS UNTS (3.12.3.2)

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Section 4
PROTECTION

4.1 BASIC FEATURES

The following features and accessories are necessary for the proper functioning of equipment and safety of operation:

4.1.1 Manual Trip

Each turbine shall be provided with a manual tripping device to close the trip valve or trip and throttle valve.

NEMA Standard 6-12-1985.

4.1.2 Overspeed Trip System

The overspeed trip system shall be sparkproof and shall include the overspeed sensing device, linkage, and a trip valve or a combined trip and throttle valve separate from the speed governor controlled valve(s).

NEMA Standard 11-14-1985.

4.1.3 Overspeed Sensing Device

The overspeed sensing device includes those elements which are directly responsive to speed and which initiate action to close the trip valve at a predetermined speed.

NEMA Standard 6-21-1979.

4.1.4 Trip Speed

The trip speed is the speed at which the overspeed sensing device is set.

NEMA Standard 6-21-1979.

4.1.5 Trip Valve

The trip valve is separate from the governor controlled valve(s) and is closed (tripped) in response to the action of the overspeed sensing device, other safety devices or manual trip device.

NEMA Standard 6-21-1979.

4.1.6 Combined Trip And Throttle Valve

The combined trip and throttle valve is separate from the governor controlled valve(s) and is closed (tripped) in response to the action of the overspeed sensing device, other safety devices or manual trip device. This valve permits manual throttling of steam to the turbine.

NEMA Standard 6-21-1979.

4.1.7 Overspeed Trip System Setting

The trip speed settings shown in Table 4-1 shall be above the speed reached due to the maximum speed rise characteristic of the governing system to avoid tripping the turbine on sudden loss of load.

NEMA Standard 6-12-1985.

When design or application of driven equipment requires trip speeds other than those shown in Table 4-1, the trip speed should be specified.

Authorized Engineering Information 6-21-1979.

Table 4-1
TRIP SPEED SETTINGS

Class of Governing System	Trip Speed Setting, Percent*
A	115
B	110
C	110
D	110

*All values are in percent of maximum continuous speed.

4.2 OVERCURRENT

A circuit breaker or contactor shall be supplied to protect the generator and controls from overload or short-circuits.

The circuit breaker shall continuously carry the generator's rated output current at rated voltage and shall be capable of interrupting the maximum available short circuit current.

The circuit breaker shall have provisions for manual opening and closing and for automatic tripping due to overcurrent.

The circuit breaker shall be designed to carry a specified overcurrent for a specified period of time without tripping.

Low voltage circuit breakers (up to and including 600V) shall be incordance with NEMA Standard AB1-1986, or ANSI/IEEE C37.13-1990.

NEMA Standard 6-12-1985.

A shunt trip should be supplied if necessary to trip the breaker in response to an external signal. Auxiliary contacts may be supplied for automatic closing of the breaker in response to other signals, or for indication of the breaker's position.

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Section 5
FACTORY TESTING

5.1 TURBINE

5.1.1 Hydro Test

1. All parts of the turbine which contain steam under pressure shall be hydro tested at a pressure not less than 1.5 times their maximum steam pressure. For steam temperatures above 750°F (400°C), the values of the test pressure shall be multiplied by a factor obtained by dividing the maximum allowable hoop stress of the material at room temperature by that of the corresponding stress value at the specified maximum steam temperature.
   Condensing turbine exhaust casings shall be steam or hydro tested at a minimum of 25 psig [172 kPa (gauge)].
   NEMA Standard 11-14-1985.
2. Water jackets, coils, or coolers shall be hydro tested to 1.5 times the specified cooling water pressure, but not less than 115 psig [793 kPa (gauge)].
   NEMA Standard 6-21-1979.
3. Pressure(s) shall be maintained for a period of 15 minutes. The test shall be considered satisfactory when no external leaks from the item under test are observed.
   NEMA Standard 6-21-1979.

5.1.2 No Load Running Test

The turbine shall be operated through the specified operating speed range at no load. The following tests and observations shall be made:

1. Check general operation
2. Measure vibration
3. Adjust the turbine control mechanism(s) and observe the operation of the speed governor and all other control devices to the extent practical.
   It should be noted that it is the turbine vendor's responsibility to provide governor and control mechanisms including all the specified features and options, however, electronic governing systems in particular may include features and options which due to system interface and operational requirements, are not practical to test in the turbine vendors shop. Proper operation of all control, governor mechanisms and systems must be rechecked, tested or verified on site as a part of the normal installation and start up procedure for the equipment.
4. Check for steam and oil tightness.
5. Check the setting of the overspeed trip and other safety devices.
6. For turbines with forced oil lubrication, check the control and lubricating oil temperatures and pressures after the oil has reached stable temperature conditions. The turbine shall be operated for a period of 1 hour without an undue rise in oil temperature. Turbines with oil ring or oil mist lubrication systems normally would not require the checking of oil temperatures during the no-load run test; however, proper operation of the oil rings when supplied shall be visually checked.
   NEMA Standard 6-21-1979.

5.2 GEAR

5.2.1 No Load Running Test

The gear shall be operated at the specified speed at no load. The following tests and observations shall be made:

1. Check general operation
2. Measure vibration
3. Check for oil tightness
4. Check the lubrication oil temperature and pressure after the oil has reached stable temperature conditions
5. Check any other safety devices.
   NEMA Standard 6-12-1985

5.3 GENERATOR

The following tests shall be made on all generators:

1. Check the resistance of armature and field windings
2. Check the exciter field current at no load with normal voltage and frequency on the generator
3. Winding high-potential test in accordance with NEMA Standard MG 1-1978 (R 1981).
4. Check general operation
5. Measure vibration
6. Check for oil tightness
7. Check the lubricating oil temperature and pressure after the oil has reached stable temperature conditions.
8. Check any other safety devices.
   NEMA Standard 6-12-1985

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5.4 COMBINED TEST (OPTIONAL)

For factory assembled turbine generator sets where a combined no load running test is applicable*, the following tests and observations shall be made:

1. Check alignment
2. Check general operation
3. Measure vibration
4. Check for oil tightness
5. Adjust and check the operation of turbine trip devices
6. Check the control and lubricating oil temperatures and pressures after the oil has reached stable temperature conditions.

NEMA Standard 6-12-1985

* Where a turbine generator set is assembled on site, a factory combined running test cannot be performed.

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Section 6
SOUND PRESSURE LEVELS

6.1 GENERAL

It is the manufacturer's intention to design and manufacture turbine generator units with satisfactory sound levels and to work cooperatively with the user to make an overall installation which will be as quiet as possible. The sound pressure level(s) measurement procedure described in these standards is presented as a guide to the user. To be meaningful, this measurement(s) should be taken on the installed turbine generator set.

However, the manufacturer does not have control over such factors as foundations, piping, and building configurations which emit, reflect, focus, or amplify the sound of the unit as well as generate other sounds. For example, piping will usually be a strong emissive source of sound-generating impulses originating in the turbine as well as the sound caused by the passage of steam in the piping system.

The user should control noise from other sources so that it does not significantly add to or completely mask that from the unit. In order to achieve this, the user should suitably insulate the steam piping.

Furthermore, it is generally impractical to isolate the turbine generator set from its environment sufficiently to separately measure its sound emission. The physical size of the equipment and the fact that it must be connected to piping makes isolation for sound measurement difficult, if not impossible.

Sound pressure levels listed in 6.2 represent sound pressure levels of the turbine, gear, and generator when operating at the maximum steam flow for which the turbine is de- signed. The maximum steam flow may be greater than that specified for operation at normal power, speed, and steam conditions.

Reduced sound pressure levels can be achieved through acoustic treatment.

Sound power levels are recognized as being beneficial in planning for noise control. Sound pressure levels are primary data upon which sound power levels can be estimated, but standard conversion procedures have not been adopted which are practical for the variety of acoustical environments encountered.

Authorized Engineering Information 6-21-1979.

6.2 SOUND PRESSURE LEVELS

Expected sound pressure levels for soleplate mounted equipment operating with maximum steam flow, normally occurring at rated power and speed and maximum steam conditions, are shown in Table 6-1.

For equipment mounted on a steel baseplate, add one additional decibel to tabulated values.

Actual sound pressure levels may not equal maximum tabulated values for all frequency bands. Overall dBA is, therefore, less than the sum of individual values.

Authorized Engineering Information 6-21-1979.

6.3 SOUND PRESSURE LEVEL MEASUREMENT PROCEDURE

Sound pressure levels shall be measured in accordance with American National Standard S5.1, Section 7.0, as it is applicable, summarized as follows:

Acoustical performance is based on a sound pressure level which is dependent on acoustical characteristics of the space in which the unit operates. All measured sound levels are assumed to be in hemispherical free field or semi-reverberant field which has room constant large enough so as to not significantly effect sound pressure levels at the measuring point.

A 6 decibel drop off in sound pressure level per distance doubling in each octave band of interest, as the microphone is moved away from each measurement location in all directions around the machine, indicates approximate free field conditions. Corrections must be made for environment when the drop off is less than 6 decibels.

All sound pressure readings shall be recorded as sound pressure levels in decibels at reference pressure of 2 times 10^{-5} Newton per square meter.

All sound pressure readings shall be made with an octave band meter set for slow response, recording the visual average of the readings.

Fluctuating noise levels equal to or higher than plus or minus 2 dBA overall shall be recorded.

The microphone shall be protected from external disturbing influences (vibration, air currents, and electric or magnetic fields) which may affect readings.

Microphone locations shall be approximately, but not less than, 1 meter from any sound source being measured and at a height 1.5 meters above the floor. Care shall be taken to avoid a position at the nodal point of standing wave. One set of readings should be all that is required if the microphone is so positioned. (This sentence is Authorized Engineering Information 1-30-91.) The position of the microphone for measuring background ambient sound and total sound shall be identical.

NEMA Standard 6-21-1979.

6.4 CORRECTION FOR BACKGROUND NOISE

Measurements of sound pressure levels should be corrected for ambient background sound pressure levels. Levels at each location should exceed background levels by at least 10 decibels in each octave band. If the difference between measured sound level and background sound

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Table 6-1
SOUND PRESSURE LEVELS

Frequency Band, Hertz	Mid-Band Frequency, Hertz	Maximum Sound Pressure Levels, Decibels				
		Turbines		Generators		
		Singlestage	Multistage	Gears	Open	Enclosed
45-90	63	98	106	105	102	92
90-180	125	94	98	101	101	91
180-355	250	91	97	97	102	92
355-710	500	89	92	95	102	92
710-1400	1000	89	90	95	101	91
1400-2800	2000	89	90	95	99	89
2800-5600	4000	89	90	95	97	87
5600-11200	8000	89	90	95	94	84
Overall dBA	...	93	95	95	105	95

level is less than 3 decibels in a given octave band, valid equipment sound level in that band cannot be determined. When the difference is greater, the following correction factor should be subtracted from the measured sound level:

Decibel correction factor =

(measured - background)dB			
3	4-5	6-9	10 and over
3	2	1	0

Consideration should also be given to effects of extraneous sound sources, such as piping, steam leakoffs or leakage from valves and piping. Sound levels from these sources may be so close to levels from the unit that a meaningful measurement will be difficult or impossible unless steps are taken to isolate the unit. It may be possible to accomplish this by insulating all piping, using acoustic barriers as appropriate, and covering some sound sources with lead blankets.

Authorized Engineering Information 6-21-1979.

6.5 Sound Resolution

Two measurements often must be added to determine the combined noise level of several sources or subtracted to find the noise output of one particular source in a noisy environment. However, noise measurements cannot be added or subtracted directly. Rather, measurements can be combined with a correction number. The correction numbers obtained from Figure 6-1 and 6-2 are approximate. However, the graphic results are fast and sufficiently accurate for most engineering applications.

The correction number is based on the difference in amplitude of two sounds - whether the sounds are being added or subtracted. When sounds are added, the correction number is added to the higher level. For example, 80 and 86 decibel sound levels differ in amplitude by 6 decibels, a difference that yields a correction number of 1 from Figure 6-1. Thus, total sound level is 87 decibels.

When background noise is subtracted from the total sound level, the correction number is subtracted also. For example, a 90 decibel background noise and a 97 decibel total sound level differ in amplitude by 7 decibels, a difference that yields a correction number of 1 from Figure 6-2. Thus the sound level without the background noise is 96 decibels.

Authorized Engineering Information 6-21-1979.

6.6 INSTRUMENTS

Sound pressure levels should be measured by means of a sound level meter which meets the requirements of American National Standard S1.4.

A full-octave-band sound analyzer, meeting the requirements of American National Standard S1.11, should be used in conjunction with the sound level meter to measure sound.

Instruments, including microphones, should receive an acoustic check on overall calibration before and after every sound pressure level test.

Authorized Engineering Information 6-21-1979.

6.7 SOUND ATTENTUATION

It is recommended that acoustical treatment for turbine generator units be applied after installation of the equipment and ensuing plant operation. Factors which affect sound levels are many and varied and may not be associated as closely with the machinery itself as with steam velocities in piping and other sound sources.

After installation and operation has commenced, an overall plant sound level can be established and corrective measures taken to isolate the major sound producing portions of the process.

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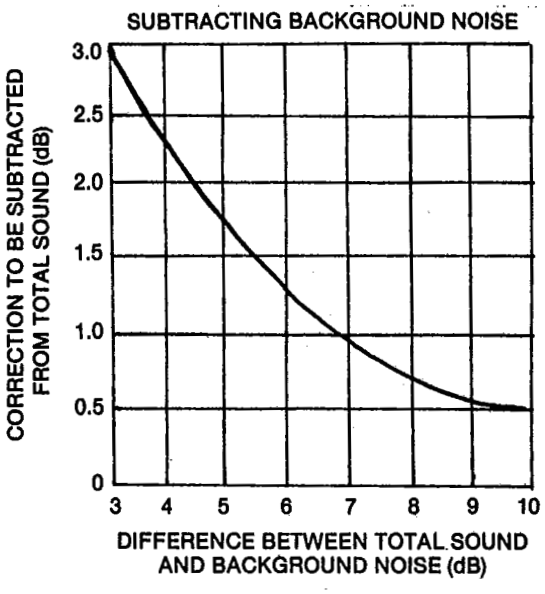


Figure 6-1
CORRECTION FOR BACKGROUND NOISE

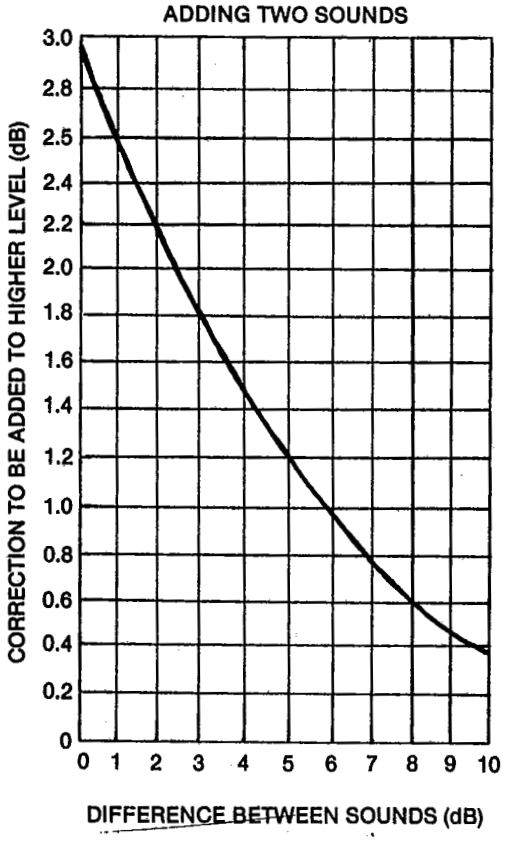


Figure 6-2
SOUND RESOLUTION

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Section 7
PREPARATION FOR SHIPMENT AND STORAGE

7.1 SHIPPING PREPARATION

The turbine gear (if used), generator, and all separate parts shall be properly tagged and identified.

At the time of shipment, all exposed nonmachined surfaces shall be protected with one coat of shop paint and coating or covering or both. All exposed machined surfaces and oil reservoir interiors shall be protected with a rust preventative. All openings except for air passageways on open type generators shall be plugged or covered. The interiors of the turbine gear (if used), and generator bearing housing shall be suitably treated to prevent rust.

Prior to shipment, the rotor of a generator with sleeve bearings shall be braced in place to prevent axial movement of the rotor during shipment.

Ocean freight or extended storage shall require additional protection and packaging.

NEMA Standard 11-14-1985.

The preparation assumes that storage will be so arranged that the equipment will be protected against loss, corrosion and weather damage.

Authorized Engineering Information 11-14-1985.

7.2 SHIPMENT

The purchaser, since he has the most complete knowledge of local conditions, should specify the delivery point and provide information on the method of handling to the point of delivery.

The manufacturer should use shipping methods and ship parts in the sequence required for orderly installation and identify all shipments by marking individual parts, assemblies or packages prior to shipment.

The manufacturer should specify the additional preparation and protective coatings that should be provided to protect the equipment if the installation is delayed.

The purchaser should advise the manufacturer of the unloading facilities available and whether skids will be necessary for rolling large assemblies into position.

Authorized Engineering Information 11-14-1985.

7.3 RECEIPT AND STORAGE OF EQUIPMENT

Upon receipt, the purchaser should check all equipment for damage which may have occurred in transit. Any damage or shortages should be reported immediately to the transportation company and a copy of the report forwarded to the manufacturer.

All material should be checked against the manufacturer's packing list, and any discrepancies reported immediately to the manufacturer.

The equipment should at all times be stored in a clean, noncorrosive atmosphere and protected against loss, weather, damage, and foreign materials such as dust, sand, and so forth. Indoor storage where constant temperature is maintained at a level which will prevent condensation is preferred. The purchaser should seek the manufacturer's advice if storage conditions are other than the above.

Special attention and care should be given to the storage of parts having exposed machined surfaces.

The generator should be stored with enough packaging removed to allow circulation of air through the windings. The winding temperature should be maintained at approximately 10°F (6°C) above ambient temperature by means of the generator's space heaters (if the generator is so equipped) or other reliable means.

The resistance of the generator insulation should be measured at the start of storage, every three months thereafter, and just prior to energization.

Before start-up, the oil or preservative used in the bearing housing and gear casing should be flushed out and replaced with clean lubricating oil of the recommended type. Grease lubricated bearings may require lubrication prior to start-up. Prior to start up, forced lubrication systems should be checked for proper operation.

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Section 8
INSTALLATION

8.1 INTRODUCTION

The turbine generator set should be installed in accordance with recommendations and instructions issued by the manufacturer.

The information contained in Section 8 is provided to assist the purchaser or his contractor in the proper handling and installation of turbine generator sets. There are many variables involved in the equipment furnished, method of shipment, and types of installation, therefore, it is not feasible to detail step-by-step procedures.

Authorized Engineering Information 11-13-1969.

8.2 SUPERVISION OF INSTALLATION

It is recommended that the manufacturer's representative supervise the installation of the turbine generator set. The installation procedure should be in accordance with recommendations and instructions issued by the manufacturer either on drawings or by other means. Such procedures are arranged and planned to obtain the most satisfactory installation and operation of the equipment.

Fully qualified labor, including qualified supervision, is required for proper installation, start-up and operation.

Authorized Engineering Information 6-21-1979.

8.3 INSTALLATION

Proper installation is necessary for satisfactory operation. The user should provide an adequate foundation to maintain alignment and should install piping to minimize external forces and moments on the turbine.

Sufficient space and necessary openings in the foundations and building structure should be provided for the installation of the equipment. Suitable openings should be provided in the building to admit the equipment. The purchaser should provide sufficient space around the equipment for servicing. Adequate space should be provided above the turbine to allow removal of the casing cover, and adequate space should be allowed behind the generator for removal of the generator rotor. Adequate floor space should be allowed for setting down the turbine cover, gear casing cover (if a gear is used), and the properly supported rotating elements of the turbine, gear (if used), and generator.

Authorized Engineering Information 11-14-1985.

8.3.1 Foundation

Foundations should be sufficiently heavy and rigid to form a permanently nonwarping structure.

The manufacturer should furnish dimensional drawings to enable the purchaser to design a suitable foundation of ample proportion and strength for the equipment specified. The foundation should be designed so that it will absorb to a large extent the vibration of the unit installed on it. The foundation should be isolated from the building structure by means of spacers (felt, cork, and so forth) so that outside vibration will not be transmitted to the foundation. The natural frequency of the foundation should not correspond to any operating speed of the unit.

Authorized Engineering Information 11-14-1985.

8.3.2 Steam Inlet and Exhaust Piping

The purchaser should insulate steam lines and the turbine to limit heat losses and to protect operating personnel.

Steam piping should be as short and as direct as possible and so arranged that no undue strain is imposed on the turbine due to expansion and contraction of the steam lines or the weight of the steam lines.

Expansion in the high pressure steam lines should be taken care of by bends, supports, or other suitable methods in the piping system. On low pressure lines, expansion and contraction should be taken care of by expansion joints or other suitable devices. To avoid localized heating, lines carrying high pressure steam should not be located too close to the foundation bearing supports.

The pressure losses in the inlet and exhaust steam piping should be taken into account when determining the required pipe sizes. The piping should be of sufficient size to give no less than the minimum specified initial and no more than the maximum specified exhaust pressure at the turbine connections when the turbine is developing rated power at rated speed.

Steam piping should be designed in accordance with appropriate codes and specifications. In order to minimize pressure drop, noise, and erosion, it is recommended that piping be sized so that the steam velocities shown in Table 8-1 will not be exceeded in the steam piping when the turbine is operating at rated power and rated steam conditions.

Table 8-1
MAXIMUM STEAM VELOCITY, IN PIPING

	Noncondensing Turbine		Condensing Turbine	
	Ft./Sec.	m/sec	Ft./Sec.	m/sec
Inlet	175	53	175	53
Exhaust	250	76	450	137
Induction	175	53	175	53
Extraction	250	76	250	76

8.3.3 Cleaning of Turbine Steam Piping

A source of clean steam, free from foreign particles, must be provided to the inlet of the turbine connections. The

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station piping and the boiler system should be cleaned in accordance with the procedures subsequently suggested in order to assure the availability of clean steam.

Steam blowing is required for all main steam, seal and admission piping before the steam turbine is put into operation. Steam blowing greatly reduces potential damage to the turbine by weld beads and pipe slag.

Steam blowing is best achieved by repeated heating and cooling which will cause alternate expansion and contraction in the piping which will help loosen pipe scale. It is for this reason that the blowdown should be at full pressure and temperature for several minutes to allow the pipe to get as near to operating temperature as possible. The piping should be allowed to cool before starting the next blow down.

A minimum of three blows should be performed, and all subsequent blows should use a polished steel target at the end of the blow down line to act as an indication of cleanliness. Targets should be polished on both sides to obtain double usage. A new target should be used for each test and the target compared to a new one until they appear to be the same. See Figure 8-1 for suggested target installation.

The purchaser should provide temporary piping required for the blowdown. It is always advisable to blow to atmosphere outside the station in an area where steam or particles would not injure personnel or affect equipment. This blow piping must be large enough to develop a mass velocity head in the permanent piping at least equal to that developed during full load operation. Blowdown lines should be installed with adequate anchors to prevent pipe whipping or damage. The trip throttle valve and strainer must be removed and all valves in the main header should be wide open.

The following procedure should be used for sizing the temporary blow down line:

Since the force on a particle is proportional to the mass velocity head of the fluid, it appears reasonable that the mass velocity head developed during the blowing cycle must be at least equal to that developed during full load operation. This should take care of most loose pieces. However, a time factor is involved; no one can be sure how long it takes pipe scale to loosen up, or such things as pieces of welding rod to work their way through the pipelines and superheater tubes.

Calculations can be made to show how much flow and what drum pressure are necessary for an assumed temporary pipe size to achieve a mass velocity head during cleaning equal to that attained during full load operation, based on the following:

1. As a first attempt, assume that the velocity at the pipe exit to atmosphere during blowdown is sonic, and that the pressure, P_p just inside the pipe at the exit is 30 psia. To make this assumption, it is necessary that all of the flow areas in the system be equal to, or larger than, the discharge area.
2. Estimate the steam conditions (pressure, enthalpy) at the boiler outlet expected during steam blowdown. From the curves in Figure 8-2 read the mass flow function, F_{30}. Calculate the massflow, Q_c, as follows:
   $Q_c = F_{30} \times A_p$
   where A_p is the area of the pipe at discharge ($in.^2$).
3. It is necessary to calculate the pressure drop through the temporary and permanent piping to arrive at a boiler pressure. Refer to Figure 8-3. This curve should be used to determine the pressure drop near the discharge end of the temporary piping, since the velocity is near sonic and an ordinary calculation of pressure drop due to friction does not apply.

In applying Figure 8-3, assume as a first trial that L is the total equivalent length of the temporary piping, including the equivalent length of elbows, tees, etc. in the temporary system. Calculate the $\frac{FL}{D}$ and enter the curve in Figure 8-3 and thus calculate P, the pressure at the distance L from the exist. Note that if $\frac{FL}{D}$ of the temporary pipe is more than 5, use a shorter L which will make $\frac{FL}{D}$ equal 5 and use corresponding P/P_p to calculate P at the shorter L. Where $\frac{FL}{D}$ is greater than 5, the pressure drop is a straight-line function of L and can be calculated by the conventional method. Then calculate, by conventional straight-line methods, the pressure drop due to friction in the piping from point L from the exit to the boiler outlet, thus arriving at the boiler outlet pressure, P_c.

4. Next, calculate the cleaning force ratio at the boiler outlet, using the calculated P_c and the expected enthalpy. This ratio compares the mass-velocity head during cleaning with that developed during normal full-load operation. The cleaning force ratio is expressed by:

$$R = \left(\frac{(Q_c)^2}{(Q_{max})}\right) x \frac{(P_v)_c}{(P_v)_{max}} x \frac{(P_{max})}{(P_c)}$$

where:

Q_c = calculated flow during cleaning, lb/hr
Q_{max} = maximum load flow, lb/hr
$(P_v)_c$ = pressure-specific volume product during cleaning at boiler outlet, ft^3/in^2
(P_{max}) = pressure at maximum load flow at boiler outlet, psia
(P_c) = pressure during cleaning at boiler outlet, psia
$(P_v)_{max}$ = pressure-specific volume product at maximum load flow at boiler outlet, ft^3/in^2

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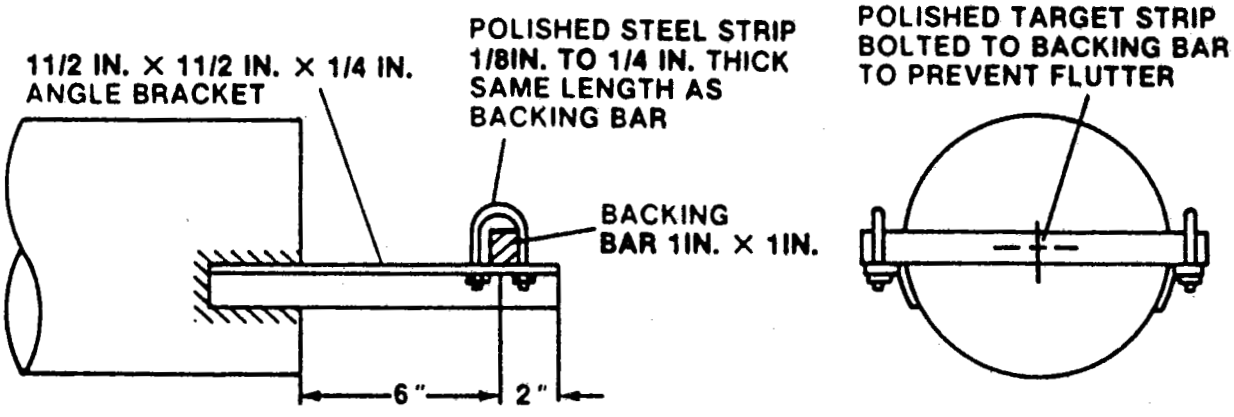


Figure 8-1
BRACKET SUPPORT FOR POLISHED TARGET

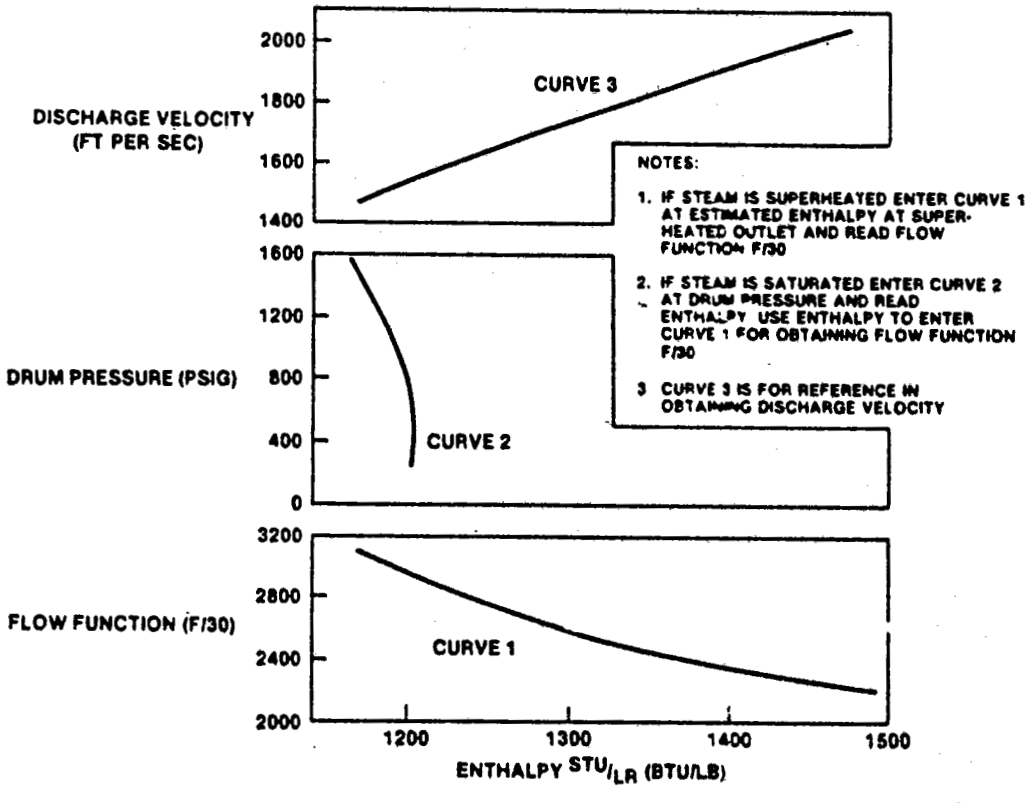
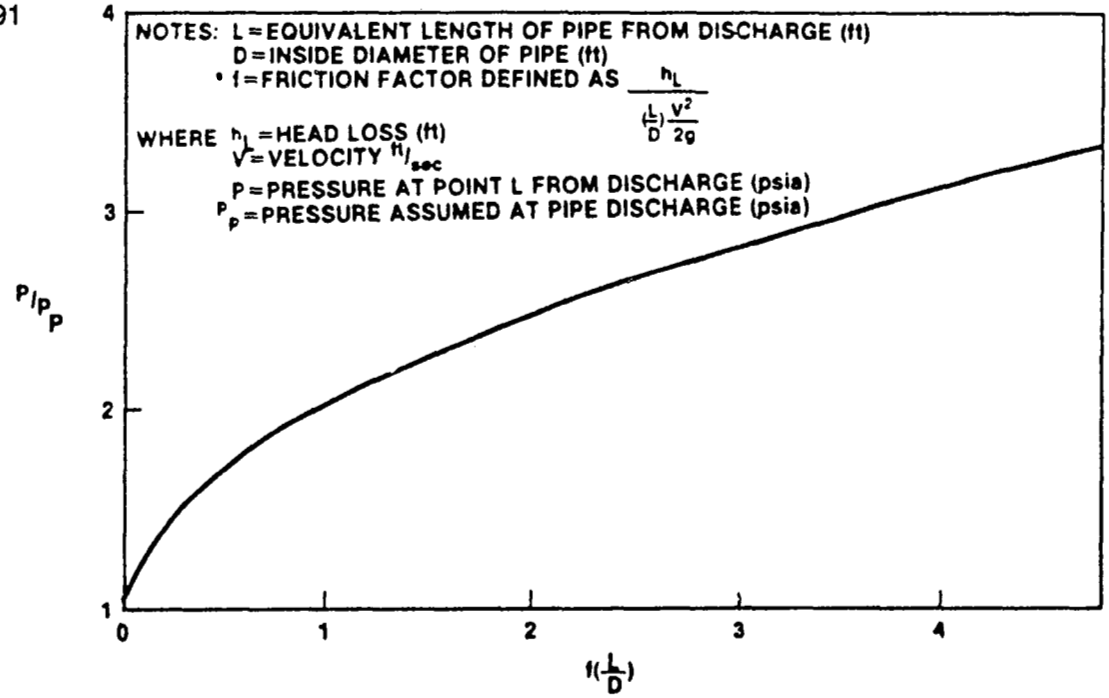


Figure 8-2
BLOWDOWN DISCHARGE VELOCITY AND FLOW FUNCTION FOR 30 PSIG DISCHARGE PRESSURE VS STEAM ENTHAPLY

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• IT WOULD APPEAR REASONABLE TO TRY f = 0.0035 AS A FIRST TRY

Figure 8-3
PRESSURE DISTRIBUTION NEAR THE END OF A PIPE DISCHARGING STEAM AT SONIC VELOCITY

5. If this ratio, R, is less than one and the steam velocity in the superheater tubes is less than twice the allowable, divide the pressure assumed inside pipe exit, P_p, by this ratio and repeat the above process. Thus, the required flow and pressures for equivalent cleaning forces can be determined, thereby establishing the required sizes for the temporary blowpipes. Note that for a discharge pressure different than 30 psia, the flow function is

$$F_p = F_{30}\frac{P_p}{30}$$

The size of the temporary pipe is a most important factor. The use of a larger pipe will result in lesser flows and lesser pressure levels required for the same cleaning force. The size effect is proportional to the ratio of diameters to the fourth power. In no case, however, should the temporary pipe have a greater flow area than the permanent piping.

Pressure readings during blowdown should be taken at the inlet to the stop valves and as close as possible to the blowdown pipe discharge. The latter connection should be made at a convenient location, but not less than 20 diameters from the discharge end of the blowpipe in order to obtain a stable pressure reading. These readings will help substantiate the calculated boiler pressure and pipe sizes selected for the blowdown operation.

A full size block valve, safely located, should be used to perform the blow. Adequate phone communication between the boiler room and the operator at the blow down valve must be established. This might also be backed up by a system of visual communication, such as indicating lights, since phone communication may become difficult due to the high noise level at the blowdown valve. An arrangement should also be made to record the pressure readings at the various stations simultaneously through proper communications.

When performing the blow, the blow down valve should first be cracked so as to get a gradual warming of all the steam lines. When the lines are adequately warmed up, open the blow down valve all the way as fast as possible. When the boiler pressure has dropped to approximately 150 psig [1035 kPa (gauge)], close the blow down valve rapidly so that the boiler pressure does not drop below 100 psig [690 kPa (gauge)].

Steam seal piping or any other lines that might bring steam to the turbine must be blown down. Weld spatter and other foreign material that may be contained within the steam seal piping can do appreciable damage to both the steam seal packing and the turbine shaft. Therefore, it is prudent to direct as much attention to the cleaning of this piping as has been stated for main steam lines.

It is important that the blowing operation be conducted after all of the field welding is completed. Although not the turbine manufacturer's responsibility, it is a good practice to have a service supervisor witness at least the final blow down.

It is left to the customer's discretion to determine the most practical method of cleaning factory prefabricated lines which may become contaminated in the field. These

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lines should be cleaned and given several good blows prior to final assembly. For short runs which cannot be blown down, mechanical cleaning may be adequate. Lines leading from the turbine to the customer's steam lines should also be blown out for the best interests of the customer.

Authorized Engineering Information 11-14-1985.

8.4 STEAM PIPING SYSTEMS

8.4.1 Introduction

Reactions of piping systems connected to steam turbines, if of sufficient magnitude, will result in misalignment of the turbine sufficient to cause rough operation and serious mechanical damage. Steam turbines have been very carefully designed to provide for thermal expansion and, at the same time, maintain close alignment between the turbine rotating and stationary parts, and also the turbine and driven equipment. The provisions for turbine thermal expansions by necessity limit the allowable values of forces and moments applied to the turbine structure by the piping connected to it.

It is the purpose here to briefly discuss piping arrangements and recommend flange loading limitations imposed on steam turbines by piping. This information is presented as an aid to the user and is not intended as a self contained thesis on piping.

The recommendations to be discussed should provide allowable values of forces and moments at the turbine connections for steam inlet, extraction, and exhaust piping.

It is not considered necessary to supply values for auxiliary piping such as steam leakoff, lubricating oil, and cooling water, but even so, this auxiliary piping should also be designed such that turbine expansion is not restrained.

Authorized Engineering Information 6-21-1979.

8.4.2 The Piping Problem as Applied to Turbines

One of the first considerations in designing any piping system is to keep the stresses in the pipe within the limits of ANSI/ASME B31.1 and any local codes that may be applicable. In general, the jurisdiction of such authorities stops at the turbine inlet and exhaust connections or other openings on the machine to which external piping systems connect.

In order to keep the strains due to forces and bending moments on the turbine connections, including the weight of the pipe, within recommended limits, the piping system design should be such that restraints and freedom of movement match the requirements of the turbine. Pipe forces which seem small may lead to large forces at the connections to the turbine and to very large forces at the turbine supports.

The forces in piping systems under operating conditions can be grouped into three classes: those due to steam pressure, temperature, and dead weight.

Authorized Engineering Information 6-21-1979.

8.4.3 Forces Due to Steam Pressure

These are most commonly associated with low pressure and vacuum lines where expansion joints are often used to provide flexibility. If an expansion joint is improperly used, it may cause a pipe reaction greater than the one which it is supposed to eliminate. An unrestricted expansion joint will cause an axial thrust equal to the effective area of the bellows times the internal pressure. The magnitude of these forces may be greater than the limits for the exhaust flange. In order to have the lowest reaction when it is found that expansion joints are required, the Standard of the Expansion Joint Manufacturers Association should be consulted.

The following figures and paragraphs represent typical installations and are offered only as guides.

Figure 8-4 shows an expansion joint in a pressure line. The axial thrust from the expansion joint tends to separate the turbine and the elbow. To prevent this, the elbow should have an anchor to keep it from moving. The turbine should also absorb this thrust and, in doing so, becomes an anchor. This force on the turbine may be greater than can be allowed. In general, this method should be discouraged.

Figure 8-5 shows the same piping arrangement as Figure 8-4 except for the addition of tie rods on the expansion joint. The tie rods prevent the elongation of the joint and take the axial thrust created by the internal pressure of the expansion joint so it is not transmitted to the turbine flange. The tie rods eliminate any axial flexibility, but the joint is still flexible in shear; that is, the flanges may move in parallel planes. The location of this type of joint in the piping should be such that movement of the piping puts the expansion joint in shear instead of tension or compression.

Figure 8-6 is an arrangement frequently used, having tie rods as indicated for noncondensing operation. This arrangement should prevent any thrust due to internal pressure of the expansion joint from being transmitted to the exhaust flange and retains the axial flexibility of the joint. It may be used for either vacuum or pressure service (by suitable arrangement of the rods).

Figure 8-7 shows a suggested arrangement for a condensing turbine with an "up" exhaust. Due to the large exhaust pipe size normally encountered on condensing turbines, the exhaust piping may be relatively stiff, and an expansion joint should be used at some point to take care of thermal expansion. An unrestricted expansion joint placed at the exhaust flange of the turbine may exert an upward or lifting force on the turbine flange which in many cases is excessive. Figure 8-7 provides the necessary flexibility to take care of thermal expansion without imposing any unnecessary lifting force on the turbine. The expansion joint is in shear which is the preferred use. The relatively small vertical expansion may compress one joint

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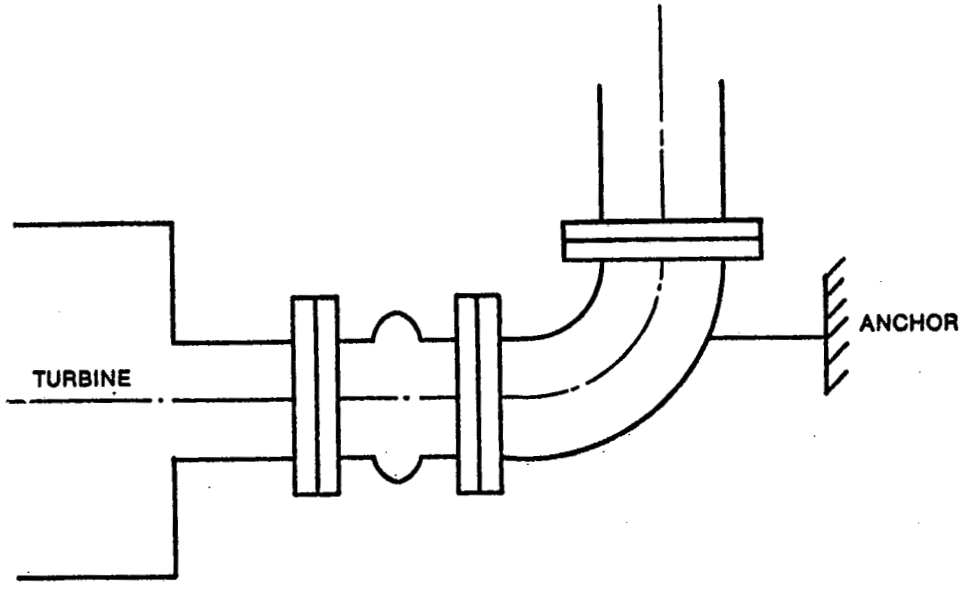


Figure 8-4
UNRESTRAINED EXPANSION JOINT
(MAY IMPOSE AN UNACCEPTABLE THRUST FORCE ON THE TURBINE.)

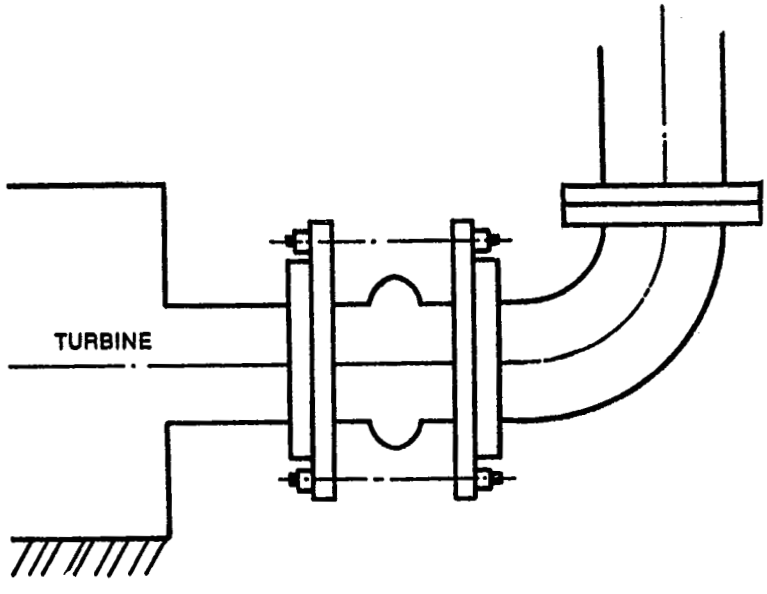


Figure 8-5
EXPANSION JOINT WITH TIE RODS
(FLEXIBLE IN SHEAR ONLY)

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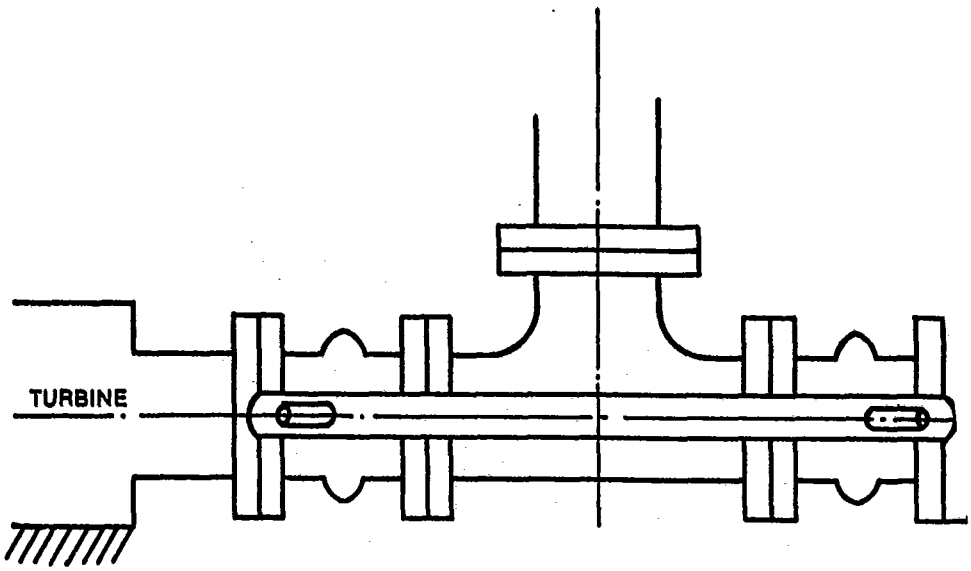


Figure 8-6
EXPANSION JOINT WITH TIE RODS FOR NONCONDENSING OPERATION (PROVIDES AXIAL FLEXIBILITY WITHOUT IMPOSING THRUST ON THE TURBINE.)

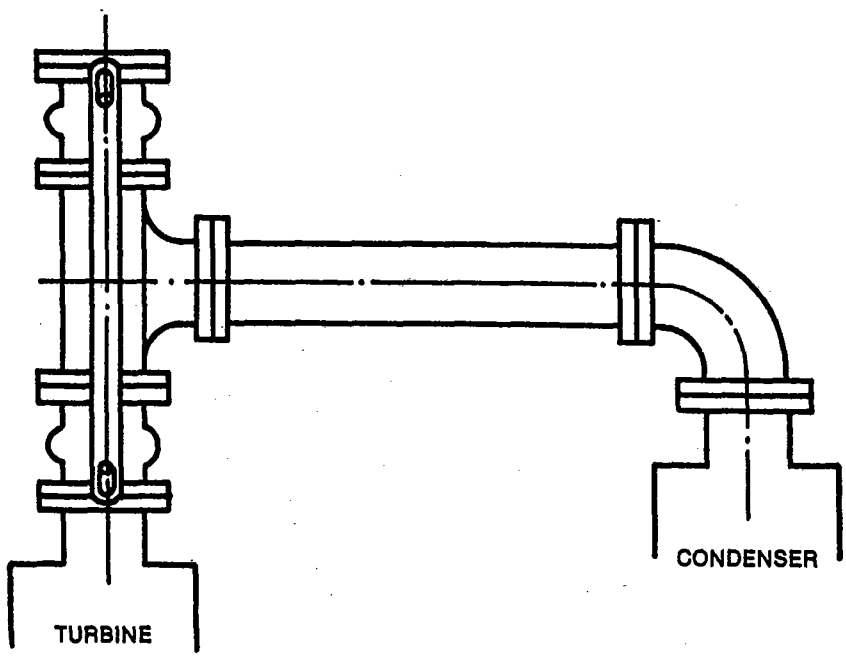


Figure 8-7
EXPANSION JOINT WITH TIE RODS FOR CONDENSING OPERATION WITH "UP" EXHAUST (PROVIDES VERTICAL FLEXIBILITY WITHOUT IMPOSING THRUST ON THE TURBINE.)

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and elongate the other which causes a small reaction only and may be well within the turbine flange limits.

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8.4.4 Forces Due to Temperature

If a pipe is connected to some point as A in Figure 8-8, and has the configuration shown by the solid line, it may assume the approximate position shown by the dash line when heated to a higher temperature, providing no restraint is offered by point B.If both points A and B are rigid points which may not move, the pipe may assume a shape similar to that shown by the dash line in Figure 8-9 when heated.

The stresses may be reduced by using expansion loops such as shown in Figure 8-10. When piping does not have to be confined to one plane, torsional flexibility may be effectively used to reduce stresses. Prestressing the pipe in the cold condition or "cold springing" may also be used to reduce the stresses in operation. These principles may be used in combination to produce a design with flexibility sufficient to keep the stresses, forces, and moments within the permissible limits in both the hot and cold conditions.

The piping system should be designed with sufficient inherent flexibility to take care of thermal expansion. Prestressing (cold springing) to reduce the maximum values of both connection reactions and piping stress is accomplished by cutting the pipe short by a predetermined amount and then forcing it into place during installation as illustrated in Figure 8-11. Forces and moments in the hot condition are thus reduced below the values they would have if the system were not cold-sprung. Points A and C of Figure 8-11 are the points to be connected by a piping systems and (delta)X and (delta)Y are the respective expansions.

Forces and moments imposed on the turbine should not exceed values calculated per Section 8.4.6 when operating within the temperature ranges shown in Table 8-2.

In the case of welded connections, it is necessary to bend the pipe by putting a moment on it when connecting it to point C to make the weld preparations parallel, as well as just pulling B up to C. If this is not done, a moment may exist in the hot condition, and desired reduction in forces and moments may not be obtained. Wherever possible, it is wise to facilitate assembly by locating field welds at points of minimum moment. Points D and E are such points.

Authorized Engineering Information 6-21-1979.

The turbine manufacturer should be consulted to assure that the turbine can withstand forces and moments which will be imposed by cold-sprung piping in the cold condition.

Authorized Engineering Information 6-21-1979.

8.4.5 Forces Due to Dead Weight

The dead weight of the piping should be entirely supported by pipe hangers or supports. There are basically two types of supports—rigid and spring. Rigid supports are necessary when an unrestricted expansion joint is used. Rigid supports may be used to limit the movement of a line to prevent excessive deflection at any point. A rigid support is not satisfactory where thermal expansion may cause the pipe to move away from the support.

On the two types of rigid supports shown in Figure 8-12, the rise of the turbine connection due to temperature may lift the base elbow from the support so the turbine would have to support the weight of the pipe. The expansion of the vertical run of pipe would relieve the pipe hanger of its load so the turbine would again have to support the weight of the pipe.

If an expansion joint with restraining tie rods is used, either a rigid pipe hanger or a base elbow with a sliding or rolling contact surface may be used as shown in Figure 8-13.

When the thrust due to an expansion joint is less than the exhaust flange limits and no restraining tie rods are used, the pipe should have an anchor as shown in Figure 8-14. Since this condition rarely exists, it is better to use the preferred arrangements as shown in Figure 8-13 and eliminate as much pipe reaction as possible rather than just stay within the limits.

Spring hangers or supports are best suited to carry the dead weight when there is thermal expansion to be considered. The movement of the pipe may change the spring tension or compression a small amount, and the hanger loading a small amount, but may not remove the load from the hanger. Published manuals on pipe design provide information on hanger spacing to give proper support. In addition to this, it may be found necessary to add additional supports or move existing supports if resonant vibration appears in the piping.

A spring support should not be used to oppose the thrust of an expansion joint. When the pressure is removed from the line, the spring support may exert a force the same as the expansion joint only in the opposite direction.

Authorized Engineering Information 6-21-1979.

8.4.6 Allowable Forces and Moments on Steam Turbines

The forces and moments acting on steam turbines due to the steam inlet, extraction, and exhaust connections should be limited by the following:

8.4.6.1 The total resultant force and total resultant moment imposed on the turbine at any connection should not exceed the values per Limit 1.

$$3F_R + M_R \leq 500D_e \qquad \text{(Limit 1)}$$

where:

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F_R = Resultant force (pounds) at the connection. This includes pressure forces where unrestrained expan sion joints are used except on vertical down ehausts. Full vacuum load is allowed on vertical down ex haust flanges. It is not included as part of the piping load from Figure 8-15:

$F_R = \sqrt{F_x^2 + F_y^2 + F_z^2}$

M_R = Resultant moment (foot-pounds) at the connection from Figure 8-15

$M_R = \sqrt{M_x^2 + M_y^2 + M_z^2}$

D_e = Nominal pipe size of the connection in inches up to 8 inches in diameter.

For sizes greater than this, use a value of

$$D_e = \frac{(16 + \text{Nominal diameter})}{3}$$

8.4.6.2 The combined resultants of the forces and moments of the inlet, extraction, and exhaust connections, resolved at the centerlines of the exhaust connection should not exceed the values per Limit 2.

a. These resultant should not exceed:

$2F_c + M_c \leq 250D_c$ (Limit 2)

where

F_c = Combined resultant of inlet, extraction, and exhaust forces, in pounds.

M_c = Combined resultant of inlet, extraction, and exhaust moments, and moments resulting from forces, in pound-feet.

D_c = Diameter (in inches) of a circular opening equal to the total areas of the inlet, extraction, and exhaust openings up to a value of 9 inches in diameter. For values beyond this, use a value of D_c equal to:

$$D_c = \frac{(18 + \text{Equivalent diameter})}{3}$$

b. The components (Figure 8-15) of these resultants should not exceed:

$F_x = 50\ D_c$ $M_x = 250\ D_c$

$F_y = 125\ D_c$ $M_y = 125\ D_c$

$F_z = 100\ D_c$ $M_z = 125\ D_c$

The components are as follows:

F_x = Horizontal components of F_c parallel to the turbine shaft.

F_y = Vertical component of F_c.

F_z = Horizontal component of F_c at right angles to the turbine shaft.

M_x = Component of M_c around the horizontal axis parallel to the turbine shaft.

M_y = Component of M_c around the vertical axis.

M_z = Component of M_c around the horizontal axis at right angles to the turbine shaft.

Allowable forces and moments for turbines with various inlet and exhaust sizes are shown on Table 8-3.

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8.4.6.3 For installation of a condensing turbine with a down exhaust and an unrestrained expansion joint at the exhaust, an additional amount of force caused by pressure loading is allowed. (This additional force is perpendicular to the face of the exhaust flange and central.) For this type of application, calculate the vertical force component on the exhaust connection excluding pressure loading. Use this number for vertical force component on the exhaust connection in making calculations outlined in 8.4.6.1 and 8.4.6.2.

The force caused by the pressure loading on the exhaust is allowed in addition to the values established by the foregoing up to a maximum value of vertical force in pounds on the exhaust connection (including pressure loading) of 15.5 times the exhaust area in square inches.

8.4.6.4 These values of allowable forces and moments pertain to the turbine structure only. They do not pertain to the forces and moments in the connecting piping, flange, and flange bolting, which should not exceed the allowable stress as defined by applicable codes and regulatory bodies.

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8.4.6.5 See Sample Problems 8A, 8B and 8C for examples of how these force and moment limitations are applied to turbine installations.

8.5 DRAIN PIPING

Individual drain piping should be provided with shutoff valves or traps.

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8.6 LEAK-OFFS

Leak-offs should be piped directly to an open drain vented to the atmosphere without valves or restrictions, or to a condensate recovery system. The pipe should be adequately sized to avoid pressure buildup.

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8.7 FULL-FLOW RELIEF VALVE

The turbine casing and internal parts should be protected against excessive pressure by the installation of a full-flow relief valve. The relief valve is connected into the piping system between the turbine exhaust connection and the first shut-off valve. This relief valve should not be confused with the sentinel warning valve which when supplied, is mounted on the turbine casing.

The full-flow relief device should be provided by the user as part of the piping installation which is external to the turbine. In condensing applications, a full-flow relief valve or rupture disc may be provided as part of the condenser or the turbine.

The size of the full-flow device should be such that it will exhaust to the atmosphere the maximum quantity of

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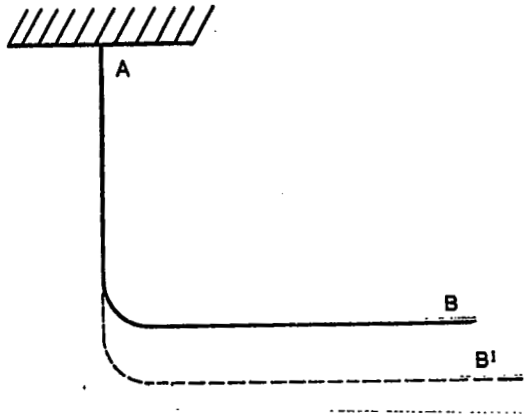


Figure 8-8
FREE EXPANSION

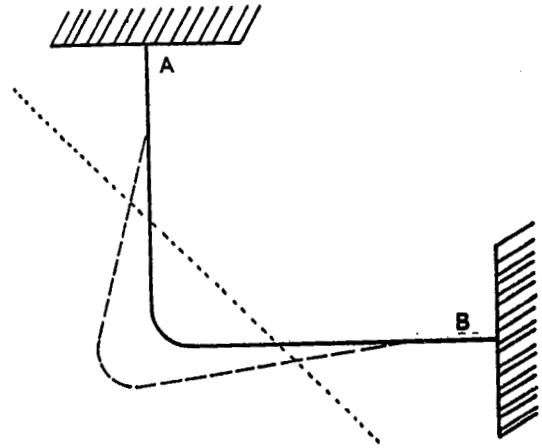
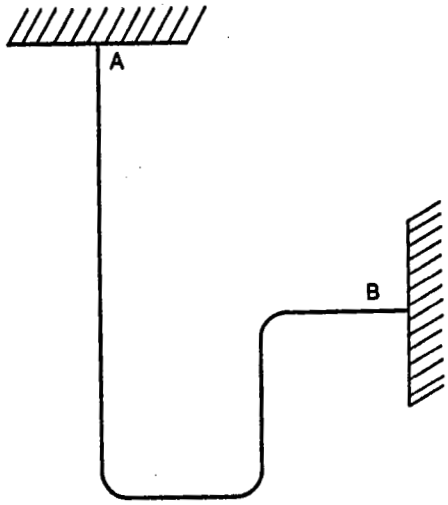


Figure 8-9
RESTRICTED EXPANSION



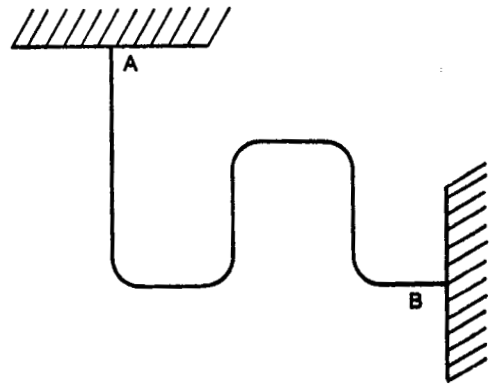


Figure 8-10
EXPANSION LOOPS

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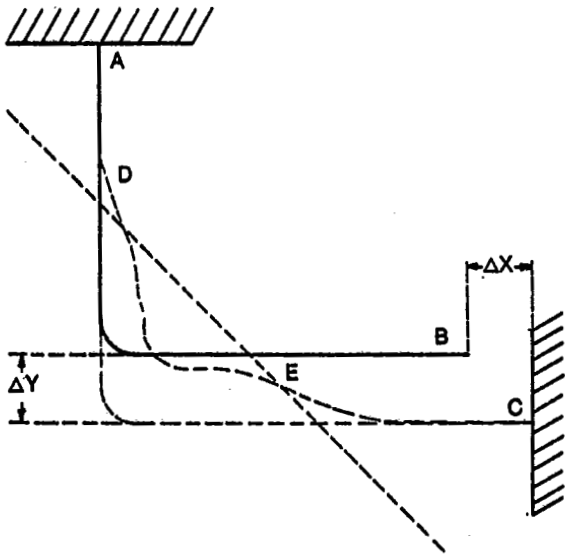


Figure 8-11
PRE-STRESSING (COLD SPRINGING)

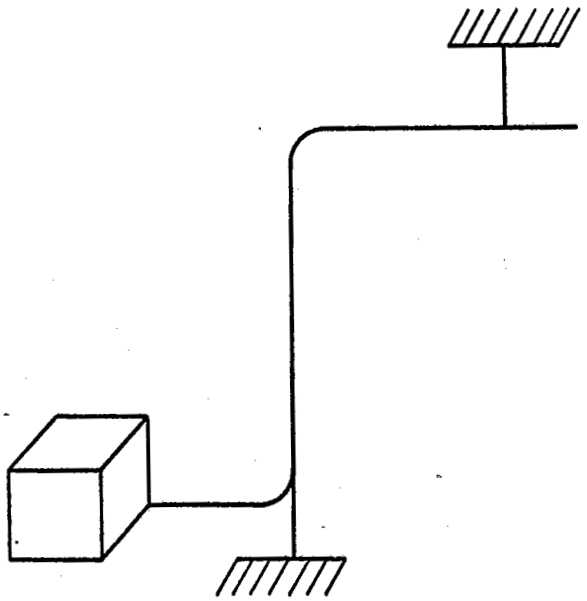


Figure 8-12
DEAD WEIGHT SUPPORT

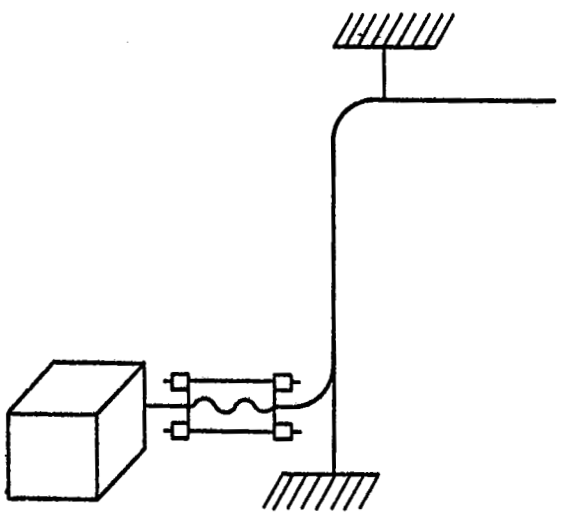


Figure 8-13
DEAD WEIGHT SUPPORT WITH RESTRAINED EXPANSION JOINT

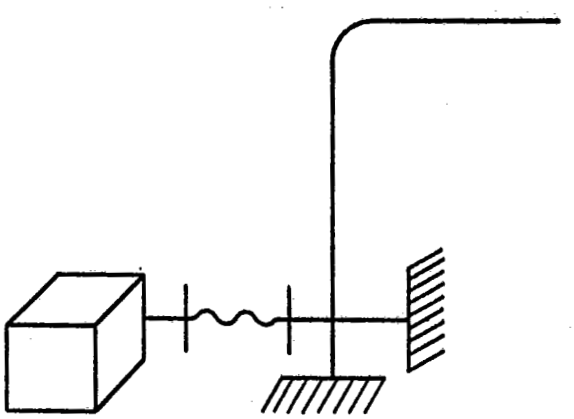


Figure 8-14
DEAD WEIGHT SUPPORT WITH UNRESTRAINED EXPANSION JOINT

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Table 8-2
Temperature Ranges for Forces and Moments

	Minimum Temperature	Maximum Temperature
Inlet Piping	Minimum ambient air temperature	50°F (28°C) above maximum inlet steam temperature.
Induction Piping	Minimum ambient air temperature	50°F (28°C) above maximum induction steam temperature.
Extraction Piping	Minimum ambient air temperature.	Maximum extraction steam temperature which can occur during operation.
Exhaust Piping (Noncondensing turbine)	Minimum ambient air temperature.	No-load exhaust steam temperature based on maximum inlet steam
Exhaust Piping (Condensing turbine)	Maximum ambient air temperature.	Saturation temperature at 5 psig [35 kPa (gauge)] 230°F (110°C).

steam (as determined by the turbine manufacturer) which will pass through the turbine nozzles with maximum initial steam conditions.

For condensing turbines, the full-flow relief device should give full relief at no more than 10 psig (70 kPa gauge).

For extraction turbines or back-pressure turbines, the full-flow relief device should open at 10 psi (70 kPa) or 10 percent (whichever is greater) above the maximum extraction pressure or maximum exhaust pressure. The relief device shall give full relief at no more than 10 percent above the "start-to-open" pressure.

If the high-back-pressure or high extraction or admission pressure trip is furnished the relief device pressures should be raised 5 psig [35 kPa (gauge)] and the high-steam-pressure trip should be set at the above "start-to-open" pressure.

Drain piping, leak-offs and relief devices should be routed to a safe area, in accordance with local codes and the manufacturer's instructions.

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8.8 COUPLING ALIGNMENT

The alignment of the couplings should be correct for successful operation.

Flexible couplings will not compensate for any appreciable misalignment. Rapid wear, noise, vibration, and actual damage may be caused by misalignment. The turbine and driven equipment, including base plate mounted equipment, should be checked for alignment after installation and prior to start up.

Coupling alignment may be made by adjustment of the shims under the turbine and driven equipment supports.

In the actual alignment of couplings, allowance should be made for expected changes in operating temperatures of the driving unit and also of the driven unit. An allowance for external expansion should be made in the "cold" coupling alignment. The final coupling alignment check should be made with the turbine and driven unit at operating temperatures.

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8.9 GROUTING

After the turbine has been leveled, the coupling alignment checked, and the foundation bolts lightly tightened, the grout should be poured to completely fill the space between the foundation and the soleplate or baseplate. There should be no air pockets in the grout. After the grout is dry, connect the piping, fully tighten the foundation bolts, and recheck the alignment.

A mixture of cement and fine sand is normally used as grout. There are other materials available which have proven successful. Care must be exercised in the use of materials which expand while setting, as they may over expand and present more of a problem than conventional materials such as cement and sand, which have a tendency to shrink slightly. (Figures 8-16 and 8-17 represent typical installations and are presented only as guides.)

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8.10 FLUSHING OIL SYSTEM

When a forced-feed lubrication system is provided, flushing of the lubrication system should be performed prior to the initial start-up in accordance with the manufacturer's recommendations.

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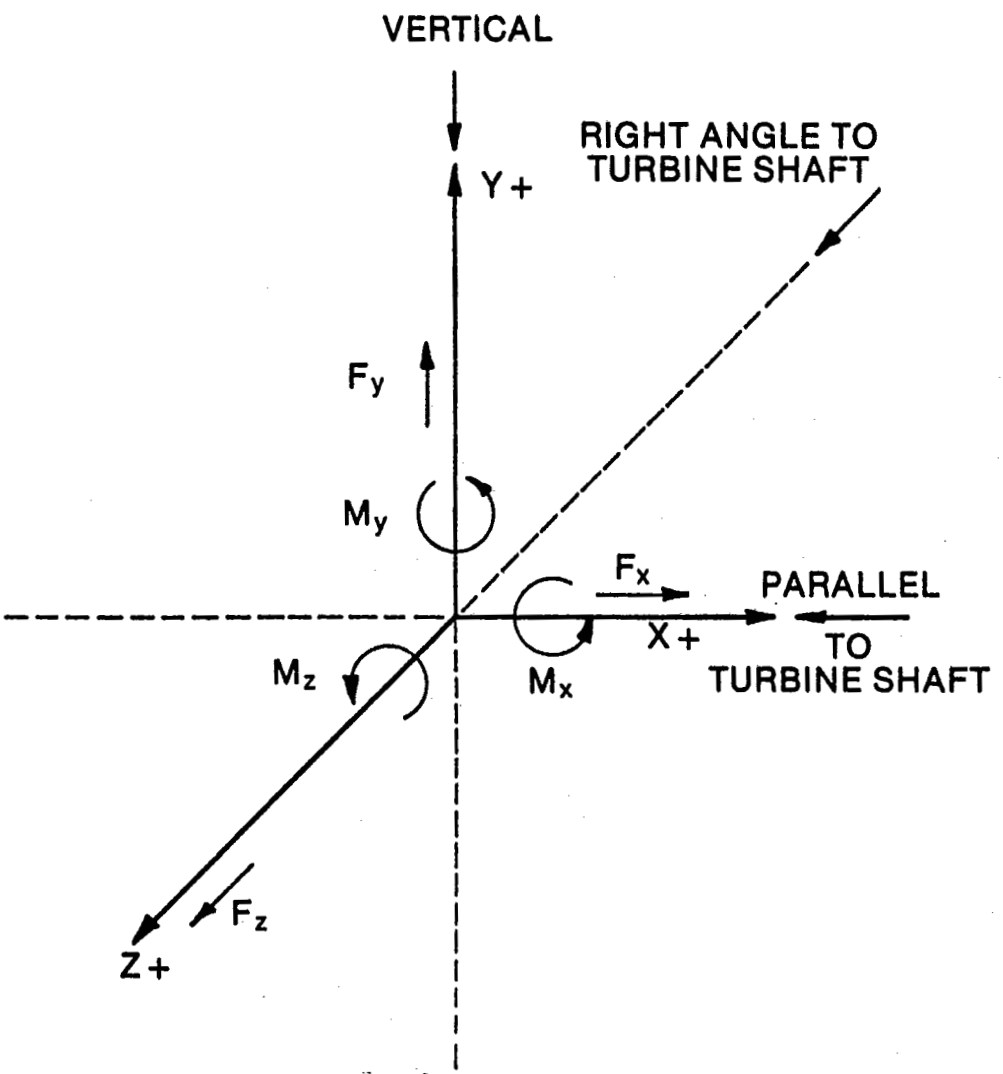


Figure 8-15
COMPONENTS OF FORCES AND MOMENTS ON TURBINE CONSTRUCTION
POSITIVE MOMENTS ROTATE CLOCKWISE WHEN VIEWED
LOOKING INTO POSITIVE FORCES

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Table 8-3
ALLOWABLE FORCES AND MOMENTS (8.4.6.2.b)

INLET INCHES	EXHAUST INCHES	FX LBS	FY LBS	FZ LBS	MX LB-FT	MY LB-FT	MZ LB-FT
2	6	316	791	632	1581	791	791
2	8	412	1031	825	2062	1031	1031
3	6	335	839	671	1677	839	839
3	8	427	1068	854	2136	1068	1068
4	8	447	1118	894	2236	1118	1118
4	10	480	1199	959	2398	1199	1199
4	12	511	1277	1022	2554	1277	1277
4	16	575	1437	1150	2874	1437	1437
4	18	607	1518	1215	3037	1518	1518
4	20	640	1600	1280	3200	1600	1600
4	24	706	1764	1411	3528	1764	1764
4	30	804	2011	1609	4022	2011	2011
4	36	904	2259	1807	4518	2259	2259
6	12	524	1309	1047	2618	1309	1309
6	16	585	1462	1170	2924	1462	1462
6	18	616	1541	1232	3081	1541	1541
6	20	648	1620	1296	3240	1620	1620
6	24	712	1781	1425	3562	1781	1781
6	30	810	2025	1620	4050	2025	2025
6	36	908	2271	1817	4541	2271	2271
8	12	540	1351	1081	2702	1351	1351
8	16	598	1495	1196	2991	1495	1495
8	18	628	1571	1257	3141	1571	1571
8	20	659	1648	1318	3295	1648	1648
8	24	722	1804	1443	3608	1804	1804
8	30	817	2044	1635	4087	2044	2044
8	36	915	2287	1829	4573	2287	2287
8	48	1111	2778	2222	5555	2778	2778
10	12	560	1401	1121	2802	1401	1401
10	16	614	1536	1229	3072	1536	1536
10	18	643	1608	1286	3216	1608	1608
10	20	673	1682	1345	3363	1682	1682
10	24	733	1833	1467	3667	1833	1833
10	30	827	2068	1654	4135	2068	2068
10	36	923	2307	1845	4614	2307	2307
10	48	1117	2793	2234	5586	2793	2793
12	18	661	1651	1321	3303	1651	1651
12	20	689	1722	1377	3444	1722	1722
12	24	747	1868	1494	3736	1868	1868
12	30	839	2096	1677	4193	2096	2096
12	36	932	2331	1865	4662	2331	2331
12	48	1125	2812	2249	5623	2812	2812
16	24	781	1952	1561	3904	1952	1952
16	30	867	2167	1733	4333	2167	2167
16	36	957	2391	1913	4783	2391	2391
16	48	1143	2858	2287	5716	2858	2858

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8.10.1 Flushing oil should be compatible with the final turbine oil.

8.10.2 Oil should be circulated through the entire system as long as necessary to remove or to flush particulate matter back to the oil reservoir. A periodic check of the oil filters or temporary screens should serve as a guide to determine when the oil is clean.

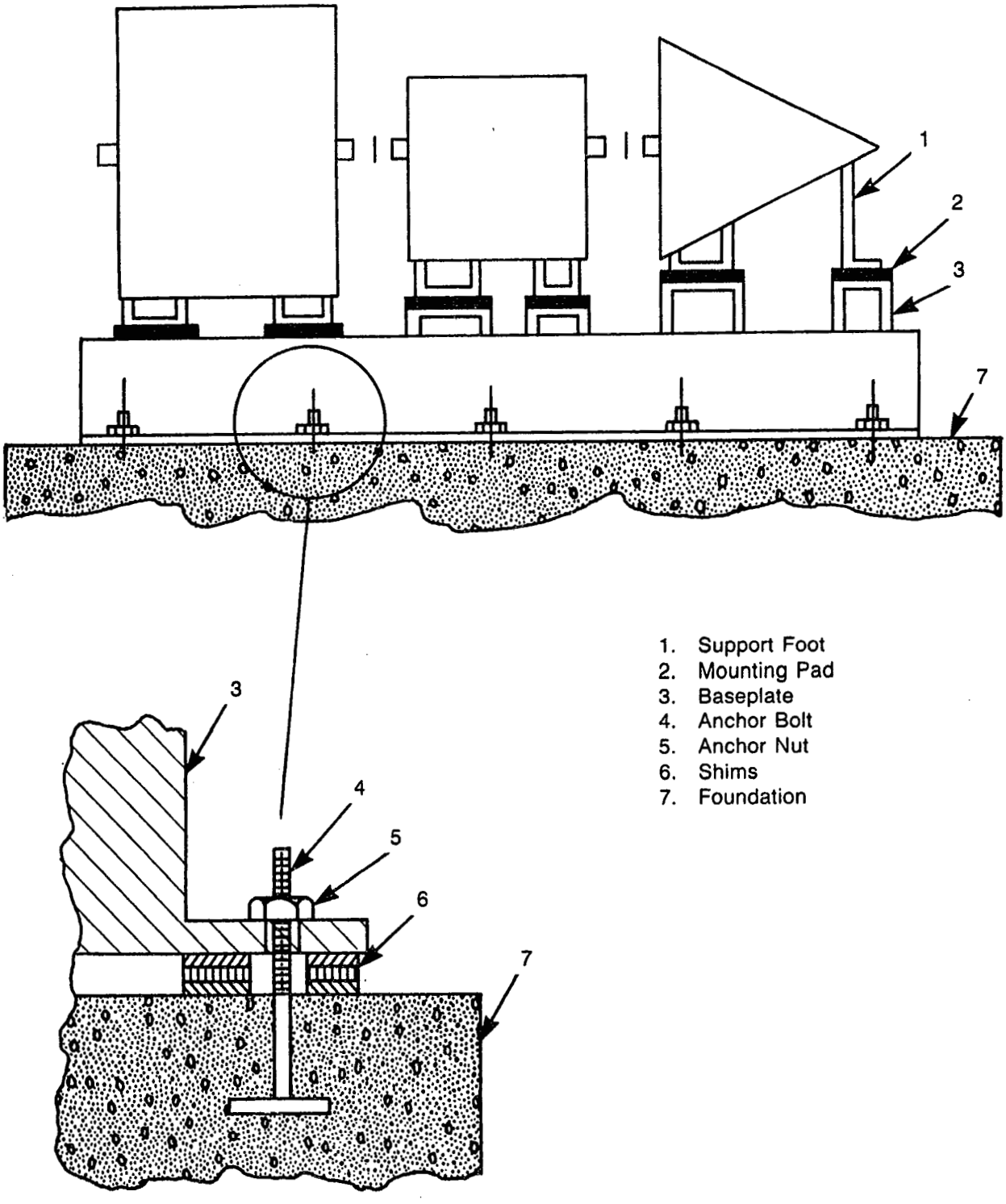
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8.11 GENERATOR LEADS

Generator leads should be sized for the current which they will carry. These leads should be insulated or shielded to avoid hazard to operating personnel.

Undesirable local heating of foundations can be prevented by bringing the leads of all phases out through the same conduit or by using nonmetallic conduits. Heat from reinforcing steel within the concrete can be avoided by making sure that continuous individual paths close to and around individual leads are not formed by this steel.

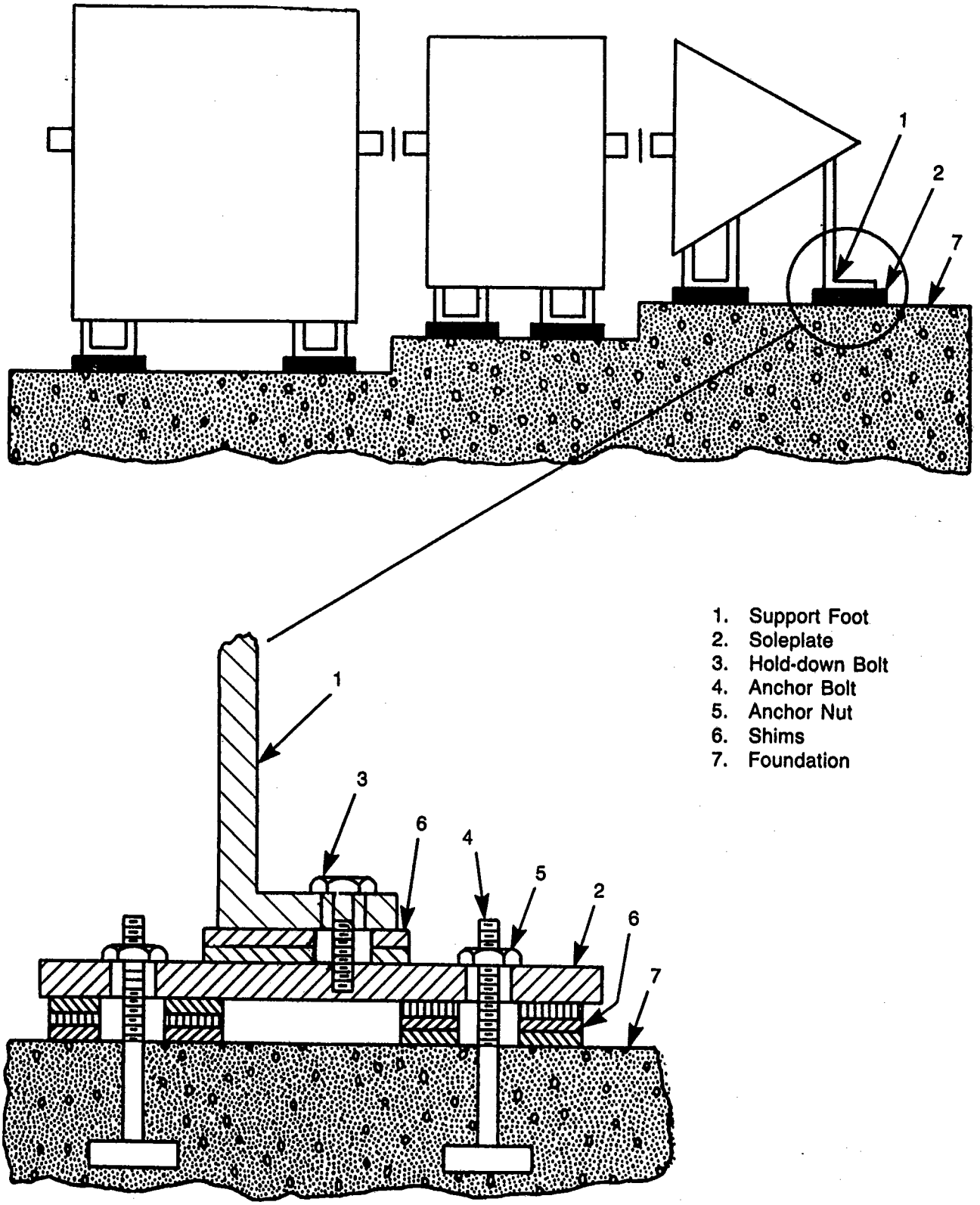
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1. Support Foot
2. Mounting Pad
3. Baseplate
4. Anchor Bolt
5. Anchor Nut
6. Shims
7. Foundation

Figure 8-16
BASEPLATE MOUNTED TURBINE AND DRIVEN EQUIPMENT

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1. Support Foot
2. Soleplate
3. Hold-down Bolt
4. Anchor Bolt
5. Anchor Nut
6. Shims
7. Foundation

Figure 8-17
SOLEPLATE MOUNTED TURBINE AND DRIVEN EQUIPMENT

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Sample Problem 8A
ALLOWABLE FORCES AND MOMENTS ON STEAM TURBINES

A steam turbine has a 4 inch side inlet and an 8inch side exhaust. Analysis of the steam piping system proposed for the turbine has determined that components of the force and moments imposed on the inlet and exhaust flange will be as listed below.

Inlet Flange

F_x = +40 lb
F_y = -100 lb
F_z = - 70 lb
M_x = +200 lb-ft
M_y = +150 lb-ft
M_z = -120 lb-ft

Exhaust Flange

F_x = -110 lb
F_y = -250 lb
F_z = +180 lb
M_x = +500 lb-ft
M_y = +300 lb-ft
M_z = +350 lb-ft

Check to see if these forces and moments are within NEMA guidelines.

1. Check *RESULTANT* forces and moments *ON INDIVIDUAL FLANGES* against Limit 1, Paragraph 8.4.6.1.

Inlet Flange

$F_R = \sqrt{(40)^2+(-100)^2+(-70)^2} = 128$ lb

$M_R = \sqrt{(200)^2+(150)^2+(-120)^2} = 277$ lb–ft

D_e = 4 inches (No correction needed for flanges 8"and smaller)

$3F_R + M_R \leq 500\ D_e$ (Limit 1)

$(3)(128) + 277 \leq (500)\ (4)$

$661 \leq 2000$ is true so forces and moments on the inlet flange are within NEMA guidelines.

Exhaust Flange

$F_R = \sqrt{(-110)^2+(-250)^2+(180)^2} = 327$ lb

$M_R = \sqrt{(500)^2+(300)^2+(350)^2} = 680$ lb–ft

D_e = 8 inches (No correction needed for flanges 8" and smaller)

$3F_R + M_R \leq 500\ (De)$ (I imit 1)

$(3)(327) + 680 \leq (500)(8)$

$1661 \leq 4000$ is true so forces and moments on the inlet flange are within acceptable limits for exhaust flange.

2. Check combined *RESULTANT* forces and moment *ON THE TURBINE* against Limit 2, Paragraph 8.4.6.2.a.

F_x = 40 - 110 = -70 lb
F_y = -100 - 250 = -350 lb
F_z = - 70 + 180 = +110 lb
M_x = 200 + 500 = +700 lb-ft
M_y = 150 + 300 = +450 lb-ft
M_z = -120 + 350 = +230 lb-ft

$F_c = \sqrt{(-70)^2+(-350)^2+(110)^2} = 373$ lb

$F_c = \sqrt{(700)^2+(450)^2+(230)^2} = 863$ lb–ft

Nominal Inlet Flange Area = $\frac{\pi (4\text{ in.})^2}{4} = 12.57\text{ in}^2$

Nominal Exhaust Flange Area = $\frac{\pi (8\text{ in.})^2}{4} = 50.27\text{ in}^2$

Total Flange Area = 12.57 + 50.27 = 62.84 in^2

$D_c = \frac{(4)(62.84)}{\pi} = 8.94$ in. (No correction needed for values 9 in. and smaller.)

$2F_c + M_c \leq 250\ (Dc)$ Limit 2

$(2)(373) + 863 \leq (250)(8.94)$

1609 LB $\leq$ 2235 is true so resultant forces and moments on the turbine are within NEMA guidelines.

3. Check the *COMPONENTS* of the combined forces and moments *ON THE TURBINE* against values calculated per Paragraph 8.4.6.2.b.

Allowable Forces and Moments

F_x = 50 D_c = 447 lb
F_y = 125 D_c = 1118 lb
F_z = 100 D_c = 894 lb
M_x = 250 D_c = 2236 lb-ft
M_y = 125 D_c = 1118 lb-ft
M_z = 125 D_c = 1118 lb-ft

Magnitudes of the actual forces and moments calculated in Part 2 of this problem are lower than the allowable magnitudes calculated above. Therefore, the components of the combined force and moments on the turbine are within NEMA guidelines.

Results from parts 1, 2, and 3 of this problem show that forces and moments imposed by the piping system are within all NEMA guidelines.

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Sample Problem 8B
ALLOWABLE FORCES AND MOMENTS ON STEAM TURBINES

A condensing turbine has a 6 inch side inlet and an 36 inch down exhaust. Analysis of the steam piping system proposed for the turbine has determined that the components of the forces and moments imposed on the inlet and exhaust flanges (excluding force on the exhaust flange due to pressure forces in the unrestrained expansion joint in the exhaust line) will be as tabulated below.

Inlet Flange

F_x = + 90 lb
F_y = -150 lb
F_z = +200 lb
M_x = -350 lb-ft
M_y = +200 lb-ft
M_z = +150 lb-ft

Exhaust Flange

F_x = 0
F_y = -250 lb
F_z = 0
M_x = 0
M_y = 0
M_z = 0

Bellows area for the expansion joint (obtained from expansion joint manufacturer) is 1030 square inches.

Pressure force developed by full vacuum in the expansion joint is:

$(14.7\ lb/in^2)\ (1030\ in^2) = 15{,}141$ lb

This is additional force in the -Y direction.

Check to see if these forces and moments are within NEMA guidelines.

1. Check *RESULTANT* forces and moments *ON INDIVIDUAL FLANGES* against Limit 1, Paragraph 8.4.6.1.

Inlet Flange

$F_R = \sqrt{(90)^2+(-150)^2+(200)^2} = 266$ lb
$M_R = \sqrt{(-350)^2+(200)^2+(150)^2} = 430$ lb–ft
D_e = 6 inches (No correction needed for flanges 8" and smaller.)
$3F_R + M_R \le 500\ D_e$ Limit 1
$(3)(266) + 430 \le (500)(6)$
$1228 \le 3000$ is true so forces and moments on the inlet flange are within NEMA guidelines.

Exhaust Flange

F_R excluding pressure force = $\sqrt{(0)^2+(-250)^2+(0)^2} = 250$ lb
$M_R = \sqrt{(0)^2+(0)^2+(0)^2} = 0$ lb

$D_e = \frac{(16+36)}{3} = 17.33$ inches

$3F_R + M_R \le 500D_e$ Limit 1

$(3)(250) + 0\ \ 500\ (17.33)$

$750 \le 8665$ is true so forces and moments on the exhaust flange are within NEMA guidelines.

2. Check combined *RESULTANT* forces and moment *ON THE TURBINE* against Limit 2, Paragraph 8.4.6.2.a.

$F_x = 90 + 0 = 90$ lb
$F_y = -150 - 250 = -400$ lb
$F_z = 200 + 0 = 200$ lb
$M_x = -350 + 0 = -350$ lb-ft
$M_y = 200 + 0 = 200$ lb-ft
$M_z = 150 + 0 = 150$ lb-ft
$F_c = \sqrt{(90)^2+(-400)^2+(200)^2} = 456$ lb
$M_c = \sqrt{(-350)^2+(200)^2+(150)^2} = 430$ lb–ft
Nominal Inlet Flange Area = $\frac{\pi (6\ in.)^2}{4} = 28.3\ in^2$
Nominal Exhaust Flange Area = $\frac{\pi (36\ in.)^2}{4} = 1017.9\ in^2$
Total Flange Area = 28.3 + 1017.9 = 1046.2 in
Equivalent Diameter = $\sqrt{\frac{(4)\ (1046.2)}{\pi}} = 36.5$ in

$D_c = \frac{(18 + 36.5)}{3} = 18.166$ in.

$2F_c + M_c \le 250\ D_c$ Limit 2
$(2)\ (456) + 430 \le 250\ (18.166)$
$1342 \le 4542$ is true so the resultant forces and moments are within NEMA guidelines.

3. Check the *COMPONENTS* of the combined forces and moments *ON THE TURBINE* against values calculated per Paragraph 8.4.6.2.b.

From Calculations in part 2, Dc = 18.166 in.

Allowable Forces and Moments

$F_x = 50\ D_c = 908$ lb $M_x = 250\ D_c = 4541$ lb-ft
$F_y = 125\ D_c = 2271$ lb $M_y = 125\ D_c = 2271$ lb-ft
$F_z = 100\ D_c = 1817$ lb $M_z = 125\ D_c = 2271$ lb-ft

Magnitudes of the actual forces and moments calculated in Part 2 of this problem are lower than the allowable magnitudes calculated above. Therefore, the components

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of the combined forces and moments on the turbine are within NEMA guidelines.

4. Check total force on the turbine exhaust flange against the limit per paragraph 8.4.6.3.
   Paragraph 8.4.6.3 states that force on the exhaust flange should not exceed 15-1/2 times the nominal exhaust area
   (15-1/2) (1017.9 in^2) = 15,777 lb

   Total force on the exhaust flange is the vector total of pressure force from the expansion joint and the forces calculated with pressure force excluded.
   Total force = -15,141 - 250 = -15,391 lb
   Results from parts 1, 2, 3 and 4 of this problem show that forces and moments imposed by the piping system are within all NEMA guidelines.

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Sample Problem 8C
ALLOWABLE FORCES AND MOMENTS FOR A TURBINE WITH FOUR EXTRACTION OPENINGS

Size of Openings (In Inches)		Area of Openings (In Square Inches)
Inlet	14	153.94
Extraction #1	10	78.54
Extraction #2	8	50.26
Extraction #3	16	201.06
Extraction #4	30	706.86
Exhaust	148	17203.40

Find the diameter of a circular opening equal to the total area

Equivalent Diameter =

$$\sqrt{\frac{4(153.94+78.54+50.26+201.06+706.86+17203.40)}{\pi}}$$

Equivalent Diameter = 153.04 inches

Equivalent Diameter must be corrected when value exceeds 9 inches

$D_c = \frac{18 + 153.04}{3} = 57.01$ inches

Calculate maximum allowable forces and moments

$F_x = 50\ (57.01) = 2851$ lb
$F_y = 125\ (57.01) = 7126$ lb
$F_z = 100\ (57.01) = 5701$ lb
$M_x = 250\ (57.01) = 14253$ lb-ft
$M_y = 125\ (57.01) = 7126$ lb-ft
$M_z = 125\ (57.01) = 7126$ lb-ft

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Section 9
OPERATION AND MAINTENANCE

9.1 INTRODUCTION

To ensure that the turbine generator receives the care and attention necessary and usual for this type of equipment, specific instructions with respect to starting up, shutting down, and routine operation should be provided by the manufacturer in the instruction manual furnished with the turbine.

Authorized Engineering Information 11-14-1985.

9.2 OPERATION

The following should be given careful consideration by the operator:

1. The steam supplied to the turbine should be free of debris. To ensure maximum protection, steam lines should be blown prior to starting.
2. The steam turbine operator should be aware of the hazards associated with contamination of the process steam with agents which promote stress corrosion cracking.
3. Avoid slugs of water and unduly wet steam.
4. Avoid great or sudden fluctuations in pressure and temperature of steam supply.
5. Provide an adequate supply of clean water free from acid or scale forming impurities for oil coolers, air coolers and the gland condensing system.
6. Provide lubricating oil of proper quality and characteristics, including initial flushing change.
7. Maintain a log of operating conditions, including steam inlet pressures and temperatures, stage pressures, oil pressures, exhaust pressures, vibration, and so forth. This is important in predicting and scheduling inspection outages.
8. Check trip valves or trip and throttle valve for operation.
9. Check overspeed trip at appropriate intervals.
10. Check auxiliary oil pumps.

Authorized Engineering Information 11-14-1985.

9.3 NONCONDENSING TURBINE OPERATION OF A MULTISTAGE CONDENSING TURBINE

Noncondensing operation of a multistage condensing turbine is not recommended unless approved by the manufacturer. High exhaust pressure and temperature can cause last stage blade flutter, casing distortion and damage and misalignment with driven machines. An increase in exhaust temperature and pressure may also affect piping forces. (See piping force calculations given in Section 8.)

Authorized Engineering Information 11-14-1985.

9.4 TYPICAL STARTING SEQUENCE FOR A STEAM TURBINE GENERATOR SET

1. Open exhaust shut off valve.
2. Start cooling water.
3. Start lubrication oil system.
4. Start steam seal system.
5. Open case drains.
6. Set or reset trip valve.
7. Crack open isolating valve.
8. Allow casing to heat up.
9. Slowly open isolating valve until governor takes control (observe manufacturer's instructions regarding critical speed).
10. Fully open isolating valve.
11. Adjust governor speed.
12. Close casing drains.
13. Match line voltage if unit is to parallel
14. Synchronize if unit is to parallel
15. Close main circuit breaker
16. Load either automatically or manually
17. Monitor turbine generator set operation until stable operation is achieved.

Authorized Engineering Information 11-14-1985.

9.5 MAINTENANCE

9.5.1 Introduction

Inspection and service should follow manufacturer's instructions. Frequency of inspection and degree of thoroughness may vary and will have to be determined by the maintenance personnel.

The following is a typical maintenance program:

Daily

1. Visually inspect turbine generator set for external damage and leaks.
2. Check oil level in reservoir and governor.
3. Check for unusual vibration and noise levels.
4. Check oil temperature and pressures.

Weekly

1. Check operation of auxiliary oil pump, if applicable.
2. Check operation of all shut down devices.
3. Check that shafts are free of oil or grease.
4. Exercise the trip valve.
5. Examine fuses, switches, and other controls

Monthly

1. Check overspeed governor.
2. Check foundation bolts for tightness.
3. Check oil and filter.

Annually

Shut down the turbine generator set and perform the following:

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1. Remove and clean steam strainer.
2. Check shaft seals for wear.
3. Check thrust bearing end play.
4. Remove sentinel warning valve and check for proper opera tion.
5. Drain water and clean foreign material from oil reservoir.
6. Drain oil from governor and flush clean, if applicable.
7. Check coupling alignment and lubrication.
8. Drain small quantity of oil from system and conduct an oil analysis. If system is equipped with an oil filter element, change the element at the time of oil change.
9. Examine grease in ball or roller bearing housings and renew if necessary, if applicable.
10. Check bearing clearance and end play.
11. Check gear tooth wear pattern, if applicable.
12. Check foundation.
13. Check alignment.
14. Check and recalibrate gauges.
15. Check generator thoroughly, blowing dirt from windings and air gap.
16. Test insulation by megger.
17. Check air gap clearance.

Authorized Engineering Information 11-14-1985.

9.6 INTERNAL WATER WASHING

Internal water washing of a turbine should be performed in accordance with the manufacturer's instructions. It is better to prevent the build up of solids than to have to remove deposits after they have formed.

Authorized Engineering Information 11-14-1985.

9.7 STEAM PURITY

Steam turbine users should be aware of the hazards associated with contamination of the steam by agents which might promote stress corrosion cracking, solids build up, erosion, and corrosion. Contaminants such as sodium, hydroxides, chlorides, sulfates, copper, lead, and silicates may result in shortened turbine life and failure of internal parts of the turbine.

Since it is not possible to prescribe the degree of contamination that steam turbine materials can tolerate in order to achieve the long life expected of internal turbine components, only general guidelines can be offered.

For small low pressure applications, turbines may operate satisfactorily on steam having purity limits set by the American Boiler Manufacturers Association. See Table 9-1.

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For larger high pressure applications and for improved reliability, the suggested guidelines for steam purity limits for both start-up and continuous operation of steam turbines are shown in Table 9-2.

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Table 9-1
WATERTUBE BOILERS RECOMMENDED BOILER WATER LIMITS AND ASSOCIATED STEAM PURITY AT STEADY STATE FULL LOAD OPERATION DRUM TYPE BOILERS

psig	Drum Pressure kPa (gauge)	Total Dissolved Solids[1] Boiler Water ppm (Max)	Total Alkalinity[2] Boiler Water ppm	Suspended Solids Boiler Water ppm (max)	Total Dissolved Solids[2,3] Steam ppm (max expected value)
0-300	0-2068	700-3500	140-700	15	0.2 - 1.0
301-450	2069-3103	600-3000	120-600	10	0.2 - 1.0
451-600	3104-4137	500-2500	100-400	8	0.2 - 1.0
601-750	4138-5171	200-1000	40-200	3	0.1 - 0.5
751-900	5172-6206	150- 750	30-150	2	0.1 - 0.5
901-1000	6207-6895	125- 625	25-125	1	0.1 - 0.5

[1]Actual values within the range reflect the TDS in the feed water. Higher values are for high solids, lower values are for low solids in the feed water.
[2]Actual values within the range are directly proportional to the actual value of TDS of boiler water. Higher values are for the high solids, lower values are for low solids in the boiler water.
[3]These values are exclusive of silica.

Table 9-2
STEAM PURITY - LIMITS

	Continuous	Start-Up
Conductivity-		
Micromhos/cm at 25°C		
Drum	0.3	1.0
Once through	0.2	0.5
SiO, ppb, max	20	50
Fe, ppb, max	20	50
Cu, ppb, max	3	10
Na + K, ppb, max		
Up to 800 psig [5516kPa (gauge)]	20	20
801 to 1450 psig [5517 to 9998 kPa(gauge)]	10	10
1451 to 2400 psig [9999 to 16548 kPa(gauge)]	5	5
Over 2400 psig [over 16548 kPa(gauge)]	3	3

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Section 10
INQUIRY GUIDE
(Authorized Engineering Information)

Job No. _____ Item No. _____
Inquiry Order No. _____
Purchase Order No. _____
Page No. _____ By _____
Date _____ Revision _____

Purchaser
Contractor
User
Applicable To: Proposal _____
For: _____

Site: _____ No. Required: _____
Service _____ Driven Equip. _____ Gear Yes/No
Manufacturer _____ Model _____

List and/or attach additional applicable standards or specifications.

_____
_____
_____
_____

Specified Conditions

	Guar.	Rated	Normal	Max.	Min.	Min. Energy	Units
Power							
Speed							
Steam Conditions							
Inlet pressure							
Inlet temperature							
Exhaust pressure							
Extraction/induction pressure							
Extraction/induction temperature							
Inlet flow							
Extraction/induction flow							
Other performance requirements							

Maximum Continuous Speed _____

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Duty
Continuous _____ Intermittent _____ Standby _____
Emergency _____ Auto start _____ Manual start _____
Other _____

Evaluation
Approximate steam rate (normal) desired _____
Steam rate measured at output of turbine _____ gear _____
Steam cost $_____ per unit flow _____
Payout period: No. of years _____
Hours per year of operation _____

Construction Single Valve _____ Multivalve _____
Horizontal shaft _____ Vertical shaft _____
Thrust _____ - _____ (Upward/downward)
Automatic extraction or induction _____
Nonautomatic extraction or induction _____
Induction/extraction _____

Governing System
NEMA Class _____
Min. speed _____ rpm, Max speed _____ rpm
Additional features _____

Speed Changer Type
Manual _____ Pneumatic _____ Electric _____

Lubrication
Supplied by: Manufacturer _____ Other _____
For turbine _____
For turbine gear _____
For driven equipment (type) _____
Flow _____ Heat load _____ Pressure _____

Mounting
Baseplate _____ Soleplate(s) _____
Supplied by _____
Extended by _____

Accessories
_____
_____
_____
_____
_____

Paint
Manufacturer's standard _____ Other _____

Shipping Preparation
Manufacturer's standard _____ Other _____

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Factory Tests

	Required	Witnessed
Hydo test	Yes	Yes/No
No-load running test	Yes	Yes/No
Dynamic balance rotor	Yes/No	Yes/No

Other _____

Site Utilities

Cooling water: None _____ Fresh _____ Brackish _____
Other _____ Temperature _____ Pressure _____

Electrical supply: ac/dc
Control(s) Volts _____ Phase _____ Hz _____
Motor(s) Volts _____ Phase _____ Hz _____
Air Supply _____ Pressure _____

Site Environment

Ambient temperature Maximum _____ Minimum _____
Elevation _____

Area classification: Class _____ Group _____ Div. _____
Control(s)
Explosion proof _____
Weatherproof _____
General purpose _____
Motor(s)
TEFC _____
Explosion proof _____
General purpose _____
Other _____

Environment Protection at Site (S or I)

Enclosed _____ Sheltered _____ Outdoor _____
Other _____
For _____ months storage prior to startup
S = Storage
I = Installation

Remarks

_____
_____
_____
_____
_____
_____

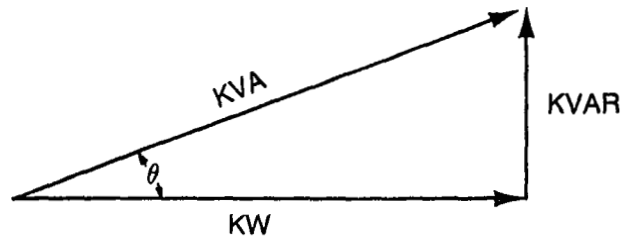
Drawings and Data to be Supplied

Certified outline drawings _____
Recommended spare parts list _____
Instruction books _____ No. _____
Other _____
_____
_____

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APPENDIX

AC Power—Power used in an alternating current electrical circuit. AC power has two components, (1) real power and (2) reactive power. These components are added vectorially to determine the apparent power.



$$KVA = \sqrt{(KW)^2 + (KVAR)^2}$$

Where:

KVA = apparent power, kilovolt-amperes
KW = real power, kilowatts
KVAR = reactive power, kilovolt-amperes reactive

Apparent power in 3-phase circuits can also be determined by the formula:

$$KVA = \frac{(V)\ (I)\ \sqrt{3}}{1000}$$

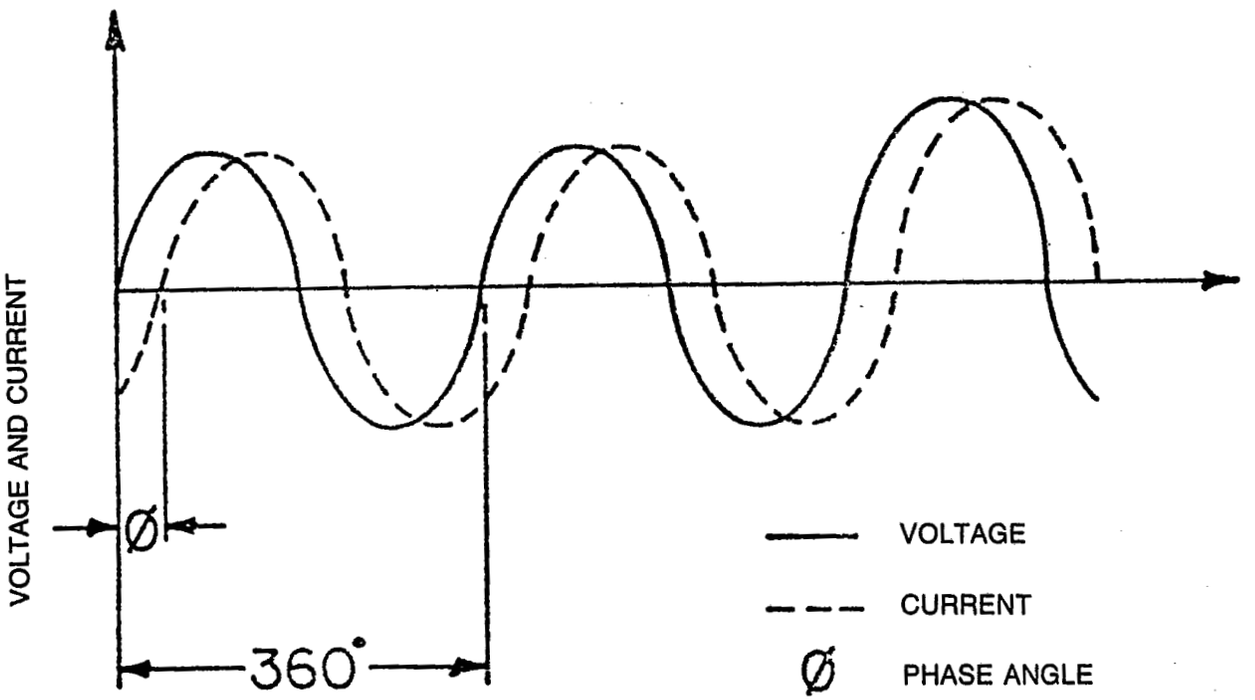
Where:

V = potential difference per phase, volts
I = current per phase, amperes

Power factor of an electric circuit is the ratio of $\frac{\text{real power}}{\text{apparent power}}$

The power factor of an electric circuit will be less than unity if the voltage wave and the current wave do not rise through the zero point at the same time. If the circuit has more inductance than capacitance, current will lag behind voltage. If the circuit has more capacitance than inductance, current will lead voltage. Considering one full cycle to be 360 degrees, the amount by which the zero point for the current wave differs from the zero point for the voltage wave is expressed as the phase angle, θ. The power factor for the circuit equals the cosine of the phase angle. A capacitive circuit will produce a leading power factor. An inductive circuit will produce a lagging power factor.

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Real power produces light, heat, or mechanical power in the equipment which makes up the load in the electrical circuit. The real power requirement of the electrical circuit determines the mechanical power which must be produced by the driver(s) of the generator(s) in the circuit.

Reactive power provides magnetization for motors in the circuit. The need for reactive power increases the current which must be carried by the electrical conductors in the circuit, but it does not add to the load which must be carried by the driver(s) of the generator(s) in the circuit.

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NEMA STANDARDIZATION

The purpose of NEMA Standards, their classification and status are set forth in certain clauses of the NEMA *Standardization Policies and Procedures* manual and are referenced below:

Purpose of Standards

National Electrical Manufacturers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for their particular needs. Existence of a National Electrical Manufacturers Association Standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard.

(Standardization Policies and Procedures, p. 1)

Definition of a Standard

A standard of the National Electrical Manufacturers Association defines a product, process or procedure with reference to one or more of the following: nomenclature, composition, construction, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Standardization Policies and Procedures, p. 2)

Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the Standards Publication may be capable of otherwise equivalent performance.

(Standardization Policies and Procedures, p. 8)

Categories of Standards

National Electrical Manufacturers Association Standards are of three classes:

1. NEMA Standard, which relates to a product, process or procedure commercially standardized and subject to repetitive manufacture, which standard has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon;
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote thereon.
3. Adoptive Standard, which is adopted in whole or in part from the standards of another organization, either domestic, regional, or international.

(Standardization Policies and Procedures, pp 7 & 16)

Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote on the standard.

(Standardization Policies and Procedures, pp. 7 & 16)

Official Standards Proposal

An Official Standards Proposal is an official draft of a proposed standard which is formally recommended to an outside organization(s) for consideration, comment and/or approval, and which has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon. *(Standardization Policies and Procedures, pp 7 & 16)*

Identification of Status

Standards in NEMA Standards Publications are identified in the foreword or following each standard as "NEMA Standard" or "Suggested Standard for Future Design." These indicate the status of the standard. These words are followed by a date which indicates when the standard was adopted in its present form by the Association.

The material identified as "Authorized Engineering Information" and "Official Standards Proposal" is designated similarly.

July 17, 1990

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STEAM TURBINE SECTION
OF THE
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MEMBER COMPANIES

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Worcester, MA 01613-0088

Coppus Engineering Corporation
Millbury, MA 01527

Dresser-Rand Company
Wellsville, NY 14895

Elliott Company
Jeannette, PA 15644-0800

General Electric
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Burlington, IA 52601-0967

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