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GE Power Systems

Steam Turbines for Industrial Applications

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Steam Turbines for Industrial Applications

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Steam Turbines for Industrial Applications

Introduction

GE has been producing industrial steam turbine (IST) drive systems since the early 1900s and has placed more than 5,000 units into service around the world. Throughout this time, the performance, reliability and cost-effectiveness of these turbine systems have improved continuously through product and packaging innovations.

This effort continues today with the formation of the IST unit within GE Power Systems to provide a broader product line and service capability to our industrial and small steam turbine users worldwide (Figure 1).

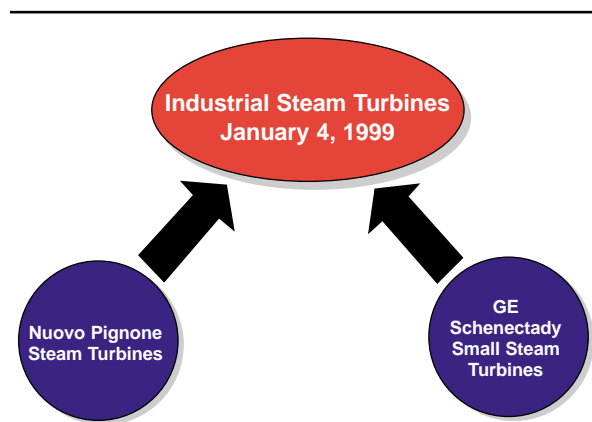


Figure 1. The industrial steam turbine (IST) business

The IST unit integrates the IST portion of GE Power Systems in Schenectady with that of our GE Nuovo Pignone unit in Florence, Italy.

This paper presents an overview of the IST unit's design approach, current product line and recent innovations.

IST Business

The IST business is based at two main business centers in Marlborough, Massachusetts, and Florence, Italy (Figure 2). Sales and application support is performed from Marlborough,

	Marlborough, Massachusetts, U.S.A.	Schenectady, New York, U.S.A.	Bangor, Maine, U.S.A.	Florence, Italy
Business Centers	X			X
Sales & Application Support	X	X		X
Detailed Engineering		X		X
Manufacturing & Assembly Center		X	X	X
Service Support	World-Wide Locations			

Figure 2. Global resources

Schenectady, and Florence. Detailed engineering is performed in Schenectady and Florence. Manufacturing and assembly centers are in Schenectady, Bangor, Maine, and Florence. Service support is achieved from worldwide locations.

IST Business Product Line

The IST business product line consists of steam turbine systems, ranging from 3 to 130 MW, that follow either an impulse or a reaction design or a combination of the two for the most efficient, cost-effective solution to plant productivity (Figure 3).

Configurations of the steam turbines consist of the following (Figure 4):

- Condensing or non-condensing sets
- Up, down, side and axial exhausts
- Single or multiple internal extractions and/or admissions
- Uncontrolled extractions
- Directly connected and gear-driven steam turbines

Geared Units

The geared steam turbine-generator package

Steam Turbines for Industrial Applications

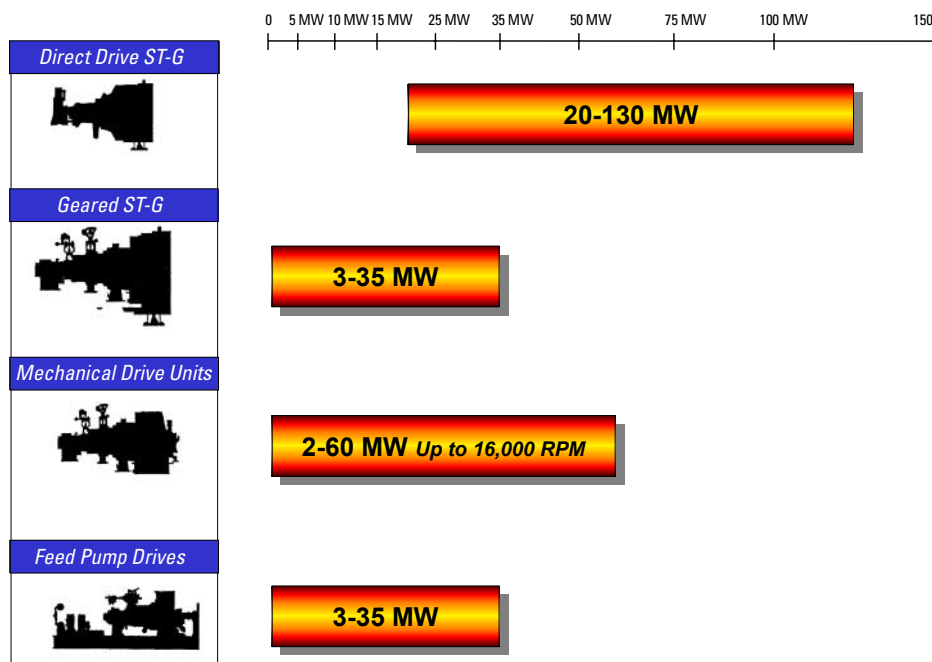


Figure 3. Product line

Steam Turbine Generators

- 3,000 to 130,000 KW, 50/60 Hz
- Applications
 - Cogeneration
 - Small Power Production
 - Combined Cycle
 - Waste to Energy
 - Geothermal Power Generation
- Configurations
 - Condensing/Non-Condensing
 - Down, up and Axial Exhaust Configurations
 - Single/Multiple Internal Extractions
 - Uncontrolled Steam Extractions
 - Direct Drive/Gear Driven
- Designs
 - Impulse
 - Reaction

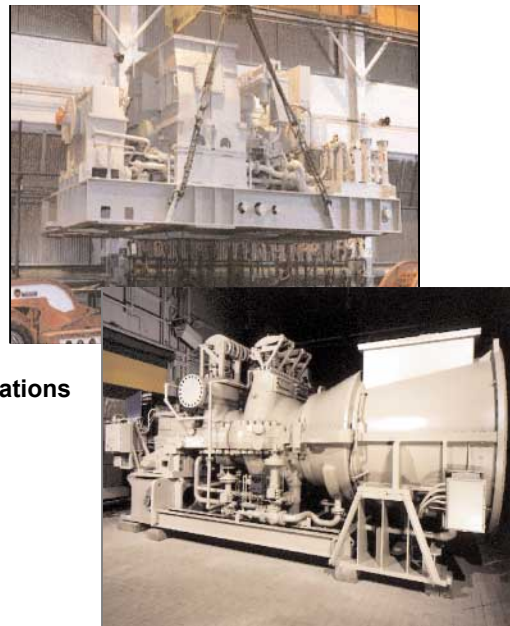


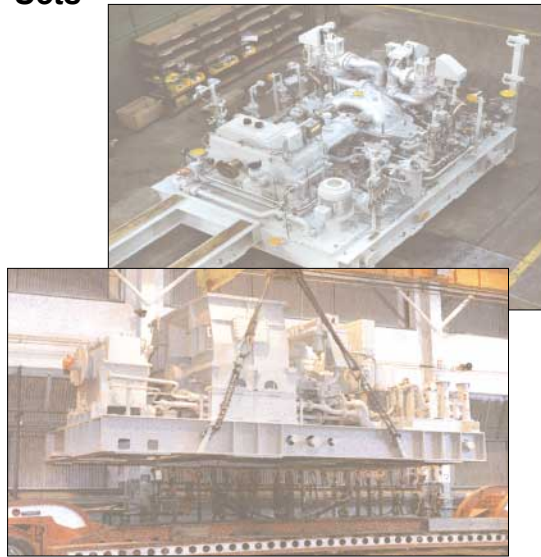
Figure 4. Product line configurations

ranges from 3 to 35 MW and may be the economical solution customers are looking for (Figure 5). The package consists of an efficient,

high-speed steam turbine driving a gearbox connected to a four-pole, 50- or 60-Hz generator. This compact package lends itself to quick

Geared Turbine Generator Sets

- Complete Packages Can Include Turbine, Gear, Oil System and Generator for Quick Installation
- Turbine Speeds Selected To Optimize Life-cycle Costs
- 1500/1800 RPM, 4-Pole Generators For 50/60 Hz Applications
- Applications to ~35 MW



Geared Units; Offering a Cost-Effective Solution

Figure 5. Geared steam turbine generator sets

installation. The turbine exhaust is adaptable to up or down orientations, and internal extraction/admission valves can be added to the steam turbine to suit a customer's process steam needs. Single-shaft steam turbine designs are available.

Mechanical Drive Steam Turbines

Mechanical-drive steam turbines (*Figure 6*) range from 3 to 60 MW (80,000 BHP), with speeds of up to 16,000 rpm, and are either condensing or non-condensing types. Complete steam turbine compressor packages as well as separate mechanical drive steam turbines, which meet API requirements, are available. Designs for a wide range of plant types and sizes are available. The IST team has extensive experience in support for major compressor suppliers, engineering companies and other users.

GE's test capabilities include:

- Mechanical running tests

- Full-train mechanical string tests
- Rotor dynamic capability, including response tests

Directly Connected ISTs

ISTs directly coupled to generators (*Figure 7*) range from 20 to 130 MW. The steam turbines can be packaged with most of the auxiliaries to ease plant design and installation problems. Axial exhausts can be used that allow a less costly building design.

This line of turbines has many applications for the use of extraction and admission process steam, employing several combinations of internal and external control valves. Using these valves provides GE's customers with process flexibility and excellent partial-load efficiency when the turbine is used to supply process steam.

Directly coupled steam turbines in combined-cycle applications must provide the performance and flexibility required for integration

Steam Turbines for Industrial Applications

- MDT's, 2,500 HP to 80,000 HP
- BFPT's, 3-35 MW
- Single or double end drive
- Inlet steam up to 1800 psig / 1000°F (12 kg/cm²g/538°C)
- Applications
 - Utility Boiler / Reactor Feed Pumps
 - LNG
 - Ethylene / Methanol
 - Urea / Ammonia
 - Refineries
 - Synfuel
 - Process air

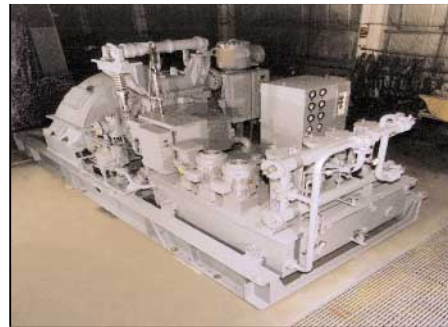
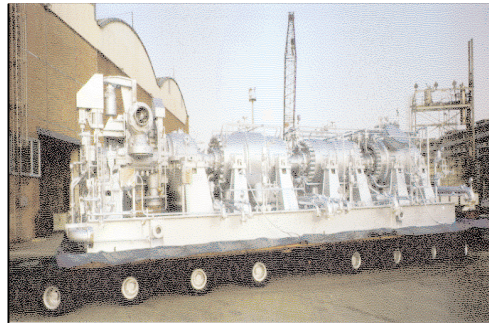


Figure 6. Mechanical drives

with gas turbines and heat-recovery boilers. Packaged arrangements, when feasible, offer shorter delivery and installation time.

The directly connected ISTs can operate with fixed-inlet pressure or sliding-inlet pressure control. They can be integrated with gas turbine and plant controls and they have auto- and remote-start capability.

Single-shaft steam turbine and gas (STAG) designs are available.

Feed Pump Turbines

Feed pump turbine drive packages are available from 3 to 35 MW. Complete steam turbine boiler feed pump packages are available, in addition to stand-alone steam turbine packages.

The boiler feed pump turbine package uses:

- A microprocessor-based electrohydraulic control system
- Modern instrumentation for remote operation
- Dual-inlet capability for a wide range

of operation, from black-start to efficient main turbine extraction operation

- Flexible exhaust configurations (up and down)
- Base-mounted packaged designs for ease of installation and startup

Geothermal Steam Turbine Generator Sets

GE offers highly reliable geothermal steam turbine generator sets (*Figure 8*). These steam turbines operate typically with saturated steam, which is provided from a geothermal source. Their unique features and materials of construction lead to long-term, reliable operation in geothermal service. The following features have been incorporated into the geothermal design:

- Inlet casings similar to those used on STAG applications, which do not have internal inlet control valves

Technology Overview

Direct Coupled

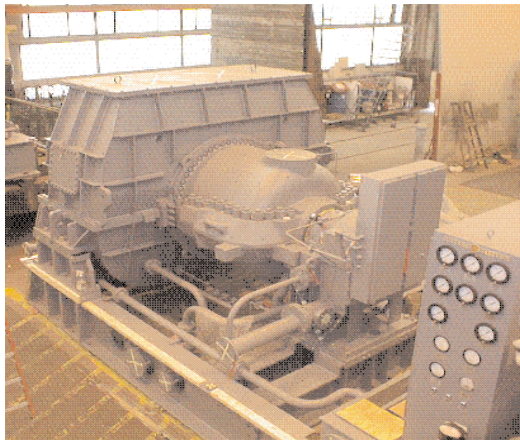


- **Quick delivery and installation**
- **Sliding or Fixed Pressure Inlet Design**
- **Modernized Combined Stop & Control Valves**
- **Reheat Option Available**
- **Extractions / Admissions**
- **Advanced Steam Path Designs**
- **Proven Exhaust Sections for 50 & 60 Hz**
- **Single-shaft Combine Cycle Designs Available**
- **Condenser Systems and Other Turbine Island Scope Available**

Figure 7. Direct coupled steam turbines

Technology Overview

Geothermal Steam Turbine-Features



- **Proven Low-Stress Rotor Designs & GE Geothermal Rotor Forging Material (NiCrMoV)**
- **12-Cr Steam Path and HP Casing**
- **Carbon Steel Exhaust Casing with Inconel Inlay at Critical Surfaces**
- **304L Stainless Steel Steam and Drain Piping**
- **Low cost Microprocessor - Based Electro - Hydraulic Control Systems - RS232 DCS link**
- **Modern Hermetically Sealed Local Instrumentation / Wiring For Reliable Long-Term Operation in a H2S Geothermal Environment.**
- **Up, Down, Side, and Axial Exhaust Configurations Available**
- **Packaged, Base-Mounted Designs**

Reliable Equipment Backed by ST Engineering/Service

Figure 8. Geothermal turbine

■ Special butterfly valves used for startup, control and emergency shutdown

■ Proven low-stress rotor designs and a special geothermal forging material formula

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- 12-chrome steel steam path and high-pressure casing
- Carbon steel exhaust casing with inconel inlay at critical surfaces to prevent erosion
- Stainless steel material for all steam and drain piping
- Modern hermetically sealed local instrumentation and wiring for reliable long-term operation in a H₂S geothermal environment
- Up, down, side and axial exhaust configurations available at 50 and 60 Hz
- Packaged base-mounted designs
- GE has extensive experience in the technology required for reliable operation in geothermal steam applications.

Modular Product Structure

GE adopted a modular component structure for its line of ISTs to achieve the cost and reliability benefits of standardization without compromising turbine performance. This approach enables the design engineer to optimize a turbine configuration for a customer's specific operating conditions by selecting and integrating pre-engineered and field-proven components from an array of alternatives and then designing a custom steam path that satisfies an application's unique requirements. Component modules that make up the building blocks of the product line include bearing standards (supports), inlet sections, inlet and extraction valve gear and exhaust sections.

These modules are shown for a typical industrial turbine in *Figure 9* and *Figure 10*. Note that the barrel section of the turbine is custom designed for each unit based on the user's specific operating conditions. GE is able to

maximize reliability and performance while minimizing product costs and delivery cycles by using this flexible modular structure. Development efforts associated with this product line center on new, improved component modules to replace or augment existing ones.

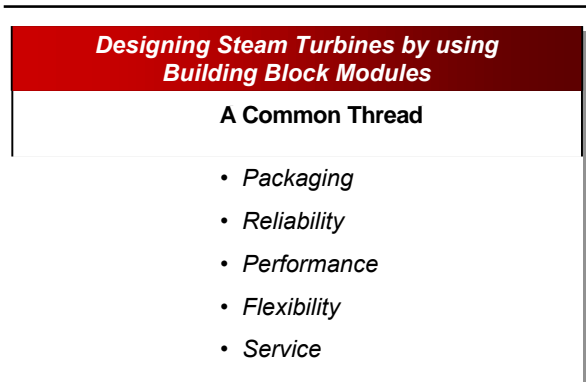


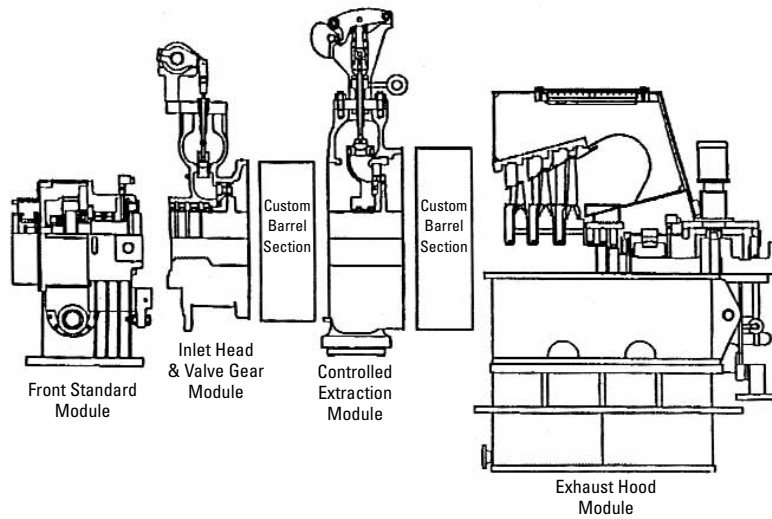
Figure 9. Modular design philosophy

Inlet Sections and Casings

Inlet section construction is a function of inlet pressure and temperature. A number of designs are available, as shown in *Figure 11*. For low-steam conditions, an economical, solid construction is employed where inlet ports are cast as an integral part of the casing. For higher-steam conditions, either a free-expanding chest design employing an integral heat chamber or a nozzle box design with an inner casing is employed. Both designs provide a high degree of thermal flexibility for long casing life under cyclical conditions.

Valve Gear

The type of valve gear used with the inlet sections is also a function of the inlet flow for a particular application. For low-flow applications, a bar lift arrangement is used that reduces cost and improves performance through reduced valve-stem leakoff flow. For higher-flow applications, a cam lift arrangement is used in which



Turbine Designed from Standard Modules with Customized Steampath

Figure 10. Industrial turbine building block structure

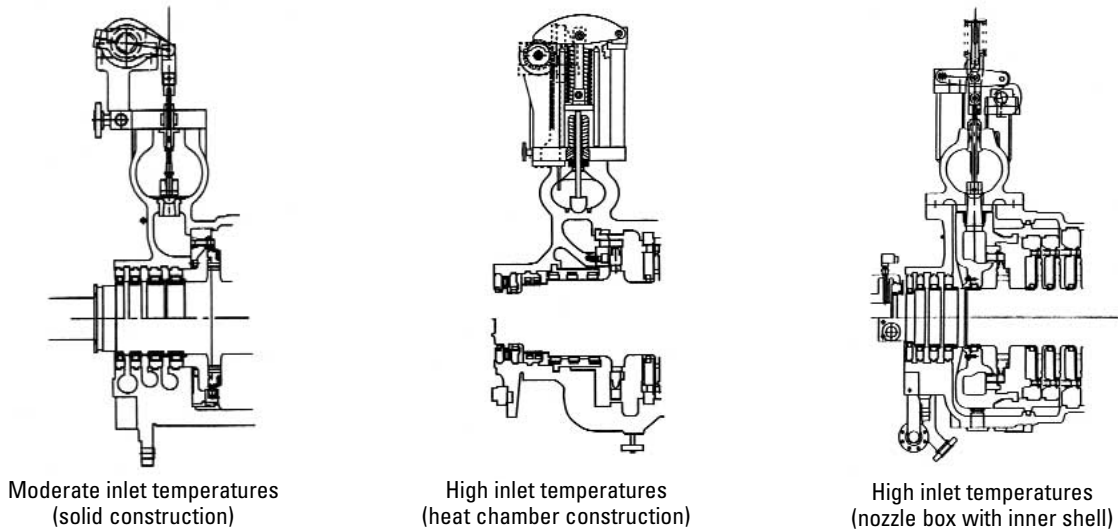


Figure 11. Alternative inlet concepts

each valve is individually supported and lifted for high valve stability and long disc and seat life. On applications with very high inlet flows, either a jumper valve is used to feed nozzles in the turbine lower half, or an entire additional set of valves is mounted in the lower half to provide inlet flow control over a wide range of operations.

Downstream of the inlet section, the casing's conical configuration allows a smooth and even increase in steam path area as the steam expands toward the exhaust. The improved conical casing designs, which utilize simple pattern pieces for each application, eliminate the use of multiple cylindrical and transitional pattern sections and result in lower costs, reduced

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foundry cycles and reduced thermal stresses in the casing.

New Inlet Section

A new inlet section module (building block) has been added to the IST structure. It can pass a flow of 1,200,000 PPH at a bowl pressure of 1800 psig and an inlet temperature of 1050°F.

Steam Utilization

Today, steam utilization is often as critical as a turbine-generator's output. One of the features incorporated into our turbine designs is the use of internal extraction/admission (induction) valves. The use of internal valving allows operation over a wide range of load and extraction flow conditions, where the turbine control system meters the through-flow to meet the demands of the process headers.

GE has extensive experience in the supply of single and double automatic extraction turbines into industrial processes. Flexibility of operation is further enhanced through the use of GE controls, which are described later. The use of internal control valves also simplifies plant design and construction by eliminating the need for multiple casing openings and com-

plex valving. However, this is secondary to the capability of efficient operation in a wide range of inlet and extraction/admission flows.

Non-Condensing Turbines

Non-Condensing turbines are used in many paper mills and desalination plants (*Figure 12*). These turbines act as pressure reducing stations and at the same time provide reliable power for these plants. Again, a matrix of components is available for a wide range of exhaust flows in both up and down configurations.

Other applications of industrial and cogeneration turbines include geothermal and district heating installations.

District Heating

District heating turbines are designed for very large extraction flows at low pressures (for winter operation). Modern designs have been developed for this application with internal valving using a grid valve to position the movable valve disc.

Improvements in Performance

Improvements in IST performance have been achieved by combining design features previ-

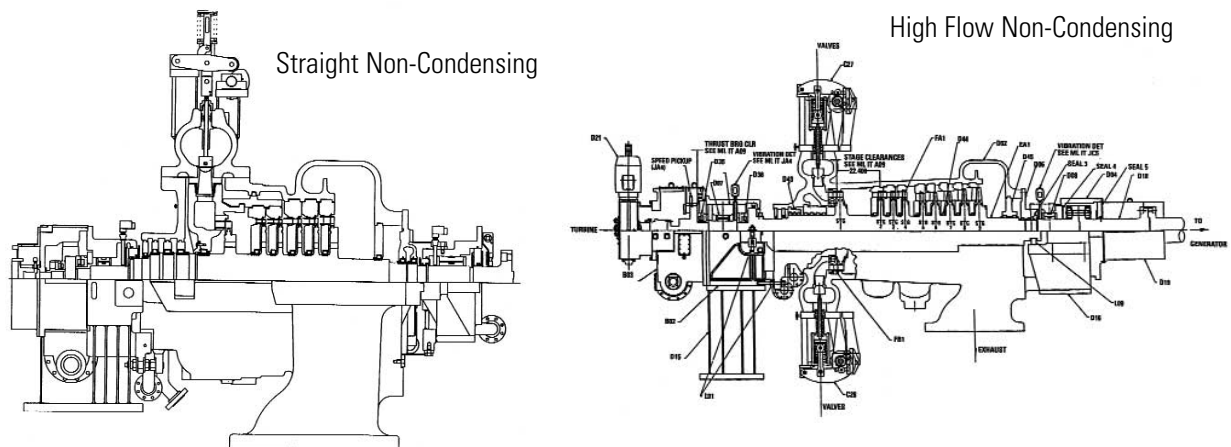


Figure 12. Turbine configurations

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ously proven on utility units, where the economic implications of performance are tremendous, with other line-specific enhancements.

These enhancements largely have been made possible by the latest computer-aided design tools, which enable the turbine designer to improve turbine performance without compromising reliability. Through the use of these tools, the aerodynamic performance, stress distributions and rotor dynamics associated with a particular turbine configuration can be estimated more accurately and optimized. As a result, more compact steam path configurations with reduced leakage, profile and secondary flow losses become a reality.

Further improvements in performance have been achieved by the increased application of efficiency-enhancing components, including round-skirted buckets in the shorter stages, locking buckets in lieu of notch blocks at the point of bucket insertion, conical sidewall diaphragms and slant-tip buckets with root and tip spill strips.

Special attention has been paid to optimizing the performance of low-pressure turbine sections, where the latest three-dimensional design tools have been employed to improve the aerodynamic performance of buckets, nozzles and exhaust hoods. As an example, the low-pressure section utilizing the 20-inch/508-millimeter last-stage bucket (*Figure 13*) shows a performance improvement of 1.5 to 2%, over the previously used design.

The last-stage bucket's design enhancements include the following:

- Continuously coupled tip construction utilizing the well-proven over/under cover concept for improved damping and modal suppression
- Loose tie wires relocated to a lower



Figure 13. 20-inch (508 mm) last-stage bucket

velocity region for improved performance and increased structural damping

- Improved dovetail design permitting optimized bucket root flow passage geometry
- Improved vane design, optimized for centrifugal untwist and radial flow distribution, to minimize aerodynamic losses
- Transonic convergent-divergent flow passage at the tip section to minimize shock losses
- Self-shielding bucket material and L-shaped cover with integral sealing rib for improved erosion protection

For the largest industrial turbines, a nonreheat, low-pressure section, utilizing a 30-inch/762-millimeter last-stage bucket, in a single-flow configuration, has been developed for outputs up to 130 MW, in a single casing, with minimal exhaust loss. The 30-inch/762 millimeter last-stage bucket has been in service on utility units for over 25 years and has an excellent operating history.

Bearings

The reliability and dependability of steam turbines depend on rotor dynamics and bearing performance (*Figure 14*). Tilting pad journal and thrust bearings are now used on the vast majority of IST applications. These bearings provide optimal rotor stability and ensure a high degree of reliability due to their tolerance of misalignment. Proper selection of these critical components is part of our design process.

For each turbine application, an in-depth lateral and torsional rotor dynamic analysis is performed following the development of a preliminary design. Consideration is given to every possible destabilizing force, such as those from partial arc diaphragms, inlet valves and extraction controls, to ensure that the component modules selected for each application will result in a turbine unsurpassed in reliability.

The steam path is the very essence of a turbine and its design essentially determines the turbine's performance.

Frequency

In many developing countries around the world, the utility, or site grid, often operates within a wide range of frequency. Steam turbine operation in such a situation can cause vibratory stress problems. When operation in a wide frequency range is expected, the turbine can be designed using tools developed for mechanical drive steam turbines, where operation at or near a natural frequency of a component is analyzed to ensure long component life.

Axial Exhausts

In the past, most steam turbines that were designed for industrial and cogeneration applications have featured a down exhaust arrangement with an underslung condenser. However, exhaust losses, as well as turbine building costs can be reduced through the use of an axial exhaust arrangement with an in-line condenser. Most GE ISTs are now available in an up, down or axial exhaust configuration. The axial



Figure 14. Turbine bearings

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exhausts (*Figure 15*) have been designed with performance in mind and incorporate aerodynamically efficient bracings and optimized casing wall geometrics. On average, the selection of an axial exhaust arrangement can improve turbine performance by 0.25 to 0.50%. For a 40 MW turbine, that can mean an additional 100 to 200 KW for the same amount of fuel. The plant arrangement benefits of the axial exhaust configuration are discussed in greater detail later.



Figure 15. Axial exhaust configuration

Turning Gear

Optional turning gear packages (*Figure 16*) are composed of an electric motor that drives a single-, double- or helical/worm reduction gear reducer through a torsionally resilient coupling. The input half of a syncro-self-shifting (SSS) overrunning clutch is mounted to the output shaft of the gear reducer, with the output half mounted to the turbine rotor. The clutch operates automatically, by mechanical means, to engage whenever the input speed (turning gear) is the same as or greater than the output speed (i.e., turbine speed). Therefore, when the turning gear motor is energized, the

clutch will engage only if the driven equipment is stationary or turning at a speed equal to the turning gear speed. This leads to one of the greatest operational characteristics of the system, the ability to catch on the fly. If the turning gear controls are configured to start the motor while the steam turbine is coasting down, it will automatically engage when the input and output clutch speeds are synchronous, thus avoiding the need for a zero speed signal (from the rotor at rest). This is by far the most advantageous means of operating the turning gear, offering the best protection to the rotating rotor while minimizing the duty cycle on the turning gear. In its simplest form, in order for it to operate, this turning gear package requires that motor power and lubricating oil be taken off the bearing supply header.

The design method and rules we follow serve to protect the turning gear from damage. If the turning gear experiences a load in excess of its design, the motor simply will trip out on overload and the turning gear components will not fail. The unit will only produce a certain amount of torque, and the components are designed to handle this load with appropriate service factors. In fact, this turning gear can be used as an excellent indicator of train integrity problems. If there is train misalignment, tip or seal rubs, the turning gear motor will draw greater amperage after breakaway as an indicator of the increase in load.

SPEEDTRONIC™ Mark VI Control

GE ISTs are available with the SPEEDTRONIC™ Mark VI Control, the latest generation of our steam turbine control product line. This turbine control system is available in either single-channel or triple-redundant configurations and offers a number of enhancements over previous generations of turbine control.

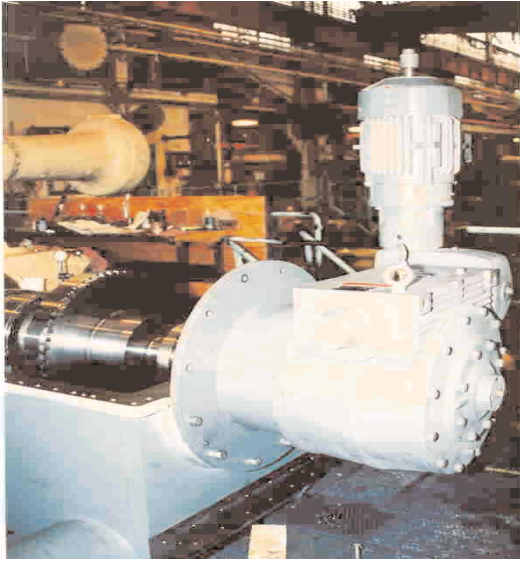


Figure 16. Turning gear

The SPEEDTRONIC™ Mark VI turbine control is the current state-of-the-art control for GE turbines. It is based on over 30 years of successful operation of electronic turbine control systems. It is designed as a completely integrated control, protection and monitoring system for generator and mechanical drive applications for gas and steam turbines. It is also an ideal platform for integrating all power island and balance-of-plant controls.

Redundancy

Mark VI control systems are available in simplex and triple redundant forms for small applications and large integrated systems, with control capability ranging from a single module to many distributed modules. The name triple module redundant (TMR) is derived from the basic architecture of three completely separate and independent control modules, power supplies, and IO Nets. Mark VI is the third generation of triple-redundant control systems that were pioneered by GE in 1983.

Sensor interface for TMR controls can be single,

dual or triple redundant, or combinations of redundancy levels. The TMR architecture allows uninterrupted operation following a single-point failure in the electronics and repair of the defective card or module while the process is running. Adding sensor redundancy increases an overall system's fault tolerance.

Another feature of the TMR is its ability to distinguish between field sensor faults and internal electronic faults. Diagnostics continuously monitor the three sets of input electronic and alarm any discrepancies between them as an internal fault versus a sensor fault. In addition, all three main processors continue to execute the correct two out of three "voted" input data.

Mark VI TMR Control Configuration

Operator Interface

The operator interface is commonly referred to as the human-machine interface (HMI). It is a PC with a Microsoft® Windows NT® operating system supporting client/server capability, a CIMPLICITY® graphics display system, a control system toolbox for maintenance and a software interface for the Mark VI as well as other control systems on the network. The HMI can be applied as:

- The primary operator interface for one or multiple units
- A backup operator interface to the plant DCS operator interface
- A gateway for communication links to other control systems
- A permanent or temporary maintenance station
- An engineer's workstation.

HMI System Structure

The HMI system can provide plant visualization

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for control systems that span a wide range of equipment. Systems using the Mark V HMI may include one or more of the following types of equipment:

- Mark V gas or steam turbine control
- Mark VI gas or steam turbine control
- EX2000 generator voltage regulator
- Generator protection
- LCI static starters
- Historians
- Engineering workstations for system tools
- System and documentation printers
- Ethernet networking components
- Arcnet networking components
- Integrated third-party systems
- HRSG controllers
- Balance-of-plant controllers
- GE integrated control system

Communications

Communications are provided for internal data transfer within a single Mark VI control or communications between Mark VI controls and peer GE control systems as well as external communications to remote systems such as a plant-distributed control system (DCS). The unit data highway (UDH) is an Ethernet-based local area network (LAN) with peer-to-peer communication among Mark VI controls, EX2000 generator excitation controls, static starters, the GE Fanuc family of PLC-based controls, HMIs and historians (Figures 17–19).

VF Series Fluid System Package

The VF series fluid system packages combine GE’s experience from the industrial, petrochemical and power industries into a robust, full-featured, highly reliable and low-maintenance product offering that is optimized to fulfill the demanding requirements of today’s competitive power generation marketplace.

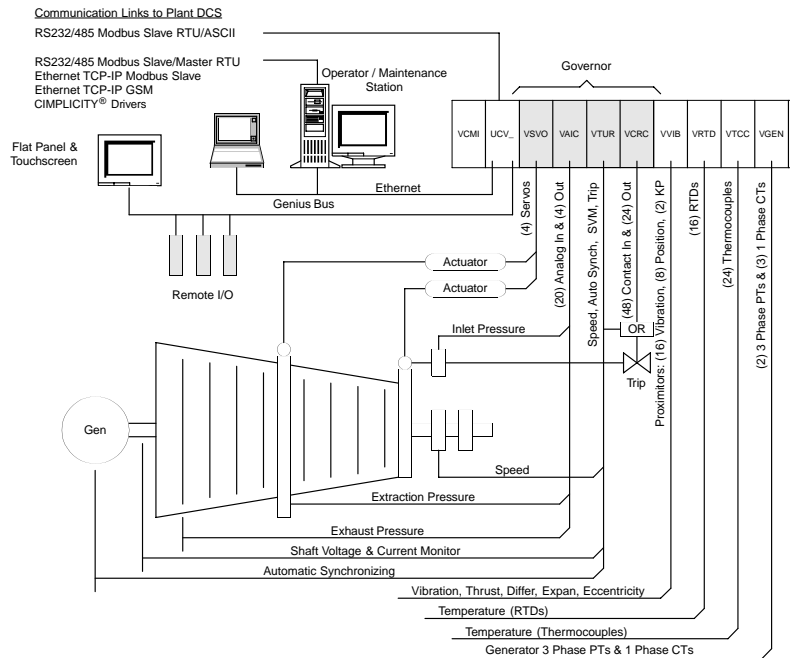


Figure 17. Industrial steam turbine control – architecture

Steam Turbine Control Cabinet



- NEMA 1 Convection Cooled
- Front Access
- Top/Bottom Cable Entrance
- Separate High & Low Level Channels
- Various Cabinet Arrangements Available

Figure 18. The Mark VI

Control Cabinet



Figure 19. The Mark VI

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The VF package includes a hydraulically separate lubrication and lubricating oil dehydration system, a hydraulic fluid supply and conditioning system and a common control console in a single package (Figure 20). The fluid system package can mount separately from the steam turbine-generator or be installed integrally with the turbine base.

Full-Feature Designs

- Redundant ac motor-driven pumps for both lubrication and hydraulic service
- Duplex lubricating oil filters and oil coolers
- DC motor-driven emergency oil pump
- Integral lubricating oil dehydration system
- Lubricating oil mist elimination system
- Redundant hydraulic filters
- Integral hydraulic fluid conditioning

and cooling system

- Oil pressure and temperature controls
- Extensive instrumentation
- Enclosed control console with integral gauge board
- Stainless steel pipe and epoxy finish coatings

Simple, Cost-Effective Installation

- A single package requiring a single foundation for the fluid system
- Compact size to ease the plant arrangement
- Suitable for four-point support or perimeter grout
- Factory performance test to verify performance
- Stainless steel pipe and factory cleaning to reduce the installation cycle

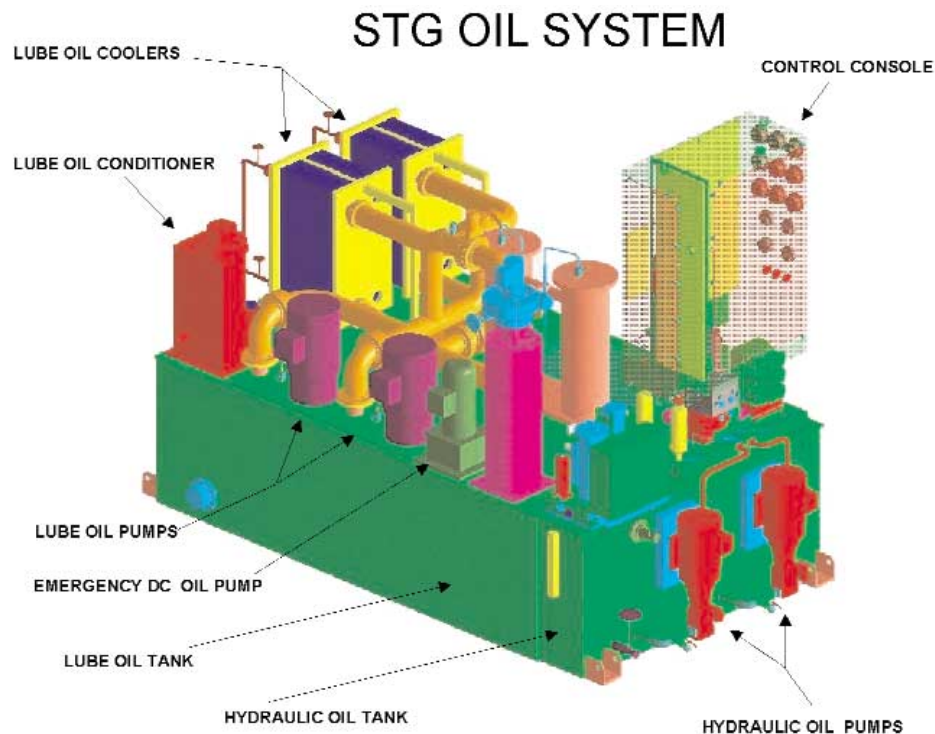


Figure 20. GE VF fluid system

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Operational Reliability

- Manufactured to fully detailed GE-produced drawings, for control and repeatability
- Simple, robust construction
- Redundant components for online maintenance
- Online testability
- Sealed reservoir and console
- Integral continuous fluid conditioning
- Two of three voting trip solenoids (electrical trip device) for fault tolerance
- Special-purpose dc motor designs for predictable and reliable performance

Performance and Economy

- Proven fluid-system components shared with other VF designs and refined by continuous improvement
- Custom selection for each site to assure performance and suitability for site conditions
- Extensive use of specialized integrated hydraulic circuits for simple assembly and leak-free construction
- Watertight construction to resist moisture contamination of fluids or damage to controls
- Integral oil-side temperature control
- Dehydration system circulating pump and heaters, which double as startup heaters
- High-performance filtration, for total fluid cleanliness
- Stainless hydraulic reservoir and stainless pipe throughout

- Lightweight hydraulically efficient reservoir construction for strength
- Epoxy-finish coatings
- Extensive control interfaces with GE's control system and the plant DCS
- Motors suitable for 50°C ambient conditions

Simple, Cost-Effective Maintenance

- Extra-severe-duty motors for extended operating life and power margin
- C-face motors with rabbet fits for easy alignment with high-tolerance, oversize couplings
- Long-service life, high-capacity filter elements
- Spin-on desiccant canister to prevent moisture from contaminating the hydraulic fluid
- Hydraulic fluid conditioning and large hydraulic reservoir that reduce stress on the operating fluid and extend fluid service life
- High-performance dehydration system eliminates free-water contamination and prevents lube oil deterioration.

Environmental Compatibility

- High-efficiency centrifugal pumps and variable-capacity hydraulic pumps to minimize power consumption
- Oil-mist elimination system to reduce oil discharges
- Integral dehydration system with no external piping or connections to the sewer to eliminate another potential source of oil discharge
- Long fluid service to reduce spent fluid disposal costs

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- High-performance, high-capacity filtration to reduce element disposal costs

Ability to Meet Site Conditions

- Customized for a specific site environment
- Optional materials for aggressive atmospheric and cooling water environments
- Large inventory of practical solutions for unique site problems
- Optional control configurations for the plant DCS or GE turbine control system
- Available local pump and motor control panels
- Highly experienced GE system engineering for fluid, innovative solutions to difficult problems

Application Range

The VF-F/Q design series includes sizes for applications with steam turbines and combined-cycle steam turbines with either air-cooled or hydrogen-cooled generators and system flow capacity from 70 up to 900 gallons per minute (nominally 10–350 MW).

The VF-HP series, VF-LP series, UT series and TCS series are designs available for industrial power, vintage machine replacement, mechanical drive and control retrofit applications.

Turbine Factory Packaging

GE has been the pioneer in the area of “packaged” industrial steam turbine-generators, which are completely assembled and aligned in the quality-controlled environment of the factory. The units can be mounted on bases for quick and easy installation and alignment verification in the field. Piping, wiring and testing are also

performed in the factory to the maximum extent possible. The benefits of factory packaging are minimized installation time and cost, with reduced risk to the schedule. To date, GE has shipped more than 120 packaged steam turbine-generators representing more than 4.5 gigawatts in output capacity.

The experience gained in packaging these smaller units has now been applied to larger units. Specifically, GE now offers packaged steam turbine-generators using up to a 23-inch/584.2 millimeter last-stage bucket in down exhaust configurations and a 30-inch/762 millimeter last-stage bucket in axial exhaust configurations. This means that units of up to 80 MW with a down exhaust and 130 MW with an axial exhaust can be shipped to site, fully assembled and base mounted, with virtually all unit piping and wiring done in the factory.

Features of the Packaged Turbine

Due primarily to shipping limits, the turbine-generator and lubrication and hydraulic systems are provided on separate prepackaged bases or skids. With nonaxial exhaust turbines the lubrication and hydraulic oil system can be installed into the turbine base.

Steam turbines come factory aligned on a base fabricated from I-beams. Optical targets are provided at each corner of the base, and their (vertical) locations relative to a common reference are recorded following factory alignment. Once the unit is on site, the base is leveled using base jacking bolts to duplicate the factory settings.

To provide an additional field alignment check, a pin is fitted at the factory in the gib key that guides the high-pressure shell at the front standard. If the pin can be easily inserted and removed after the base is leveled in the field, then no twists and strains have been put into

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the base during field installation and the upper-half casing need not be removed to confirm the alignment.

On units supplied with a spray chamber in lieu of a gland condenser, the entire steam seal system can be fabricated and assembled in the factory prior to shipment, thus saving considerable time and installation cost in the field.

On other units, because of its size, the skid-mounted gland condenser system is installed separately beside or below the turbine. All steam seal piping is factory assembled, and a flanged connection is provided at the edge of the base for field interconnection to the gland condenser.

A low-profile combined lubrication and hydraulic system can be provided for mounting in close proximity to the turbine-generator. The system design and the short distance between the turbine-generator and the lubrication and hydraulic system minimize the vertical drop required for proper oil drainage and allow axial exhaust turbine-generators to be mounted at or close to grade for lower building and installation cost.

Feed and drain piping are assembled in the factory and are terminated at a single point at the edge of the turbine base. Only a short length of prefabricated interconnecting piping, with flanged connections and flexible expansion joints needs to be installed in the field. Installation and flushing time in the field is minimized because the feed and drain piping is mounted on the turbine base, and the combined lubrication and hydraulic skid are pre-cleaned in the factory.

All turbine-generator electrical devices and sensors are prewired in the factory with connections terminated in junction boxes located on the bases.

Figure 21 shows a typical 80 MW automatic-extraction condensing steam turbine without a base, mounted on a traditional pedestal. The unit's exhaust is directed downward into an underslung condenser.

Foundation complexity, as well as installation time and cost, can be reduced by selecting a base-mounted down exhaust unit with an on-skid lubrication and hydraulic oil system, as shown in *Figure 22*.

Axial Exhaust

Costs can be further reduced by selection of an axial exhaust configuration. *Figure 23* shows an axial exhaust turbine of the same capacity and similar functionality that is base mounted in a low-profile configuration.

The following describe the advantages of the packaged axial-exhaust, low-profile design over the unpackaged down exhaust design.

Improved Turbine Performance

The performance of an axial exhaust unit is typically 0.25 to 0.50% better than a comparable down exhaust unit. The present value of the fuel savings over the operating life of the unit can range from 2.5 to 12.5% of equipment cost.

Reduced Building Costs

The overall height of the building can be lowered significantly by the low-profile design. The total amount of concrete required and the complexity of the foundation design are reduced significantly.

Reduced Installation Costs

The packaged design includes pre-assembled and pre-cleaned piping as well as all unit electrical and instrumentation wiring that is terminated in junction boxes for reduced field installation time. Additionally, the time required to install the axial condenser and check the align-

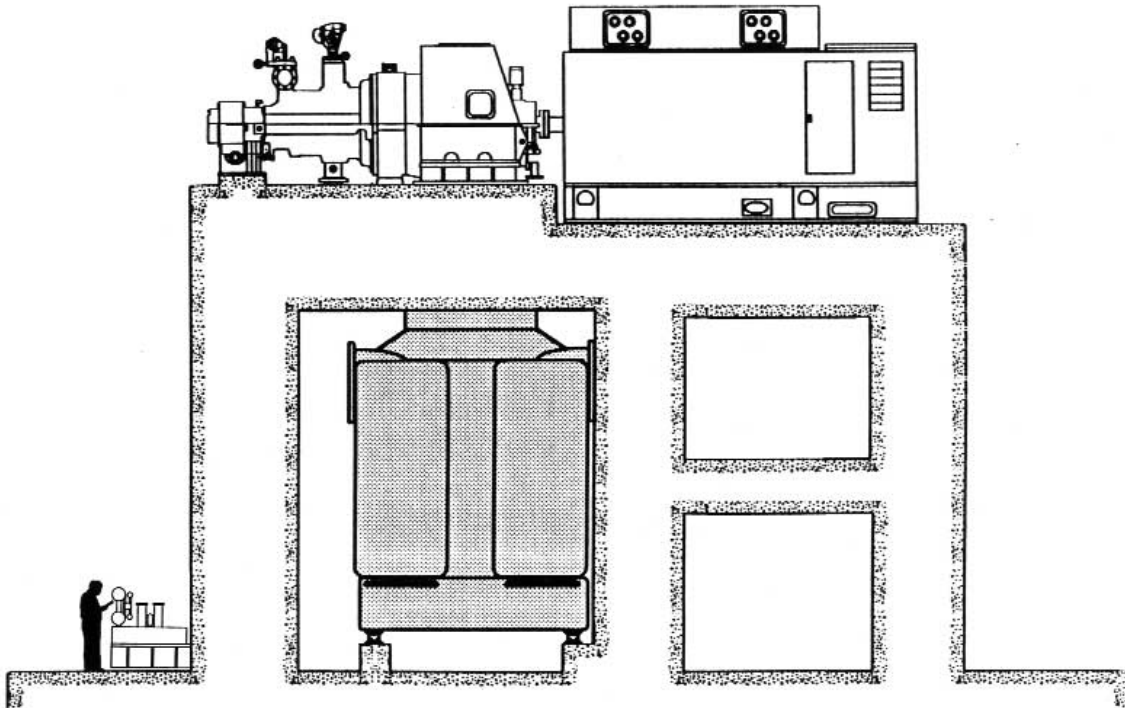


Figure 21. Unpackaged down exhaust unit in pedestal installation

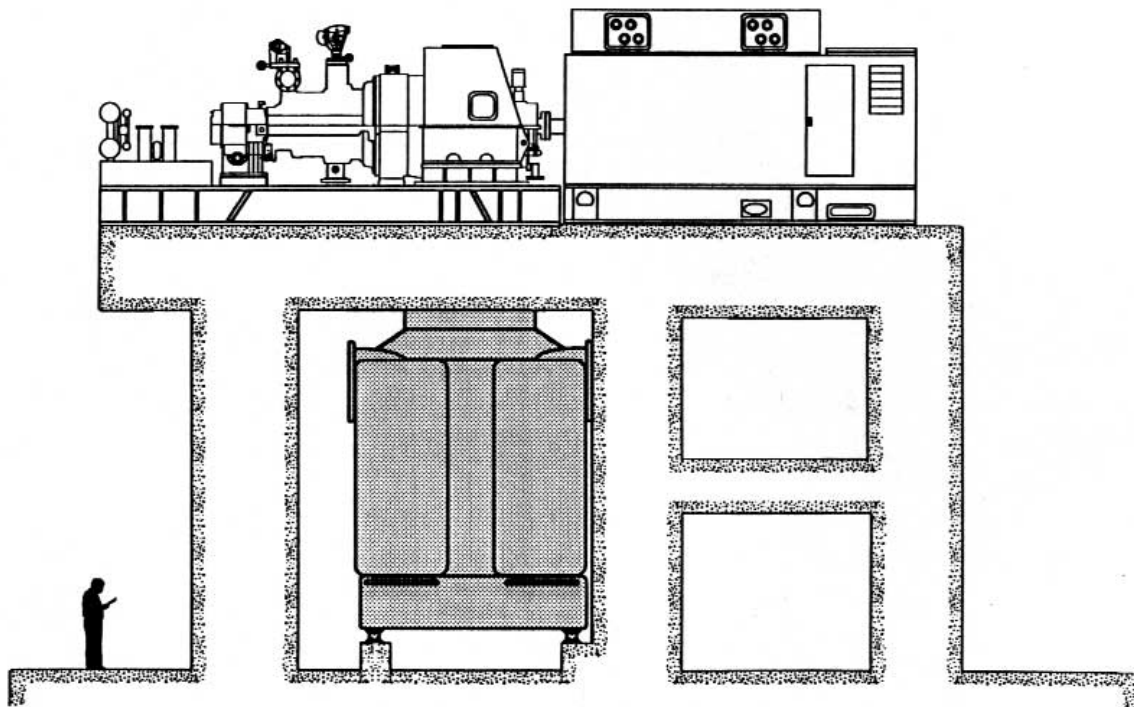


Figure 22. Packaged down exhaust unit in a pedestal installation

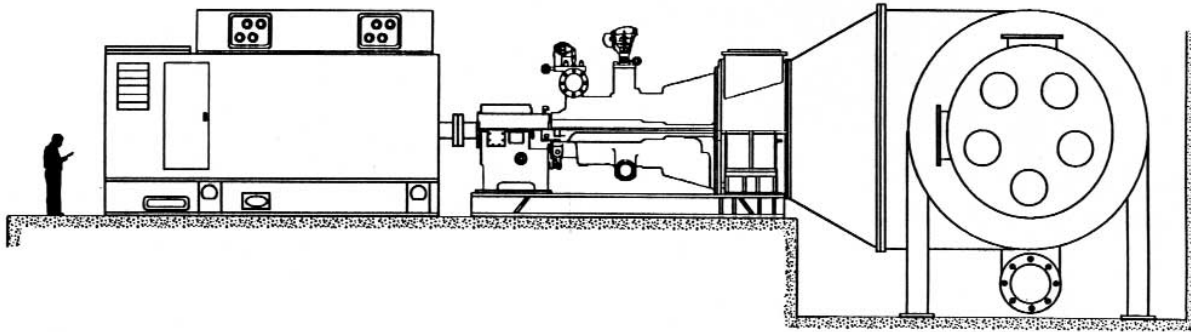


Figure 23. Packaged axial exhaust unit in a low-profile installation

ment of the turbine stationary and rotating parts is reduced.

Reduced Installation Time

Experience has demonstrated that a packaged turbine-generator can be installed in up to 40% less time than an unpackaged unit. With reduced potential for field installation delays, plants can be brought on line faster than ever thought possible.

Cost Comparison

A cost comparison between the alternatives shown in *Figure 21* and *Figure 23* are shown in *Figure 24*.

Approximately a half million dollars (U.S.) in total cost is saved by selecting the packaged turbine-generator with an axial exhaust in a low-profile installation. It should be noted that these savings do not include any fuel cost savings or savings associated with a faster plant startup. These savings vary from application to application but can be quite significant for many independent power projects.

It should also be noted that although the economic advantages of selecting a base-mounted axial exhaust design are considerable compared to a comparable unpackaged GE design with a down exhaust, they are even larger in comparison to the multicasing designs offered

by other manufacturers. These designs incorporate separate high-pressure and low-pressure turbines interconnected by a cross-under pipe. The turbine-generator unit arrives on site in several more pieces than a GE single-casing unit; utilizes a higher and more elaborate foundation; and requires significantly more time on site for field piping, wiring and alignment.

Design Standardization

Increased Design Standardization

GE has optimized the standard components utilized in its building-block structure, to reduce the number of “special” and infrequently used modules. Greater use of optimized and frequently applied component modules results in reduced design, drafting, sourcing and manufacturing times.

Increased Design Automation

An automated design system has been developed to optimize turbines for specific applications by selecting and combining standard component modules. The system automatically lays out the turbine steam path from which many turbine component detail drawings can be downloaded and created electronically, with an absolute minimum of drafting time.

While the turbine design is automated and

Savings From Low Profile Base Mounted Axial Exhaust Steam Turbine

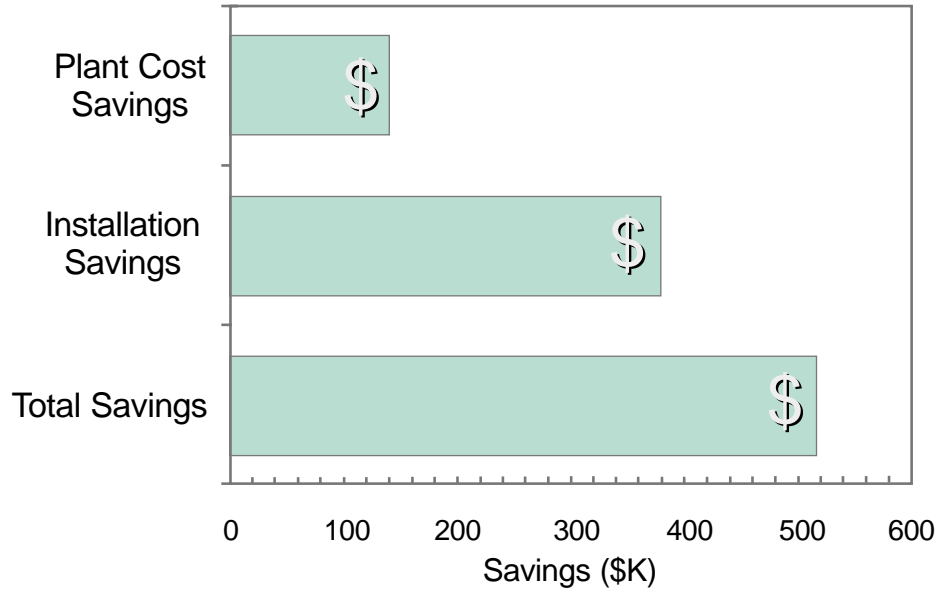


Figure 24. Savings from a 40 MW base-mounted turbine with an axial exhaust and low-profile plant layout

developed from standardized hardware modules, a full mechanical analysis is done to check steady-state and vibratory stresses on the machine. This design process results in a steam turbine configuration with maximum power density that has been fully analyzed in its custom configuration. The level of design automation employed enables the development of first-level casting and forging drawings within a few weeks following receipt of an order.

Sourcing Partnerships

GE has developed partnerships with major suppliers of long-lead and high-value turbine components. Extensive producibility reviews have been held with these suppliers to make sure our designs can be executed by them in minimal time while still ensuring high quality. These reviews have led to several changes in the design of head castings for reduced cycles, such as the

use of customized conical barrel-section patterns. To reduce rotor-forging cycles, GE has reserved a number of slots in our major forging vendors' production plans to ensure custom rotor forging availability in the minimum possible cycle time.

Additionally, our automated production planning system with its electronic data interchange communications, allow automatic placement of many component orders with suppliers immediately following the release of a design for manufacture. As many as half of all purchase orders placed by GE are now executed directly through the system with minimum buyer intervention.

Manufacturing Initiatives

Increased use of numerically controlled machine tools has led to a reduction in manufacturing cycles for casings, rotors and steam

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path components. Major subassemblies, such as the front standard, the valve gear and the oil system, can be fully assembled and tested before final unit assembly. This parallel manufacturing approach results in shorter total cycle times.

Increased Packaging

Increased assembly and packaging of steam turbines in the factory allows significant reduction in the time from site delivery to synchronization. Less work done on the site also minimizes the risk of unforeseen installation problems, which can extend project schedules.

Project Execution

Every order is executed by a project team headed by a project manager. This single-point contact coordinates all technical communication to and from the customer and acts as the focal point for internal coordination. Proper communication and project support from these experts is critical to the timely completion of the turbine-generator set as well as its integration into a customer's site.

Conclusion

Many innovations have been developed and adopted in the IST product line, to better meet the needs of industrial users. While improving upon the previous generation of turbines, basic product line attributes have been retained.

These well-known and proven features have made GE a leader in the areas of performance, reliability, dependability, maintainability and life-cycle costs. Enhancements to the product line further build on these strengths without compromising one for the other. As a matter of policy, GE attempts to develop product line improvements that not only are applicable to the new units it builds but also can be retrofitted into the large and ever-expanding fleet of industrial units already operating in plants around the world. Through this approach, users of older GE turbines are able to benefit from newly developed enhancements in the product line.

Our experience suggests that power producers, particularly those employing gas turbines as the primary heat source for the steam turbine, require faster delivery cycles than were required in the past. GE has taken steps to reduce its cycle times for its industrial steam turbine-generators to respond to this need. A combination of integration as well as design, manufacturing and sourcing initiatives has made these reductions possible.

GE's IST business unit has a broad product line, can offer shorter delivery cycles on its products (as short as 12 months or even less) and provides responsive quotes at competitive prices (budgetary quotes within 48 hours).

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