Post-it® brand fax transmittal memo 7671 | # of pages ▸ 1

To Syed Arif	From Paul Darst
Co.	Co.
Dept.	Phone # 488 4925
Fax # 922-6979	Fax #

TO: Syed Arif, DEP Air Quality

FROM: Paul Darst, Department of Community Affairs

SUBJECT: DCA's review of TECO's 1994 10-Year Site Plan

DATE: 15-Jun-95

Pursuant to section 186.801, F.S., the DCA recently performed a draft review of Tampa Electric's 1994 10-Year Site Plan. According to the statute we are to review 10-year site plans for consistency with the State Comprehensive Plan. The following passage from the draft review pertains to the 10-year site plan's consistency with Air Quality Policy 3 in the State Comprehensive Plan:

> Air Quality Policy 3: Reduce sulfur dioxide and nitrogen oxide emissions and mitigate their effects on the natural and human environment.
>
> The requirements of Title IV of the Clean Air Act are consistent with the direction of SCP Air Quality Policy 3. TECO's ability to meet the Title IV requirements will determine its consistency with Air Quality Policy 3. TECO proposes to add 436 MW of new capacity in the 1994-2003 forecast period. Of this capacity, 254 MW will be generated from coal gas, with fuel oil backup, and the remaining 182 MW will be generated from natural gas, with fuel oil backup. This new generation will cause additional emissions of sulfur dioxide and nitrogen oxides from the TECO system, contributing to TECO's decision, mentioned above, of meeting the Clean Air Act requirements through purchase of emission allowances and switching to lower-sulfur-content coals. The Department notes that TECO could have reduced its future sulfur dioxide and nitrogen oxides emissions by choosing natural gas rather than coal gas for its proposed Polk Power Station Unit 1 power plant.

The review was sent to TECO for their comments. We received the following comment on the preceding passage.

> Tampa Electric Company does not agree with the implication that future emissions of sulfur dioxide and nitrogen oxides could have been substantially reduced by using natural gas, instead of coal gas, for the proposed Polk Power Station Unit 1. The differential in sulfur content, and therefore sulfur dioxide emissions between natural gas and the coal gas proposed to be burned in Unit 1 is minimal and the emissions of nitrogen oxides will be controlled to levels comparable to that of natural gas.

We would like to have your opinion on this. Are we correct in our assertion about natural gas, or is TECO correct? Please call me at 488-4925.

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15.10 UTILITY COMMENTS

TECO offered comments and corrections to the draft review of its 1994 plan. The corrections have been incorporated into this final report. TECO's comments are reproduced below.

TECO's first comment refers to the following passage from section 15.8.2 of the Department's review:

Air Quality Policy 3: Reduce sulfur dioxide and nitrogen oxide emissions and mitigate their effects on the natural and human environment.

. . . . The Department notes that TECO could have reduced its future sulfur dioxide and nitrogen oxides emissions by choosing natural gas rather than coal gas for its proposed Polk Power Station Unit 1 power plant.

TECO commented as follows:

Tampa Electric Company does not agree with the implication that future emissions of sulfur dioxide and nitrogen oxides could have been substantially reduced by using natural gas, instead of coal gas, for the proposed Polk Power Station Unit 1. The differential in sulfur content, and therefore sulfur dioxide emissions between natural gas and the coal gas proposed to be burned in Unit 1 is minimal and the emissions of nitrogen oxides will be controlled to levels comparable to that of natural gas.

Department response:

The discussion of the BACT determination for nitrogen oxides in appendix D of the Final Environmental Impact Statement for the TECO Polk Power Station Unit 1 states that "The emission limit of 25 ppmvd when burning syngas is higher compared to 9 ppmvd when burning NG [natural gas] in a combustion turbine due to the difference in composition and heat content between the two fuels." The EIS also states that, because of the uncertainty in actual system performance and the high cost of a SCR control system, the actual BACT for nitrogen oxides for Polk Unit 1 will be determined following a data collection period. The Department acknowledges that testing may demonstrate that Polk Unit 1's actual emissions of nitrogen oxides are less than the projected 25 ppmvd. Whether they will be less and whether they will be as low as the 9 ppmvd from natural gas, however, remains to be seen.

Table 2 in the BACT discussion in the EIS contains projected annual emissions from Polk Power Station for sulfur dioxide, nitrogen oxides, and other regulated air pollutants. Sulfur dioxide emissions are projected as 2,469 tons per year from the 260-MW Unit 1 when burning syngas as primary fuel and a total of 720 tons per year from the two 220-MW combined cycle units burning natural gas as primary fuel. Nitrogen oxides emissions are projected as 1,923 tons per year from Unit 1 on syngas and a total of 1,308 tons per year from the two combined cycle units on natural ga

Syed – Please check over my response above for appropriateness.
Give me a call.
—Paul Darst

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HOLLAND & KNIGHT

A Partnership Including Professional Corporations

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Suite 600
P.O. Drawer 810 (ZIP 32302-0810)
Tallahassee, Florida 32301

904-224-7000
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Washington, D.C.
West Palm Beach

December 16, 1994

RECEIVED
DEC 19 1994
Bureau of
Air Regulation

Mr. C. H. Fancy, P.E.
Chief, Bureau of Air Regulation
Department of Environmental
Protection
Twin Towers Office Building
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

Re: PSD-FL-194(A) Polk County -- Polk Power Station

Dear Clair:

Attached for your files is the affidavit of publication of the Notice of Intent to Issue Permit Amendment for PSD-FL-194(A), concerning Tampa Electric Company's Polk Power Station. The Notice was published in the December 3, 1994, edition of The Lakeland Ledger.

Please let me know if you have any questions or require additional information.

Sincerely,

HOLLAND & KNIGHT

Larry

Lawrence N. Curtin

Attachment
cc w/o att:
Mr. Greg Nelson
Mr. Steve Jenkins
S. Arif
B. Oven
J. Kissel, SW Dist
J. Harper, EPA
J. Bunyak, NPS

LNC/mrh
TAL-54885

AFFIDAVIT OF PUBLICATION

THE LEDGER

Lakeland, Polk County, Florida

Case No......................

STATE OF FLORIDA)
COUNTY OF POLK)

Before the undersigned authority personally appeared Robert Lee, who on oath says that he is Classified Manager of The Ledger, a daily newspaper published in Polk County, Florida; that the attached copy of advertisement, being a

Notice of Intent to Issue Permit

in the matter of

PSD-FL-194 (A)

in the

Court, was published in said newspaper in the issues of

December 3,

1994

Affiant further says that said The Ledger is a newspaper published at Lakeland, in said Polk County, Florida, and that the said newspaper has heretofore been continuously published in said Polk County, Florida, daily, and has been entered as second class matter at the post office in Lakeland, in said Polk County, Florida, for a period of one year next preceding the first publication of the attached copy of advertisement; and affiant further says that he has neither paid nor promised any person, firm or corporation any discount, rebate, commission or refund for the purpose of securing this advertisement for publication in the said newspaper.

Signed: [signature]
Classified Advertising Manager

by Robert E. Lee who is personally known to me

Sworn to and subscribed before me this 3rd

day of December A.D. 19 94

BILLIE MORLAN
MY COMMISSION # CC 191354
EXPIRES: April 6, 1996
Bonded Thru Notary Public Underwriters

Billie Morlan
Notary Public
BILLIE MORLAN

My Commission Expires

Holland & Knight
Acct. 12610

STATE OF FLORIDA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
NOTICE OF INTENT TO ISSUE PERMIT AMENDMENT
PSD-FL-194(A)

The Department of Environmental Protection (Department) gives notice of its intent to issue a permit amendment to Tampa Electric Company, Post Office Box 111, Tampa Florida 33601-0111, to reflect modifications to the affected source and an extension of the expiration date. This facility consists of a 260 megawatt (net) integrated coal gasification combined cycle (IGCC) source located approximately 13 miles southwest of Bartow, Polk County, Florida. The modifications include the following: increasing the size and operating parameters of the auxiliary boiler, replacement of uncovered coal piles with coal silos, decreasing NO_x emission limits for the IGCC combustion turbine, monitoring requirements for the auxiliary boiler, and updating of applicable regulatory requirements. Modeling results show that increases in ground level concentrations are less than Prevention of Significant Deterioration (PSD) significant impact levels. These emissions will not cause or contribute to a violation of any ambient air quality standard or PSD increment.

A person whose substantial interests are affected by the Department's proposed permitting decision (amendment) may petition for an administrative proceeding (hearing) in accordance with Section 120.57, Florida Statutes (F.S.). The petition must contain the information set forth below and must be filed (received) in the office of General Counsel of the Department at 2600 Blair Stone Road, Tallahassee, Florida 32399-2400, within 14 days of publication of this notice. Petitioner shall mail a copy of the petition to the applicant at the address indicated above at the time of filing. Failure to file a petition within this time period shall constitute a waiver of any right such person may have to request an administrative determination (hearing) under Section 120.57, F.S.

The Petition shall contain the following information; (a) The name, address, and telephone number of each petitioner, the applicant's name and address, the Department Permit File Number and the county in which the project is proposed; (b) a statement of how and when each petitioner received notice of the Department's action or proposed action; (c) A statement of how each petitioner's substantial interests are affected by the Department's action or proposed action; (d) A statement of the material facts disputed by Petitioner, if any; (e) A statement of facts which petitioner contends warrants reversal or modification of the Department's action or proposed action; (f) A statement of which rules or statutes petitioner contends require reversal or modification of the Department's action or proposed action; and (g) A statement of the relief sought by the petitioner, stating precisely the action petitioner wants the Department to take with respect to the Department's action or proposed action.

If a petition is filed, the administrative hearing process is designed to formulate agency action. Accordingly, the Department's final action may be different from the position taken by it in this Notice. Persons whose substantial interests will be affected by any decision of the Department with regard to the application/request have the right to petition to become a party to the proceeding. The petition must conform to the requirements specified above and be filed (received) within 14 days of publication of this notice in the Office of General Counsel at the above address of the Department. Failure to petition within the allowed time frame constitutes a waiver of any right such person has to request a hearing under Section 120.57, F.S., and to participate as a party to this proceeding. Any subsequent intervention will only be at the approval of the presiding officer upon motion filed pursuant to Rule 28-5.207, Florida Administrative Code.

The application/requests are available for public inspection during normal business hours, 8:00 a.m. to 5:00 p.m., Monday through Friday, except legal holidays at:

Department of Environmental Protection
Bureau of Air Regulation
111 S. Magnolia Drive, Suite 4
Tallahassee, Florida 32301

Department of Environmental Protection
Southwest District
3804 Coconut Palm Drive
Tampa, Florida 33619-8218

Any person may send written comments on the proposed action to Mr. John Brown at the Department of Environmental Protection, Bureau of Air Regulation, Mail Station 5505, 2600 Blair Stone Road, Tallahassee, Florida 32399-2400. All comments received within 14 days of the publication of this notice will be considered in the Department's final determination.

K264-12 3 1994

K264

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NOV 18 1994
Bureau of
Air Regulation

TAMPA ELECTRIC COMPANY
POLK POWER STATION

DESCRIPTIONS OF SELECTED COMBUSTION TURBINE AND AUXILIARY BOILER FOR POLK UNIT 1

Submitted to:
FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION
Bureau of Air Regulation
Tallahassee, Florida

Submitted by:
TAMPA ELECTRIC
A TECO ENERGY COMPANY

Tampa, Florida

October 1994

TAMPA ELECTRIC COMPANY
POLK POWER STATION

DESCRIPTIONS OF SELECTED COMBUSTION TURBINE AND AUXILIARY BOILER FOR POLK UNIT 1

1.0 INTRODUCTION

Condition of Certification No. XIII.O.1 for the Tampa Electric Company Polk Power Station requires that the following information shall be submitted to the Florida Department of Environmental Protection (FDEP), Bureau of Air Regulation within 12 months of certification:

> "1. Description of the finally selected turbine and the auxiliary boiler to be installed at the facility. The description shall include the specific make and model numbers, and any changes in the proposed method of operation, fuels, emissions, or equipment."

To address this requirement, this document provides the following information for the selected combustion turbine and the auxiliary boiler for Polk Unit 1 at the Polk Power Station:

2.0 Selected Combustion Turbine

- 2.1 Description of the GE Model MS7001F combustion turbine
- 2.2 Design enhancements for Polk Unit 1

3.0 Selected Auxiliary Boiler

- 3.1 Description of the ABCO packaged watertube boilers
- 3.2 Special design features for Polk Unit 1

4.0 Changes in the Operation, Fuels, Emissions, or Equipment for the Combustion Turbine and Auxiliary Boiler Since Certification

- 4.1 Combustion turbine changes
- 4.2 Auxiliary boiler changes

2.0 SELECTED COMBUSTION TURBINE

2.1 DESCRIPTION OF THE GE MODEL MS7001F COMBUSTION TURBINE

Tampa Electric Company has selected the advanced General Electric Company (GE) Model MS7001F combustion turbine for Polk Unit 1. This is the same combustion turbine that was considered in the site certification process and referred to as the advanced GE 7F turbine. The following commercial brochures describe the selected GE Model MS7001F combustion turbine.

GAS TURBINE REFERENCE LIBRARY

The Design and Development of the Advanced GE MS7001F Heavy-Duty Gas Turbine

D.E. Brandt

Manager
Gas Turbine Engineering and Development
Turbine Technology Department
Schenectady, New York

CONTENTS

INTRODUCTION

The MS7001F gas turbine is a totally new 3600 rpm heavy-duty design, directed at a broadly based application in the 60 Hz power generation industry. It has a simple-cycle ISO rating of 141 MW with a heat rate of 9,995 Btu/kWh (LHV) at a firing temperature of 1260C (2300F) on natural gas fuel. This gas turbine has been designed for both simple and combined cycle applications, and will operate on all conventional gas turbine fuels, as well as coal-derived gas produced in an oxygen-blown integrated gasification combined-cycle (IGCC) installation. In natural gas combined-cycle applications, the total plant output will be in excess of 200 MW, with a heat rate less than 6828 Btu/kWh (LHV), depending upon the plant configuration and the type of steam cycle selected. The 595C (1100F) exhaust temperature allows for outstanding reheat steam conditions.

Printed in USA

The technologies associated with the gas turbine have seen substantial advancement during the past decade. This has been driven by economic considerations, such as the rapid increase in the cost of energy, as well as the acceptance of the gas turbine as a reliable source of power. Additionally, the cycle arrangement flexibility of the gas turbine with its progressive add-on features and its comparatively low demand on investment resources have made the gas turbine a very attractive alternative when electrical capacity expansion is being considered or when a demand exists for large amounts of thermal energy in conjunction with power generation. These market forces have provided the necessary impetus to drive a substantial investment in the technologies associated with gas turbines. Materials and process developments have resulted in higher quality components due to tighter process control, higher strength alloys, and improved high-temperature coatings. Advanced analytical methods coupled to improved understanding of materials behavior have resulted in a considerable improvement in the optimization of design. Recent developments in our understanding of the combustion process have substantially improved the emissions associated with elevated firing temperatures. Advances in heat transfer, fluid flow, structural and dynamic analysis, and aerodynamics have all set the stage for a major development in the design of advanced heavy-duty gas turbines. This paper discusses the features and characteristics of a new heavy-duty gas turbine that takes advantage of these latest technological advances.

GENERAL DESCRIPTION

Figure 1 illustrates the general configuration of the MS7001F gas turbine. It consists of a single rotor of bolted construction supported by two 419 mm (16.5 in.) diameter, four-element, tilting-pad bearings, with the output flange on the compressor end. Thrust is absorbed by a 635 mm (25 in.) x 432 mm (17 in.) tilting-pad thrust bearing with eight shoes on both sides of the thrust bearing runner. The thrust bearing load capability is 80,000 lb in both fore and aft directions so as to allow flexibility in simple - and combined-cycle applications.

The compressor is an 18-stage axial flow design with a pressure ratio of 13.5; the turbine is a three-stage design characterized by being intermediate between full reaction and impulse. The exhaust diffuser directs the flow of exhaust gases axially into either an exhaust stack or a heat recovery boiler.

The combustion system consists of 14 combustors oriented at a 13° angle. Each combustor is 356 mm (14 in.) nominal diameter.

The stator casings are of horizontally-split design to provide ready access to the internal parts during maintenance operations. The inlet and the forward and aft compressor casings are of nodular cast iron, while the compressor discharge and turbine shell casings and the exhaust frame are steel fabrications.

The first-stage nozzle and the first-and second-stage buckets are air cooled via internal cooling circuits sourced from compressor discharge and the 17th compressor stage. the second-and third-stage nozzles are cooled via external circuits sourced from the 13th compressor stage. All buckets are coated for corrosion protection.

CYCLE SELECTION

The gas turbine is a viable prime mover in the selection of alternatives for power generation. This requires that a new design accommodate a broad range of applications including simple-cycle, cogeneration, combined-cycle, heat recovery, and IGCC. For this reason,the cycle needs to be balanced in pressure ratio to satisfy both simple- and heat recovery-cycle requirements.

Initial studies over a range of firing temperatures indicated that a value of 1260C (2300F) represented a reasonable firing temperature consistent with long component lives, advanced cooling methods, material capabilities, and effective corrosion protective coatings. Given the selection of the firing temperature, it was then necessary to select a cycle pressure ratio. Figures 2 and 3 illustrate the basis for selection of 13.5:1 as the design pressure ratio for this air cooled machine in the simple-and combined-cycle mode.

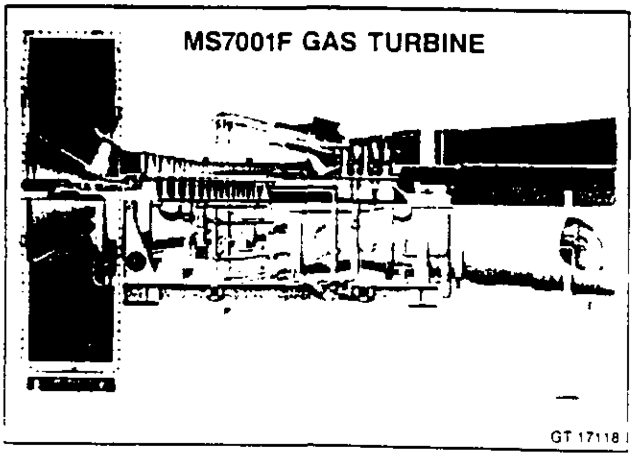


Figure 1

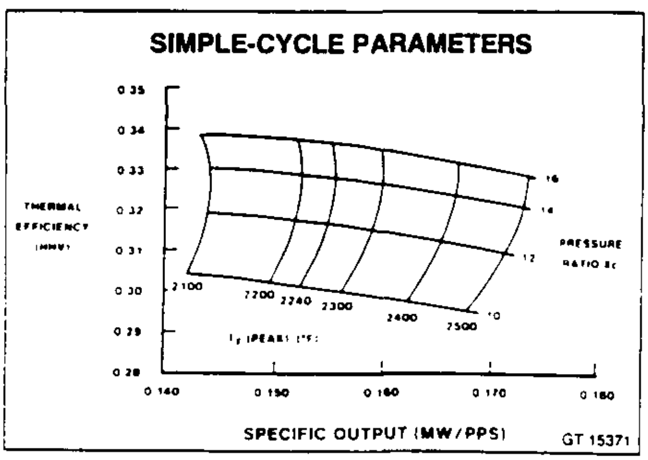


Figure 2

COMBINED-CYCLE PARAMETERS

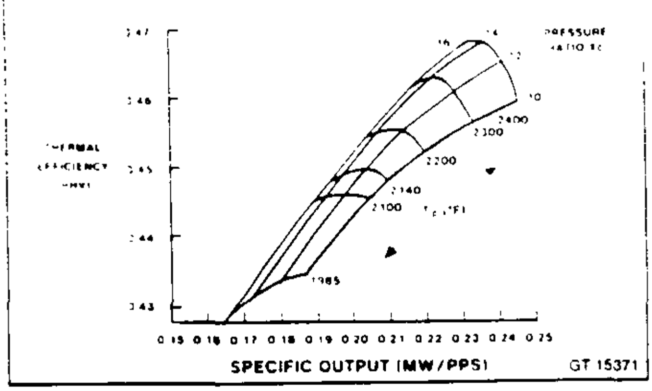


Figure 3

When selecting cycle parameters for simple-cycle applications, it is important to provide as high a power density for the power plant as possible. In this regard the specific output is a significant measure. The greater the output per pound of air flow, the smaller the gas turbine. From Figs. 2 and 3 it can be seen that the specific work peaks at approximately 14:1 for a firing temperature of 1260C (2300F).

Combined-cycle applications require a cycle configuration that emphasizes thermal efficiency. With a firing temperature of 1260C (2300F), the highest efficiency is obtained at a pressure ratio of 13.5:1 in combined-cycle application.

With the firing temperature and pressure ratio established, optiminal compressor flow can now be determined. Of major consideration in this decision is the exit annulus area of the turbine. Once a successful design is conceptualized for the first turbine stage at a specific firing temperature, it becomes necessary to determine just how large a last-stage bucket can be, while maintaining mechanical integrity and aerodynamic performance. The MS7001F utilizes GTD-111 as the alloy for all three turbine buckets. GTD-111 is a derivative of Rene 80 with improved hot corrosion resistance. It also has a 50 percent improved creep strength and a 20 percent improvement in 649C (1200F) LCF capability over U-500. The strength of GTD-111, together with a new aerodynamic turbine design with a moderate exit Mach number, established the flow at 408 kg/sec (900 lb/sec). The net result is a turbine efficiency which is significantly higher than that of the MS7001E turbine.

GAS TURBINE DESIGN

Compressor

The compressor for the MS7001F is an axial flow, 18-stage compressor with extraction provisions at stages 5 and 13. The compressor aerodynamic and mechanical design closely follows that of the 17-stage MS7001E (633 lb/sec, 3600 rpm), but with an additional zero stage. For convenience in maintaining this relationship, the MS7001F compressor stages are numbered 0 through 17 rather than 1 through 18.

The MS7001F compressor was developed by first applying a scale factor to the diameters of the MS7001E, then increasing the annulus area an additional amount to achieve the desired flow, and lastly adding a zero stage. As a result, the MS7001F is aerodynamically similar to the MS7001E, and most of the blading is interchangeable with the MS7001E except for length. Stages 0 and 1 have been designed for operation in transonic flow using design practices applied by the aircraft gas turbine designers. As a result of using this conservative design approach, variable stators, in addition to variable inlet guide vanes, are not required for surge control. The MS7001F compressor contains three exit guide vane rows to straighten the flow entering the compressor diffuser in order to enhance its performance.

Surge control of the compressor is accomplished through variable inlet guide vanes (VIGV) and selective bleed at the 13th stage. When the unit is started, the VIGV are at their minimum setting, and they are controlled during a prescribed schedule as a function of corrercted speed as the unit accelerates. At 100 percent speed the VIGV are full open for simple-cycle applications; for combined-cycle applications, they are at an intermediate setting and then open as a function of load and exhaust temperature to maintain maximum thermal efficiency. The 13th-stage bleed valves close during startup when the generator breaker closes.

The low stage loading, which has resulted in a very rugged MS7001E compressor, is retained in the MS7001F. This has resulted in retention of a very high level of compressor efficiency in the MS7001F.

Higher-strength alloys have been applied in order to accommodate the increased compressor blade stresses. Custom 450 stainless steel has been selected for the VIGV and stages 0 through 8. A higher-strength version of AISI 403 with columbium addition is the alloy of choice in stages 9 through the exit guide vanes. The net result of the application of these higher-strength alloys is that the applied stress/yield strength ratio is equivalent to that of the MS7001E (Fig. 4). The application of Custom 450 will have an additional benefit in corrosive environments. Field and laboratory testing of this alloy in very acidic salt environments (ph = 4) has demonstrated that it can be applied without coatings for corrosion protection. In these tests a variety of coatings was applied to AISI 403 and custom 450 and compared with uncoated Custom 450. The field tests were performed on MS7001E machines operating in industrial environments that had proven to be very aggressive to NiCd coated AISI 403. Uncoated Custom 450 demonstrated a clear superiority over any other non-Custom 450 based system, as well as coated Custom 450 (Fig. 5). Those coated systems, which appeared to be equivalent to bare Custom 450 in the Laboratory tests, did not hold up in the field tests. Erosion was the main cause of coating failure. Of particular interest is the result wherein coated Custom 450 resulted in shorter lives than bare Custom 450. The mechanics causing this dichotomy are not understood at this time and require further study.

MS 7001E/MS 7001F COMPRESSOR ROTOR BLADE RELATIVE STRESS COMPARISON

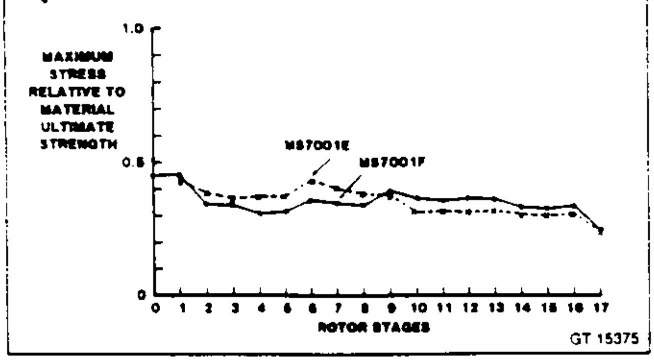


Figure 4

The dynamic behavior of compressor blading is of great concern to the compressor designer. For this reason, full-scale wheelbox testing of the stage zero blading was performed before the final design was committed to manufacturing. This testing was accomplished in GE's Gas Turbine Development Laboratory low-pressure wheelbox facility. This facility permits the testing of fully-bladed, full-scale rotors up to 4.3 m (170 in.) diameter at rated machine speeds and pressures as low as two psia. The blades are instrumented to determine their dynamic response while being excited by air jets as a dynamic stimulus. Extensive efforts have been applied over the last decade to develop advanced computer-based predictive techniques that will accurately predict the dynamic response of complex unshrouded compressor and turbine blading. The results of this effort are demonstrated in Fig. 6, where the predicted and measured Campbell Diagrams are compared for the 0 stage compressor blading. Not only is the prediction exceptionally accurate, but it is clear that dynamic responses of the blade are well clear of the forcing functions of significance at operating speed.

Turbine

The MS7001F turbine is a three-stage design with the first-stage bucket unshrouded and the second- and third-stage

CORROSION RESISTANCE ACIDIC LABORATORY TESTS

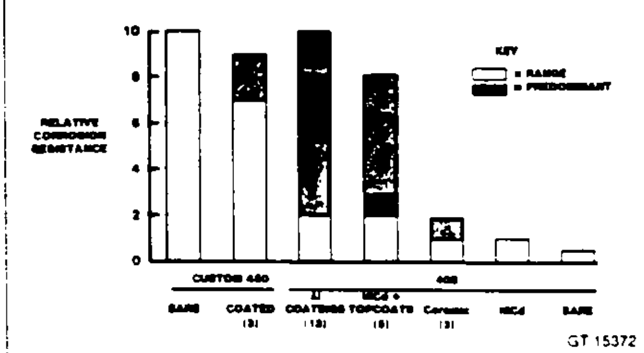


Figure 5

CAMPBELL DIAGRAM

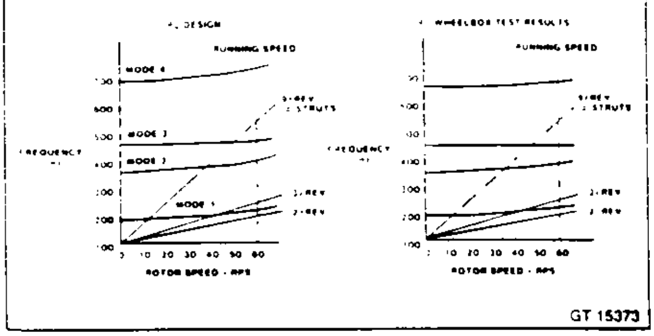


Figure 6

buckets equipped with integral Z-form tip shrouds. This newly designed turbine is two percent higher in efficiency than the MS7001E turbine. Unlike the compressor, the MS7001F turbine represents a totally new aerodynamic design with zero exit swirl at full load and a moderate exit Mach number. As a result of this conservative design approach, the turbine is capable of significant uprating.

Each of the three rotor stages consists of 92 investment-cast buckets of GTD-111 (Fig. 7). The first - and second-stage nozzles are constructed of 24 two-vane, investment-cast FSX-414 segments, and the third-stage nozzle of 20 three-vane, investment-cast FSX-414 segments. The first- and second-stage buckets and all three nozzle stages are air cooled. The first-stage bucket is convectively cooled via serpentine passages with turbulence promoters formed by coring techniques during the casting process (Fig.8). The cooling air leaves the bucket through holes in the tip as well as in the trailing edge. The second-stage bucket is cooled by convective heat transfer using Shaped Tube Electrode Machining (STEM) drilled radial holes with all cooling air exiting through the tip. The first-stage nozzle contains a forward and aft cavity in the vane, and is cooled by a combination of film, impingement, and convection techniques (Fig. 9) in both the vane and sidewall regions. There are a total of 575 holes in each of the 24 segments. The second-stage

FIRST-SECOND-AND THIRD-STAGE BUCKETS

Figure 7

FIRST-STAGE BUCKET COOLING PASSAGES

Figure 8

nozzle is cooled by a combination of impingement and convection techniques while the third-stage nozzle is cooled by convection. The advanced cooling techniques applied in the MS7001F turbine components are the result of extensive aircraft engine development, as well corrolative field testing performed on cooled components in current production heavy-duty machines. In addition, hot cascade tests were performed on MS7001F first-stage components to validate the heat transfer design assumptions. The efficient use of cooling air made possible by the advanced cooling methods applied is further enhanced by the reduced vane surface area of the first-stage nozzle, achieved by low solidity. The particular vane shape selected has also been developed for aircraft engines, and is illustrated in Fig. 9.

In order to further enhance the excellent hot corrosion and oxidation resistance of GTD-111, all three stages of buckets are coated. The first-stage coating is a patented alloy of Co, Cr, Al, and Y, applied by the PLASMAGUARD™ low-pressure plasma spray method. The second-stage bucket is coated with a patented alloy of Co, Cr, and Y, also applied by the PLASMAGUARD low-pressure plasma spray method. The third-stage bucket is coated with a high Cr coating, which is applied by a pack process and is subsequently given a diffusion heat treatment. The first-stage coating possesses outstanding high-temperature, hot-corrosion resistance with a 3X improvement over uncoated GTD-111. The second-stage coating has been specifically developed to provide exceptional resistance to both high- and low-temperature hot corrosion. The high Cr coating of the third stage focuses principally on providing protection against low-temperature hot corrosion.

FIRST-STAGE NOZZLE COOLING

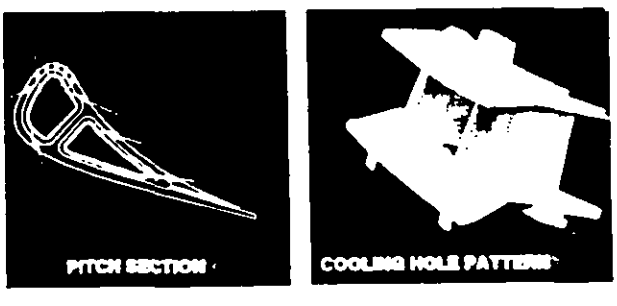


Figure 9

The buckets of all three stages are designed with long shanks and integral cover plates. These shanks provide for isolation of the gas path from the wheel rim and for mechanical damping of the bucket system via seal/damping pins located under the platform and in the cover plate edges. This system, in combination with the interlocking bucket tip Z shrouds, has proven very effective and durable in similar designs found in the MS7001E and other production machines. Careful attention has been given in designing the bucket shank regarding the transition between the bucket airfoil root and the dovetail to assure that high stresses are avoided due to structural discontinuities.

The first- and second-stage stationary shrouds are two piece designs where the gas side inner shroud is separate from the supporting outer shroud in order to provide freedom for expansion/contraction for improved low cycle fatigue (LCF) life. The first-stage shroud is cooled by impingement, film, and convective means.

The cooling circuit for the turbine components consists of both internal and external circuits (Fig. 10). The first- and second-stage buckets, the first-stage nozzle and the first-stage shroud are cooled by an internal cooling air circuit, while the second- and third-stage nozzles are cooled by an external cooling air circuit. The internal circuit is supplied by 17th stage and by compressor discharge air, and the external circuit by 13th stage extraction air. The first-stage nozzle and shroud cooling air is supplied from the compressor discharge plenum housing the combustion transition pieces. The bucket cooling is supplied by air flowing radially inward at the 17th stage compressor wheel, hence through 15 holes drilled axially through the distance piece, and then over the forward face of the first-stage turbine wheel. The bucket cooling air then flows through the bore of the first-stage bucket wheel into the chamber between the first- and second-stage wheels to the root of the first- and second-stage buckets. This circuit also provides air to heat the bores of the second- and third-stage wheels and to purge the wheelspaces, as shown in Fig. 10. The external circuit consists of piping between the 13th stage extraction belt and the turbine shell.

MS 7001F COOLING CIRCUIT

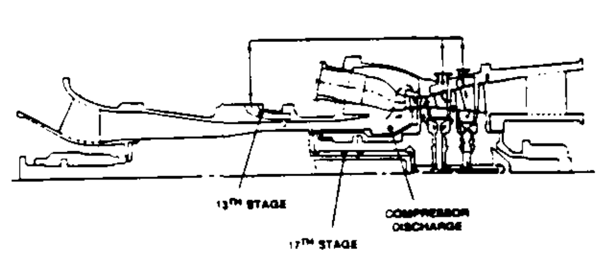
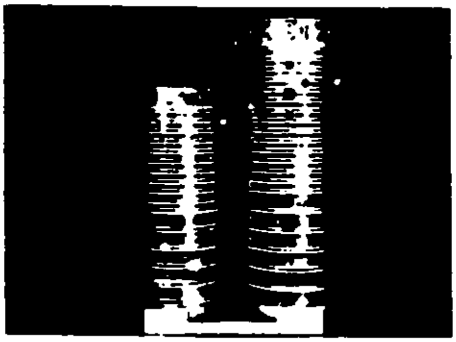


Figure 10

7F AND 7E COMBUSTION LINERS



GT 15369

Figure 11

Combustor

The MS7001F combustion system consists of 14 combustion chambers with 356 mm (14 in.) nominal diameter combustion liners. Transition pieces conduct the combustion gases to the first-stage nozzle.

The liners are constructed in a manner identical to the MS7001E liners (Fig. 11) but are 30 percent thicker and 213 mm (8.4 in.) shorter. This particular design provides for extensive and effective film cooling of the liner wall, as well as penetrations for combustion and dilution air and for cross-fire tube connections. The MS7001F liners are constructed of Hastelloy-X material, as are the other product line liners, with the addition of HS-188 in the lower 282 mm (11.1 in.) portion and the application of thermal barrier coating to the internal surface. These additions provide for improved high-temperature strength and a reduction of metal temperatures and thermal gradients. A flow sleeve surrounds the liner to provide a controlled flow path for the combustion, dilution, and cooling air.

The liner cap represents a change over the MS7001E design in that it provides for six fuel nozzles in lieu of one (Fig. 12). This multi-fuel nozzle arrangement was selected as a result of the superior field experience with a prototype multi-fuel nozzle system on an operating MS7001B/C gas

COMBUSTION LINER CAP

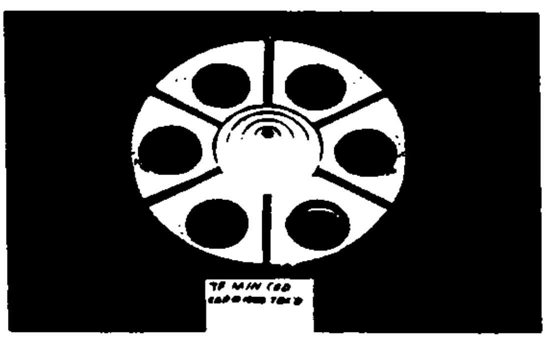


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Figure 12

MULTI AND SINGLE FUEL NOZZLE COMBUSTION NOISE

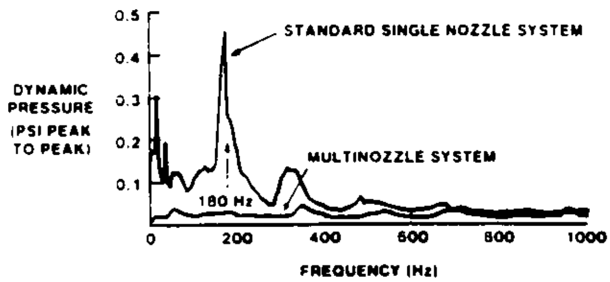

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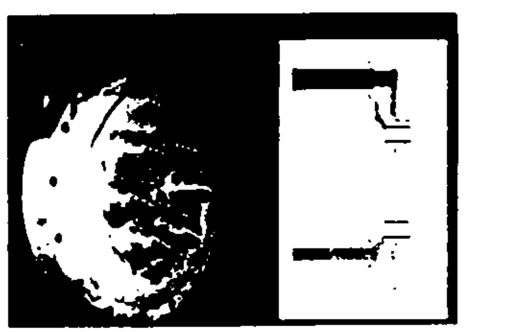
Figure 13

turbine in utility service with water injection for NO_x control.[1] This test, confirmed by extensive laboratory full-scale combustion tests, clearly demonstrated the reduced combustion noise (dynamic pressure) level achieved when operating with multi-fuel, as opposed to single fuel nozzle systems (Fig. 13). The noise reduction resulting from replacing the single nozzle with a multi-nozzle system reduced the combustion system wear to the point where combustion inspection intervals of the test machine could have been extended from 3,000 to 12,000 hr. Additionally, the application of the multi-fuel nozzle concept results in a shorter flame, contributing to the MS7001F combustion system being 23 inches shorter than the MS7001E system. The six fuel nozzles are mounted directly on the combustion end cover such that no more piping connections are required than if a single fuel nozzle were employed. This is accomplished through manifolding integral with the cover (Fig. 14).

The transition piece is constructed of two major assemblies (Fig. 15). The inner transition piece is surrounded by a perforated sleeve with the same general shape as the transition piece. This perforated sleeve forms an impingement cooling shell causing jets of compressor discharge air to be directed onto the transition piece body. The air, after impinging on the transition piece body, then

FUEL NOZZLE/COMBUSTION COVER ASSEMBLY



GT 15366

Figure 14

TRANSITION PIECE WITH
IMPINGEMENT SLEEVE

GT 15365

Figure 15

flows forward in the space between the impingement sleeve and transition piece into the annulus between the flow sleeve and the combustion liner. It then joins additional air flowing through bypass holes provided in the flow sleeve to provide the air for the combustion/cooling/dilution processes. The aft frame of the transition piece is cooled through the action of compressor discharge air flowing through holes drilled such that the air enters the main gas stream as a film on the inside surfaced of the aft frame. The impingement sleeve is fabricated of AISI-304 stainless steel, the transition piece body of Nimonic 263, and the aft frame of cast FSX-414. The internal surface of the transition piece is provided with a thermal barrier coating to minimize metal temperatures and thermal gradients.

This combustion system has outstanding smoke characteristics (Von Brand number of 99) and exceptional emissions performance. Water or steam is used to control NO_x to a level consistent with U.S. EPA new Source Performance Standards and with most California Air Quality Management District requirements.

The combustion system possesses two spark plugs in adjacent combustors and two sets of redundant flame detectors in adjacent combustors opposite from the spark plugs. Ignition in all chambers is accomplished by means of cross firing. This redundant system has proven highly reliable in the combustion systems of other multi-combustor configurations.

Rotor

The MS7001F rotor is of bolted disk and shaft construction and consists of two major groups: the compressor and turbine.

The compresor rotor is made up of 16 bladed disks plus a stub shaft on the forward end and a disk/cylinder on the aft end. The rotor assembly is bolted together by fifteen 76.2 mm (3 in.) diameter 12 Cr bolts located on a 940 mm (37 in.) diameter bolt circle. The blades are solidly retained in the wheel rims via dovetails and fixed in position via spacers. This form of attachment and location has proven extremely reliable in over 3700 gas turbines in all types of service. The forward stub shaft and the stage 1 through 15 disks are of NiCrMoV steel, while the 16th- and 17th-stage forging are of CrMoV steel. Stages 14 and 16 are not spun at speeds in excess of 5000 rpm in order to develop compressive residual stresses which, when combined with the normal stresses due to centrifugal loads and thermal gradients, result in low bore stresses during operation. These parts are also spun at −40C (−40F) to ensure freedom from detrimental defects. This additional hot spin is limited to the aft end of the compressor, where larger transient thermal gradients are experienced, following the same practices applied in the MS7001E gas turbine.

The turbine rotor is constructed of three wheels separated by spacers and an aft bearing shaft. These are all bolted to the distance piece. The wheels and the forward spacer are hot and cold spun in a fashion similar to that described for compressor disks. The main turbine bolting is of 12 Cr alloy and consists of twelve 76.2 mm (3 in.) bolts at a 1.12 m (44 in.) diameter bolt circle. The distance piece is joined to the first turbine wheel by thirty 50.8 mm (2 in.) diameter bolts of 12 Cr alloy on a 1.12 m (44 in.) diameter bolt circle. The compressor and turbine rotors are joined at the marriage joint by thirty 50.8 mm (2 in.) diameter bolts of IN-718 alloy operating on a 1.12 m (44 in.) diameter bolt circle. The turbine buckets are held in the wheel rim by means of fir tree dovetails. They are retained in position by a 360° lock wire, which nests in grooves machined in both the bucket and the wheel. This positive, yet easily removed, system has been in use in all MS6001 machines produced.

The construction of the rotor provides rabbetted fits between each component to ensure precise and permanent alignment. The bolt circle diameters have been made as large as possible, without interfering with blade and bucket dovetails, to produce a very rigid rotor. Only rigid body (rotor deflection energies less than 60 percent of system energies) modes exist below 100 percent speed. The first flex mode is at 13 percent of operating speed. Unbalance response calculations indicate a 100 percent speed margin of 8.38 mm/sec (0.33 in./sec), with a mid-span unbalance of 4 W/N, with respect to the 12.7 mm/sec (0.5 in./sec) alarm limit. Analysis of the entire rotor/bearing/stator system indicates that no resonant condition exists within 6 percent of the operating speed.

Stator

The MS7001F stator is of combined cast and fabricated construction. The inlet is grey cast iron, and the compressor casings are of ferritic nodular cast iron while the compressor discharge casing, turbine shell, exhaust frame, and combustion outer casings are fabricated of SA516 carbon steel.

The inlet casing is simlar to the MS9001E (885 lb/sec 3000 rpm) except that the bearing housing is integral with the lower half casing. (The MS9001E possesses a separate bearing housing located within the inlet casing.)

The turbine shell supports the second- and third-stage nozzles cantilevered from the first-, second-, and third-stage shrouds in a fashion identical with the MS7001E designs. The first-stage nozzle is also supported in a fashion identica to these machines. It is held at its outer diameter in a retaining ring assembled to the turbine shell and supported at its inner diameter by the compressor discharge casing.

The exhaust frame assembly supports the aft bearing as well as the AISI-347 exhaust diffuser. It is cooled by air supplied from an off-base blower as is the practice with the MS7001E family of gas turbines.

The gas turbine support system consists of four support legs and two gib blocks. The forward support legs are fixed, while the aft support legs are pivotal. With this design, the axial growth of both the rotor and stator is aft from the thrust bearing forward support leg system. One gib is integral with the forward compressor casing and the other integral with the exhaust frame; both are located on the vertial center plane of the unit. This method of support, together with the integral No. 1 bearing and the centerline supported No. 2 bearing, assures precise internal and external alignment control under all operating conditions.

ACCESSORY DESIGN

The MS7001F accessories are all electrical motor driven. Each major system is designed to be installed on a separate skid, except the fuel gas stop ratio valve, which is installed on the lube-oil skid. The skids, together with their functions, are listed in Table I.

The decision to use separate skids for each system was made to provide the greatest plant arrangement flexibility, the easiest maintenance accessibility and improved reliability. The skids are designed for indoor or outdoor construction. When supplied with lagging, all panels are hinged so that the sides can be completely opened to facilitate servicing and observation. In addition the lagging can be simply lifted from the skid in a straight pull after unbolting it from the base. Nothing is mounted to the inside of the lagging except the vent fan. All gages can be conveniently read from the outside of the skid without restriction.

With respect to maintenance, sufficient space is provided so that any component may be serviced directly without having to remove piping or other components. Filters and coolers are oriented vertically so that they can be serviced by vertical pulls. All components and flanges are located outside the skid base so that this constrained area need not be accessed for any service or maintenance function.

A typical plant arrangement is shown in Fig. 16. In this arrangement, the skids and the turbine/generator are located on grade with a side inlet. Other inlet configurations are available including overhead and underneath. Customer preference will dictate this, a well as other configurations, with the prime concern being ready crane coverage without the necessity of removing or avoiding ducting and machinery. The flexibility of self-contained skids also allows arrangements to suit customer needs and to provide sufficient lay down space for overhaul. All accessory systems, except for the starting skid, may be placed in a basement so that a classic turbine hall configuration can be acomplished.

The gas turbine is coupled to the hydrogen-cooled generator using a rigid coupling. The 2200 hp starting motor is connected to the generator collector end through a torque converter (Fig. 17). A normal start cycle for this configuration is 12 minutes to full-speed no-load, followed by 18 minutes to full load, for a total startup time of 30 minutes. Two combined-cycle arrangements are available, single-shaft and multi-shaft. In the single-shaft arrangement, the steam turbine is interposed between the gas turbine and the generator. In this arrangement, it is only necessary to remove the starting skid to service the generator; the steam turbine being left in place. In the multi-shaft arrangements, one or more gas turbines are utilized to generate steam to drive a single steam turbine which drives a generator that is divorced from that driven by the gas turbine.

Table I
MS7001F CONTROLS AND ACCESSORY SKIDS

Skid	Size	Function
Lube oil	11′ × 34′	Supplies cooled & filtered lube, sealing and hydraulic oil to turbine & generator, contains fuel gas stop & control valves
Liquid fuel	11′ × 31′	Supplies filtered liquid fuel to gas turbine
Atomizing air	11′ × 16′	Supplies atomizing air for combustion
Cooling fan	11′ × 16′	Supplies ventilation and exhaust frame cooling air
Cooling water (2)	11′ × 38′	Supplies cooling water for lube oil, atomizing air, & generator
Water injection	11′ × 28′	Supplies treated water for NO_x control
Starting	7′ × 10′	Contains starting motor & torque converter
Air processing	5′ × 8′	Supplies air to pulse-clean the inlet filters
Control cab	11′ × 11′	Contains the turbine & generator control panels and DC supply
Excitation	10′ × 13′	Supplies & regulates the generator field current

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POWER PLANT ARRANGEMENT

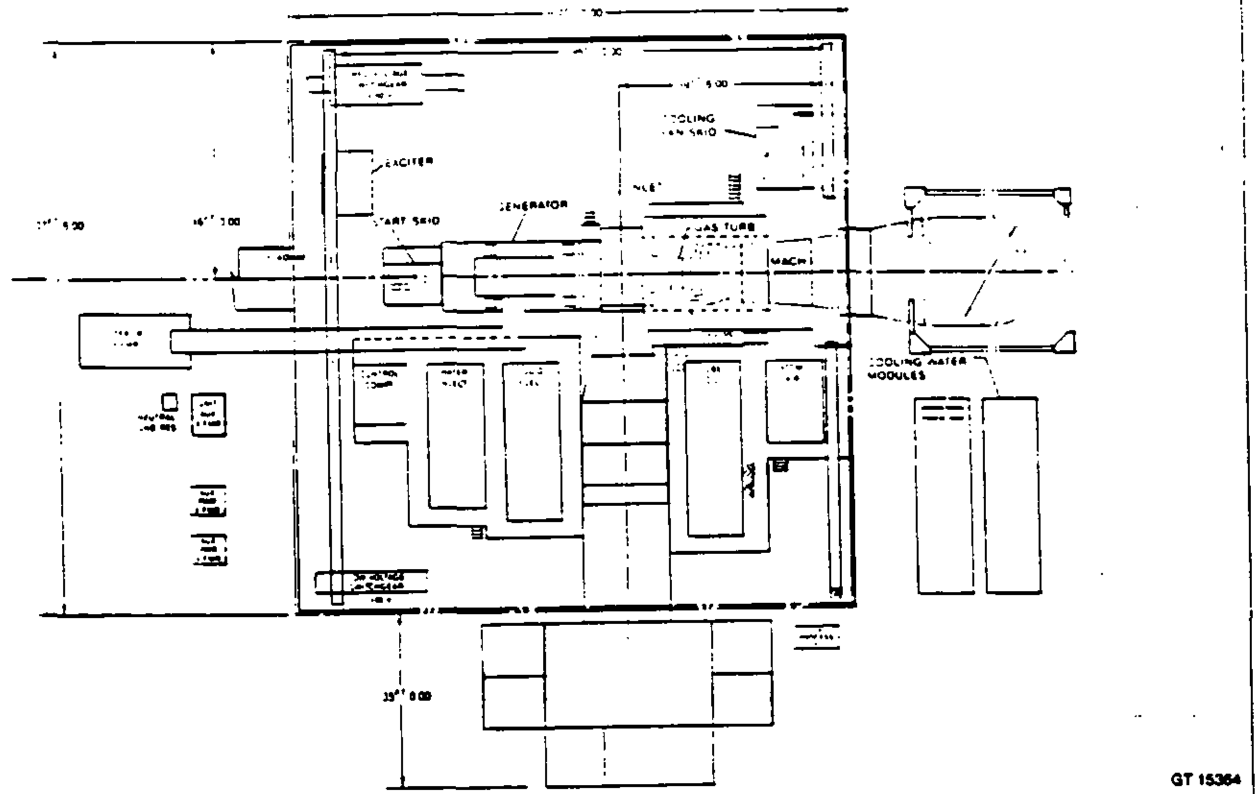


Figure 16

MS7001F ARRANGEMENT WITH HYDROGEN-COOLED GENERATOR

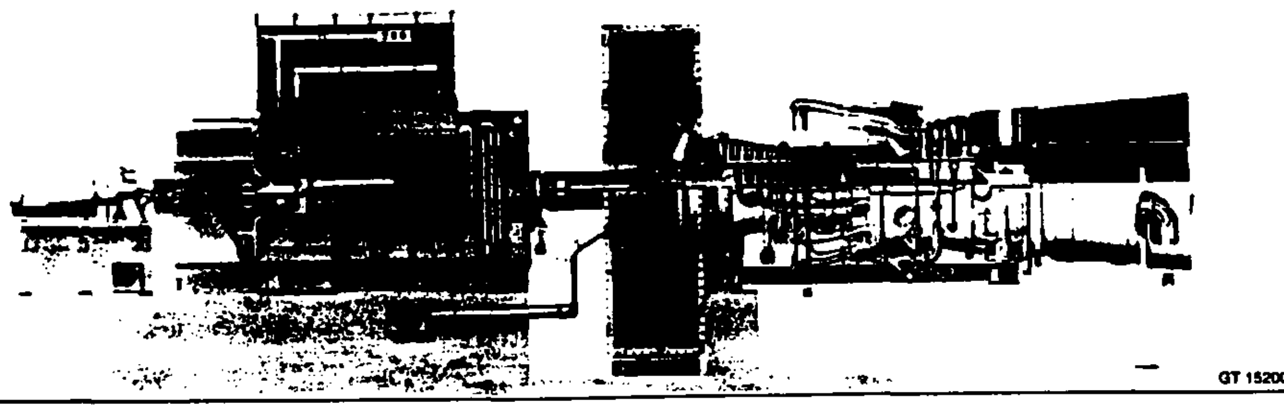


Figure 17

TEST PROGRAM

The design of the MS7001F gas turbine is supported by a three-phase test program:

Phase I — Fundamental studies and component tests
Phase II — Factory prototype test
Phase III — Field prototype test

The Phase I effort has included the development and application of advanced analytical methods and computer techniques in order to accurately predict three dimensional viscous fluid dynamics, boundary layer heat transfer, dynamic response of blading, dynamic response of complex systems and complex material behavior. Where practical, the result of these advanced analytical tools were checked on models and components to ensure the accuracy of the predictions. One example was cited in reference to the "0" compressor blade dynamic response (Fig. 6). Other examples include hot cascade testing of the first-stage nozzle and liquid crystal studies of the first-stage nozzle and bucket to verify heat transfer assumptions, flow testing of the rotor cooling circuit and other components, materials behavior testing under calculated strain/time/temperature cycles, dynamic response, wheelbox testing of all turbine buckets, exhaust system flow testing, and maintainability studies. A major development effort was involved in all aspects of the combustor design. The multi-combustor concept allows full machine conditions to be applied to an individual combustor under laboratory conditions. This has permitted complete and thorough development of the MS7001F combustor prior to actually operating the machine. Because of this, great confidence in both the aerodynamic performance, mechanical integrity, and emissions performance of this key system was demonstrated early in the program.

Also incorporated in the Phase I effort has been field testing of selected materials and configurations in order to gain both manufacturing and operating experience. Included in this effort has been the field testing of impingement-cooled transition pieces, application of N-263 in transition pieces, advanced bucket coating systems, thermal barrier coatings, and new compressor blade materials.

The Phase II test effort is largely aimed at verifying the compressor performance and obtaining component and system performance and operating data. During this phase, a full compressor map will be determined; including surge margin. Also, during this phase, extensive rotor and stator instrumentation will be included to measure temperatures, pressures, hot gas path profiles, blading dynamic behavior, and system dynamic behavior.

The test configuration for this phase is illustrated in Fig. 18. The load is provided by a 17-stage MS7001E axial flow compressor,which is capable of absorbing 80 percent of the MS7001F output. Full rated firing temperature will be achieved by throttling the machine flow at the compressor inlet. The MS7001F compressor will be mapped, and the surge margin confirmed, by a combination of means including variable speed operation, variable flow through inlet guide vane, and throttling modulation and variable pressure ratio through injection of load compressor flow into the compressor discharge upstream of the combustor. Stage by stage, as well as overall performance, will be determined.

FACTORY PROTOTYPE TEST ARRANGEMENT

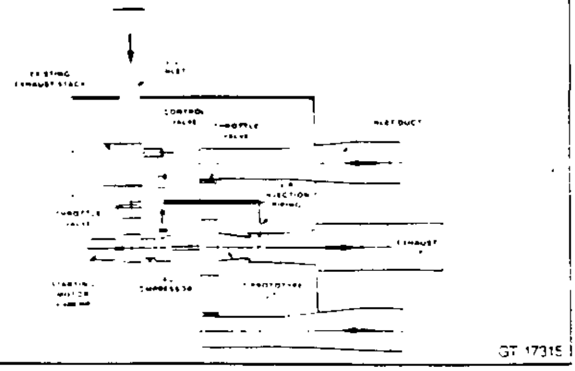


Figure 18

The Phase II test period is planned for one year duration.

The Phase III test involves a full load test at a customer site. In preparation for this, the factory prototype unit will be refurbished with a new rotor. The new Phase III rotor will have more extensive turbine-end instrumentation and less extensive compressor instrumentation than the Phase II rotor (see Table II). The primary objective of the Phase III test is to verify all design and performance parameters, exclusive of developing a full range compressor map, which will be accomplished in Phase II. Metal, cooling circuit, and gas path temperatures; cooling circuit and cycle pressures; component and system dynamic behavior will all be determined under both transient and steady state conditions. Cycle and emissions performance will also be determined under normal steady state conditions.

Each of the component and system data bases developed during Phase II and Phase III will be compared with the analytical predictions before the MS7001F design will be fully validated for commercial application.

Table II
MS7001F PROTOTYPE TEST INSTRUMENTATION

	Factory Test	Field Test
Compressor		
Dynamic pressure/strain	106	40
Temperature	230	50
Pressure	248	35
Combustor		
Dynamic pressure/strain	82	20
Temperature	310	200
Pressure	148	70
Turbine		
Dynamic strain	36	60
Temperature	1256	700
Pressure	321	240
Bearings		
Temperature	57	50
Pressure	14	20
Accessories		
Dynamic strain	10	30
Temperature	54	100
Pressure	120	160

SUMMARY

This paper has presented the design approach, configuration, and application of a totally new heavy-duty gas turbine. The development of this turbine system has absorbed well over 300 man-years of direct design effort plus extensive supporting developmental effort. It will have involved some nine years from the gleam in the engineer's eye to the production of economical and reliable power on the first customers grid. It has been nurtured during a period of uncertain energy cost, increasingly tighter environmental standards and lagging load growth. However, it appears that, even as it is making its debut, an awareness is developing in both developed and developing societies that efficient, clean, and reliable power generation is essential to healthy economies. From this realization, then, the MS7001F is being introduced with the confidence that its contribution to progress in power generation simple-cycle, combined-cycle and the integrated gasification combined cycle modes will be firmly established.

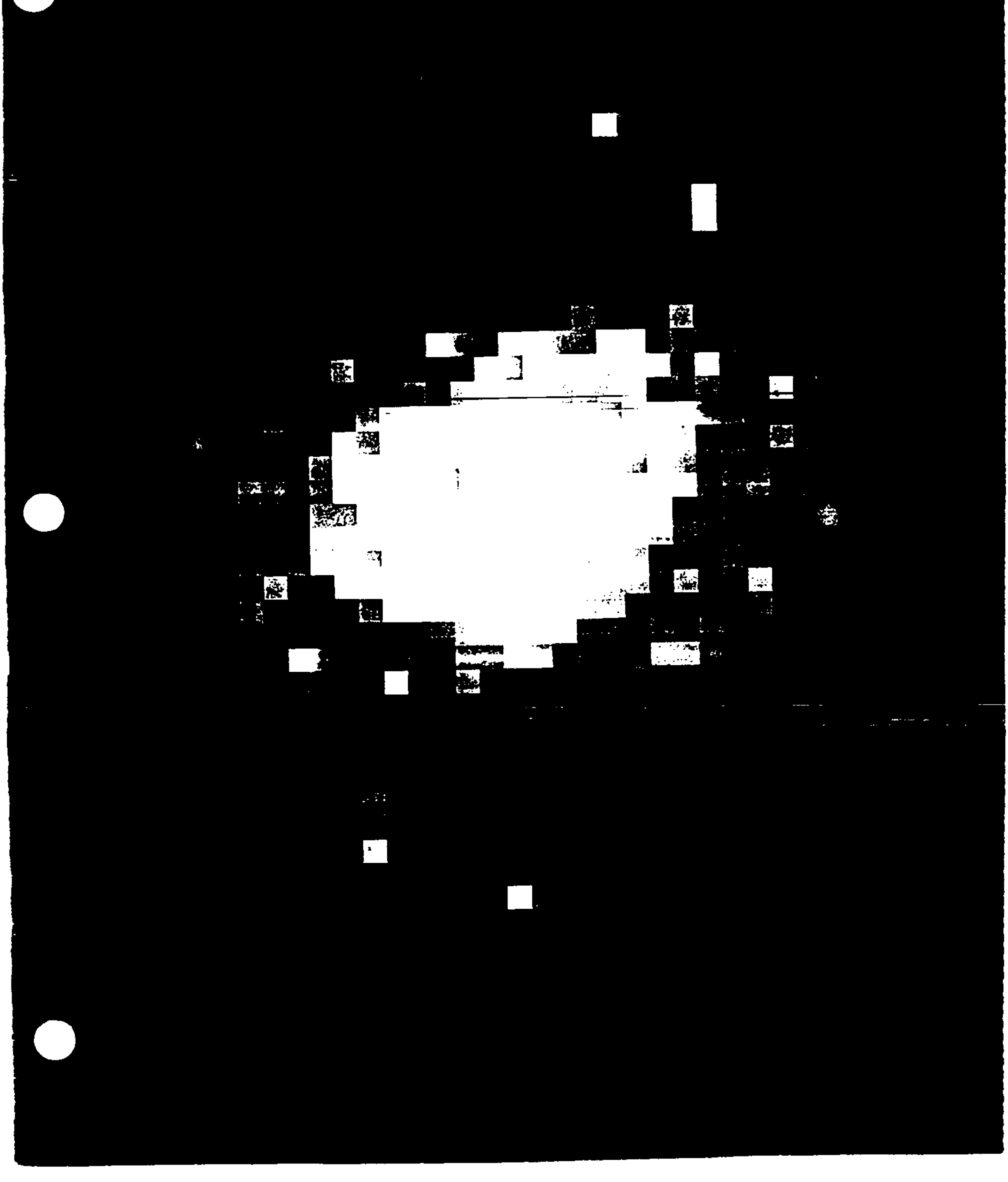
REFERENCES

[1] "High Reliability Gas Turbine Combustion Project," Electric Power Research Institute, EPRI AP-3885, Project 1801-1, Final Report, may 1985.

[2] "GE SPEEDTRONIC™ Mark IV Control System," 1984 State of the Art Seminar, GER-3426 (Available from GE Company, Turbine Business Operation, Schenectady, New York).

MS7001F ADVANCED DESIGN GAS TURBINE

New flexibility in power generation



THE WORLD'S MOST ADVANCED GAS TURBINE

In every respect — output, efficiency, reliability, availability and ease of maintenance — the new MS7001F heavy-duty gas turbine outperforms all previous machines. Projections of 98% reliability, 95% availability, 3000 hours mean time between failures (MTBF) and in excess of 50% cycle efficiency in combined-cycle operation dramatically underscore its inherent superiority.

Nominally rated at 140 MW with a firing temperature of 2300°F, the 7F gas turbine has been designed to meet 60Hz power generation needs for reliable, efficient performance under peaking and baseload operation while utilizing a wide variety of fuel options.

The 7F gas turbine is designed to operate efficiently on natural gas, distillate fuel, or the medium-Btu gas fuel provided in the IGCC mode of installation. As a result, it is the ideal machine to make phased capacity additions — the progressive generation (PROGEN™) concept — realistically viable for electric utilities. The 7F machine is also the most efficient and cost-effective choice for large industrial systems. It provides opportunities for increased economic benefits in industries such as chemical processing, petrochemical refining and oil recovery, where there is a demand for large amounts of thermal energy in conjunction with power generation.

Significant Advances In Turbine Technology

To achieve the higher performance standards of the 7F gas turbine, GE engineers utilized major technological advances based on concepts tested and proven in the Company's aircraft engine business, heavy-duty gas turbine laboratories, and the GE Corporate Research and Development Center. These include the development of advanced cooling techniques; special high-strength alloys and improved high-temperature coatings; and component and system dynamic testing, enabling extensive aerodynamic and mechanical design refinements.

Primary areas of new design are in the axial-flow compressor; the multi-fuel-nozzle combustors; the first-stage nozzle and buckets; the off-base accessory arrangement; and the front-end drive which allows the use of an axial exhaust to enhance heat recovery applications.

Increased Output, Higher Efficiency

The new 7F machine's advanced efficiency will yield significant fuel savings over the life of the unit. In addition, reliability is extremely high due to its designed-in capability to permit maintenance and repair while the machine is running. For example, the off-base accessory skids incorporate redundant components arranged to facilitate replacement of parts without shutting down the unit or inhibiting its ability to carry a full load. The design of the entire 7F gas turbine, including the accessories, focuses on enhanced visual inspection and ease of maintenance.

Optimal Performance With Add-On Capability

The MS7001F is GE's first major new combustion design since 1980. Five years in development and pretest, it is based upon principles proven during the design and manufacture of over 4000 GE combustion turbines in successful operation around the world.

The new 7F turbine is the first machine to effectively close the loop on the flexible PROGEN planning option of progressive capacity addition over a period of years with operation in three modes: Simple-cycle; Combined-cycle; and Integrated Gasification Combined-Cycle.

In simple-cycle applications using natural gas as fuel, the 7F is nominally rated at 140 MW with a firing temperature of 2300°F and an exhaust temperature of 1100°F. In combined-cycle operation burning natural gas, the total plant output is in excess of 200 MW. At 1100°F, the exhaust temperature is high enough to justify a reheat steam cycle. Thus, the 7F is a cost-effective machine for peaking service, with the added capability to provide major fuel savings in baseload combined-cycle operations. Further, the machine will operate effectively on the medium-Btu gas derived from coal in an integrated gasification combined-cycle (IGCC) mode. The availability of the advanced-design MS7001F turbine with modular add-on capability increases flexibility and reduces investment risk in meeting power generation needs into the next century.

The MS7001F rotor is of experience-proven bolted disk and shaft construction and consists of two major sections: the compressor and the turbine. The compressor rotor with its 18 bladed disks is ready for assembly to the 3-stage turbine.

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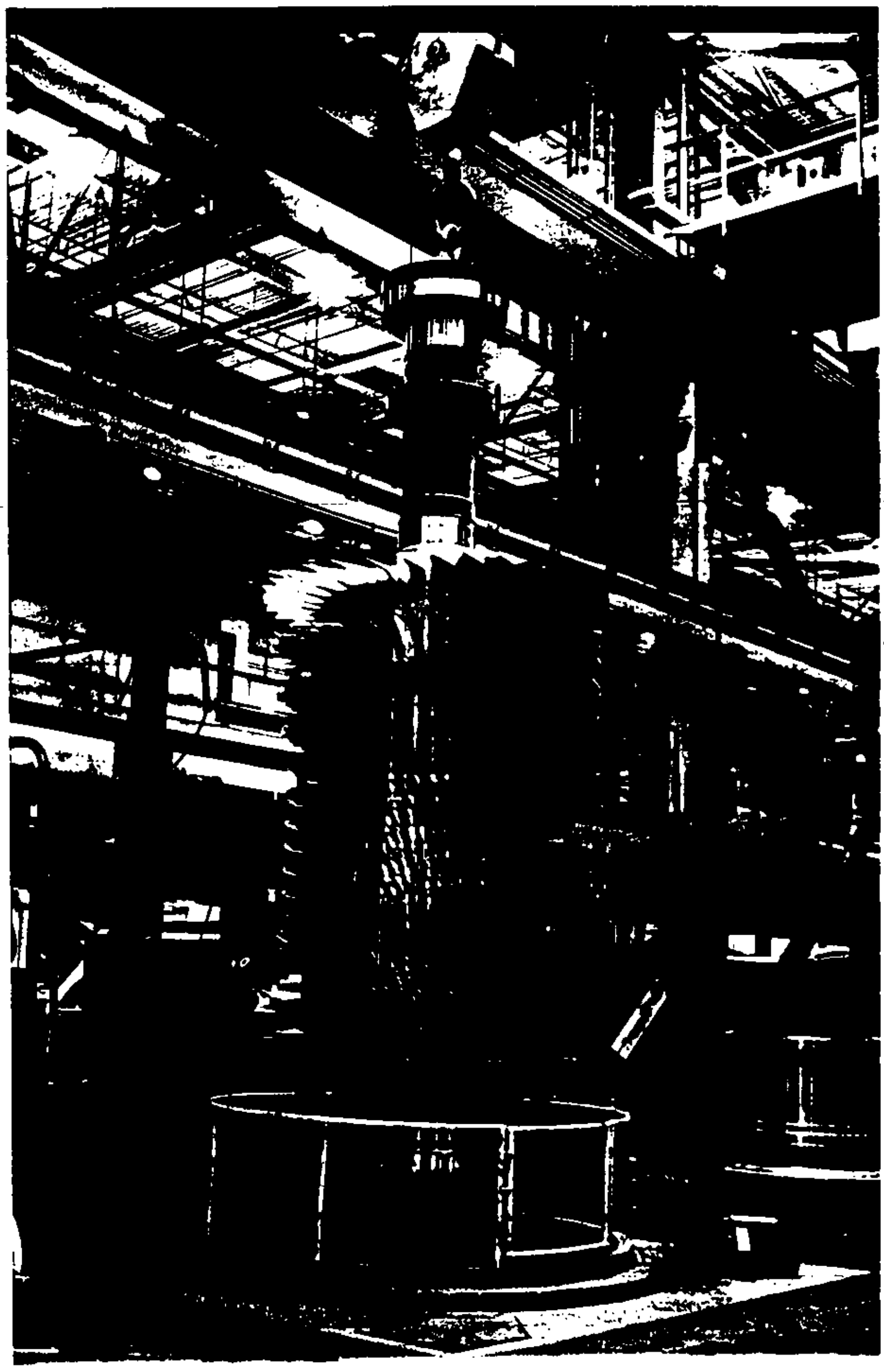

RELIABLE SIMPLE-CYCLE OPERATION

With 70% higher output than the proven MS7001E, the 7F gas turbine is the one machine that can best provide the additional power needed to meet peak demands expeditiously and economically.

The increase in efficiency of a full two percentage points over the former design represents potential savings of literally millions of dollars in operating economies. For example, when installed in simple-cycle mode to serve peaking needs, a 7F gas turbine can potentially save 5200 barrels of oil or 28 million cubic feet of gas each year over the projected 25-year service life of the machine.

In addition to higher efficiency, the 7F machine provides greatly improved reliability due to the redundant design of the controls and accessories systems as well as the auxiliary power supply.

The 7F machine provides the opportunity to add large blocks of power relatively fast. GE will be able to build and erect a 7F simple-cycle plant and have it operating to meet demand within 24 months from date of order.

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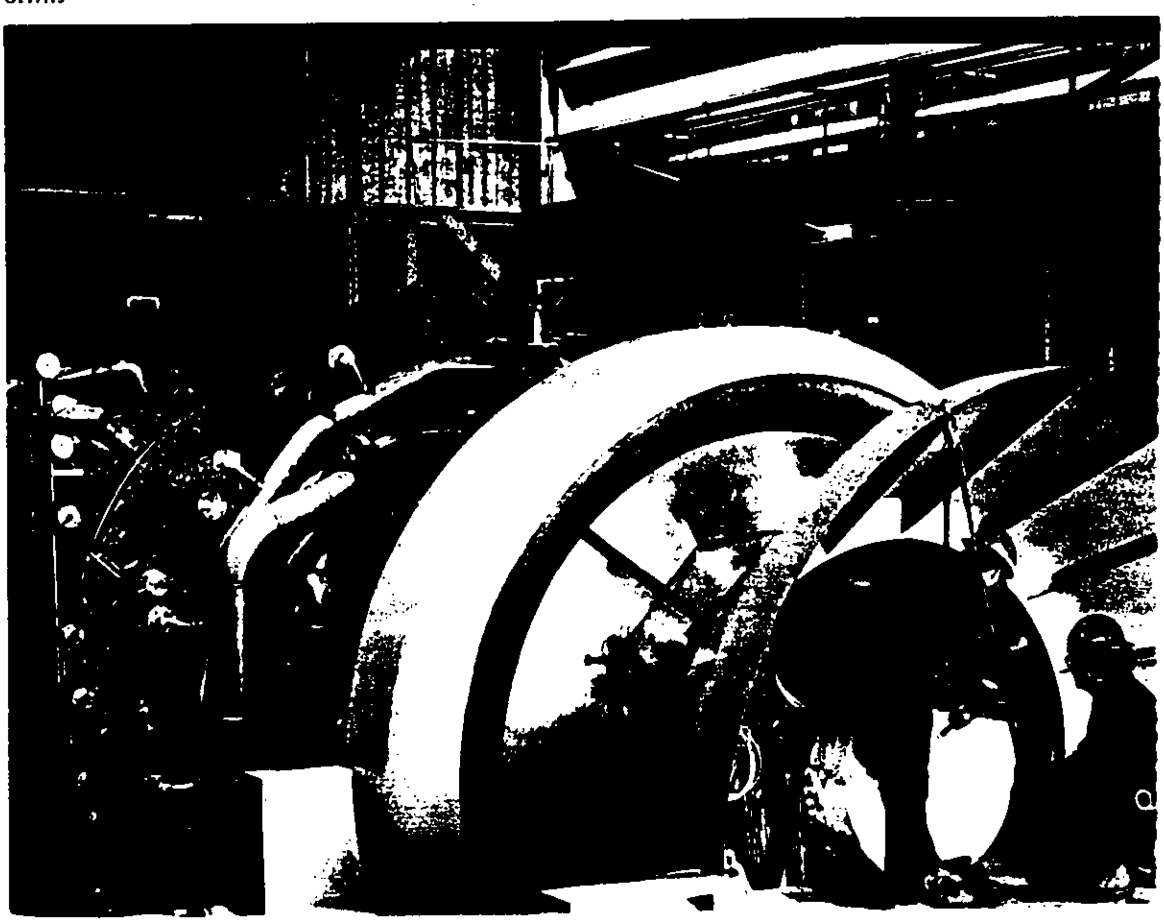

All components of the MS7001F gas turbine were extensively tested during development. Testing of the first production unit began in the spring of 1987.

EFFICIENT COMBINED-CYCLE OPERATION

Because of its higher firing temperature and its higher exhaust temperature (1100°F), the 7F machine produces higher rated steam conditions. When the exhaust is passed through a heat recovery steam generator to power a steam turbine generator in the combined-cycle mode, fuel-to-electric-output energy efficiency exceeding 50% (LHV) is viable for the first time.

The front-end-drive design and axial exhaust configuration of the 7F turbine are ideally suited to in-line plant arrangement for simple- or combined-cycle operation, with the benefit of eliminating an elbow section upstream of the boiler.

In addition — like other GE gas turbines in over 56 combined-cycle plants worldwide — the 7F machine is designed to be environmentally clean. The combustion system has outstanding smoke characteristics and exceptional emissions performance. Water or steam is used to control NO_x to a level consistent with U.S. EPA New Source Performance Standards and with most California Air Quality Management District requirements. Installed in combined-cycle mode for mid-range to baseload operation, the 7F gas turbine will operate with a clear stack and at emission levels that can meet the most stringent pollution control standards.

Virginia Power Company is installing the first 7F gas turbine in combined-cycle operation. In addition to high efficiency and low capital costs, the utility cites turnkey construction and warranted performance by GE as major factors in selecting the 7F machine.

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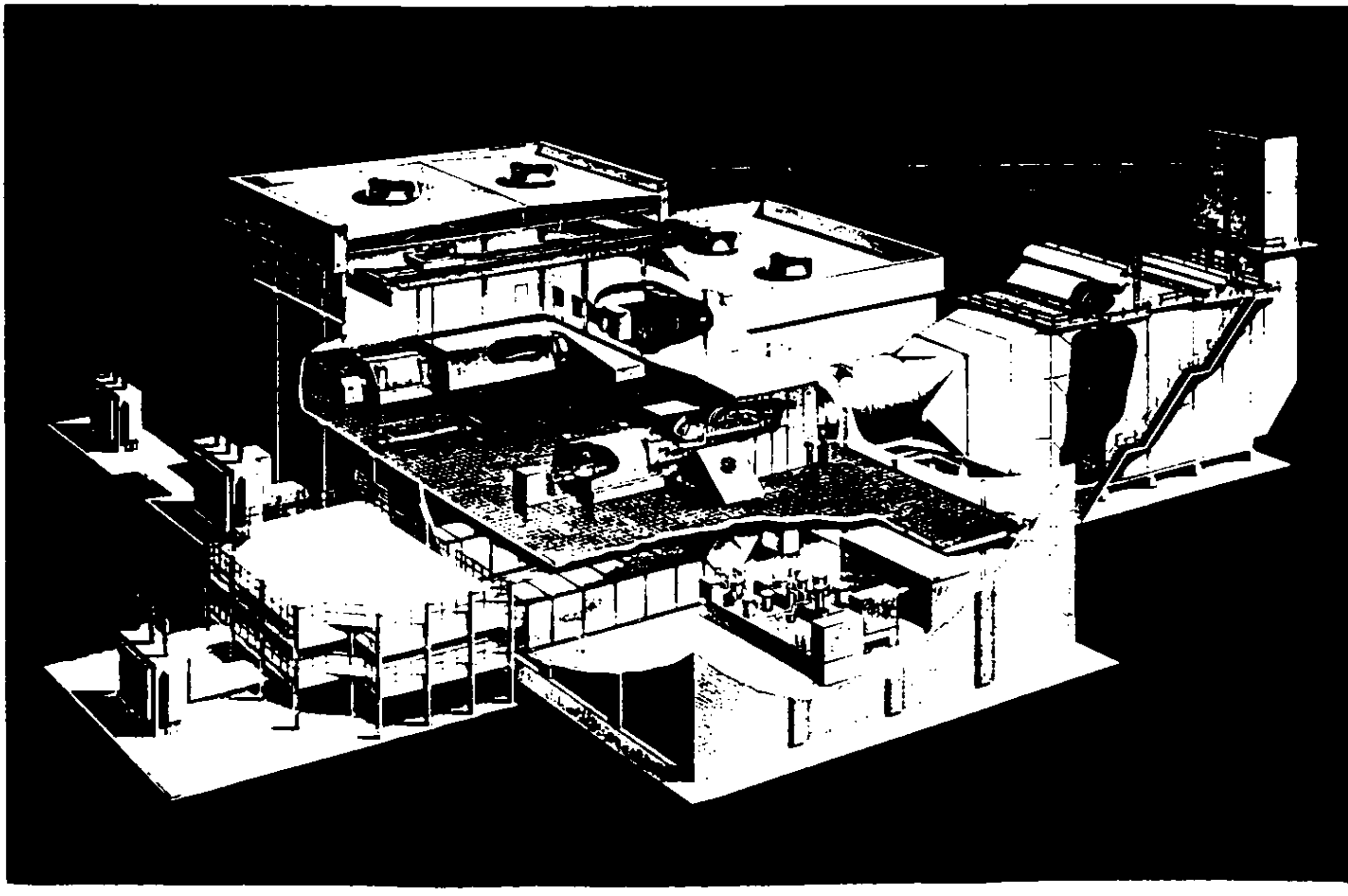

PROVEN IGCC OPERATION

The 7F gas turbine inherently has the capability to efficiently utilize the medium-Btu gas produced in coal gasification systems. This fuel flexibility is a major advantage of the 7F machine, giving utilities the option of adding gasification equipment in the future as the third and final step in the PROGEN system concept. With coal being the most abundant fossil energy resource in the United States, this capability provides inherent protection against fluctuations in fuel availability and price.

As a participating partner in the Cool Water Coal Gasification Project near Daggett, California, GE has been instrumental in demonstrating the practicality of producing power cleanly and efficiently with gasified coal as a fuel. The nation's first commercial coal gasification plant, Cool Water began operation in June 1984, producing clean synthesis gas from 1000 tons of coal each day to generate up to 120 megawatts of electricity.

The experience gained in this pioneering project sponsored by the Electric Power Research Institute puts GE in the optimal position to assist in long-term IGCC power plant planning, installation and operation.

This 100 MW combined-cycle power plant located in southern California burns clean gas derived from a coal gasification process.

GT11500

ADVANCED DESIGN FEATURES

Significant advances in all elements of gas turbine design technologies have been made in recent years. These developments have made feasible the design of the new MS7001F heavy-duty gas turbine, while maintaining the design life standards of the experience-proven MS7001E machine.

Higher Firing Temperature

The firing temperature of the 7F gas turbine has been elevated from MS7001E's 2020°F to 2300°F, permitting the achievement of a 2% increase in efficiency and a 70% increase in output.

New Cooling Techniques

To accommodate the higher firing temperature, the 7F turbine employs advanced cooling techniques developed by GE for aircraft engines.

The first- and second-stage buckets of the MS7001F as well as all three nozzle stages are air-cooled. The first-stage bucket is convectively cooled by means of serpentine passages with turbulence promoters that are formed during the casting process. The cooling air leaves the bucket through holes in the tip as well as in the trailing edge.

New Combustion Liner Design

The MS7001F combustion system consists of 14 combustion chambers with 14-inch nominal diameter combustion liners. These liners are constructed in a manner similar to the liners used in the MS7001E gas turbine, except they are 30% thicker and over eight inches shorter. This new design provides for extensive and effective impingement cooling of the liner wall with the higher firing temperature.

The liner cap incorporates six fuel nozzles. This reduces both noise and combustion wear, extending combustion inspection intervals beyond those associated with single-fuel-nozzle combustors.

Additionally, the multi-fuel nozzle concept results in a shorter flame which contributes to the overall 7F combustion system (including the transition piece) being 23 inches shorter than the MS7001E system.

New Compressor Design

The MS7001F compressor's aerodynamic and mechanical design closely follows that of the 17-stage MS7001E (633 lb./sec., 3600 rpm), but with an added zero stage and increased annulus area. The first two stages of the 7F compressor have been designed for operation in transonic flow, eliminating the need for variable stators for surge control. The 7F compressor contains three exit guide vane rows to straighten out the flow leaving the compressor and enhance its performance.

New Turbine Design

The 7F turbine features an effective aerodynamic design with zero exit swirl at full load and a moderate exit Mach number. To facilitate combustion inspection, two large manways are designed into the turbine shell. By means of these enlarged openings in the combustor bulkhead, each combustion chamber can be serviced without affecting the adjacent chambers.

Proven Generator Design

The 3600 rpm hydrogen-cooled generator utilizes an experience-proven design incorporating completely self-contained ventilation systems to protect against dirt, moisture and other contaminants. The high initial response of the static excitation system minimizes voltage fluctuations. No moving parts are required, resulting in high machine reliability.

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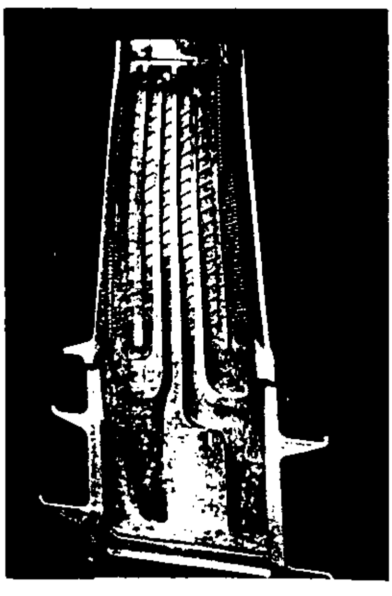

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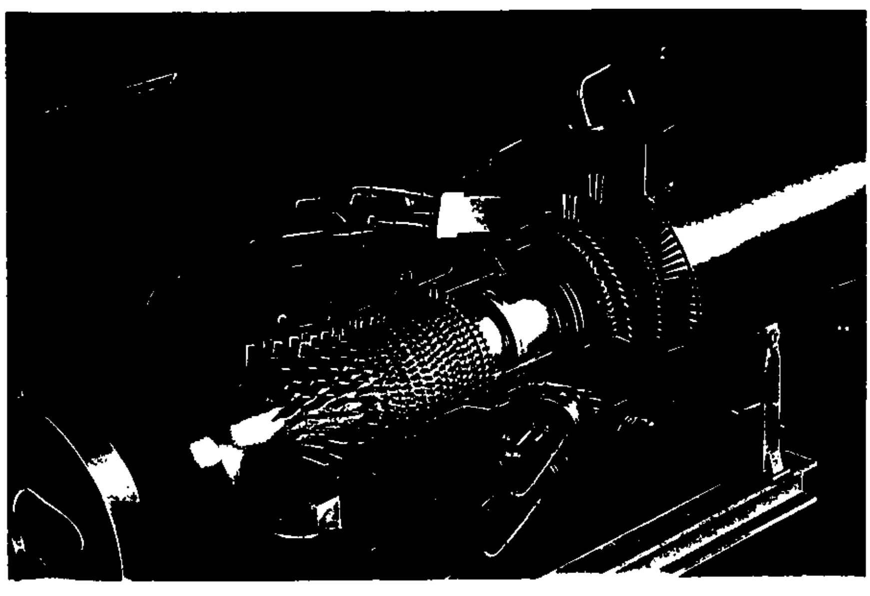


ACCESSORY SYSTEM AND CONTROLS

Each of the major accessory systems of the MS7001F gas turbine is designed to be installed on a separate skid utilizing electric-driven auxiliaries. This greatly improves crane coverage and working space around piping, valves and components. A significant benefit of this arrangement is the ability to utilize redundant components such as fuel and lube oil pumps, fans, filters and heat exchangers. In most cases, individual components can be replaced without the need to remove unassociated piping, wiring or adjacent components.

The roofs of all skids and the turbine enclosure are simply bolted to the side panels, permitting easy removal and overhead access, facilitated by the fact that no equipment is supported from the roof. In addition, all gauges can be conveniently read from outside the skids.

The 7F machine utilizes the advanced SPEEDTRONIC™ MARK IV Control System, consisting of redundant computer sections with a video display and membrane switch operator interface. The system can be enhanced for remote control and condition monitoring by the addition of the DATATRONIC™ Information and Control System.

The SPEEDTRONIC MARK IV Control System utilizes three control sections which are isolated from each other. A fourth computer regulates the data exchange between the three primary control sections. In this way, there is no common tie between the controls that could cause a failure to all the sections at one time.

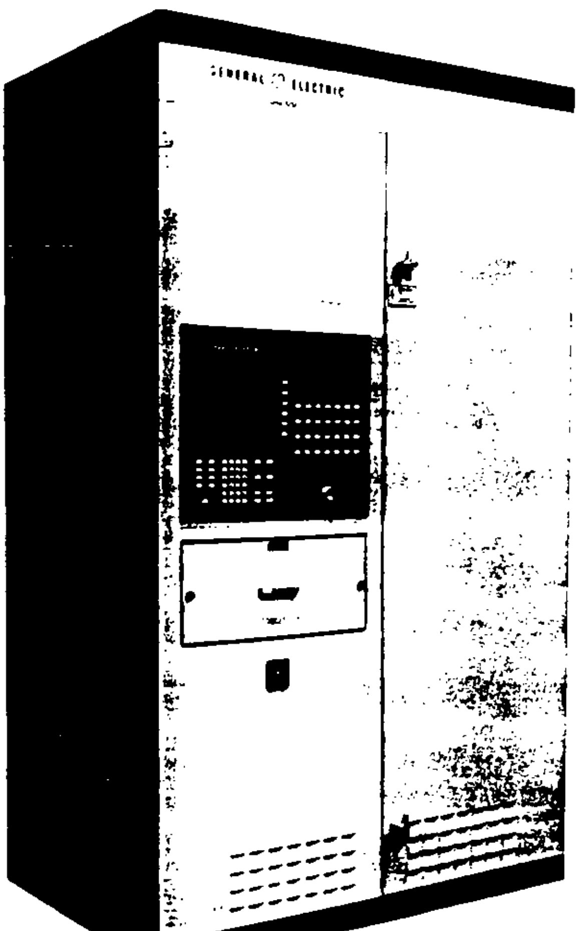
Redundant sensors are included in the system to increase control availability for turbines in applications where sensor failures are more likely and replacement may not be possible while the turbine is operating.

On-line diagnostics locate and identify faults, which can then be isolated and repaired without disruption to the turbine operation.

Failure rates have been reduced by decreasing the number of electronic components directly controlling the turbine. Most failures can be serviced on-line without the system being upset, shut down or tripped.

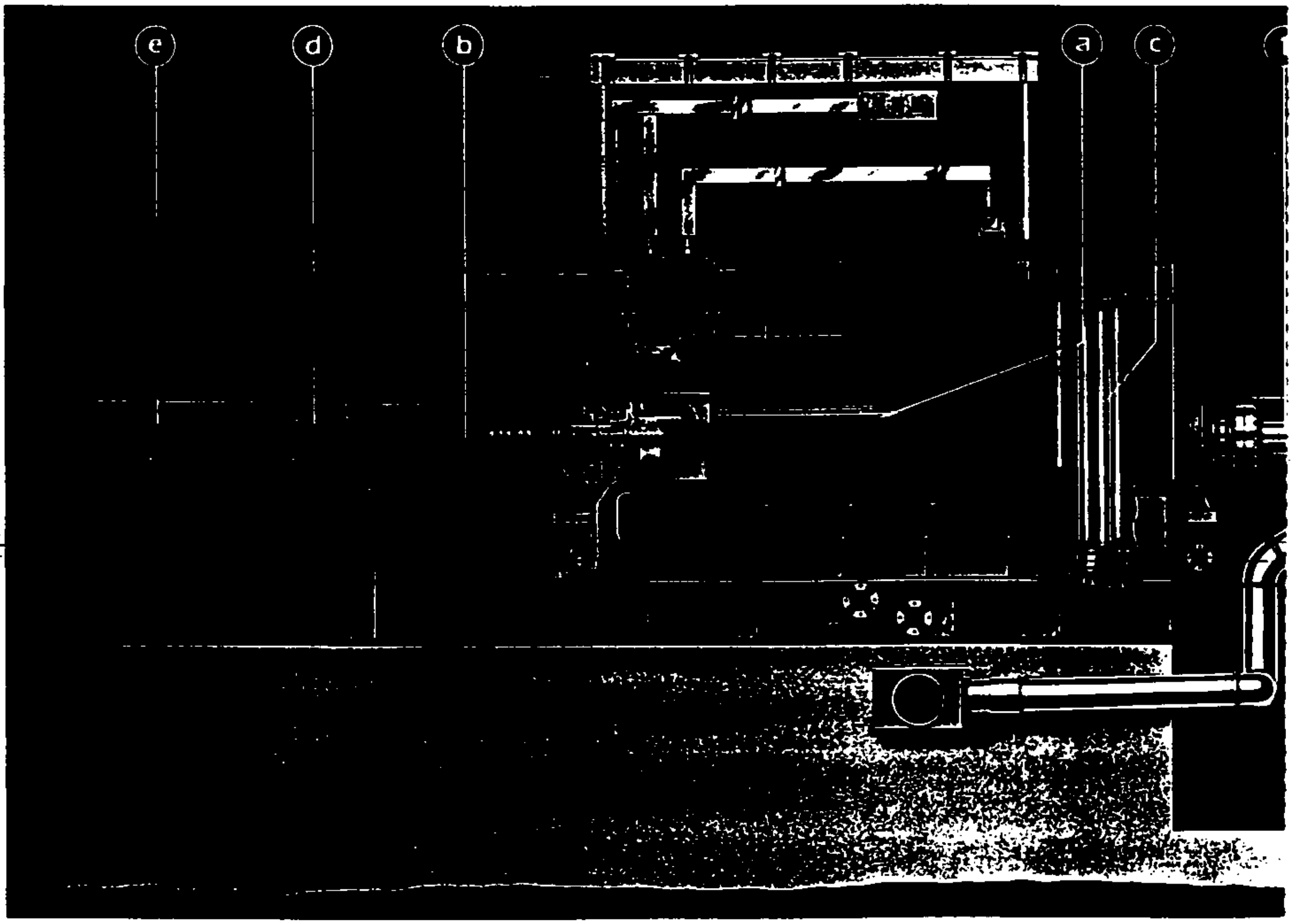
The 16-bit microprocessors used in the Mark IV Control have greatly reduced the large, complex, costly and less reliable systems required in the past for three-channel redundancy.

GT17285



More than 150 displays can be called up from the SPEEDTRONIC™ MARK IV Control System's memory. A drawer-mounted printer can produce a hard copy of any display. A CRT located right in the center of the control panel provides a broad overview of current operating conditions. A series of membrane switches on a central pad enables the operator to run the turbine and also to select detailed displays to investigate particular conditions of interest.

GT15200-1



Compressor

(1) Load Coupling — Short, rigid coupling directly connected to generator coupling. **(2) Axial/Radial Inlet Casing** — Proven design provides uniform inlet flow to compressor. **(3) Journal Bearings** — Bearings are tilting-pad type for improved rotor stability. **(4) Compressor Blading** — Evolution from 7E compressor with a zero stage added. Blade lengths increased for added flow. Blade material has been upgraded. **(5) Compressor Design** — Based on proven axial-flow design. Casing material upgraded to accommodate higher temperature and pressures.
(6) Rigid Forward Support — In combination with the forward thrust bearing, limits thermal expansion of gas turbine into generator.

(7) Wheel Construction — Machined to nearly constant stress cross-section with contact faces at maximum diameter for high rotor stiffness. **(8) Through-Bolt Construction** — Large bolts at maximum bolt circle provide rigid rotor with required torque capability for front-end drive.

Turbine Stator Casings

(9) Horizontally Split — All casings split on horizontal centerline with through-bolting to facilitate maintenance.

Combustion System

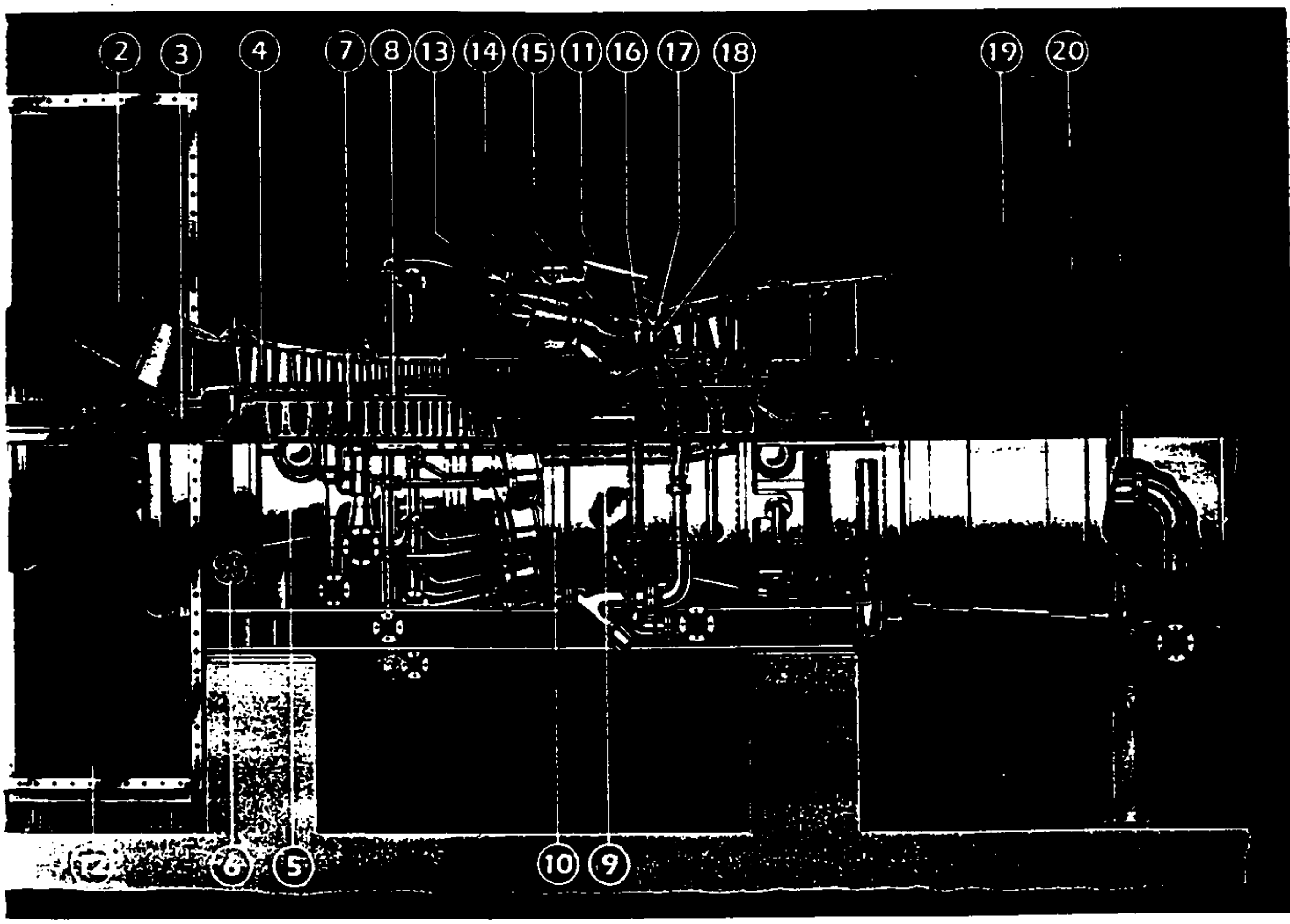
(10) Combustor Bulkhead — Combuster outer cans attached over elongated holes in combustor bulkhead to permit removal of transition piece without lifting turbine shell.

(11) Top and Bottom Manway Access — Permits an alternate way for removing the transition piece and Stage 1 nozzle without lifting turbine shell. **(12) Inlet Orientation** — Available in up, down or side arrangement. **(13) Fuel Distribution** — Single fuel line connection for each combustor en cover. **(14) Reverse Flow Combustion Chambers** — Supplement the impingement- and film-cooling of the liners and transition pieces, prolonging parts life. **(15) Impingement-Cooled Transition Piece** — Separate perforated shield around transition piece causes compressor discharge air to impinge on and effectively cool the transition piece

Turbine

(16) Nozzle Design — Sidewalls

THE MS7001F ADVANCED TECHNOLOGY HEAVY-DUTY GAS TURBINE



and internal surfaces of vanes impingement-cooled with compressor discharge air. **(17) Stage 1 Stationary Shroud Design** — Gas path insert of high-temperature alloy, extensively impingement- and film-cooled and coated for maintenance of tight clearances with the Stage 1 bucket tip. **(18) Bucket Design** — Stage 1 bucket uses a turbulated serpentine-cooled design with trailing edge bleed cooling, based on aircraft engine technology. Stage 2 uses turbulated radial cooling holes. Stage 3 is uncooled. Stages 2 and 3 have integral Z-lock shrouds for vibration control, and all three stages have long shanks for vibration control and isolation of gas-path temperatures from the turbine wheels.

Exhaust

(19) Exhaust Diffuser — Straight axial (permitted by front-end drive) is insulated for thermal stability and reduced heat loss from exhaust before entering heat recovery system. **(20) Exhaust Thermocouples** — Three sets of 9 thermocouples each supply signals to each of the three SPEEDTRONIC MARK IV computers. The thermocouples are used for control and also for monitoring the combustion system.

Generator

(a) Hydrogen Cooled Generator — Experience-proven design incorporates completely self-contained ventilation system to protect against dirt, moisture and other contaminants. Generator operates at 3600 rpm. **(b) Static Exciter** — The high initial response will minimize voltage fluctuations during system disturbances. Static excitation system has no bearings or other moving parts, resulting in high machine reliability. **(c) Hydrogen Cooler** — Hydrogen has a thermal conductivity of nearly seven times that of air, and its ability to transfer heat through forced convection is about 50% better than that of air. Also with hydrogen cooling, there is practically no deterioration of the stator winding insulation because of corona. **(d) Torque Converter** — Permits the elimination of a turning gear by acting as a hydraulic turning device during cooldown. **(e) Starting Motor** — 2200 hp motor connected to the generator collector end provides normal total start cycle of 30 minutes to baseload.

A CONTINUING COMMITMENT FROM THE INDUSTRY LEADER

The new 7F gas turbine is the latest affirmation of GE leadership in advancing turbine technology. With a hundred-year history of innovation and over 4000 combustion turbines operating successfully around the globe, GE is committed to provide a continuing standard of excellence in all that we do:

- *The industry's broadest selection of high-performance steam and gas turbine designs*
- *Turnkey systems: feasibility studies, engineering and design, construction, installation, operation and maintenance, financing*
- *Refuse-to-energy projects*
- *Cogeneration expertise*
- *High-technology upgrade programs*
- *Pre-engineered parts and components*
- *Worldwide locations and total service support*

For the technology and commitment to meet power generation needs in the '90s and beyond, you have a valuable resource in GE.

G-11651-1

The MS7001F Advanced Technology Gas Turbine is built in one of the world's largest and most modern heavy-duty gas turbine plants located in Greenville, South Carolina.

RDC-25115-12

Much of the extensive developmental work done to make the 7F machine the basic gas turbine for the '90s was done in the Turbine Development Laboratory in Schenectady, N.Y.

U.S.A.

GE Power Systems

TURBINE BUSINESS OPERATIONS
One River Road
Schenectady, New York 12345

GEA-11769 10M 7/87

2.2 DESIGN ENHANCEMENTS FOR THE COMBUSTION TURBINE FOR POLK UNIT 1

The following provides a description of the design enhancements for the GE Model MS7001 F combustion turbine which will be incorporated for Polk Unit 1.

Combustion Turbine

- Firing temperature was increased to 2,350 degrees Fahrenheit (°F)
- Increased pressure ratio in compressor
- Optimizing cooling for nozzles in the three turbine stages and buckets in the first two stages
- Compressor casing made into a single span casing
- Eliminated 5th-stage compressor bleed; added 9th-stage bleed
- Shortened and repositioned 9th-stage compressor blades on the rotor
- Fifteenth-stage compressor wheel material changed to CrMoV; same as 16th stage
- Revised combustion system components:

  - Flow sleeve design
  - Cast combustion cover
  - Revised baffle plate design
  - Cast transition piece aft frame

- Larger combustion cans to accommodate higher flows of low-British-thermal-unit (Btu) syngas
- Nozzles and connections on combustion cans for admitting and blending nitrogen for nitrogen oxides (NO_x) control

Auxiliary Equipment

Packaged modules consisting of:

- Interconnecting module housing gas and purge valves, flow divider, lube oil feed and drain, and water injection equipment with shorter lengths of piping.
- Accessory module housing the lube oil, atomizing air and liquid fuel systems.
- Packaged electrical and electronic control compartment containing the Mark V Speedtronic turbine control, generator control panel, EX-2000 excitation system, direct and alternating current (DC and AC) motor controllers, battery charger, and batteries eliminating the field interconnections and debugging of these systems.

3.0 SELECTED AUXILIARY BOILER

3.1 DESCRIPTION OF THE ABCO PACKAGED WATERTUBE BOILER

Tampa Electric Company has selected an ABCO Industries, Inc., "D"-type packaged watertube boiler system for Polk Unit 1. The auxiliary boiler system includes the following components:

Watertube Boiler

The watertube boiler is an ABCO Industries, Inc., "D"-type with "membrane" wall radiant furnace section and bare tube convection section. The unit is sized for steam at 415 pounds per square inch gauge (psig) operating pressure downstream of the steam stop-check valve. The design pressure is 475 psig. The burner plenum frame mounts directly to the front wall of the radiant section.

The boiler has two major design features for achieving reduced emissions:

1. Prevent furnace gases from short circuiting the furnace. The ABCO boiler accomplishes this by making the division wall between the furnace and convection section of the membrane construction, thus gas tight so leakage does not occur.
2. Maintain as cold a fire box as possible. NO_x production is a function of temperature. Seventy to 80 percent of NO_x formation during combustion occurs in the initial 30 to 40 percent of the furnace volume. The ABCO water cooled membrane wall design, including the water cooled furnace front wall maintains low fire box temperatures and thus helps minimize NO_x formation.

Casing

The radiant furnace section is of membrane wall construction covered with 3 inches of mineral fiber insulation and protected by a 0.04-inch corrugated aluminum lagging. The membrane wall provides gas tight construction, thereby eliminating the potential for corrosion of the casing. The rear target wall and burner front wall of the radiant section also utilize carbon steel membrane tubes that cover 100 percent of the area of the walls. The front and rear walls are gas tight with the roof, floor, and sides. A hinged 15- by 18-inch door is provided for access to the radiant section. Three "forced"-air cooled observation ports are provided: (1) in the burner for observation of the furnace, and (2) in the rear wall for observation of the flame.

Drums

A 42-inch inside diameter (I.D.) upper drum and a 30-inch I.D. lower drum, each with an elliptical manway in each end, are provided. The steam drum internals include distribution piping for feedwater, chemical feed, and continuous blowdown. Three-stage separation is provided with primary separation by means of baffles with secondary separation utilizing cyclone separators and final separation by a V-bank chevron-type separator to give 0.2 ppm or less solids in the steam based on American Society of Mechanical Engineers (ASME)-recommended boiler water quality. Exposed portions of the steam and water drums are covered with 3 inches of mineral fiber insulation protected by 12-gauge carbon steel lagging.

Tubes

The boiler tubes are 2 inches outside diameter (O.D.) by 0.105 inch by SA-178A and use an in-line tube arrangement. The tubes will be attached to the drums by rolling and flaring. Tube holes have a single groove.

Economizer

A vertical gas flow, horizontal, finned tube economizer is located at the boiler outlet. The economizer will be supported by a galvanized structural steel frame. The economizer casing will be insulated and covered by a 0.04-inch aluminum lagging. Also included:

- Duct between boiler outlet and economizer, with access door.
- Expansion joint.

Stack

The stack, 44-inch I.D., will terminate 75 feet (ft) abovegrade and will be located on top of the economizer.

Burner

To meet the heat input plus emissions requirements, the boiler is equipped with a Coen Company low-NO_x burner system, which includes:

- Burner CPF1LN-32
- Windbox inlet damper
- Oil pilot, electrically ignited
- Valve trains
- Flame management system with Allen Bradley SLC 500 programmable logic controller
- First-out annunciator
- Flue gas recirculation system

The following duty specification and commercial brochure provide additional information on the ABCO packaged watertube boiler.

DUTY SPECIFICATION

DESIGN STANDARDS

The design, material and workmanship of all pressure parts shall be in strict conformity with the rules and regulations in effect at the date of contract as required by:

1. The A.S.M.E. BOILER AND PRESSURE VESSEL CODE, SECTION I.
2. The laws of the State of Florida.
3. Requirements of the HARTFORD Steam Boiler Inspection and Insurance Company, under whose inspection the pressure parts of each unit shall be constructed.

This boiler will be used for intermittent service, generally for plant black-start following maintenance shutdowns. It shall be designed for starting and continuous operation without extended utilities except as listed below (fuel and boiler feedwater).

DESIGN AND OPERATING CONDITIONS

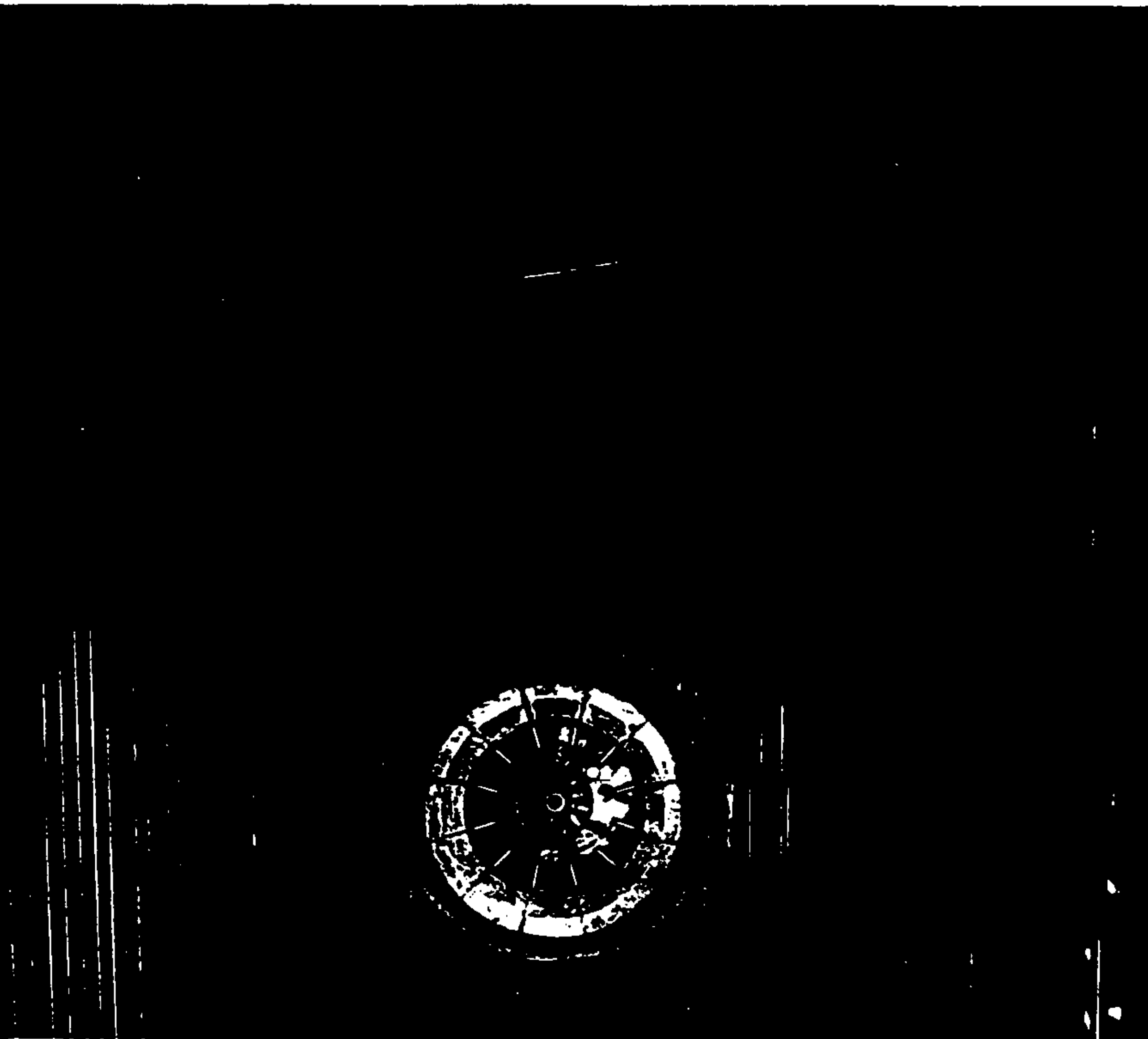
Design Steam Capacity	98,160	Lb/Hr.
Maximum Continuous Load Steam Capacity	98,160	Lb/Hr.
Design Pressure	490	PSIA
Operating Pressure	430	PSIA
Steam Temperature	452	°F
Feedwater Supply Temperature	60/240	°F

BOILER FEEDWATER

Source	Boiler Feedwater Treating Plant	
Treatment	Demineralized (for high pres. boilers)	
Pressure	150	PSIG
Temperature	40-200	°F
Typical Analysis:		
Conductivity	0.1	uMHO/cm
Total Dissolved Solids	0.005	PPM(Na)
SiO_2	0.010	mg/l
pH	6-8	

FUEL ANALYSIS

Type		No. 2 Fuel Oil	
Pressure at Burner		45	PSIA
Temperature at Burner,	min	40	°F
	max	100	°F
Specific Gravity		0.876	
Flash Point		100	°F
Pour Point		20	°F
Minimum Heating Value:			
LHV		129,811	Btu/gal
HHV		137,600	Btu/gal



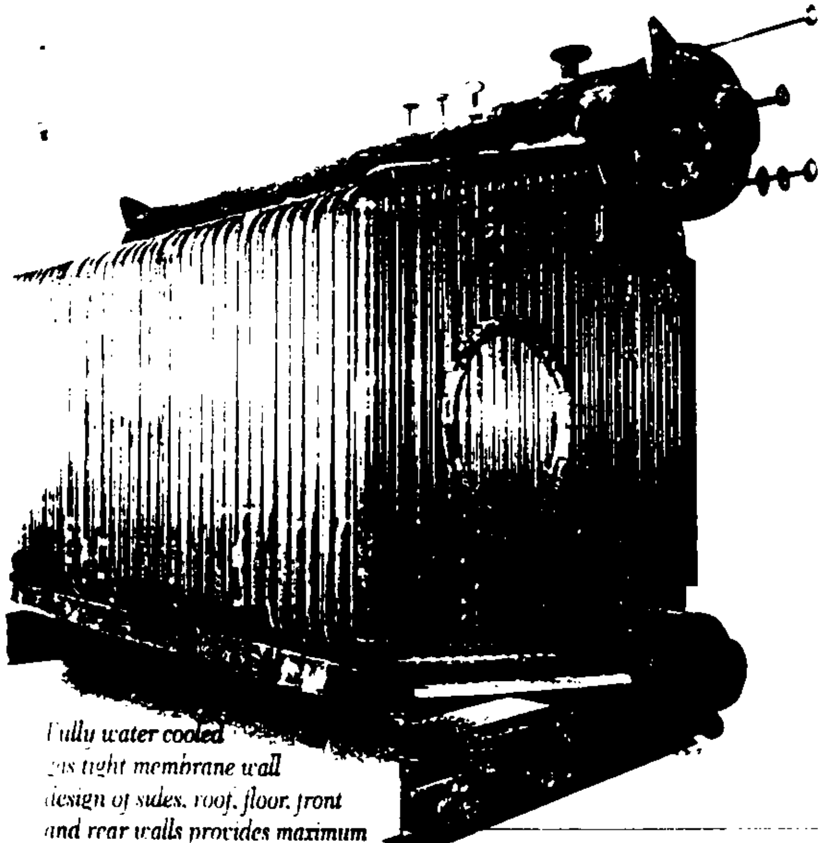
PACKAGED WATERTUBE BOILERS

- D-type Watertube
- Gas, oil, gas/oil
- Steam capacity 10,000-225,000 pph
- 15-1,200 psig
- Steam temperatures up to 900°F

abco industries inc.

custom designed boiler systems

Since 1923



Fully water cooled gas tight membrane wall design of sides, roof, floor, front and rear walls provides maximum cooling surface and minimum long term maintenance due to the elimination of refractory. Adjacent membranes of all furnace and outboard convection tubes are welded together to form a gas tight water cooled panel. The membranes are attached to the tubes via continuous submerged arc welds on each side to assure maximum heat transfer and minimum tube wall and membrane temperatures. This prevents the short-circuit of hot furnace gases to the convection zone and eliminates condensation and corrosion between tubes and outer casing.

ABCO Industries, Inc. specializes in custom designed boiler systems. Whether stimulated by the latest environmental emissions standards, client requirements or advances in engineering, we continually provide leading edge technology in our products. We have designed an even more efficient, longer lasting watertube boiler to meet our customer's most stringent emissions standards. Customers and competitors alike say our 100% membrane wall design is the best they have seen. We are becoming the American standard for packaged watertube boiler construction and proudly present our latest design in the D-type Packaged Watertube Boiler.

Primar
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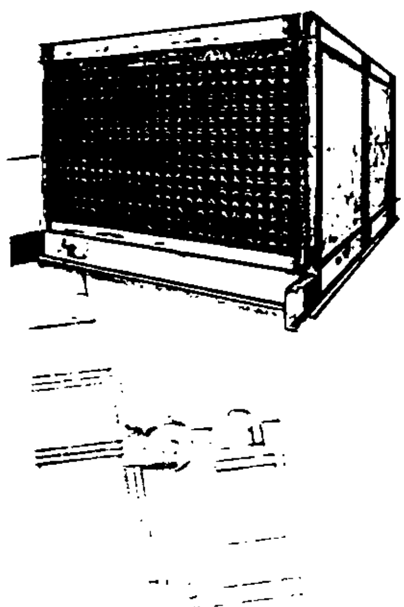
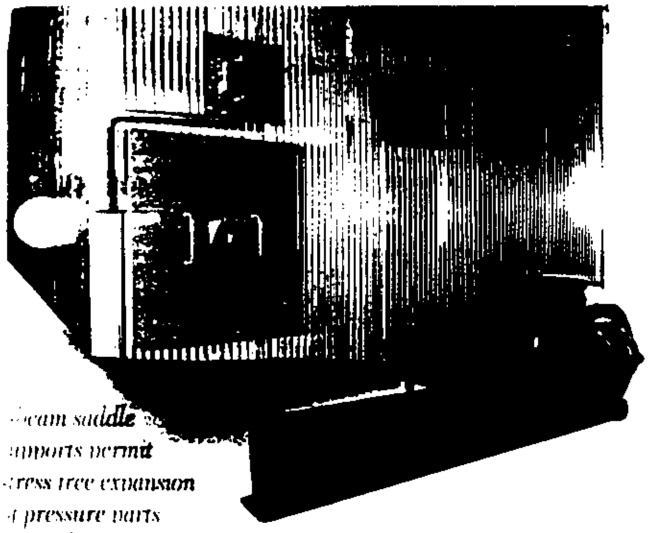
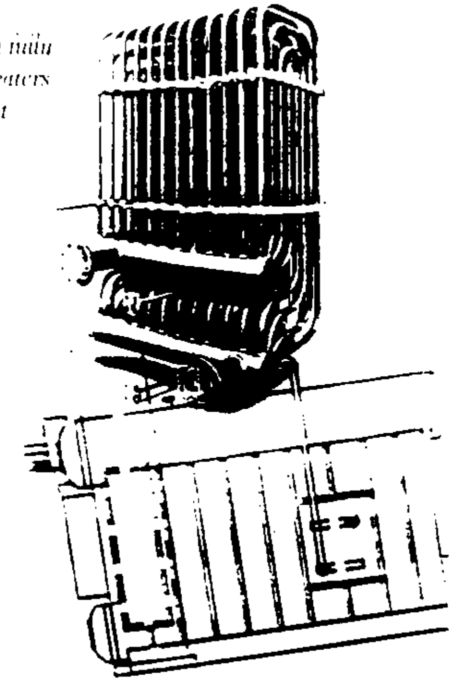
- Each package is individually engineered to meet your specific application.
- Low CO & NOx emissions as required; simply tell ABCO engineers your permit requirements.
- Baffle wall is of membrane construction resulting in absolute zero leakage to the convection zone; essential for NOx, CO and UHC control.
- Steam generating capacities from 10,000 through 225,000 pph available. Pressures to 1200 psig. Superheat temperatures to 900°F.
- Traditional refractory replacement is necessary every 2-3 years, while replacement of ABCO's full membrane steel wall is totally a function of the water treatment system and is no more frequent than replacement of boiler tubes.



Economizers available to optimize efficiency.



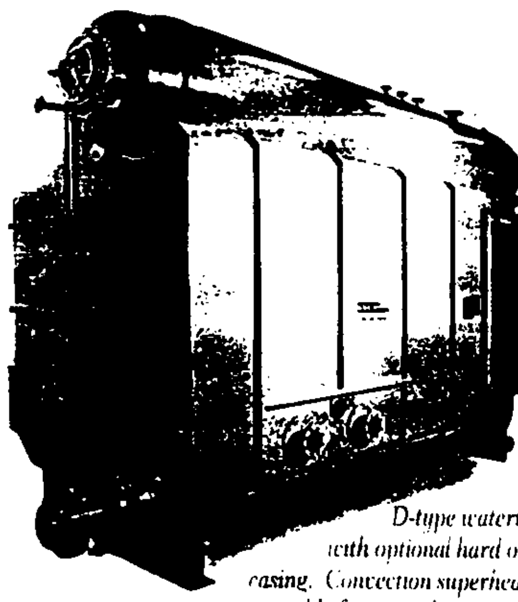
...eam saddle ...upports permit ...tress free expansion ...f pressure parts ...nd full access to the underside ...f the furnace floor. Corrugated outer cover ...tandard for tube access with optional hard ...asing available. Observation points allow ...ull view of the fire side.



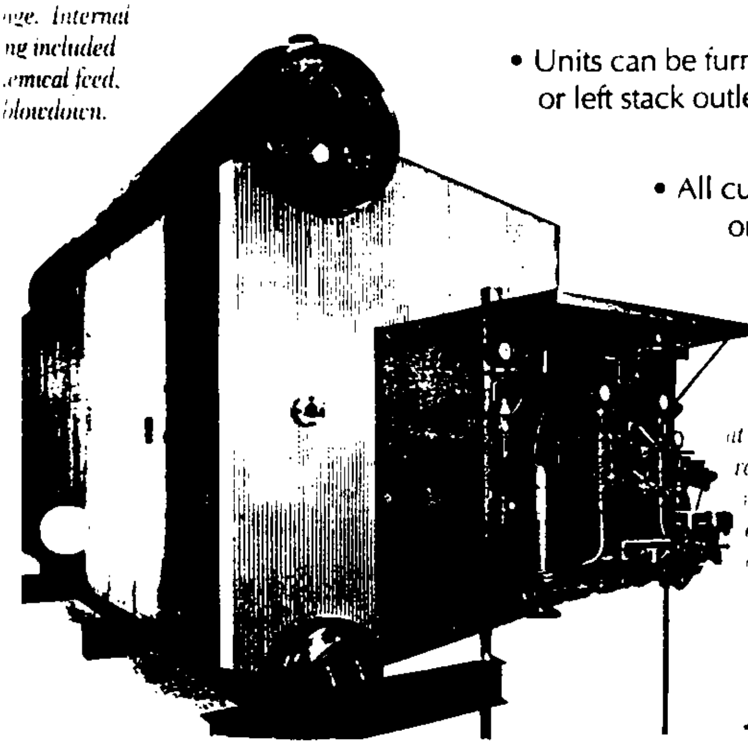
...nvection tube, ...verted loop, and radiant ...ainable superheaters ...vailable. Radiant ...uperheaters ...re drained.

- Gas, oil, gas/oil firing.
- ASME construction. FM, IRI & NFPA optional.
- Complete factory assembly and hydrostatic testing.
- Custom designed furnace volume, radiant and convection heating surface to meet requirements for your application.
- Boiler may be sized for a specific temperature "window" to permit installation of a selective catalytic reduction unit.
- Serrated tube holes standard. Tubes can be seal welded as an option.
- Units can be furnished with right or left stack outlets.
- All customer drawings done on CAD.

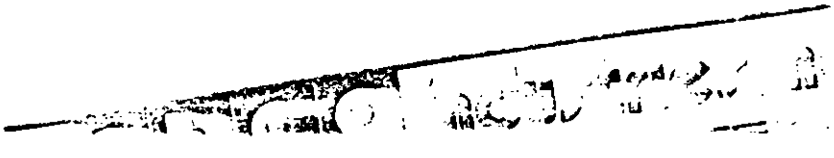
...nd baffle and ...eparator insure ...m. Cyclones ...ilable to meet ...he parts per ...ge. Internal ...ng included ...emical feed, ...blowdown.

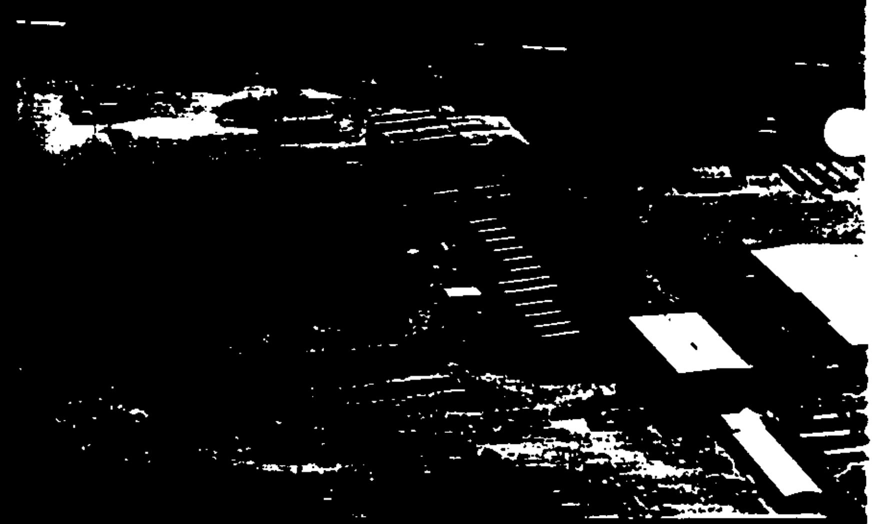


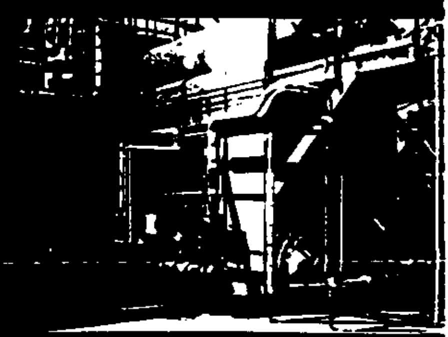
D-type watertube with optional hard outer casing. Convection superheaters removable for ease of maintenance or replacement (see openings lower left).



A completed gas and #6 oil fired D-type watertube boiler ABCO engineered and manufactured for the Dormitory Authority State of New York. It is designed to generate 60,000 pph steam and operate at 150 psig. ABCO packaged watertube boilers meet steam capacity ranges of 10,000-225,000 pph at pressures of 15-1,200 psig with superheat temperatures up to 900°F and are individually engineered to meet your specific application. Low CO and NOx emissions are available as required by your permit.







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3.2 SPECIAL DESIGN FEATURES FOR POLK UNIT 1

The following special design features have been incorporated into the auxiliary boiler system for Polk Unit 1:

- Boiler equipped with a low-NO_x burner.
- Flue gas recirculation to reduce NO_x production.
- Extended surface economizer to increase unit efficiency.
- Furnace conservatively designed with low heat release rates and lower furnace temperatures that reduce NO_x production.

4.0 CHANGES IN THE OPERATION, FUELS, EMISSIONS, OR EQUIPMENT FOR THE COMBUSTION TURBINE AND AUXILIARY BOILER SINCE CERTIFICATION

4.1 COMBUSTION TURBINE CHANGES

No changes in the operation, fuels, or equipment for the combustion turbine for Polk Unit 1 have been made since the certification of the Polk Power Station.

As described in the Postcertification Design Update document submitted to FDEP in May 1994, NO_x emissions from the Polk Unit 1 combustion turbine have been decreased since certification to partially offset increases in NO_x emissions from the sulfuric acid (H_2SO_4) plant and auxiliary boiler due to design updates. Tables 4-1 and 4-2 show the decrease in NO_x emissions from the combustion turbine.

4.2 AUXILIARY BOILER CHANGES

No changes in the fuel for the auxiliary boiler for Polk Unit 1 have been made since certification of the Polk Power Station. As described in the Postcertification Design Update document, the operation, equipment, and emissions for the auxiliary boiler have been changed based on current detailed design efforts.

The proposed auxiliary boiler for the Polk Power Station facility will furnish the steam required for aspiration of the startup and process burners during startup and change-out of the gasifier, the steam required to start up the air separation unit and H_2SO_4 plant, and the seal steam for the steam turbine seals. Based on updated steam requirements for the project determined during detailed design, the size of the unit needed to be increased compared to the size of auxiliary boiler indicated in the Site Certification Application (SCA). The updated steam demand is now established at 98,160 pounds per hour (lb/hr) (120 million British thermal units per hour [MMBtu/hr]) versus approximately 35,000 lb/hr (49.5 MMBtu/hr) as originally estimated.

Table 4-1. Summary of Criteria Pollutant Emission Changes Due to Design Updates

Emission Source	Change In Pollutant Emission Rate (tpy)				
	SO_2	NO_x	PM	CO	VOC
IGCC CT	0.0	-11.1	0.0	0.0	0.0
Thermal oxidizer	-154.2	-3.5	-51.7	0.0	0.0
H_2SO_4 plant	154.2	41.6	56.1	6.1	3.5
Auxiliary boiler	9.9	12.6	11.0	15.8	3.9
Coal handling	0.0	0.0	-1.1	0.0	0.0
TOTAL	**9.9**	**39.6**	**14.3**	**21.9**	**7.4**

Source: ECT, 1994.

Table 4-2. Summary of Annual NO_x Emissions

Emission Source	NO_x Annual Emission Rate (tpy) Before Update	After Update	Change
IGCC CT	1,044.0	1,032.9	-11.1
Auxiliary boiler	4.0	16.6	12.6
Thermal oxidizer	11.4	7.9	-3.5
H_2SO_4 plant	0.0	41.6	41.6
Total	**1,059.4**	**1,099.0**	**39.6**

Source: ECT, 1994.

New operating modes for the auxiliary boiler were established at 3,000 hours per year for full load operation and up to 8,760 hours of standby (no load) operation versus 1,000 hours of operation and no standby operation estimated in the preliminary designs.

The auxiliary boiler was relocated to provide minimum safe distances from the fuel oil tanks and the heat recovery steam generator (HRSG) stack platform and to accommodate space requirements for equipment in the vicinity of the boiler.

Table 4-1 shows a summary of the criteria pollutant emission changes, and Table 4-2 shows a summary of the changes in annual NO_x emissions for the combustion turbine and the auxiliary boiler is due to the design updates. Table 4-3 provides updated emissions and stack parameters for the auxiliary boiler.

Table 4-3. Updated Emissions and Stack Parameters for the Auxiliary Boiler (EP 12)

Pollutant	Short-Term lb/hr	Short-Term g/sec	Annualized* tpy	Annualized* g/sec
Emissions				
PM	7.0	0.88	12.5	0.358
SO_2	6.4	0.81	11.2	0.324
NO_x	8.6	1.08	16.6	0.478
CO	5.3	0.67	18.0	0.529
VOC	2.6	0.33	5.1	0.147
Lead	0.007	0.0009	0.0137	0.0004
Stack Parameters				
Stack height	75 ft		22.9 m	
Stack exit temperature	375°F		464 K	
Stack exit velocity	50 ft/sec		15.2 m/sec	
Stack diameter	3.7 ft		1.12 m	

Note: lb/hr = pounds per hour.
m = meter.
K = Kelvin.
ft/sec = feet per second.
m/sec = meters per second.

*Annualized emissions based on 3,000 hr/yr of full operation and 5,760 hr/yr of standby operation.

Sources: Texaco, 1992.
ECT, 1994.