Startup and Testing of Siemens V84.3A Combustion Turbine in Peaking Service at Hawthorn Station of Kansas City Power & Light Company

TR-108609

Interim Report, November 1997

Prepared by
Duke/Fluor Daniel, Inc.
3353 Michelson Drive
Irvine, CA 92698

Authors
R. Ball
B. Mastrodonato

Prepared for
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

EPRI Project Manager
G. H. Quentin

Generation Group

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION(S) THAT PREPARED THIS REPORT

Duke/Fluor Daniel, Inc.

ORDERING INFORMATION

Requests for copies of this report should be directed to the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, CA 94523, (510) 934-4212.

REPORT SUMMARY

Worldwide pressures to reduce power generation costs have led domestic and foreign manufacturers to build high-efficiency gas turbines using leading-edge technology. To assure the staying power of these turbines, EPRI launched a multi-year Durability Surveillance Program in 1991 to monitor advanced industrial gas turbines currently produced by major turbine manufacturers. This report discusses the startup and initial site testing of a new Siemens Model V84.3A combustion turbine at the Hawthorn Station operated by Kansas City Power & Light Company (KCPL).

Background

High-temperature materials and advanced blade cooling techniques have resulted in gas turbines with turbine inlet temperatures of 2350°F and higher, yielding greater fuel efficiency, extended availability, and lower maintenance costs. EPRI has tracked initial operation of such new units to assure their reliability and favorable life-cycle costs. The Siemens V84.3A gas turbine model offers new features, including hybrid burner ring(HBR®) combustion in lieu of silo combustors in earlier models. New blade technology derived from Pratt & Whitney aero-engine developments helps assure longer life, including first- and second-stage rotating blades made of single crystal alloys and ceramic thermal barrier coatings (TBC) on first-stage vanes.

Objectives

- To evaluate durability of advanced gas turbines measured in terms of reliability, availability, and maintainability.
- To measure gas turbine effectiveness in terms of life cycle costs by contrasting benefits of unit performance gains (for example, fuel efficiencies) with cost penalties of maintenance required to refurbish or replace hot gas path parts.

Approach

The first Siemens Model V84.3A advanced gas turbine was installed as Unit #6 at KCPL's Hawthorn Station in Kansas City. EPRI previously selected the unit for durability surveillance, which will involve on-line monitoring and periodic hot-gas-path inspection. The unit came on-line for site commissioning tests with fuel oil in June 1997 and natural gas beginning in August 1997. KCPL will shutdown the unit before the 1998 summer peaking season to install an optical pyrometer for monitoring first-

stage blade surface temperatures on-line. KCPL expects the unit to be fully available after commissioning for peaking service during the summer of 1998.

Results

Factory testing of the V84.3A unit went beyond the permissible operating range (up to 180 MW). The manufacturer accomplished this by varying the engine rotational speed over a wide range at loads up to baseload with use of a water friction brake. This technique permitted more severe operating conditions than might be encountered during typical power plant operation over a short period of time. During site testing runs in the summer of 1997, separate baseload tests were conducted on fuel oil and natural gas.

EPRI Perspective

This report covers the startup and testing of the Siemens V84.3A (60Hz) unit before being commissioned and turned over to KCPL. Following a deliberate series of factory tests in Berlin during 1995-96, the unit was delivered to Hawthorn Station in Kansas City in January 1997. The unit was first fired on fuel oil in June 1997, but commissioning tests on natural gas were delayed until September 1997 when natural gas fuel supply lines to the unit were completed (this required clearing of an easement before the line could be installed). The manufacturer, Siemens Power Corporation (SPC), looks forward to results of the Hawthorn Station durability surveillance as an important adjunct to its factory testing. Subsequent volumes in EPRI's Advanced Gas Turbine Guideline Series will cover the durability surveillance in more detail for the first three years of operation following commissioning.

TR-108609

Interest Categories

Combustion turbine/combined cycle plants

Keywords

Advanced gas turbines
Diagnostic monitoring
Site testing

ABSTRACT

The subject of this report is the Startup and Testing of the Siemens V84.3A gas turbine Unit #6 at the Hawthorn Station of Kansas City Power & Light Co. Currently, there are insufficient on-line data available to produce a detailed report.

The V84.3A utilizes advances in the aero-engine technology in the heavy duty design to increase the efficiency and output of the engine. Based on designs from Pratt and Whitney, Siemens developed new aerodynamic blading designs, blade cooling and used new blade manufacturing and coating methods, which allowed them to increase the turbine inlet temperature to 2,390°F (1310°C).

Such inlet temperature coupled with the advanced compressor design yields simple cycle thermal efficiency of 38%, LHV Heat Rate of 8,980 Btu/kWh (9472.6 kJ/kWh) and output of 170 MW for the V84.3A. Exhaust flow is 1,000 lb/sec (454 kg/sec) and emissions of less than 25 ppm NO_x are expected

This performance is made possible by advances in new blade materials. The first and second stage rotating blades are made of **single crystal (SC) superalloys**, which allow 85°F (29.4°C) higher operating temperature than the directionally solidified (DS) blades and 130°F (54.4°C) higher than the conventional equiaxed superalloys without additional cooling air. The low cooling air requirement also improves cycle performance.

Siemens also developed the annular combustor concept called the Hybrid Burner Ring (HBR®) combustor. The HBR ®uses the premix burners from previous designs and installs 24 of them in the HBR®. This design results in low residence time yielding low NO_x emissions and low combustor cooling air demand which yields high efficiency.

CONTENTS

1 INTRODUCTION 1-1
Description of Scientific Units 1-4

2 ADVANCED INDUSTRIAL GAS TURBINES 2-1
Introduction 2-1
Background of Advanced Industrial Gas Turbines 2-1
Currently Marketed Advanced Industrial Gas Turbines 2-1
Siemens V84.3A Advanced Gas Turbine 2-4

3 SYSTEM DESCRIPTIONS FOR KCPL'S SIEMENS V84.3A AT HAWTHORN STATION 3-1
EPRI Systems and Descriptions 3-1
Turbine Data Acquisition System 3-2
Bently Nevada Data Manager® 2000 3-3
Bently Nevada Data Manager® 2000 System Features 3-4
Data Collection 3-4
Connectivity 3-5
Flexible Configuration 3-5
Data Manipulation and Archive 3-5
Bently Nevada Data Manager® 2000 Startup / Shutdown Features 3-6
Blade Temperature Monitoring System (BTMS) 3-6
Objectives of the EPRI Pyrometer System at KCPL's Hawthorn Station 3-6
Need for BTMS Monitoring 3-9
Parsec Data Evaluation & Display System (DEDS) 3-10
Predictive Maintenance 3-10
Prevention of Catastrophic Failures 3-11
BTMS Technology Advancements Since 1992 3-11

Results from previous Blade Temperature Monitoring 3-13

4 PERFORMANCE RETENTION IN GAS TURBINE POWER PLANTS 4-1

Performance Retention and Degradation (Deterioration).. 4-1

Degradation - Recoverable by Washing/Cleaning 4-2

Degradation - Recoverable from Icing 4-3

Degradation - Non Recoverable by Washing/Cleaning... 4-3

Miscellaneous Components.. 4-4

References 4-5

5 TESTING OF SIEMENS V84.3A INSTALLED AT KCPL'S HAWTHORN STATION 5-1

Gas Turbine Full-Load Tests 5-2

Testing of the Siemens Model V84.3A Gas Turbine 5-2

Hawthorn Unit #6 Commissioning Tests 5-5

Fuel Oil 5-5

Results.. 5-5

Equipment Modifications... 5-5

Planned Modifications.. 5-6

Fuel Gas Testing 5-6

Results.. 5-6

KCPL’s Hawthorn Station Unit #6 Milestones 5-6

Conclusion 5-8

LIST OF FIGURES

Figure 1-1 Hawthorn Power Station Layout 1-1
Figure 1-2 V84.3A Gas Turbine Arrangement 1-2
Figure 2-1 Siemens V84.3A Prototype (at Full Load Test Stand) 2-6
Figure 2-2 Siemens V84.3A Compressor (left) and Turbine (Right) Blades 2-6
Figure 2-3 Hybrid Burner Model 2-7
Figure 2-4 V84.3A Cross-Section Showing Hybrid Burner Ring 2-7
Figure 2-5 Cooling Air Reduction with HBR™ Combustor 2-8
Figure 2-6 V84.3A Compressor Flow Path Design 2-9
Figure 2-7 First Stage Stationary and Rotating Turbine Blades 2-10
Figure 3-1 KCPL's Hawthorn Station Durability Surveillance Computer Network Schematic Layout 3-1
Figure 3-2 BTMS Schematic Diagram 3-9
Figure 5-1 Siemens V84.3A Prototype 5-1
Figure 5-2 Full Load Test Facility 5-2
Figure 5-3 The prototype V84.3A undergoing tests in Berlin 5-3
Figure 5-4 Siemens Power Corporation, KCPL's Hawthorn Station Unit #6, Commissioning Schedule 5-7

LIST OF TABLES

Table 1-1 Description of Scientific Units 1-4
Table 2-1 Currently Marketed 60 Hz Advanced Gas Turbines.. 2-2
Table 2-2 Currently Marketed 50 Hz Advanced Gas Turbines.. 2-3
Table 3-1 Bently Nevada Data Manager® 2000 Display Package Options 3-4
Table 3-2 Specifications for the Pyrometer, Data Sampling Unit (DSU) and Data Management Unit (DMU) 3-12
Table 5-1 KCPL's Hawthorn Station Unit #6 Milestones 5-6

1

INTRODUCTION

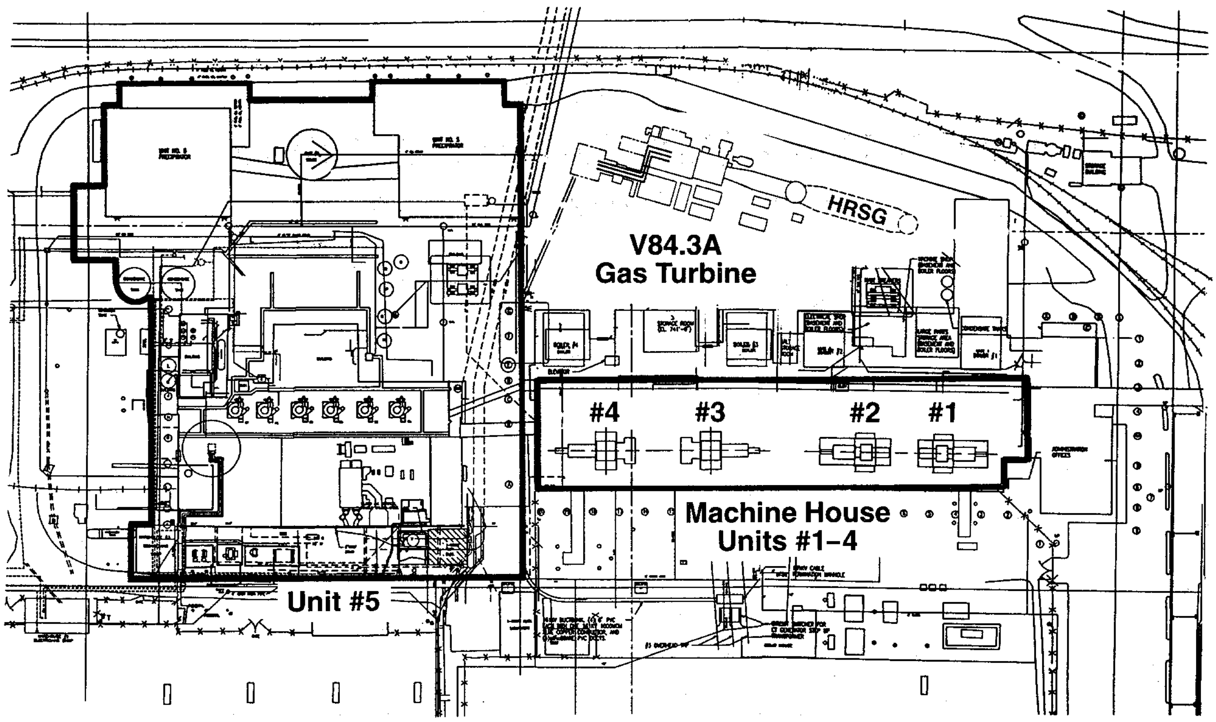


Figure 1-1
Hawthorn Power Station Layout

EPRI in 1991, initiated the Durability Surveillance of Advanced Gas Turbines (AGT) based on a comprehensive program of on-line monitoring and regular periodic unit inspections. The objectives of this program are to subject early-production units of new gas turbine power plants to an intense field surveillance to uncover the potential problems or deficiencies in early units, and permit corrective actions which will result in a more durable and efficient fleet.

An additional objective is to establish benchmarks for output, heat rate, availability, mechanical characteristics, maintenance costs and component life for these new machines., which will be used by utilities to aid in planning, purchasing and operating advanced gas turbines in simple and combined cycle applications. Utilities will need the guidelines to help specify, evaluate and operate these new turbines at the lowest life cycle cost. The AGT units monitored by EPRI Durability Surveillance include Advanced Gas Turbines from GE, ABB and Siemens.

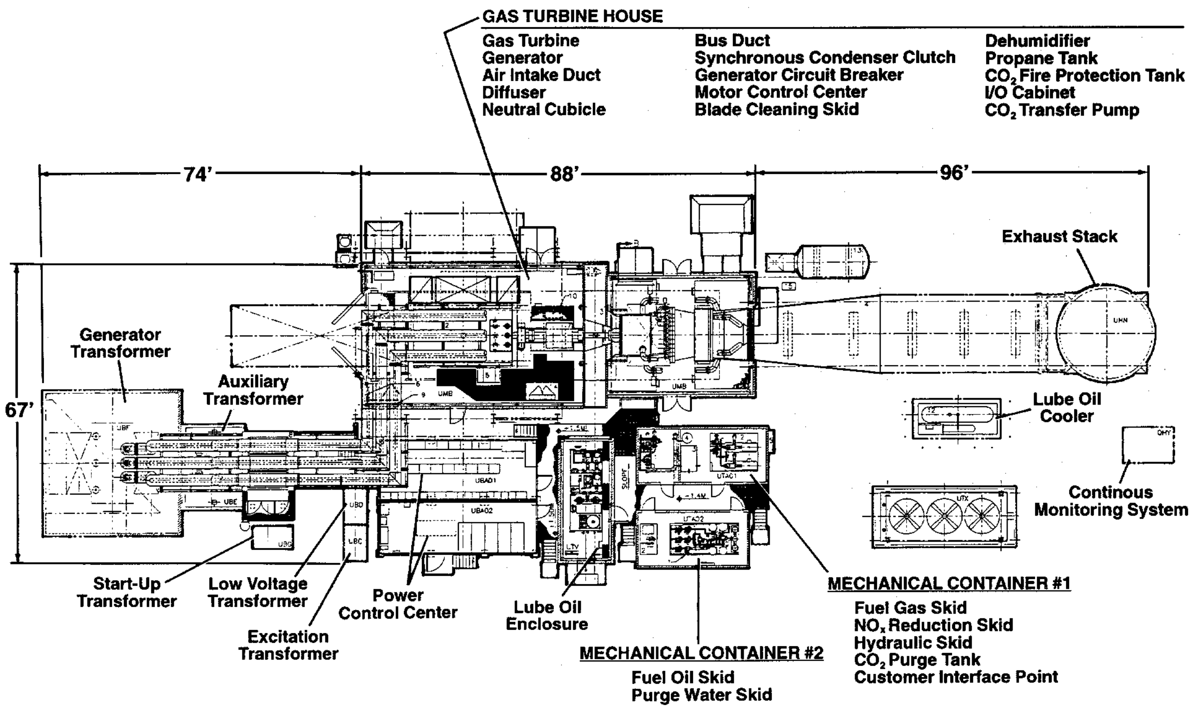


Figure 1-2
V84.3A Gas Turbine Arrangement

The subject of this report is the Durability Surveillance of the Siemens V84.3A as Unit #6 at the Hawthorn Station of Kansas City Power & Light Co. The V84.3A utilizes advances in aero-engine technology in the heavy duty design to increase the efficiency and output of the engine. Based on designs from Pratt and Whitney, Siemens developed new aerodynamic blading designs, blade cooling and used new blade manufacturing and coating methods, which allowed them to increase the turbine inlet temperature to 2,390°F (1310°C).

Such inlet temperature coupled with the advanced compressor design yields simple cycle thermal efficiency of 38%, LHV Heat Rate of 8,980 Btu/kWh (9472.6 kJ/kWh) and output of 170 MW for the V84.3A. Exhaust flow is 1,000 lb/sec (454 kg/sec) and emissions of less than 25 ppm NO_X are expected.

This performance is made possible by advances in new blade materials. The first and second stage rotating blades are made of **single crystal (SC) superalloys**, which allow 85°F (29.4°C) higher operating temperature than the directionally solidified (DS) blades and 130°F (54.4°C) higher than the conventional equiaxed superalloys without additional cooling air. The low cooling air requirement also improves cycle performance.

Siemens also developed the annular combustor concept called the Hybrid Burner Ring (HBR®) combustor. The HBR® uses the premix burners from previous designs and installs 24 of them in the HBR®. This design results in low residence time yielding low NO_x emissions and low combustor cooling air demand which yields high efficiency.

Description of Scientific Units

Throughout this document U.S. Customary Units have been utilized. For the convenience of the reader, S.I. units have also been included with the U.S. Customary Units and are enclosed in parenthesis.

The following table is provided for information concerning the conversion of units in this document.

Table 1-1
Description of Scientific Units

Units	U.S. Customary	S.I.	Conversion
Length	Feet	Meter	1 ft. = .304m
Area	$Feet^2$	$Meter^2$	1 $ft.^2$ = $.092m^2$
Volume	$Feet^3$	$Meter^3$	1 $ft.^3$ = $.028m^3$
	U.S. Gallon	Liter	1 Gal. = 3.785 l
Temperature	°F Fahrenheit	°C Celsius	(°F-32)/1.8 = °C
Torque	ft.-lb.	N-m	1 ft.-lb. = 1.355 N-m
Work	ft.-lb.	J	1 ft.-lb. = 1.355 J
Heat Content	Btu	kJ	1 Btu = 1.055 kJ
Energy	kW-h	kJ	1 kW-h = 3600 kJ
Pressure	psi	kPa	1 psi = 6.894 Pa
	Bar	kPa	1 Bar = 100kPa
Power	Hp	kW	1 Hp = .745 kW
Heat Rate	Btu/kWh	kJ/kWh	1 Btu/kWh = 1.0548 kJ/kWh

2

ADVANCED INDUSTRIAL GAS TURBINES

Introduction

A discussion on various features and characteristics of currently marketed advanced industrial gas turbines is presented in this section. A comparison of the key design and performance parameters for advanced gas turbines in 60 Hz and 50 Hz power generation service is provided.

Background of Advanced Industrial Gas Turbines

Advanced industrial gas turbines have been developed in the last decade with features that take advantage of the latest technology in different areas such as materials and manufacturing processes. The increased use of gas turbines to generate electric power and the highly competitive power generation market have led to the development of high performance engines.

Currently Marketed Advanced Industrial Gas Turbines

Tables 2.1 and 2.2 provide comparison of important design and performance parameters of advanced gas turbines marketed for the 60 Hz and 50 Hz power generation markets. Some common features of gas turbines marketed by domestic and foreign manufacturers for the 60 Hz market are the turbine inlet temperature of 2,300°F (1260°C) and higher, ISO power rating on natural gas of 150-165MW, and maximum thermal efficiency (LHV) approaching 38% as is evident from Table 2.1. For the 50 Hz power generation market common features of newly developed advanced gas turbines are similar to the 60 Hz machines as far as turbine inlet temperature and thermal efficiency are concerned. 50 Hz power rating on natural gas fuel ranges from 220-240 MW (see Table 2.2)

Table 2-1
Currently Marketed 60 Hz Advanced Gas Turbines

Manufacturer	ABB	GE	GE	Siemens	Westing-house	Westing-house
Model	GT 24	MS7001F	MS7001FA	V84.3A	501F	501G
Base Load Output, MW	165	156	159	170	163	230
TIT/RIT, °F TIT/RIT, (°C)	2255 (1235)	2300 (1260)	2350 (1288)	2390 (1310)	2462 (1350)	2600 (1427)
Heat Rate, Btu/kWh Heat Rate, (kJ/kWh)	9075 (9600)	10390 (10962)	9500 (10023)	8980 (9474)	9469 (9991)	8860 (9346)
Efficiency %, LHV	37.5	32.84	35.92	38.0	36.04	38.5
Pressure ratio	30.0	13.5	15.0	16.5	14.0	19.2
Mass Flow Rate, lbs/sec Mass Flow Rate, (kg/sec)	829 (376)	955 (433)	941 (426.8)	1000 454	990 (449.0)	1200 (544)
Exhaust Temperature, °F Exhaust Temperature, (°C)	1130 (610)	1100 (593)	1092 (589)	1044 (562)	1076 (580)	1100 (593)
Combustor System	EV Low NO_x SEV	Quiet Combustors Can - annular	Dry Low NO_x, can-annular	Hybrid burner ring	Premix lean-burn hybrid, can-annular	Dry Low NO_x, Can - annular
No. Of Combustor	2,(30, 24 Burners)	14	14	1,24 Burners	16	16
Site	GPU Gilbert Station	PEPCO Station H (2nd Site)	FP&L Martin Plant	KCP&L	FP&L	Lakeland
Startup Date	4Q 1995	2Q 1992	4Q 1993	2Q 1997	3Q 1993	Ship 1996

Notes:

1. *All the data presented here refers to ISO conditions.*
2. *The rated values given here are for the machines fired with the natural gas fuel.*
3. *A significant amount of data presented here is excerpted from Turbomachinery International [3] and various other sources [1,2,4-12].*

Table 2-2
Currently Marketed 50 Hz Advanced Gas Turbines

Manufacturer	ABB	GE	Siemens	Westing-house	Westing-house
Model	GT 26	MS9001FA	V94.3A	701F	701G
Base Load Output, MW	240	226	240	235	up to 300
TIT/RIT, °F TIT/RIT, (°C)	2255 (1235)	2350 (1288)	2390 (1310)	2462 (1350)	
Heat Rate, Btu/kWh Heat Rate, (kJ/kWh)	9029 (9526)	9500 (10096)	8890 (9474)	9469 (9790)	
Efficiency %, LHV	37.8	35.66	38.0	36.78	
Pressure ratio	30.0	15.0	16.5	15.6	
Mass Flow Rate, lb/sec Mass Flow Rate, kg/s	1195 (542)	941 (614.5)	1375 (624)	990 (665.0)	
Exhaust Temperature °F Exhaust Temperature (°C)	1130 (610)	1092 (589)	1044 (562)	1076 (547)	
Combustor System	EV Low NO_x SEV	Dry Low Nox, can-annular	Hybrid burner ring	Premix lean-burn hybrid, can-annular	Dry Low NO_x, Can -annular
No. of Combustor	2,(30, 24 Burners)	14	1	16	16

Notes:

1. *All the data presented here refers to ISO conditions.*
2. *The rated values given here are for the machines fired with the natural gas fuel.*

3. *A significant amount of data presented here is excerpted from Turbomachinery International [5] and various other sources [6-12].*

Special Characteristics of Advanced Industrial Gas Turbines

Some of the latest technological advances implemented in developing these machines as compared to their predecessors designs, which were mostly uprated from the then existing designs, are the following:

- Developments in the areas of materials and manufacturing processes which resulted in higher strength alloys, improved high temperature coatings, and higher quality components.
- Better understanding in the areas of aerodynamics, fluid flows and heat transfer in combination with the advances in structural and dynamic analysis and powerful computational analytical tools have contributed to significant improvements in the design phase of these machines.
- Better understanding of the combustion process has significantly improved the emissions associated with the higher firing temperatures.
- Improved cooling techniques for hot gas path components is an important contributing factor in the development of advanced gas turbines with the turbine inlet temperature of 2300°F (1260°C) and higher.

Siemens V84.3A Advanced Gas Turbine

The overall design concept of Siemens heavy-duty gas turbines has remained unchanged for three decades, incorporating the following features:

- Two outboard bearings
- Stiff rotor design with only one system critical speed below operating speed
- Disk-type rotor design with Hirth serration and center tie rod
- Generator drive from the compressor intake side compressor intake side
- Axial gas turbine exhaust
- Free standing compressor and turbine blading
- Four stage turbine section

The evolutional development process towards Siemens advanced gas turbines involves the following activities:

- Based on experience (Statistical component and System Data)
- Failure probability Analysis (Fault Tree, Redundancy)
- Failure mode and effect Analysis (FMEA)
- Life Cycle Cost Analysis (Also for Complete Combined Cycle Plant)*
- Three Dimensional Flow Path Design (Controlled Diffusion)
- Computer Aided Design (CAD for Gas Turbines, Auxiliaries and Power Plants
- Extensive Testing of Components and Systems
- Metallurgical R&D for Advanced Materials and Coatings
- Metallurgical Testing (Rainbow Testing in Power Plants)
- Assessment of Maintainability and Inspectability (Ram Data)
- Full Load Factory Test of Gas Turbines

** Life Cycle cost analyses are performed not only for gas turbines or simple cycle plants but for Siemens turnkey GUD® combined cycle plants to identify the expected long term advantage of selecting the right components and systems.*

The V84.3A utilizes advances in the aero-engine technology in the heavy duty design to increase the efficiency and output of the engine. Based on designs from Pratt and Whitney, Siemens developed new aerodynamic blading designs, blade cooling and used new blade manufacturing and coating methods, which allowed them to increase the turbine inlet temperature.

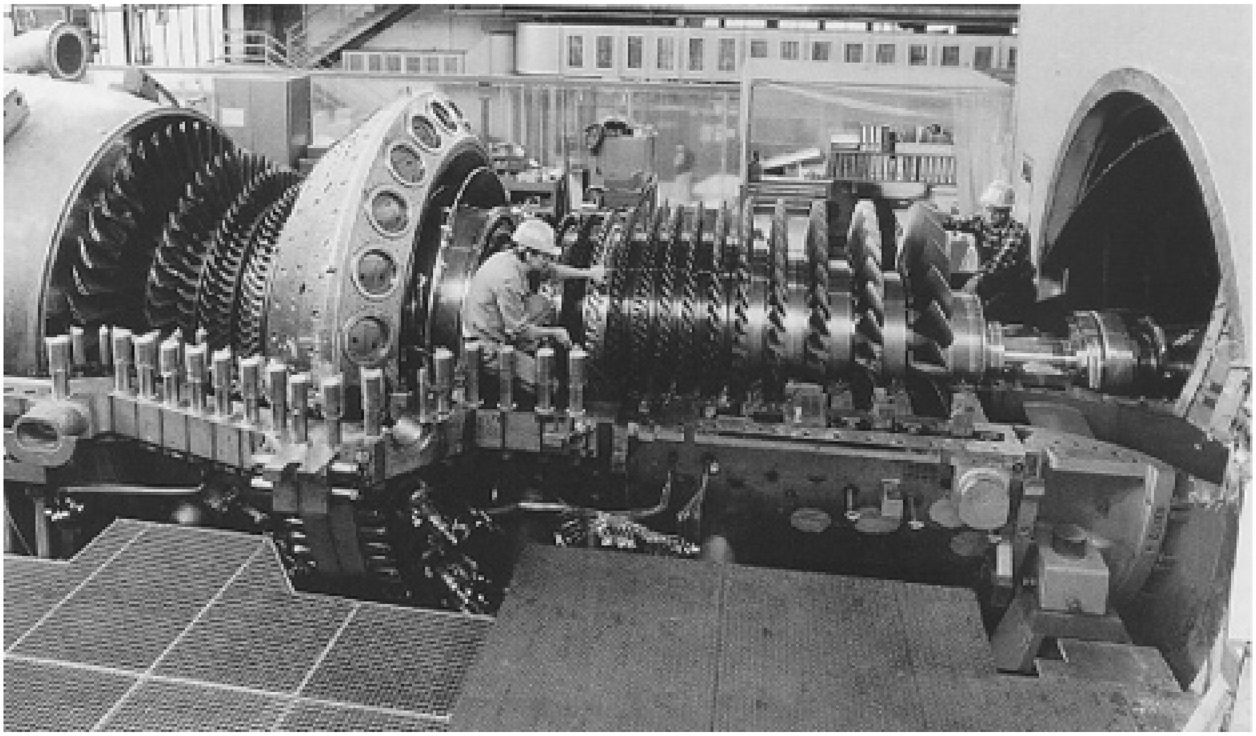


Figure 2-1
Siemens V84.3A Prototype (at Full Load Test Stand)

This performance is mainly achieved by advances in new blade materials. The first and second stage rotating blades are made of **single crystal (SC) superalloys**, which allow 85°F (29.4°C) higher operating temperature than the Directionally Solidified (DS) blades and 130°F (54.4°C) higher than the conventional equiaxed superalloys without additional cooling air. The low cooling air requirement also improves cycle performance. Also, each blade can be removed individually with the rotor installed in it’s bearings.

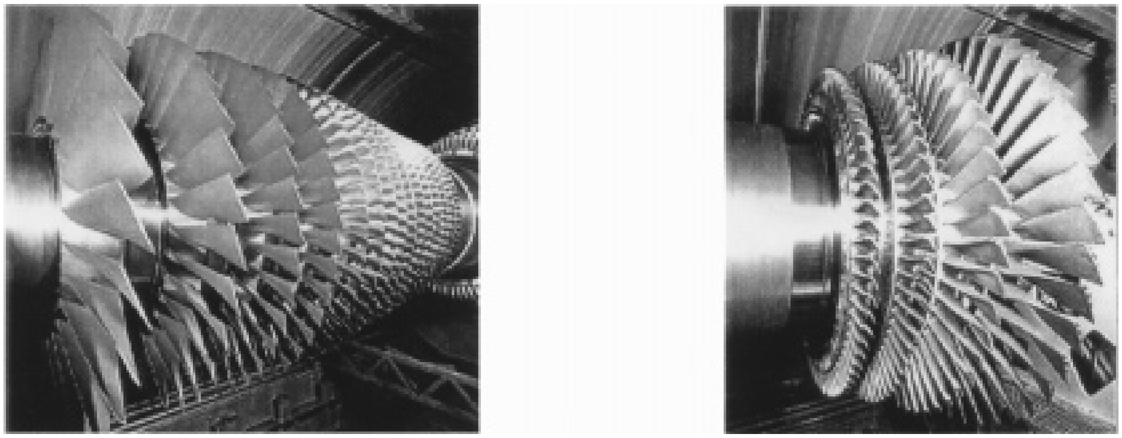


Figure 2-2
Siemens V84.3A Compressor (left) and Turbine (Right) Blades

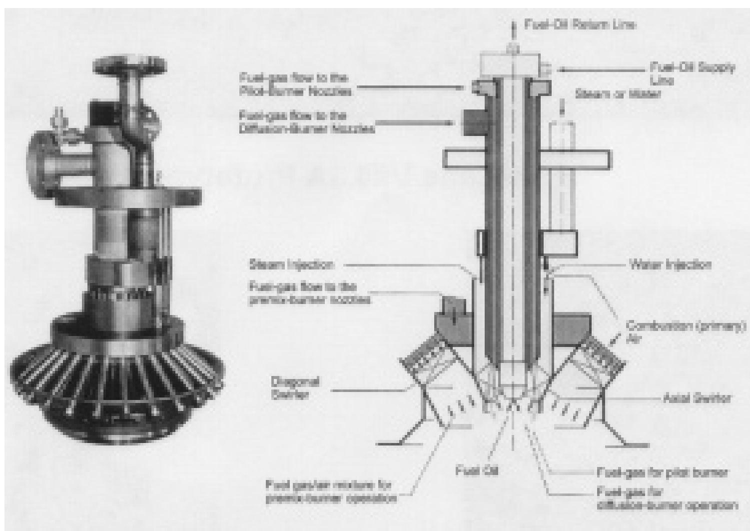


Figure 2-3
Hybrid Burner Model

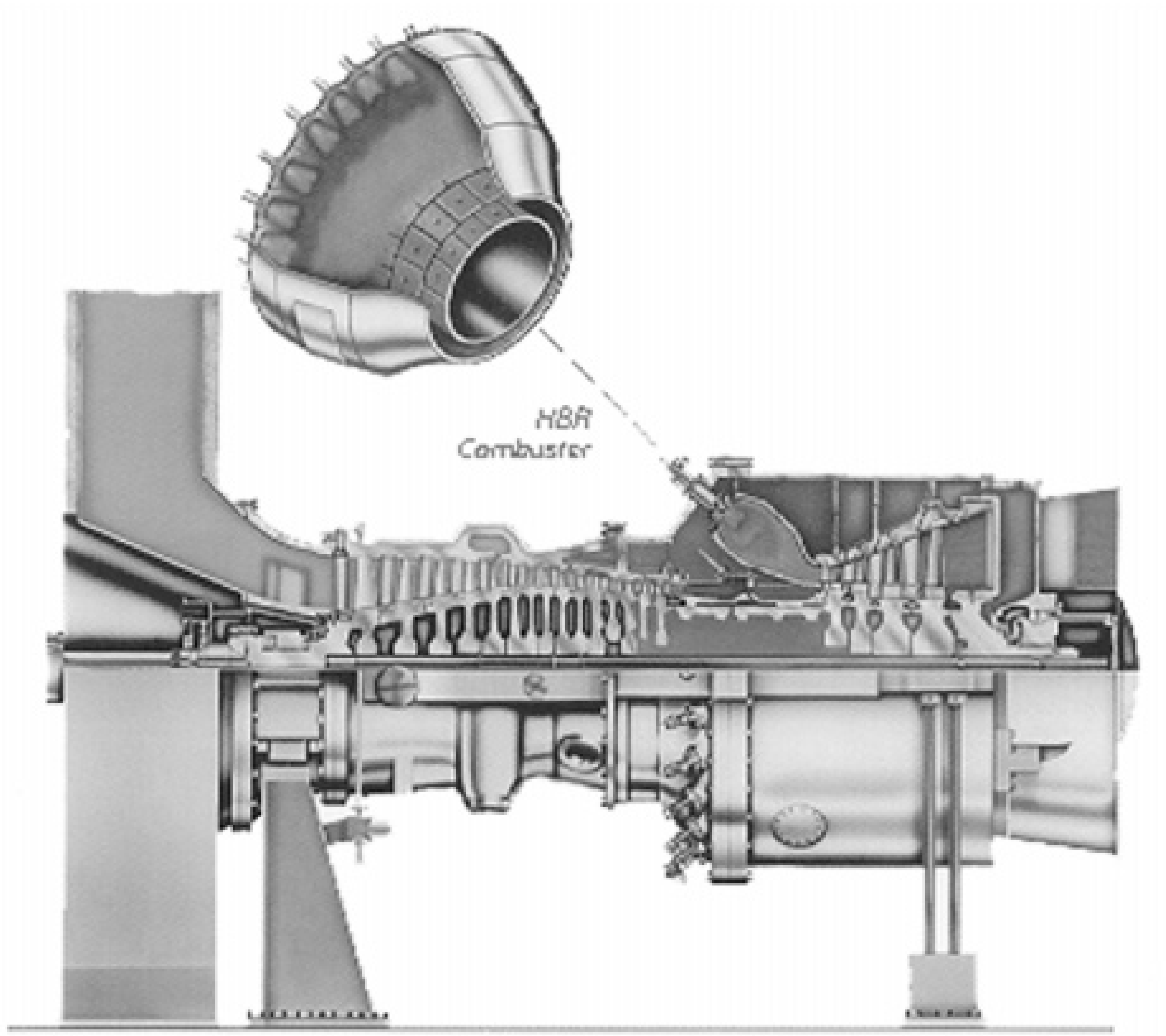
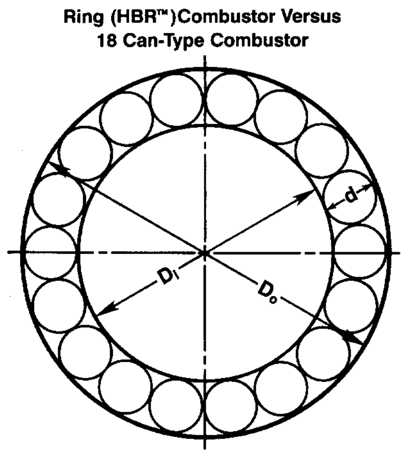


Figure 2-4
V84.3A Cross-Section Showing Hybrid Burner Ring

All four (4) vane rows are cooled. The first stage vanes are coated with Thermal Barrier Coating (TBC), which reduce the airfoil metal temperatures (of cooled airfoils) by 230°F (110°C). The two layer TBC coat consists of the bond coat of MCrAlY and outer ceramic layer of ZrO_2 (Zirconia).

Siemens also developed the annular combustor concept called the Hybrid Burner Ring (HBR®) combustor. The HBR® uses the premix burners from previous designs and installs 24 of them in the HBR®. This design results in low residence time yielding low NO_x emissions and low combustor cooling air demand which yields high efficiency. (See **Figure 2-5**)

Individually replaceable tiles are used to reduce the thermal stress in the combustor.



HBR™ Combustor	Can-Type Combustor
Outer Diameter $D_o = 1.41$ Inner Diameter $D_i = 1.00$	Can Diameter $d = 0.21$ Number of Cans $z = 18$
Ratio of Combustion Cross-Sections	
$F_{HBR} = (D_o^2 - D_i^2)\,\pi/4$ $F_{HBR} = 0.776$	$F_{Can} = 18\,d^2\pi/4$ $F_{Can} = 0.623$
Ratio = 80%	
Ratio of Wall Surfaces to be Cooled	
$L_{HBR} = (D_o + D_i)\,\pi$ $L_{HBR} = 7.57$	$L_{Can} = 18\,d\,\pi$ $L_{Can} = 11.87$
Ratio = 157%	

Figure 2-5
Cooling Air Reduction with HBR™ Combustor

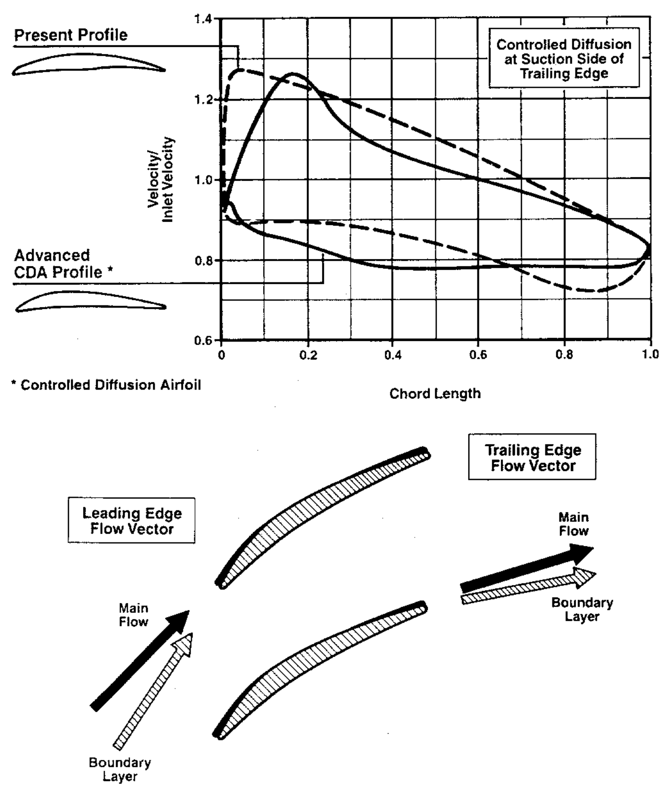


Figure 2-6
V84.3A Compressor Flow Path Design

Figure 2-6 illustrates the side wall correction for the stationary compressor blading at the hub and blade tip sections. A more wedge-shape leading edge and a more rounded suction side reduces locally high velocity components. Through more uniform deceleration, the boundary layer even at the trailing edge, does not experience any flow separation.

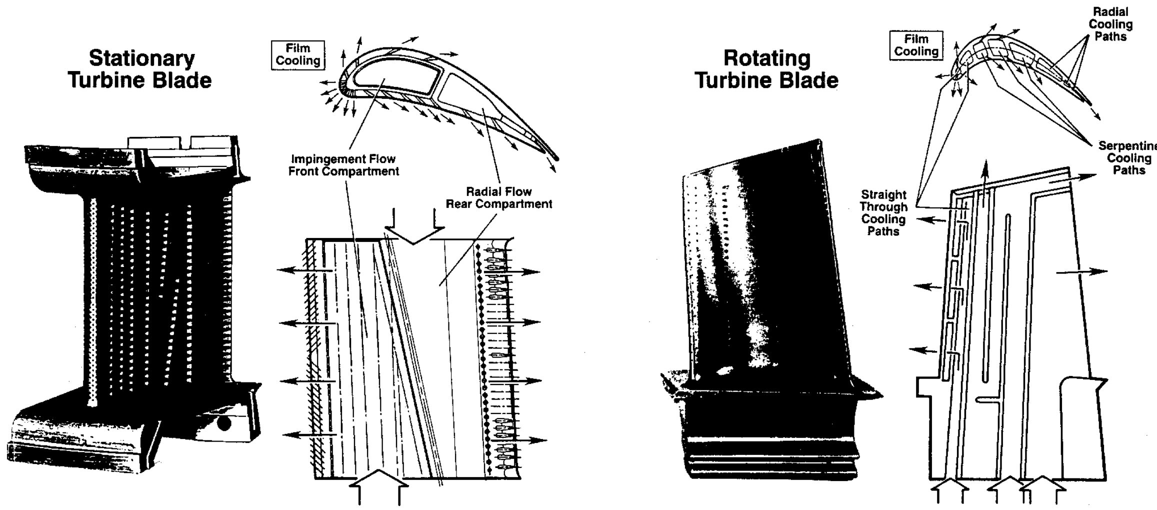


Figure 2-7
First Stage Stationary and Rotating Turbine Blades

Figure 2-7 illustrates the sophisticated first-stage stationary blade cooling which receives cooling air for the leading edge of the blade from the compressor discharge at the blade row's inner diameter. The trailing blade section, which operates at a reduced main flow pressure level, receives cooling air from its outer diameter through the compressor discharge chamber formed by the outer casing surrounding the combustor.

References

1. Bobrowich, J., Day, W. H., and H. Termuehlen. *Introducing the V84.3A: Thirty Years of Evolution to the Siemens V84.3A Gas Turbines.* Presented at Press Conference at Power-Gen Americas '94 Conf., Orlando, FL, Dec. 1994.

2. Becker, B., Maghon, H., and H. Termuehlen. *The V84.3A Model Gas Turbine.* Presented at Power-Gen Americas '94 Conf., Orlando, FL, Dec. 1994.

3. Barker, Thomas. *Siemens' New Generation*. Turbomachinery International, Jan/Feb 1995, pp. 20-22. Norwalk, CT (USA).

4. Farmer, Robert. *See 57% Net Efficiency Combined Cycles Powered by 2400°F. '3A' Series Gas Turbines.* Gas Turbine World, Jan/Feb 1995, pp. 16-28. Fairfield, CT.

5. Johnson, Paul. *V84.3A Gas Turbine Takes Aero-Engine Technology to New Heights.* Diesel & Gas Turbine Worldwide, Jan/Feb 1995, pp. 10-14.

6. Becker, B., Schulenberg, and H. Termuelen. *The '3A-Series' Gas Turbines with HBR® Combustors.* ASME Paper No. 95-GT-458. Presented at ASME Turbo Expo, Houston, Texas, June 5-8, 1995.

7. Chellini, R. *High Technology Turbine Blades from New Siemens Center in Berlin.* Diesel & Gas Turbine Worldwide, Oct. 1996, pp. 66-68

8. Becker, B. and H. Termuehlen. *Evolution of Siemens Gas Turbine Technology.* Presented at Mexico Power 96, Monterrey, Mexico, October 8-10, 1996.

9. Becker, B., Balling L., and H. Termuehlen. *Advanced Siemens V84.3A and V94.3A Gas Turbines.* Presented at Latin America Power '97 Conference, Caracas, Venezuela, April 19-30, 1997.

10. Boehm, W., Raake, D., Regenery, Seume, J., and K. Terjung. *Testing the Model V84.3A Gas Turbine - Experimental Techniques and Results.* Presented at the Power-Gen Intl. Conf, Orlando, Florida, Dec. 4-6, 1996.

11. Czech, N., Schmitz, F., and W. Stamm. *Advanced Coatings for Gas Turbine Blades.* VGB Kraftwerkstechnik 77 (1997), Number 3.

12. Beele, W., Czech, N., Schulenberg, T., and W. Stamm. *Thermal Barrier Coatings Advancing Efficiency.* Modern Power Systems (MPS), Aug 1997, pp. 19-21. Dartford, Kent (UK).

3

SYSTEM DESCRIPTIONS FOR KCPL'S SIEMENS V84.3A AT HAWTHORN STATION

EPRI Systems and Descriptions

Below is a system block diagram that describes the complete EPRI Durability Surveillance Monitoring and Analysis Systems at KCPL's Hawthorn Station:

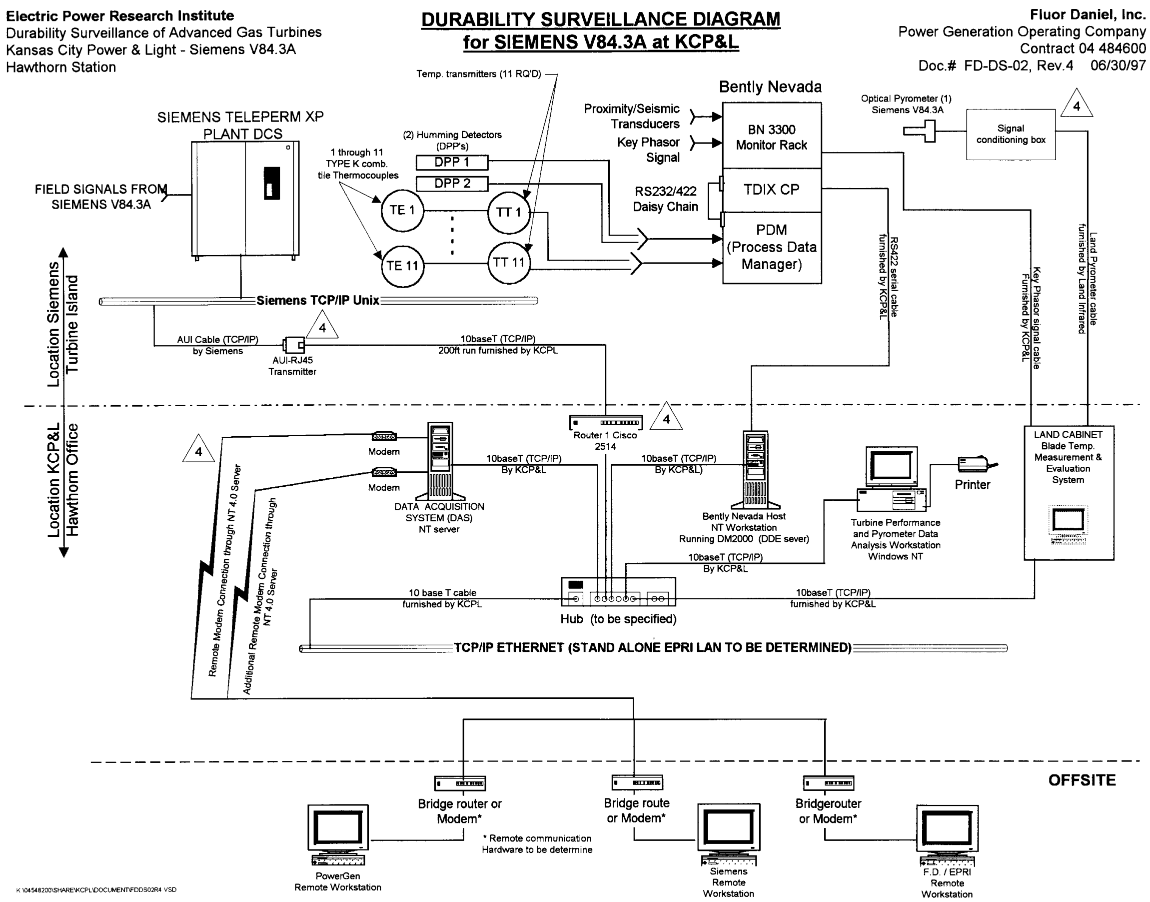


Figure 3-1
KCPL's Hawthorn Station Durability Surveillance Computer Network Schematic Layout

Turbine Data Acquisition System

The Turbine Data Acquisition System (DAS) is responsible for the data collection, processing, storage and display of the Siemens V84.3A's parameters. The DAS is a real time, on-line condition monitoring system developed by Parsec Automation, Inc., designed to perform integrated aerothermal and mechanical monitoring and analysis of the gas turbine. Inputs to the DAS are provided from several sources, including a serial link to the Siemens Teleperm turbine control system, several hardwired signals from Siemens prototype instrumentation, and blade temperature data from the Optical Pyrometer System

The purpose of the Turbine Monitoring package is to provide both real-time and historical views of the temperature, vibration and other critical data being generated by the turbine. This data is made available to the operator through the use of graphical images representing various views of the turbine.

By selecting an area of the turbine, the operator can analyze the turbines activity in real-time via the applications Analysis module. The real-time data is updated directly on the image of the turbine within the Analysis module. The Analysis module also provides a means of trending multiple variables. Data is collected on all major components of the V84.3A, including:

- Inlet / Compressor Section - Compressor inlet and outlet flow, temperature and pressure is monitored to help analyze the compressor's efficiency
- Combustor & Hot Gas Sections - Combustor Liner Pressure and exit temperature/pressure are monitored. The temperature data from the optical pyrometers allow for extensive analysis to be done on the combustors' performance.
- Bearing Metal Temperatures - compressor, turbine, generator, exciter and thrust bearing temperatures are monitored
- Exhaust Gas Temperature and Temperature Spreads
- Performance and Aerothermal Data - Aerothermal equations are used extensively to determine critical performance parameters of the V84.3A, including compressor pressure ratio, efficiency and consumed power, combustor inlet air mass flow, turbine efficiency, temperature ratio, gross power, heat rate and efficiency.
- Transient Event Data - The effects of transient events on the turbine performance parameters are of interest to the EPRI program,especially in a peaking unit such as the unit at KCPL's Siemens V84.3A at Hawthorn Station
- Vibration / Dynamic Data Analysis - Steady State and Transient State.

A weekly routine involves compiling trend graphs, summary charts and performance charts on the gas turbine in all of the above sections. This data will be kept for the duration of the three year program.

Since studies and comparisons are going to be made on an ongoing basis, it will be very important to be able to refer back to an initial characterization of the gas turbine in it's baseline condition. The development of this baseline will be accomplished by the EPRI project after summer peaking data from 1998 is available. Several objectives for the baseline study include:

1. To formulate a baseline for the Siemens V84.3A with respect to mechanical parameters, aerothermal performance parameters and transient behavior.

2. To update and tune the DAS database, alarm limits and aerothermal parameters.

To develop new performance maps which would aid in the health monitoring of the machine, and to aid in evaluating the performance retention capabilities of overall and individual components of the gas turbine.

Bently Nevada Data Manager® 2000

The Data Manager® 2000 system is an advanced and flexible Data Acquisition and Display package, The system consists of software programs, one or more dedicated data acquisition computers each with up to twelve communications processors, and any number of non-dedicated display computers.

This system works in conjunction with the Bently Nevada 3300 series vibration monitoring equipment. It is a separate and stand alone data acquisition system that is completely capable of operating on it's own. Data Manager® 2000 does however, have the capability (which was exercised here) to receive data points from other sources for correlation purposes.

The system consists of two separate software packages: the Display Package and the Data Acquisition Package (with or with out startup / shutdown capabilities). The Display Package allows the user to display the machinery data in a user definable manner (i.e. plots, lists and reports). The Data Acquisition Package acquires the machinery data from the Bently Nevada communications processors. (TDM, DDM, PDM, DDI, TDIX and TDIXconnX) as well as the aforementioned external devices. This portion of the system must be on a data acquisition computer running Windows NT.

Table 3-1
Bently Nevada Data Manager® 2000 Display Package Options

Waveform Data	Static Data	Other Outputs
orbit	trend	alarm annunciation
orbit/timebase	fast trend	alarm event list
timebase	multi-variable	system event list
cascade*	trend	reports
full cascade*	current values	
spectrum	acceptance region	
full spectrum	bar graphs	
waterfall	X vs Y	
full waterfall	polar*	
	Bode*	
	tabular listing	

* Available only on systems with startup / shutdown capability.

Bently Nevada Data Manager® 2000 System Features

Data Collection

- Storage for 50 vector event and waveform event files per point
- 400 line Asynchronous spectrum (from DDI and TDIX)
- Trend storage for a maximum of 10,000 trend intervals per variable for each point

Connectivity

- Communications interface to TDM, TDIX (including TDIXconnX) and DDI communications processors via RS232 or RS422, and to DDM and PDM communications processors via RS422. Twelve communications processors maximum per station.
- Access a maximum of 480 process data points from external devices using Modbus or NetDDE.

- Display screens on any X Windows station. (with X Window interface option)
- Compatible with Windows 95 or Windows NT supported computers, networks, modems, and printers.
- Access via telephone connection using a modem

Flexible Configuration

- On-Line configuration of any data acquisition computer station on the network from any display computer on the network.
- Configuration that permits flexible assignment of monitors to Keyphasor transducers, allowing the system to be configured on a machine train basis.
- A maximum of 512 points (all of which may contain dynamic data) per machine train.
- Automatic alarm notification to a display computer.
- Automatically freeze dynamic and vector alarm data associated with a particular machine train.
- User selectable trend intervals.
- Software alarm setpoints.

Data Manipulation and Archive

- Archive capability that allows you to conveniently store machinery data.
- Baseline and conditional baseline storage that lets you compare waveform data.
- Multiple graph queuing for unattended output to the printer

Bently Nevada Data Manager® 2000 Startup / Shutdown Features

The system installed at KCPL's Hawthorn Station will have the following features as a result of the startup / shutdown capable software:

- High resolution 1X/2X amplitude and phase static data, waveform data (on command and at instance of alarm), and automatically triggered startup/shutdown (SU/SD) data for post-transient analysis.

- Fast trend static data at four second resolution for all channels and waveform fast trend at 40 second resolution.
- Transient storage of up to 320 static samples (used for polar, Bode, and fast trend plots) and up to 32 waveform samples (used for cascade and waterfall plots) per channel in the communications processor.
- Storage of a maximum of 50 transient data file uploads per point.
- Startup or shutdown transient data acquired on a delta rpm basis through hardware and software selectable options.
- Automatic upload of transient data from a contact closure initiated startup or shutdown.
- Modification of startup and shutdown parameters "on the fly" (TDIX only)
- Storage for two delta rpm buffers (startup and shutdown) and one delta time buffer with 320 static samples and 32 waveform samples for each buffer (TDIX only).
- Necessary data available for Bently Nevada Engineer Assist software to perform an audit.
- Plots in Bode or polar format

Blade Temperature Monitoring System (BTMS)

Objectives of the EPRI Pyrometer System at KCPL's Hawthorn Station

- To develop a system to continuously monitor rotating blade temperature over many years of operation in a utility plant environment.
- Develop a non-intrusive monitoring system
- Develop a system to detect blocked blade cooling passages
- Utilize a system that allows for quick analysis of the data provided

The optical pyrometer system at KCPL's Hawthorn Station, will be responsible for collecting, monitoring and evaluating temperature data on the gas turbine's first stage blades.

The optical pyrometers collect thermal radiation emitted by the blade surface. The radiation is converted to a 4-20mA high frequency signal which is then sent to the

Blade Temperature Monitoring System for processing. The 4-20 mA signal contains thirty to forty temperature samples, taken uniformly along the blade surface, for each of the blades on the turbine stage being monitored. High speed signal processing electronics are able to extract the individual temperature samples and correlate them with the calibrated temperature range. A temperature "profile" can then be displayed for visual interpretation.

The optical pyrometer system can be extremely helpful to the gas turbine operator in identifying trouble in the hot gas path early enough to avoid a catastrophic failure. If any blades are experiencing temperatures out of line with the expected temperature, the blade temperature profile display will quickly identify the troubled blade or blades. Hot blades may result from blocked cooling passages, loss of blade coating, or other causes. Over the course of the three year program, three minute scans of the blade temperatures will be collected and permanently stored. Short term or long term trends of the blade temperatures can be displayed and analyzed to aid the gas turbine operator in determining the durability of the turbine blades and plan maintenance schedules accordingly.

Knowledge of cooled blade temperature is critical, since defects (restrictions) in the cooling passages of an individual blade may dramatically shorten the blades life. For example, moderate blade surface metal temperature increases of more than 100°F may cut blade life in half.

One of the most important areas to be monitored, in advanced gas turbines is the surface metal temperatures of the 1st stage rotating blades. Blade temperature is currently the limiting factor in advanced gas turbine design and development. By monitoring and studying the effects of the gas turbine operation on the turbine blades themselves, through the use of the optical pyrometers, more timely results are available.

Blade temperature data can also be trended simultaneously with other gas turbine parameters, including: load, ambient air temperature, exhaust gas temperature (Avg.), compressor discharge pressure and inlet guide vane angle. Trending these parameters alongside the blade temperature data will help the operator better understand how the turbine blades are affected by various conditions.

The following features characterize the Land Infrared BTMS:

- Modularity   Subsystem design simplifies deployment and maintenance
- Expandability   Single data processing unit field expandable to handle up to 6 turbines

- Reliability — Electronics separated from harsh turbine environment by a fiber optics link
- Ease of Use — Menu structured PC control for automatic or manual operation
- Compatibility — Tabular data can be used in any spreadsheet program accepting ASCII file format.

Below is a schematic diagram of the pyrometer system that was developed for this purpose.

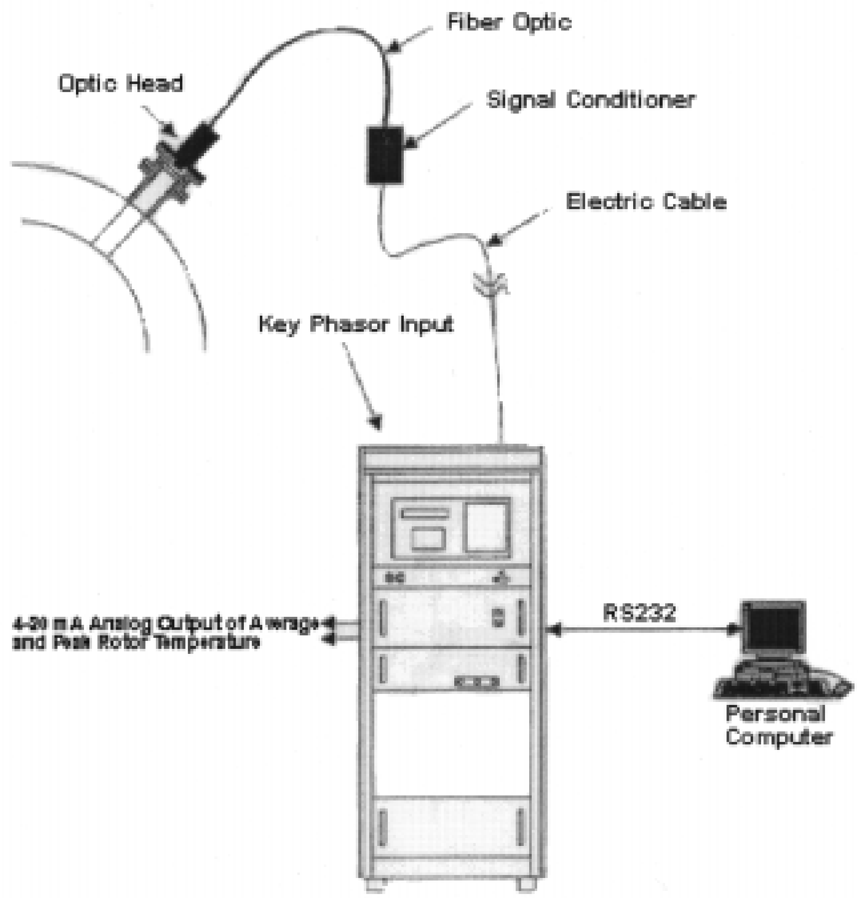


Figure 3-2
BTMS Schematic Diagram

Need for BTMS Monitoring

An increase in the use of cooled blades, in advanced industrial gas turbine units, has created new demands for turbine instrumentation. Without BTMS monitoring, calculation of blade temperature from exhaust gas thermocouple signals gives only a rough estimate of average turbine blade temperature. Such calculations do not provide data about metal temperature on individual blades.

Parsec Data Evaluation & Display System (DEDS)

The DEDS workstation for KCPL's Hawthorn Station, is being developed separately from the Optical Pyrometer Data Collection System. Parsec Automation was given the contract to develop a user-friendly, versatile GUI that could interpret the blade temperature readings and perform extensive analysis operations on the data. The DEDS utilizes National Instruments LabVIEW™ Software, the leading software for pure data acquisition applications. LabVIEW™ offers powerful data processing and analysis features in a functional, user-friendly GUI. The DEDS can access and display temperature data in both (near) real time and historically to multiple users, both local and remote.

The analysis features of the DEDS include:

- Indication of overall turbine blade temperature
- Indication of "hot" or "warm" turbine blades
- Long term historical trending of turbine blade temperatures
- Correlation of turbine blade temperatures with other turbine parameters (MW's, Inlet Temp., EGT, CDP, Hot Gas Temps.)
- Listing of ten highest peaks
- Temperature signature curve, for analysis of turbine performance changes.

The DEDS is designed to receive and display header and temperature data from the Pyrometer and the Turbine Data Acquisition Systems and store the information for display and archival purposes. Data can be displayed in tables or as trend graphs. The acquisition systems gather 3000 turbine blade temperature readings at three minute intervals throughout the day. The DEDS (utilizing LabVIEW™ software) creates near real time temperature profile trend displays for each turbine blade. Local and remote users can access and view a range of information and manipulate how the information appears in the display.

Predictive Maintenance

BTMS is also effective in predicting future failure or degradation of blade performance. It has the ability to store blade surface temperature data over long periods of time. By trending blade temperature data over time, small increases in blade surface temperatures (at similar operating conditions) can be indicative of blade related problems.

BTMS Technology Advancements Since 1992

EPRI ordered it first BTMS equipment for PEPCo's Station H in 1990 using the best available technology at this time. Many lessons have been learned since then including the following technology advancements:

- Optical pyrometer technology has advanced such that losses within the pyrometer have been reduced through utilization of advanced materials, making it possible to observe lower blade temperatures such as are observed in the second and third stages of the GE MS 7221 FA Turbine at FP&L's Martin Station.

- PC computing power and available software have advanced such that a more user friendly approach to data collection, analysis and display developed for future site applications and for possible retrofit to existing sites.

- Development and use of a "cold alignment tool" to align the pyrometer's line of sight after turbine outages when the pyrometers are re-installed. This alignment tool insures that the pyrometer scans the same area of the blade as before the outage and helps insure repeatability of pyrometer readings.

- Development of a "hot alignment tool" to better control the position of the blade scanned by the pyrometer. This tool will be able to remotely align the pyrometer's line of sight while the turbine is running. It will compensate for any shift due to growth of components inside the turbine.

With these tools an overheated blade can be quickly detected, enabling corrective action to be taken to prevent unnecessary and costly turbine damage.

Table 3-2
Specifications for the Pyrometer, Data Sampling Unit (DSU) and Data Management Unit (DMU)

Specifications for Pyrometer, DSU and DMU	
Optical Resolution:	200:1 typical
Fiber Optics Link:	High Temperature, flexible, ruggedize construction, 20 feet/ 6 meters long
Measurement Range:	1200 to 2000°F / 650 to 1100°C
Response Time:	5 Microseconds exponential time constant
Temperature resolution:	1°F / 0.5°C
Accuracy:	5°F / 2.5°C
Output:	4-20mA linear with temperature
Cable Length:	200 feet / 61 meters
Power requirement:	24VDC, 100 mA, supplied from DSU
Data Sampling Unit (DSU)	
Inputs:	Two (2) pyrometers and one (1) key phasors
Outputs:	(1) RS232C serial communications link (2) 4-20 mA signal linear with average temperature per pyrometer (3) 4-20 mA signal linear with peak temperature per pyrometer
Power Requirement:	110 VAC at 50/60 Hz, 10 Amps or 220 VAC at 50/60 Hz, 5 amps
Enclosure:	Modules designed to fit standard 19 inch rack mount (enclosure variants available)
Data Management Unit (DMU)	

The DMU comprises the following features as standard:

Pentium based Personal Computer running Land Turbine Software

Two RS232C serial communications ports

Mouse

DAS-16 analog input card

VGA Graphics

Modem

Results from previous Blade Temperature Monitoring

The application and operation of BTMS equipment has resulted in capturing data which has significantly altered the initial maintenance of several units. EPRI has actively detected irregularities on specific turbine blades, which provided very rewarding results to both the utility companies and to the gas turbine manufacturers to focus on a potential problem which could have causes a significant hat gas path outage.

4

PERFORMANCE RETENTION IN GAS TURBINE POWER PLANTS

Performance Retention and Degradation (Deterioration)

Overall gas turbine performance retention is dependent on how well the individual components of the gas turbine maintain their original performance characteristics referenced to the unit performance test and resulting Baseline Data. With the passage of time, the components in the turbine hot gas path and overall turbine flow path become fouled, eroded, corroded and covered with products of combustion, even with a good inlet air filtration system and when using a clean fuel such as natural gas.

The result is a progressive reduction in the ability of the compressor section of the gas turbine to convert mechanical energy into potential energy of the working fluid, or produce mechanical energy from the potential energy of the working fluid by the turbine. The mass flow of the working fluid through the engine may also be reduced as a result of the component deterioration. This, the original turbine output and heat rate are not fully retained over time, resulting in output and heat rate degradation.

Overall turbine performance degradation is defined as either recoverable or non-recoverable by washing and cleaning. There is still a possibility to recover the non-recoverable degradation by a major overhaul and engine upgrade as described below:

- **Recoverable Performance Degradation** is caused by compressor and turbine fouling and deposits and can recovered by washing/cleaning of the compressor and turbine.

- **Degradation Non-recoverable by washing and cleaning**. Performance restoration can be achieved by performing turbine overhaul in addition to the simple washing or cleaning techniques. It is defined as non-recoverable degradation (by washing), which is nonetheless partially recoverable during Hot Gas Path Inspection when the upper shell of the turbine and/or compressor is removed and the air and the hot gas path is accessible for thorough cleaning and for replacement of worn or defective parts.

- **True Non-recoverable Degradation** or permanent degradation may exist in gas turbines and may be difficult to be restored by conventional Hot Gas Path or Major Inspection. Overall gas turbine uprate may be required to restore this type of degradation and typically result in performance increase compared to new and clean baseline conditions.

The following provides a background on the various mechanisms that are responsible for overall (gas turbine) and individual (component) performance degradation (deterioration):

Degradation - Recoverable by Washing/Cleaning

Even with an excellent air filtration system a gas turbine (compressor and turbine) is still susceptible to ingestion and accumulation of particulate matter such as dust, pollen and other impurities. Over a period of time this leads to significant fouling of the flow path as well as blockage of the air filter. Oil leaks into the compressor and heavy hydrocarbons, when present in the atmosphere, can act as a glue to attach the dust particles to the compressor airfoil and shroud to further increase the fouling problem. In advanced gas turbines such as the Siemens V84.3A machine, where the pressure ratio is relatively high, the higher temperatures in the back end of the compressor may thermally crack the oily substances to form a fairly thick coating on the surfaces.

When a heavy oil stream is burned in a gas turbine, the hot end of the turbine is also subjected to deposits originating from the metals contained in the oil as well as any fuel additives.

The build up of material results in fouling which changes the inlet angle, increases the surface roughness, and decreases the throat opening of the airfoil. Since as much as two-thirds of the power developed in the turbine is consumed by the compressor of advanced gas turbines, the effect on the gas turbine performance is most significant. On the other hand, these turbines employ coatings on the compressor airfoil surfaces which makes the blades smoother and reduces the fouling rate as well as making them easier to clean.

Fouling of the compressor and turbine flow path surfaces causes varying degrees of individual component performance degradation (such as decreases in the efficiency and gas flow rate) resulting in overall gas turbine output and heat rate degradation over a period of time. Fouling is the single most predominant cause for gas turbine performance deterioration, typically 70 to 80 percent of the loss.

The compressor surge margin may also be reduced as a consequence of the fouling of the flow path.

The compressor and turbine may, however, by cleaned to remove the deposits by various "washing" techniques without having to disassemble the engine. The following are three techniques for washing:

1. **On-line Dry Cleaning**: This technique consists of introducing abrasive material such as rice husks or pecan shells into the suction of the compressor of the gas turbine. This method has been used in the past on the gas turbines with un-cooled blades and is not recommended for the advanced gas turbines with intricate cooling schemes and channels, which could be plugged by the abrasive materials.

2. **On-line Wet Cleaning**: Water mixed with a non-toxic and non-flammable detergent is utilized to accomplish washing of the compressor. In areas with high concentration of ambient particulates, methods using fine spray of de-mineralized pure water (without detergent) have been used with success in daily on-line water wash. This had allowed the operators to maintain performance with the gas turbine running, without the need to shut the machine down for off-line soak wash.

3. **Soak Wash**: This method is employed with the engine shut down and results in the most thorough cleaning of the compressor and the hot-end components.

Degradation - Recoverable from Icing

Another form of recoverable degradation is the icing of the air filter or the front end of the compressor. The resulting performance deterioration could be more severe than due to fouling, but is usually temporary in nature unless the compressor is damaged by the ice particles breaking loose or due to a severe reduction in the air flow through the compressor leading to compressor surge.

Degradation - Non Recoverable by Washing/Cleaning

This type of deterioration may be caused by erosion of the blade surfaces by ingested particulate matter and damage to the compressor and turbine flow path due to corrosion caused by ingestion of substances such as salt and airborne chemicals, including smog.

Particles greater than 20 microns are usually responsible for erosion and may cause:

- changes in the inlet metal angle, profile and throat opening of the airfoils
- increased blade tip and seal clearances; and
- increased surface roughness

The hot end of the turbine, consisting of the combustion system, turbine and exhaust diffuser, is also subjected to erosion and corrosion caused by any metals, such as alkalis, vanadium and lead or their compounds, which may be encountered when firing heavy oil, or in the fuel additives. Even with a clean gaseous fuel such as natural gas, hot end component corrosion may be expected due to surface oxidation resulting in the forming of rough scale.

Increases in the tip and seal clearances may also be caused by the ingestion of particulates leading to reduced performance. This form of deterioration may not be recovered by washing/cleaning techniques.

The performance of the gas turbine may be recovered during an overhaul when:

- any distortion of the cylinder causing an eccentricity in clearances and thus the corresponding increases in the leakage path;
- erosion or corrosion of the compressor disks and annulus surfaces causing roughness of the flow path, and;
- distortion of the platforms resulting in a decrease in the aerodynamic performance and increased leakage. The non-recoverable deterioration, however, is normally quite small.

There are, however, methods available to recover this permanent degradation. Since the replacement of the parts causing this permanent degradation is not practical due to their cost, it is possible to uprate the entire machine with the state of the art components, which would allow higher firing temperature. Such (and similar) upgrades are typically performed after several years of operation when the new materials and technologies (such as blade cooling) afford the manufacturers and owners to perform a major plant uprate with major commercial/financial benefits resulting.

Miscellaneous Components

If leakage of the bleed valve or the flange and horizontal joint occurs, gas turbine performance will not be maintained. Components such as the gearbox, generator and auxiliaries over time, also lose their initial performance and contribute to the overall loss in gas turbine performance. The contribution of these miscellaneous components towards the overall gas turbine performance deterioration is generally quite small.

References

1. Diakunchak, I. S., "Performance Deterioration in Industrial Gas Turbines," Transactions of the ASME, Vol 114, April 1992.

2. Flashberg, L.S., "Measurement of Combustion Turbine Non-Recoveralbe Degradation," ASME Paper No. 92-GT-264.

3. Lakshminarasiha, A.N., et. al., "Modeling and analysis of Gas Turbine Performance Deterioration," Transactions of the ASME, Vol. 116, January 1994.

5

TESTING OF SIEMENS V84.3A INSTALLED AT KCPL'S HAWTHORN STATION

The V84.3A utilizes advances in the aero-engine technology in the heavy duty design to increase the efficiency an output of the engine. Based on designs from Pratt and Whitney, Siemens developed new aerodynamic blading designs, blade cooling and used new blade manufacturing and coating methods, which allowed them to increase the turbine inlet temperature to 2,390°F (1310°C).

Such inlet temperature coupled with the advanced compressor design yields simple cycle thermal efficiency of 38%, LHV Heat Rate of 8,980 Btu/kWh (9472.6 kJ/kWh) and output of 170 MW for the V84.3A. Exhaust flow is 1,000 lb/sec (454 kg/sec) and emissions of less than 25 ppm NO_x are expected.

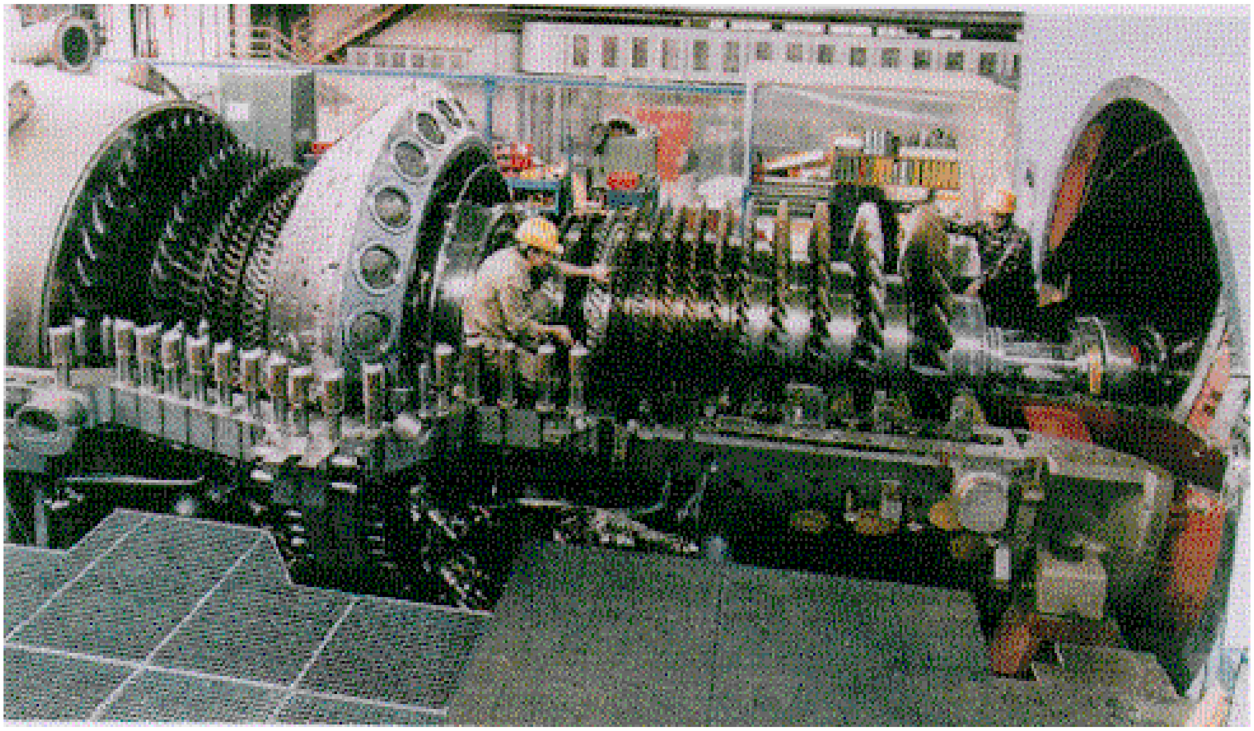


Figure 5-1
Siemens V84.3A Prototype

Gas Turbine Full-Load Tests

In December of 1994, this first V84.3A gas turbine reached an output of 170MW on the test stand. Full load testing was performed over the last years in this facility to develop high-temperature gas turbines. The water friction brake of the test stand can handle more than 180 MW at 3600 RPM.

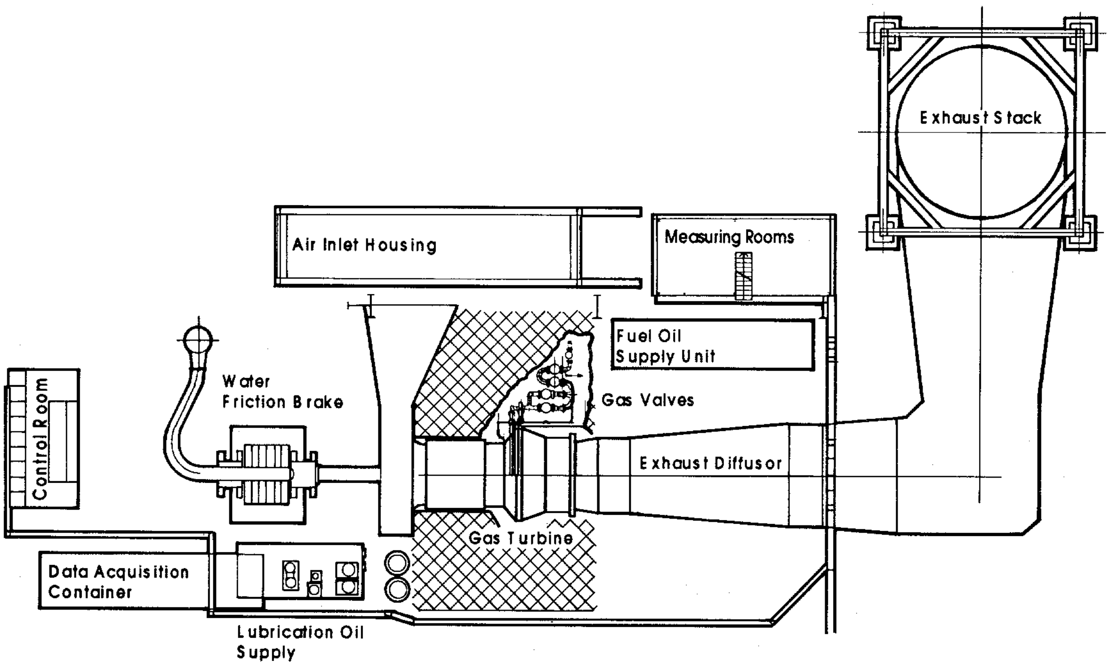


Figure 5-2
Full Load Test Facility

Testing of the Siemens Model V84.3A Gas Turbine

There are several prime objectives to the engineering of current heavy-duty industrial gas turbines.

- High efficiency
- Low emissions
- High reliability and availability
- Low specific cost through power density
- High Turbine inlet and outlet temperatures

Most power generation customers are looking to long term operation at the plant site as the real test, however, they are also looking to obtain the benefits of rapid innovation and of the improvement of machine performance. This can be accomplished on manufacturers test beds under abnormally severe conditions. Siemens makes it a practice to test each model of a new series in this manner.

Siemens utilizes a dedicated facility to conduct these tests at the Berlin Gas Turbine plant. (See **Figure 5-3**) This test facility provides the space and infrastructure necessary for the extensive instrumentation that is necessary to carry out and monitor the testing procedures and associated data analysis.

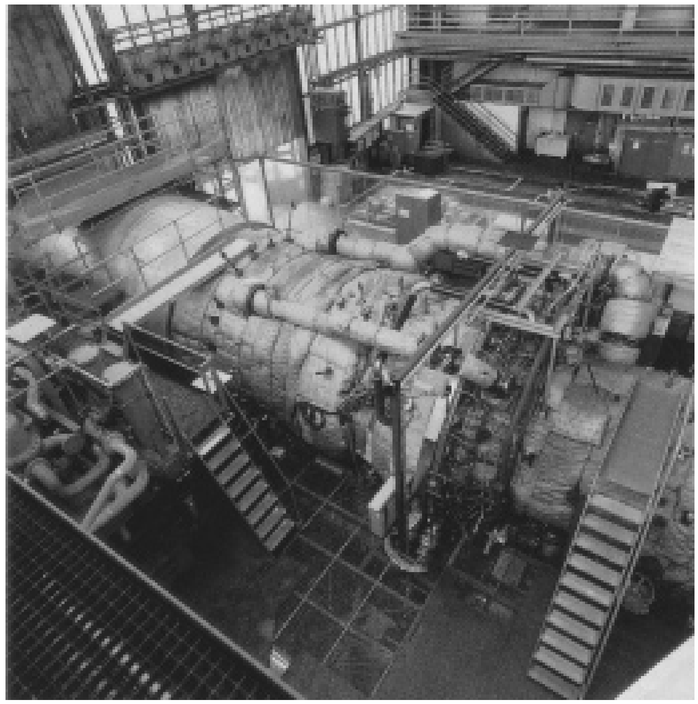


Figure 5-3
The prototype V84.3A undergoing tests in Berlin

The prototype test program is typically structured as follows:

1. Commissioning (Fuel: Natural Gas)

2. Performance test at base load

3. Verification of safe operation

   — Speed variations assure low stresses in the blading throughout the operating range

   — Tip clearance measurements verify running clearances

   — Turbine vane and rotor blade temperature measurements verify proper cooling

4. Combustion optimization on natural gas

5. Commissioning for operation with light heating oil, combustion optimization

6. Optimization of oil operation, oil starts

7. Detailed measurements of component performance, e.g. flow field measurements in the compressor and the turbine and mapping of the surge line.

Detailed measurements of component performance show that the overall efficiency was attained by close attention to component design such as the aerodynamics or the cooling design discussed above and consequently high component efficiencies.

Component optimization in the prototype machine is based on detailed instrumentation, some of which is implemented in a novel fashion. Examples are fast-moving optical pyrometer probe for the mapping of vane temperatures from up-stream and the installation of thermocouples with close attention to geometry in regions of high temperature gradients in turbine vanes.

Measuring results are validated based on redundant measurements:

- blade vibrations by strain gages and optical techniques
- radial tip clearances by contact sensors and abrasion pins
- blading temperatures by optical pyrometer and thermocouples

This test facility permits testing the machine throughout and beyond the permissible operating range, primarily by varying the rotational speed over a wide range at loads up to base load with the water friction brake. Thereby, the test bed provides more severe operating conditions than encountered during typical power plant operation in a short period of time. This benefits the customer by providing proven technology despite fast innovation.

Hawthorn Unit #6 Commissioning Tests

The following geometries have been tested during the Commissioning Phase of this project.

Fuel Oil

- Siemens fuel oil nozzles, with and without water injection via the central lance.
- Parker-Hannifin (P-H) 60°, with and without water injection via the central lance.
- Parker-Hannifin (P-H) 95°, with and without water injection via the central lance -24 x 1.3.
- Parker-Hannifin (P-H) 95°, with and without water injection via the central lance -24 x 1.3 - plus using the pre-mix oil nozzles.
- Parker-Hannifin (P-H) 95°, with H_2O lance - 36 x 1 @ 5° included angle.

Results

- No major advantage between P-H and Siemens fuel nozzle. Unit has been changed back to original Siemens nozzle and original H_2O lances @ 24 x 1.3.
- Bet results (NO_x, Humming) seem to be with a mix of central lance and pre-mix nozzle water injection.
- As of 10/97 this yields 80-90% load at ~42ppm NO_x.

Equipment Modifications

- TLa 1 - TLa 4 Seal Air Plates
- Flow orifices in axial portion of the burner (similar to the arrangement in Berlin)
- Rebuild pre-mix oil burner for water injection. Added H_2O line to inject H_2O through fuel oil pre-mix nozzles, as well as the standard H_2O lances. A mixture of H_2O flow to the two injection points was tried.

Planned Modifications

- Replacement of TLe 1 and TLa 1 Blade Rows
- Upgrade of TLe 1 Cooling Filter Air Tubes
- Install Pyrometer Sight Tube

Fuel Gas Testing

- Fuel Gas, diffusion, dry
- Fuel Gas, diffusion, with water injection
- Fuel Gas, pre-mix, dry
- Fuel Gas, pre-mix, with water injection

Results

- Base load achieved with diffusion, dry.
- Humming occurs when water is injected.
- Base load achieved with pre-mix, dry, at very low pilot gas flows
- Further optimization scheduled.

KCPL's Hawthorn Station Unit #6 Milestones

Table 5-1
KCPL's Hawthorn Station Unit #6 Milestones

Civil contractor at site, begin piling	8/13/96
Generator arrives at site	10/16/96
Combustion turbine arrives at site	01/11/97
Fuel Oil available	06/20/97
First Fire (FSNL)	06/27/97
Synchronized	07/02/97

Base load (Oil, diffusion Burner, Dry):	09/29/97
Fuel Gas Available	8/18/97
Base Load (Gas, Diffusion Burner, Dry)	9/16/97
Base Load (Gas, Pre-mix, Dry)	10/21/97

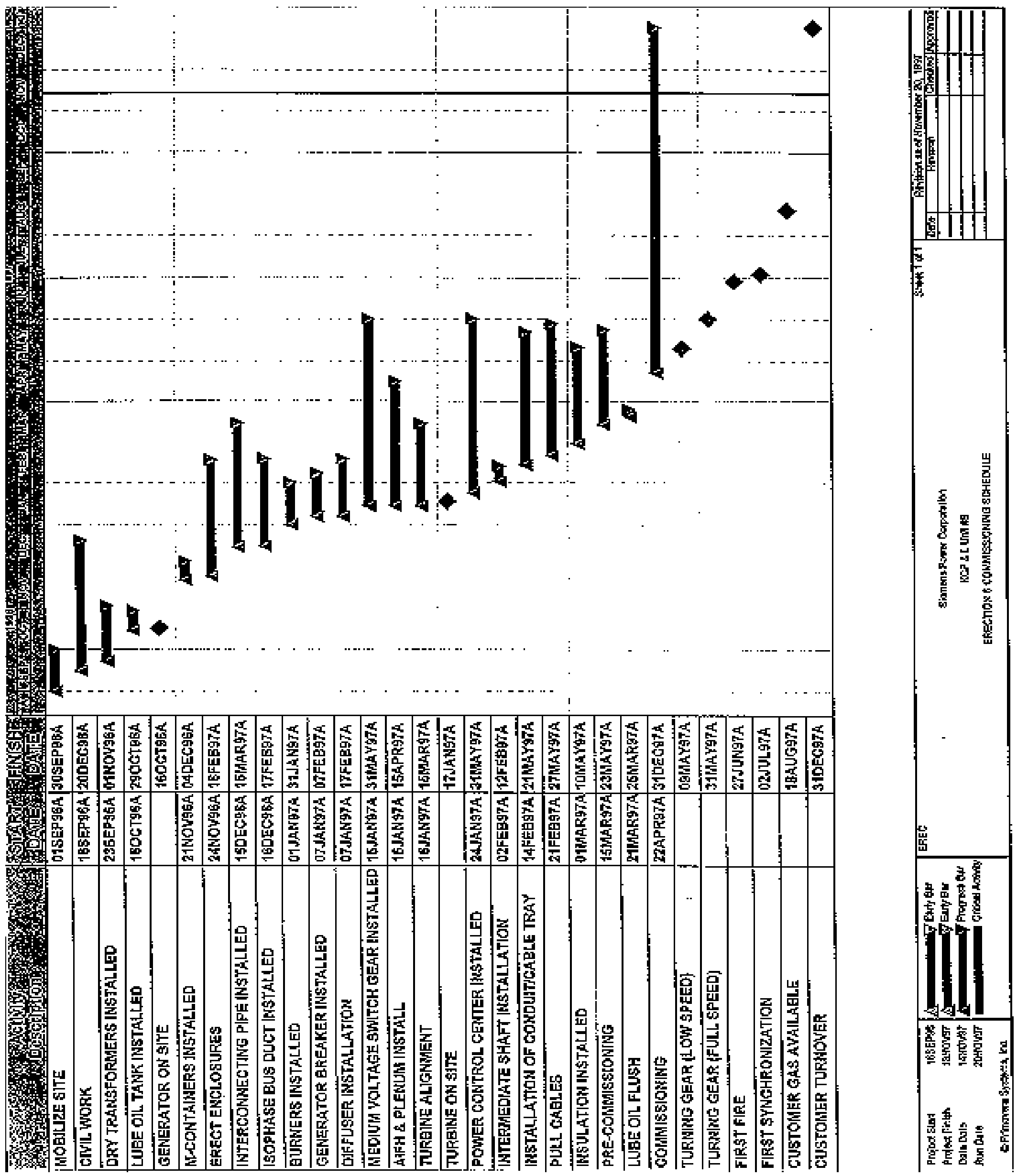


Figure 5-4
Siemens Power Corporation, KCPL's Hawthorn Station Unit #6, Commissioning Schedule

Conclusion

After the successful testing of the first V84.3A gas turbine, it arrived at the Hawthorn Station on January 11, 1997 to be assembled with the already supplied generator and synchronized clutch. Because of the already available full-load gas turbine test data including an efficiency in excess of 38%, it is expected that the simple cycle plant will perform as expected. Installation and start-up of the gas turbine plant preceded to meet the requirement for generating summer peak capacity. Initial operation began as listed above in **Table 5-1**.