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First V84.3A Gas Turbine Installation at Hawthorn Station

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Abstract

The first V84.3A gas turbine as tested at the full-load test facility of the Siemens gas turbine factory in Berlin, Germany has now been installed at the Kansas City Power & Light (KCP&L) Company's Hawthorn Power Station. The unit will be started in spring of this year and is scheduled to be available in June for the 1997 summer peak.

In times when active power is not in demand, the generator can be operated as a synchronous condenser. For this mode of operation, a synchronous clutch has been installed between the gas turbine and the generator.

The advanced V84.3A gas turbine has been chosen because of its high simple cycle efficiency based on the measured 38% in the test facility, providing peaking capacity with a minimum on fuel costs. In addition, later conversion to highly efficient combined cycle operation can easily be performed without the need for external air or even steam cooling systems.

Introduction

Hawthorn Power Station History

The Hawthorn Power Station became the first large power plant of KCP&L to satisfy the growing demand for electricity in the late 1940's. Located nine miles northeast of downtown Kansas City at the Missouri River, it occupies a 550 acre site. The first two coal-fired steam units #1 and #2 were ordered in 1948. Both 66 MW non-reheat units went into commercial operation in 1951. Further increasing demand for electric power required ordering more efficient reheat steam turbine units in 1950 and 1953 rated at 100 MW each to be available for commercial operation in 1953 and 1955, respectively.

In 1965, KCP&L announced their then largest single project by installing a 500 MW reheat steam unit at the Hawthorn Station site. When this unit #5 went into operation in 1969, it increased KCP&L's capacity by 50%.

Hawthorn Station V84.3A Gas Turbine Project

On February 8, 1995 a contract was signed to install the first V84.3A gas turbine at the Hawthorn Station site.

After the units #1 through #4 were retired in 1982, unit #5 generated only 450 MW/500 MVA at the Hawthorn site. The demand for more capacity led to an upgrade of the steam cycle of this unit to generate power in excess of 480 MW. During peak demand in the winter and even more in the summertime, unit # 5's maximum capacity was not suffcient and became limited by its generator's apparent power capacity (MVA Rating).

Therefore, the decision was made to install a V84.3A gas turbine for supplying additional peaking capacity for about 500 hours per year to cover both the summer and winter peak demand. In addition, a synchronous clutch will allow the gas turbine generator to operate as a synchronous condenser for about two months in the winter and three months in the summertime, producing a maximum of 83 MVAR apparent capacitive power for supporting the system, in particular allowing unit #5 to operate at full-load without its generator limiting the maximum capacity of this unit.

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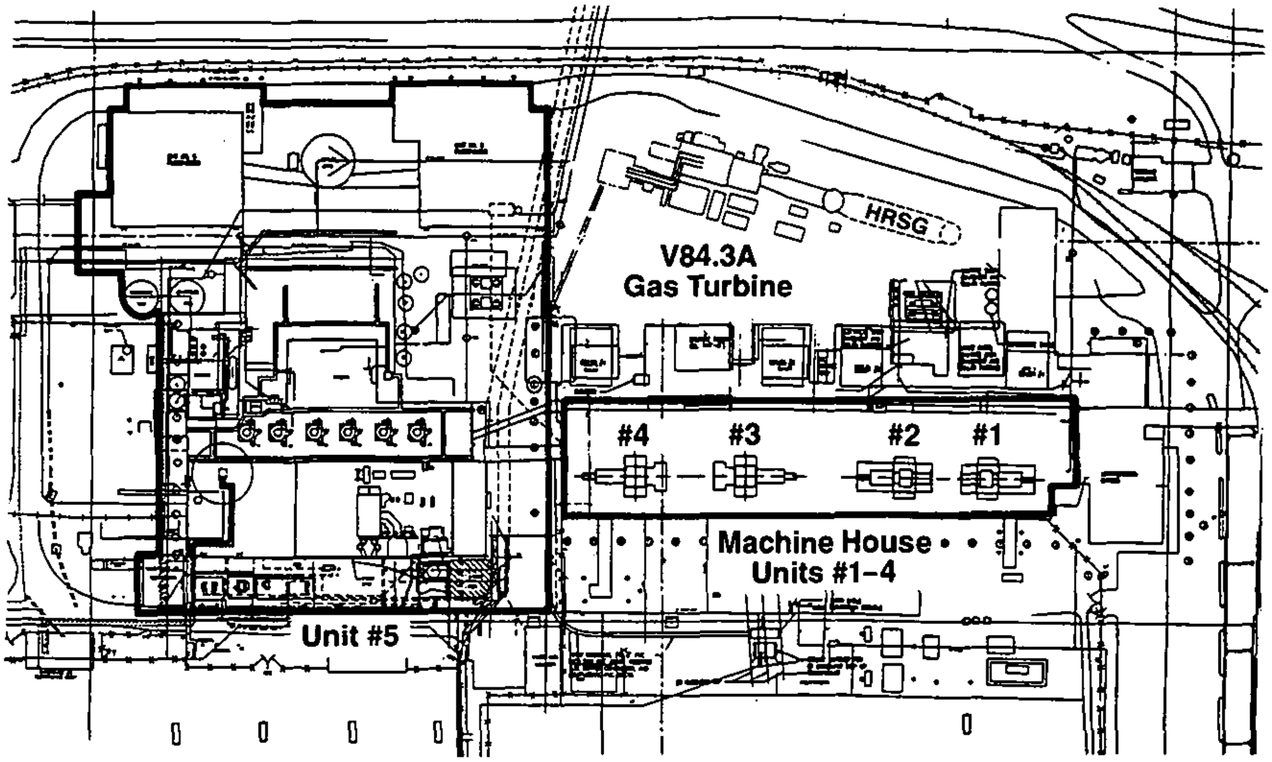


Figure 1. Hawthorn Power Station Layout

V84.3A Gas Turbine Site Arrangement

With Hawthorn units #1 through #4 being retired but not demolished, selecting the proper arrangement of the gas turbine became important. Shown in **Figure 1** is the arrangement of the V84.3A unit indicating that also the space for installing a heat recovery steam generator (HRSG) would be available. There is even sufficient space between the unit #1 through #4's old machine house and the V84.3A gas turbine to install a second gas turbine after demolishing some of the old boiler equipment.

The 100 MW size steam turbine of unit #4 could be rebuilt and used for repowering[1]. Another option would be supplying a new steam turbine to optimally match the steam conditions of one or two new HRSG's. Such a steam turbine could be installed into the old machine house after removing unit # 1 and #2 steam turbine[2].

V84.3A Gas Turbine

The first V84.3A gas turbine is shown in **Figure 2** leaving the gas turbine factory to be shipped to the Hawthorn Station[3&4]. This unit was developed as the most advanced gas turbine featuring an aero-engine derived flow path designed by Pratt & Whitney and Siemens under a long-term technology exchange agreement signed in 1988.[5]

Figure 3 shows how the compressor flow path design of the V84.3 gas turbine was changed into the V84.3A compres-

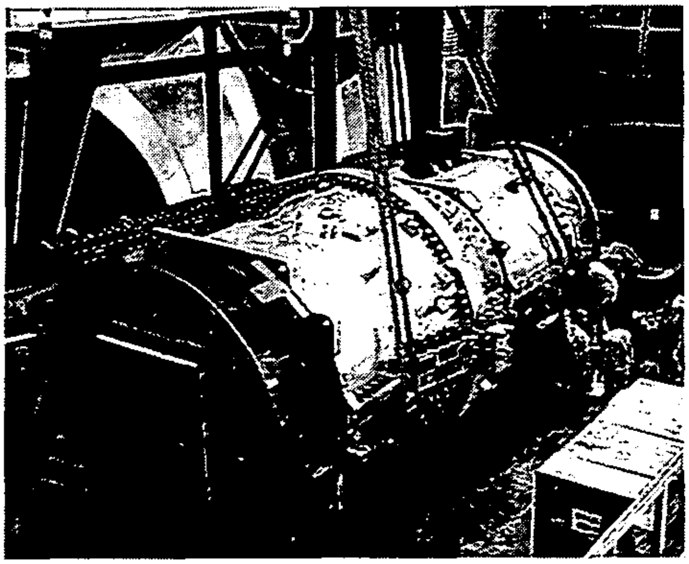
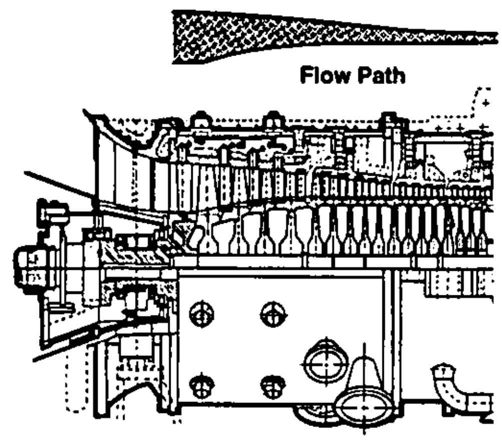
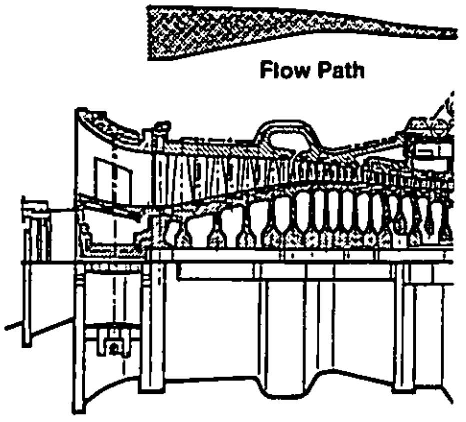


Figure 2. First V84.3A Gas Turbine Ready for Shipment



V84.3
Compressor Section



V84.3A
Compressor Section

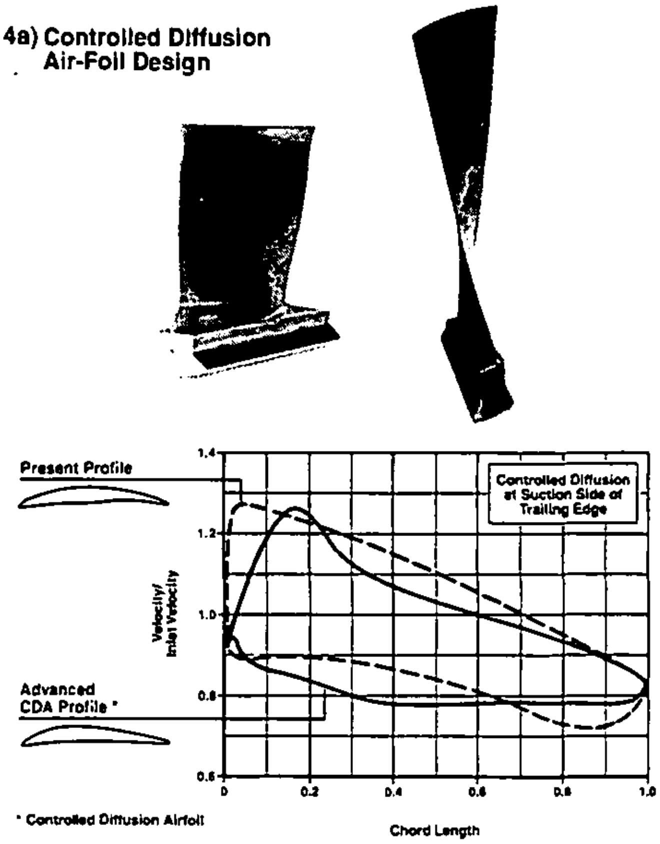
Figure 3. Comparison of Compressor Flow Path Design

sor design. The 15-stage compressor of the V84.3A unit has been designed for about the same flow capacity and pressure ratio as the 17-stage compressor of the V84.3 machine. However, a steeper increase of the curved inner diameter contour at about the first five stages was adopted providing a larger sum of circumferential rotating blade velocity, which consequently permits the reduction of compressor stages without having an adverse effect on performance.

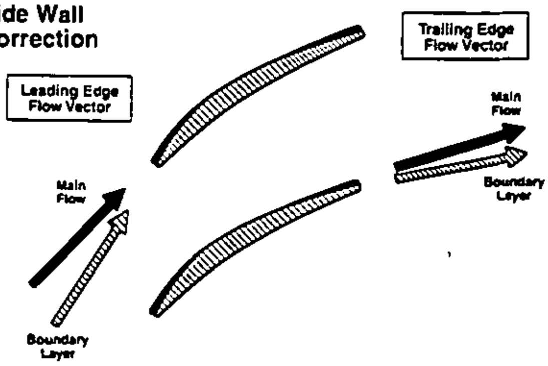
For the three-dimensional compressor blade profiles, illustrated in **Figure 4**, controlled diffusion air-foil design as applied earlier for the V84.3 first stages of rotating blades was now used for designing the entire compressor flow path (4a). This technique provides a higher level of stability during deceleration of the flow and a thinner boundary layer on the suction side of the compressor blade profiles.

In addition, this figure shows the side wall correction for the stationary compressor blading at the hub and blade tip

4a) Controlled Diffusion
Air-Foil Design



4b) Side Wall
Correction



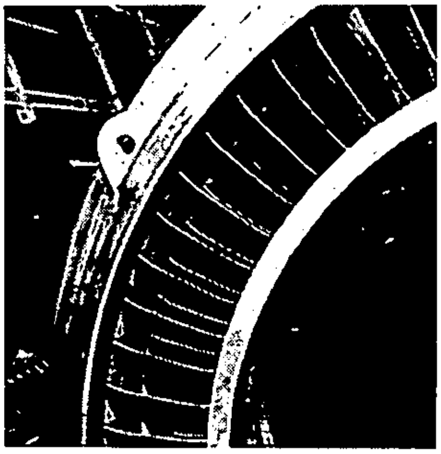


Figure 4. Compressor Flow Path Design

sections (4b). 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. By reducing the flow at the vicinity of the hub and blade tip, boundary losses are minimized.

The turbine design has been adopted from the previous Siemens 4-stage design concept. However, more sophisticated blade cooling technique as well as metallurgical advances such as single crystal blading have been applied. With the exception of the last stage rotating blades, all turbine stationary and rotating blades are air cooled.

Cooling air is provided at different pressure and temperature levels from compressor extractions to provide the best possible cooling effect and at the same time achieve optimal unit thermal performance. Flow straightening profiles in the turbine exhaust section are supplied to reduce exhaust losses.

The high-performance blading of the 4-stage turbine section is illustrated in **Figure 5**. Free-standing blades are utilized in all stages to provide optimal flow conditions without any disturbance caused by dampening or shroud members. Also illustrated in this figure are the four stages' stationary blades. The turbine blading is designed for improved performance due to the minimization of any turbulent boundary zone and to provide a low entry velocity at the leading edge pressure side of the blade with continuous increase of the flow acceleration. All blades are designed for reliable long-term operation with the most efficient blade profiles.

Figure 6 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. Extensive film cooling is used to improve the cooling efficiency and to eliminate the need for an external first stage cooling air intercooling system. The applied high temperature blade design technology has been proven in aircraft engines operating at much higher firing temperatures.

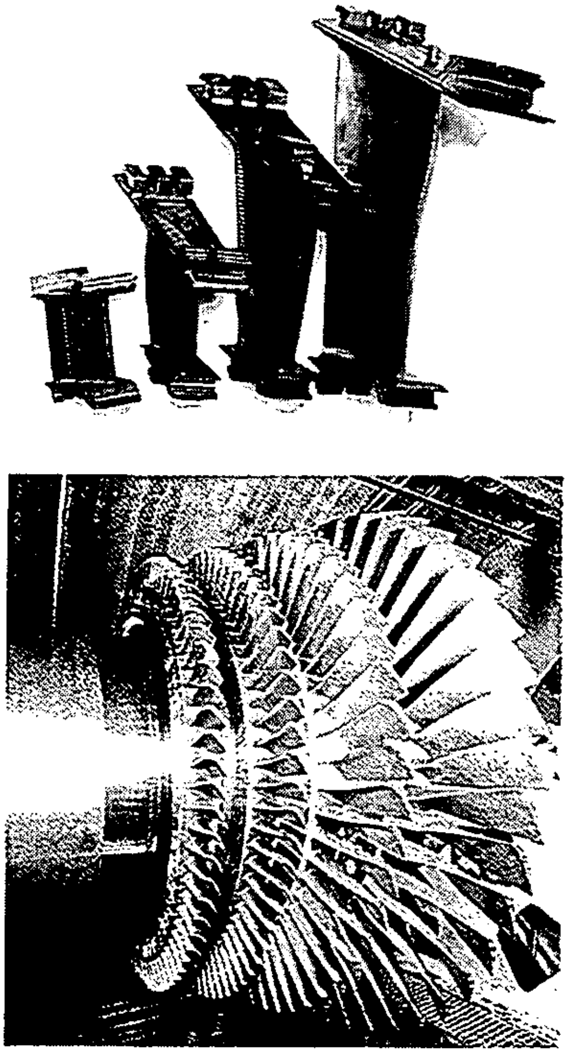


Figure 5. Four-Stage Turbine Blading

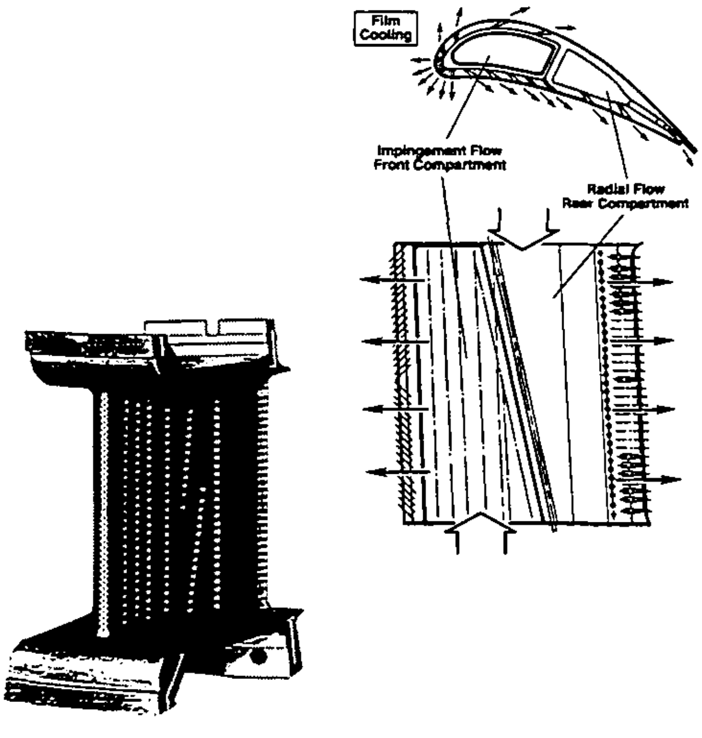


Figure 6. First Stage Stationary Turbine Blade

Hybrid Burner Ring (HBR™) Combustor

The HBR combustor with its 24 hybrid burners, illustrated in **Figure 7**, combines all the advantages of optimal combustion, including:

- High efficiency combustion
- Low NO_x and CO emissions
- High operating flexiblity
- Minimum cooling air demand
- Fully symmetrical design utilizing a small variety of tiles
- Optimal size and number of burners
- Compact design with good accessibility
- Optimal circumferential temperature distribution
- Multiple fuel capability

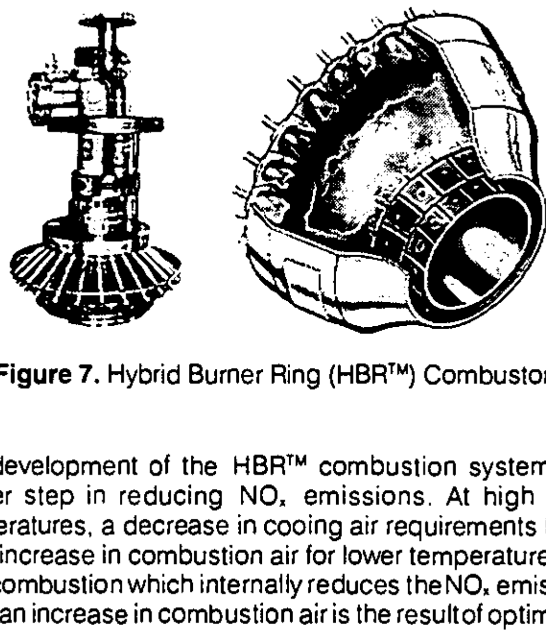


Figure 7. Hybrid Burner Ring (HBR™) Combustor

The development of the HBR™ combustion system is a further step in reducing NO_x emissions. At high firing temperatures, a decrease in cooing air requirements leads to an increase in combustion air for lower temperature permits combustion which internally reduces the NO_x emission. Such an increase in combustion air is the result of optimizing the cooling air system. Heat shield pads are cooled by jet impingment which requires only a minimum amount of cooling air being taken from the compressor discharge flow.

Based on extensive hybrid burner experience and test results from the full-load test facility, NO_x emissions of less than 25 ppm when burning natural gas is expected[5&6].

The HBR™ combustor provides excellent accessibility. Two manholes are easily opened, and a full inspection of all high-temperature components as well as maintenance work can be performed. **Figure 8** illustrates the inspection of one of the 24 burners.

Gas Turbine Full-Load Tests

In December of 1994, this first V84.3A gas turbine reached an output of 170 MW on the test stand, shown in **Figure 9**[7].

Figure 8. Inspection of Burner in HBR™ Combustor

Full-load testing was performed over the last years in this facility to develop high-temperature gas turbines. The water friction break of the test stand can handle more than 180 MW at 3600 rpm. **Figure 10** reveals the steps taken to full-load test the .3 and .3A-Series gas turbine models over a period of approximately three years, starting with test of the V84.3 gas turbine with a flow path developed by Siemens[8]. The next step was to introduce within the same envelope dimensions of the outer casing the flow path design jointly developed by Pratt & Whitney and Siemens which was installed and initially tested with horizontally arranged cylindrical combustion chambers.[9]

The last test series was performed with the latest development of the HBR™ combustor. This testing has been successful in supporting the extensive development work to build reliable advanced gas turbines. The efficiency of 38% was already confirmed during the initial test with HBR™ combustors in December of 1994. For reliable long-term operation, measurements of gas turbine blade temperatures and stress levels are of highest importance. Since full-load testing was performed, actual data under most severe operating conditions even with rated speed deviations were collected.

Redundant measurements of blade temperatures were performed by thermocouples and infrared pyrometer sensor, providing a solid base of information about blade surface temperatures, temperature distribution and the proper function of the blade cooling. The data from the test facility, when compared to the originally calculated expected data, were in close agreement.

Redundant measurement of dynamic blade stressing by strain gages and optical dual-probes also showed good agree-

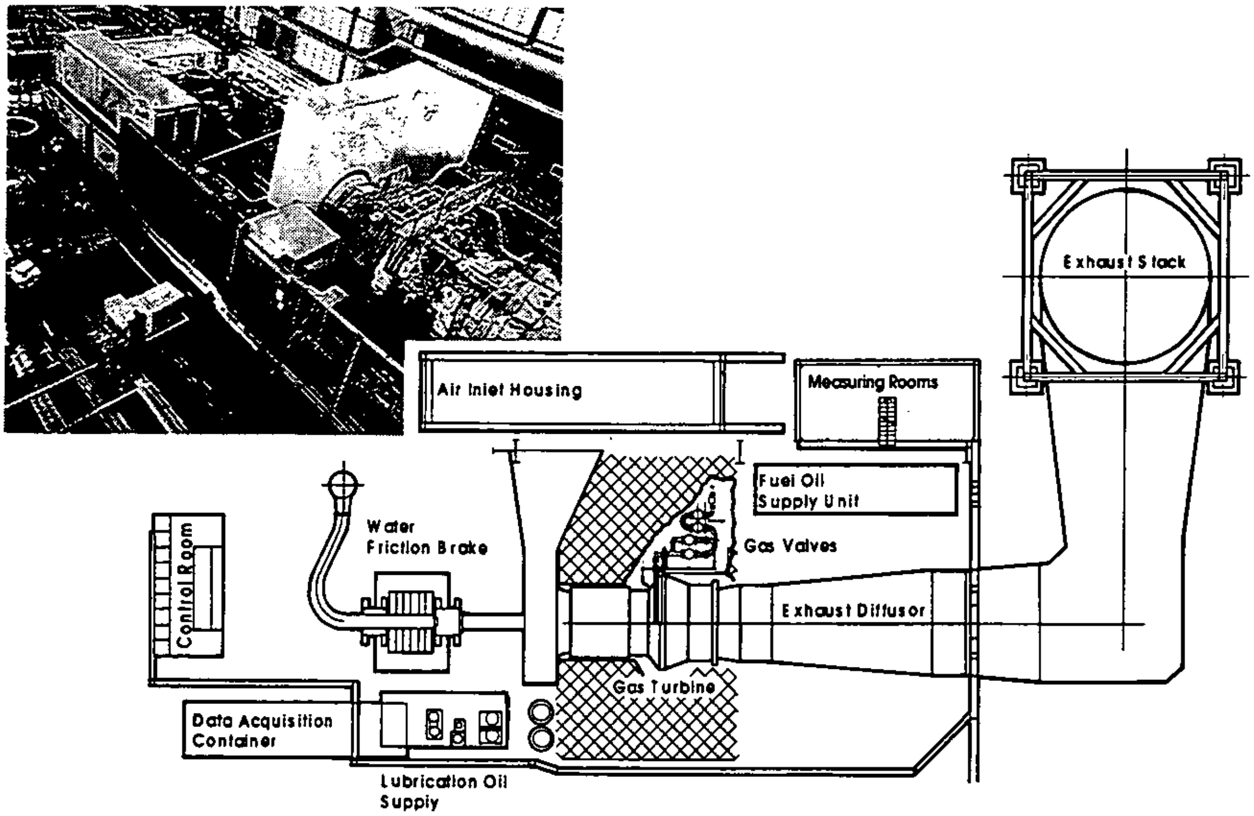
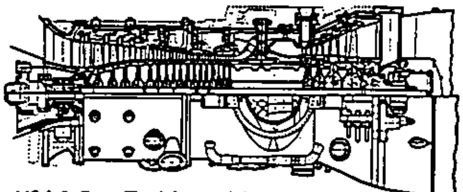
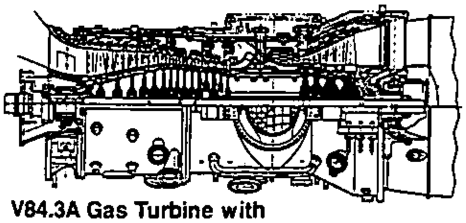


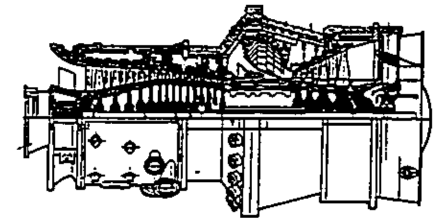
Figure 9. Full-Load Test Facility



V84.3 Gas Turbine with Cylindrical Combustion Chambers



V84.3A Gas Turbine with Cylindrical Combustion Chambers



V84.3A Test Gas Turbine with HBR Combustor

Figure 10. V84.3A Gas Turbine Full-Load Test Sequence

ment with the calculated expected stress levels. **Figure 11** shows that the dynamic stressing under full-load conditions in all four turbine blade rows are below 22% of the permissible dynamic stress level.

To gain further long-time insight into the V84.3A gas turbine operating behavior, an agreement has been signed to perform a Durability Surveillance test program with EPRI, which will include an infrared pyrometer measurement of the first stage turbine blade temperatures.

Air-Cooled Generator

The air-cooled 200 MVA / 16 kV generator has been lifted from the railroad car onto the foundation at the Hawthorn power station by a hydraulic gantry lift as illustrated in **Figure 12**[10]. The complete generator was the heaviest piece to be handled at the site.

The generator is designed for a power factor of 0.85 and 170 MW output at a cold gas (air inlet) temperature of 40°C (104°F); operating within Class B insulation limits [acc. to ANSI]; however, Class F insulation is provided. The capacity diagram in **Figure 13** reveals the generator operating capacity under various operating conditions. The maximum capacity changes with the cold gas temperature. As shown, the capacity increases at 10°C (50°F) to 242 MVA.

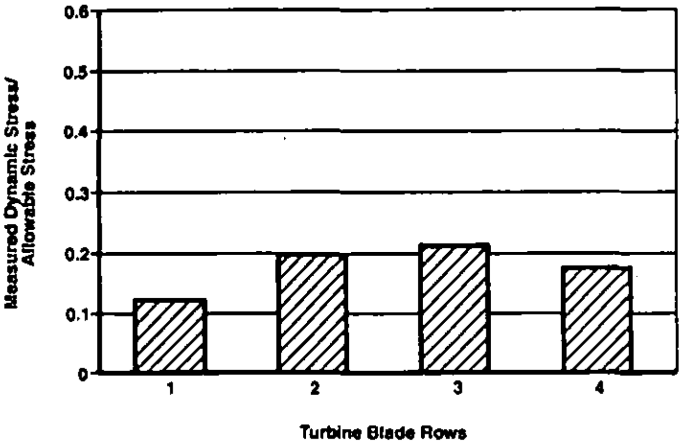


Figure 11. Measured Dynamic Loading of Rotating Turbine Blades

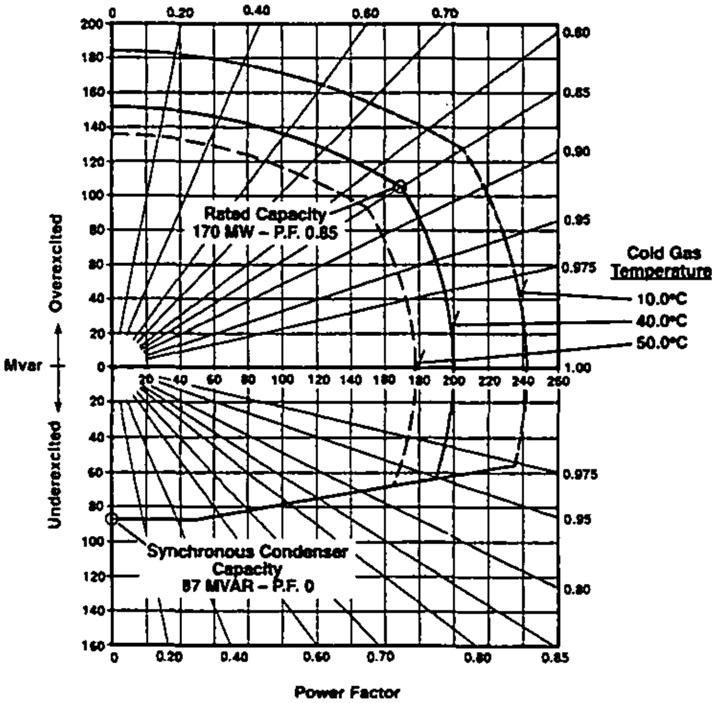


Figure 13. Reactive Capacity Curve

With the selected direct cooling system, the air inlet temperature for the gas turbine and generator is the same. Both the gas turbine and generator following a decrease in inlet temperature by an increase in their maximum output. The generator capacity diagram also reveals the operating range for the generator operating in a synchronous condenser mode. When under excited and operating without active power at a power factor of zero, the apparent capacity of the generator is 87 MVAR.

The internal generator design is shown in **Figure 14**, providing an optimal cooling scheme for both the stator and rotor without any local hot spots. The arrangement of single-stage compressor fans on each side of the rotor ideally supplies cooling air into multiple flow paths of the stator and rotor. Air filters are installed upstream of the generator air intake

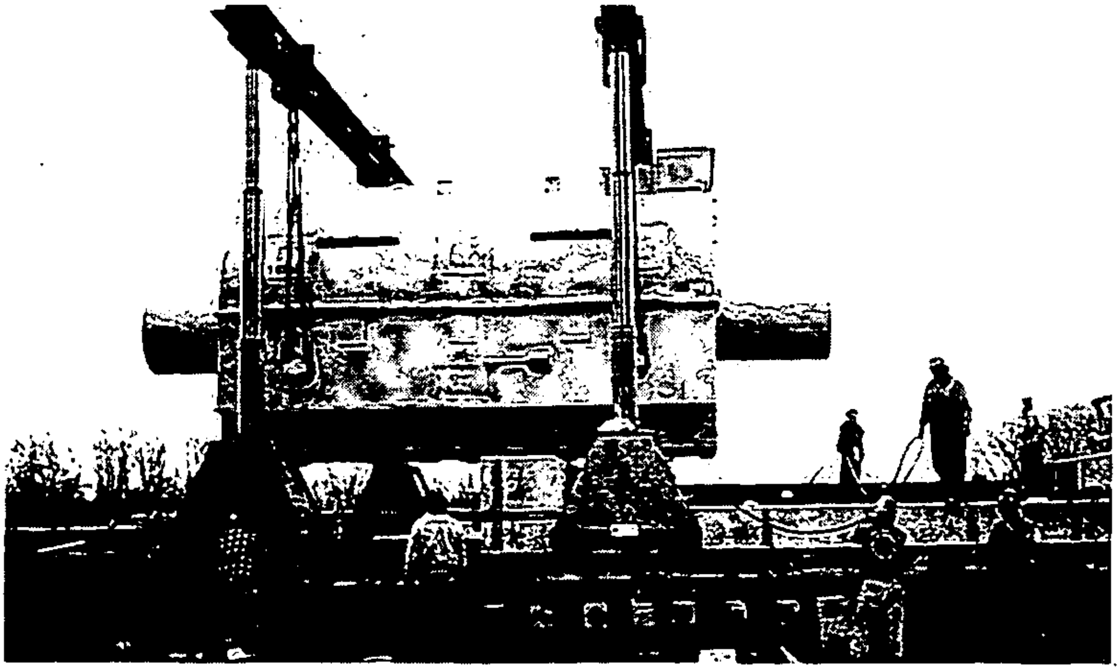


Figure 12. Lifting of Generator onto Foundation

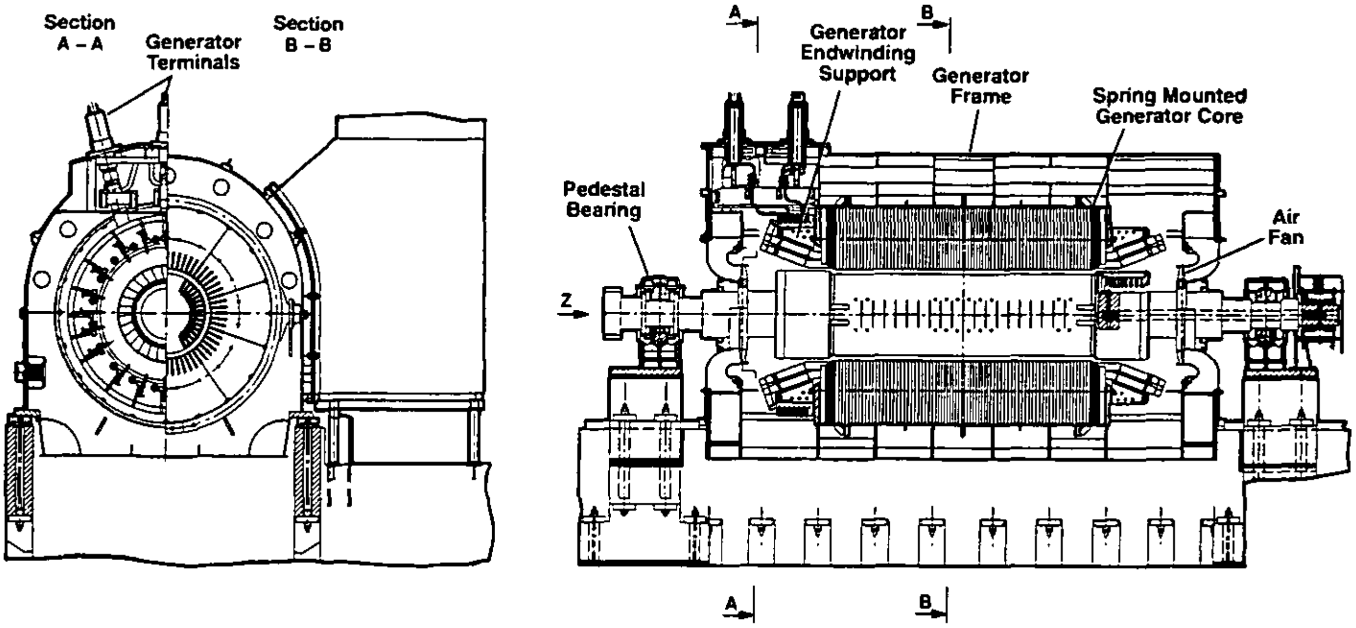


Figure 14. Air-Cooled 200 MVA Generator

to avoid contamination of the generator internals.The active generator core is assembled into the lower housing after it was VPI-treated. This vacuum/pressure impregnation (VPI) process is performed in the vacuum chamber and oven shown in **Figure 15** providing a protective layer over the total winding assembly and the laminated iron core of the generator, making it extremely resistant against any environmental influence. MICALASTIC® insulation is used, which has proven unchanged high quality insulation performance for decades in generator windings for any rating and under most severe site conditions worldwide.

Synchronous Clutch

For the first time in the U. S., a large heavy-duty gas turbine will be equipped with a synchronous clutch for operation of the generator as a synchronous condenser. For this mode of operation, the generator has to be synchronized to the grid, motoring at rated speed. Such operation of the generator can only be performed with the turbine being disconnected from it. The clutch shown in **Figure 16** is installed between the gas turbine and the generator to allow the following modes of operation to be performed:

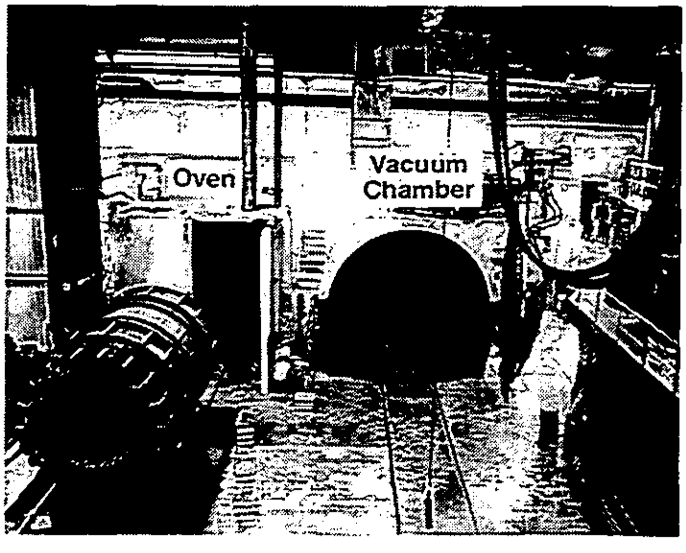


Figure 15. Generator Impregnation Facility

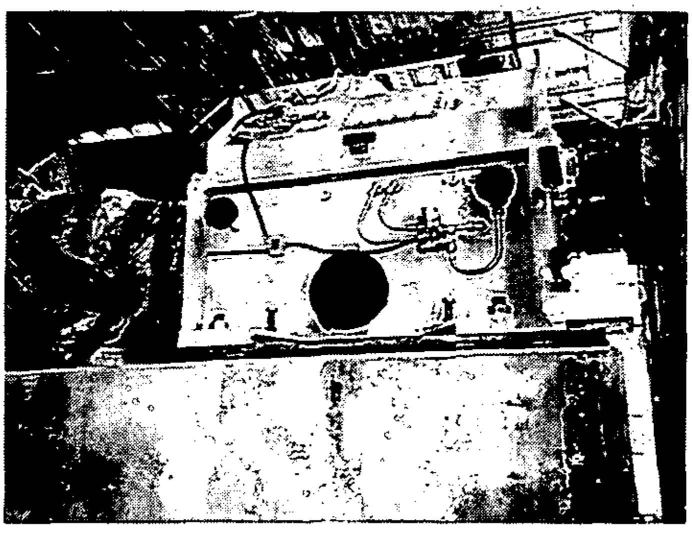


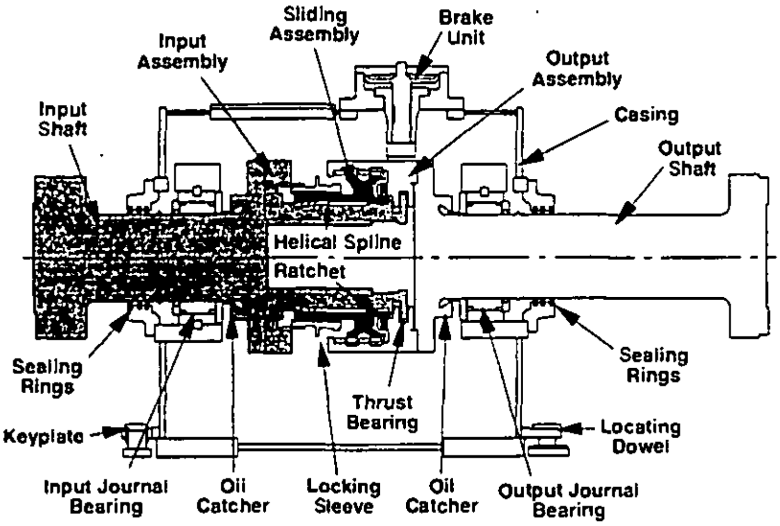
Figure 16. Synchronous Clutch Installation

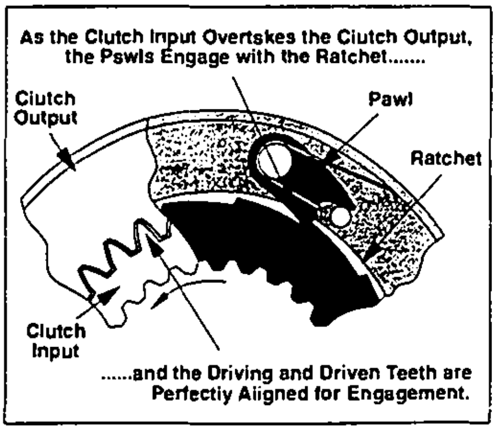
- Gas turbine and generator run in unison during load operation
- Generator operates as a synchronous condenser at rated speed and turbine runs at turning gear speed
- Start-up of gas turbine driven by generator and frequency converter
- Shut down of gas turbine and generator in unison or gas turbine only

For performing these functions, a synchronous clutch of the SSS Clutch Company has been selected, featuring an automatic engagement and locking system as shown in **Figure 17**, assembly drawing 17a.[11] The automatic engagement system consists of a helical splined stub shaft and an axially moving bushing with two rows of teeth for the clutch engagement as well as the ratchet and pawl system matching the clutch engagement teeth (17b). This mechanical system automatically engages the clutch whenever the turbine speed tries to exceed the generator speed. This function is performed by the helical sliding assembly moving from the disengaged to the engaged position.

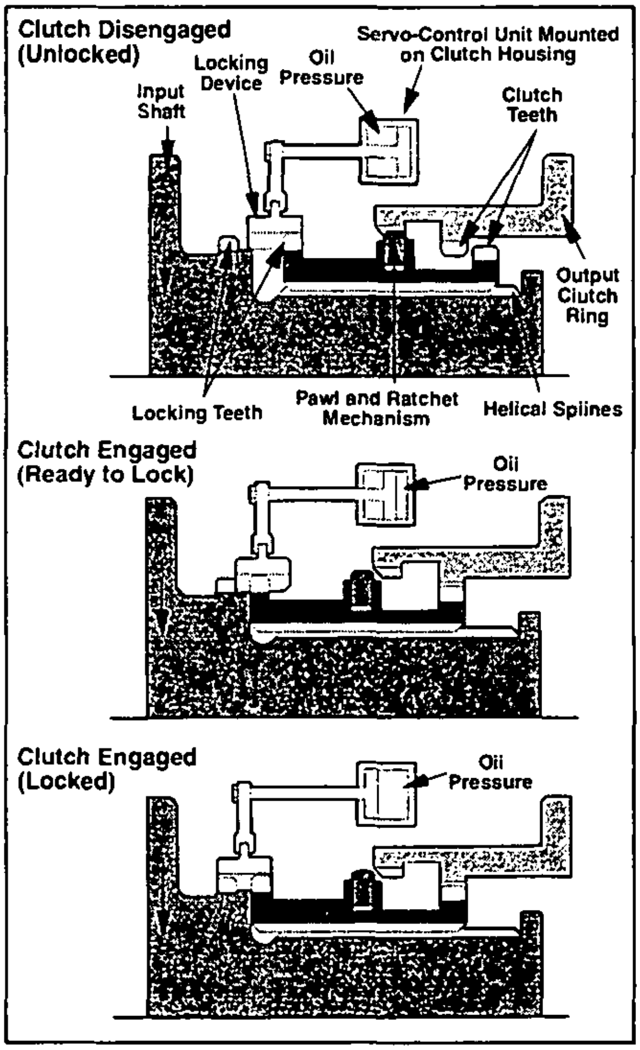
For unit start-up with the generator and its frequency converter driving the turbine, the clutch must be locked by the hydraulic locking system (clutch engaged and locked). This automatically controlled hydraulic locking is not needed for normal load or synchronous condenser operation. The various functions of the clutch are illustrated below (17c). Before the clutch can automatically disengage, it must first be

17a) Assembly Drawing





17b) Clutch Teeth Alignment



17c) Modes of Operation

Figure 17. Synchronous Clutch

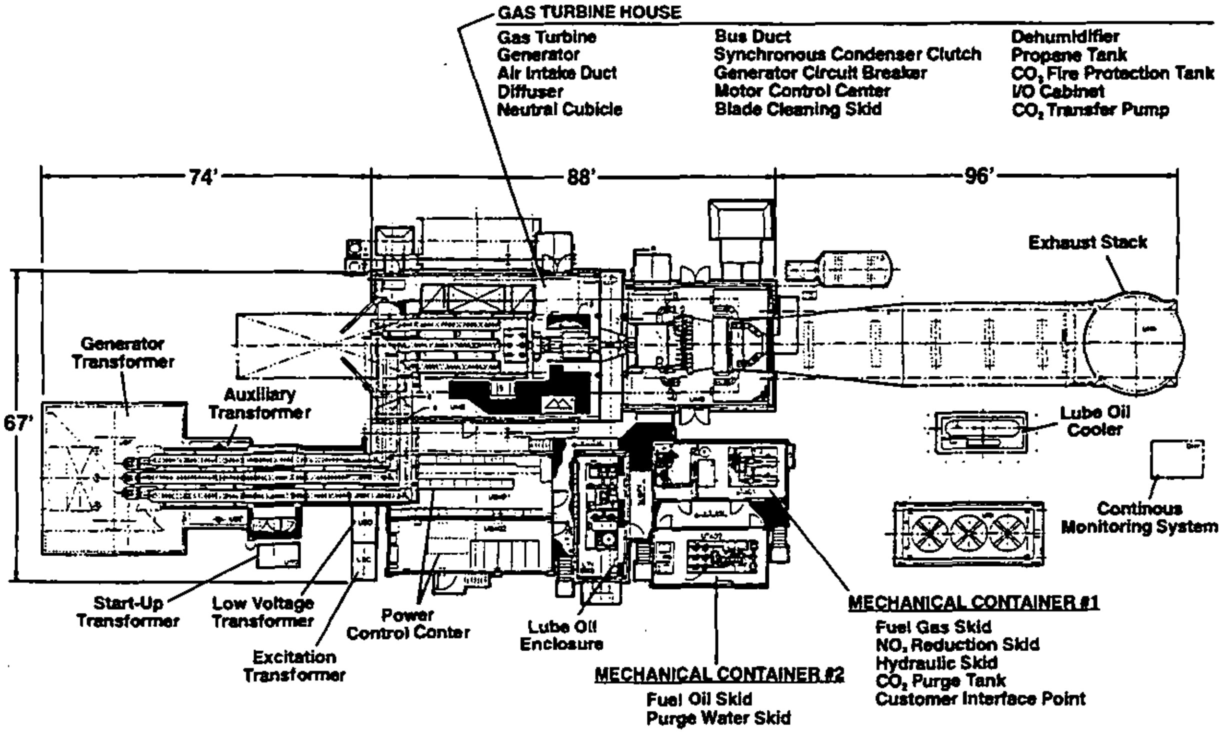


Figure 18. V84.3A Gas Turbine Arrangement

unlocked. For changing from synchrounous condenser operation to positive power operation, the generator has to be brought down to turning gear speed. To accellerate this process a brake unit is provided. After locking the clutch at turning gear speed the gas turbine can be started up by the generator and its frequency converter.

Both clutch stub shafts are supported by tilted pad journal bearings and the generator stub also features a thrust bearing. Relative axial movement between the turbine and generator stubs is therefore not possible in any clutch operation mode.

V84.3A Simple-Cycle Plant Layout

The V84.3A simple cycle plant arrangement drawing of **Figure 18** shows the gas turbine-generator with all its auxiliaries from the stack to the transformer. The various auxiliary systems are pre-assembled and pre-tested in containers ready for interconnection and start-up.

Fin-fan lube oil coolers are provided and together with the direct air-cooled generator arrangement, they eliminate the need for any cooling water supply.

A 206-foot tall stack has been installed. Its transition duct connects to the gas turbine diffuser.

Conclusion

After the successful testing of the first V84.3A gas turbine, it has 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 will proceed to meet the requirement for generating summer peak capacity. Initial operation should start in springtime to optimize operation under various operating conditions including synchronized condenser operation of the generator.

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