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Maintenance and Inspection of the Gas Turbine PGT25 DLE

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بسم الله الرحمن الرحيم

Dedications

I dedicate this thesis to …

Dear mom ♥ ,
Dear brothers ,
my beautiful sisters ,
All members of my family, young and old,
Everyone who studied me and contributed to my education.

Khalil Takieddine.S

Acknowledgment

Grace and praise to **ALLAH**, first and foremost, who guided me to accomplish this work.

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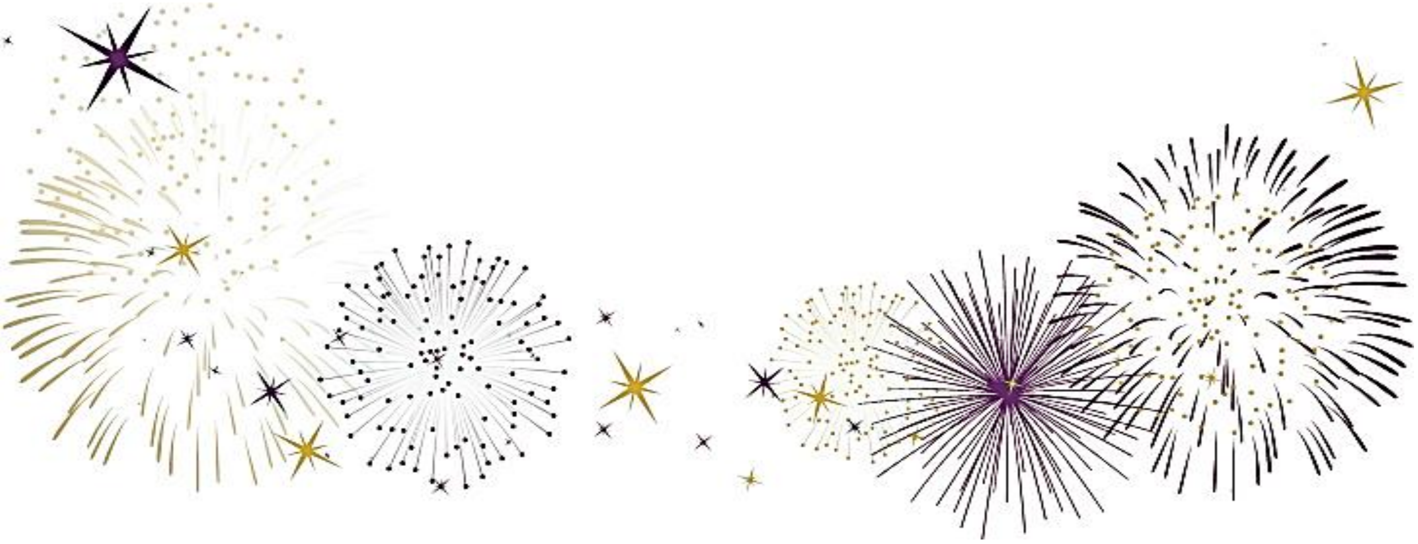

Maintenance and Inspection of the Gas Turbine PGT25 DLE

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Abstract

Reliability and efficiency of industrial gas turbine in different applications considered as challenge, it is important to design a maintenance program using all available maintenance tools, such as the borescope. The beroscope inspection is one of the most important inspections that proved to be effective to know the internal situation of different parts without the need for disassembly. The case study we took in this work is an inspection of the aerodirivative gas turbine PGT25 DLE used in mechanical drive application, includes a LM 2500 gas generator and power turbine, equipped with new technology Dry Low Emission combustor DLE. We conducted an inspection of all parts of the gas turbine through some holes dedicated to it; after inspection, we found some issues and damages in some parts. We should understand these issues, damage, and know their causes in order to limit or minimize the expected risks and damages, which lead to loss of the machines and operators. There are many factors that must be taken seriously; one of the most important factors of all is the combustion process. Talking about the combustion process means dealing with two main factors: fuel gas and air or oxygen, and each one have characteristics that must be respected to avoid any problem.

Keywords : Gas Turbine, Maintenance, Borescope Inspection, Fuel Gas, Combustion Chamber.

Maintenance et Inspection de la Turbine à Gaz PGT25 DLE

Auteur : Khalil Takieddine SOUID **Encadreur :** Dr. Abderrahmane BELLAOUAR

Résumé

La fiabilité et l'efficacité des turbines à gaz industrielles dans différentes applications considérées comme un défi, il est important de concevoir un programme de maintenance utilisant tous les outils de maintenance, tels que le borescope. L'inspection au borescope est l'une des inspections les plus importantes qui se sont révélées efficaces pour connaître la situation interne de différentes pièces sans nécessiter de démontage. L’étude de cas que nous avons suivi dans ce travail est une inspection de la turbine à gaz aérodirivante PGT25 DLE utilisée dans les applications d’entraînement mécanique, y compris un générateur de gaz LM 2500 et une turbine de puissance, équipée de la nouvelle technologie de combustion sèche à faibles émissions DLE. Nous avons effectué une inspection de toutes les pièces de la turbine à gaz par le biais de trous lui étant dédiés. Après inspection, nous avons trouvé des problèmes et des dommages dans certaines parties. Nous devons comprendre ces problèmes, les dommages et en connaître les causes afin de limiter ou de minimiser les risques et les dommages attendus, entraînant la perte des machines et des opérateurs. De nombreux facteurs doivent être pris au sérieux. Le processus de combustion est l’un des facteurs les plus importants. Parler du processus de combustion signifie traiter de deux facteurs principaux : le gaz combustible et l'air ou l'oxygène, et chacun présente des caractéristiques qui doivent permettre d'éviter tout problème.

Mots clés : Turbine à Gaz, Maintenance, Inspection du Borescope, Gaz Combustible, Chambre de Combustion.

صيانة وفحص التوربين الغازي PGT25 DLE

المشرف: د. بلعور عبد الرحمان

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ملخص

موثوقية وكفاءة توربينات الغاز الصناعية في تطبيقات مختلفة تعتبر تحديًا، من المهم تصميم برنامج صيانة باستخدام جميع أدوات الصيانة المتاحة، مثل.بوروسكب borescope. التفتيش بالبوروسكوب هو واحد من أهم عمليات التفتيش التي يتم إجراؤها لتكون فعالة. دراسة الحالة هي فحص لتوربينات الغاز الهوائية PGT25 DLE المستخدمة في تطبيق القيادة الميكانيكية، وتشمل التوربينات الغازية LM 2500 وتوربينات الطاقة، ومجهزة بتقنية Dry Low Emission combustor DLE. لقد أجرينا فحصًا لجميع أجزاء التوربينات الغازية من خلال بعض الثقوب المخصصة لها؛ بعد التفتيش، وجدنا بعض القضايا والأضرار في بعض الأجزاء. يجب أن نفهم هذه القضايا، والأضرار، ومعرفة أسبابها من أجل الحد من خطر الإصابة. هناك العديد من العوامل التي يجب أن تؤخذ على محمل الجد؛ أحد أهم العوامل على الإطلاق هو عملية الاحتراق. الحديث عن عملية الاحتراق يعني التعامل مع عاملين رئيسيين: الوقود والهواء أو الأكسجين .

الكلمات المفتاحية: توربينات الغاز، الصيانة، فحص بوريسكوب، غاز الوقود، غرفة الاحتراق.

Nomenclature

CPF Central Processing Facility

FCP First Calgary Petroleums

CAFC Central Area Field Complex

HC Hydrocarbon

HHV High Heat Value

LHV Low Heat Value

LPG Liquefied Petroleum Gas

MLE Menzel Ledjmet East

SH Sonatrach

NGL Natural Gas Liquid

GG Gas Generator

CRF Compressor Rear Frame

CRFV Compressor Rear Frame Flange Accelerometer

DLE DLN Dry Low Emissions (NOx)

°C Degrees Centigrade (Celsius)

°F Degrees Fahrenheit

CDP Copressor Discharge Pressure

CFF Compressor Front Frame

FOD Foreign Object Damage

GT Gas Turbine

Hg Mercury

HP High pressure

HPT High Pressure Turbine

HPC High Pressure Compressor

kW Kilowatt

IGB Inlet Gearbox

OGV Outlet Guide Vane

OAT OUT Side Temperature

NPT Power Turbine Speed

PT Power Turbine

NOx Oxides of Nitrogen

P0 Gas Turbine Inlet Pressure

TMF Turbine Mid Frame

Ti Compressor Inlet Total Temperature

T3 Compressor Discharge Temperature

atm Standard Atmosphere

VSV Variable Stator Vane

VG Variable Geometry

EMU Engine Maintenance Unit

TOB Time between overhauls

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SUMMARY

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Chapter III: PGT25 Dry Low Emission Aeroderivative Gas Turbine Engine Description

Chapter IV: Maintenance of gas turbine engines

Chapter V: Borescope Inspection Results and Discussion

General Introduction

Many countries in the world rely on fuel economy, especially the third world countries to meet their needs, including the country of Algeria.

To ensure the smooth of transportation of these fuels, this requires the presence of turbines with high efficiency and periodic follow-up maintenance of the equipment and intervention in the case of failure or any defect .

Among these maintenances, the periodic inspection that includes the Borescope that can reaches all parts of the turbine, making it easier to discover the infected parts.

The combustion gas turbines, as with any rotating power equipment, require strict and periodic maintenance and inspections in order to ensure availability, efficiency and high performance within the limits of safety, with repair and replacement of parts to achieve optimum availability and reliability.

The parts that are unique to the gas turbine, because of this feature, are combustion chambers, liners and transition pieces. These, along with the turbine nozzles and buckets, are referred to as the "hot-gas path" parts. The inspection and repair requirements of the gas turbine lend themselves to establishing a pattern of inspections, starting with very minor work and increasing in magnitude to a major overhaul, and then repeating the cycle [1].

One major asset of the aero-derivative industrial engine is the borescope capability built into the design. Borescoping facilitates inspection of critical internal parts without disassembling the engine. Complete borescoping of the aero-derivative engine can be accomplished in some hours. These inspections can be optimized to reduce unit outages, and maintenance cost for the users specific mode of operation, while maintaining maximum availability and reliability. Inspections can be classified as operational or shutdown. The operational inspections are used as indicators of the general condition of the equipment and as guides for planning the disassembly maintenance program.

There are no provisions for borescoping the heavy industrial gas turbine. The heavy-industrial units must be disassembled for all inspections. The inspection and replacement of the fuel nozzles, combustor, and transition duct of a heavy industrial gas turbine with 10 to 12 can-annular combustors takes more hours than Aero-derivative gas turbine [2].

Some very resourceful field technicians have developed techniques to borescope the compressor, combustor, first stage turbine nozzles, and all different parts of the aero-derivative gas turbine trough access holes are provided. These provisions, consisting of many holes through the casings and internal stationary shrouds, have been designed to allow the penetration of the optical borescope probe through sections of a non-operating turbine for visual observation of the rotating and stationary parts without removing the turbine or compressor upper cases [2].

The major components of a gas turbine engine are the compressor, combustor and the turbine. At start up, air is sucked in the compressor by an auxiliary source, the air is pressurized and raised in temperature by the compressor and is introduced in the combustor where it is mixed with fuel and burned. The hot combustion gases then enter the turbine where they expand causing the turbine to rotate and generate mechanical work. The mechanical work is used in turn, to drive compressor and other components on the engine. This severe conditions of work especially the parts of combustor, Requires taking some precautions especially with fuel qualities.

The problems discussed in this study, and the photographs used, are taken from actual aeroderivative gas turbines PGT25 DLE and other new models equipped with new type of combustor called a Dry Low Emission (DLE) combustor has emerged as a reliable and effective design for reducing pollutant emissions. All gas turbines have at one time or another, experienced these or similar problems. Therefore, the reader is cautioned not to conclude that a particular problem is associated only with a specific gas turbine model or manufacturer [1].

In this study, we try to analyze the various images taken during the borescope inspection of the stationary and rotating parts of aeroderivative gas turbine to understand the general state of the machine, understand the various issues and damage that occurred in different parts of gas turbine. Then trying to figure out the factors causing the damage and work to find appropriate solutions in terms of: firstly the efficiency and secondly the costs.

Our project is composed of five chapters: the first chapter is devoted to the description of MLE field, their properties, central processing facilities (CPF) and their process and utilities systems devoted to the treatment the different product of MLE, gas LPG condensate, oil in specification requested and with high equipment efficiency. In the second chapter, we will touch on bibliographic studies of gas turbine, and we present general information of gas turbines. In the next chapter, we talked in detail on aeroderivative gas turbine PGT 25 DLE, with main and auxiliary components. In addition, we describe the maintenance represented by borescope inspection; we have talked about it in detail. The last one, five chapter will be devoted to the photo taken by the borescope for the stationary and rotating components, results and their discussions including solutions proposed.

Chapter I: Menzel Ledjmet East Plant (MLE) Field Representation

Chapter I: Menzel Ledjmet East Plant (MLE) Field Representation

I.1 Introduction:

Oil & Gas industry is a vast industry and it fuels the whole world, oil is lifeblood of the industrialized nations Oil has become the world's most important source of energy since the mid-1950s, and is one of the most important raw materials we have. Its products underpin modern society, every day we use hundreds of things that are made from oil or gas.

Oil and gas wells produce a mixture of hydrocarbon gas, condensate or oil; water with dissolved minerals, usually including a large amount of salt; other gases, including nitrogen, carbon dioxide (CO_2), and possibly hydrogen sulfide (H_2S); and solids, including sand from the reservoir, dirt, scale, and corrosion products from the tubing. The purpose of oil and gas processing is to separate, remove, or transform these various components to make the hydrocarbons ready for sale. In this chapter, we describe Central Processing Facility (CPF) including utilities of Menzel Ledjmet East Plant (MLE).

I.2 Field description:

I.2.1 Field History:

The Menzel Ledjmet East (MLE) gas field is a commercial project being jointly developed by Sonatrach (SH) and First Calgary Petroleum Ltd (FCP), and now is Partnership with (Eni) an Italian company.

The MLE field lies within the Ledjmet Block 405b in the Berkine Basin of Algeria approximately 220 km south-east of Hassi Messaoud. CAFC oil processing facilities is built adjacent to MLE CPF. Gathering System Plant and pipeline design life years 25 years.

The MLE Project includes a system of producing wells and a production gathering system designed to collect the hydrocarbon fluids and transport them to the central process facility. The Central Processing Facilities (CPF) separates gas and liquid products and delivers them to the product pipelines for transportation to the final delivery point on the existing Sonatrach system. All MLE equipment is sized to cater for both MLE and CAFC GAS SWP. The storage export systems and most of utilities equipment are sized to cater also for CAFC TAGI Oil facilities. MLE CPF is sized to a nominal sales gas capacity of 300

MMSCFD 8.48 million standard m^3 per day (design guaranteed 350 MMSCFD 9.89 million standard m^3 per day). The main power for the MLE Plant comes from the MLN substation (34km away from the Plant) via two OHLs (Overhead Lines). The OHLs terminate in the 60kV.

Recently there is:

→ MLE GAS 26 wells.
→ CAFC GAS 20 wells.
→ CAFC OIL 16 wells.
→ MLE 6 gathering Manifolds.
→ CAFC GAS 3 gathering Manifolds.
→ CAFC OIL 5 gathering Manifolds.
→ Re-Injection gas wells 3
→ Re-Injection water wells 3

→ A Central Processing Facility (CPF) and the Central Area Field Complex (CAFC) facilities, including sales gas compression, CO_2 removal, LPG recovery, oil and Condensate stabilization products storage and pumping system, oil Treatment, associated gas dehydration, water (produced and source) Treatment, gas injection system, water injection system, New gas, oil and water Gathering Systems including flow lines, manifolds and infield trunk lines to CAFC Associated Facilities and Infrastructure

→ Associated utilities, including electrical systems, hot oil, water, flare system, fuel gas, instrument/plant air system, nitrogen, closed and open drains, chemical injection, water treatment system, diesel system.

→ 4 export pipelines for sales gas, LPG, Condensate and Oil (overall 550 km).

The Central Processing Facility produces 245 MMSCFD of Sales Gas (design flow rate) from MLE, while when CAFC gas will be available; it will produce 350 MMSCFD of Sales Gas (design flow) [1].

1.2.2 Geographical position:

MLE Central Processing Facility Coordinates: 30°11’19”N 7°41’27”EThe proposed location for the plant is show in the figure I.1 below:

Figure I.1: MLE Central processing Facility Location

I.2.3 Meteorological Data:

Facilities and equipment for the MLE Gas project are designed for the following environmental conditions Table I.1:

Table I.1: Environmental conditions of MLE Gas project [1].

FACTORS	CONDITIONS
Relative Humidity (max/min)	50% / 15%
Average Annual Rainfall	120 mm
Maximum wind speed (for structural design)	50 m/s at +10m elevation
Normal wind speed (for equipment/machinery operation)	38 m/s at +10m elevation
Normal wind speed (for dispersion/radiation)	2 - 10 m/s
Prevailing Winds	North West
Site Elevation (above sea level) – Approximate	250 Meters
Atmospheric Pressure	0.985 bars
Design Temperature Maximum (Summer)	55 ºC
Design Temperature Minimum (Winter)	-5 ºC
Typical Rate of Change of Temperature	10 ºC / hr
Soil Temperature Maximum (1.5 m below surface) - Summer	30 ºC
Soil Temperature Maximum (1.5 m below surface) - Winter	20 ºC
HVAC Design Dry Bulb Temperature – Summer	50 ºC
HVAC Design Dry Bulb Temperature – Winter	1 ºC
Dust	High
Saline Air	Low
Sandstorm	High

I.3 Feed Composition:

I.3.1 Menzel Ledjmet East (MLE):

The plant is designed to handle a range of feed compositions representing regional differences across the field and with time also. There is uncertainty in each of these reservoir parameters. The range of composition accounts for variation of the fluid composition with reservoir depletion and phased development. Typically becoming less rich in heavier hydrocarbons [1].

Table I.2: Design Case Compositions far MLE CPF Feed Fluid [1].

Component	Lean (Mole %)	Expected (Mole %)	Rich (Mole %)
N_2	0.236	0.227	0.244
H_2S	0.000	0.000	0.000
CO_2	1.830	1.477	1.282
nC1	80.331	77.685	76.425
nC2	9.746	10.362	10.253
nC3	3.300	4.041	4.427
iC4	0.524	0.666	0.796
nC4	0.957	1.250	1.492
neo-C5	0.010	0.013	0.016
iC5	0.341	0.500	0.652
nC5	0.321	0.452	0.573
C6	0.407	0.571	0.734
Benzene	0.032	0.045	0.059
C7	0.371	0.511	0.595
Toluene	0.080	0.108	0.125
C8	0.356	0.486	0.525
Ethyl benzene	0.008	0.011	0.012

Meta&Para Xylenes	0.066	0.088	0095
Ortho Xylene	0.017	0.023	0.025
C9	0.257	0.321	0.275
C10	0.185	0.244	0.238
C11	0.129	0.172	0.180
C12	0.095	0.131	0.147
C13	0.081	0.111	0.123
C14	0.064	0.088	0.100
C15	0.046	0.072	0.088
C16	0.037	0.057	0.072
C17	0.033	0.049	0.059
C18	0.025	0.039	0.053
C19	0.018	0.031	0.046
C20	0.018	0.028	0.040
C21	0.013	0.023	0.036
C22	0.011	0.020	0.031
C23	0.009	0.017	0.028
C24	0.008	0.015	0.025
C25	0.007	0.012	0.021
C26	0006	0.011	0.020
C27	0.004	0009	0.017
C28	0.004	0.007	0.015
C29	0.003	0.006	0.011
C30+	0.014	0.021	0.042
TOTAL	100.000	100.000	100.000

I.3.2 CAFC:

Two gas streams from CAFC SWP Gas will join the MLE plant upstream of the MLE slug catcher:

→ One stream of lean gas coming from a dedicated gathering system to MLE inlet manifold (reservoir design rate of approx. 67 MMSCFD).

→ One stream of rich gas coming from a dedicated gathering system to MLE inlet manifold (reservoir design rate of approx. 48 MMSCFD).

Table I.3: Design Case Composition for CAFC SWP Gas [1].

COMPONENT (Mole %)	CAFC RICH +/- 5%			CAFC LEAN 5%		
	LEAN	EXPECTED	RICH	LEAN	EXPECTED	RICH
N2	0.449	0.467	0.462	0.091	0.095	0.095
H_2S	0.000	0.000	0.000	0.000	0.000	0.000
CO_2	2.670	2.773	2.747	1.424	1.490	1.487
C1	67.051	66.331	65.696	88.425	88.142	87.917
C2	11.225	11.105	10.999	5.154	5.138	5.124
C3	4.505	4.679	4.866	1.289	1.349	1.413
iC4	1.309	1.359	1.414	0.421	0.441	0.462
nC4	1.686	1.751	1.821	0.368	0.385	0.403
neo-C5	0.000	0.000	0.000	0.002	0.003	0.003
iC5	1.016	1.056	1.098	0.290	0.303	0.317
nC5	0.752	0.781	0.812	0.142	0.148	0.155
C6	1.245	1.293	1.345	0.318	0.333	0.349
Mcyclopentane	0.182	0.189	0.197	0.000	0.000	0.000
Benzene	0.087	0.091	0.094	0.004	0.004	0.004

Cyclohexane	0.121	0.125	0.130	0.000	0.000	0.000
C7	1.027	1.067	1.110	0.296	0.310	0.324
Mcyclohexane	0.264	0.275	0.286	0.001	0.001	0.001
Toluene	0.142	0.147	0.153	0.005	0.005	0.006
C8	0.964	1.001	1.041	0.292	0.306	0.320
Ethylbenzene	0.027	0.028	0.029	0.002	0.002	0.002
M-Xylenes	0.129	0.134	0.140	0.002	0.002	0.003
P- Xylenes	0.129	0.134	0.140	0.002	0.002	0.003
O- Xylene	0.050	0.052	0.054	0.002	0.002	0.002
C9	0.676	0.702	0.730	0.207	0.216	0.227
C10	0.766	0.795	0.827	0.195	0.204	0.213
C11	0.593	0.616	0.640	0.164	0.171	0.180
C12	0.471	0.489	0.509	0.136	0.142	0.149
C13	0.393	0.408	0.425	0.117	0.122	0.128
C14	0.311	0.324	0.336	0.094	0.099	0.103
C15	0.263	0.273	0.284	0.080	0.084	0.088
C16	0.211	0.219	0.228	0.066	0.069	0.073
C17	0.176	0.183	0.190	0.057	0.060	0.063
C18	0.155	0.161	0.167	0.048	0.050	0.053
C19	0.135	0.141	0.146	0.047	0.049	0.052
C20	0.114	0.119	0.123	0.039	0.041	0.042
C21	0.096	0.100	0.104	0.038	0.040	0.042
C22	0.082	0.085	0.088	0.030	0.031	0.033

C23	0.070	0.072	0.075	0.026	0.027	0.028
C24	0.064	0.066	0.069	0.021	0.022	0.023
C25	0.055	0.057	0.059	0.017	0.018	0.019
C26	0.045	0.047	0.048	0.017	0.018	0.018
C27	0.045	0.046	0.048	0.017	0.017	0.018
C28	0.036	0.037	0.039	0.013	0.013	0.014
C29	0.033	0.034	0.035	0.008	0.009	0.009
C30+	0.179	0.186	0.193	0.033	0.035	0.036
Total (Mole %)	100	100	100	100	100	100

I.4 Products:

1.4.1 Sales Gas:

Gas composition is a description in quantitative terms of the proportions of chemical constituents or components (flammable components such as methane, ethane, propane, heavier hydrocarbons, non flammable components such as water, oxygen, nitrogen and carbon dioxide and contaminants, such as radioactive materials, mercury and sulphur) that make up what is generically known as natural gas. These components combine together define the thermodynamic properties of the gas such as: viscosity, compressibility characteristics, density,enthalpy and decompression characteristics... These properties, in turn, determine the way in which the gas behaves as a fluid within high pressure pipelines, compressors, regulators and other components of a pipeline system.

The composition of the gas determines all the parameters that are included in the specification. The specified gas is exported to Gassi Touil, pressure at the Pipeline may vary between 50 bar and 71 bar. Maximum temperature is 60 °C [1].

I.4.2 Oil product:

Common oil storage tanks are provided for MLE & CAFC Gas and future CAFC TAGI Oil storage is based on:

- Oil on-spec: approximate 2 days of combined design production. Five tanks are to be provided. (4 equal tank 4904 m3 of working capacity, 1 tank 4053 m3 of capacity). Off-spec oil storage shall be provided and dedicated to MLE only;
- Oil off-spec: about 12 hours of design production.

The four oil storage tanks are operated as follows:

- One tank on fill.
- One tank on export.
- One tank settling prior to export.
- One tank Empty as spare tank.

It is expected that the 4 equal tanks in operation is rotated daily such that the tank settling the previous day will become the export tank the next day. Oil is exported to Hassi Berkine [1].

I.4.3 Condensate product[1]:

Condensate storage tanks are provided for MLE Plant and his storage is based on:

- Condensate on-spec: 14pprox.. 4 days of design production. Two equal sized tanks are provided.
- Condensate off-spec: 18 hours of design production.

Condensate is exported to Gassi Touil via pipeline.

The Two-condensate storage tanks are operated as follows:

- One tank on fill
- One tank on settling and then export

It is expected that the tanks in operation will be rotated every two days such that the tank filling the previous days will become the settling and export tank the next days.

I.4.4 LPG product:

LPG storage is provided as follows:

- LPG on-spec: 3 x 500 m^3
- LPG off-spec: 1 x 500 m^3

This storage volume is provided for the MLE CPF and is also used for combined MLE & CAFC Gas buffer storage. LPG is exported to Gassi Touil via pipeline [1].

I.5 Process description[1]:

The CPF plant facilities process the well fluids to produce sales gas that meets the calorific value specification. Condensate and oil that meet the vapor pressure and density specifications and LPG that meets the required composition specifications.

The CPF facilities consist of:

- → Production reception and slug catching;
- → Gas pre-treatment facilities to remove H_2S and mercury impurities;
- → CO_2 Removal;
- → Gas dehydration;
- → Gas chilling;
- → Gas dew pointing facilities to remove heavy gas components (LPG) in order to achieve the gas calorific value specification;
- → Gas export compression and metering;
- → Condensate stabilization;
- → LPG recovery (De-Butaniser) and LPG Treatment;
- → Condensate recovery;
- → LPG storage and export;
- → Condensate storage and export;
- → Oil storage and export.

Certain provisions have been made at the MLE CPF for the integration of the Central Area Field Complex (CAFC TAGI OIL) facilities. MLE Plant is sized for combined flow from MLE gathering system and CAFC rich and lean gas streams.

The oil and condensate storage and export facilities are designed for the combined production of MLE plant plus CAFC TAGI oil plant. Most of the utilities are designed to supply also CAFC TAGI Oil facilities. The export pipeline facilities include pig launchers; line sectioning valves (in accordance with Algerian regulations); tie-in facilities to existing export infrastructure.

The following figure I.2 shows the MLE + CAFC overall block diagram.

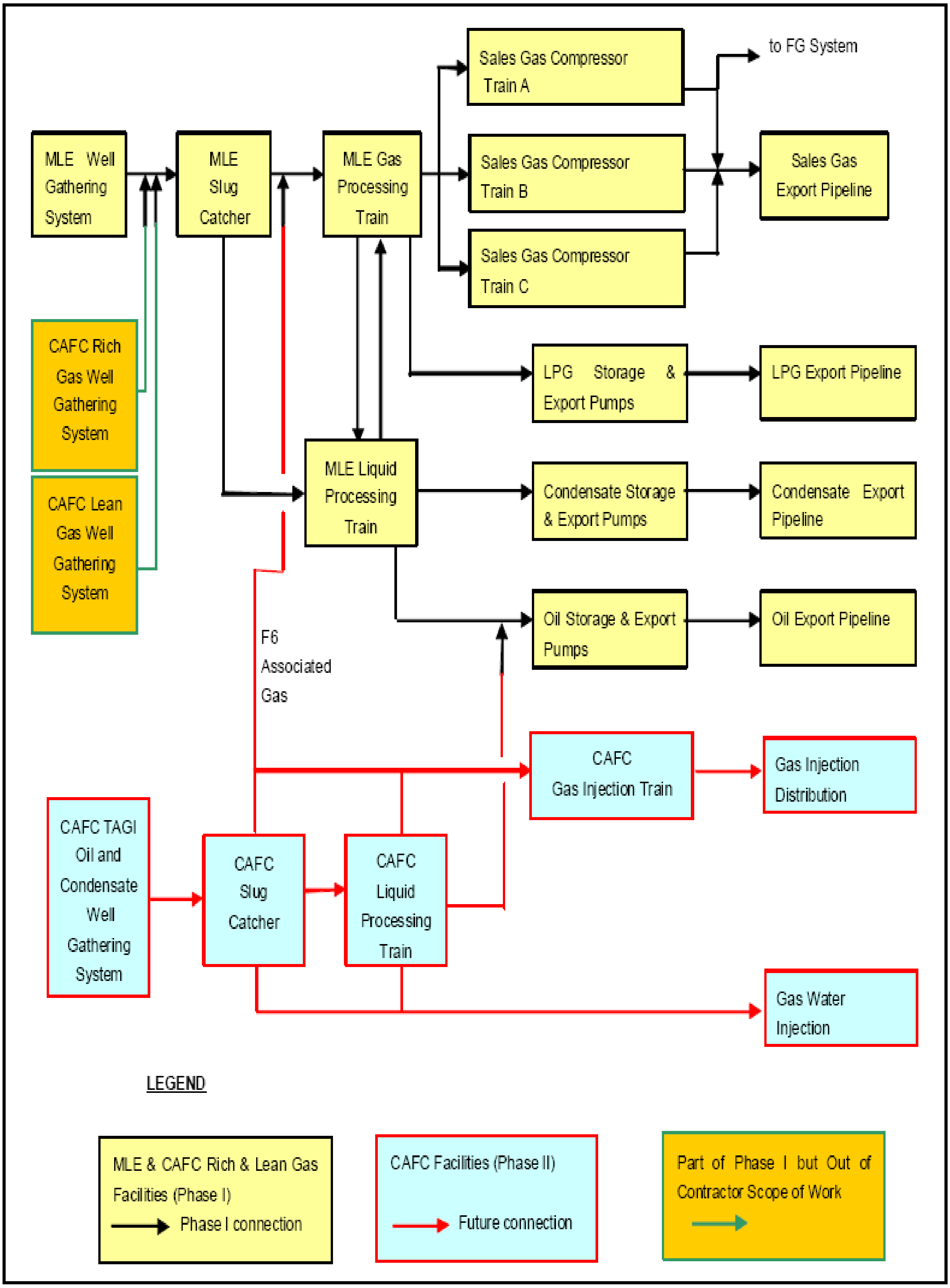


Figure I.2: MLE + CAFC Overall Block Diagram [1].

I.6 Reception facilities:

The production gathering system consists of a network of individual well flow lines connected via field manifolds to four trunk lines that deliver produced fluids to the Reception Facilities at the CPF. Production from the four trunk lines flows into a 42” diameter inlet manifold, which transports fluids to the Slug-Catcher.

The purpose of the inlet manifold and Slug-Catcher system is to [1]:

→ Receive the fluids from the production gathering system
→ Separate the produced fluids into gas, hydrocarbon liquid and water phases
→ Provide surge volume and liquid hold-up for condensate and produced water delivered from gathering system
→ Provide a stable feed of gas and condensate to the process train
→ Provide a source of fuel gas to the Fuel Gas system.

I.6.1 Reception facilities and Slugcatching Sys 20 [1]:

System performs a first separation between liquid and gaseous phases of the incoming raw gas from MLE gathering. It includes also a pig receiver from gas pipeline. The incoming gas passes through the Slug Catcher where it impinges suitable surfaces to make moisture and heavier hydrocarbons particles to settle downwards while the relatively dry gas is routed to scrubber for a more accurate filtration and demisting.

The Slug Catcher is a finger type separator. Eight 115 m long inclined 36” fingers has been sized to handle and to separate gas from liquid, the finger-type slug catcher has been sized to provide both slug storage of 325 m^3 plus 15 minutes hold up of total liquid production and a gas-liquid separation of liquid particles bigger than 2000 µm.

Gas from Slug Catcher is sent to the Inlet Gas Cooler and then to the Inlet Gas Scrubber, and the total liquid from Slug Catcher is sent to condensate separator.

I.6.2 Gas Pre-treatment to remove H_2S & Hg Impurities Sys 30:

The purpose of the Gas treatment Unit (System 30) is to remove mercury and H_2S present in the inlet gas. Gas from MLE well is saturated with water and contains mercury and trace of H_2S. Water has to be removed from gas to prevent ice and Hydrate formations in the deep dew pointing where temperatures lower than – 70°C, are reached. The H_2S and mercury will contaminate the LPG unless removed. Mercury and H_2S removal facilities are provided to pre-treat the gas stream. It is estimated that the majority of the well stream mercury will partition into the liquids stream but nevertheless, the gas has been considered saturated with mercury. Mercury has to be removed to prevent damage to aluminum heat exchangers used for deep dew – pointing. Moreover, export gas is required to be free from H_2S. Three dedicated Removal Beds are foreseen for removal of mercury first and then of H_2S from gas.

Eliminating H_2S from hydrocarbon gas or liquid requires the use of absorbent bed which removes sulfur by an irreversible chemical reaction. Once the sulfur has reacted with the metal oxide present in the absorbent, it is chemically bound onto the material [1,2].

I.6.3 CO_2 Removal Sys 28:

The purpose of the CO_2 Removal Unit is to reduce the CO_2 to a concentration lower than 2%mol in the sales gas in order to meet normal sales gas specifications. The CO_2 removal is achieved by splitting the feed gas as follow, one stream is routed to the Acid Gas Inlet Separator, while the other one bypass the contactor. According to the information from the CO_2 analyzer, the operator will set manually the set point of the flow controller (max 10% of process gas flow rate).

The Gas Sweetening unit is designed to remove carbon dioxide (CO_2) from raw gas feed for the Sales gas production by means of chemical/physical absorption. Acid gas reacts with the Di-ethanolamine (DEA) according to the chemical reactions [1].

I.6.4 Gas Treatment (Dehydration) Sys 24:

The Gas Dehydration System is designed to reduce the water content in the sweet gas stream coming from System 30, where it is in saturated condition. Water content is reduced in order to avoid formation of hydrates along the pipeline. A hydrate is a physical combination of water and other small molecules of hydrocarbons to produce a solid, which has an “ice-like” appearance but possesses a different structure than ice. Their formation in gas and/or NGL systems can plug pipelines, equipment, and instrument, restricting or interrupting flow. Molecular sieves dehydrate the gas up to a water content of one ppmv. This is required for the low dew point (approximate -85°C required for the Turbo expander dew pointing) Dehydration Package consist of three Dehydration Beds, The beds operate under adsorption/regeneration cycling such that one bed is being regenerated at any time with the other two dehydrating the gas [1].

Feed gas drying is required[1]:

- → To meet the dryness specification for sales gas, i.e., water dew point.
- → To prevent ice and hydrate formation in the Gas Chilling System (system 25), which will cause blockages in piping and equipment.

I.6.5 Gas Conditioning (Chilling & Dewpointing Units) Sys 25:

The Gas Conditioning System consists of the Turbo Expander System and the associated heat interchangers. The Gas Conditioning System cools the gas to condense liquids there by reducing the calorific value of the gas to meet the sales gas specification.

De-Ethaniser is a fractionating Column, provided with a reboiler for heating and a condenser for overhead vapors, with the scope to separate light gas (methane and ethane) from heavier hydrocarbons [1].

The de-ethanising process requires external heat, in this case supplied in the De-Ethaniser Reboiler by hot oil. A stream of the De-Ethaniser product, flows to the Reboiler, where is partly vaporized absorbing heat from the hot oil. The De-Ethaniser overhead vapor flows to the De-Ethaniser Condenser, and then to the De-Ethaniser Reflux Drum. De-Ethaniser contains 28 trays to separate the C2 and lighter components from the feed. The liquid flows down and across the trays in the Column. The hot vapors, stripped out in the Column, go overhead to the De-Ethaniser Overhead Condenser. The Column bottom is divided in two sections, with a separation baffle. This allows sending all the liquids from the bottom tray to the De-Ethaniser reboiler. This is required to minimize light components in the bottom product stream. De-Ethaniser reboiler partially vaporizes the liquid to remove light ends and provide stripping vapors. These enter the Column below the bottom tray. Net liquids from the reboiler compartment overflow into the Column net bottoms compartment. The Gas Conditioning System has the duty to reduce drastically the condensable hydrocarbons (heavier HC), still present in the sweet and dried gas, so that condensation of hydrocarbons in the export pipeline are avoided [2].

Retrograde condensation has long been known to occur at reservoir conditions. Recognition that it also occurs in typical processing conditions was an early result of computer calculations using equations of state to predict vapor-liquid behavior. The calculations show that the pressure is reduced, heavier HC liquid forms. The heavier hydrocarbon, more the dew point temperature increases as the pressure is lowered.

When gas is transported in pipelines, consideration must be given to the control of the formation of hydrocarbon liquids in the pipeline system. Condensation of liquid is a problem in metering, and also in fuel gas system, pressure drop and safe operation. Condensation of liquid can also be a major problem with two-phase flow and liquid slugging. To prevent the formation of liquids in the system, it is necessary to control the hydrocarbon dew point below the pipeline operating conditions. Since the pipeline, operating conditions are usually fixed by design and environmental consideration; single-phase flow can only be assured by removal of the heavier hydrocarbons from the gas. The unit is designed to reduce the hydrocarbon dew point of the treated natural gas feed coming from the Gas Dehydration System [1].

I.6.6 Sales Gas Compression & Metering Sys 27:

Conditioned gas leaving the Gas Recompressed in system 25 is compressed up to the suitable pressure for the export in pipeline. Gas Handling Unit consists of three independent Gas Turbine Driven Sales Gas Compressor Packages UK-27-02A/B/C. During normal operation two compression trains are operating and one is in standby mode. Stand-by package (train) is lined up manually, because no automatic changeover is foreseen [1].

The sales gas compression system receives treated gas from process train. The purpose of the gas compression and Export system is to:

- → Compress the gas from the dry gas process system to export pressure.
- → Meter the compressed gas to custody transfer accuracy.
- → Transport the residue gas product via pipeline to the Sonatrach Transportation pipeline at Gassi touil.

The primary source of LP fuel gas is from the Suction header of the Sales Gas Compressors.

Gas from the Sales Gas Compressors is metered in the Sales Gas Fiscal Meter. This meter consists of 3*50% streams of pressure and temperature compensated orifice meter runs. From metering panel, gas analysis, specific gravity, heating value and status alarm signal are transmitted and displayed on DCS. Total flow is computed by metering station. Metering panel is common for all gas, LPG, oil, condensate unit [1] .

I.6.7 Crude Treatment & Stabilization Sys 21:

The Condensate stabilization operation is performed by warming-up the feed to release the lighter components from the top of the stabilizer Column. The System 21 includes mainly the Condensate Separator to receive liquid feed from System 20, the stabilizer Column and off-gas compression facilities to recover the gas relieved from top of stabilizer Column. Normally, the crude or condensate is processed into a Stabilizer Column to achieve a maximum Reid Vapor Pressure (RVP) [1].

RVP is a standard indicator of volatility, or how quickly a fuel evaporates, and is a key quality control factor, in particular when considering the condensate storage. If the product is too volatile, it will evaporate in warm weather despite venting control.

Volatile fractions also ignite easily, incurring a safety risk and more stringent safety regulations.

The condensate stabilizer reduces vapor pressure of the condensate by removing the lighter components.

The stabilizer process requires external heat, in this case supplied in the stabilizer reboiler by hot oil. A stream of the stabilizer product, flows to the Reboiler, where is partly vaporized absorbing heat from the hot oil [2].

The stabilizer contains 19 valve trays to separate the lighter components from the feed. The liquid flows down and across the trays in the Column. The hot vapors, stripped out in the Column, are recirculated to gas section. The Column bottom is divided in two sections, with a separation baffle. This allows sending all the liquids from the bottom tray to the stabilizer Reboiler. This is required to minimize light components in the bottom product stream.

Stabilizer Reboiler partially vaporizes the liquid to remove light ends and provide stripping vapors. These enter the Column below the bottom tray. Net liquids from the reboiler compartment overflow into the Column net bottoms compartment. The overhead gas stream from the stabilizer is recycled to the Inlet Gas Scrubber, by the Off-gas Compressors [1].

I.6.8 Recuperation & treatment Sys 32:

I.6.8.1 LPG recovery & treatment:

The De-Butaniser has two performance requirements. The first is to stabilize the bottoms liquid from the Column by removing as much butane and lighter components as possible. The second requirement is to recover LPG (propane and butane) without recovering excessive pentanes (C5s) into the overhead LPG product. The LPG product specification is for a maximum of 0.4 mole % pentanes plus. The Column bottoms product is stabilized to ensure that the product oil and condensate RVP specification is achieved. The summer operating condition governs the RVP specification. For the worst case, summer operation a maximum RVP of 0.45 bar applies. Notwithstanding the RVP specification, the oil and condensate shall be stabilized to ensure that the rundown products may be stored in floating roof tank at the maximum ambient temperature of 55 °C [1].

The De-Butaniser is a fractionating Column. The debutanizing process requires external heat, in this case supplied in the De-Butaniser Reboiler by hot oil. The Column bottom is divided in two sections, with a separation baffle. This allows sending all the liquids from the bottom tray to the De-Butaniser reboiler. This is required to minimize light components in the bottom product stream. De-Butaniser reboiler partially vaporizes the liquid to remove light ends and provide stripping vapors. These enter the Column below the bottom tray. Net liquids from the reboiler compartment overflow into the Column net bottoms compartment. The De-Butaniser overhead vapor flows to the De-Butaniser Condenser, and then to the De-Butaniser Reflux Drum, they contain 47 valve trays to separate the C3 & C4 and lighter components from the feed. The liquid flows down and across the trays in the Column. The hot vapors, stripped out in the Column, go overhead to the De-Butaniser Overhead Condenser. The De-Butaniser overhead gases are totally condensed. The condensed hydrocarbon flows by gravity into the De-Butaniser Reflux Drum. A portion of the liquid in Debutaniser Reflux Drum is returned to the top of the Column as reflux by LPG pumps. The remaining portion is also pumped to molecular sieves treatment beds [2].

LPG collected in the De-Butaniser Reflux Drum, then is pumped by LPG pumps to the LPG Treatment system prior to storage and export, LPG may be contaminated by water, H2S and mercury, carried by the condensate to the De-Butaniser, the gas, via the De-Ethaniser, is previously treated to remove impurities. During normal operation LPG is sent to LPG Treatment and by LPG pumps to On-Spec LPG Storage Spheres [1].

I.6.8.2 Condensate and Oil recovery systems:

The 23 stabilized De-Butaniser bottom is routed to the Condensate Recovery system that separates lighter components by flashing process. The pressure Condensate Recovery Separator is selected to ensure the condensate RVP and density specifications are met and also to ensure that the recovered condensate is stabilized suitable for atmospheric storage at ambient temperatures in floating roof tanks, pressure decreasing has the effect of driving more heavy components into the condensate, causing the condensate RVP to decrease and the condensate specific gravity to increase. Decreasing the side draw off flow rate (mainly C5 and C6 components) has the same effect as decreasing the pressure of the condensate flash vessel, causing the condensate RVP to decrease and the condensate specific gravity to increase [3].

The vapor recovered from the Condensate Recovery Separator is condensed by means of air cooler Condensate Condenser. The condensed liquids, from the Condensate Condenser, accumulate in the Condensate Receiver. The liquids from the Condensate Receiver are pumped to storage by the two Condensate Pumps, through the Condensate Rundown Cooler and then to condensate storages tanks.

The heavy oil separated in the Condensate Recovery Separator is recovered by the Heavy Oil Pumps. The heavy oil, after combined with the De-Butaniser bottom is sent first to De- Butaniser Feed Heater, then to stabiliser Feed Heater and to Oil Rundown Cooler and finally to Oil Storage Tanks [1,3].

I.6.9 LPG storage & pumping system (Sys 33):

The LPG product is stored into three dedicated LPG Storage Spheres, before being routed to export pipelines at proper conditions in accordance with the requirements of the Algerian Regulations. Spherical tanks are used for the storage of those products which can be maintained in liquid form at ambient temperature by the imposition of pressure alone [2]. There are three LPG storage spheres, each sized for 500 m^3 storage.

The LPG is exported by the LPG Export Pumps, Stage of pumping is provided by means pumps sized as 3x50% based on combined MLE + CAFC Gas SWP flow.

During start up and plant upsets, the LPG product may not be produced to specification and therefore Off-Spec LPG Storage Sphere is provided to allow the off-spec product to be stored for later re-run. The off-spec LPG is sent for re-run by the 2 x 100% Off-Spec LPG Re-Run to the Condensate Separator [1].

I.6.10 Condensate storage & pumping system (Sys 35):

The condensate product is stored into two dedicated Condensate Storage Tanks, before being routed to export pipelines at proper conditions in accordance with the requirements of the Algerian Regulations.

The condensate product is pumped by 2x100% Condensate Pumps (100% is referred to the condensate production for MLE and CAFC Gas SWP) to the Condensate Storage Tanks. Each storage tank is sized for two days production from MLE and CAFC Gas SWP. A sample connection is provided to monitor storage tanks inlet streams conditions. Moreover, a sample connection for each tank is provided to monitor internal conditions. Metering Panel is common for all gas, LPG, oil and condensate systems.

The two storage tanks are operated in the following manner:

- → One tank is filling with rundown condensate product
- → One tank is settling for the first 8 hours and is export for the following hours (a dedicated “Settling time completed” alarm is provided for each tank to highlight the operator that the tank should be put in export phase).

During start up and plant upsets, the condensate product may not be produced to specification and therefore an Off-Spec Condensate Storage Tank is provided to allow the off-spec product to be stored for later re-run [1].

I.6.11 Oil storage & pumping system (Sys 22):

The oil product is stored into four dedicated Oil Storage Tanks, before being routed to export pipelines at proper conditions in accordance with the requirements of the Algerian Regulations. The oil is exported by the Oil Export Pumps. Two stages of pumping have been provided, oil booster pumps and oil export pumps.

The four storage tanks are operated in the following manner:

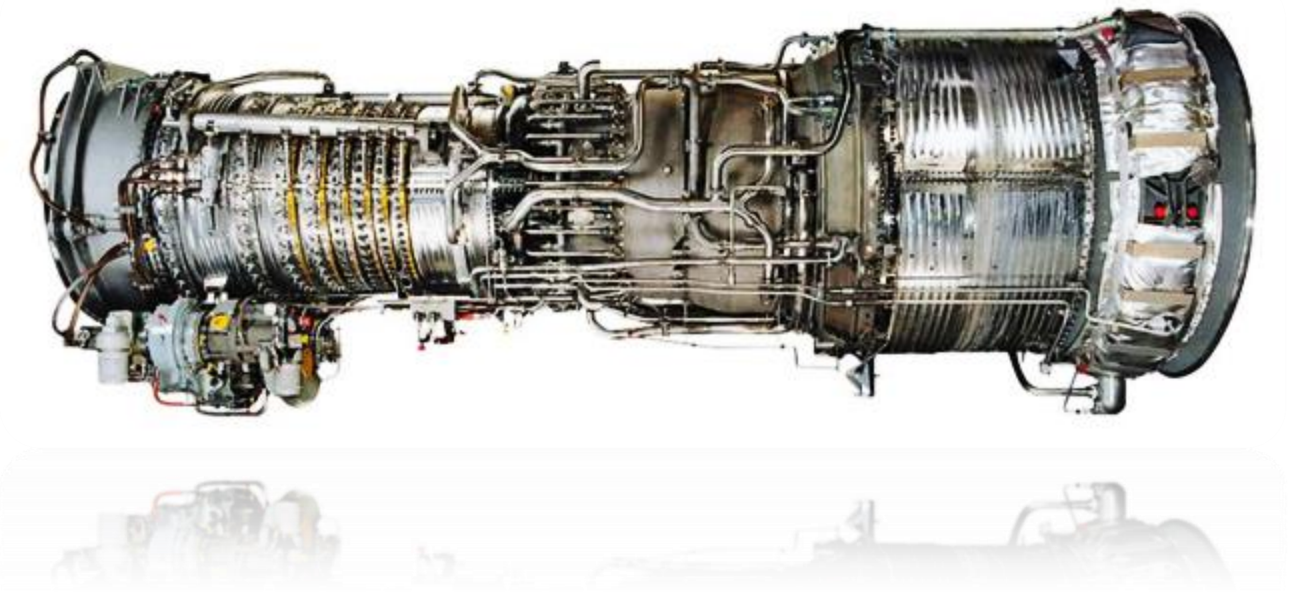
- → One tank is filling with rundown oil product
- → One tank is on export
- → One tank is settling prior to export
- → One tank is emptied

During start up and plant upsets, the oil product from MLE may not be produced to specification and therefore an Off-Spec Oil Storage Tank is provided to allow the off-spec product to be stored for later re-run [1].

I.7 Conclusion:

In this chapter, we talk about the importance of the oil and gas industry in the world. And how to extract and separate petroleum products for use in various fields, whether industrial or local, after many processes of separation and processing, in order to achieve the standards required for petroleum products, we use a set of successful systems for processing in the form of the train, and other auxiliary systems. Ensuring good performance and high efficiency of equipment in safety and security is sufficient to achieve the objectives set.

Chapter II: Gas Turbine Engine Overview



Chapter II: Gas Turbine Engine Overview

II.1 Introduction:

A gas turbine is a combustion engine that can convert natural gas or other liquid fuels to mechanical energy. The development of the gas turbine was less rapid as a stationary power plant in competition with steam for the generation of electricity and with the spark-ignition and diesel engines in transportation and stationary applications. Nevertheless, applications of gas turbines are now growing at a rapid pace as research and development produces performance and reliability increases and economic benefits.

Recently gas turbines have been used for many aerospace and industrial applications for many years. They are used successfully to power craft as well as industrial applications.

In this chapter we will touch on bibliographic studies of gas turbine, we're going to look at the basics of gas turbines. What are they? When were they developed? How do they work?... Etc.

II.2 History of the gas turbine engine:

Today turbine engines power the majority aircraft and other fields such as Petroleum Industry, power plants. These engines have come to play a significant part in many applications. We will look back in time and examine some historical developments and inventions that have led to today's gas turbine engine technology.

Hero's engine (aeolipile) in the 50s:

It most likely served no practical purpose, and was rather more of a curiosity; nonetheless, it demonstrated an important principle of physics that all modern turbine engines rely on [4].

Trotting Horse Lamp - Chinese:

It emerged in the 1000. It was used by the Chinese at lantern fairs as early as the Northern Song dynasty. When the lamp is lit the heated airflow rises and drives an impeller with horse-riding figures attached on it, whose shadows are then projected onto the outer screen of the lantern [4].

Chimney Jack - 1500:

It was drawn by Leonardo da Vinci: Hot air from a fire rises through a single-stage axial turbine rotor mounted in the exhaust duct of the fireplace and turning the roasting spit by gear-chain connection [5].

Giovanni Branca - 1629:

Jets of steam rotated an impulse turbine that then drove a working stamping mill by means of a bevel gear, developed by Giovanni Branca [6].

John Barber (1734–1801) – British:

He was born in Nottinghamshire and moved to Warwickshire in the 1760s to manage collieries in the Nuneaton area. He patented several inventions the most remarkable being one in 1791 "A Method of Rising Inflammable Air for the Purposes of Procuring Motion". This is the patent of a Gas turbine [7,8].

Bresson – French:

In Paris in 1837, Bresson had the idea to heat and compress air then deliver this to a combustion chamber and to mix this with fuel gas and then burnt. The combustion products were to be used to drive "a wheel like a water wheel" [2].

Franz Stolze (1836-1910) – German

Dr. Stolze took out a patent for gas turbine engine in 1872. This engine used a multi-stage reaction turbine and a multistage axial flow compressor. He called this a "Fire Turbine". Tests were made in Berlin and trials were carried out between 1900 and 1904 but no success [9].

Rene Armengaud and Charles Lemale - French:

In 1903, they built and successfully tested the first of several experimental gas turbines with internally water cooled disks and blades [3].

Charles Gordon Curtis (1860-1953) - American:

Born in Boston, Massachusetts he patented the first US gas turbine in 1899. Among his other achievements was the Curtis steam turbine of 1896. He sold the rights to the turbine to GE in 1901[13].

Aegidius Elling (1861–1949) - Norwegian:

Norwegian inventor considered in some quarters to be the father of the gas turbine. In 1903 he designed and constructed the first constant pressure gas turbine. His first machine had an output of 11hp and the second 44hp [10].

Jakob Ackeret (1898-1981) - Swiss:

He worked at Escher Wyss AG in Zurich as Chief Engineer of Hydraulics and was considered as an expert on gas turbines; known for his research on axial flow compressors, airfoil theory, aerodynamics and high-speed propulsion problems. He is recognized as a pioneer of modern aerodynamics [11].

Alan Howard (1905–1966) American:

He worked for the GE Company in Schenectady, NY and the steam turbine activities of the company. He is considered as the key figure in GE efforts to develop the gas turbine as he was appointed to a wartime committee part of the general wartime effort to develop gas turbines for military aircraft propulsion [12].

Pratt and Whitney-1963:

The introducing of the GG4/FT4, which is the first commercial aeroderivative gas turbine [14].

Siemens – 1995:

The first manufacturer of large electricity producing gas turbines to incorporate single crystal turbine blade technology into their production models, allowing higher operating temperatures and greater efficiency [15].

Over the past few decades, turbine engines that rely on turbines and jet engines have developed rapidly, with the message taking on a greater role with the acceleration of the aircraft. However, the very high cost of effective compressors and turbines and the continued need for moderate turbine inlet temperatures have not only led to very difficult tasks for all types of engineers, but have also constrained the use of these engines for use in medium / large supersonic aircraft or faster speeds of sound. However, turbines are still attractive for use in high-speed, medium to medium-speed vessels and for various industrial applications [16].

II.3 Types of Gas Turbines:

II.3.1 Aeroderivative Gas Turbines:

Aeroderivative gas turbines for stationary power are adapted from their jet and turbo shaft aircraft engine counterparts. While these turbines are lightweight and thermally efficient, they are usually more expensive than products designed and built exclusively for stationary applications. The largest aeroderivative generation turbines available are 40 to 50 MW in capacity. Many aeroderivative gas turbines for stationary use operate with compression ratios in the range of 30:1, requiring a high-pressure external fuel gas compressor. With advanced system developments, larger aeroderivative turbines (>40 MW) have achieved over 43 percent simple-cycle efficiency (LHV) [17].

II.3.2 Industrial Gas Turbines:

Industrial gas turbines, or frame gas turbines, are exclusively for stationary power generation and are available in capacities from 1 to over 300 MW. They are generally less expensive, more rugged, can operate longer between overhauls, and are more suited for continuous base-load operation with longer inspection and maintenance intervals than aeroderivative turbines. However, they are less efficient and much heavier. Industrial gas turbines generally have more modest compression ratios (up to 16:1) and often do not require an external fuel gas compressor. Larger industrial gas turbines (>100 MW) are approaching simple-cycle efficiencies of approximately 40 percent (LHV) and combined-cycle efficiencies of 60 percent (LHV) [17].

Industrial plants use gas turbines between 500 kW to 40 MW for on-site power generation and for direct mechanical drive applications. Small gas turbines also drive compressors on long distance natural gas pipelines. In the petroleum industry, turbines drive gas compressors to maintain well pressures and provide compression and pumping for refineries and petrochemical plants. In the steel industry, turbines drive air compressors used for blast furnaces. In process, industries such as chemicals, refining and paper, and in large commercial and institutional applications turbines are used in combined heat and power mode generating both electricity and steam for use on-site [17].

II.4 Gas turbine applications:

Nevertheless, applications of gas turbines now are growing at a rapid pace as research, development produces performance and reliability increases and economic benefits. The success of the gas turbine in replacing the reciprocating engine as a power plant for high-speed aircraft is well known; especially for high power applications, the gas turbines are widely used. The development of the gas turbine was less rapid as a stationary power plant in competition with steam for the generation of electricity and with the spark-ignition and diesel engines in transportation and stationary applications. The sizes of gas turbines can vary from 500kW to 250MW according to their applications [18,19].

Sometimes we shall find it necessary to use the distinguishing terms 'aircraft gas turbine' and 'industrial gas turbine figure II.1. The first term is self-explanatory, while the second is intended to include all gas turbines not included in the first category. This broad distinction has to be made for three main reasons. Firstly, the life required of an industrial plant is of the order of 100.000 hours without major overhaul, whereas this is not expected of an aircraft gas turbine. Secondly, limitation of the size and weight of an aircraft power plant is much more important than in the case of most other applications of the gas turbine. Thirdly, the aircraft power plant can make use of the kinetic energy of the gases leaving the turbine, whereas it is wasted in other types and consequently must be kept as low as possible. These three differences in the requirements can have a considerable effect on design and, in spite of the fact that the fundamental theory applies to both categories, it will be necessary to make the distinction from time to time [20]. Turbo machinery of gas turbines designed specifically for an industrial purpose tends to look more like that of traditional steam turbines in mechanical appearance than the familiar lightweight constructions used in aircraft practice.

The widest applications of the aero-derivative gas turbine have been in pumping sets for gas and oil transmission pipelines, electricity generation and naval propulsion. In the case of natural gas pipelines, the turbines use the fluid being pumped as fuel and a typical pipeline might consume 7-10 per cent of the throughput for compression purposes. In recent years, the value of gas has increased dramatically and this has led to a demand for high-efficiency pumping units. A major pipeline might have as much as 1500 MW of installed power and the fuel bills are comparable to those of a medium-sized airline. Pumping stations may be about 100 km apart and the gas turbines used range in power from 5 to 25 MW [20].

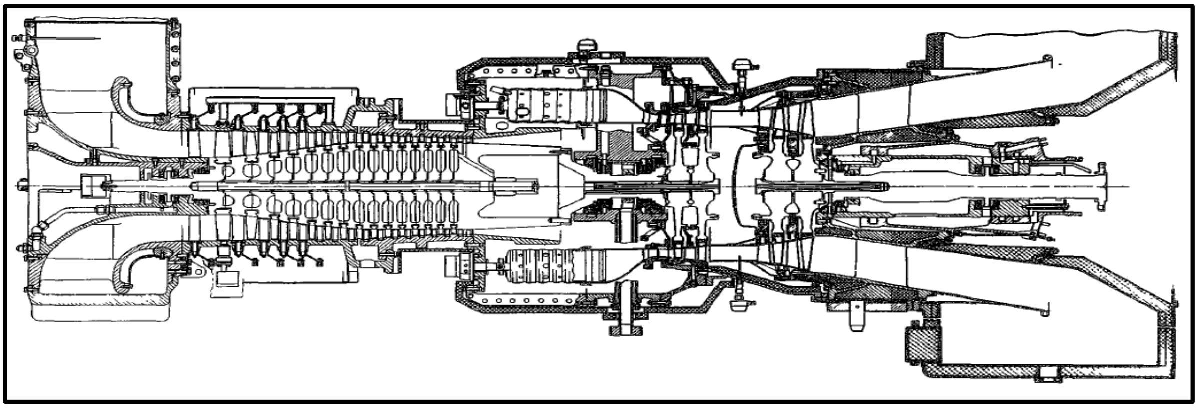


Figure II.1: Industrial gas turbine with separate power turbine (courtesy European gas turbine) [20].

Many compressor stations are in remote locations and aircraft derivative units of 15 to 25 MW are widely used. Other operators may prefer the use of industrial gas turbines and in recent years a number of heat-exchangers have been retrofitted to simple cycle units. With oil pipelines, the oil is often not suitable for burning in a gas turbine without expensive fuel treatment and it becomes necessary to bring a suitable liquid fuel in by road.

Gas turbines were used successfully in a few high-speed container ships, but the rapid increase in fuel prices in the mid-seventies led to these ships being re-engine with diesels; the converted ships suffered a major loss in both speed and cargo capacity, but high speed could no longer be justified. The picture with respect to naval operations is quite different, however, and many navies (e.g. Britain, U.S.A., Canada, and Netherlands) have now accumulated a large amount of gas turbine experience. A gas turbine was first used in a Motor Gun Boat in 1947, and aero-type engines (Rolls-Royce Proteus) were first used in fast patrol boats in 1958. The potential of aero-derivative engines for main propulsion of warships was soon realized and the Canadian DDH-280 class were the first all gas turbine powered warships in the western world, using a combination of Pratt and Whitney FT-4’s for ‘boost’ power and FT-12’s for ‘crnise’. The Royal Navy selected the Olympus as boost engine and the Rolls-Royce Tyne for cruise duties; the Royal Netherlands Navy also selected this machinery arrangement. The Olympus and Tyne are the only naval gas turbines to have been proved in battle, operating with great success in the Falklands War. The U.S. Navy adopted the GE LM 2500, derived from the TF39 advanced turbofan, and this engine has been widely used around the world. With the increasing electrical needs of warships, and the absence of steam for use in turbo generators, gas turbine driven generators also offer a very compact source of electricity.

Aeroderivative gas turbines are also being used to balance the integration of variable power sources, like wind and solar, into the electricity grid [20, 21].

II.5 How Gas Turbines Work:

Aeroderivative gas turbines, like all gas turbines, use a continuous intake of air and a continuous injection of fuel to create a hot, pressurized gas flow that expands through the turbine. In the compressor, a series of rotating blades pressurizes the incoming air in stages; this pressurization heats the air. In the combustor, chemical energy from the burning fuel adds far more heat. The hot, pressurized gas expands through the turbine blades and rotates the shaft that drives the compressor at the front of the engine, continuing the cycle figure II.2. From this basic configuration, the remaining energy not used to drive the compressor can be captured in useful ways for various applications. In aircraft engines, the hot exhaust gas passes through additional turbines to rotate a shaft driving a propeller or fan that provides most of the aircraft’s thrust. Aeroderivative and other industrial gas turbines work in a similar way, adding more turbines to extract energy from the hot exhaust gas to power a shaft. For industrial applications, the shaft is connected to an external electricity generator, a pump, a compressor or a ship’s drivetrain.

Aeroderivative gas turbines for combined heat and power generation, also called cogeneration. In this configuration, the exhaust heat of the gas turbine is used to produce steam to directly heat a building or industrial process. Aeroderivative gas turbines can convert

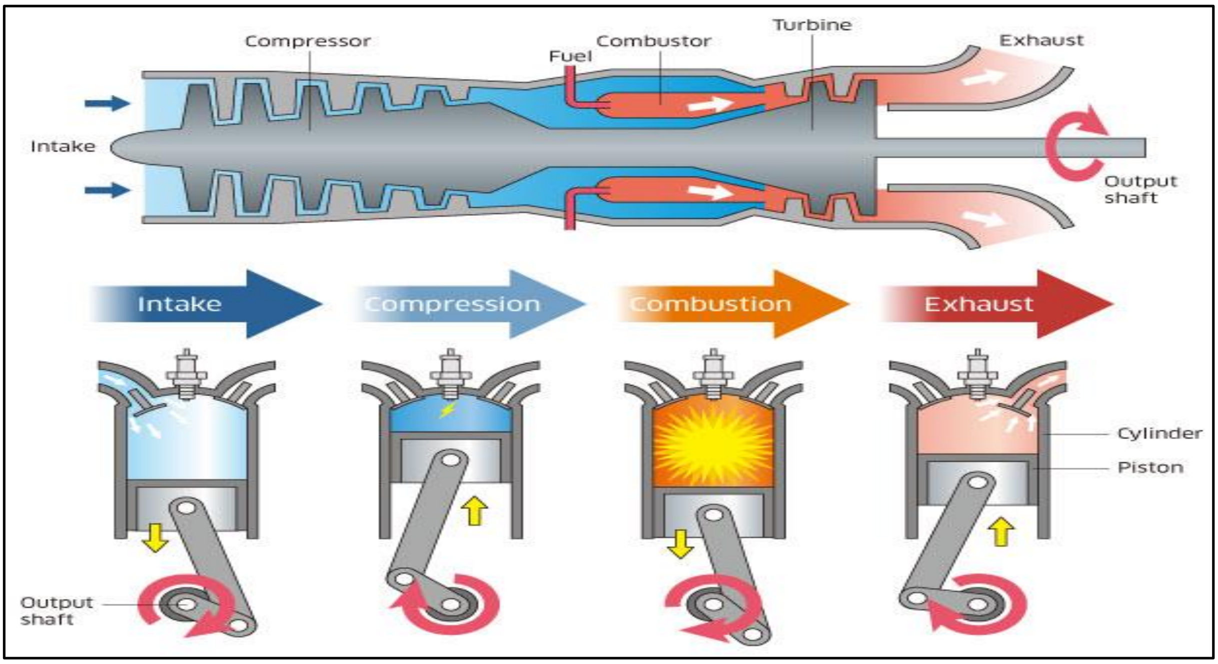
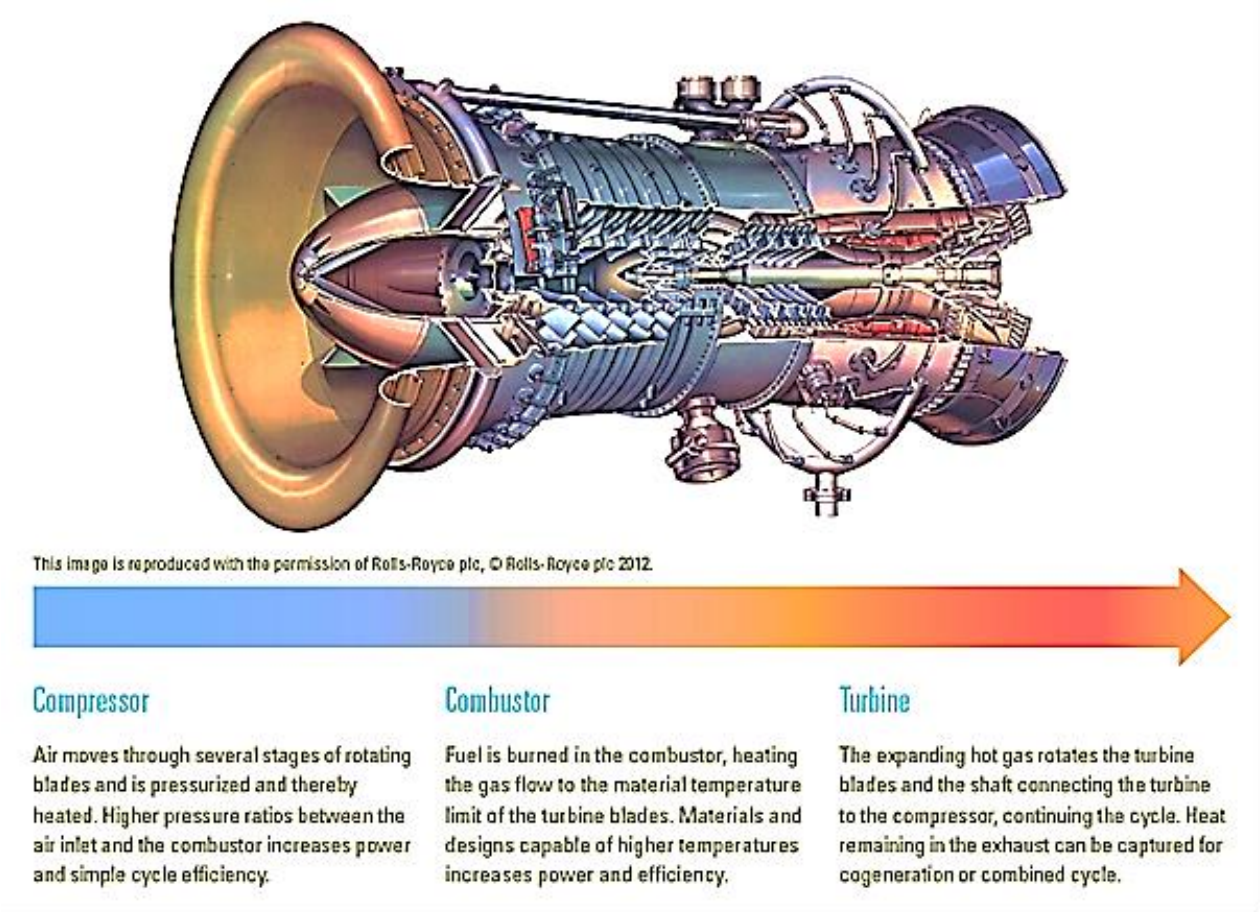


Figure II.2: Principle of gas turbine operation [22].

40 percent of fuel energy into electricity; when configured for cogeneration, system efficiency can exceed 80 percent, as far less of the fuel's chemical energy is lost as unused heat [21].



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Compressor

Air moves through several stages of rotating blades and is pressurized and thereby heated. Higher pressure ratios between the air inlet and the combustor increases power and simple cycle efficiency.

Combustor

Fuel is burned in the combustor, heating the gas flow to the material temperature limit of the turbine blades. Materials and designs capable of higher temperatures increases power and efficiency.

Turbine

The expanding hot gas rotates the turbine blades and the shaft connecting the turbine to the compressor, continuing the cycle. Heat remaining in the exhaust can be captured for cogeneration or combined cycle.

Figure II.3: Aeroderivative gas turbine cutaway [23].

II.6 Theoretical cycles:

A cycle is a process that begins with certain conditions, progresses through a series of additional conditions, and returns to the original conditions. The basic GTE cycle is named for the Boston engineer, George Brayton, who proposed it in the late nineteenth century.

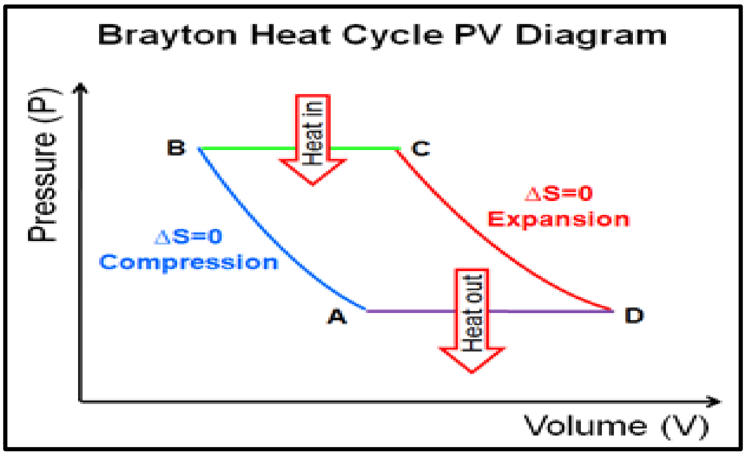


Figure II.4: The Brayton cycle [24].

The Brayton cycle is one in which combustion occurs at constant pressure. In GTEs, specific components are designed to perform each function of the cycle separately. These functions are intake, compression, combustion, expansion, and exhaust. Refer to figure II.4 as we explain the Brayton cycle graphically.

→ Intake – At point A, air enters the inlet at atmospheric pressure and ambient temperature.

→ Compression – As the air passes through the compressor, it increases in pressure and temperature. The air decreases in volume (line A-B).

→ Combustion – At point B, combustion occurs at constant pressure while the addition of heat causes a sharp increase in volume (line B-C).

→ Expansion – The gases at constant pressure and increased volume enter the turbine and expand through it. As the gases pass through the turbine rotor, the rotor turns kinetic energy into mechanical energy. The expanding size of the passages causes further increase in volume and a sharp decrease in pressure and temperature (line C-D).

→ Exhaust – The gases are released through the stack with a large drop in volume and at constant pressure (line D-A).

The cycle is continuous and repetitive in a GTE. The functions occur simultaneously throughout the system [24].

II.7 Factors affecting engine performance:

There are many factors, such as aerodynamics and thermodynamics, that have a direct impact on the effective performance of GTE. In this chapter, we will discuss many common factors, like the effect of ambient temperatures, the effect of compressor cleanliness and fuel. Etc. As gas turbine technicians, we will be concerned in our daily operation of the GTE.

II.7.1 Effect of Ambient Temperature:

In discussions of temperature effects on GTE, you will often hear the term Navy standard day. This term refers to a theoretical condition seldom duplicated except in some permanent test situations and is used only as a reference or standard. A standard day is indicated by the following conditions at sea level: barometric pressure 29.92 Hg, humidity (water vapor pressure) 0.00 Hg, and temperature 15°C. Operation of engines above or below 10°C will proportionally affect engine power output by as much as 15 or 20 percent.

The power and efficiency of a GTE are affected by both outside and inside variables. Air has volume that is directly affected by its temperature. As the temperature decrease, the volume of air for a given mass decreases and its density increases. Consequently, the mass weight of the air increases, causing the engine to operate more efficiently. This happens because less energy is needed to achieve the same compression at the combustion chambers. In addition, cooler air causes lower burning temperatures. For example, propulsion GTE is operating at 100 percent GG speed with 100 percent PT speed. The ambient (external air) temperature is 21°C. If the temperature were increased to 49°C, the volume of air required would increase. The mass weight would decrease the figure II.5 show the variation of pressure ratio versus turbine inlet temperature. Since the amount of fuel added is limited by the inlet temperature the turbine will withstand, the mass weight flow cannot be achieved; the result is a loss of net power available for work. The plant may be able to produce only 90 to 95 percent of its rated horsepower, figure II.6 show specific fuel consumption versus pressure ratio and turbine inlet temperature [25].

On the other hand, if the ambient temperature were to drop to -17°C, the volume of air (mass) required would decrease. However, the mass weight would increase. Since the mass weight is increased and heat transfer is better at higher pressure, less fuel is needed to increase volume. This situation produces quite an efficient power plant. It has a GG speed of 85 to 90 percent and a PT speed of 100 percent [25, 26].

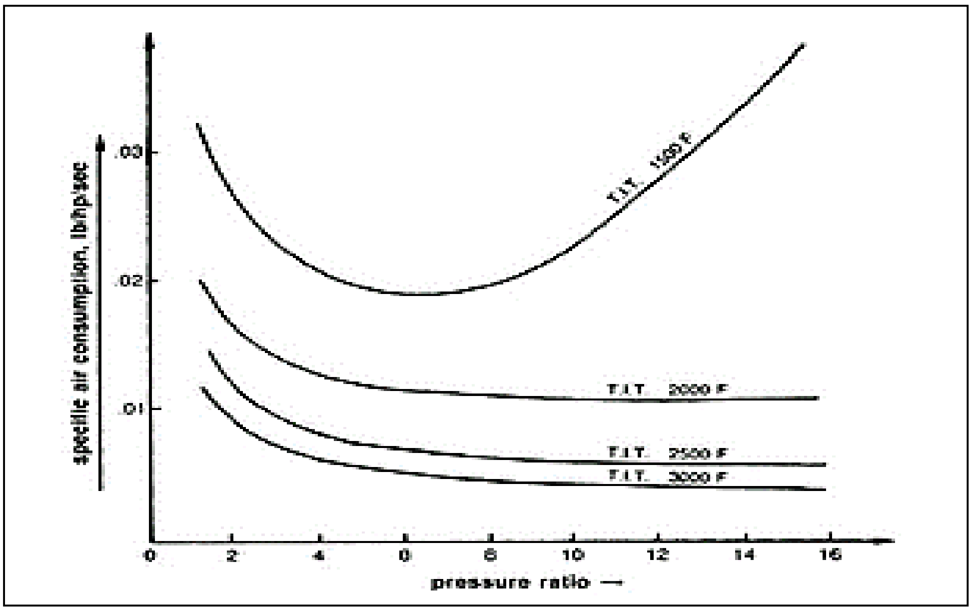


Figure II.5: Specific Air versus pressure ratio and turbine inlet temperature [25].

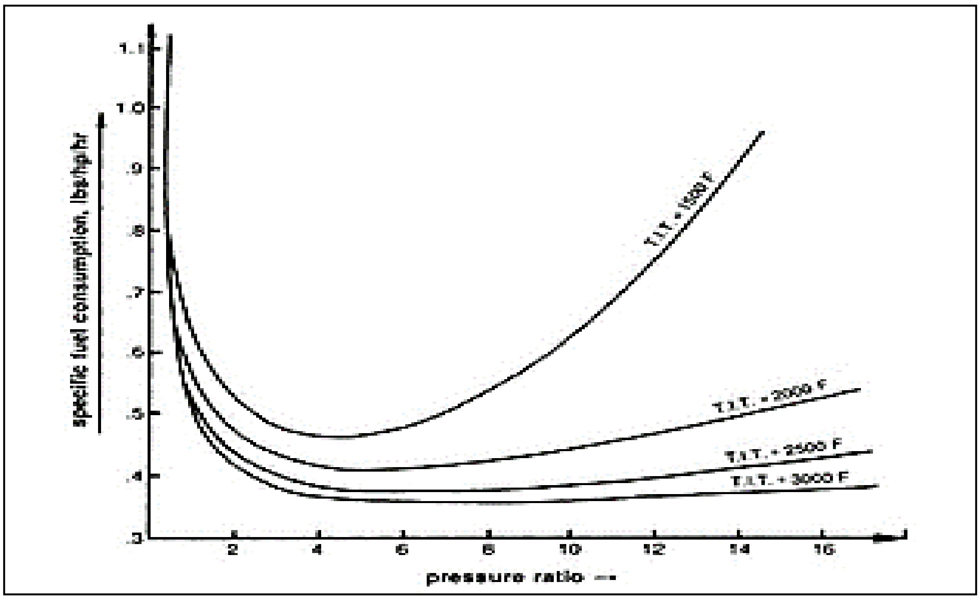


Figure II.6: Specific fuel consumption versus pressure ration and turbine inlet temperature [25].

In a constant speed engine, the differences in temperature will show up on exhaust gas temperature. In some cases, it will show up on the load the engine will pull. For instance, on a hot day of 49°C, the engine on a 300-kW generator set may be able to pull only 275 kW. This is due to limitations on exhaust or turbine inlet temperature. On a day with -17° ambient temperature, the same engine will pull 300 kW. It can have an exhaust or turbine inlet temperature that is more than 38°C, lower than average.

Here again, less fuel is needed to increase volume and a greater mass weight flow. In turn, the plant is more efficient [25,26].

II.7.2 Ambient pressure:

The impact of operating the engine at lower ambient pressures (for example, due to site elevation or simply due to changing atmospheric conditions) is that of a reduced air density (figure II.7). The engine, thus, sees a lower mass flow (while the volumetric flow is unchanged). The changed density only affects the power output, but not the efficiency of the engine. However, if the engine drives accessory equipment through the gas generator, this is no longer true because the ratio between gas generator work and required accessory power (which is independent of changes in the ambient conditions) is affected [27].

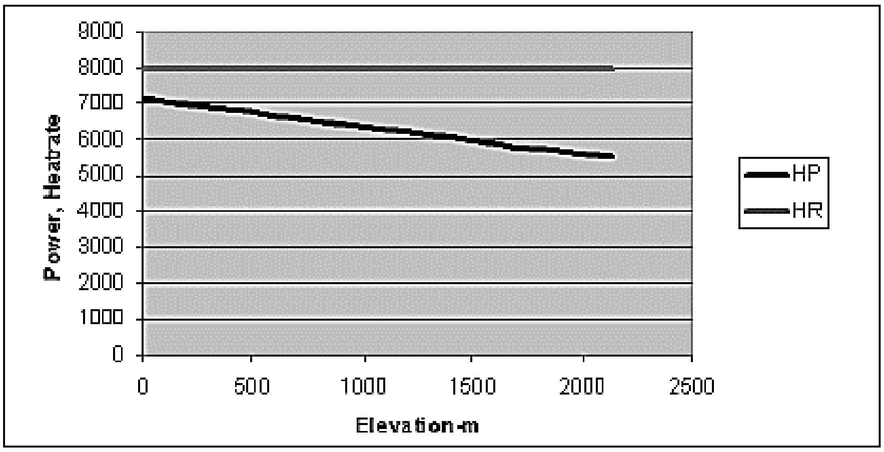


Figure II.7: Power and heat rate as a function of site elevation (Typical).

II.7.3 Fuel:

While the influence of the fuel composition on performance is rather complex, The fuel gas pressure at skid edge has to be high enough to overcome all pressure losses in the fuel system and the combustor pressure, which is roughly equal to the compressor discharge pressure P_2. The compressor discharge pressure at full load changes with the ambient temperature, and, therefore, a fuel gas pressure that is too low for the engine to reach full load.

Gas fuels for gas turbine are combustible gases or mixtures of combustible and inert gases with a variety of compositions covering a wide range of heating values HV and densities. The combustible components can consist of methane and other low molecular weight hydrocarbons, hydrogen, and carbon monoxide. The major inert components are nitrogen, carbon dioxide, and water vapor. It is generally accepted that this type of fuel has to be completely gaseous at the entry to the fuel gas system and at all points downstream to the fuel nozzle (ASME B133, 1992).

Gaseous fuels can vary from poor quality wellhead gas to high quality consumer or “pipeline” gas. In many systems, the gas composition and the quality may be subject to variations. Typically the major sources of contaminants within these fuels are:

Solids, water, heavy gases present as liquids, oils typical of compressor oils, hydrogen sulfide H_2S, hydrogen H_2, carbon monoxide, carbon dioxide and siloxanes.

Other factors that will affect turbine or combustion system life and performance include lower heating value (LHV), specific gravity (SG), fuel temperature, ambient temperature.

Some of these issues may coexist and be interrelated. For instance, water, heavy gases present as liquids, and leakage of machinery lubricating oils may be a problem for turbine operators.

Water in the gas may combine with other small molecules to produce a hydrate, a solid with an ice-like appearance. Hydrate production is affected, in turn, by gas composition, gas temperature, gas pressure, and pressure drops in the gas fuel system. Liquid water in the presence of hydrogen sulfide (H_2S) or CO_2 will form acids that can attack fuel supply lines and components. Free water can also cause turbine flameouts or operating instability if ingested in the combustor or fuel control components.

Heavy hydrocarbon gases present as liquids provide many times the heating value per unit volume than they would as a gas. Since turbine fuel systems meter the fuel based on the fuel being a gas, this creates a safety problem, especially during the engine startup sequence when the supply line to the turbine still lay be cold.

Hydrocarbon liquids can cause:

- → Turbine overfueling, which can cause an explosion or severe turbine damage.
- → Fuel control stability problems, because the system gain will vary as liquid slugs or droplets move through the control system.
- → Combustor het streaks and subsequent engine hot section damage.
- → Overfueling the bottom section of the combustor when liquids gravitate toward the bottom of the manifold.
- → Internal injector blockage over time. When trapped liquids pyrolysis in the hot gas passages.
- → Liquid carryover is known in cause for rapid degradation of the hot gas path components in a turbine.

The condition of the combustor components also has a strong influence, and fuel nozzles that have accumulated pipeline contaminants that block internal passageways will probably be more likely to miss desired performance or emission targets. Thus, it follows that more

Maintenance attention may be necessary to assure that combustion components are in premium condition. This may require that fuel nozzles be inspected and cleaned at more regular intervals or that improved fuel filtration components be installed [27].

II.7.4 Relative humidity:

The impact on the engine performance would be better described by the water content of the air (say, in mole percent). Since the water concentration in the air for the same relative humidity increases with increasing temperature, the effects on engine performance are negligible for low ambient temperature and fairly small (in the range of 1 or 2 percent) even at high temperature of 38°C (100°F). Since the water content changes the thermodynamic properties of air (such as density and heat capacity), it causes a variety of changes in the engine, such that on some engines performance is increased humidity, while other engines show reduced performance at increased humidity [27].

II.7.5 Effect of compressor cleanliness:

Another factor that will have a great effect on performance is the condition of the compressor. A clean compressor is essential to efficiency and reliability. During operation at sea, the compressor takes in a high volume of salt contaminated air. Salt buildup is relatively slow in the compressor and will occur more on the stator vanes and the compressor case than on rotating parts. Centrifugal force tends to sling salt contaminants off the rotor blades.

Any oil ingested into the engine coats the compressor with a film and will rapidly increase contamination of the compressor. The film traps any dust and other foreign matter suspended in the air. The dust and dirt absorb more oil, which traps more dirt, and so forth. If left unattended, the buildup of contamination (either oil or salt) will lead to a choking of the compressor and a restricted airflow. This restricted airflow will require the main fuel to schedule more fuel to produce an equivalent horsepower. The combustion gas temperatures will rise until loss of power, and damage to the turbine may result. Contamination, if not controlled, can induce a surge condition in the compressor during engine start. It will also reduce the life of the compressor and turbine blading through corrosion of the engine parts [26].

II.8 Advantages and disadvantages of gas turbine:

II.8.1 Advantages:

- ✓ Very high power-to-weight ratio, compared to reciprocating engines.
- ✓ Smaller than most reciprocating engines of the same power rating.
- ✓ Moves in one direction only, with far less vibration than a reciprocating engine.
- ✓ Fewer moving parts than reciprocating engines.
- ✓ Greater reliability, particularly in applications where sustained high power output is required.
- ✓ Waste heat is dissipated almost entirely in the exhaust. This results in a high temperature exhaust stream that is very usable for boiling water in a combined cycle, or for cogeneration.
- ✓ Low operating pressures.
- ✓ High operation speeds.
- ✓ Low lubricating oil cost and consumption.
- ✓ Can run on a wide variety of fuels.
- ✓ Very low toxic emissions of CO and HC due to excess air, complete combustion and no “quench” of the flame on cold surfaces.

II.8.2 Disadvantages:

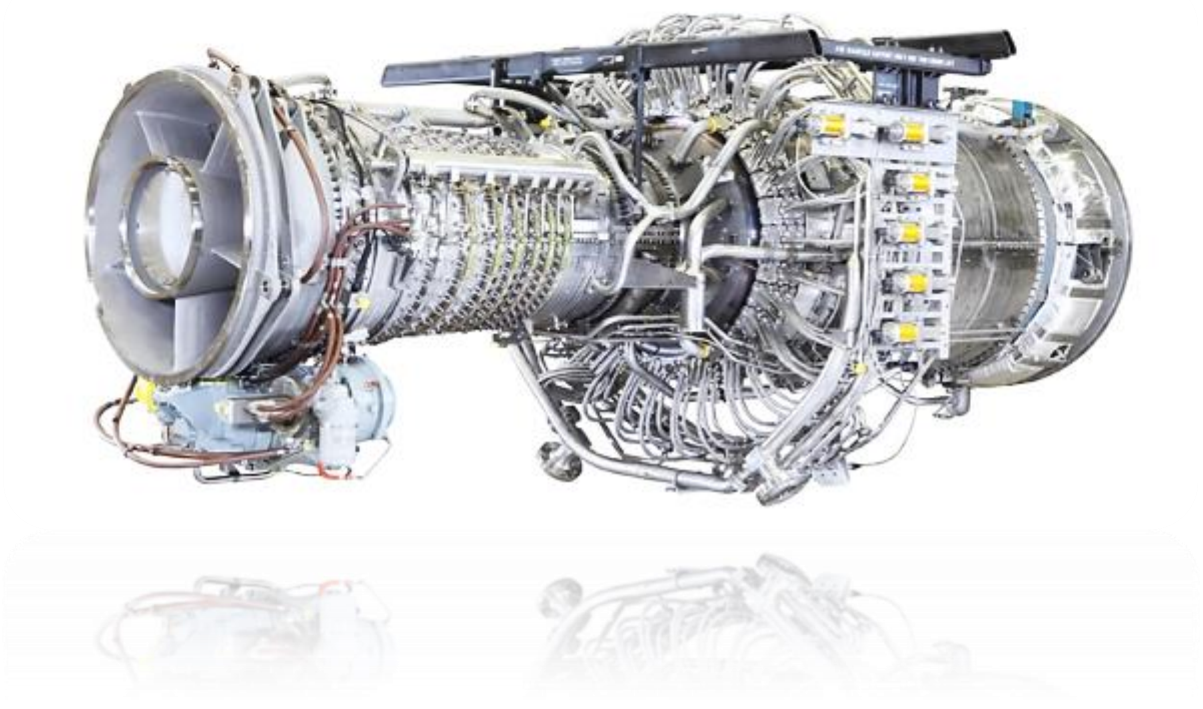
- × Cost is very high
- × Less efficient than reciprocating engines at idle speed
- × Longer startup than reciprocating engines
- × Less responsive to changes in power demand compared with reciprocating engines
- × Characteristic whine can be hard to suppress [28].

II.9 Conclusion:

Gas turbines are the most versatile item of turbo machinery today; they are used to power aircraft and land vehicles, to drive generators (alternators) to produce electric power, and to drive other devices such as pumps and compressors. Gas turbine performance is established by three basic parameters: mass flow, pressure ratio, and firing temperature. The three subsystems that comprise the gas turbine proper are the compressor, combustor, and turbine.

Service requirements of aircraft and industrial gas turbines differ from other power plants principally in the fact that several key components operate at very high temperatures and thus have limited lives and have to be repaired or replaced periodically to avoid failures during operation.

Chapter III: PGT25 DLE Aeroderivative Gas Turbine Engine Description



Chapter III: PGT25 DLE Aeroderivative Gas Turbine Engine Description

III.1. Introduction:

LM2500 has been produced for more than 35 years, with a basic design that is now over 40 years old. Although the engine was originally designed and designed for marine use, industrial applications were found on oil platforms, natural gas pressure stations, power plants and joint pipeline pumping stations.

The engine is available today in many different configurations, either as gas generator or in gas turbines. Works with gas or liquid fuels, and you may have energy production. In this chapter, we will describe gas turbines PGT25 DLE that consists of a gas generator in the industrial LM 2500 gas turbine and through PGT25 electrical turbine and its auxiliary components. Including lubrication, fuel system, gas entrances etc.

III.2 Power Gas turbine 25 description:

III.2.1 General information:

The PGT25 is a jet derivative gas turbine composed by the gas generator of the LM 2500 industrial gas turbine and the PGT25 power turbine. Both Gas Generator and Power Turbine are mounted on a common baseplate, as a single group. On the baseplate is mounted an acoustical enclosure that holding the group. On the baseplate are also installed a part of auxiliary system (synthetic and mineral oil console, etc.). Around outside of the enclosure are installed the walkways with handrails and the enclosure is equipped with the doors for turbo generator inspection and maintenance [29].

III.2.2 PGT25 assembly:

The PGT25 (LM 2500 + HSPT) is an aero derivative gas turbine consists of a variable geometry compressor, an annular combustion, a high pressure turbine, an accessory drive gearbox, and controls and accessories (figure III.1).

The power turbine is composed of a 6-stage low-pressure turbine rotor, a low-pressure turbine stator, and a turbine rear frame. It is aerodynamically coupled to the gas generator and is driven by the gas generator exhaust gas. The high-speed coupling shaft adapter is connected to the power turbine rotor and provides shaft power to the connected load. The inlet duct and center body are the engine inlet components.

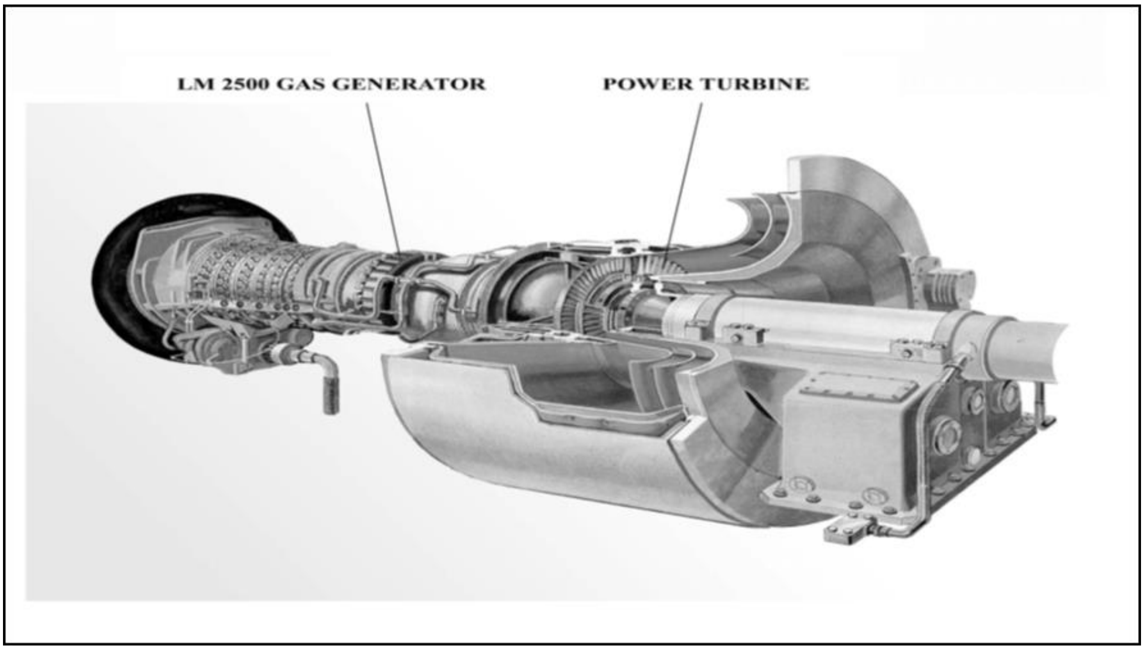


Figure III.1: PGT 25 (GG-LM2500+HSPT) assembly [30].

III.2.2.1 The LM 2500 gas generator:

The gas turbine (LM2500) is composed by the gas generator of aero-derivative type that is a single shaft engine equipped with axial compressor; the LM 2500 gas generator incorporates a 16-stage axial-flow compressor capable of reaching an 18:1 pressure ratio inlet guide vanes and adjustable stator vanes on the first six compressor stages provide for efficient operation over the entire operating range; dry low emission (DLE) chamber and two stage high pressure turbine; an accessory drive system and controls and relevant accessories. The engine is equipped with gas fuel system [30].

III.2.2.2 The high-speed power turbine HSPT:

The High Speed Power Turbine (HSPT) is a two-stage high-speed turbine aerodynamically Coupled to the Gas generator and driven by the gas generator exhaust gases. The Power Turbine rotor is connected to the Centrifugal Compressor shaft. The inlet duct and center body are the engine air inlet components. The engine is completely assembled and tested in factory; the power turbine items are mounted on the common baseplate except for the ignition system and bleed air valves. Part of the ignition system is shipped loose for mounting on site. The gas generator is shipped as an assembled unit in a metal reusable container. The reminder of the equipment is shipped in wooden crates [30].

III.3 Functional description:

Before to perform the first unit start-up, or once GT enclosure ventilation has been stopped, a pre-start purge sequence is carried out for purging the Unit enclosure. When the starting system is actuated, ambient air is drawn through the air inlet plenum assembly, filtered and compressed in the axial-flow compressor. When the starting system has accelerated the rotor to ignition speed, the spark plug is energized and fuel is turned on. The resulting fuel/air mixture is injected, by means of burners, in the combustion chamber and ignited by the spark plug. When the chamber is lit, as indicated by the flame detectors, the start-up sequence continues. Air from the compressor flows enters the combustion zone through the combustion liner.

The hot gases from the combustion chambers enter the 1st stage fixed nozzles and the 1st stage turbine wheel buckets and subsequently the 2nd stage nozzles and 2nd stage wheel buckets. In the nozzle rows, the energy of the jet is increased, with an associated pressure drop and is absorbed as useful power on the turbine rotor.

After passing through the 2nd stage buckets, the gases are directed to the Gas Turbine power shaft passing through the two stage nozzles and relevant power rotor buckets alternatively. Then the exhaust will be discharged into the exhaust duct and stack to the atmosphere. Resultant shaft rotation is used to produce the power turning the Centrifugal Compressor [30].

III.4 Aero-derivative gas turbine components:

A gas turbine unit consists of various components, which includes main and auxiliary components that we will described below. Like the compressor for delivering pressurized air to the combustion chamber or combustors where the actual combustion occurs, the expander section comprising the turbine where the exhaust gases are expanded to do work.

III.4.1 Main components:

The LM 2500 + DLE GT Assembly consist of a gas generator, power turbine and high speed coupling shaft showing in figure III.2.

III.4.1.1 Gas Generator:

III.4.1.1.1 Compressor:

The compressor is a 16 stages high-pressure ratio axial flow design. The main components of the compressor are:

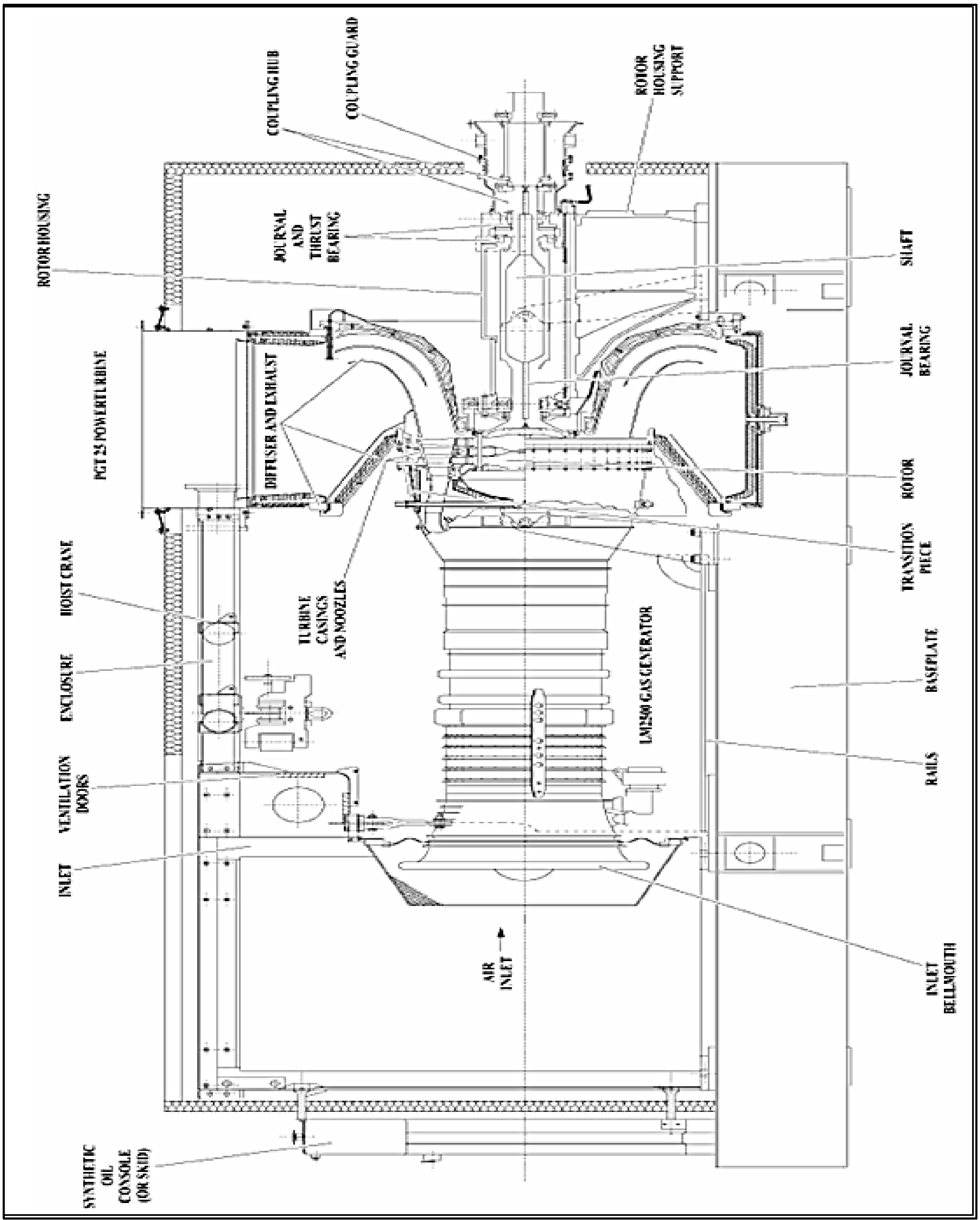


Figure III.2: Typical cross section of aeroderivative gas turbine PGT25 [30].

- → Compressor front frame,
- → Compressor rotor,
- → Compressor stator,
- → Compressor rear frame.

The primary purpose of the compressor show in figure III.3 is to compress the air to the combustor; part of the air is used to cool the engine, for temperature control and for Customer use, as required. Air taken in through the front frame flows through the compressor successive stages and the stator vanes and is compressed as it passes from stage to stage. Finally, the air has been compressed in the ratio of 18:1 [30].

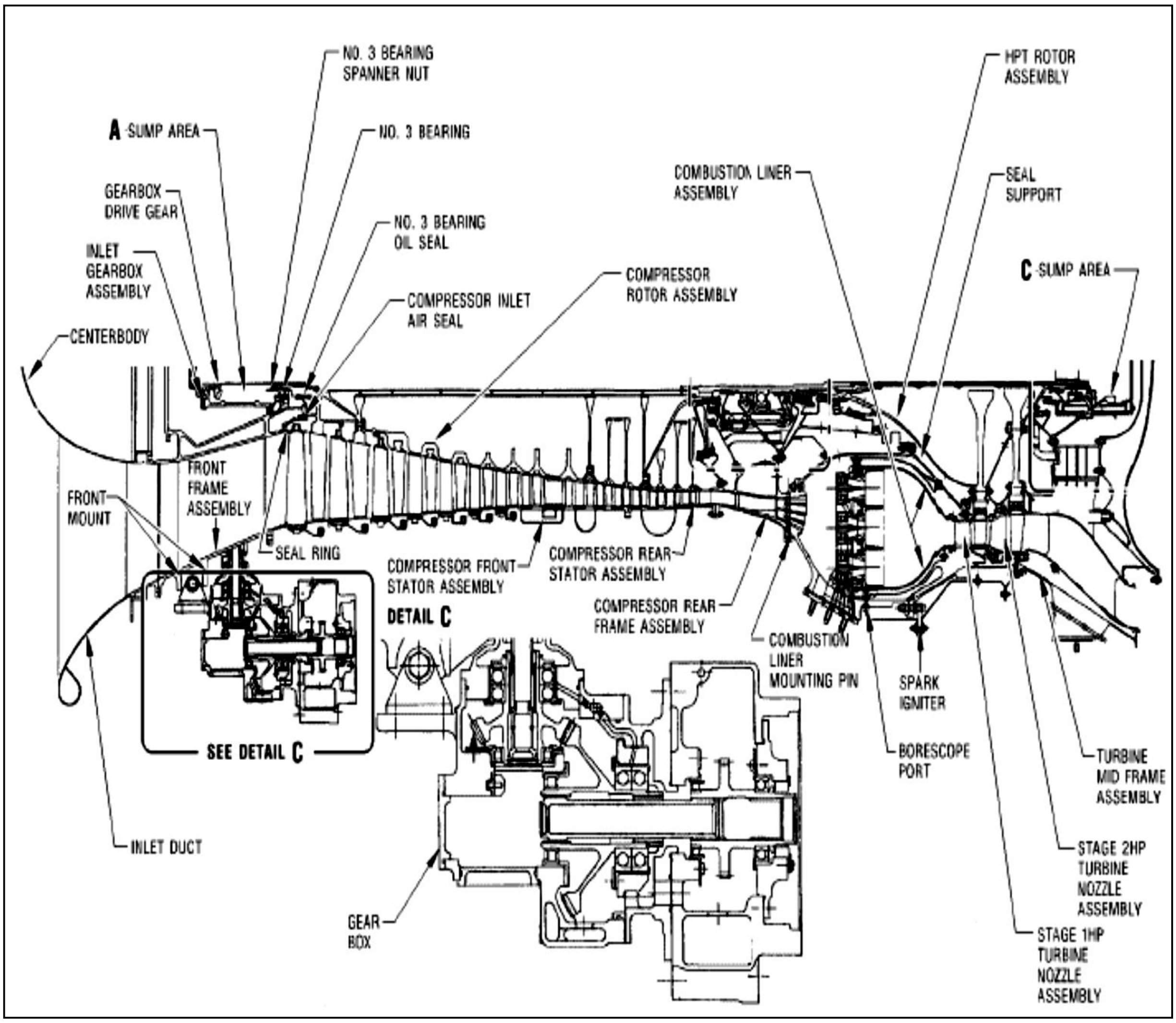


Figure III.3: LM2500 Gas Generator assembly – Cross section [30].

III.4.1.1.2 Compressor support:

The front of the compressor stator is supported by the front frame casing and the front of the compressor rotor is supported by the No.3R roller bearing which is housed in the front frame hub (A-sump) Figure III.4. The rear of the compressor stator is supported by the rear frame casing and the rear of the rotor is supported by the No.4B ball and No.4R roller bearing which are housed in the compressor rear frame hub (B-sump).

The supports for the Gas Generator rotors consist of a four-bearing system: The No.3R and 4R bearings are roller bearings mounted on the forward and aft compressor shaft respectively. Bearing No.4B is a ball bearing and is used to carry the thrust load of the gas generator rotor. The No.5R bearing is a roller bearing supporting the rear shaft of the gas generator turbine rotor [30].

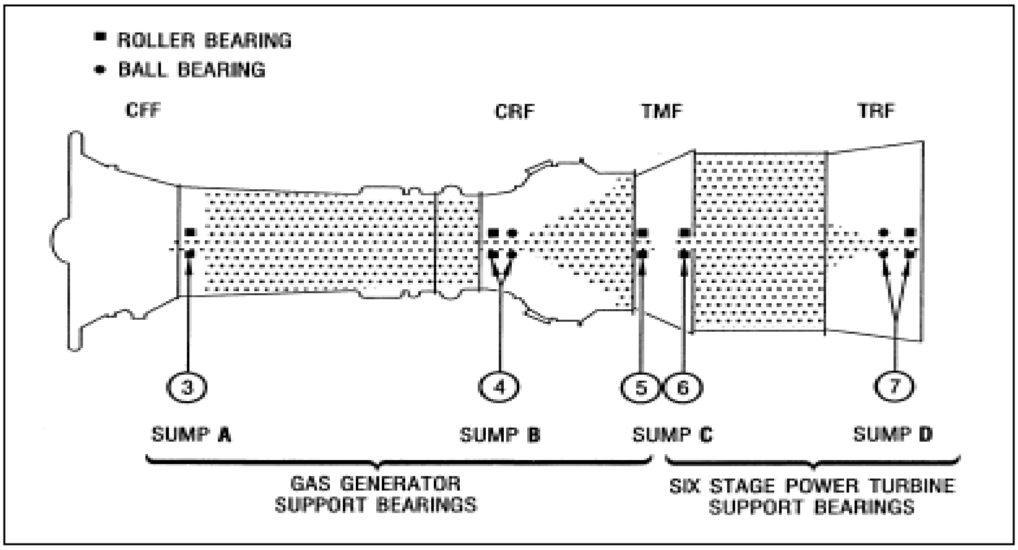


Figure III.4: Gas generator and gas turbine bearings.

III.4.1.1.3 Compressor front frame:

The front frame assembly forms a path for compressor inlet air figure III.5. Struts between the hub and outer case provide lubrication supply and scavenge for the **A**-sump components. The frame also supports the compressor rotor front bearing, inlet duct, center body, and forward end of compressor casing, compressor inlet seals, inlet gearbox and the **A-**sump end cover.

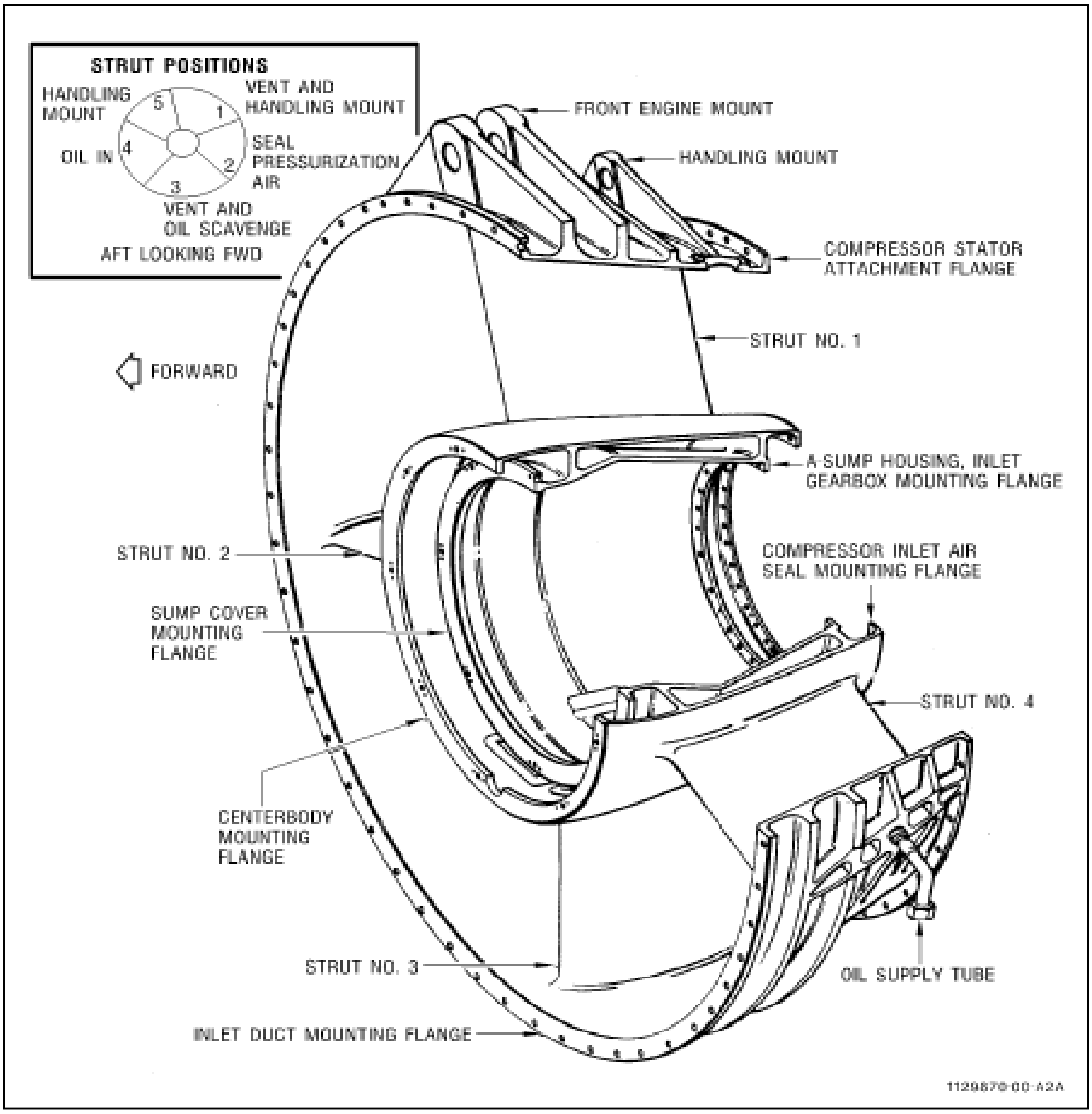


Figure III.5 : Front frame assembly [30].

III.4.1.1.4 Compressor rotor:

The compressor rotor show in figure III.6 is a spool/disk structure. Use of spools makes it possible for several stages of blades to be carried on a single piece of rotor structure. It consists of seven major structural elements and three mains bolted joints; all the assembled parts compose the compressor rotor with the 16 stages of blades. Interfering rabbets are used in all flange joints for good positioning of parts and for rotor stability.

An air duct supported by the rear shafts, routes pressurization air aft through the center of the rotor for pressurization of the B-sump seals.

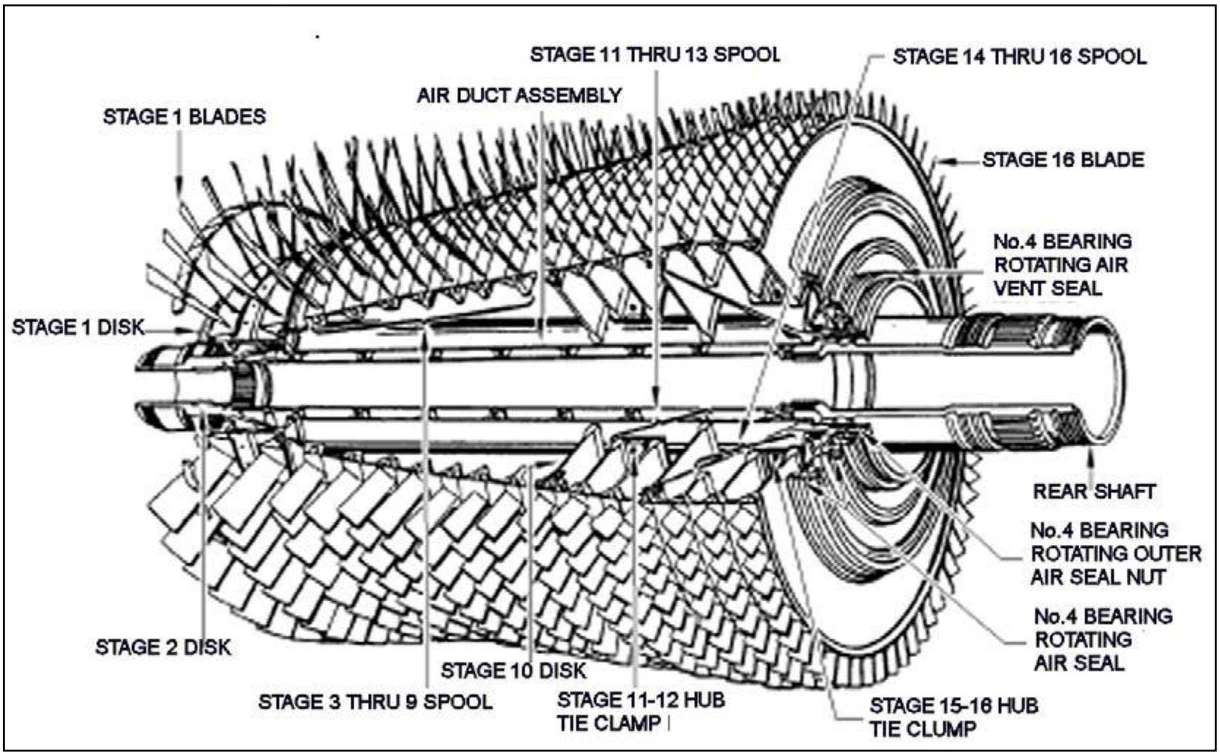


Figure III.6: Compressor rotor assembly.

III.4.1.1.5 Compressor stator:

The compressor stator figure III.7 consists of two front casing halves and two rear casing halves, each split horizontally with all four pieces bolted together. They house the compressor variable and fixed vanes and provide a structural shell between the compressor front frame and the compressor rear frame. The stator has 1 stage of inlet guide vane (IGV) and 16 stages of stator vanes.

The IGV’s and stages 1 through 6 are variable and their angular positions change as a function of compressor inlet temperature and gas generator speed. The variability gives the vane airfoil the optimum angle of attack for efficient operation without compressor stall. The vane positions are controlled by a variable geometry control. Three bleed manifolds are welded to the stator casing. Bleed air is extracted from the inner annulus area at the tips of the stage 8 vanes and is used for sump pressurization and cooling. Bleed air extracted at the stage 9 vanes, is used for power turbine cooling, power turbine forward seal pressurization and power turbine balance piston cavity pressurization. Bleed air extracted at stage 13 vanes, is used for cooling stage 2 high-pressure turbine nozzle [29, 30].

The IGV's and stage 1 and 2 are shrouded. These shrouds are held together with bolts. Stage 1 and 2 vane shrouds mate with rotor teeth seals. The variable vanes are actuated by a pair of master levers. Each of the master lever forward ends is positioned by and hydraulic actuator Adjustable linkages connect directly from the master levers to the actuating rings of the variable vanes.

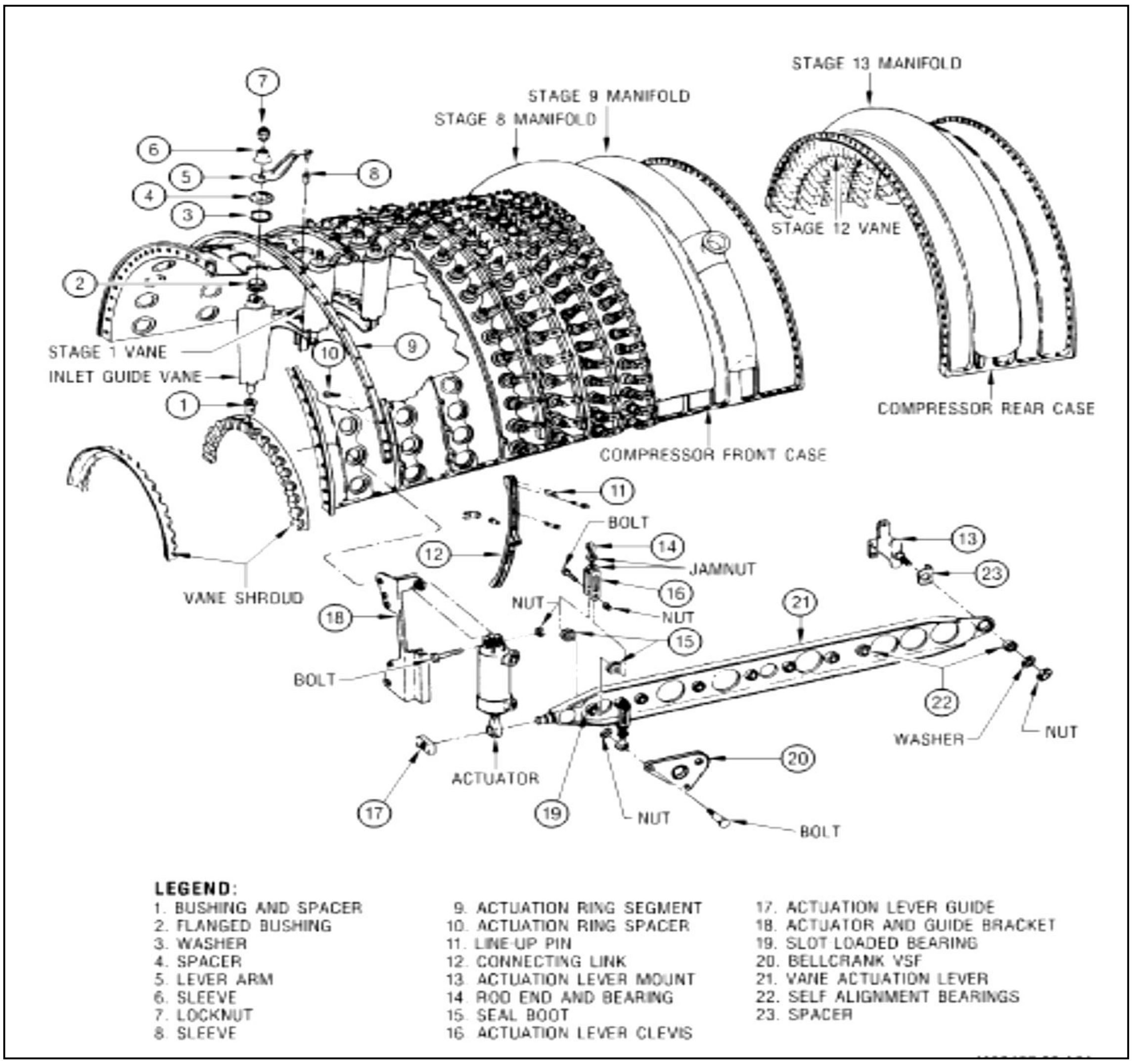


Figure III.7: Compressor stator assembly[30].

III.4.1.1.6 Compressor rear frame:

The compressor rear frame assembly consists of the outer case, the struts, the hub and the B-sump housing figure III.8. Its outer case supports the 30 fuel premixers and one spark igniter. Bearing axial and radial loads and a portion of stage 1 nozzle load are taken in the hub and transmitted through 10 radial struts to the case. The hub struts and outer casing are a one-piece casting. This casing is welded to the fuel embossment ring and bolted to the aft case.

To provide compressor discharge air, an internal manifold within the frame extracts air from the combustion area and routs it to the struts 3, 4, 8, 9.

The B-sump housing is fabricated from casting that forms the sump cavity and supports the sump seals, a sheet support cone and a machine circumferential flange. Service tubing attachment points are made with standard fittings, which allow the housing to be removed from the frame without braking permanent connections [31].

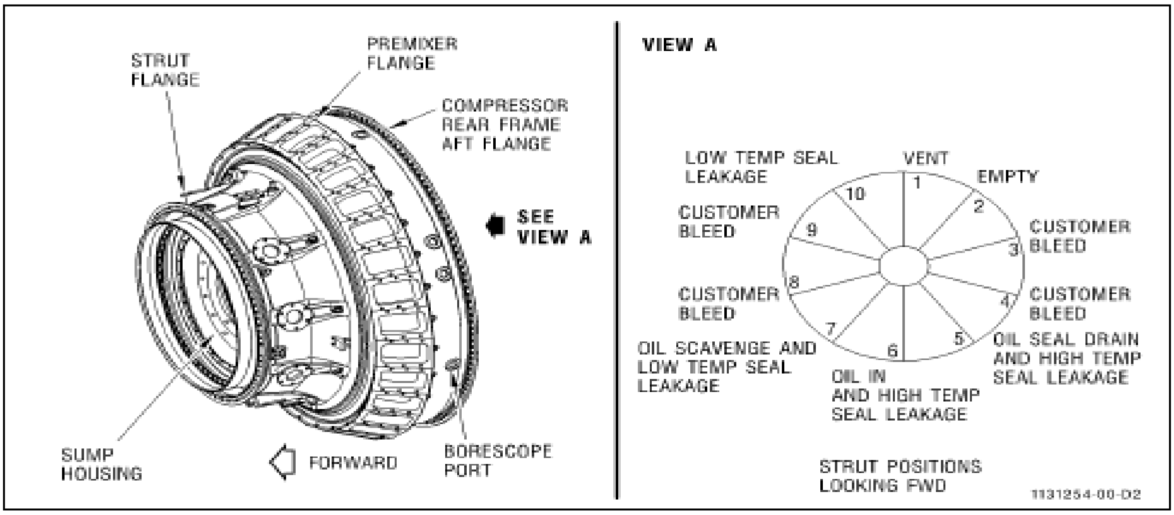


Figure III.8: Compressor rear frame[31].

III.4.1.1.7 Turbine mid frame:

The turbine mid frame figure III.9 supports the aft end of the high-pressure turbine rotor. It is bolted between the rear flange of the compressor rear frame and the front flange of the power turbine stator. The frame provided a smooth diffuser flow passage for high-pressure turbine discharge air into the power turbine. The power turbine stage 1 nozzles assemble to the turbine mid frame [31].

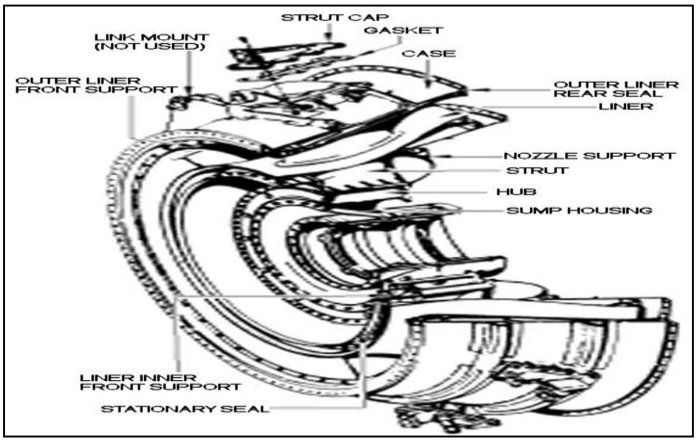


Figure III.9: Turbine mid Frame

III.4.1.2 Combustor:

The combustor is annular and consists of four major components riveted together, cowl (diffuser) assembly, dome, inner skirt and outer skirt.

The cowl assembly, in conjunction with the compressor rear frame, serves as a diffuser and distributor for the compressor discharge air. It furnishes uniform air flow to the combustor throughout a large operating range and provides uniform combustion and even temperature distribution at the turbine.

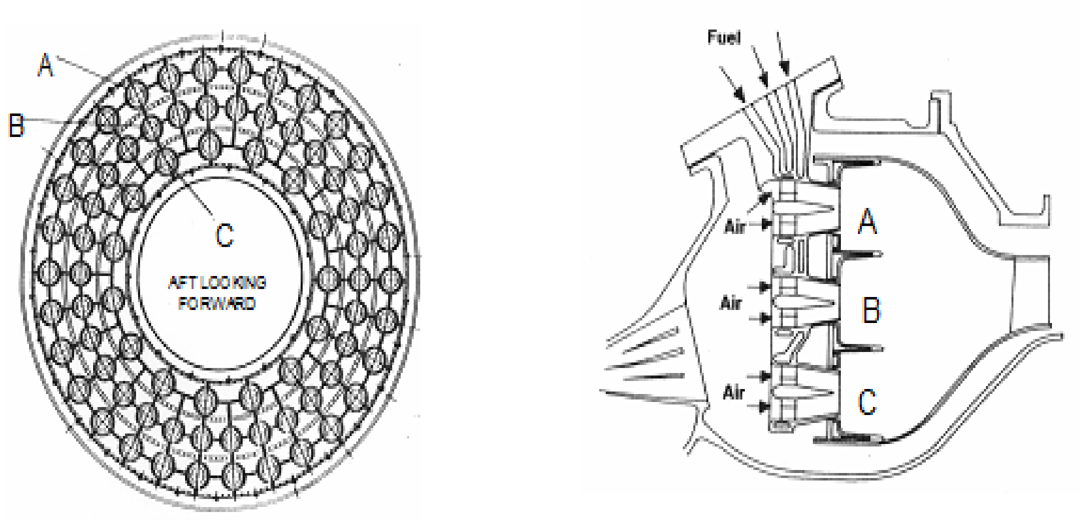
The combustor is mounted in the compressor rear frame on the equally spaced mounting pins in the forward (low temperature) section of the cowl assembly. These pins provide positive axial and radial location and assure centering of the cowl assembly in the diffuser passage. The mounting hardware is enclosed within the compressor rear frame struts so that airflow is not affected.

Thirty vortex-inducing, axial swirl cups in the dome (one at each fuel nozzle tip) provide flame stabilization and mixing of the fuel and air. The interior surface of the dome is protected from the high temperature of combustion by a cooling-air film. The combustor liners are a series of overlapping rings joined by resistance- welded and brazed joints. They are protected from the high combustion and cooling air enters through closely spaced holes in each ring. These holes help to center the flame and admit the balance of the combustion air. Dilution holes are employed on the outer and inner liners for additional mixing to lower the gas temperature at the turbine inlet. Combustor/turbine nozzle air seals at the aft end of the liners prevent excessive air leakage while providing for thermal growth [29].

III.4.1.2.1 Dry Low Emission (DLE) Combustor:

A relatively new type of combustor called a Dry Low Emission (DLE) combustor has emerged as a reliable and effective design for reducing pollutant emissions figure III.10 shows the basic combustor configuration. The “dry” term refers to the DLE combustor’s ability to run without the injection of water or steam into the combustion chamber. The DLE combustor uses active control systems to regulate air-fuel flow through a complex array of injection nozzles.

This allows the air fuel ratio (AFR) and combustion temperature to be properly controlled within a narrow band of 1500°C-1650°C flame temperatures [32]. An example of a DLE combustor is the aeroderivative Turbine PGT25 DLE Low-NOx Combustor. The LM2500 Dry Low Emissions (DLE) gas turbines employ a triple annular combustor.



End view showing the 75 cups

Cross section of 3 cup assembly

Figure III.10: DLE Combustor [31].

III.4.1.2.2 Combustion process:

Gas fuel is introduced into the combustor via 75 air/gas premixers packaged in 30 externally removable and replaceable modules. The mixers produce a very uniformly mixed lean fuel/air mixture. Half of these modules have two premixers and the other half have three. The 75 premixers, or cups, as they are often referred to for the DLE, are arranged in three rings or domes figure III.11. The middle ring is referred to as the pilot or the B ring and has 30 cups. The pilot ring is always fueled. The inner ring is referred to as the C ring and has 15 cups, whereas the outer ring, which is referred to as the A ring, as if the pilot has 30 cups. Unlike the pilot ring, fuel to the cups in the inner and outer rings has to be turned on and off by means of staging valves. This is because of the limited flame temperature (or fuel-air ratio) range over which the combustor can operate.

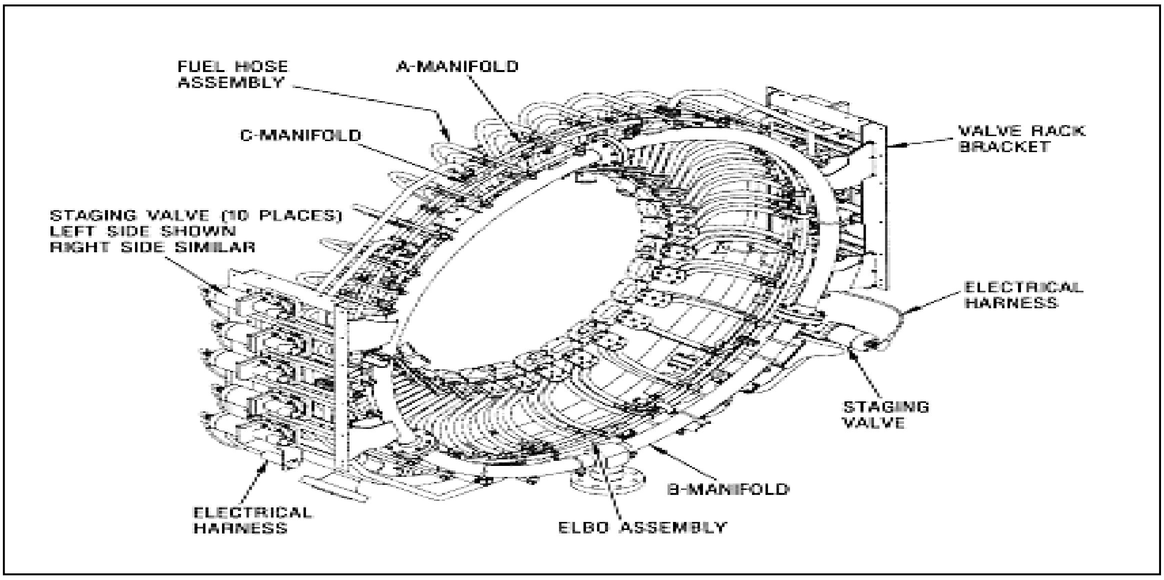


Figure III.11: Fuel hose and premixer replacement [31].

The flame temperature range is limited by thermal stress limits on the high side and lean blowout on the low side. The minimum bulk or average flame temperature for an LM6000 ranges from approx. 1815 C ° at no load sync idle to approx. 1593 C ° at maximum power, whereas the maximum bulk or average flame temperature ranges from approx. 1899 ° at no load sync idle to approx. 1649 C ° at maximum power.

With such a limited flame temperature operating range, it is necessary to "stage" the combustor, it is necessary to turn sections of the combustor "on" and "off". In the current design, 15 staging valves supply the inner ring, one cup per staging valve, and 10 staging valves supply the outer ring, three cups per staging valve. One additional staging valve, as described later, is used to control the fuel flow level to what was originally referred to as an enhanced lean blowout (ELBO) circuit that is connected to 15 of the 30 pilot cups [33].

Staging valves allow different fueling configurations for the combustor, ranging from B-only for starting and idle operation, to fueling of all three rings (ABC) for operation at high power. As mentioned earlier, different combustor configurations are required to keep the combustor flame temperature within limits. The different combustor configurations are shown in Figure III.12.

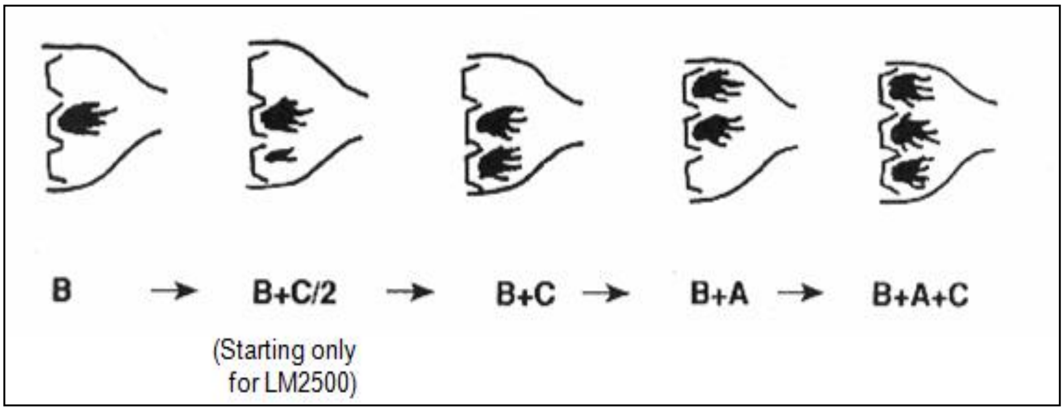


Figure III.12: Combustor configurations [31].

III.4.1.3 High-speed power turbine:

The high-speed power turbine (H.S.P.T.) assembly consists of a turbine rotor figure III.13, a turbine stator, a turbine exhaust frame, a diffuser and two barrel bearing housing, which supports the output shaft. Two support legs support the turbine stator. It is connected to the Gas Generator by a transition piece bolted at one side, to the rear flange of the Gas Generator and at the other side to the 1st stage case of Power Turbine. The mentioned transition piece has also the function to permit the gas flowing from the Gas Generator discharge to the Power Turbine 1st stage blades and then to the 2nd stage blades of the Power Turbine rotor. The systems permit the free expansion of the turbine and the correct concentricity of the stator and rotor [30].

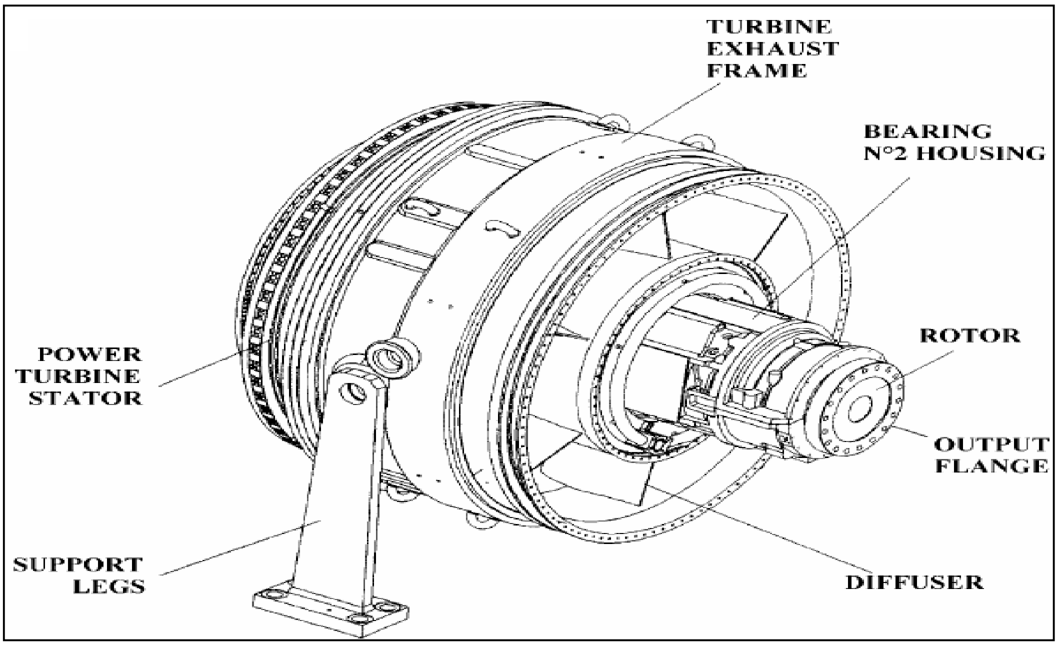


Figure III.13: H.S.P.T assembly.

III.4.1.3.1 Power turbine rotor:

The power turbine rotor is a two stages low-pressure turbine shaft supported by two tilting pad journal bearings by oil continuously lubricated, housed in the turbine stator. Near to the journal bearing coupling side (exhaust side) is installed a thrust bearing carrying the thrust load of the power turbine rotor.

The lubrication means of HSPT bearings is constituted by mineral oil supplied by an oil console common to the Centrifugal Compressor connected with HSPT by a flexible coupling.

III.4.1.3.2 Power turbine stator:

The power turbine stator consists of two casing halves split horizontally; stages 2 turbine nozzles. On the turbine stator are housed two bearing housing containing the journal bearing gas generator side and the journal and thrust bearing coupling side. In the stator are also installed the piping ducting the cooling air to the parts requiring cooling means; the exhaust frame with gas diffusers; the 1st and 2nd nozzle stages [30].

III.4.2 Auxiliary components :

III.4.2.1 Inlet Section :

The inlet section direct airflow into the compressor is the inlet of engine; consists of an elevated air inlet compartment and inlet ducting with silencing provisions connected to the turbine inlet plenum. This system combines the function of filtering and silencing the inlet air with the function of directing air into the gas generator. It provides a smooth non-turbulent airflow into the compressor. This section is composed by an inlet duct and a center body.

III.4.2.2 Filter House:

The turbine through the air filter system sucks turbine combustion air. This air filter is then cleaned to give the air filter greater cleaning efficiency and greater life. The system is designed as a self-cleaning filtering system composed by a series of cartridges in front of each one of this is installed a nozzle blowing air in counter direction of the normal suction air flow, the system is automatically operated when the cleaning grade of filter cartridges exceed a provided limit. Downstream the filtering system is installed an anti-icing system composed by an air heater mixing the hot air, coming from the axial compressor cooling and sealing air system, to avoid the ice formation in the air suction that can cause damages to the engine.

Downstream the filter is installed a silencing system composed by several silencer panels installed inside the air inlet duct.

III.4.2.3 Fuel gas system:

A natural gas system is available for use in low emission application. The PGT25 DLE fuel gas system includes a fuel manifold, flexible hoses, fuel/air premixer valves and fuel staging valves.

The gas manifold is a multi-chambered five pieces, that supplies high pressure fuel to the premixers; primary fuel, enhanced lean blow out valve circuit with premixers.

The premixers are used to produce a very uniformly mixed, lean fuel/air mixture. The staging valves, installed on the manifold, control the fuel distribution to the three combustor domes.

The gas system is composed by:

- A fuel gas treatment & gas analyzer containing;
- a gas heater to increase the temperature to a required one;
- an automatic isolation valve with the relevant control and vent solenoid valves;
- an analyst station to check the chemical composition of gas;
- A “Y” filter upstream the shut off valves;
- An automatic vent valve upstream the shut-off valves;
- Two shut-off valves with relevant solenoid vent valves;
- Three metering valves, one for each gas manifold subdividing the gas supplied to the burners to obtain the minimum possible pollution though the DLE control system [29].

III.4.2.4 Ignition system:

During start, the ignition system produces the high-energy sparks that ignite the fuel air mixture in the combustor. It consists of one ignition exciter, one ignition lead and one spark igniter. A dual ignition system is optional. One ignition has been accomplished, combustion shall continue without additional ignition from the spark igniter until the engine is shut down.

III.4.2.5 Exhaust section:

The Gas Generator engine is supplied with eight exhaust thermocouples installed annularly around the exhaust casing controlling the exhaust gas temperature by the UCP “Mark VI”. The Power Turbine axial exhaust plenum will be connected to the exhaust duct, into which the turbine exhaust gases are discharged before being ducted to the silencer and then vented to atmosphere through the exhaust stack. Six thermocouples controlling the exhaust gas temperature are installed radially to the final exhaust plenum. It is included and connected to the exhaust duct/stack a continuous emission monitoring system in order to keep the exhaust gases always inside the pollution clearances recommended by local laws [29].

III.4.2.6 Starting means:

The starting system includes the driving equipment to bring the unit to self-sustaining speed during the starting cycle. It is also used periodically to motor the gas generator for water washing. Then starter drives the gas generator to a speed which, after light off, shall permit it to continue to accelerate to idle unassisted. The starting system is composed by a hydraulic starting motor installed at the bottom of the engine connected to a hydraulic starting skid, this one gives the motion to the compressor rotor through a transfer gearbox, a radial shaft and an inlet gearbox installed on the engine.

The hydraulic starter consists of a variable displacement type hydraulic motor with piston stroke controlled by a wobble plate. It is equipped with an over running clutch to prevent the motor from being driven by the gas generator when the hydraulic supply pressure and flow are reduced to zero. The complete starting system is already installed on the engine and connected through the oil supply and discharge piping/hoses to the oil tank of the hydraulic starting skid [29].

III.4.2.7 Variable stator control system:

The variable stator control system senses the gas generator speed and compressor inlet temperature (CIT), positioning consequently the variable compressor stator vanes. For any one temperature and any one speed, the variable compressor stator vanes take one position and remain in that position until the gas generator speed or temperature (CIT) changes.

The control provides hydraulic flow to the head and rod-ends of the variable stator vane actuators as a function of feedback position, gas generator speed and compressor inlet temperature. The variable stator actuators receive high-pressure oil from the variable stator vane control and move the variable stator vanes. A movement of the two actuators is transmitted through master levers and actuation rings to the individual vanes. Lubrication system provides an ample supply of filtered lubricant at the proper temperature and pressure for operation of the turbine and its associated equipment. Lubricating fluid is circulated to the turbine accessory gear with starting means, to the turbine bearings, to the load gearbox and gas generator bearings. A portion of the pressurized fluid is diverted and filtered again for use by hydraulic control devices as control fluid and as supply to other systems [29].

III.4.2.8 Lubrication systems:

There are two oil systems:

- → Synthetic oil for Gas Generator
- → Mineral oil for Power Turbine (HSPT) and Centrifugal Compressors.

III.4.2.8.1 Synthetic oil:

The lubrication system is of the recirculating dry sump type. The oil flow in the system varies directly with gas generator speed. Lube oil from a packager provided storage tank is fed to the lube element of the engine mounted lube and scavenge pump. The lube element supplies oil to the engine sumps and gearboxes via a packager provided lube supply duplex filter, anti-static check valve and individual oil jets. The lube oil is scavenged from the bearing sumps and gear boxes via individual scavenge pump elements. The combined scavenge oil flow is returned to the lube oil storage via anti-static check valve, packager provided lube scavenge filters, and an oil cooler. Since the scavenge pump elements have a combined flow rating larger than the supply element, the scavenge oil is mixed with air which is removed in the lube storage tank de-aerator system. Sump air and oil is vented to an engine gearbox mounted air-oil separator where the oil is removed from the mixture and returned to the lube storage tank de-aerator system.

The air is vented overboard via a packager provided air-oil demister or into the exhaust duct via a flame arrestor. Gas Generator utilizes pumps with five scavenge elements: one for each of the A-sump, B-sump and C-sump, plus two elements for the accessory gearbox. The accessory gearbox is scavenged with the A-sump and the air-oil separator is scavenged with the accessory gearbox [30].

III.4.2.8.2 Mineral oil:

The mineral oil, as before mentioned, is used for lubrication of the Power Turbine (HSPT) bearings and BCL bearings. The mineral oil console is installed on the proper baseplate outside the turbine enclosure and contains the pumps, duplex filters and local Gauge board with the instruments The Lube oil reservoir installed in the mineral oil skid.

Major system components include:

- → Main and 1st emergency lube oil pump,
- → Stand-by and 2nd emergency lube oil pump,
- → Lube oil double filters with replaceable cartridges and transfer valve,
- → A Temperature Control Valve,
- → Oil/air heat exchanger with two separate pipe bundles and common motor fans, cooling the mineral and synthetic oil on a separate baseplate.
- → A PCV regulating the oil pressure on the bearings header.

The lube oil pumped from the lube oil reservoir to the bearing header flows through the cartridge type filter providing 25 micron filtration and then through the heat exchangers to remove excess of heat. After lubricating the bearings the oil, flows back through various drain lines to the reservoir [30].

III.4.2.9 Fire protection system:

The fire protection system is comprised of a distribution system of piping for the delivery of CO_2 from a bank of high-pressure cylinders to the required gas turbine compartments in the event of a fire. This bank of high-pressure cylinders is located on an Off-Base skid and maintains saturated liquid carbon dioxide at a storage pressure of 51 bar at 21.1°C.

The fire protection system control panel is mounted in the Off-Base cabinet, where the CO_2 high-pressure cylinders are located. The interconnecting field piping, which is usually supplied by the installer, delivers the CO_2 from the turbine control room to the gas turbine compartments, where it connects to the piping that distributes the CO_2 into the compartments through nozzle orifices. Two separate distribution systems are used: an initial discharge and an extended discharge. Within a few seconds after actuation, sufficient CO_2 flows from the initial discharge system into the gas turbine compartments to rapidity build up an extinguishing concentration (normally 34%).

A CO_2 concentration (usually 30%) is then maintained by the gradual addition of more CO_2 from the extended discharge system compensating for compartment leakage. Carbon dioxide flow rate is controlled by the size of the orifices in the discharge nozzles in each compartment for both the initial and extended discharge systems. The orifices for the initial discharge system permit a rapid discharge of CO_2 to quickly build up an extinguishing concentration. Orifices for the extended discharge system are smaller and permit a relatively slow discharge rate to maintain an extinguishing concentration over a prolonged period of time (based on the turbine frame size's emergency roll down and cool down periods) to minimize the likelihood of a fire re-igniting [29,30].

III.5 Air/Gas path:

III.5.1 Primary airflow:

The Gas Generator compressor draws air through the inlet duct and the front frame. After being compressed to an approximate ratio of 18:1, the air enters the combustion section where some of it is mixed with fuel, and the mixture burned, after igniting by a spark plug. The remainder of the air is used for centering the flame in the combustor and for cooling the combustor and some parts of the high-pressure turbine.

Some of the energy in the hot combustion gas is used to turn the high-pressure turbine rotor, which is coupled to and turns the compressor rotor. Upon leaving the high-pressure turbine section, the gas passes in the power turbine section. Most of the remaining energy is extracted by the power turbine rotor, which drives the high speed coupling shaft forward adapter. This one mates to the packager supplied coupling shaft [29].

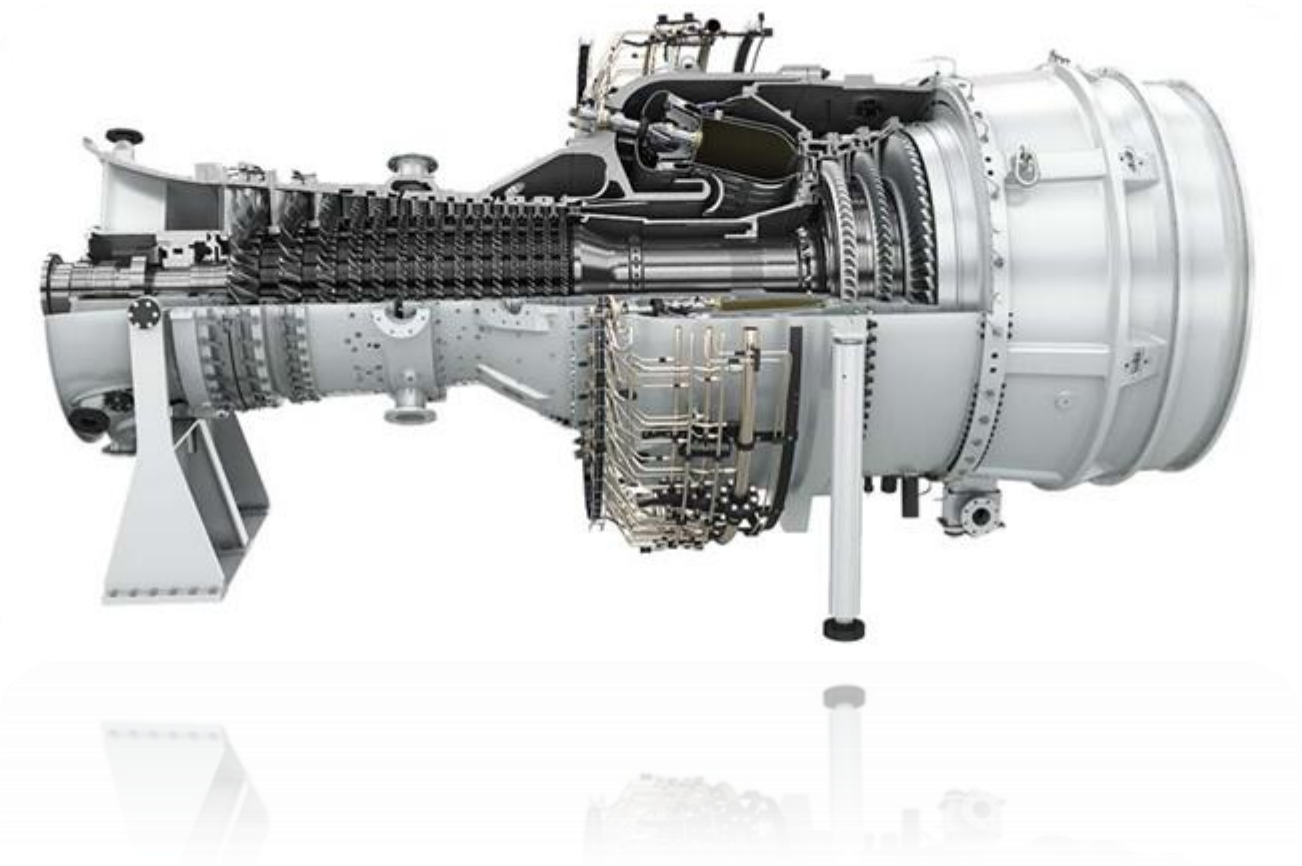
III.5.2 Bleed air:

From some stage of axial compressor is bled into an external manifold that pipes it to the Power Turbine for cooling of the wheel space, blades, nozzle and shaft cooling air. As well is piped to cool the high pressure (Gas Generator shaft) turbine and sump “C” [29].

III.6 Conclusion:

PGT25 gas turbines are one of the most widely used devices in the field of oil and gas, since they have many applications in many factories and regions. Therefore, all its basic and secondary parts must be identified in order to quickly diagnose damage and facilitate maintenance.

Chapter IV: Maintenance of gas turbine engines



Chapter IV: Maintenance of gas turbine engines

IV.1 Introduction:

Maintenance costs and machine availability are among the most important concerns of gas turbine equipment owner. Therefore, a careful maintenance program should be implemented to reduce the costs of the owner while increasing equipment efficiency.

In order for this maintenance program to be effective, owners should develop a general understanding of the relationship between operating plans and factory priorities, and recommendations by all manufacturers regarding the number of inspections and other key factors that affect machine life and correct retroactivity.

In this chapter, we will discuss the maintenance and maintenance schedule for gas turbines, focusing on inspection maintenance types as well as Borescope Inspections holes.

IV.2 Definition of maintenance:

Maintenance is work that is carried out to preserve an asset (such as turbine or motor...), in order to enable its continued use and function, above a minimum acceptable level of performance, over its design service life, without unforeseen renewal or major repair activities [34].

IV.3 Types of maintenance:

IV.3.1 Preventive Maintenance:

Preventive maintenance can be defined as follows: Actions performed on a time- or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level [35].

IV.3.1.1 Periodic maintenance (Time Based Maintenance TBM):

The basic maintenance of equipment made by the users of it. It consists of a series of elementary tasks (data collections, visual inspections, cleaning, lubrication, retightening and screws…) for which no extensive training is necessary, but perhaps only a brief training. This type of maintenance is the based on TPM (Total Productive Maintenance) [36].

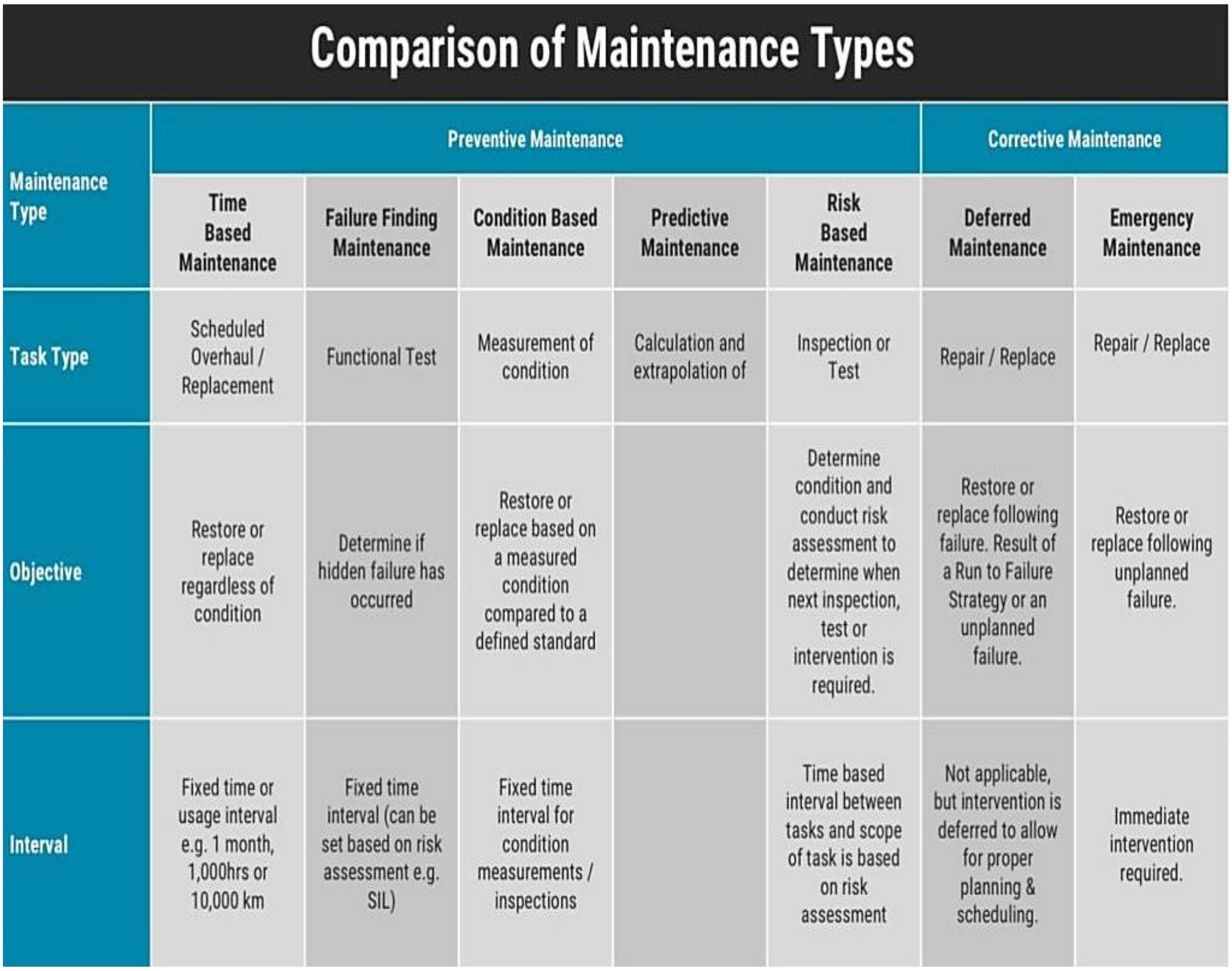
IV.3.1.2 Predictive Maintenance:

It pursues constantly know and report the status and operational capacity of the installations by knowing the values of certain variables, which represent such state and operational ability. To apply this maintenance, it is necessary to identify physical variables (temperature, vibration, power consumption, etc.), which variation is indicative of problems that may be appearing on the equipment.

IV.3.2 Corrective maintenance [34]:

Corrective maintenance is implemented right after a defect has been detected on a piece of equipment or a production line: its objective is to make the piece of equipment work normally again, so that it can perform its assigned function. Corrective maintenance can be either planned or unplanned depending on whether or not a maintenance plan has been created.

Table IV.1 : Comparison of maintenance types [37].



Comparison of Maintenance Types

Maintenance Type	Preventive Maintenance					Corrective Maintenance	
	Time Based Maintenance	Failure Finding Maintenance	Condition Based Maintenance	Predictive Maintenance	Risk Based Maintenance	Deferred Maintenance	Emergency Maintenance
Task Type	Scheduled Overhaul / Replacement	Functional Test	Measurement of condition	Calculation and extrapolation of	Inspection or Test	Repair / Replace	Repair / Replace
Objective	Restore or replace regardless of condition	Determine if hidden failure has occurred	Restore or replace based on a measured condition compared to a defined standard		Determine condition and conduct risk assessment to determine when next inspection, test or intervention is required.	Restore or replace following failure. Result of a Run to Failure Strategy or an unplanned failure.	Restore or replace following unplanned failure.
Interval	Fixed time or usage interval e.g. 1 month, 1,000hrs or 10,000 km	Fixed time interval (can be set based on risk assessment e.g. SIL)	Fixed time interval for condition measurements / inspections		Time based interval between tasks and scope of task is based on risk assessment	Not applicable, but intervention is deferred to allow for proper planning & scheduling.	Immediate intervention required.

IV.4 Maintenance Planning:

Advanced planning for maintenance is necessary for utility, industrial, independent power and cogeneration plant operators in order to maintain reliability and availability. The correct implementation of planned maintenance and inspection provides direct benefits in the avoidance of forced outages, unscheduled repairs, and downtime. The primary factors that affect the maintenance planning process are show in Figure IV.1 [38].

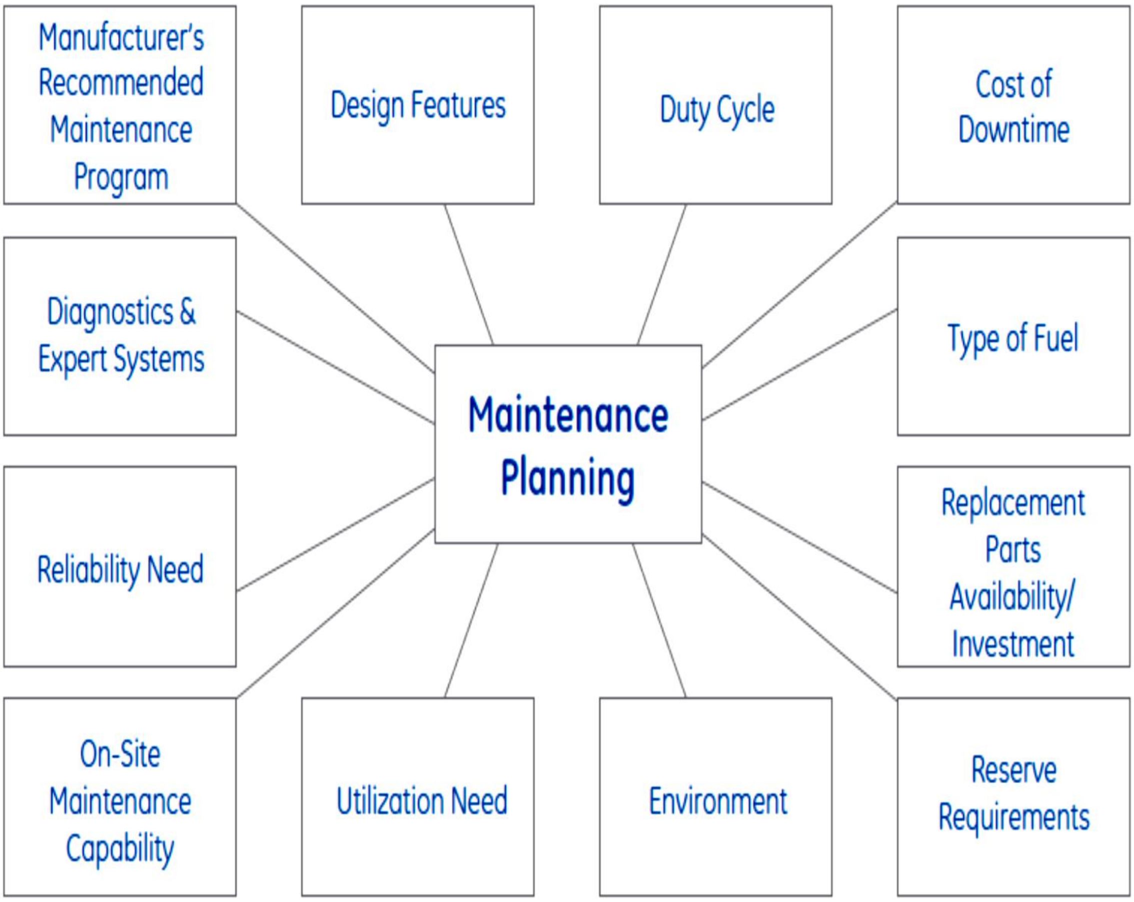


Figure IV.1: The maintenance planning process.

IV.5 Maintenance of gas turbine:

As with any power equipment, gas turbines require a program of planned inspections with repair or replacement of damaged components. A properly designed and conducted inspection and preventive maintenance program can do much to increase the availability of gas turbines and reduce unscheduled maintenance Gas turbines in combined cycle plants face a more and rougher operation with daily starts and stops and power varying depending on renewables production capacities.

On the other hand, the technology must still improve to challenge the highest efficiencies possible with very low emissions. Inspections and preventive maintenance can be expensive, but not as costly as forced shutdowns.

Nearly all manufacturers emphasize and describe preventive maintenance procedures to ensure the reliability of their machinery, and any maintenance program should be based on manufacturer’s recommendations. Inspection and preventive maintenance procedures can be tailored to individual equipment application with references such as the manufacturer’s inspection book, the operator’s manual, and the preventive maintenance checklist [25].

IV.6 Maintenance requirements for Power Turbine PGT25:

The on condition maintenance philosophy is applied on power turbine also, based on borescope inspections every 4,000 running hours or six months (same as gas generator).
Typical disassembly maintenance at 25,000 (hot section inspection) and 50,000 running hours (major inspection), are expected for continuous duty operation, up to base load, with natural gas fuel, no steam or water injection and are given for reference only since actual activities must be based also on the results of borescope inspections. Such activities are normally aligned with those on the gas generator and are not planned additional shut downs for power turbine maintenance [30].

IV.7 Maintenance Inspections:

Maintenance inspection types may be broadly classified as standby, running, and disassembly inspections. The standby inspection is performed during off-peak periods when the unit is not operating and includes routine servicing of accessory systems and device calibration. The running inspection is performed by observing key operating parameters while the turbine is running.

The disassembly inspection requires opening the turbine for inspection of internal components. Disassembly inspections progress from the combustion inspection to the hot gas path inspection to the major inspection as shown in Figure IV.2. Details of each of these inspections are described below.

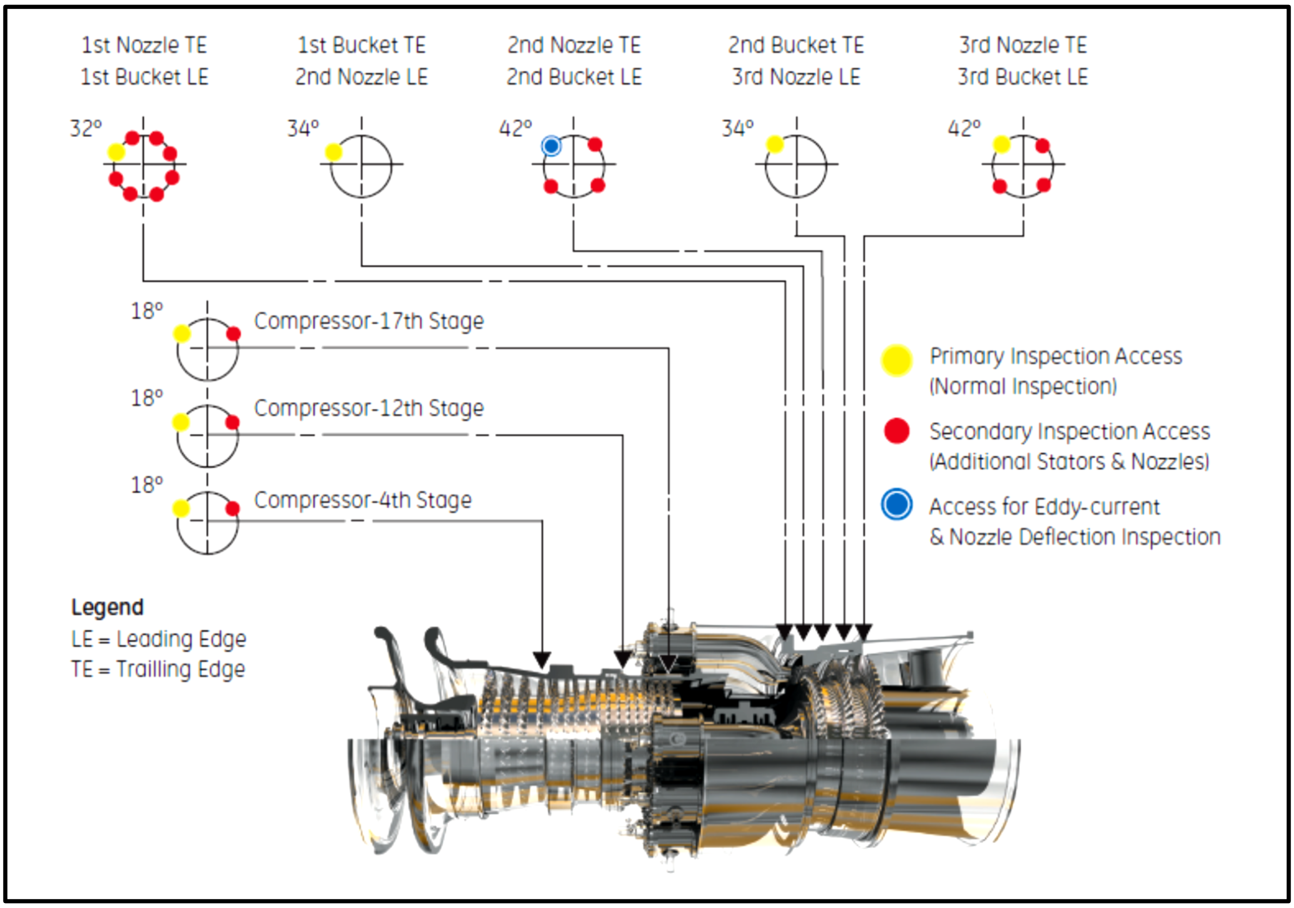


Figure IV.2: Gas turbine borescope inspection access locations [38].

IV.7.1 Standby Inspections:

Standby inspections are performed on all gas turbines but pertain particularly to gas turbines used in peaking and intermittent-duty service where starting reliability is of primary Concern.

This inspection includes routinely servicing the battery system, changing filters, checking oil and water levels, cleaning relays, and checking device calibrations. Servicing can be performed in off-peak periods without interrupting the availability of the turbine. A periodic startup test run is an essential part of the standby inspection.

Careful adherence to minor standby inspection maintenance can have a significant effect on reducing overall maintenance costs and maintaining Aeroderivative turbine reliability.

It is essential that a good record be kept of all inspections and maintenance work in order to ensure a sound maintenance program [38].

IV.7.2 Running Inspections:

Running inspections consist of the general and continued observations made while a unit is operating. This starts by establishing baseline-operating data during startup of a new

Unit and after any major disassembly work. This baseline then serves as a reference from which subsequent unit deterioration can be measured.

Data should be taken to establish normal equipment startup parameters as well as key steady state operating parameters. Steady state is defined as conditions at which no more than a 5°F change in wheel space temperature occurs over a 15-minute time period. Data must be taken at regular intervals and should be recorded to permit an evaluation of the turbine performance and maintenance requirements as a function of operating time.

This operating inspection data: load versus exhaust temperature, vibration level, fuel flow and pressure, bearing metal temperature, lube oil pressure, exhaust gas temperatures, exhaust temperature spread variation, startup time, and coast-down time. This list is only a minimum and other parameters should be used as necessary.

A graph of these parameters will help provide a basis for judging the conditions of the system. Deviations from the norm help pinpoint impending issues, changes in calibration, or damaged components.

A sudden abnormal change in running conditions or a severe trip event could indicate damage to internal components. Conditions that may indicate turbine damage include high vibration, high exhaust temperature spreads, compressor surge, abnormal changes in health monitoring systems, and abnormal changes in other monitoring systems.

It is recommended to conduct a borescope inspection after such events whenever component damage is suspected [38].

IV.7.3 Rapid Cool-Down:

Prior to an inspection, a common practice is to force cool the unit to speed the cool-down process and shorten outage time. Force cooling involves turning the unit at crank speed for an extended period to continue flowing ambient air through the machine.

This is permitted, although a natural cool-down cycle on turning gear or ratchet is preferred for normal shutdowns when no outage is pending.

Forced cooling should be limited since it imposes additional thermal stresses on the unit that may result in a reduction of parts life.

Opening the compartment doors during any cool-down operation is prohibited unless an emergency requires immediate compartment inspection.

Cool-down times should not be accelerated by opening the compartment doors or lagging panels, since uneven cooling of the outer casings may result in excessive case distortion and heavy blade rubs [38].

IV.7.4 Combustion Inspection:

The combustion inspection is a relatively short disassembly inspection of fuel nozzles, liners, transition pieces, crossfire tubes and retainers, spark plug assemblies, flame detectors, and combustor flow sleeves.

This inspection concentrates on:

→ The combustion liners,
→ Transition pieces,
→ Fuel nozzles,
→ In addition to the final covers, which have been recognized as the first to need replacement and repair in a good maintenance program.

Proper inspection, maintenance, and repair of these items will contribute to a longer life of the downstream parts, such as turbine nozzles and buckets [38].

Figure IV.3 : PGT25 Combustion Section parts.

IV.7.5 Hot Gas Path Inspection:

The purpose of the hot gas track is to examine the parts exposed to high temperatures of hot gases emitted from the combustion process. The full range of hot gas trajectory testing includes the combustion test, as well as the detailed inspection of turbine nozzles, fixed-point membranes and turbines.

To perform this test, remove the upper half of the turbine cover.

Before removing the shell, central mechanical support of the machine using mechanical jacks is necessary to ensure proper alignment of the rotor to the fixed part, to obtain half a fine crust, and to prevent twisting of the hard-shell casings [38].

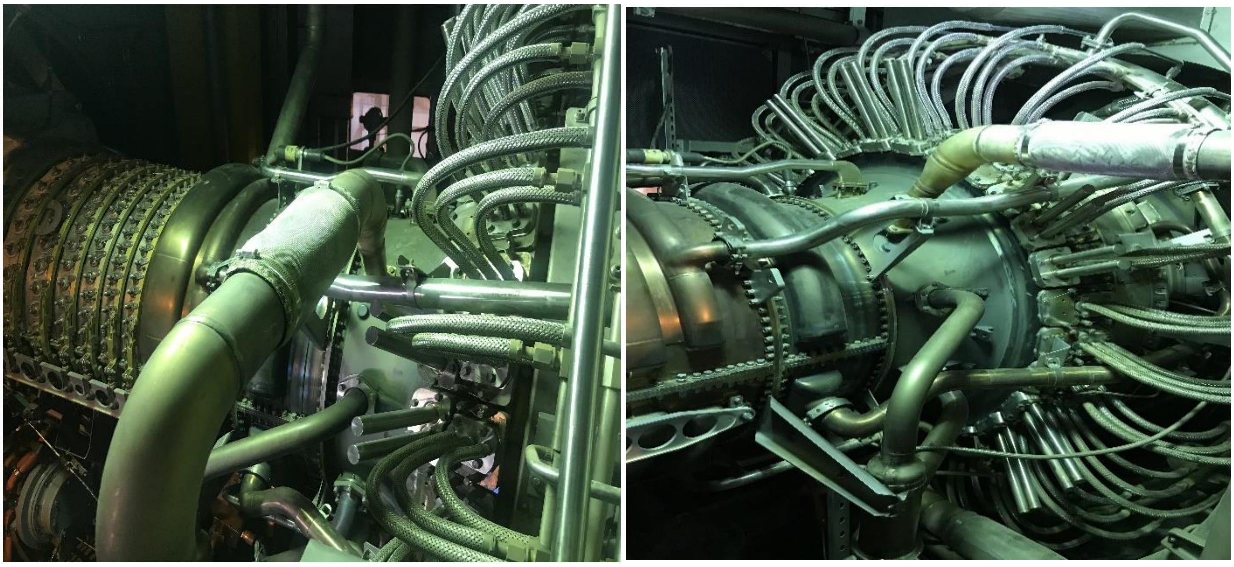


Figure VI.4: The PGT 25 - hot gas path.

IV.7.6 Major Inspection:

The purpose of the major examination is to examine all the rotary and internal fixed components of the inlet during the exhaust.

The main test includes testing all major components from edge to edge of gas turbines, which deteriorate during normal turbine operation. This test includes pre-combustion elements and the hot gas path, and requires the development of gas turbines from the edge to the full edge of the horizontal joints, as shown in Figure IV.5.

Removal of all top covers allows access to rotor, rotary rotor and bearings. Before removing covers, covers, and frames, the unit must be properly supported.

The appropriate midline support using mechanical jacks and lift sequence procedures is necessary to ensure proper alignment of the rotor with the fixed part, to obtain half a thin crust, and to prevent twisting the covers while they are in the vicinity of the half.

The major inspection requirements are:

- → Inspect all casings, shells, frames / diffusers for cracks and corrosion.
- → Check the flow of the compressor flow and compressor flow path for dirt, corrosion, corrosion and leakage.
- → Check rotary blades and fixed rotors for side clearance, rubbing, damage to objects, corrosion and cracking.
- → Wheels, pressure gears, edges, and cross sections should be closely checked for corrosion, deformation, cracking, or vandalism.
- → Check the rotor unit for cracks, body damage.
- → Check the bearings and seals for removal and corrosion… [38].

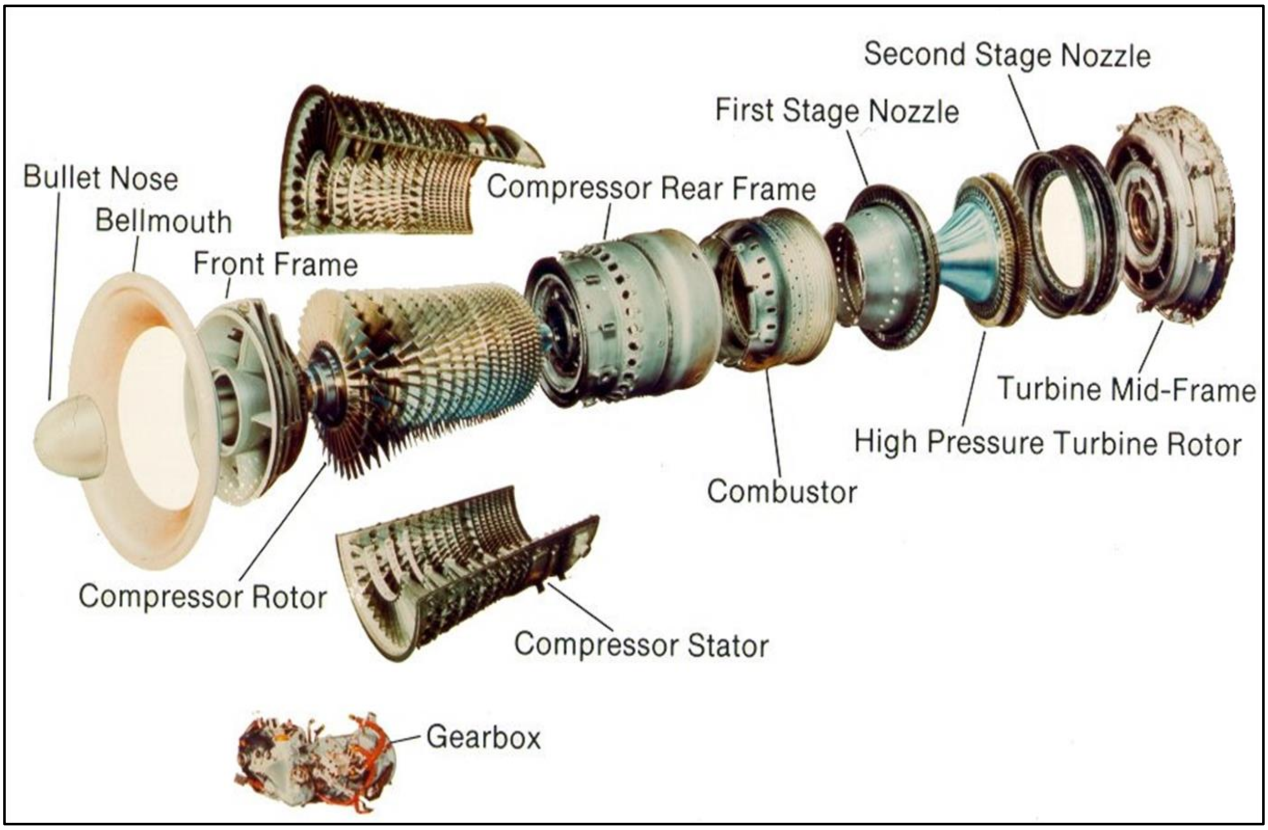


Figure IV.5: The PGT 25 - Disassembly inspections [31].

IV.8 Borescope Inspections:

Gas turbines are designed to allow borescope inspection. Inspection borescope makes it possible to assess the condition within the gas turbines. To take full advantage of the borescope examination, results must be recorded in detail, with images or video. In this way, comparison with the previous scan will be possible. Repeated inspections will allow the user to evaluate the deterioration rate and maintenance schedule required.

The gas turbines are supplied with tight-fitting openings through internal fixed casings and covers to allow penetration of the optical telescope into the gas flow path.

Optical borescope allows optical inspection of fixed and fixed parts without removing turbine casings.

A borescope mapping is done manually to open the unit only when necessary to repair or replace the parts. The planning should include the first examination and recording of the circumstances, whether written, photocopied or recorded at initial start-up, screening, periodic recording or results. The application of the monitoring program, using a borescope, will allow scheduling of Power outages and pre-planning of spare parts requirements, resulting in reduced maintenance costs and increased availability and reliability of gas turbines [39].

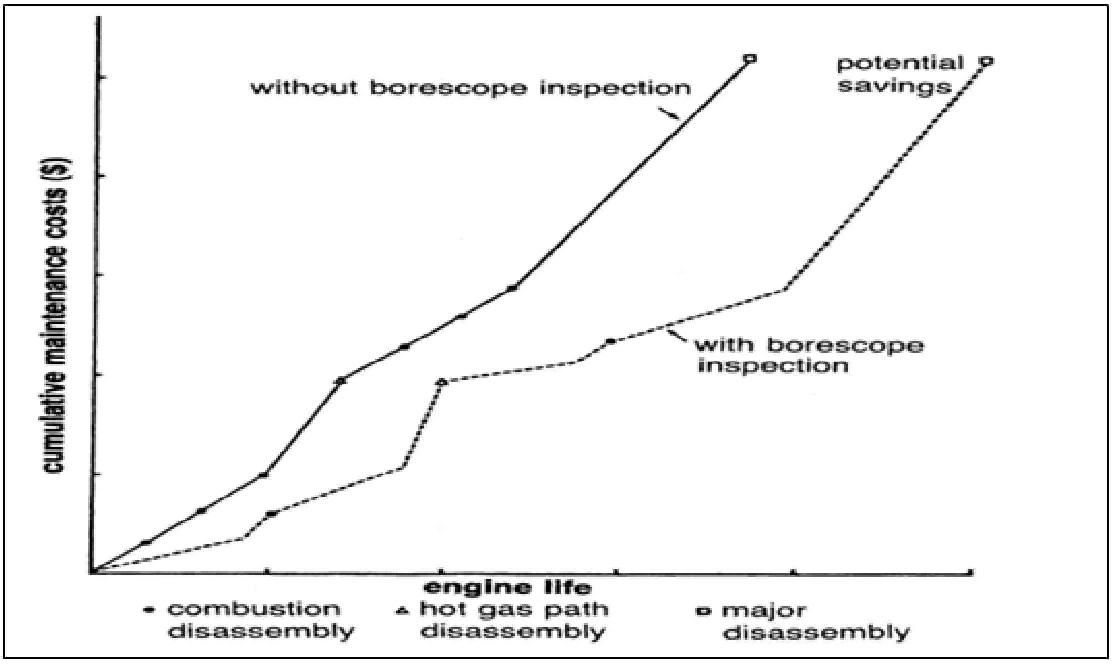


Figure IV.6: Effect on planned maintenance with usage of Borescope [39].

IV.8.1 Areas of inspection:

In the hands of a qualified technician, the borescope allows rapid inspection of the following areas with minimum outage time, manpower and loss of production [30]:

→ Transition piece (Between gas generator and power turbine).

→ Power turbine nozzles

→ Power turbine buckets.

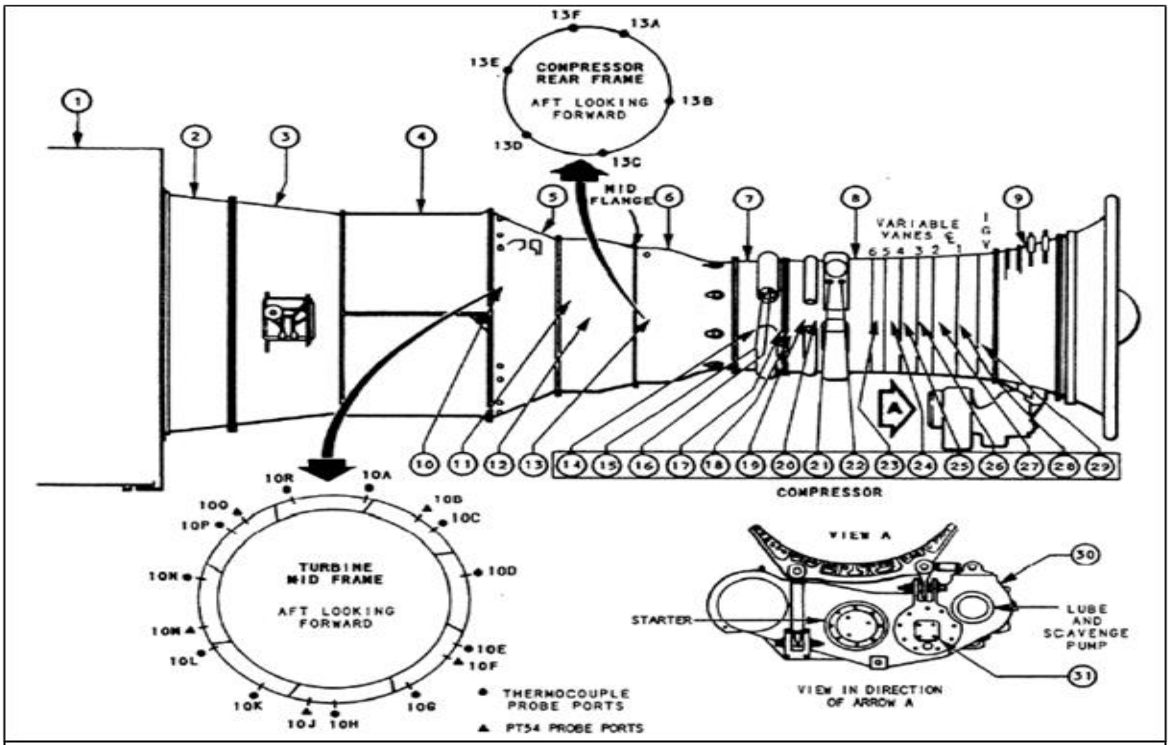
Table IV.2: Borescope inspection criteria [30].

Access area	***Inspect for***
Transition piece	• Thermal shield damage • Cracks • Outer liner deformation
Power turbine nozzles	• Foreign object damage • Corrosion • Cracks • Trailing edge bowing • Erosion • Burning
Power turbine buckets	• Foreign object damage • Corrosion • Blisters • Erosion • Cracks • Rubbing • Missing metal

IV.8.2 Borescope inspection access holes:

Borescope inspection access holes are being provided on the General Electric aero-derivative Gas Turbine PGT 25 DLE models. These provisions, consisting of radially aligned holes through the casings and internal stationary shrouds, have been designed to allow the penetration of the optical borescope probe through sections of a non-operating turbine for visual observation of the rotating and stationary parts without removing the turbine or compressor upper cases.

Figure IV.7 shows a schematic of the PGT 25 model turbine showing the location of the borescope ports and the areas accessible for inspections [30, 40].



1. Exhaust Duct
2. Outer Cone
3. Turbine Rear Frame
4. Turbine Case
5. Turbine Mid Frame
6. Compressor Rear Frame
7. Rear Compressor Casing
8. Front Compressor Casing
9. Compressor Front Frame
10. Turbine Mid Frame Ports
11. Compressor Rear Frame Port
12. Compressor Rear Frame Port
13. Compressor Rear Frame Port
14. Stage 15 port
15. Stage 14 port
16. Stage 13 port
17. Stage 12 port
18. Stage 11 port
19. Stage 10 port
20. Stage 9 port
21. Stage 8 port
22. Stage 7 port
23. Stage 6 port
24. Stage 5 port
25. Stage 4 port
26. Stage 3 port
27. Stage 2 port
28. Stage 1 port
29. Stage 0 port
30. Transfer Gearbox
31. Drive Pad Cover Plate

Figure IV.7: Borescope inspection ports of aero-derivative gas turbine PGT 25

IV.8.2.1 Compressor:

Fifteen borescope inspection ports are in the compressor near the 3 o'clock split line. A port is located at every compressor stator stage. These vane ports start at the IGVs and work aft in the same direction as the airflow (except for stage 8, which is internally blocked). Stator stages 9 and 13 borescope ports require you to remove piping interferences.

IV.8.2.2 Combustor and HP turbine:

Aft of the right-hand side compressor ports are six circumferentially positioned ports, just forward of the mid-flange of the compressor rear frame. From these ports, you can inspect the combustor, the stage 1 HP turbine nozzle assembly, and a few fuel nozzles. Near the aft flange of the compressor rear frame on the right-hand side of the engine are two HP turbine stator ports that you can use for viewing the air-cooled turbine blades. The Pt5.4 pressure probe harness adjacent to the after flange of the turbine mid-frame is located aft of the stage land 2 turbine ports. Five pressure probes are located circumferentially around the turbine mid-frame at the inlet to the LP turbine. All five probes extend radially into the gas path and can be removed to inspect the LP turbine inlet and the HP turbine exhaust.

When used in conjunction with gas path, vibration, and trending analysis techniques, borescope inspections often provide the final step in the process of identifying an internal problem. However, it would be misleading to think that periodic borescope inspections could be a substitute for the other analysis techniques. Borescope inspections are useful in providing a general view of the condition of critical components, but they are limited by the gas turbine design, borescope design, and capability of the inspector [30].

IV.8.3 Borescope inspection advantages:

- ✓ Internal on site visual checks without disassembly.
- ✓ Extends periods between scheduled inspections.
- ✓ Allows accurate planning & scheduling of maintenance actions.
- ✓ Monitors condition of internal components.
- ✓ Increased ability to predict required parts, special tools and skilled manpower [41].

IV.9 Conclusion:

To ensure high efficiency and better service in the performance of gas turbines, the owner must follow the maintenance instructions in accordance with the manufacturer's recommendations and periodic inspection and storage of spare parts for immediate replacement

Recording and analyzing operating data is also necessary for preventive maintenance and planning.

One of the key factors in achieving this goal is the owner's commitment to work on an ideal maintenance and inspection program and follow the published maintenance guidelines using Borescope inspection, which in turn reaches most parts of the turbine through special outlets.

Compared to PGT25 heavy gas turbines, it is very easy to replace damaged parts, provided turbines operate according to ideal standards (entry temperature, fuel gas composition, pressure ratio, etc.).

Chapter V: Borescope Inspection Results and Discussion

Chapter V: Borescope inspection results and discussion

V.1 Introduction:

One of the main advantages of a dynamic aerodynamic engine is the compact telescope capability. Endoscopy makes it easy to inspect important interior parts without disassembling the engine. A full telescope can be made within a few hours. Training, identification of the use of the borescope equipment, the experience of the components to be studied, and the type of degradation that can occur, will provide the operator with the necessary knowledge to analyze and determine the condition of the parts being examined.

Some field technicians have extensively developed techniques for determining the range of compressors, combustion nozzles and turbines for the first stage, and all the different parts of the access slots are provided for air-derived gas turbines. These provisions, which consist of many holes during the internal linings and linings, are designed to allow penetration of the optical cavity sensor through the non-functioning turbine sections to control rotary optical parts and fixed parts without removing turbines or overhead compressor bags.

The problems discussed in this chapter, images used, are taken from actual gas turbines. Experienced all gas turbines simultaneously or other problems or the like. Therefore, the reader is warned not to conclude that a particular problem relates only to a specific gas turbine model or station.

V.2 Borescope inspection of PGT 25 different parts:

Except for some aero-derivative gas turbines, borescope ports are rarely provided within the compressor section of the gas turbine. However, the compressor inlet guide vanes and the axial compressor blades are accessible via the clean air compartment immediately upstream of the gas turbine. It is advisable to use extreme caution when inserting the borescope probe into the blade path, be sure the rotor is locked so that it cannot be turned in the first inserting. For a thorough examination, a borescope can be inserted through the inlet guide vanes and all stage blades inspected as the compressor rotor are turned, by turning the rotor all the compressor blades can be viewed. If there are tar-like, substance on the leading edge of the airfoil demonstrates the detail that can be achieved. This amount of contamination does affect compressor performance [31].

V.3 Equipment required:

In inspection of different parts of turbine PGT 25 DLE, we used XL GO+ borescope.

V.4 XL GO+ Borescope description:

Whether you are climbing a 100-meter tower to inspect a wind turbine gearbox, crawling atop a refinery heat exchanger or creeping under a turbofan jet engine on a test stand, a portable Video borescope is essential.

The XL Go™ VideoProbe® system combines portability with performance delivering sharp, clear digital images on a system designed to meet inspection needs across a wide range of industry applications.

XL Go+ combines cordless operation with a host of features found in systems three times as large. Unlike other video borescopes, the XL Go has no bulky base unit, no backpacks, no tethered scopes or power cords to get in the way ensuring unlimited inspection access and unprecedented ease of use [42].

Figure V.1: XL Go+ VideoProbe (Borescope) [42].

V.4.1 Go+ Borescope properties:

V.4.1.1 Image Quality:

The ultra-compact XL Go+ VideoProbe system does not sacrifice image quality for the sake of portability. Its white LED and crystal–clear active matrix VGA LCD give inspectors the sharp, detailed images needed to ensure accurate detection and analysis, even in applications with poor lighting conditions. Increased probe light output improves the image quality and the likelihood of a thorough inspection. The increase in light output also improves performance in larger area applications.

The XpertBright TM LCD has enhanced image quality for better readability in sunny or snowy outdoor environments and harsh indoor lighting. An intuitive user interface makes it easy to save still images or record motion video to the internal flash memory or removable USB Thumb Drive. Coupled with Servomotor All-Way® articulation, XpertSteer offers quick, responsive steering. When you stop steering the probe stops moving - no more overshooting. A bump steering feature enables tight probe control. A small "bump" of the joystick moves the probe at a small increment for better defect visibility. Different parts of the Borescope (XL Go+ VideoProbe) are show in Figure V.2 [42].

V.4.1.2 Operating Temperature:

A built-in sensor at the top of the camera monitors the temperature and provides three levels of on-screen indicators to prevent damage caused by overheating in environments.

The probe can have faster access to high-temperature applications that require cooling time (e.g., aircraft engines) [42].

V.4.1.3 Ruggedness:

The XL Go+ VideoProbe system is constructed to withstand the rigors of the industrial workplace. Shock absorbing materials and seals are strategically incorporated to resist impact damage and to prevent dust and water intrusion.

To ensure top performance in a wide range of environmental conditions, XL Go+ has been subjected to a battery of performance tests (Rain and Blowing Rain • Test Method 507.4 Humidity, Salt Fog, Sand and Dust, Explosive Atmosphere, Vibration, Shock, Icing/Freezing Rain, Radiated Emissions, Radiated Susceptibility). All tests were performed on a fully functioning system, including monitors [42].

V.4.1.4 Measurement:

The XL Go+ is the only video borescope to offer ShadowProbe®, StereoProbe® and Comparison measurement capabilities. Inverse + and Zoom features allow precise cursor placement, and the Supported Measurement Features are: length/distance, depth, point to line, skew area multi-segment length, circle gauge, 3x zoom windows and five measurements per image.

Figure V.2: Different parts of the Borescope XL Go+™ VideoProbe [42].

V.5 The state of the equipment and beyond:

The main steps of a borescope inspection could be:

- Press the stop button.
- Cool down the rotor (5 to 48 hours).
- Isolation of turbine, the fire protection system has been disabled and locked and the feeding system has been disabled, purged and locked.
- Open the enclosure doors when Gas turbine inner temperature is below 60 °C.
- Secure the gas turbine.
- Scaffold the place to access to the desired endoscopic locations.
- Unbolt and gain access to the inner parts of the gas turbine.
- Position the borescope and make photos of parts.
- Report the findings.
- De-isolation and scaffold.
- Check everything is in the right order and close the enclosure door.
- Restart.

Today a borescope inspection is conducted by a technician who must access to the borescope hole on the casing. Safety instructions demand that:

1. Not to open the enclosure doors when the gas turbine is hot as it might rapidly cools down the compressor casing endangering the compressor blades, which might then rub or be compressed [31].

2. Not to access to the hot casings for men without wearing with adequate equipment if casing temperatures are over 40 °C [31].

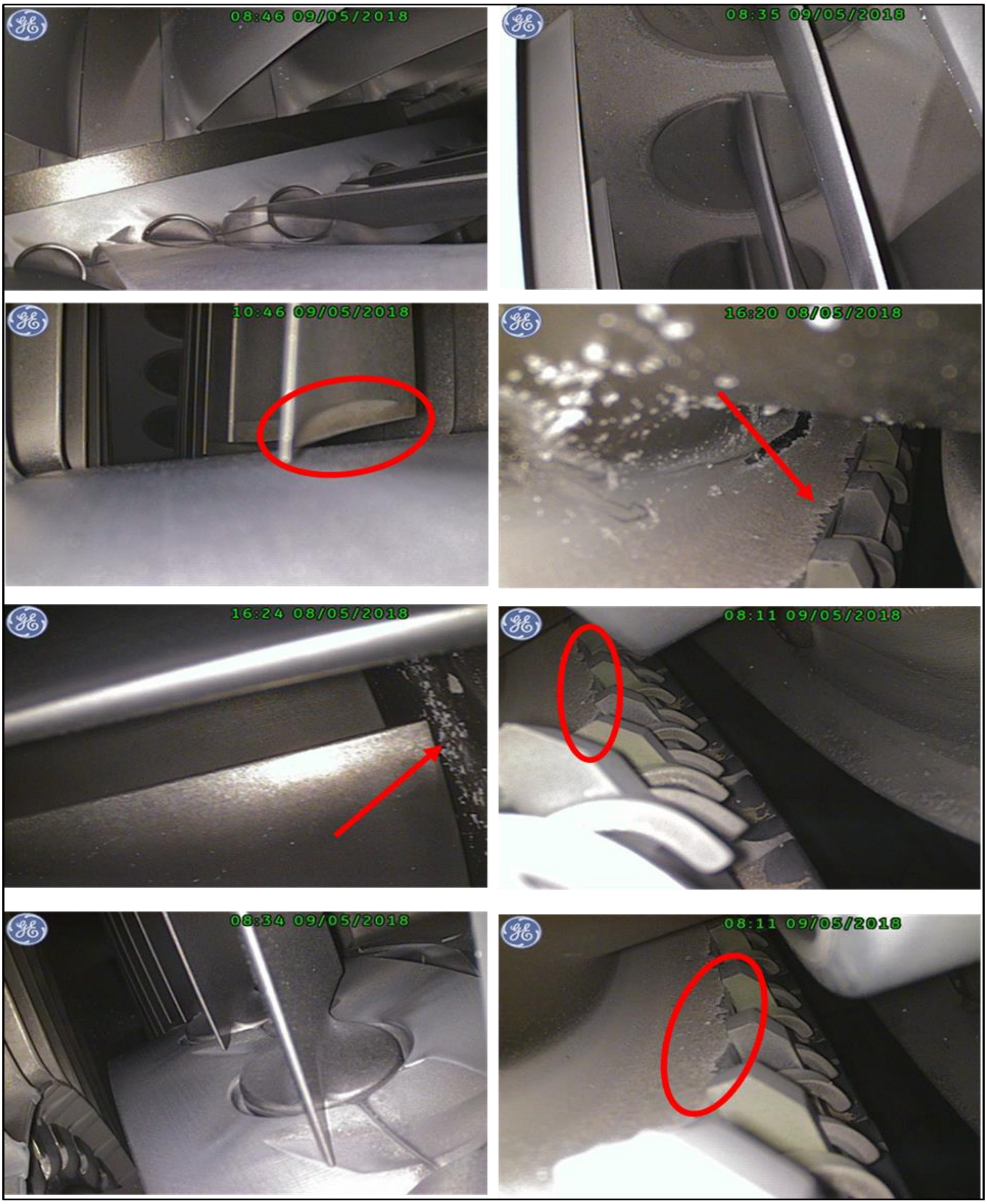
V.5.1 Inlet section Inspection:

→ Good condition.

Figure V.3: Borescope inspection show Inlet section of turbine in good conditions.

V.5.2 Axial compressor inspection:

- → Stator & rotor blade are in good conditions.
- → Presence of dust and grains of sand in the axial compressor
- → The last stages of the axial compressor are slightly corroded



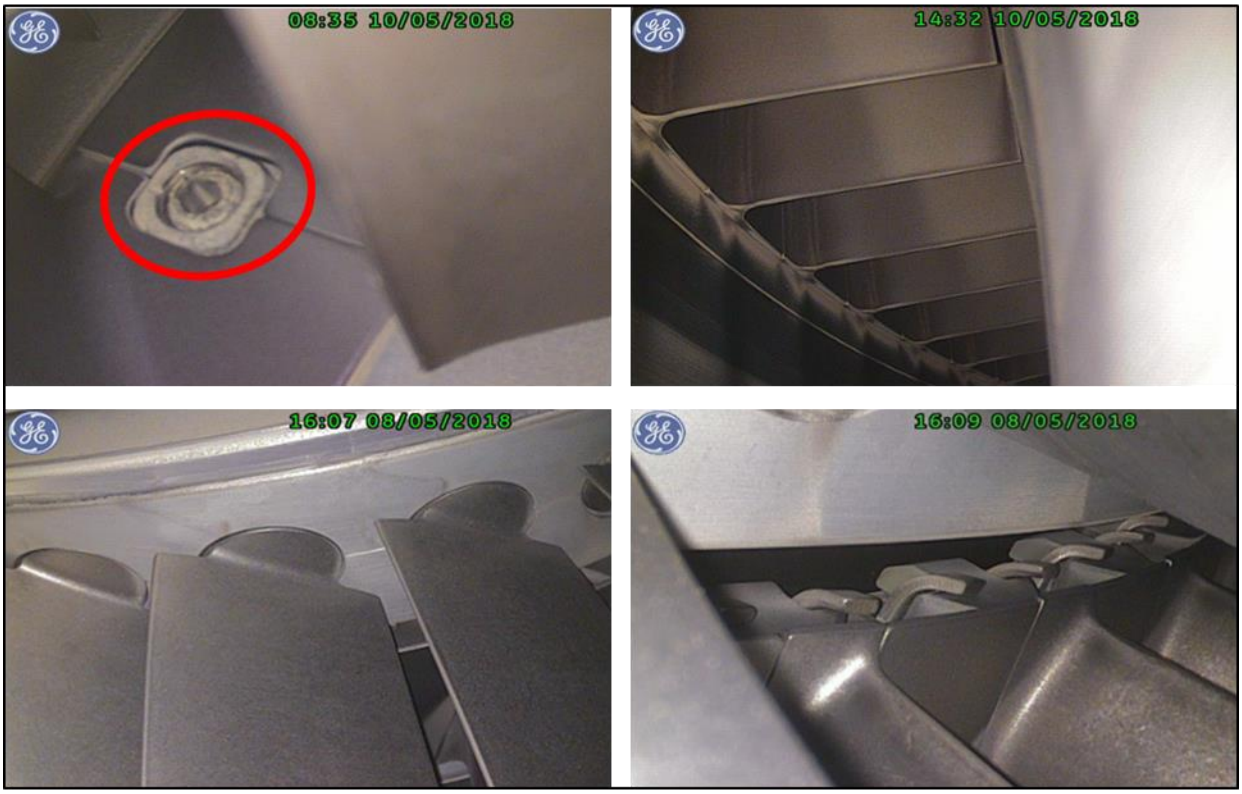
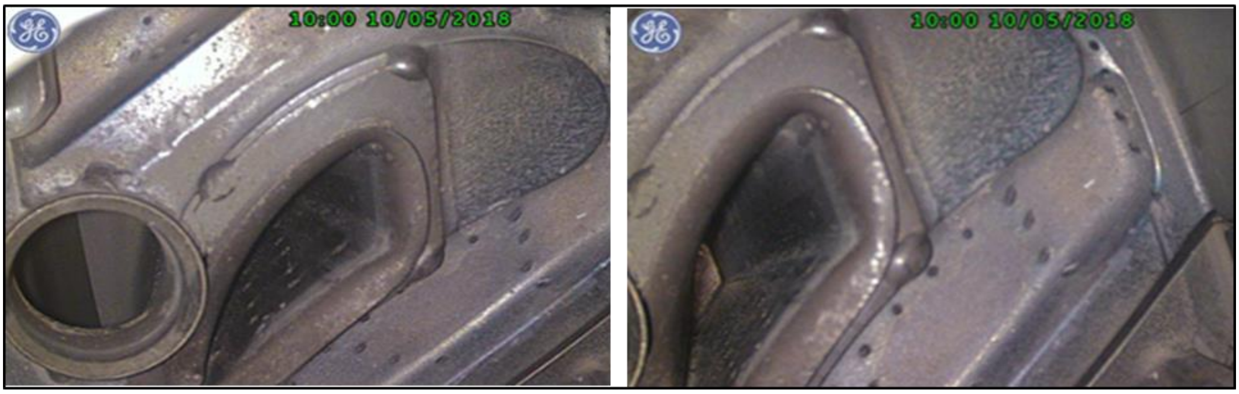
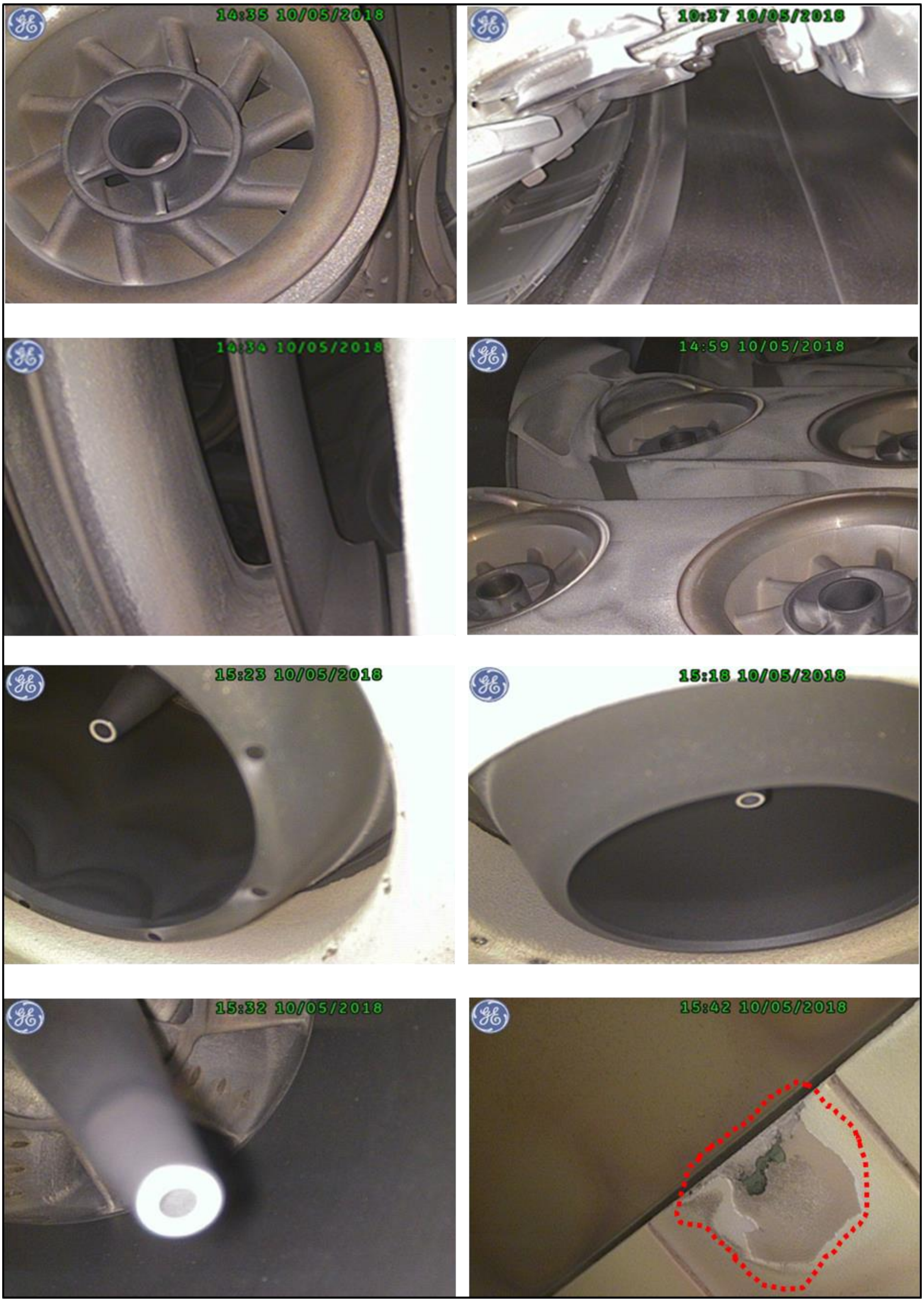


Figure V.4: Internal borescope view of axial compressor (blades + vanes).

V.5.3 CRF & combustion chamber inspection :

- → CRF in good conditions.
- → Tearing of the coating develop.
- → Appearance the new points losing of coating.
- → Discoloration deposit on the coating.
- → Trace of heavy impurities in the combustion.





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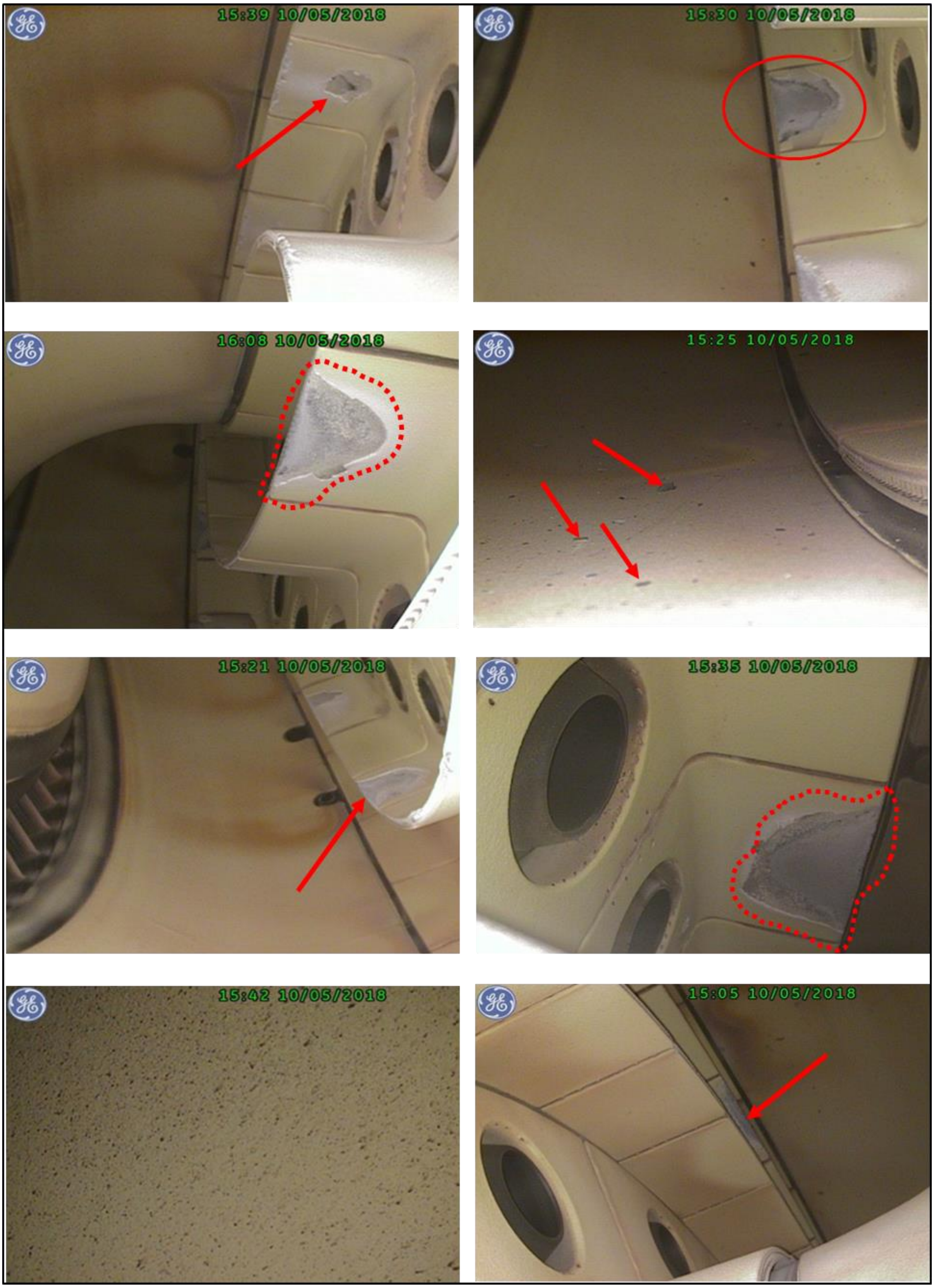


Figure V.5: Internal borescope view of CRF& combustion chamber.

V.5.4 HPT& nozzles buckets inspection:

- → Presence the debris of coating in the cooling holes of the HPT buckets and nozzles.
- → General conditions of HPT are acceptable.

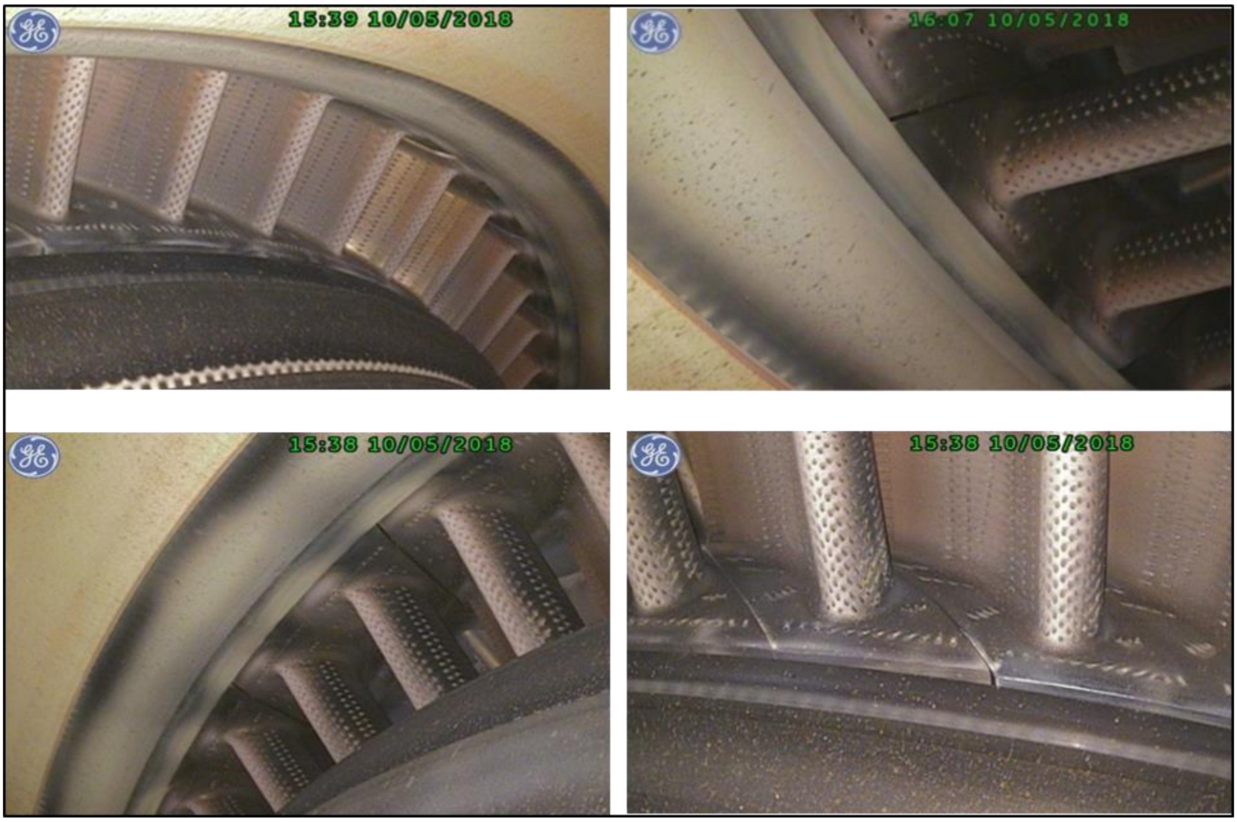


Figure V.6: The borescope assay shows discoloration on HPT slots, coating and some burns, a sign of irregular combustion.

V.5.5 TMF Inspection:

- → The results of the borescope examination in the turbine showed that the TMF was in good condition and there was no damage.

Figure V.7: The interior view with the borescope probe shows that the TMF was in good condition.

V.5.6 Power turbine inspection:

→ General conditions of the power turbine are acceptable.

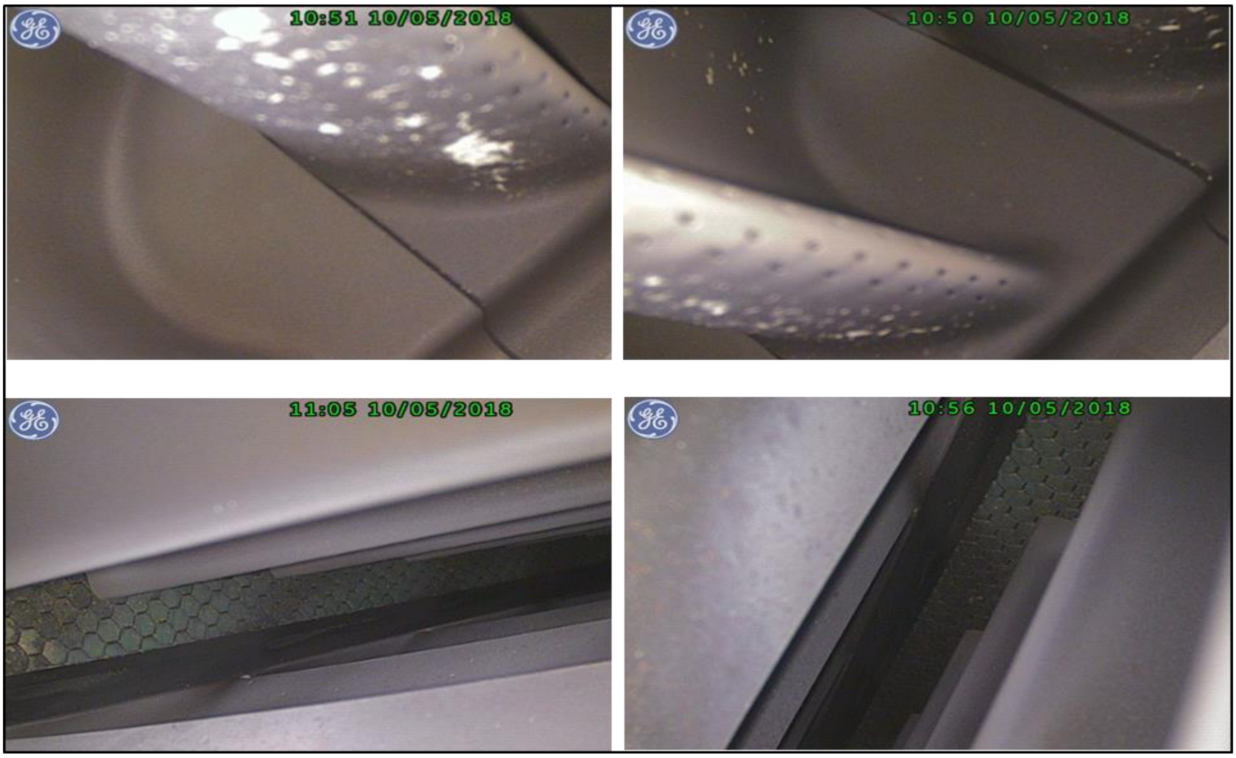


Figure V.8: Borescope inspection show that power turbine of turbine in good conditions.

V.5.7 Air filters condition:

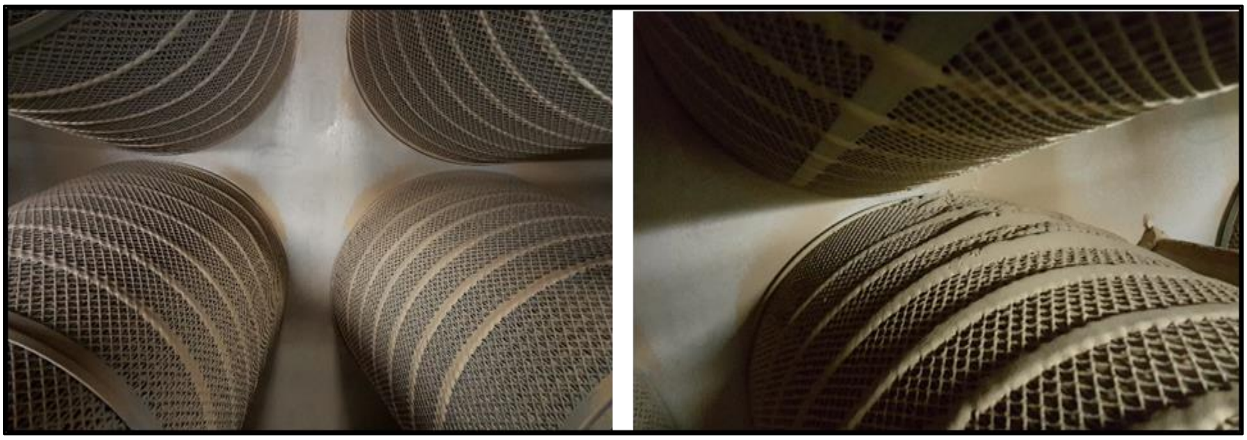
→ 1st stage acceptable (for axial compressor)

→ 2nd stage degraded (for axial compressor)

→ 3rd stage very degraded (for cooling air)

First stage:

Second stage:



Third stage:

Figure V.9: Condition of air filters

V.6 Investigations and Discussions:

Gas turbine engines not only absorb air, but also absorb countless aerosol particles, which may have different negative impacts on the turbine operation efficiency, including performance degradation, compressor pollution, port efficiency and component failure such as the formation of compressor cracking and corrosion in cold and hot sections.

Performance of gas turbines is a function of many factors, including, but not limited to turbine design. Updated component technology, operational status, ambient conditions and environmental factors. Turbine degradation accumulates with increased working hours.

This study focuses on predictive modeling of degradation of gas turbine performance by integrating operational variables and weather factors with the aim of improving customer maintenance recommendation, optimization planning, asset management and failure prevention.

According to this study of examine the borescope, we found some problems in different parts of the turbine, the images were taken by the Borescope XL Go+, so after the examination we found the following damages and problems:

- → The presence of some scratches and dirt in the axial compressor level.
- → The loss of a large part of the combustion chamber coating.
- → Burning of the hydrocarbons.
- → The discoloration of the combustion chamber, fuel nozzles and the sediment of a lot of carbon on the walls of the CC…

We propose the following solutions for central compressor and hot turbine section including combustion chamber.

V.6.1 Axial compressor investigation and solution:

We found some dirt in the blades of the PGT 25 DLE 2500 gas turbine, which can lead to scratches, erosion of blades, and possibly damage to all successive components of gas turbines. If pollution continues to accumulate compressor efficiency, it will continue to deteriorate, and we will lose all components of the turbine because the compressor and all the different components of the gas turbines work together.

The dirt causes particles to adhere to surface and ring particles increases in oil or water. The result is the accumulation of materials that cause increased roughness of the surface and to some extent changes to the shape of the flap. Particles that cause fouling are usually smaller than 2 to 10 microns. Common examples are smoke, sand, oil fog, carbon and sea salt. The dirt can be controlled by the proper air purification system.

There are generally four different types of dirt deposits that can be found within a central compressor: salts, heavy hydrocarbons (oils and wax), carbon dust and other dirt.

The Gas Turbine Compressor works like a highly efficient air filter, which collects and deposits a large proportion of any solid materials carried by ambient air and is handled at the input of gas turbines. In addition, due to the heat of compression the temperature of the air passing through the compressor will rise to more than 600 F° so that any solids or chemicals dissolved in water will fall onto the compressor blades.

Oil and wax are usually waste from compressor washing or ambient air pollution. In general, the components do not cause significant damage but they can act as bonding agents for dirt or sand in the compressor, thus they contributing to corrosion.

Dirt sand and other types of dust, from the environment because the turbines are installed in the desert in this case, are mainly introduced into the gas turbines through the input filter, which is indicative of insufficient filtration of the input or saturation of the candidate dirt.

High-efficiency filters must be able to capture more than 95% of the problematic pollution up to 1.0 microns. Poor filtration can result in corrosion in the engine, and solid particles attack the rotary parts. Collisions between high-speed rotary blades and airborne particles lead to the removal of metal parts from the blade surfaces. Small particles such as micron diameter can cause corrosion. Particle and shape composition can significantly affect corrosion rates. The code files are designed so carefully that even minor corrosion can alter the features to the extent that engine performance is affected. Corrosion is an massive problem, because it causes permanent damage, and eventually requires the parts to be renovated or replaced. Corrosion is proportional to particle concentration and can significantly reduce engine life in harsh service with poor filtration.

This can be decontaminated with a wash solution; the healing effort may be small, such as washing through water or detergents online, or the detergents used to wash the forearm, as recommended by the gas turbine manufacturer. However, if the wash / rinse length is insufficient, the residue will be distributed over a larger portion of the surface of the flap.

A properly operated filter system protects gas turbines from corrosion, corrosion and fouling; helps to achieve performance, efficiency and life expectancy.

A properly functioning filter system will protect the gas turbine from erosion, corrosion, and fouling; and help achieve performance, efficiency, and life expectations. However, a filter system that is not functioning properly exposes the gas turbine to these undesirable elements resulting in shorter time-between-overhauls (TBO), reduced power output, and increased fuel consumption. In this case we should check the filtration system if the filters is saturated we should change it immediately [43].

V.6.2 Hot section parts investigations and solutions:

The life expectancy of most hot section parts is dependent on various parameters and is usually measured in terms of equivalent engine hours. The following are some of the major parameters that effect the equivalent engine hours in most machinery, especially gas turbine:

- Type of fuel.
- Firing temperature.
- Materials stress properties.
- Effectiveness of cooling systems.
- Numbers of starts.
- Numbers of trips.
- Firing temperature.
- Back pressure.
- Turbine fouling (combustion deposits)…

V.6.2.1 Type of fuel:

All problems in hot section parts and losses are related to the combustion process. Manufacturers set very strict parameters regarding the quality of the combustible gases to avoid possible damage to the hot parts of gas turbine. In the table 3 bellow, we show a Comparison of fuel gas composition between the result of the analysis of laboratory and the ideal composition.

Table V.1: comparison between gas laboratory analysis and topical analysis.

Component	**B-Chromato/Analyses**			**Topical analysis**	**Range**	**UNITES**
C1 Methane	83.924	81.977	84.686	95.0	87.0 - 97.0	% molaire
C2 Ethane	12.238	11.699	12.772	3.2	1.5 - 7.0	% molaire
C3 Propane	0.010	0.010	0.010	0.2	0.1 - 1.5	% molaire
iso-C4 iso-Buthane	0.034	0.030	0.042	0.03	0.01 - 0.3	% molaire
n-C4 n-Buthane	0.026	0.022	0.033	0.03	0.01 - 0.3	% molaire
iso-C5 iso-Pentane	0.000	0.000	0.000	0.01	trace - 0.04	% molaire
n-C5 n-Pentane	0.000	0.000	0.000	0.01	trace - 0.04	% molaire
C6+ Hexane	0.000	0.000	0.000	0.01	trace - 0.06	% molaire
CO_2	1.784	1.451	2.527	0.5	0.1-1.0	% molaire
N_2 Azote	0.484	0.331	3.002	1.0	0.2-5.5	% molaire
He Helium	0.021	0.012	0.021	Trace	Trace-0.02	% molaire
TOTAL	100.000	100.000	100.000	100.000	100.000	% molaire

Compositions of gaseous fuels can vary quite widely depending on their source and can contain a number of hydrocarbon species along with inert gases as well as contaminants (Higher hydrocarbons, water, inert gases nitrogen and carbon Dioxide, sulfur, carbon monoxide etc. The fuel gas composition from laboratory analysis given in table V.1 state very clearly that there is presence of liquids in the fuel gas. Knowing fully that no natural gas supplied is free of liquids, which may be present from liquid hydrocarbons in the gas stream, liquids from lubricating systems, and water condensation in the pipeline, great care should be used in fuel handling system.

V.6.2.2 Risks of contaminants in fuel gas:

V.6.2.2.1 Variations in Heating Value:

Variation in the heating value, as a result, of gas phase composition variation affect gas turbine emissions, output and combustor stability changes greater than 10% require gas control hardware modifications, but are not a common problem in a stabilized distribution systems.

Variations in heating value could be an issue if gas is purchased from a variety of suppliers depending on the daily or weekly variations in gas price. In this situation, the user should ensure that the variations are within the values allowed by the contract agreement with GE. Online instruments that determine and monitor heating value are available from several suppliers and should be used if significant variations are expected. Slugging of hydrocarbon liquids affects, the energy delivered to the turbine and can result in significant control problems and potential hardware damage [44].

For this and other reasons described below, all liquids must be eliminated from the gas supplied to the turbine.

V.6.2.2.2 Autoignition of Hydrocarbon Liquids:

Liquids are formed from the condensable higher hydrocarbons found in natural gas, as well as moisture from water vapor. Moisture is undesirable because it can combine with methane and other hydrocarbons to generate solids in the form of hydrates. Hydrocarbon liquids are a much more serious issue because liquids can condense and collect over long periods of time, then result in liquid slugging as gas flow rates are increased after a period of reduced power operation. This can lead to:

- → Uncontrolled heat addition
- → Autoignition at compressor discharge temperature (625 F to 825 F/329 C to 451 C range)
- → Potential for promoting flashback and secondary/ quaternary re-ignitions
- → Varnish-like deposits

Carry-over of liquids to the turbine can result in uncontrolled heat release rates if sufficient quantities are present, resulting in possible damage to the hot gas path. A more common problem, however, is with the exposure of small quantities of hydrocarbon liquids to compressor discharge air. Dry Low NOx combustion systems require pre-mixing of gas fuel and compressor discharge air in order to produce a uniform fuel/air mixture and to minimize locally fuel rich NOx-producing regions in the combustor.

Typical autoignition temperatures (AIT), the temperatures required for spontaneous combustion with no ignition source, the figure V.11 below shows the auto-ignition temperatures of hydrocarbons at atmospheric pressure. Methane has the highest auto-ignition temperature. As the number of carbon atoms in the hydrocarbon increases, the auto-ignition temperature decreases. In other words, heavier hydrocarbons tend to auto-ignite before lighter hydrocarbons. Increased pressures can also reduce the auto-ignition temperature, so it is important to minimize the residence time of the fuel gas in the combustor so that controlled combustion occurs in the correct place.

For these liquids are in the 400 F to 550 F (204 C to 288 C) range and fall below compressor discharge temperature. Exposure to compressor discharge air above the AIT will result in instantaneous ignition of the liquid droplets, causing in some cases premature ignition of the pre-mixed gases, often called “flashback.” Because of the seriousness of the problem, GE specification 41040E does not allow any liquids in the gas fuel.

The presence of higher hydrocarbons can also affect the emissions signature of a gas turbine. The longer hydrocarbon chains result in a higher flame temperature within the combustor, increasing the NOx emissions, even when Dry Low Emissions combustors are used. In liquid form, NOx emissions will be similar to those produced when operating on diesel fuel. NOx formation can be by a number of ways, but thermal NOx is by far the most dominant. Therefore, anything done to increase the combustion temperature, such as using fuels with higher hydrocarbon species will have a detrimental impact on NOx emissions to atmosphere. It is possible to provide and apply a NOx factor based on the assessment of a specific fuel. For example a fuel with high level of Ethane, C_2H_6, for example 20 mol%, may add as much as 10% NOx to the total [45].

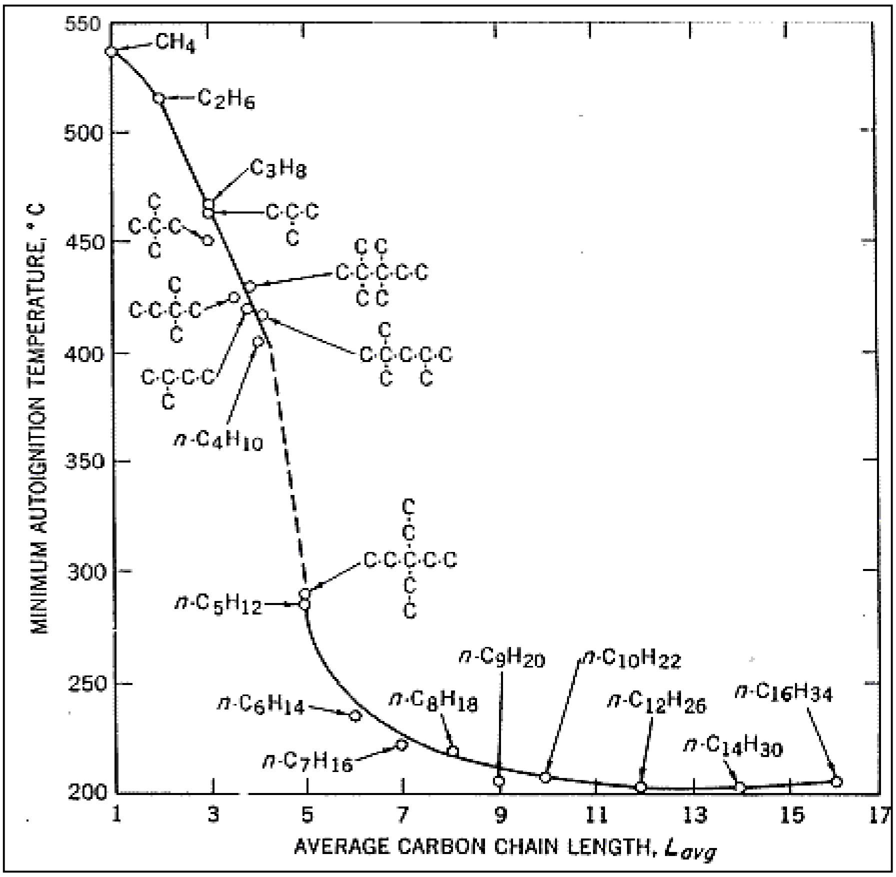


Figure V.10: Minimum Auto-ignition Temperature of Hydrocarbons [45].

V.6.2.2.3 Sedimentation and occlusion:

Important losses of the thermal barrier coating (TBC) in combustion chamber it can caused by presence of particulates greater in size than approximately 10 microns because this particulates prevent erosion and deposits. Erosion rates are exponentially proportional to particle velocity, and areas that experience high gas velocities are more susceptible to erosion. So we should be sure that our fuel gas cleans from particulates prevent damages and problems. This missing of coating can also prevent plugging of cooling holes, and this will result in increasing of temperature and case damages above-mentioned.

V.6.2.2.4 Sulfur:

Sulfur can occur in both gaseous and liquid fuels. In gaseous fuels, it is usually found in the form of hydrogen sulfide (H_2S), although the component of element sulfide occurs in rock gas.

Liquid fuels, especially heavy fuel oils, can contain very high levels of sulfur, although increasing legislation drives operators to use diesel or low sulfur fuels. Hydrogen sulfide is highly toxic and can pose unique challenges for operators as well as in the operation of gas turbines.

In the presence of sodium, potassium or vanadium contaminants commonly found in air in offshore or in coastal environments or in liquid fuels. Further assessment will be required as the reaction of these metals and their salts with sulfur results in the production of sodium and potassium sulfates which are highly corrosive to modern materials, such as nickel alloys used in the hot gas path components, for example turbine nozzle and rotor blades [45].

V.6.2.2.5 Inert Gases Carbon Dioxide (CO_2):

Many associated gases and biogases contain inert gases, often in significant quantities (50%, or higher, by volume is not unknown). While these gases are generally benign, CO_2 can react in the presence of moisture producing a weak acid. Generally, gas turbines are able to operate on gases with high inert gas contents.

Inert gases act as a diluent, reducing the heat content available in the fuel, and so greater fuel volumes are required to achieve the same output power compared to standard natural gas. This necessitates a redesign of the fuel system to handle the higher gas volumes, and potentially the need to enlarge the burner gas passages and injectors. The higher mass flow caused by the need for greater fuel volumes can boost the power output available from the gas turbine, providing other design limits are not exceeded. Therefore, it is necessary to confirm the effectiveness of CO_2 removal system [45].

V.6.2.3 Starts and Trips Factor:

Trip factor is the number of equivalent starts when the engine experiences a trip. For instance, trip factor of 8 means that each trip is equivalent to 8 starts. Each engine trip, especially if it is an emergency trip from base load, causes hot end components to experience severe thermal gradients over a short time interval (the turbine airfoil metal temperatures may decrease hundreds of degrees in seconds). The result is a negative impact on hot end parts' mechanical integrity and life.

Startups, on the other hand, are slower and turbine components experience a moderate rate of temperature increase and hence much lower thermal gradients. Thus, originally each trip was considered equivalent to 20 starts as to its effect on the gas turbine cyclic life and the inspection interval. Maintenance intervals are calculated using operational data in a mathematical formula, one component of which is the number and type of trips experienced. Thus, a high trip factor means more frequent inspection intervals. Table V .2 show all hours of operation, starts and trips for gas turbine. We can see clearly this turbine with minimum of hours operation have the highest number of trips. This is one of the most important reasons that led to the damage mentioned earlier.

Table V.2: Hours of operation, starts and trips of aeroderivative gas turbine PGT25 (month of 08May 2018).

Machine	**TK3**
Operation Hours	25095
Numbers of Starts	219
Numbers of Trips	126

V.6.2.4 Ambient temperature:

Gas turbine performance is critically limited by the predominating ambient temperature, mainly in hot and dry regions.it occurs because the power output is inversely proportional to the ambient temperature. The temperature drop provides an augment in the air density and consequently elevates air mass flow rate. This behavior increases the power output and efficiency at about 0.7% per degree Celsius for aeroderivative gas turbine [46].

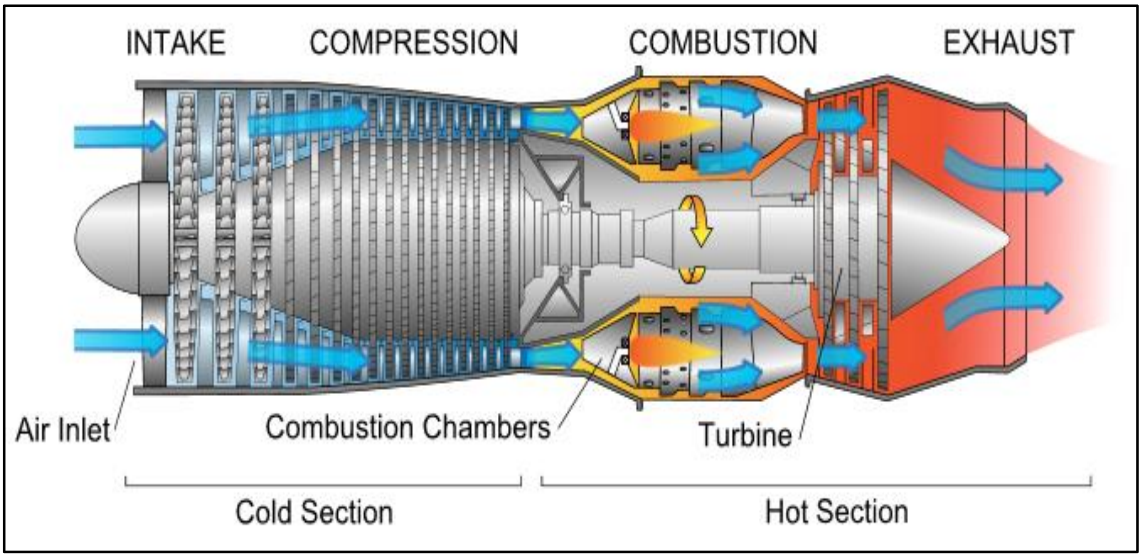


Figure V.11: The airway in the turbine [48].

V.6.3 Suggested solutions:

V.6.3.1 Reinforcement of the System 45:

Fuel gas conditioning requires the removal of both liquid and solid contaminants from the gas stream. There are several ways to accomplish this; the existing system (Sys 45 Fuel gas system and distribution) in our power plant is dedicated to accomplish this treatment. The equipment used in this system arranged as follows: fuel gas knockout drum, preheater and filters.

In reason to improve the fuel quality and removal of both liquid and solid contaminants from the gas stream, I propose strengthen the system 45 by coalescing filter or combined filter-separator To become as follows a vertical gas separator Represented by knockout drum followed by either, coalescing filter or combined filter-separator, super heater and another filters is existing. A sectional view of a coalescing filter is shown in Figure V.12. The gas enters the inside of the filter elements and flows outward. Very small liquid droplets are coalesced into larger droplets as they travel through the filter elements. These large droplets then fall away from the outer surface of the elements and are collected in the bottom of the vessel. A properly sized filter will prevent the re-entrainment of liquid droplets into the gas stream, but the efficiency of this device will drop off dramatically if operated beyond its design flow rate[44].

The filter separator combines changeable filter elements along with vane mist eliminator in a single vessel, as illustrated in Figure V.13. The gas first passes through the filter elements, enabling smaller liquid particles to be coalesced while the solids are removed. Because of the coalescing effect, the vane is able to remove more free liquid particles than either the dry scrubber or the vertical gas separator alone. This combines the efficiency of the vane separator with that of the coalescing filter in one vessel. As with the coalescing filter described above, the filter separator maintains its guaranteed separation efficiency from 0% to 100% of its design flow capacity. Filter separators are often used in lieu of filters when high liquid rates are expected [44].

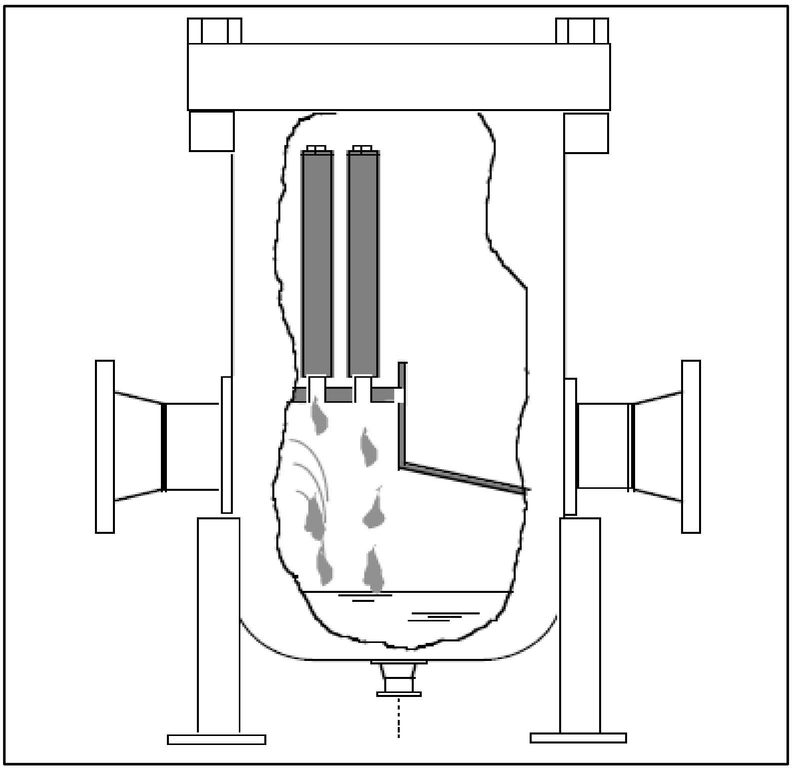


Figure V.12: Coalescing filter.

The filter separator also removes solids from the gas stream, but must be taken off-line periodically in order to replace the dirty filter elements. For this reason, base-loaded units require a duplex arrangement that permits maintenance to be performed on one unit while the other is in service.

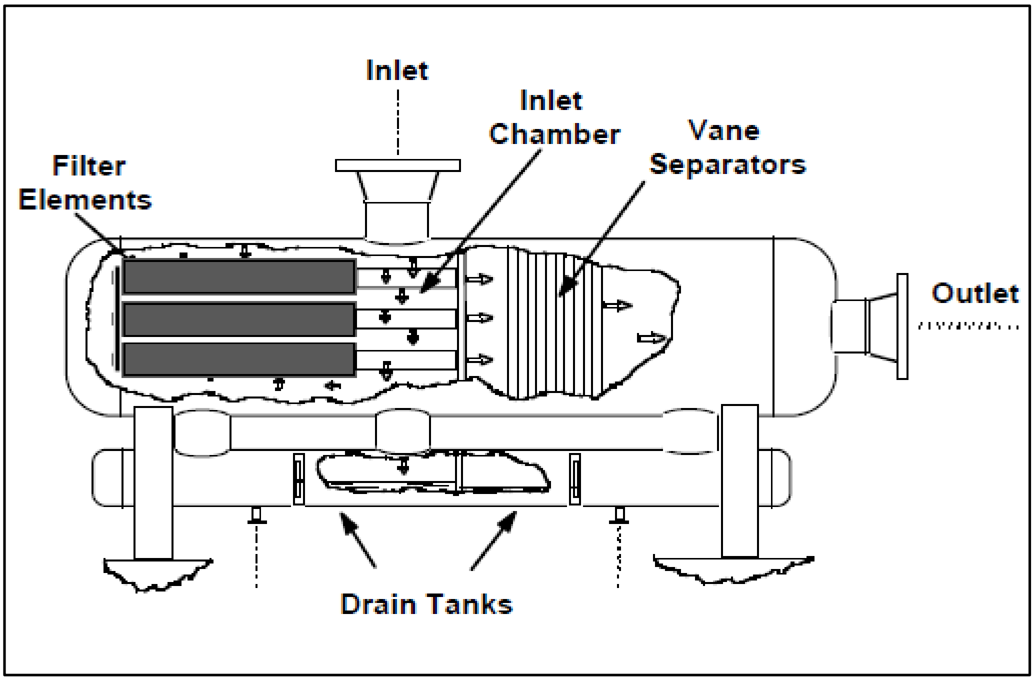


Figure V.13: Combined filter-separator.

Equipment should be located as close as possible to the combustion gas turbine. This is especially true of the super heater since liquids can condense in the line downstream from the heater after the unit has shut down, the shorter the line lower the volume of condensates.

V.6.3.2 Inlet temperature:

We talk about inlet temperature (Ti), Someone might wonder Why we talk only about (Ti) While there is many parameters?

We should answer this question; we talk only about (Ti) because Gas turbine performance is established by three basic parameters: mass flow, pressure ratio, and firing temperature and these three parameters is related directly with (Ti). Therefore, we must give great attention to this variable. Even with the presence of clearly and specifically fuel gas if we not regulate these problems, the machine will not work with good way and this will leads to important losses and damage in different parts of the gas turbines.

Therefore, we suggest the following solution:

V.6.3.2.1 Inlet cooling systems:

The cooling system at the entrance is a useful option for gas turbines for applications where large operations occur in warmer months and where low relative humidity is common. Cold air, the most intense, gives the device a higher flow rate and mass ratio, leading to an increase in the production and efficiency of turbines. This is a cost-effective way to add machine capacity during periods of peak power on utility systems.

There are three basic systems available to cool the entrance:

V.6.3.2.1.1 Inlet air cooling system:

Figure V.14 shows a simple sketch of the system herein studied, which consists of a standard gas turbine power plant consists of compressor, combustion chamber and turbine.in this work three different inlet air cooling techniques are proposed for analysis: evaporative cooling, absorption and mechanical chiller.

Gas turbine performance will be evaluated with each cooling method and compared with values of the base-case (without any cooling system).the working fluid passing through the compressor is the air, and it assumed to be an ideal pas, while in the turbine the working fluid are the flue gases.

A brief description of each inlet cooling technology will be presented in the subsequent in the subsequent section.

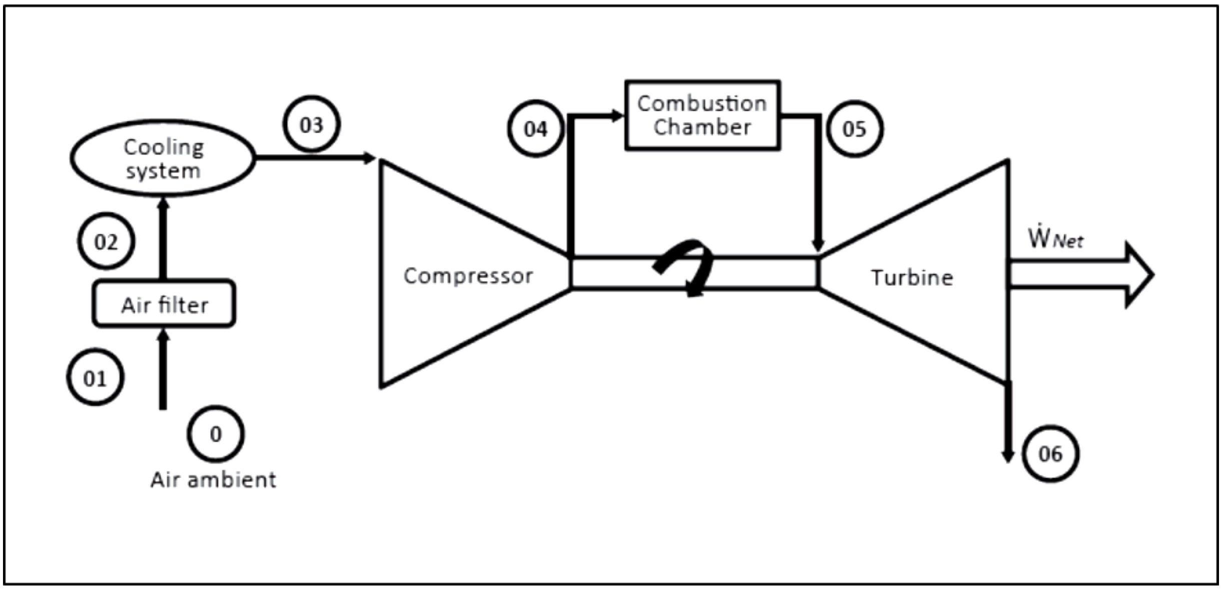


Figure V.14: Representation of the gas turbine cycle with cooling system.

V.6.3.2.1.2 Evaporative cooling:

Evaporative cooling is most appropriated cooling system to hot dry areas, because it utilizes the latent heat of vaporization to cool ambient temperature from the dry-bulb to the wet-bulb temperature. The process employed by this cooling method convert sensible heat in latent heat, being the ambient air cooled by evaporation of the water from wet surface of the panel (cooling media) to the air. In Figure V.15, a typical evaporative cooling system.

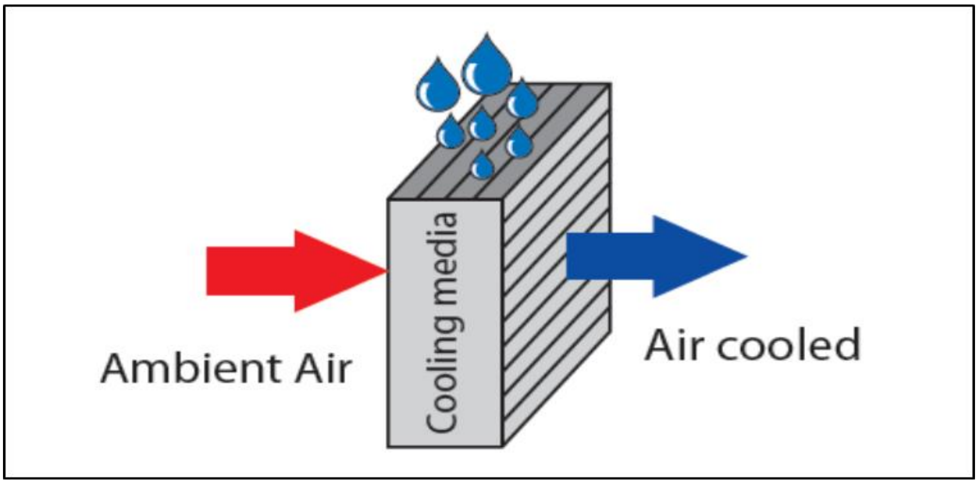


Figure V.15: Schematic representation of the evaporative coil (cooling media)

V.6.3.2.1.3 Absorption and mechanical chiller system:

Another alternative to provide air cooled to the gas turbine is the cooling chiller mechanism. Figure V.16 shows a typical architecture used in the heat exchange of the chiller systems.

There are two currently available chiller options to cool the compressor intake air:

Mechanical refrigeration and absorption cooling [46].

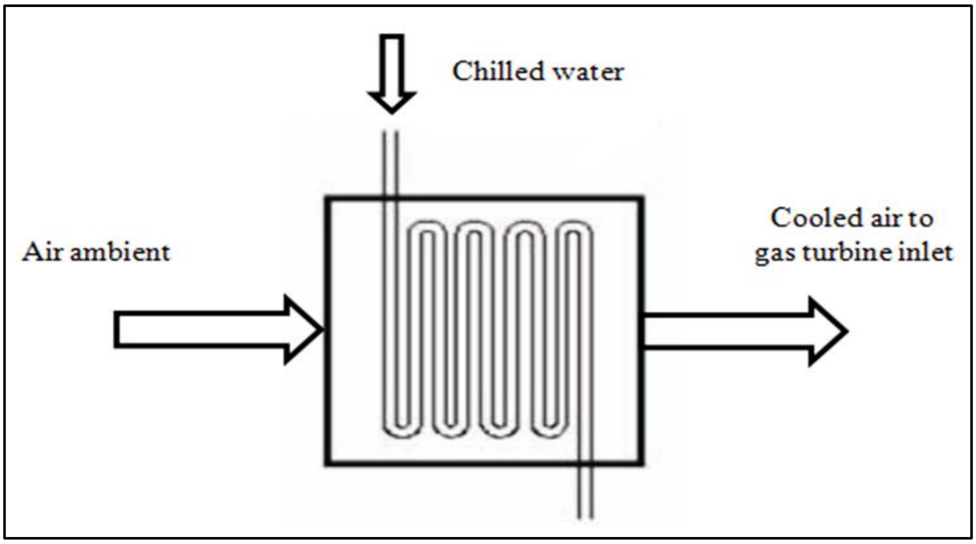


Figure V.16: Schematic representation of the chiller coil.

The power required to drive the absorption chiller is usually obtained by the recovery of the heat from turbine exhaust gases, and the chilled water is passed through a heat exchanger to cool the ambient temperature.

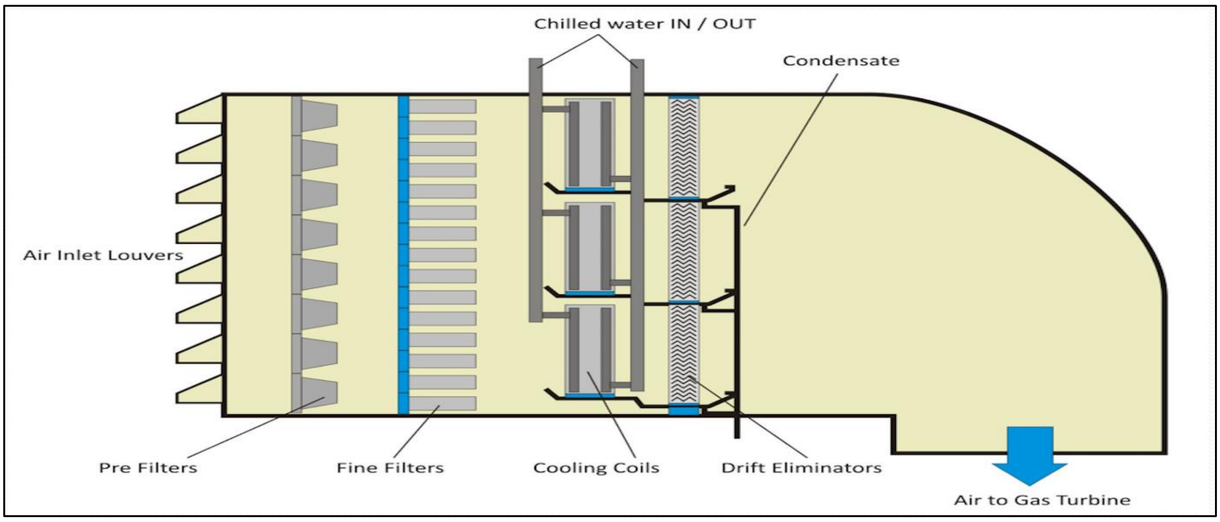


Figure V.17: Typical of Absorption and mechanical chiller system [47].

Conclusion:

According to what we have done before, what we have studied and the treatment of the images that was taken by the Borescope, as a result, we find that many factors can affect the performance as well as the efficiency of the gas turbine. These problems can be conclude as follows:

Scratches, dirt, cracks, corrosion, and corrosion coating of the combustion chamber, clogging of cooling nozzles, etc. These problems appear because of many factors like combustion fuel, ambient air temperature, sulfur, Autoignition of Hydrocarbon Liquids, etc.

We can offer some solutions that can be successful to avoid these affects in the gas turbine like:

1. Reinforcement of the System 45 that treats the fuel.
2. Addition system for cooling air ambient.
3. Changing air filters.

Overall conclusion

The maintenance requirements of the aeroderivative gas turbine in oil & gas applications, and exactly in our study in mechanical drive application, while maintaining maximum availability and reliability. One major asset of the aero-derivative gas turbine engine is the boroscope capability built into the design. Boroscoping facilitates inspection of critical internal parts without disassembling the engine. Complete boroscoping of the aero-derivative engine can be accomplished in some hours Provided that operator calcified, the good use of borescope equipment, and experience with the components to be viewed as well as the type of deterioration that can occur, will provide the operator with the necessary knowledge to analyze and identify the condition of the parts inspected.

Boroscope the compressor, combustor, first stage turbine nozzles and all different parts of the aero-derivative gas turbine trough access holes are provided, with the borescope inspection, we can discover some problems and damages that occurred in different parts of gas turbine. Many factors affect the life of turbine and their sufficient, one of the most important factors at all is the quality and composition of fuel burned in a gas turbine impacts particularly to the combustion system and high section power turbine. The fuel specified for a given application is usually based on availability and price. Natural gas is a typical fuel of choice for gas turbines due to its low cost, widespread availability, and low resulting emissions especially with the AGT PGT25 equipped with new system DLE combustor. In many systems, the gas composition and quality may be subject to variations. Typically, the major sources of contaminants within these fuels are:

Solids, water, heavy gases present as liquids, lube oil from upstream compressors (especially reciprocating compressors), hydrogen sulfide, carbon dioxide, etc.

The understanding of fuels used in modern high performance, high efficiency gas turbines, and the contaminants contained within these fuels, is critical in achieving the goals of high availability and reliability, but at the same ensuring the environmental needs are fully met. Supply of the fuels of the right quality, or with the correct fuel treatment and handling methods, can result in achieving these goals, while the use of fuels outside the advised specifications can result in increased maintenance requirements or premature component failure.

To reduce and limit the issues and damages provided by poor fuels we can took some precautions and use arrangement of clean-up equipment that is necessary to meet the requirement.

In addition to the fuel factor, there is another factor of ambient air temperature, which in turn leads to excessive combustion chamber temperature. This factor can cause damages to the combustion chamber, in a simple description the turbine exist in dry and hot environment in the desert.

In fact, the addition of the turbine cooling system can increase the efficiency, reliability and longevity of turbines by improving temperature and humidity. Thereby, we find that the cooling system can play a huge role to decrease this problem (excessive combustion chamber temperature) in addition to that the cooling of the other turbine's parts.

Dirt Sand and other types of dust from the environment are primarily introduced into the gas turbine through the inlet filter. These leavings can decrease the amount of the entering air inside the turbine, as well as it can paste in the compressor. The good filtration guaranteed high efficiency of the axial compressor, if some fouling or deposits are detected. So that washing and cleaning is highly recommended.

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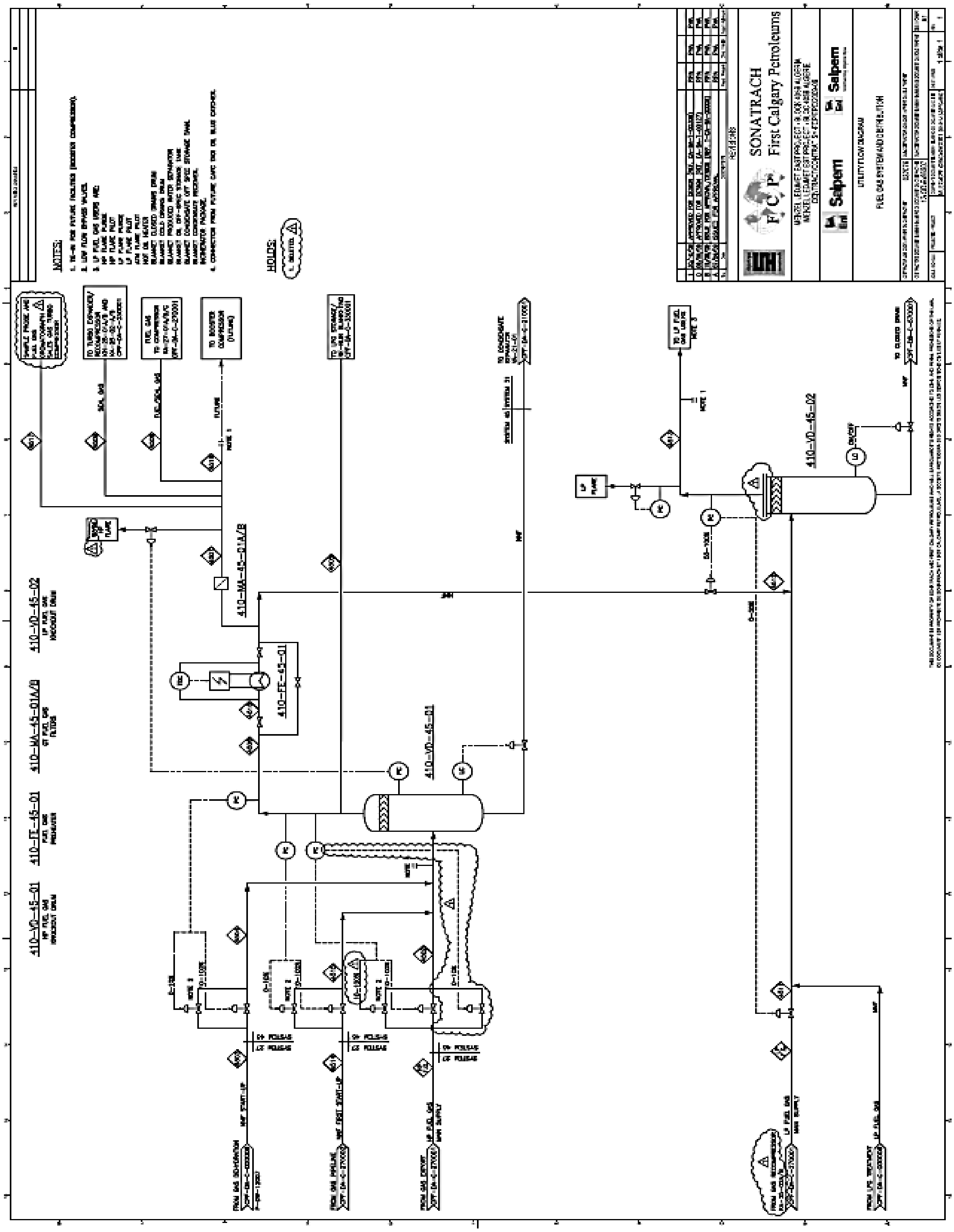
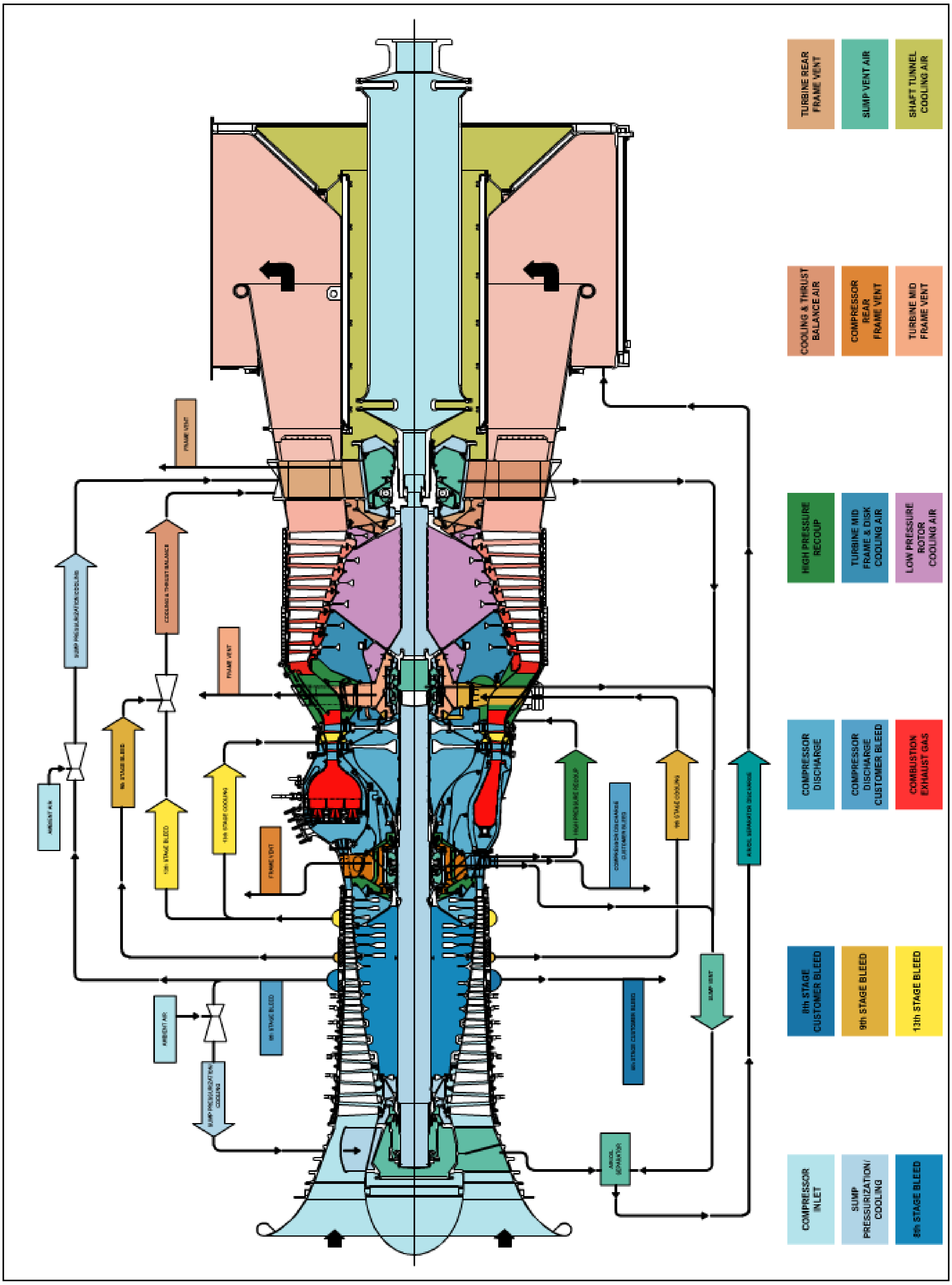
Appendix A: PFD of Fuel gas system



Appendix B: 2500 Airflow



Appendix C: Intake Filter System