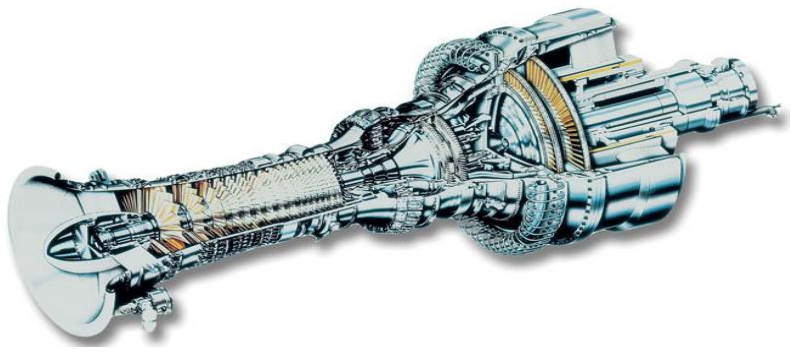
# Basics of Gas Turbine (PGT25)



# Introduction to Gas Turbine

## Types of Turbines and its application

- A machine for producing continuous power in which a wheel or rotor, typically fitted with vanes, is made to revolve by a fast-moving flow of water, steam, gas, air, or other fluid.
- Internal Combustion Engine Vs External Combustion Engine
- A Gas Turbine, also called a combustion turbine, a type of Internal Combustion Engine.
- But unlike Internal combustion engines such as Diesel & Automotive IC Engines where intermittent combustion takes place, in Gas Turbine continuous combustion process takes place.

## History of Gas Turbines:

- Two types of Gas Turbines; Industrial & Jet Engines
- First working gas turbine was only made in 1905 by the Frenchman Rateau.
- First gas turbine for power generation became operational in 1939 in Switzerland. It was developed by the company Brown Boveri.
- Post 1980's, Natural gas made its breakthrough as fuel. Since then, gas turbines have increased in popularity.
- New high-temperature materials, new cooling techniques and research in aerodynamics strongly improved the efficiency of the jet engine. It therefore soon became the primary choice for many applications.
- Foreign Manufacturers: General Electric (GE), Pratt &Whitney, SNECMA, Rolls Royce, Honeywell, Siemens – Westinghouse, Alstom
- Indian Manufacturer: Kaveri Engine by GTRE (DRDO), BGGTL (Bharat Heavy Electricals Ltd.)

# Types of Gas Turbines:

## Generator Drive (ISO conditions - natural gas - electrical generator terminals)

| | ISO RATED POWER kW | HEAT RATE kJ/kWh | EFFIC. % | PRESSURE RATIO | EXHAUST FLOW kg/sec | lbs/sec | TURBINE SPEED RPM | EXHAUST TEMPERATURE °C | °F |
|---|---|---|---|---|---|---|---|---|---|
|  GE10-1 | 11,250 | 11,489 | 31.4 | 15.5 | 47.5 | 104.7 | 11,000 | 482 | 900 |
|  PGT16 | 13,720 | 10,295 | 35.0 | 20.2 | 47.3 | 104.3 | 7,900 | 491 | 919 |
|  PGT20 | 17,464 | 10,238 | 35.2 | 15.7 | 62.5 | 137.7 | 6,500 | 475 | 887 |
|  PGT25 | 22,417 | 9,919 | 36.3 | 17.9 | 68.9 | 151.9 | 6,500 | 525 | 976 |
|  PGT25+ | 30,226 | 9,084 | 39.6 | 21.5 | 84.3 | 185.9 | 6,100 | 500 | 931 |
|  PGT25+G4 | 33,057 | 9,047 | 40.0 | 23.2 | 89.6 | 197.7 | 6,100 | 510 | 950 |
|  LM6000* | 42,262 | 8,787 | 41.1 | 28.0 | 125.0 | 275.0 | 3,600 | 455 | 851 |
|  LMS100* | 98,196 | 7,997 | 45.0 | 40.0 | 206.9 | 456.0 | 3,600 | 417 | 782 |
|  MS5001 | 26,830 | 12,687 | 28.4 | 10.5 | 125.2 | 276.1 | 5,094 | 483 | 901 |
|  MS5002E* | 31,100 | 10,285 | 35.0 | 17.0 | 102.0 | 225.0 | 5,714 | 511 | 952 |
|  MS6001B | 42,100 | 11,230 | 32.1 | 12.2 | 141.1 | 311.0 | 5,163 | 548 | 1,026 |
|  MS7001EA | 85,400 | 10,990 | 32.7 | 12.6 | 292.0 | 643.0 | 3,600 | 537 | 998 |
|  MS9001E | 126,100 | 10,650 | 33.8 | 12.6 | 418.0 | 921.0 | 3,000 | 543 | 1,009 |

(*) DLE Combustion

- Description of various Gas Turbines manufactured by GE:
  - ✓ PGT: Pignone Gas Turbine
  - ✓ MS : Mechanical Structure
  - ✓ LM : Land & Marine

## Gas Turbine Applications:

- **Jet Engines**
  - Military & Commercial Aircrafts

- **Turbo Propellers**
  - Ships, Locomotives, High-End Cars etc.

- **Industrial Operations (Heavy Duty Gas turbines i.e. Industrial or Frame type)**

- **Aero-Derivative Gas Turbines (Lighter weight unit, derivation of an aircraft jet engine, typically for land applications)**
  - Electricity generation
  - Mechanical drive ; eg. compressors for natural gas pipelines.

# Advantages and Disadvantages of Gas Turbine

- **Advantages of Gas Turbine Engines (compared to other drive equipment)**

**For Same HP (power developed)**

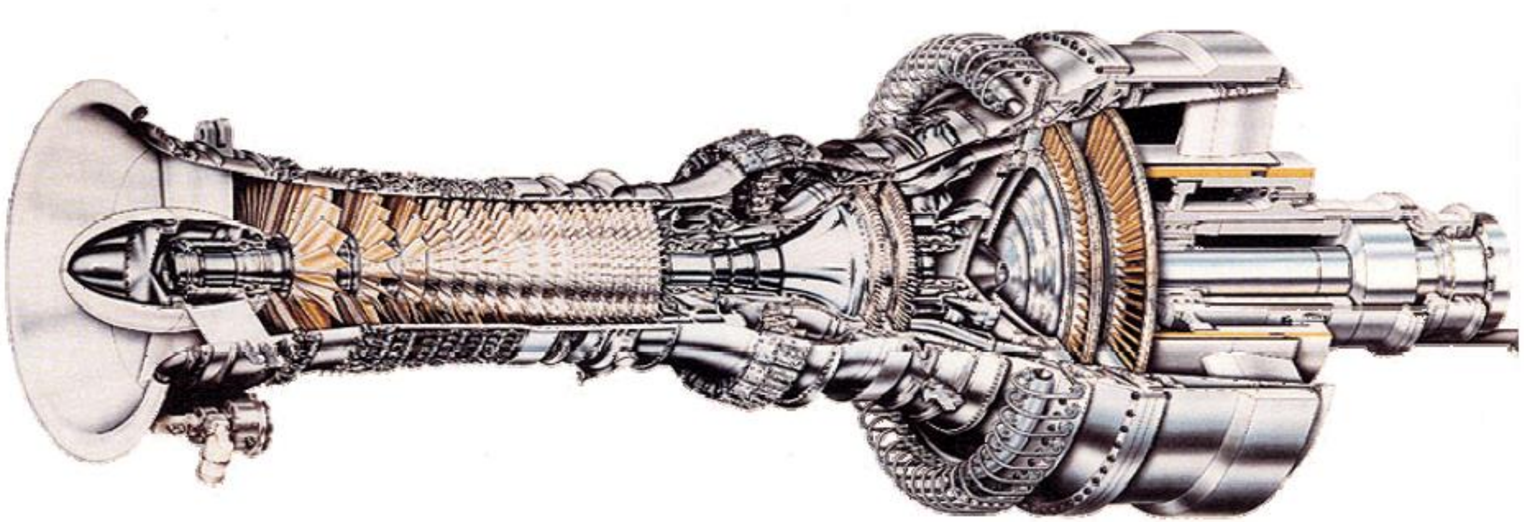
- Very high power-to-weight ratio, compared to reciprocating engines, steam turbines;
- Quick Start and fast loading
- Greater reliability, particularly in applications where sustained high power output is required
- Can run on a wide variety of fuels.
- Very low toxic emissions of CO and UHC

- **Disadvantages of Gas Turbine Engines**

- Comparatively less efficient.
- Complicated control system.
- Cost is very high

# Gas Turbine PGT25+ DLE

GE Aero Derivative Gas Turbine



## Gas Turbine PGT25+

- Constructional features of PGT 25+ machines
- Auxiliaries system of PGT 25+ machines
- Protection & Control Systems
- DLE Combustion system
- Performance Monitoring

## Constructional features of PGT25+ machines:

- **Gas Generator (GG) consist of:**
  - Inlet Plenum & IGV
  - High Pressure Axial Compressor (HPC)
  - Variable Stator vane System (VSV)
  - Gas Generator (GG)
  - Combustion Chamber
  - Gearbox (IGB, TGB & AGB)
  - Bearings

- **Power Turbine (PT) consist of:**
  - Power Turbine (PT)

**Constructional features of PGT25+ machines**

## GG Major Components of GG:

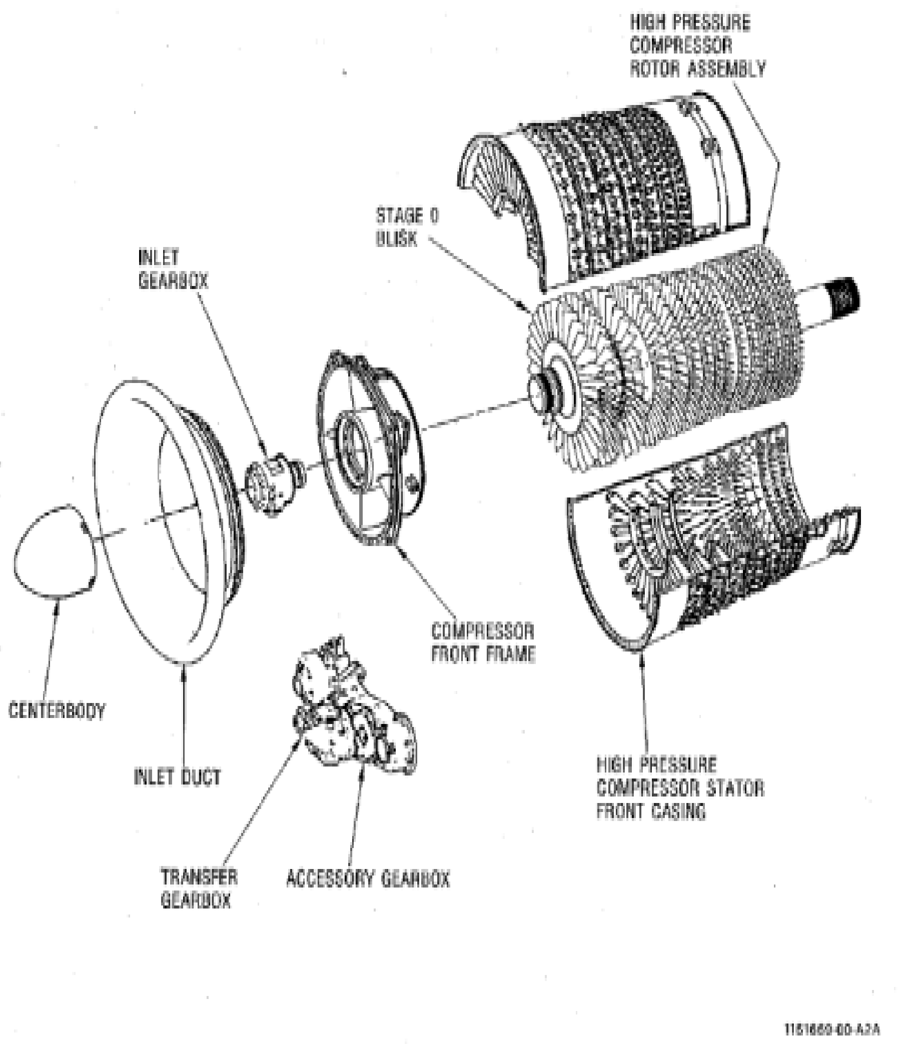



Figure 4-3. Gas Generator Major Components (Sheet 1 of 2)

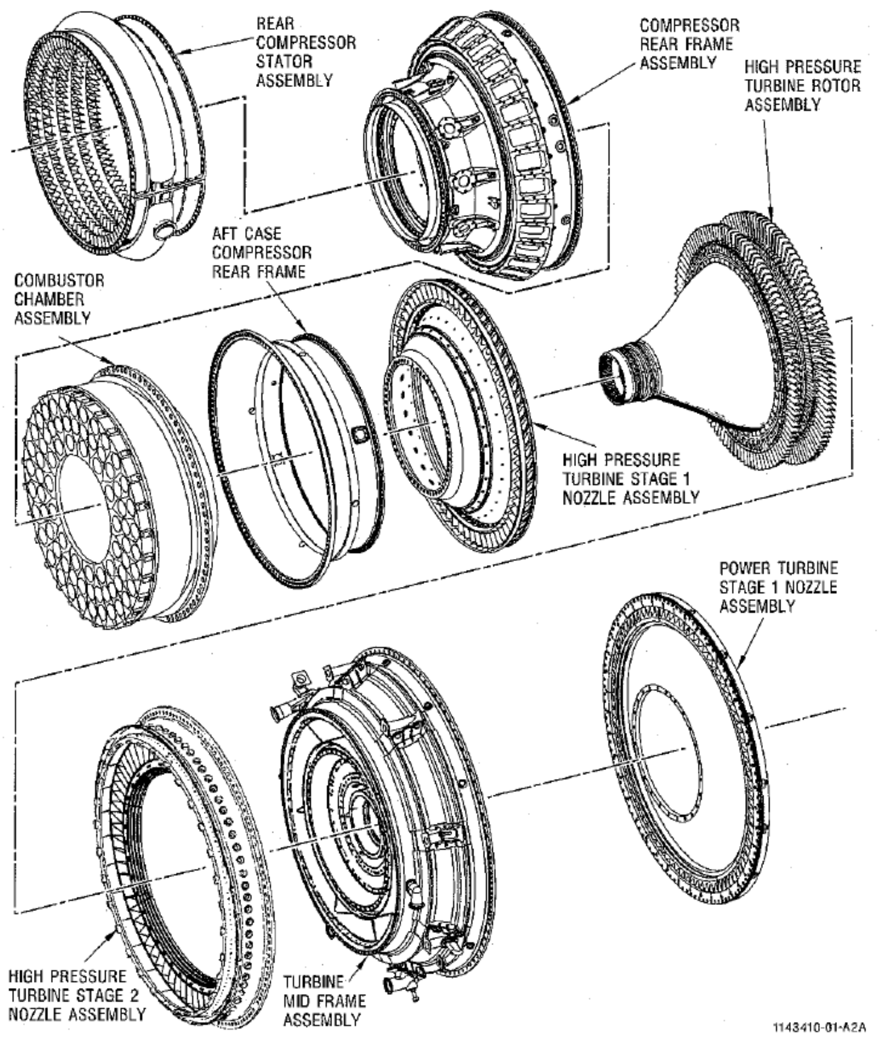
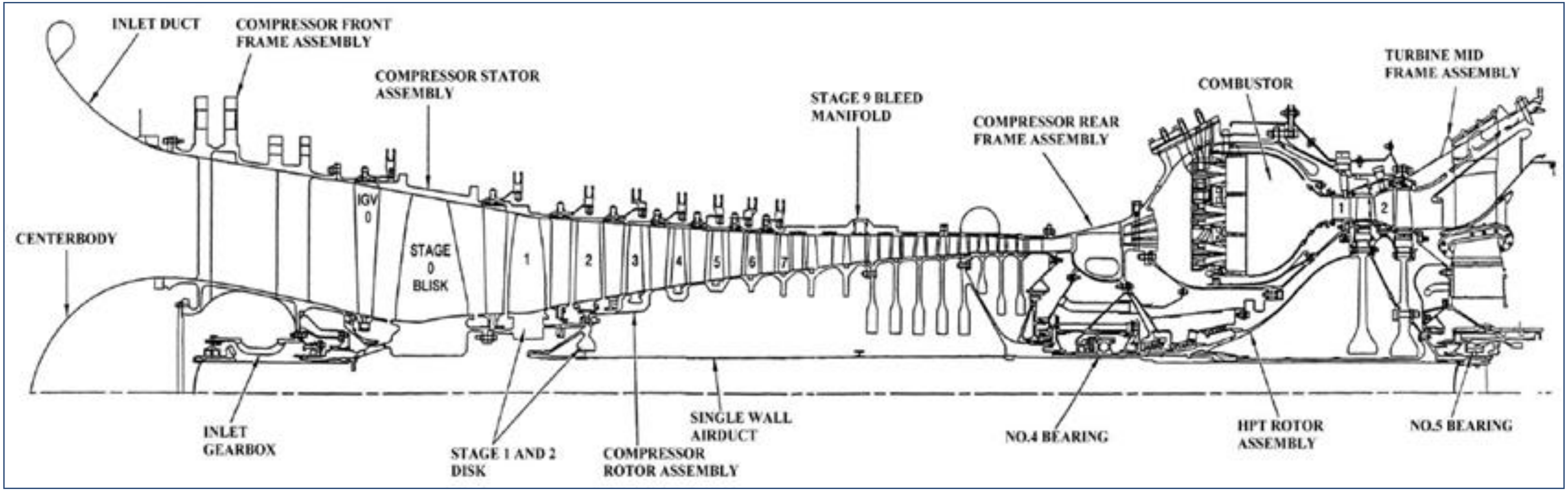



Figure 4-3. Gas Generator Major Components (Sheet 2 of 2)

## Cross Sectional View of GG:



## Inlet Plenum & IGV's:

- Inlet Plenum facilitate the smooth change in direction of inlet air sucked through Air Inlet Filters & fed to Axial Compressor Inlet section.
- Inlet Guide Valves means the first stage ("0") of the Axial Compressor.
- Opening of the IGV is regulated by the VSV System

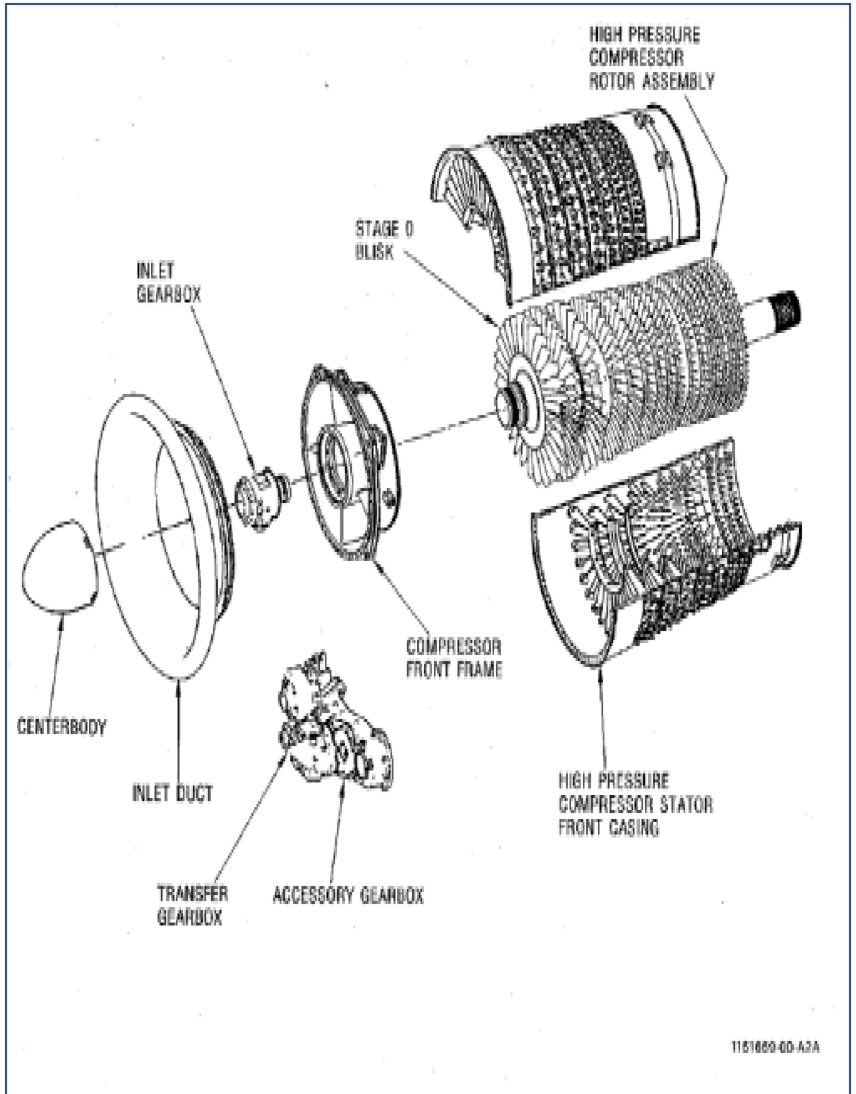



Figure 4-3. Gas Generator Major Components (Sheet 1 of 2)

## Purpose of IGV's:

- To limit the quantity of air flow into Axial Compressor during start-up

## Axial Compressor:

### Main Function of Axial Compressor :

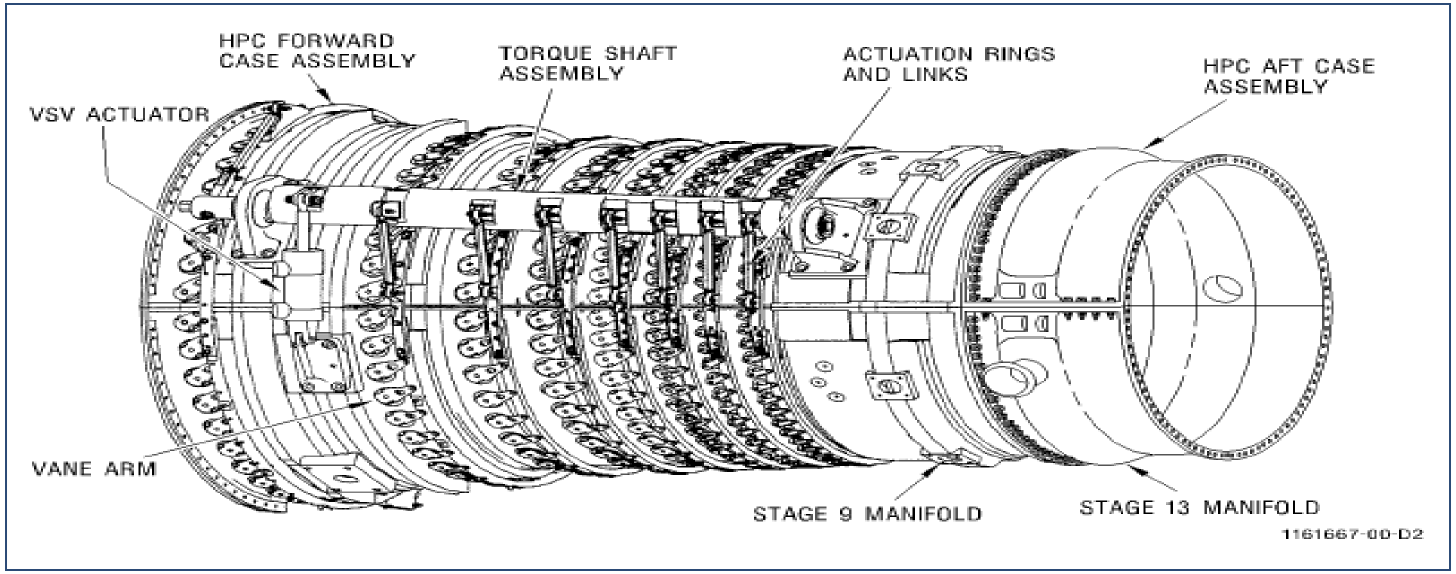
- Primary purpose of the compressor section is to compress huge quantity of air for combustion
- Some of the air is extracted for engine component cooling, sump pressurization.

### Advantages of Axial Compressor :

- Continuous flow, High Efficiency & Large Flow Rate particularly in relation to their size & cross section

### Features:

- Axial Compressor is a 17-stage, high pressure ratio, axial flow design.
- Major components include:
    - Compressor rotor
    - Compressor stator
- The number designation for the stages begins with stage 0 and ends with stage 16.
- Axial Compressor stator consist of one stage of IGVs, Stage 0-15 stages of stator vanes and outlet guide vanes (OGV)- (Stage 16).



## Variable Stator Vane (VSV) System:

### Main Function of Variable Stator Vane (VSV) System :

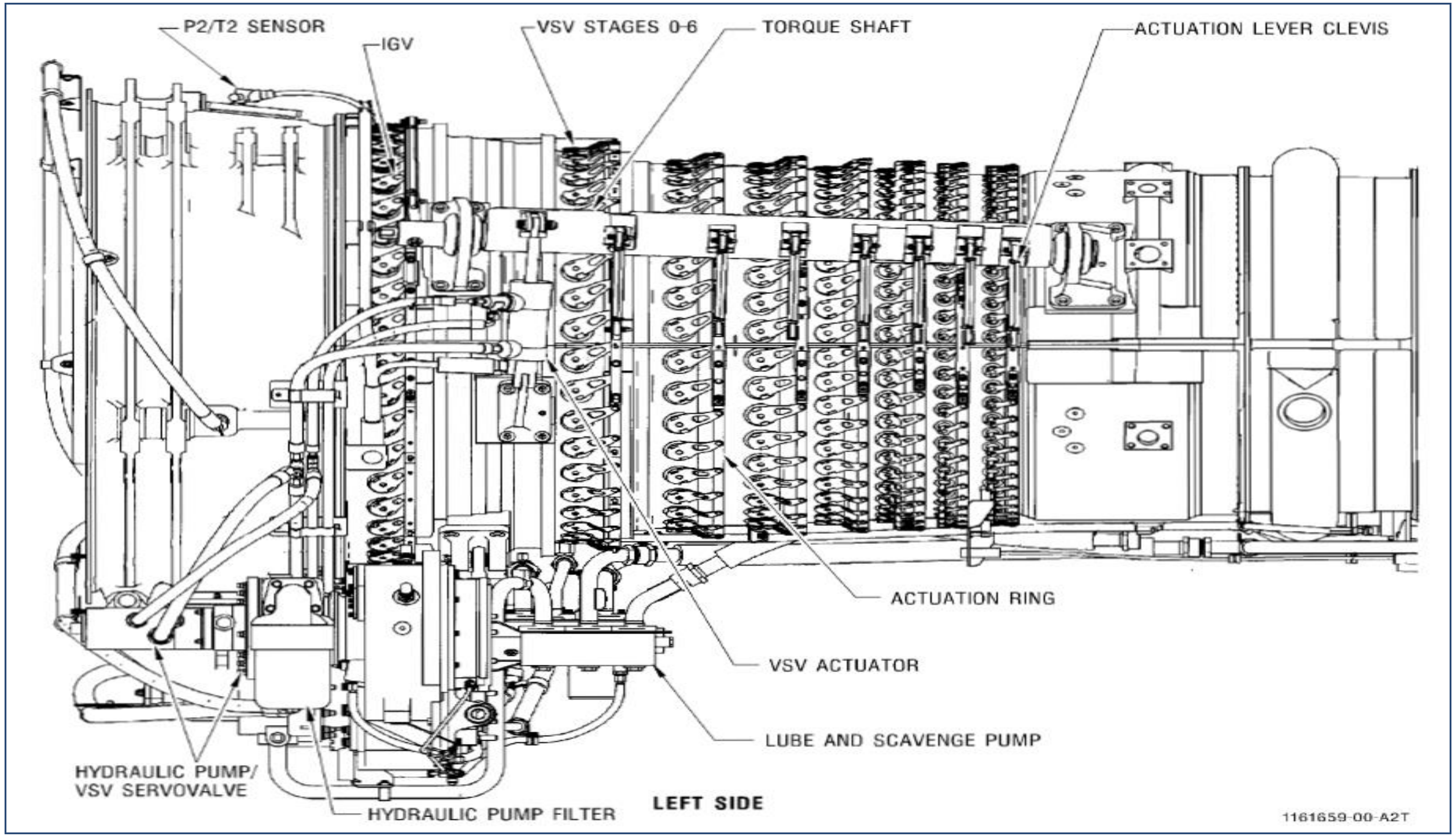
- To prevent the Axial Compressor stall & increase efficiency over wide operating pressure ratio
- During the normal operation of GT, regulate air flow as per requirement of Combustion Control.

### Features:

- On the Axial Compressor Stator, IGV, Stage 0 through 6 are variable. Their angular positions change as a function of Compressor Inlet temperature (T2) and GG Speed (NGG).
- This variability gives the vane the optimum angle of attack for efficient operation without compressor stall
- The VSV is an electro-hydraulic system consisting of following components :
    - AGB mounted Hydraulic Pump,
    - VSV Servo valve,
    - VSV actuators with integral Linear-Variable Differential Transducers (LVDT) to provide feedback position signals to the off engine electronic control.

## Variable Stator Vane (VSV) System:

- The variable vanes are actuated by a pair of torque shafts.
- Each of the torque shaft forward ends is positioned by a hydraulic VSV actuator.
- Linkages connect directly from the torque shaft to the actuating rings of the variable vanes



## Actions to be taken after $CO_2$ release:

### Actions to be taken by field personal after $CO_2$ has been released into the GT Enclosure

Entry in any compartment NOT to be done without wearing of BA set till all compartments are purged & oxygen level checked. Also the entry should be allowed only after the permission of Station In-Charge or Lead Operations.

- Do not open any door for next 30 minutes. Allow the slow discharge of $CO_2$ to maintain inert atmosphere inside the enclosure.
- After this, open all the doors of all compartments for next 30 minutes to allow ventilation. Provide service air hoses in enclosure.
- Then only the authorized personal wearing BA set has to enter after permission from CS In-charge or Lead Operations to open the $CO_2$ operated ventilation dampers manually.
- $CO_2$ dampers are to be opened manually by entering the compartment using BA set.
- After all dampers are open, go for purging of compartments by running ventilation fans / pressurization fans for min 30 minutes keeping all doors closed.
- After this, Oxygen to be checked on both the sides of enclosure.
- If $O_2$ is ok, allow entry with confine space entry permit. But do not allow unrestricted entry.

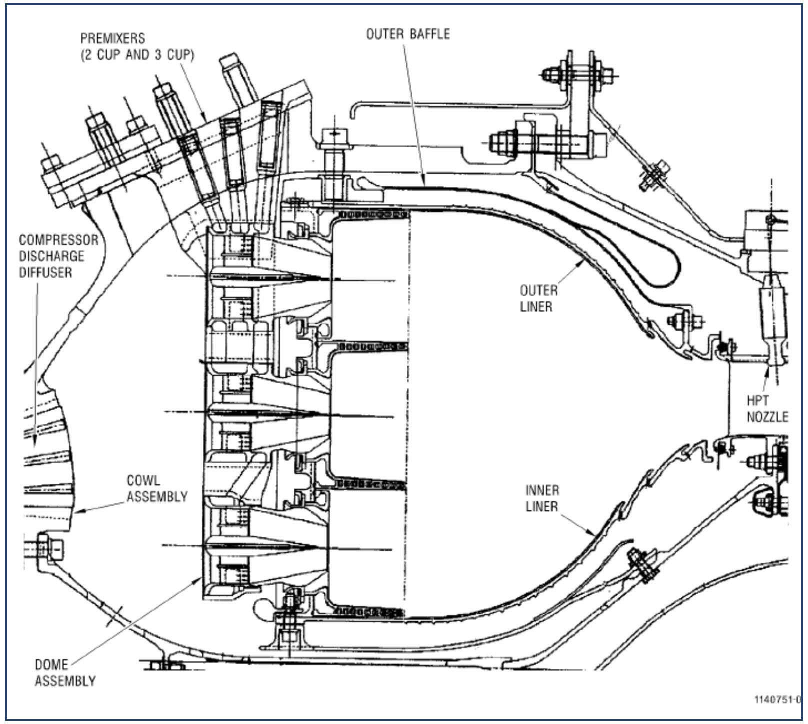
**Combustion Section:**

**Features:**

- Combustor is of a triple annular design consisting of five major components:

1. Cowl (diffuser) assembly ; 2. Dome ; 3. Inner-liner ; 4. Outer-liner ; 5. Baffle.

- Cowl assembly serves as a diffuser and distributor for the compressor discharge air uniformly throughout a large operating range.
- Dome of the combustor supports 75 segmented heat shields that form the three annular burning zones in the combustor, known as the outer or A-dome, the pilot or B dome, and the inner or C-dome.




- The Ignition system produces the high-energy sparks that ignite the fuel/air mixture in the combustor during starting The system consists of one ignition exciter, one lead, and one igniter plug.

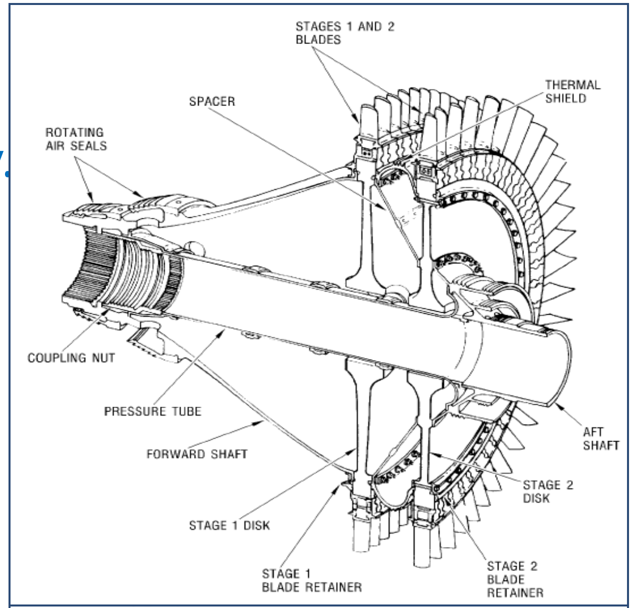
- Once ignition occurs, combustion becomes self-sustaining and continues without the igniter.

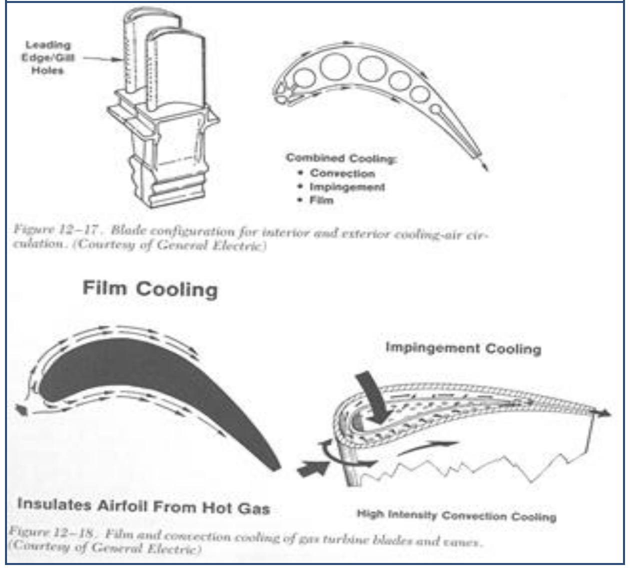
- Two ultraviolet flame sensors monitor the combustion flame

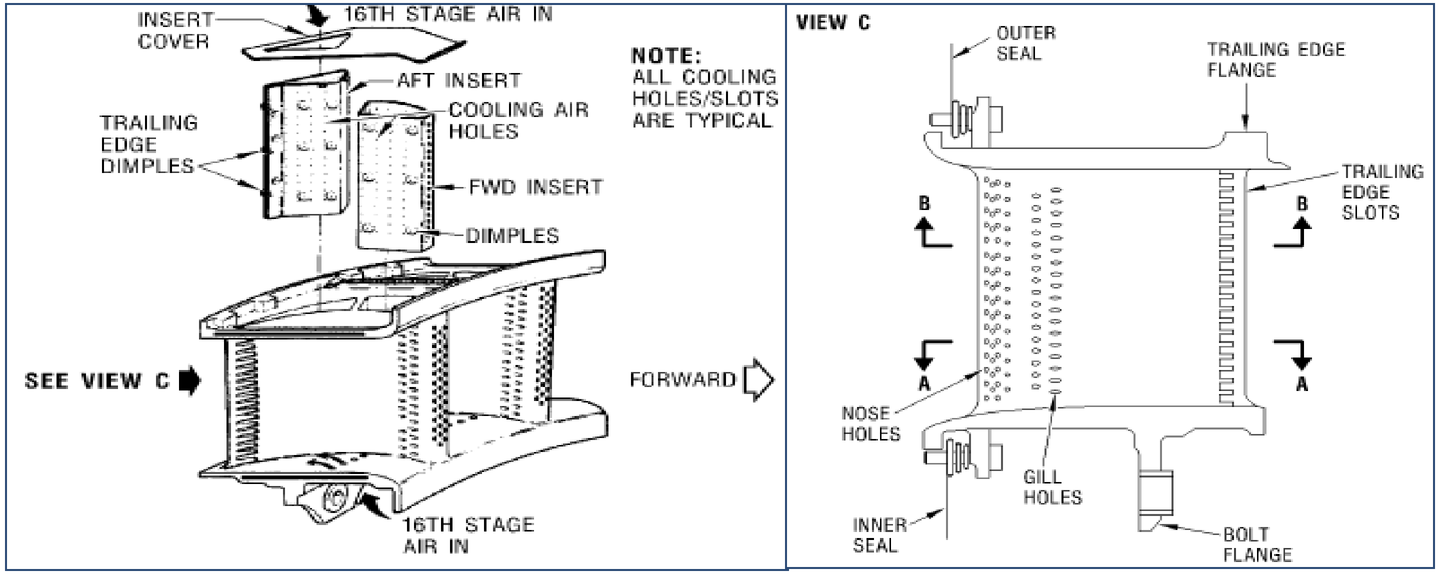
# Gas Generator (GG) Stator:

## Features:

- ➢ Gas Generator (GG) is an air-cooled, two stage design with high efficiency.
- ➢ Gas Generator (GG) section consists of :
    - ❖ Rotor mounted with 1st & 2nd stage blades
    - ❖ Stator with 1st & 2nd stage nozzle assemblies.
- ➢ Stage 1 HPT nozzle directs high pressure gases from the combustion section onto stage 1 turbine blades at the optimum angle and velocity.
- ➢ 1st Stage Nozzle vanes are air cooled by convection and film cooling. 2nd Stage Nozzle vanes are air cooled by convection.



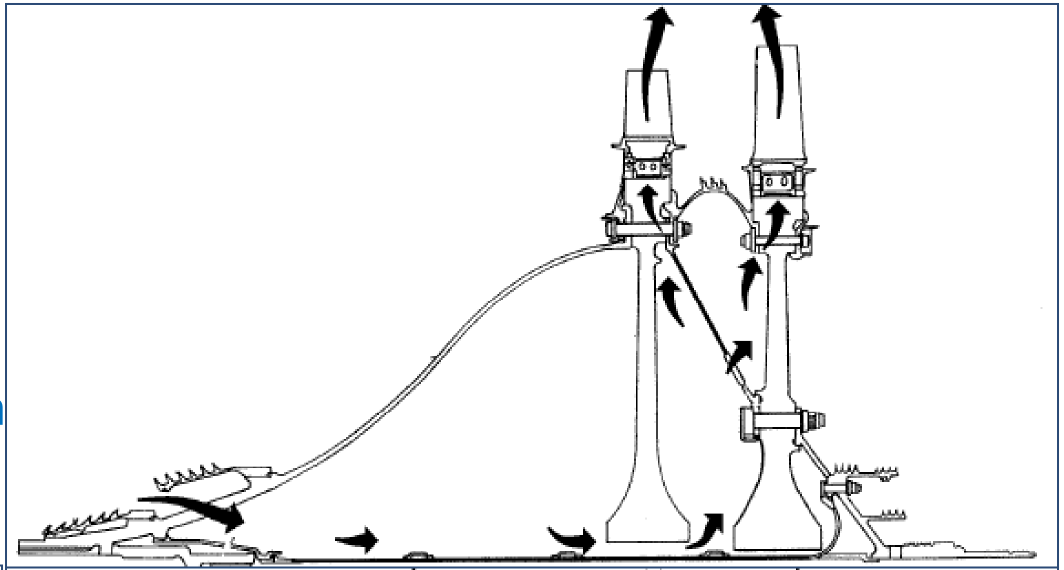



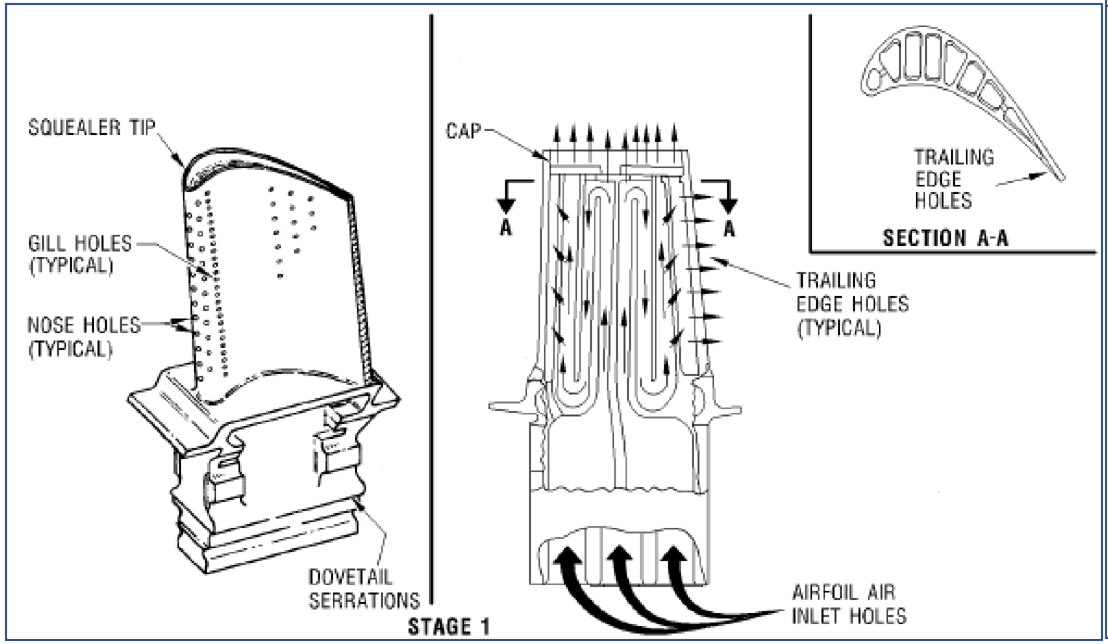
## Gas Generator (GG) Rotor:

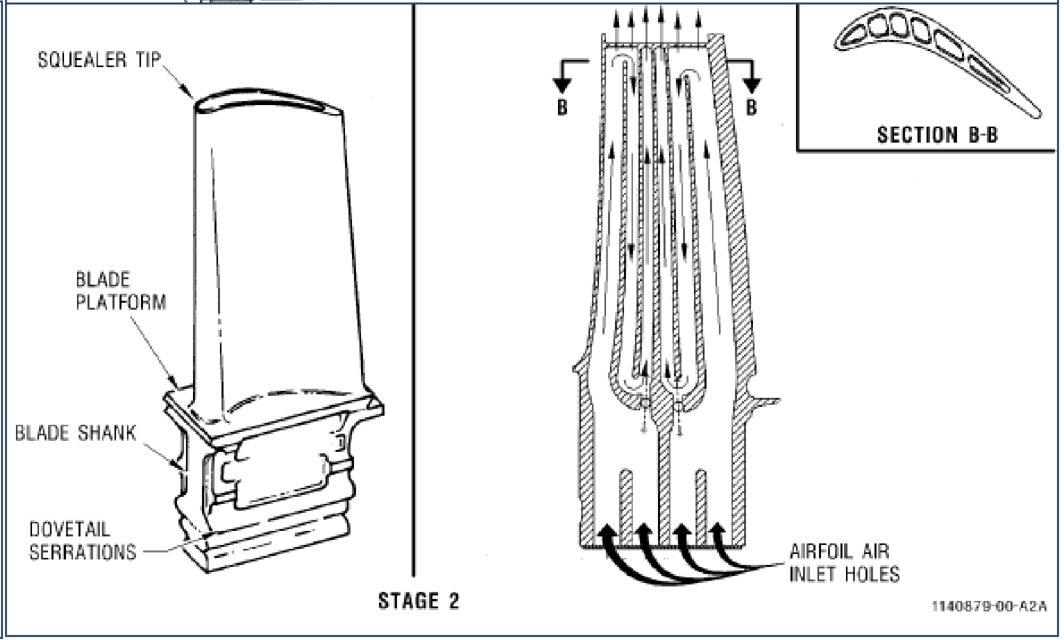
### Features:

- Rotor Blades are cooled by compressor discharge air Which flow through the dovetail & blade airfoil.

- Rotor blades are cooled by a combination of internal convection, leading edge internal impingement & extern film cooling.





## Accessory Drive Components:

## Main components of Accessory Drive Components :

➢ Inlet Gear Box (IGB) : Transfer power from the High Pressure Axial (HPC) compressor rotor to TGB.

➢ Transfer Gear Box (TGB) : Transfer power from the Inlet Gear Box (IGB) through radial drive shaft to the Accessory Gear Box (AGB)

➢ Accessory gear Box (AGB) : Provides drive provisions for the following:

- ❖ Hydraulic starter that drives the Axial Compressor rotor through the TGB assembly
- ❖ Lube and scavenge pump
- ❖ Hydraulic pump/VSV servo-valve
- ❖ Air-Oil Separator
- ❖ For manual rotation of the Axial Compressor rotor system during bore-scope inspection

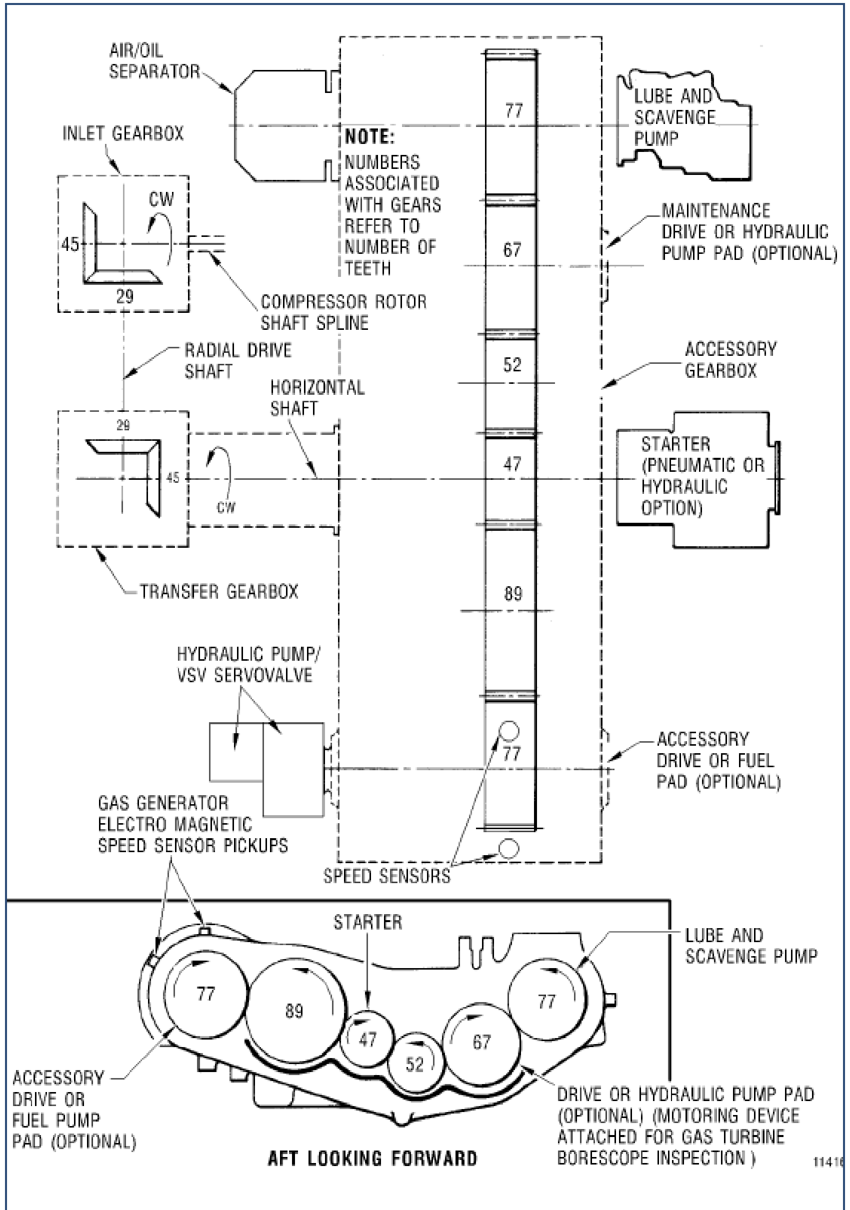
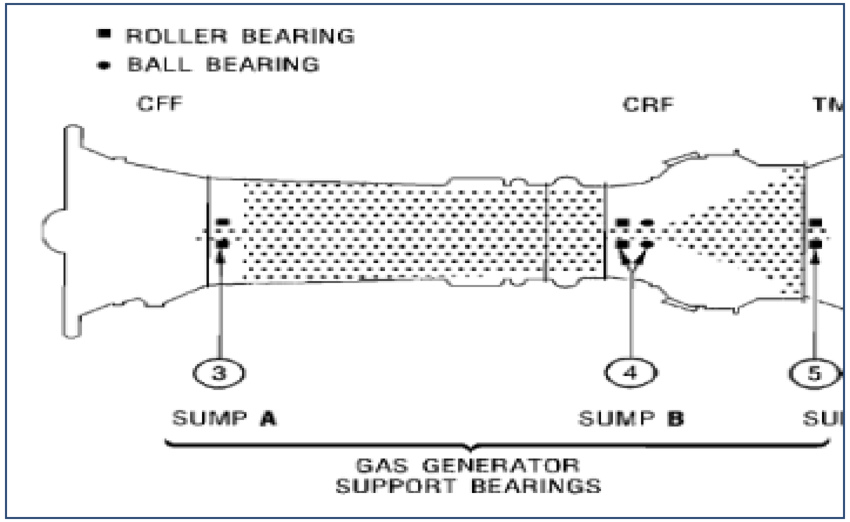



Figure 4-22. Accessory Gearbox

## Bearings : Gas Generator (GG):

## Bearings :

- Axial Compressor & GG shaft are supported by has Roller & Ball Bearings
- Bearing 3R & 4R Roller Bearings are mounted on forward & aft side of Axial Compressor shaft respectively
- 4B Ball Bearing is used to carry the thrust load of the Gas Generator rotor.
- Complete bearing assembly is called as Sump. Sump consist of a Roller or Ball Bearing enclosed at the center of two double wall like compartments ; Inside one consist of Synthetic Oil & other consist of pressurization air, bleed from the 9th stage of Axial Compressor



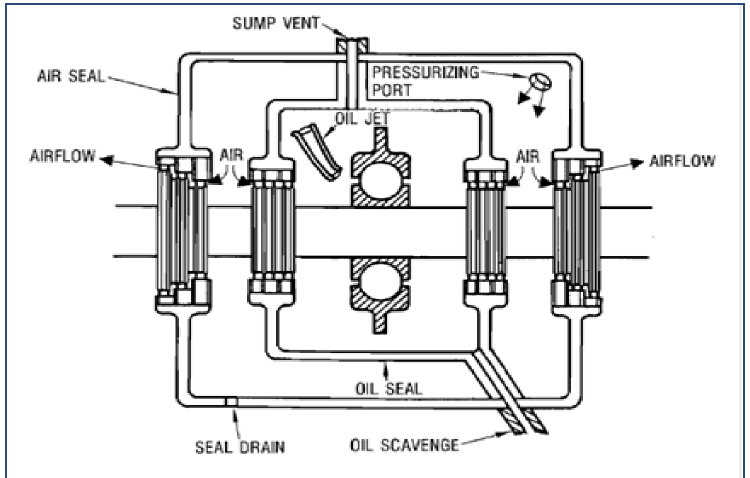



Figure 5-7. Sump Function Diagram (Typical)

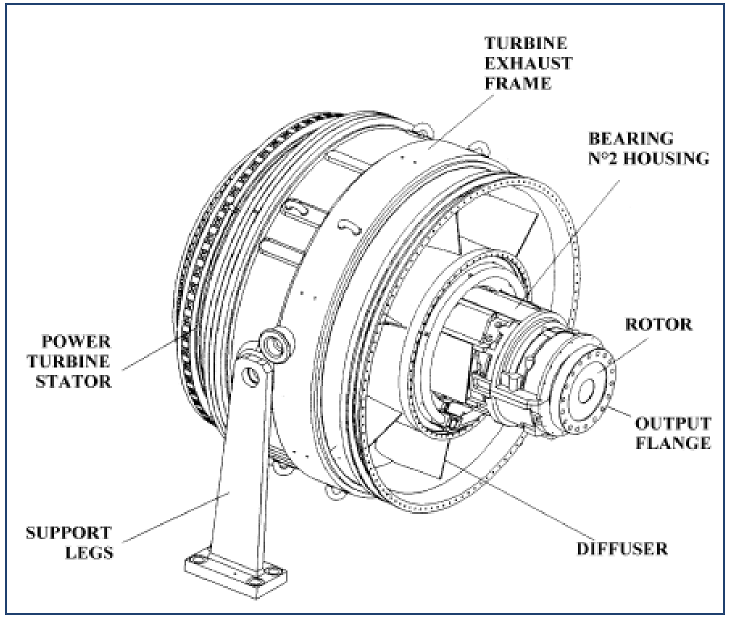
## Power Turbine (PT) & Bearings:

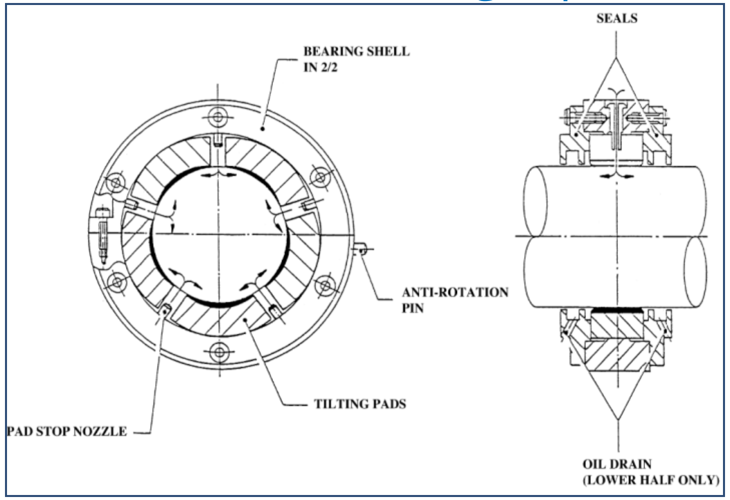
- Power Turbine (PT) section consists of :
  - Rotor mounted with 1st & 2nd stage blades
  - Stator with 1st & 2nd stage nozzle assemblies.

- Stage 1 Nozzle is assembled directly to the Turbine Main Frame & directs gasses exited from the GG & directs them towards the 1st stage blades of power turbine.

- Blades are coated with corrosion & oxidation protection

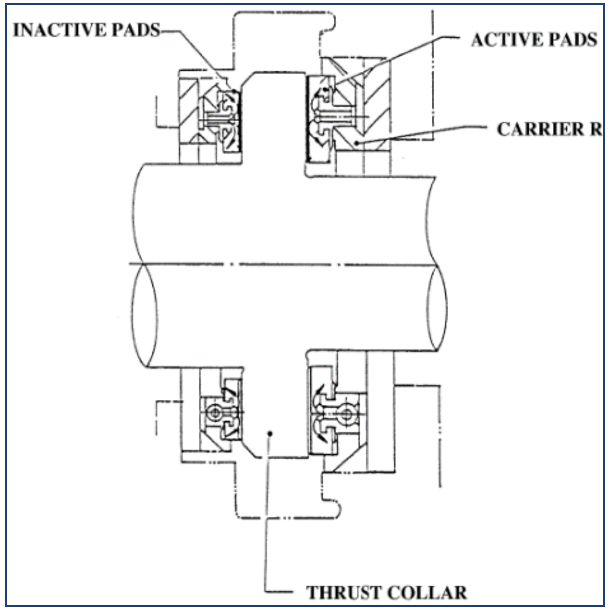
- Power Turbine rotor is supported with 2 Journal bearings.
- One Thrust bearing is provided to absorb the relative axial on the PT




Tilting Pad type Journal Bearing

Tilting Pad type Thrust Bearing



## Main Auxiliaries system

- Air inlet filtration system
- Lube oil system
  - Mineral Oil System
  - Synthetic Oil System
  - Hydraulic Oil System
  - Lube Oil Cooler System
- Ventilation system
- Hydraulic Starting system
- Fire & gas detection system

# Auxiliaries system of PGT 25+ machines

## LUBRICATING OIL SYSTEM:

- **Function of Lube Oil system in PGT25+**
    - Lubricate and cool the rotor bearings, sumps, and the inlet, transfer, and accessory gearboxes.
    - Operate the actuators for the VSV system and compressor discharge pressure (CDP) bleed valve.

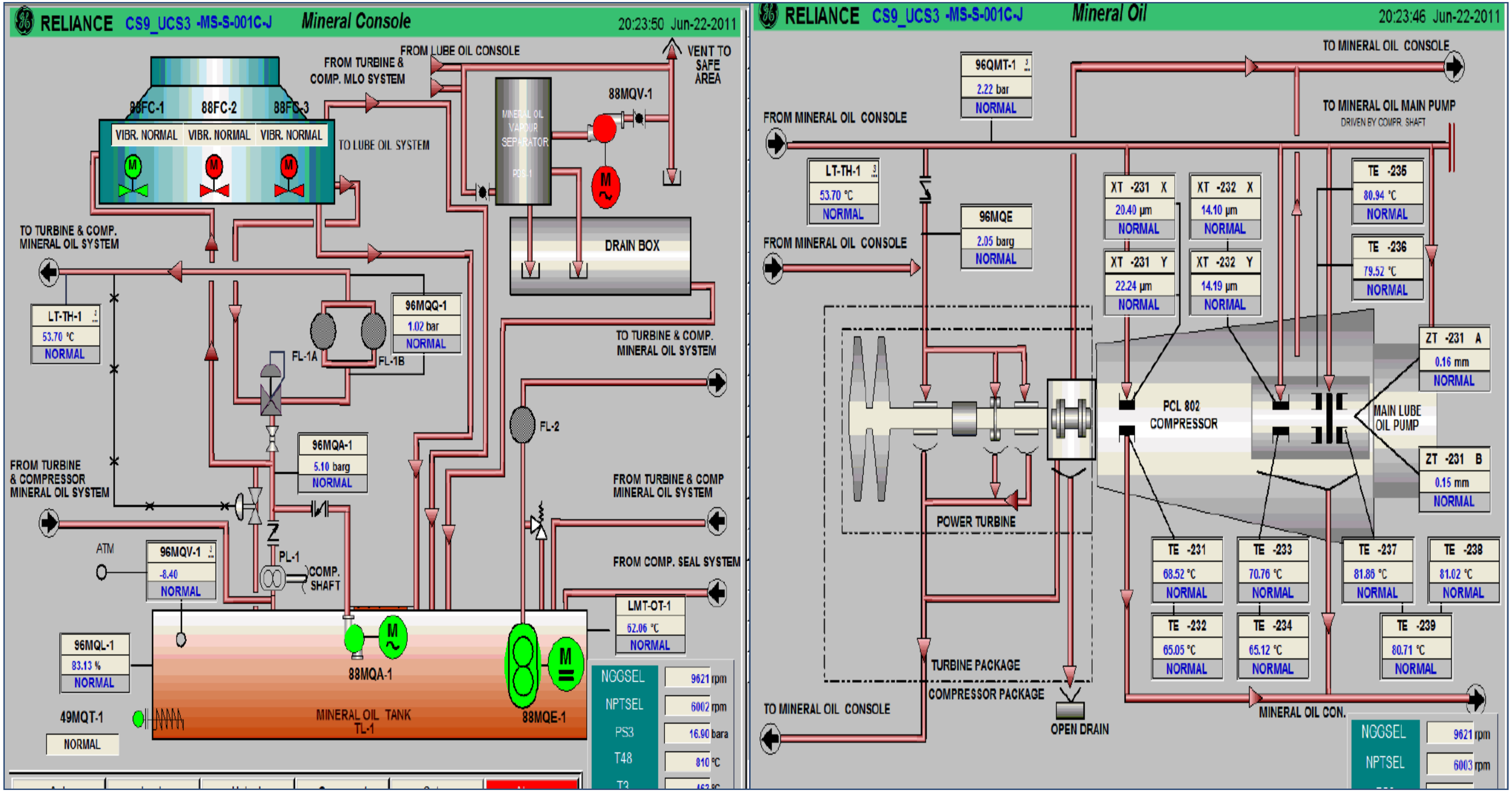
- PGT25+ Gas Turbine is equipped with two lubricating oil systems:
    - Mineral lube oil system
        - Lubricate the bearings of the P.T. (Power Turbine), the gear and the compressor
    - Synthetic oil system
        - Lubricate & cool bearings of GG, sumps and the accessory gear box
    - Hydraulic / Control Oil System
        - VSV actuation
        - Bleed valve operation

## Lubricating Oil System : Mineral Oil System

### Mineral Oil System:

- Lubricates Power Turbine (PT) & Cent. Compressor bearings
- AC powered Auxiliary Oil Pump (AOP) to circulate oil till Main Oil Pump (MOP) is able to provide the requisite oil for lubrication
- DC Powered Emergency Oil Pump (EOP) comes in line & provides oil to PT during cool-down in case of AC power supply failure.

# Lubricating Oil System : Mineral Oil System

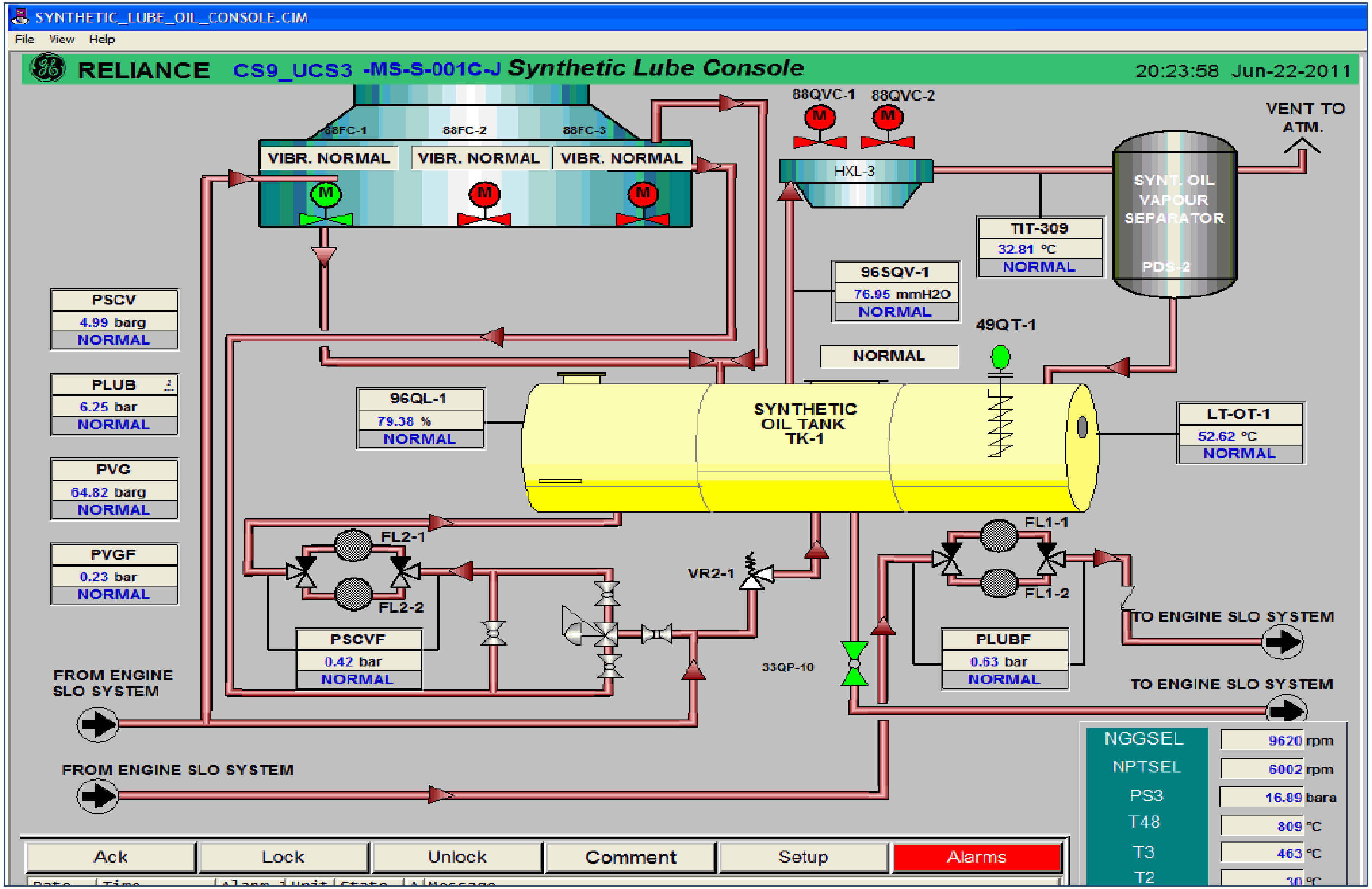


## Lubricating Oil System : Synthetic Oil System

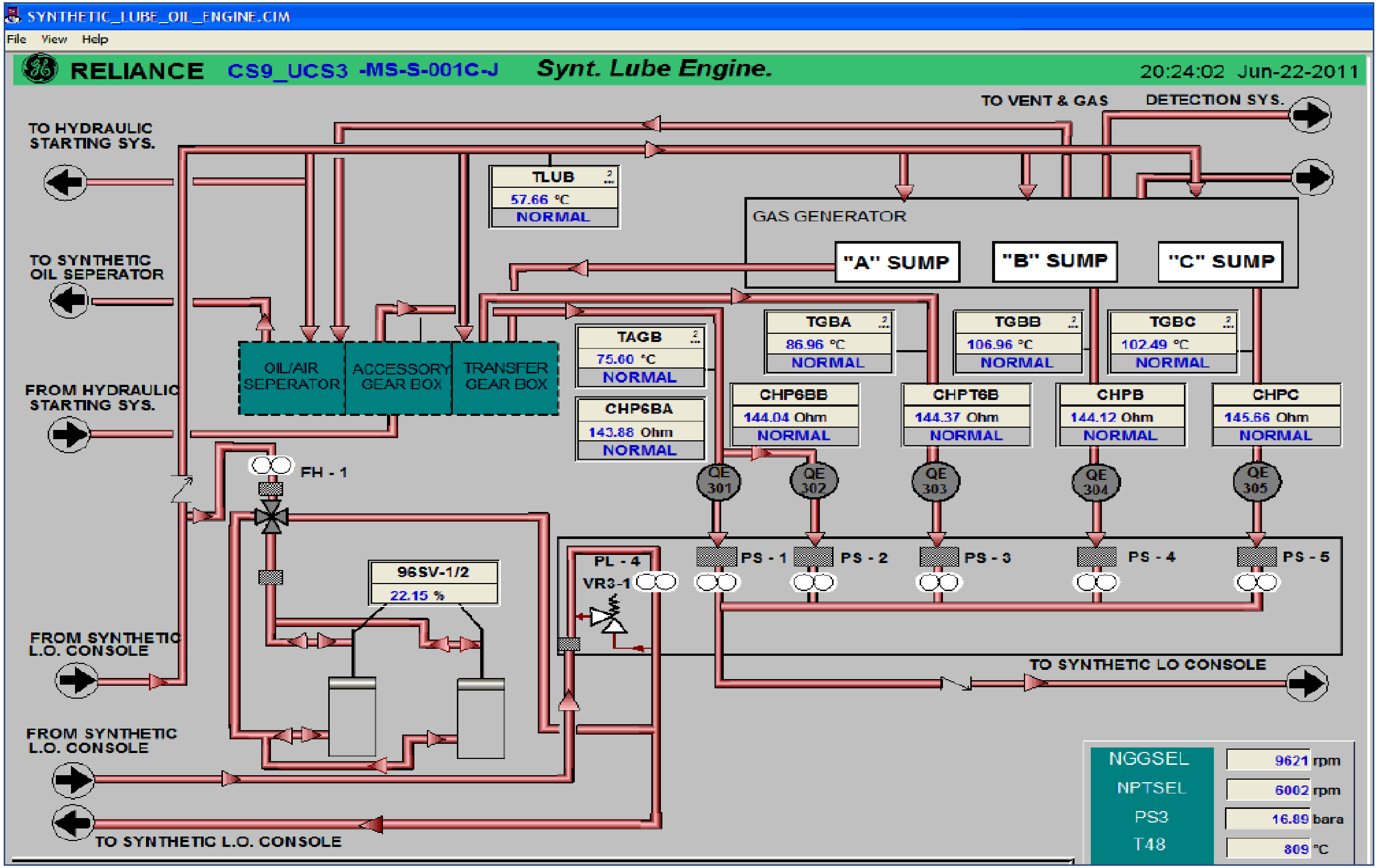
### Synthetic Oil System:

- Lubricate & cool bearings GG rotor bearings, sumps and the accessory gear box & also used for VSV actuation
- Instead of the conventional LO System, here the oil flows into the bearings due to gravity & is pulled through them by scavenge pumps.
- Oil return lines are provided with Chip Detectors which sense presence of any magnetic particle in return oil from GG bearings.

# Lubricating Oil System : Synthetic Oil System



# Lubricating Oil System : Synthetic Oil System



## Lubricating Oil System : Hydraulic Oil System

### Hydraulic / Control Oil System:

- Part of Synthetic Oil is pressurized up to high pressure & then utilized to actuate few of the auxiliary systems of GT.
- A Positive Displacement pump pressurizes (up to 85 to 88 BarG) some of the Synthetic Oil
- Hydraulic Oil actuates Variable Stator Vanes (VSVs) & Axial Compressor Bleed Valve
- In order to meet the sudden variation in Oil pressure on the control elements, a accumulator is provided in the Hydraulic Oil line. Main function of the accumulator is absorb any variation in pressure of the Hyd. Oil & maintain a constant force on the actuator
- Return oil from the Hydraulic system is directed back to the Synthetic oil tank

# Lubricating Oil System : Lube Oil Coolers

## Lube Oil Cooler System:

- Cools the Mineral & Synthetic Oil
- AC powered three Lube Oil Cooler Fans (Main, Auxiliary, Stand-by)are provided (3x 50% control sequence)

## Logics:

- Auxiliary fan selection done from HMI

  - Aux fan starts when temp high alarm is detected. Though temp normalized, fan to be stopped manually.
- Main fan starts when flame detected in combustion chamber. Main fan stopped typically 2 hrs after flame-out
- Stand-by fan starts if LO temp exceeds a defined value on 2oo3 logic.
  - It will continue to run & will not stop till completion of 10 min.
  - If temp dropped below defined value, it will stop & not start within 5 min.
- Cooler fan control sequence & changeover :
  - LO cooler fan vibration high is detected. Cooler fan will start/stop as per above logic.
  - When any LO cooler fan starts, vibration high logic is inhibited for fixed time.
  - LO Cooler fan will trip on high vibration in-spite of Remote/Local selection.

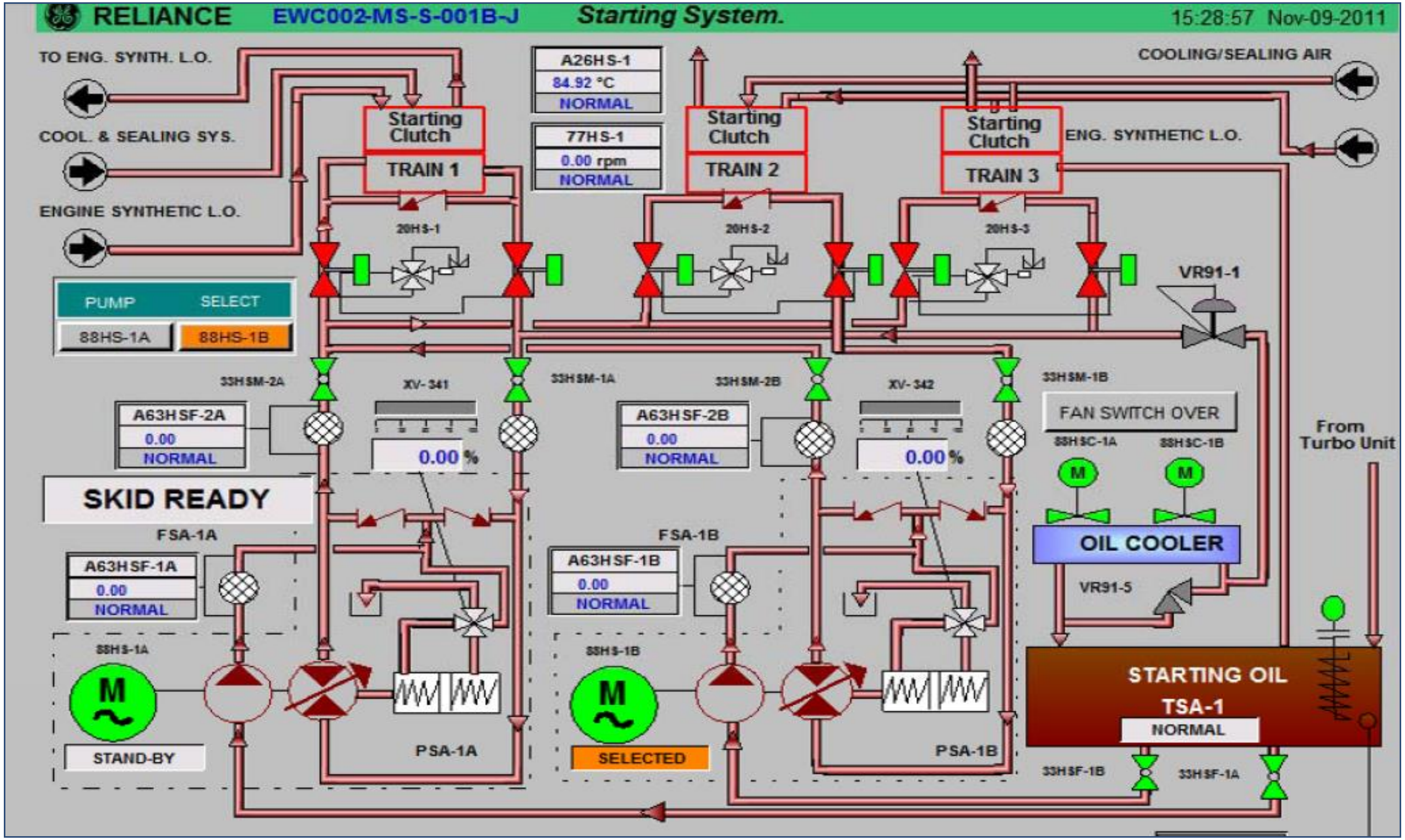
## Ventilation System:

### Principle of operation: Forced Draft type ventilation system

### Ventilation system for PGT25+:

- Two AC powered ventilation fans (88BA-1, 88BA-2). In addition one DC powered vent fan is provided
- Only one fan operates at one time, one fan is in "duty" and another is in "stand-by" mode.
- Fans operate only if the dampers in the respective duct are in fully open condition.
- One fan comes in line immediately after GTC start command is given
- Stand-by fan comes in line in Auto only if enclosure pressure drops below alarm limit & enclosure doors are in closed condition.
- If still enclosure pressure remains low, normal shutdown of machine is activated (provided the enclosure doors are closed or else S/d occurs after 10 min delay time)
- Emergency fan starts 1) if both AC fans fail or 2) Enclosure temp > HH limit
- If enclosure temp > HH limit for more than 60 sec, depressurized s/d of GT activated (Hi 85 Hi-Hi 90 degC).
- Fans changeover takes place if Gas detected in ventilation outlet. If Gas concentration raises again, depressurized s/d of GT activated.

# Hydraulic Starting System:



**Hydraulic Starting System:**

- Hydraulic starting system is common for the 3 GTC's for:
- Break away the turbine rotor from standstill position & increase the speed till self sustaining condition of the gas turbine is reached.
- In case of with motoring trip, to provide the proper cool-down, rotate the GG rotor for about 5 min.
- The starter is composed by two pumping groups bearing two hydraulic motors with variable capacity pistons.
- A pressure regulator able to vary the inclination angle of the pistons-plane modifies the pistons stroke.
- The starter is connected to the Gas Turbine with a fluid clutch, cooled and lubricated with synthetic oil supplied by the Gas Turbine, to prevent the starter from being driven by the gas generator when the hydraulic supply pressure and flow are reduced to zero and the gas generator speed is greater than that of the starter.
- Axial Piston Pump (Swash Plate) working principle animation

**Fire Detection System:**

**Fire/Heat rise detectors arrangement in EWPL Gas Turbines:**

Gas Turbine Enclosure consists of:

- Flame detectors:
  -There are total 3 No. of flame detectors (FD-705-A/B/C) installed in GTC compartment.

- Heat Rise Detectors:
  -There are 6 No. of heat rise detectors installed in GTC compartment –

    - 2 detectors are located above the front turbine frame (above inlet to axial air compressor),
    - 2 detectors are installed above the HPT casing
    - Remaining 2 detectors are installed in path of air ventilation provided for Power turbine (PT) i.e. one near inlet duct air path & other at the outlet duct air path.

## Interlocks for fire/heat rise detector actuation:

## Interlocks for FIRE DETECTOR actuation in GTC (PGT+25) for CS01 to CS09:

| Detector Actuation | Alarms in MARK-VI | GTC Tripping | GTC Tripping |
|---|---|---|---|
| 1oo3 Fire detector | Fire detector alarm | No GTC Tripping initiated | No $CO_2$ release. |
| 2oo3 Fire detector | 1. Fire in Accessory Compartment<br>2. Fire Detected Trip | GTC No-Motoring Depressurized Trip Initiated | $CO_2$ released in GTC Enclosure |
| 1oo3 Fire detector Fault | Fire detector fault alarm | No GTC Tripping initiated | No $CO_2$ release. |
| 2oo3 Fire detector Fault | Both Fire detector fault alarm | Normal Shutdown in 5 Sec | No $CO_2$ release. |

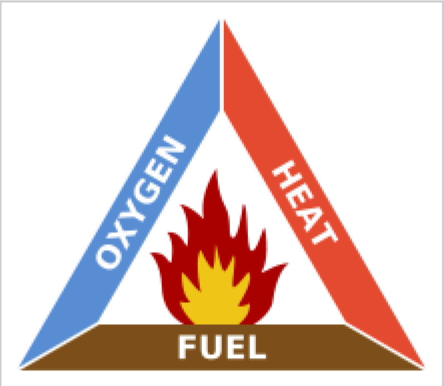
## Interlocks for fire/heat rise detector actuation:

## Interlocks for HEAT RISE DETECTOR actuation in GTC (PGT+25) for CS01 to CS09

| Detector Actuation | Alarms in MARK-VI | GTC Tripping | CO2 Release |
|---|---|---|---|
| 1oo4 Heat Rise Detector in GG compartment | UA-939 "Fire Detected Trip" alarm | GTC No-Motoring Depressurized Trip. | CO2 released in GTC Enclosure |
| 1oo4 Heat Rise Detector in GG compartment **Fault** | Detector Fault Alarm | No GTC Tripping initiated | No CO2 release. |
| 2oo4 Heat Rise Detector in GG compartment, **Fault** | Both Detector Fault Alarm | Normal Shutdown in 5 Sec | No CO2 release. |
| 1oo2 Heat Rise Detector in Load compartment. | UA-939 "Fire Detected Trip" alarm | GTC No-Motoring Depressurized Trip. | CO2 released in GTC Enclosure |
| 1oo2 Heat Rise Detector in Load compartment **Fault** | Detector Fault Alarm | No GTC Tripping initiated | No CO2 release. |
| 2oo2 Heat Rise Detector in Load compartment **Fault** | Both Detector Fault Alarm | Normal Shutdown in 5 Sec | No CO2 release. |

## Fire Extinguishing system:

- $CO_2$ Flooding System is used as a Fire Extinguishing System in PGT25+
- $CO_2$ Flooding system extinguishes fires by reducing the oxygen content of the air in the compartment from an atmospheric normal of 21 percent to less than 15 percent, an insufficient concentration to support combustion.
- To reduce the oxygen content, a quantity of carbon dioxide $CO_2$ equal to or greater than 34 percent of compartment volume is discharged into the compartment in one minute and, recognizing the reflash potential of combustibles exposed to high temperature metal, it provides an extended discharge to maintain an extinguishing concentration for a prolonged period to minimize the likelihood of a reflash condition.




The fire triangle.

## Typical arrangement & methods of release:

### Typical arrangement of $CO_2$ flooding system for Turbine Enclosures:

- Separate $CO_2$ Cylinder banks for Quick discharge & Slow Discharge
- Separate weighing mechanism for each $CO_2$ cylinder
- Separate $CO_2$ releasing arrangement for each cylinder
- Different piping sizes for Quick discharge & Slow Discharge for delivering $CO_2$ into the enclosure
- Different Nozzle sizes
- $CO_2$ operated dampers in enclosure ventilation ducts
- Electric hooters & Visual lamps for providing intimation regarding release of $CO_2$
- Manual release levers for both the $CO_2$ Cylinder banks

### Three methods by which $CO_2$ is released in turbine enclosure :

- Automatic release of $CO_2$ after detection by fire/heat rise detectors
- Pushing of Emergency Push Button on either side of the turbine compartment
- Pulling Manual release lever of $CO_2$ bank

## Operating modes of PGT25+

**Diff. modes of Gas Turbine operation:**

- Off Mode
- Crank Mode
- Idle Mode
- Manual Mode
- Automatic Mode
- Remote Mode

Only one mode can be selected at any time. Mode selection is allowed only if the relevant permission conditions are met.

## Diff. modes of Gas Turbine operation:

### Off Mode :

- Automatically set upon system initialization, i.e. UCP power-up or CPU reset.
- Disables or prohibits any control functions.
- In this mode Gas turbine cannot be started & all auxiliary equipment, except lube oil heaters, are disabled.
- Off Mode can only be selected by the operator when the GT has come to a complete stop, and all sequences have been completed.

### Crank Mode :

- This sequence allows the completion of Axial Compressor purge
- If this operational mode is selected, the unit START sequence is held when the engine shaft crank speed is reached (about 21% of speed) until the sequence is switched to IDLE, MANUAL, AUTO or REMOTE operational mode without stopping the engine.

## Diff. modes of Gas Turbine operation:

### Idle Mode :

- Ignition takes place & after the machine flame is detected, GG Speed loads upto the IDLE Speed condition.
- If this operational mode is selected, the unit START sequence is held at the Idle stage (gas generator at 6800 rpm and power turbine over 2000 rpm) until the EXTENDED IDLE TIMER is elapsed (30 min.) then automatic normal shutdown is activated, or the sequence is switched to MANUAL, AUTO or REMOTE operational mode.

### Manual Mode :

- In this mode, start sequence will not be interrupted till the engine reaches FSNL Speed.
- At the end of sequence, Unit Start, Stop, Raise / Lower speeds, Alarm Reset command from the MARK-VI are enabled.

## Diff. modes of Gas Turbine operation:

### Automatic Mode :

- In this mode, start sequence will not be interrupted till the engine reaches FSNL Speed.
- At the end of sequence external load set point from the Station RTU/CCC/SCADA is enabled.
- In this mode, the unit is under external control from CCC system
- Start/Stop from SCADA not possible

### Remote Mode :

- In this mode, start sequence will not be interrupted till the engine reaches FSNL Speed.
- At the end of sequence external load set point from the Station RTU is enabled.
- Unit Start, Stop commands come from Station RTU/SCADA
- In this mode, the unit is under external control from SCADA system

**Diff. modes of Gas Turbine operation:**

**Calibration Crank Sequence :**

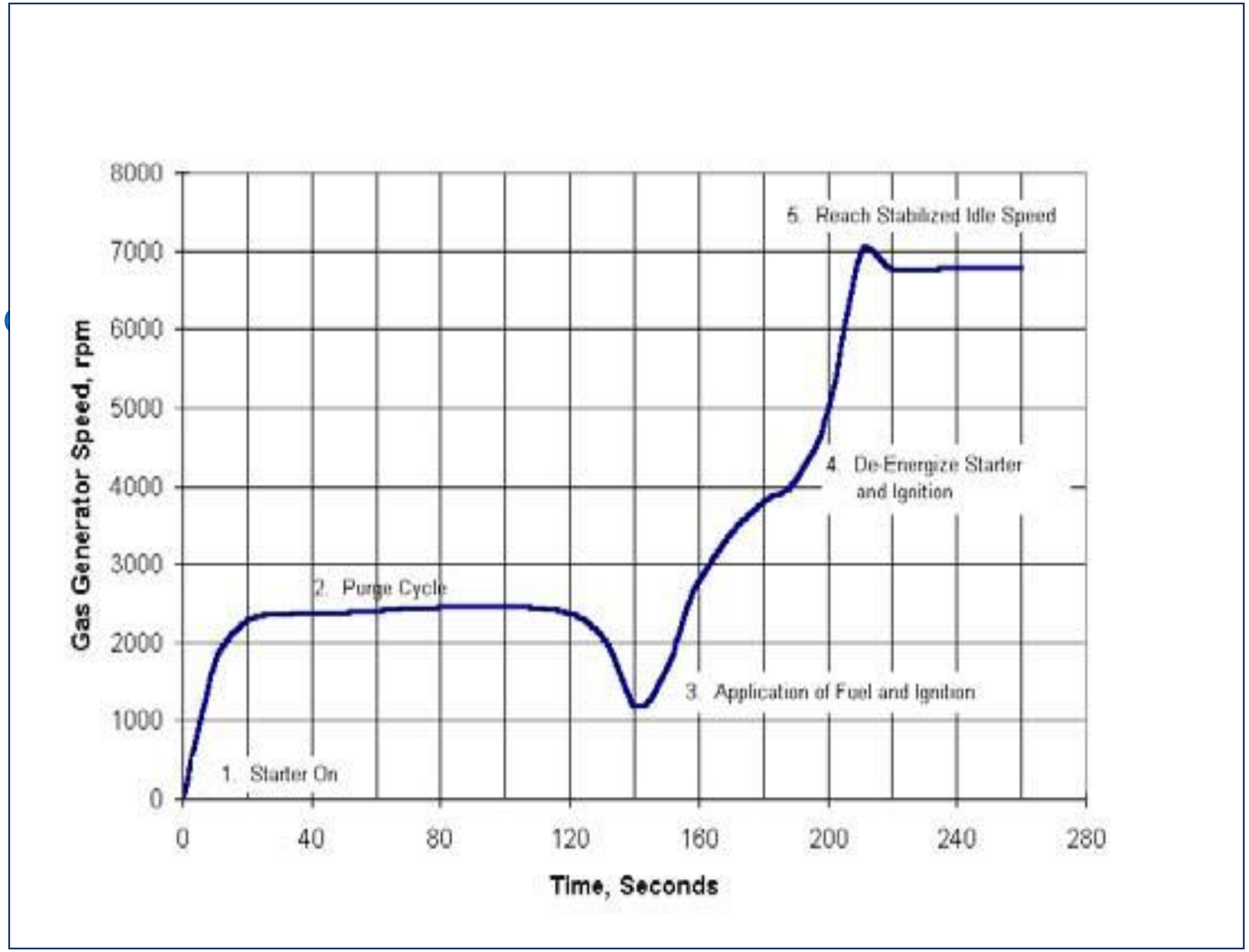
- In this condition the servo-mechanism calibration procedures are enabled on Mark VI tool box interface (VSV variable geometry and CDP bleed valve).
- During this mode, VSV Calibration test is performed & Gas generator speed is maintained at crank value.
- Also it is possible to operate the fuel metering valve calibration procedure. But further start sequence is not possible.

**Water-wash Mode :**

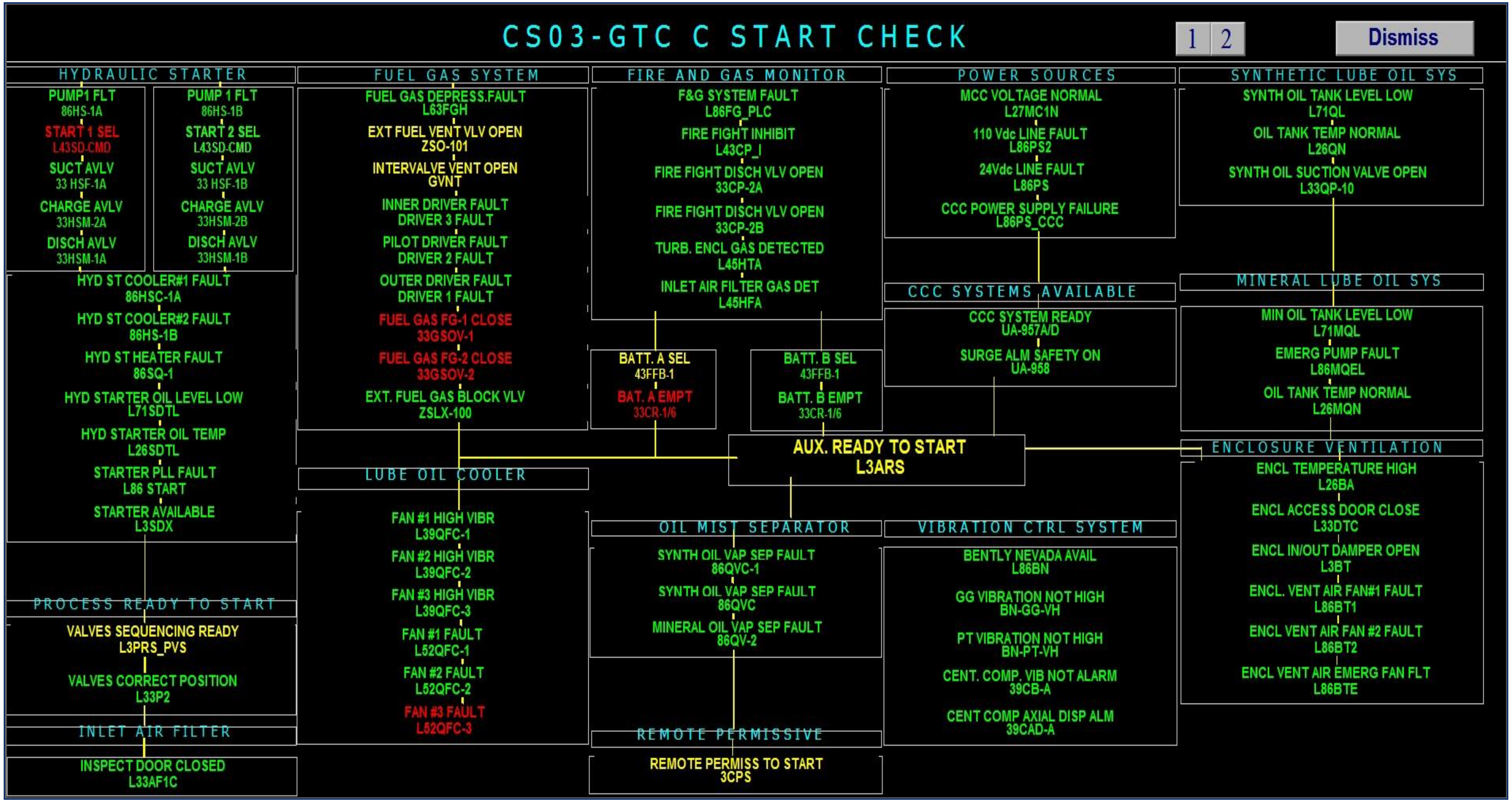
- If this operational mode is selected, the unit START sequence is held at the water wash crank speed (about 12% of speed) until the operator give stop command or the sequence is switched to IDLE, MANUAL, AUTO or REMOTE operational mode without stopping the engine.
- Under this mode, Online & Offline Water-wash of the GG can be carried out.

**PGT25 start-up :**

1. GG crank
2. GG-PT purge sequence
3. Fire sequence (Ignition)
4. Starter cut-out and Warm-up sequenc
5. Acceleration to Idle speed

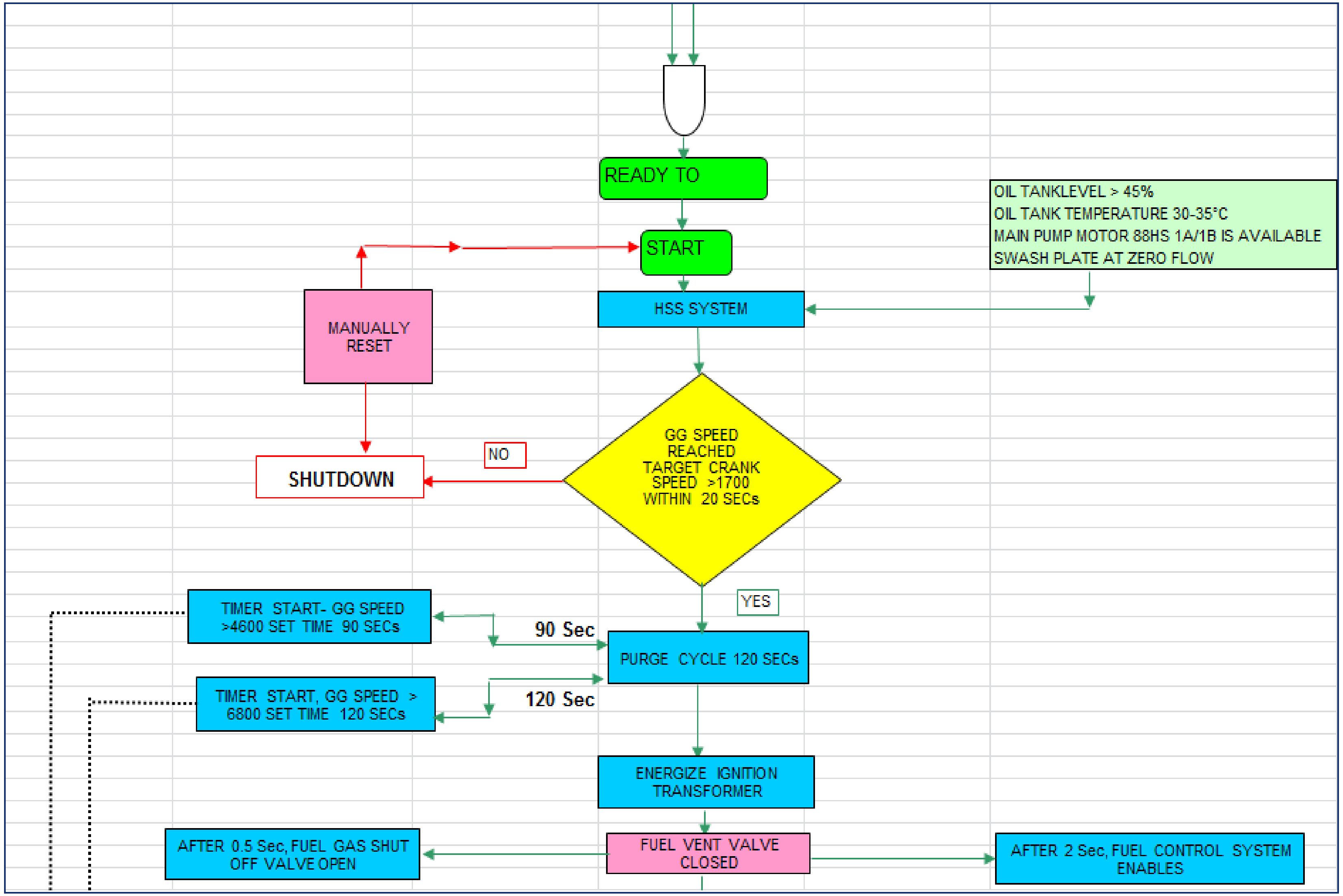


## PGT25 start-up :

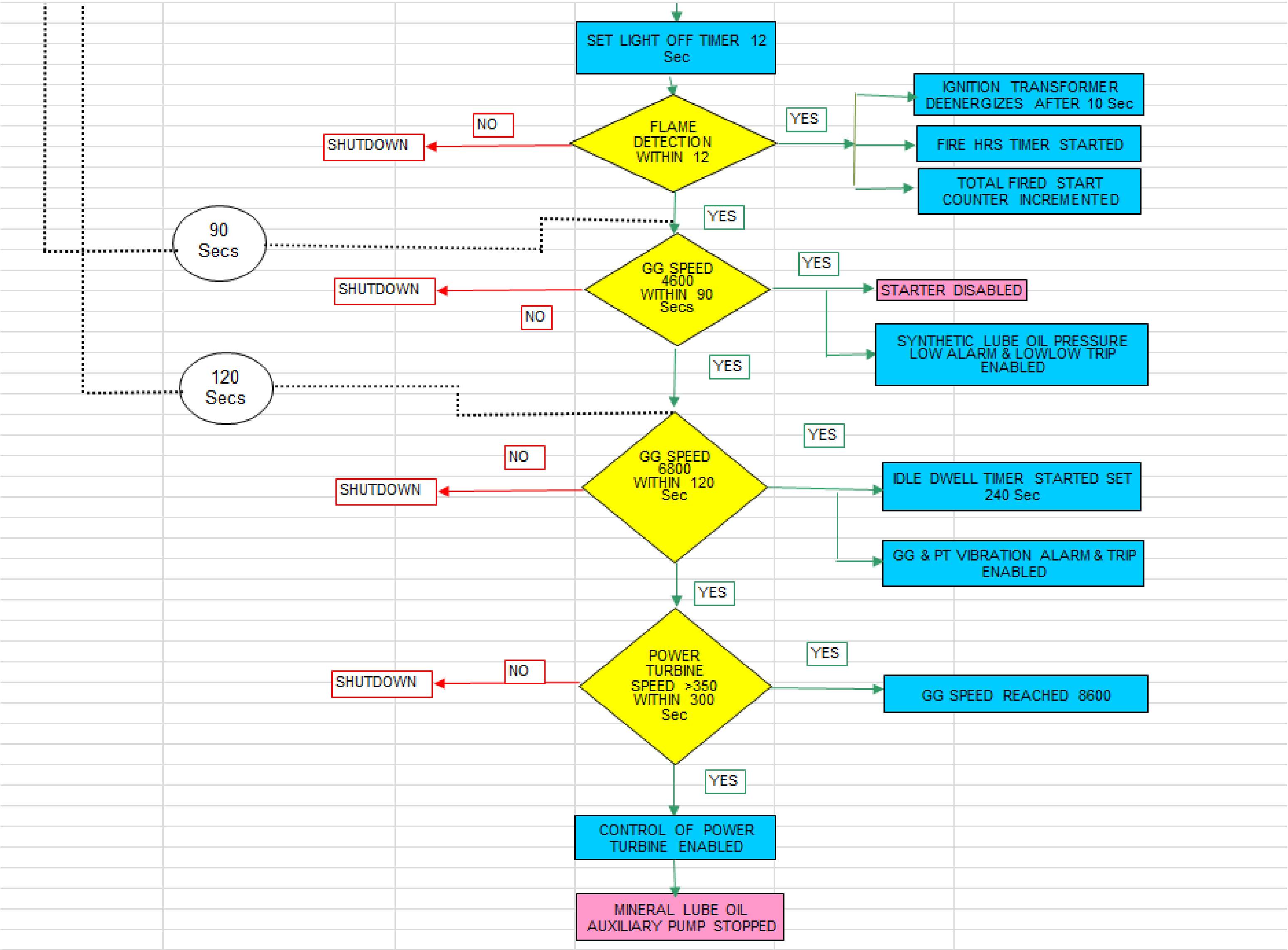


## PGT-25 Start-up flowchart:

Start Permissive are in healthy state



# PGT-25 Start-up flowchart:



## Gas Turbine starting sequence:

| | |
|---|---|
| WARM UP TIME | 300 sec |
| WATER WASH REMAINING TIME | 2400 sec |
| AUX CRANK SEQ REMAINING TIME | 300 sec |
| AUX STARTUP REMAINING TIME UPON START | 1600 sec |
| PURGE REMAINING TIME | 120 sec |
| FAIL TO LITE PURGE REMAINING TIME | 120 sec |
| CORE IDLE REMAINING TIME | 1680 sec |
| CORE IDLE COOLDOWN TIME | 300 sec |
| COOLDOWN MOTORING REMAINING TIME | 300 sec |

**Step to idle conditions:**

- Fuel gas temperature (TE-100 A/B) high high (150 DegC)
- PT, GG cumulative accelerometer vibration high high (VSHH-1023 for GG and VSHH-1024 for PT). After 10s if the vibration does not stop, then normal shutdown will be activated.
- PT exhaust temperature (TE-203/1 to TE-203/6) high high (615 DegC).
- GG exhaust temperature (TE-202/1 to TE-203/8) high high (860 DegC).
- PT bearing-1 & 2 temperature (TE-212/1, TE-212/2, TE-215/1 & TE-215/2) high high (120 DegC).
- PT thrust bearing inactive and active side temperature (TE-213/1, TE-213/2, TE-214/1 & TE-214/2) high high (130 degC).

## Pressurised Motoring Trip conditions:

### The Trip action from ESD-PLC:-

- Mineral Lube oil temperature (TE-315 A/B/C) high high (79 Deg C)
- Mineral tank differential pressure (PDIT-311 A/B/C) high high (5 m Bar)
- CC discharge pressure (PIT-147) high high (102 Barg)
- CC Suction pressure (PIT-148) Low Low (48 Barg initially but changed as per process requirement)
- CC discharge temperature (TIT-149) high high (99 DegC)
- Seal gas header pressure (PIT-108) Low Low (0.4 Barg)
- Surge Trip from CCC

### The Trip action from MARK-VI controller:-

- Pressurized ESD (XS-947) from PLC.
- Fuel gas metering valve drivers (ZT-104B, ZT-106/B & ZT-108/B) fault
- GG discharge pressure (PIT-201 A/B)) high high or both sensors fault
- Combustor chamber flame detector (FLAMEDT A/B) Low Low or both sensors fault
- Fuel gas temperature (TE-100 A/B) high high (150 DegC)

## Pressurised No motoring Trip conditions:

### The Trip action from ESD-PLC:-

- Synthetic oil pressure (PIT-305 A/B) low low (1.03 Barg)
- Mineral header pressure (PIT-324 A/B/C) low low (0.9 Barg)
- Compressor radial vibration (XSHH-926) high high (Digital signal to ESD PLC)
- Compressor axial displacement (ZSHH-927) high high (Digital signal to ESD PLC)
- Customer ESD activated (XS-928)
- UCP pressurized ESD (XS-918/A)

### The Trip action from MARK-VI controller:-

- GG discharge pressure (PIT-201 A/B) stall detection
- Hydraulic starter speed (SE-211) high high
- Clutch temperature (TE-241) high high (30 DegC)
- GG speed (ST-200 A/B) high high (10200 RPM) or both sensors fault
- PT speed (ST-202 A/B) ) high high (6710 +/-25) or both sensors fault
- No motoring ESD XS-946 from ESD PLC
- UCP pressurized ESD (XS-918/D)

## De-Pressurised Trip conditions:

### The motoring trip action from ESD-PLC:-

- Turbine enclosure inlet gas detector (AE-700 A/B/C) high high (10% LEL)

### The no motoring trip action from ESD-PLC:-

- Compressor seal gas primary vent pressure (PIT-111 and PIT-112) high high (9 Barg)
- Air inlet filter gas detector (AE-703 A/B/C and AE-704 A/B/C) high high
- Fire detected in turbine (FD-705 A/B/C)
- Heat raise detector enclosure (TSHH 700/1A, 700/1B, 700/C, 700/D) high high (163 DegC)
- Heat raise detector enclosure (700/2A, 700/2B) high high (232 DegC)
- Manual release of $CO_2$ activated (HS-701/A or HS-701/B)
- Field ESD push buttons activated (HS-702/A or HS-702/B)
- Customer ESD de-pressurize command (XS-929)

### The no motoring trip action from MARK-VI Controller:-

- Fire detected trip (UA-939)
- Air inlet gas detected trip (UA-945) (From F&G system)
- Turbine enclosure gas detected trip (UA-944)
- Note:- Trip conditions to be manually reset before start-up

## Normal Stop conditions:

## The shutdown action from MARK-VI controller:-

- Turbine enclosure inlet gas detector (AE-700 A/B/C) high high (10% LEL)
- AGB Scavenge oil temp TE304/A and TE304/B both sensors fault
- "A" Sump and TGB Scavenge oil temp TE305/A and TE305/B both sensors fault
- "B" Sump and TGB Scavenge oil temp TE306/A and TE306/B both sensors fault
- "C" Sump and TGB Scavenge oil temp TE307/A and TE307/B both sensors fault
- GT exhaust temp TE203/1 to TE-203/6 fault of 3 or 4 adjacent sensors.
- PT wheel space first stage temp (TE-208/1,2 and TE-209/1,2) high high (365 & 415 DegC) or both sensors fault
- PT wheel space second stage temp (TE-210/1,2 and TE-211/1,2) high high (465 DegC) or both sensors fault
- Ventilation air inlet damper closed (ZAL-700,701,702) (2oo3 logic)
- PT bearing1 temp (TE-212/1 & TE-212/3) (120 DegC) high high or both sensors fault
- PT bearing2 temp (TE-215/1 & TE-215/3) high high (120 DegC) or both sensors fault
- PT thrust bearing active side temp (TE-214/1 & TE-214/3) high high (130 DegC) or both sensors fault
- PT thrust bearing inactive side temp (TE-213/1 & TE-213/3) high high 130 DegC) or both sensors fault
- Remote stop command (Xs-1031)
- Fault of both fan motors (86BA-1 & 86BA-2)
- Inlet filter differential pressure (PDIT-212/1,2,3) high high for station CS02 to CS09 (18 mBar)
- Inlet filter differential pressure (PDIT-214/1,2,3) high high for station CS01 (17.6 mbar)
- Turbine enclosure temp (TE-217/1,2,3) high high (90 DegC)
- Turbine enclosure temp (TE-218/1,2,3) high high (90 DegC)

**Protection Systems of Gas Turbine:**

- Over Speed
- High Exhaust Temperature
- Low Lube Oil Pressure
- High Lube Oil Temperature
- Loss of Flame
- High Vibration
- Combustion Monitoring
- Customer Trip
- Fire Detection in Compartment Enclosures

## Control limits:

- **Maximum Fuel Limiting Loop** This logic prevents over-firing during the normal operation
- **Minimum Fuel Limitation** This logic prevents flame-out due to fast fuel demand variations during the transients operation.
- **T54/T48 Control** This Control is a closed loop PID that limits the maximum temperature of the Gas Generator. This control is the limiting control during high power operation.
- **PS3 Control** The PS3 Control is a closed loop PID Control that limits fuel as a function of the ratio between PS3 pressure and atmospheric pressure.
- **T3 Control** The T3 NGG Control is a closed loop PID Control that limits fuel as a function of Exhaust Axial Compressor Temperature, compensated by Gas Generator Speed and the modelled Axial flow.
- **NGG Acceleration Control** The Acceleration Control is a closed loop PID control that limits the acceleration of the Gas Turbine during rapid load changes to prevent a stall.
- **NGG Deceleration Control** The control is a closed loop PID control that limits the deceleration of the Gas Turbine during rapid load changes to prevent flameout.

## Critical Parameters to be monitored:

**Following are the Critical Parameters to be monitored of Gas Turbine**

- Chip Detectors & Synthetic Oil Sump Temperatures
- Synthetic Oil Clutch Temp
- Casing & Bearing Vibrations & Temperatures
- GG & PT Exhaust Temperatures ; Wheel-Space Temperatures
- Combustion Dynamic Pressures

## Critical Parameters – Chip detectors

- The engine is equipped with electrical/magnetic remote-reading chip detectors in the AGB (2), TGB (1), Sump-B (1) and Sump-C (1).
- Normal resistance across detectors are 150 ohms.
- Each chip detector indicates chip collection when resistance across the detector pins is less than 100 ohms.
- Inspection required if any of the detectors detects metal chips. It is recommended to check all the detectors even if one detector detects the chip.
- There is no logic involved for auto action to GTC i.e. GTC trip/ normal shutdown/ step to idle
- Intentional shutdown required to inspect the detectors.

## Critical Parameters – Combustor Dynamic Pressure

- The gas generator (GG) is equipped with two acoustic sensors mounted on the combustor case.
- The pressure transducers are piezoelectric charge devices which results electricity from pressure.
- Combustor dynamic pressure fluctuates due to disturbance in DLE (Dry Low Emission) system parameters like improper mixture of air and fuel, combustion Gas composition change .

- MARK-VI Control Logic:-
  - PX36 high Alarm when Combustor dynamic pressure is greater than 4 psi (0.276 bar) for 10 seconds. OR
  - Step to Idle when Combustor dynamic pressure is greater than 6 psi (0.41 Bar) for 15 seconds, OR
  - Step to Idle when Combustor dynamic pressure is greater than 9 psi (0.62 bar) for 5 seconds.

## DLE Combustion system

- **Combustion system:**
  - Premixed flames at lean air/fuel ratio are intrinsically unstable.
  - For high stability of flame and for protect against lean blowouts (losses of flame) an enhanced lean blow-out system (ELBO) is provided,
  - ELBO supplies continuously a small amount of fuel to pilot nozzles.
- That amount of flow to pilot nozzles is augmentable through ELBO staging valve opening, to enhance stability during transients.
- The Dry low NOx gas system requires highly accurate metering of each mass rate of gas flow to the three separate fuel manifolds (valves GFMVO, GFMVP, GFMVI).

## Combustion System:

### Combustion System Design Criteria

- Reliable Ignition
- Good Combustion Stability

} **Operation**

- High Combustion Efficiency
- Low Smoke
- Satisfactory Emissions Levels

} **Environmental Regulations**

- Minimum Pressure Loss

} **Performance**

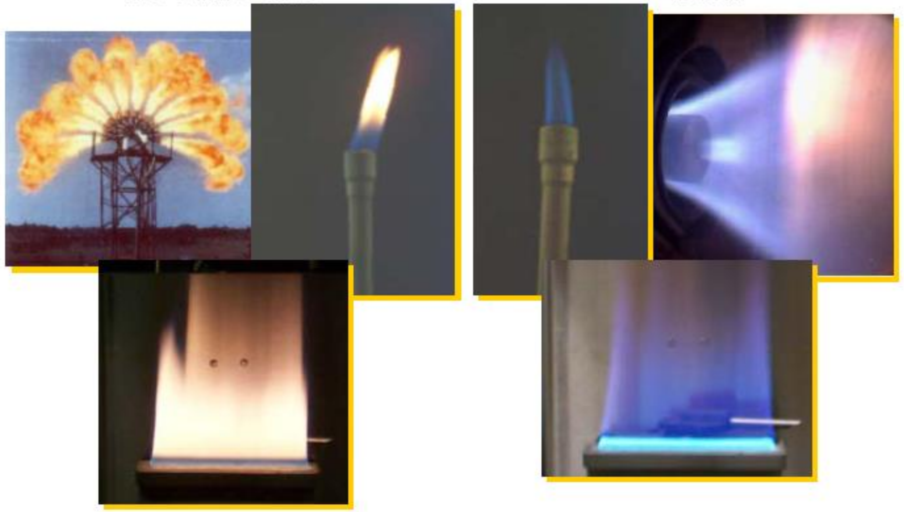
- Satisfactory Combustor Exit
- Temperature Distribution
- Life

} **Durability**

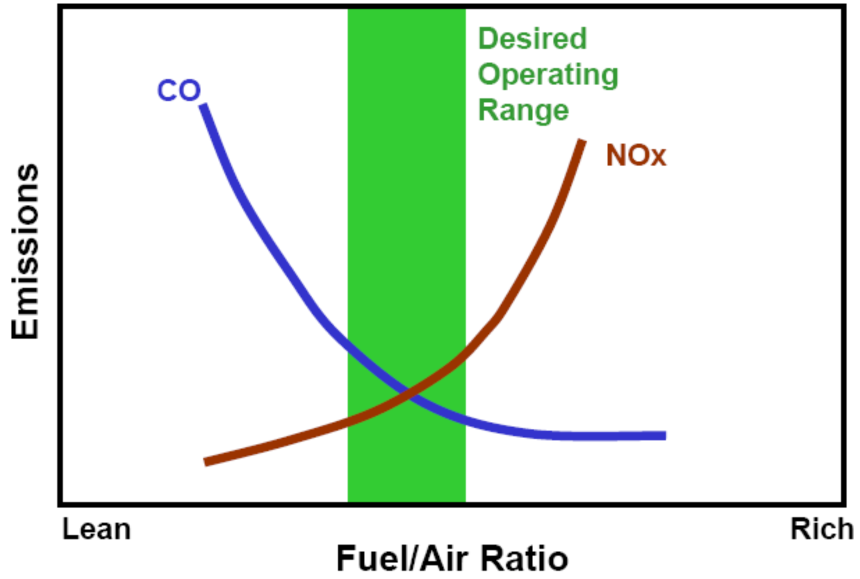
### Industrial Gas Turbine Combustion Systems

- **Conventional Combustion**
  - Diffusion Combustion
  - Historical Design
- **Dry Low Emissions (DLE or DLN) - "SoLoNOx"**
  - Lean Premixed Combustion
  - Superior Emissions Performance
  - Offered Since 1992

| Diffusion Flames | Premixed Flames |
| --- | --- |
| Fuel and Air Mix and Burn At the Same Time | Fuel and Air Mix and Then Burn |



### Emissions Characteristics



**DLE is Pollution Prevention**

***Reduction of Combustion-Generated Exhaust Emissions through Understanding and Control of Combustion Process***

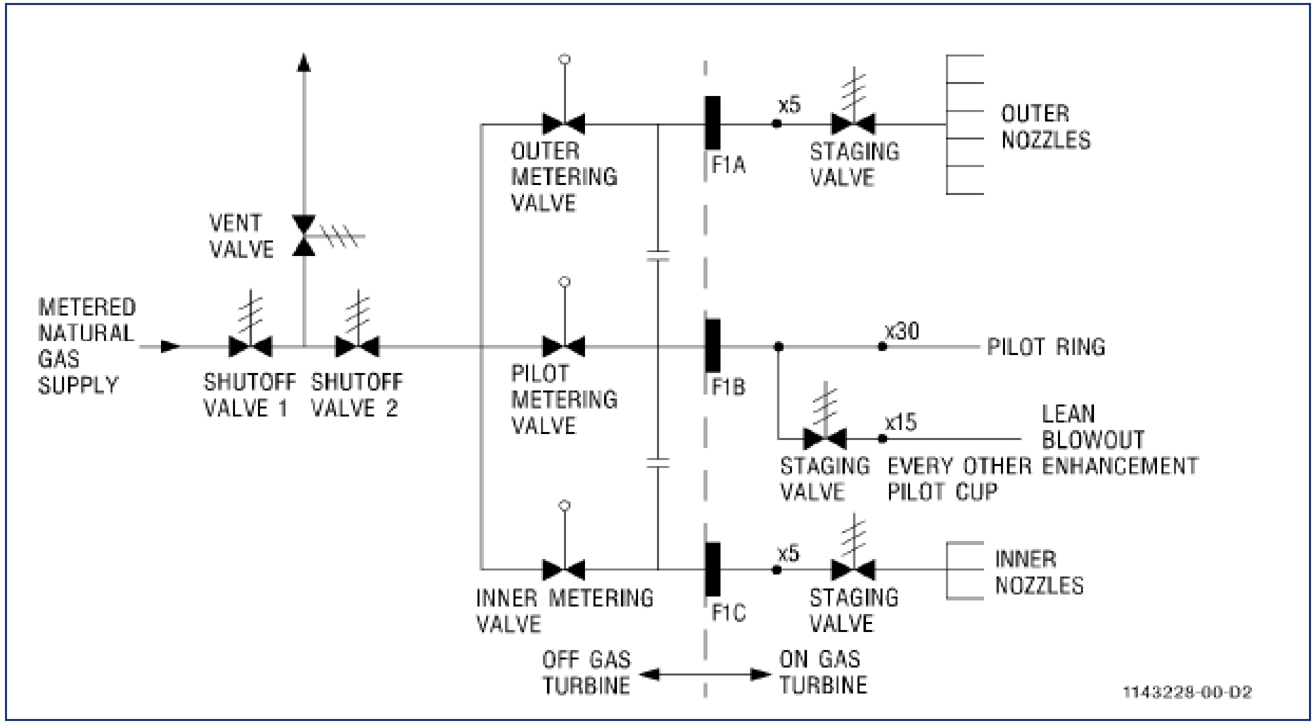
**More Cost-Effective Than Exhaust Clean Up**

- **Lean Premixed Combustion Reduces NOx, CO and UHC Emissions**
- **NOx are Reduced**
  - Lowering Flame Temperature
    - Lean Combustion
    - Premixing to Eliminate "Hot Spots"
- **CO and UHC are Reduced**
  - Increasing Combustion Residence Time (Volume)
  - Combustor Design to Prevent Local Quenching

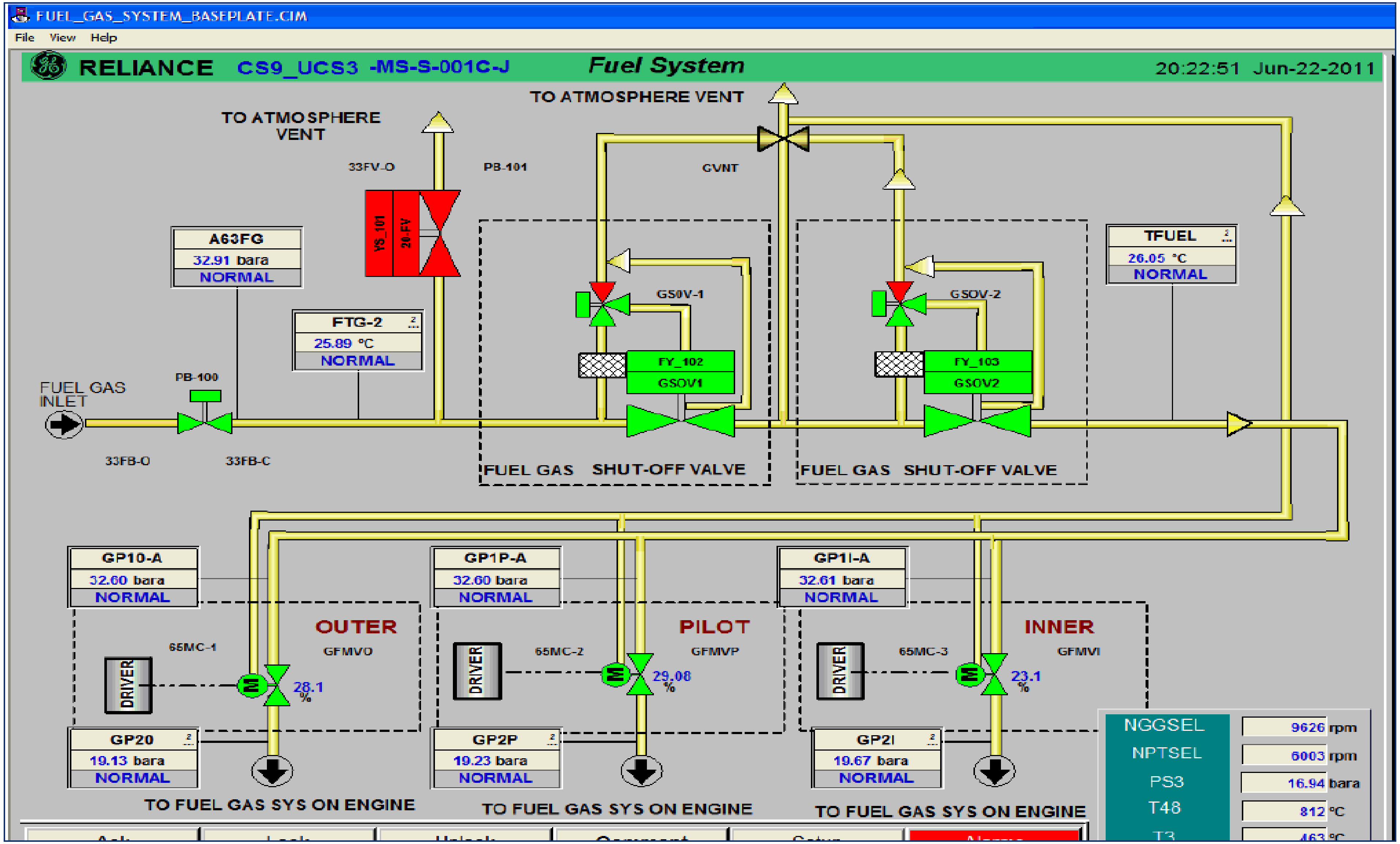
- In this process nitrogen oxides are formed by two mechanisms: Thermal NO and Organic NO.

- The predominant mechanism in the formation of NOx in gas turbine combustors depends on such conditions as the reaction temperature, the resident time at high temperature, the fuel/air ratio in and after the combustion reaction zone, the fuel composition [the fuel bound nitrogen (FBN) content], the combustor geometry, and the mixing pattern inside the combustor.

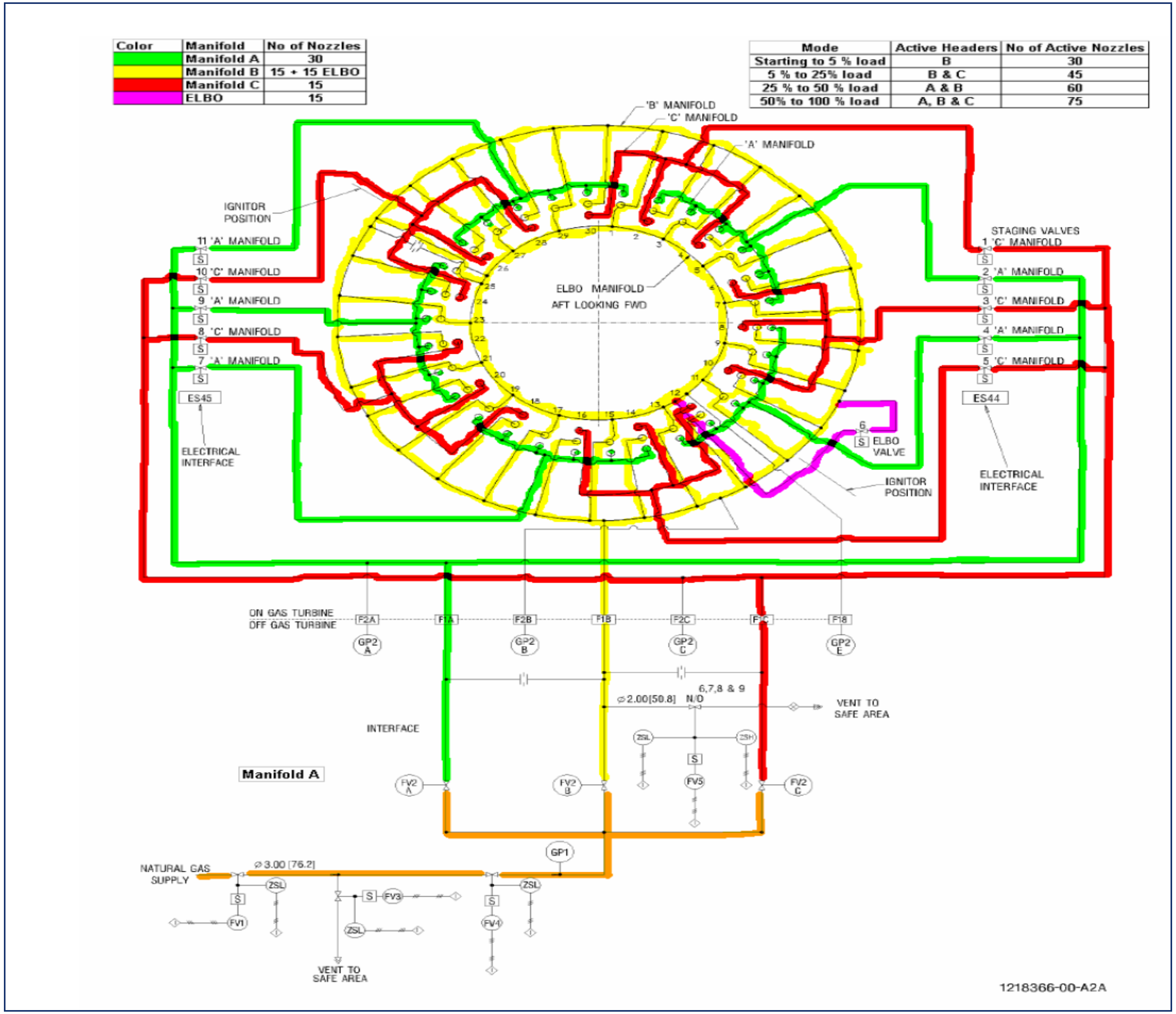
- **Staging valves:** The function of staging valves is to maintain fuel flow while transition period of four stages (B, BC,AB & ABC). There are 11 Staging valves including 1 ELBO. (10 + 1)
- **Manifold A :** Has 5 Staging valves each staging valve connected to 6 Burners
- **Manifold C :** Has 5 Staging valves each staging valve connected to 3 Burners
- **ELBO:** Enhanced Lean Blow Out used to stabilize the Flame.
- **Manifold B :** Has 30 Burners out of which 15 Burners are connected to ELBO & remaining 15 connected directly with B Manifold header



# Combustion system



# Combustion system



## DLE System:

The DLE (Dry Low Emissions) system is a pre-mixed combustion system which enables gas turbine to reach 25 ppm NOx and CO without water or steam when burning natural gas fuel.

The following factors influence the emission of NOx

- Flame Temperature
- Firing Temperature
- Ambient Temperature
- Ambient pressure
- Relative Humidity

Combustion Products:

| S No | Product | Reason | Range ppm |
|---|---|---|---|
| 1 | NO – Nitric Oxide | Oxidation of Atmospheric Nitrogen | 20 – 220 |
| 2 | NO-Nitrogen dioxide | Oxidation of Fuel bound Organic Nitrogen | 2 - 20 |
| 3 | CO-Carbon monoxide | Incomplete combustion | 3 - 200 |

**Air-fuel ratio** (AFR) is the mass ratio of air to fuel present during combustion represented by $\alpha$

**Stoichiometric ratio** : The Ideal Air – Fuel ratio required for complete combustion. – $\alpha_{st}$

**Actual Air Fuel ratio:** The actual ratio of Air-fuel that is burnt completely in actual combustion process. $\alpha_{ac}$

**Equivalence Ratio** $\lambda = \alpha_{ac} / \alpha_{st}$

If $\lambda < 1$ --- **Air Fuel mixture is rich**

If $\lambda = 1$ --- **Air Fuel mixture is Stoichiometric**

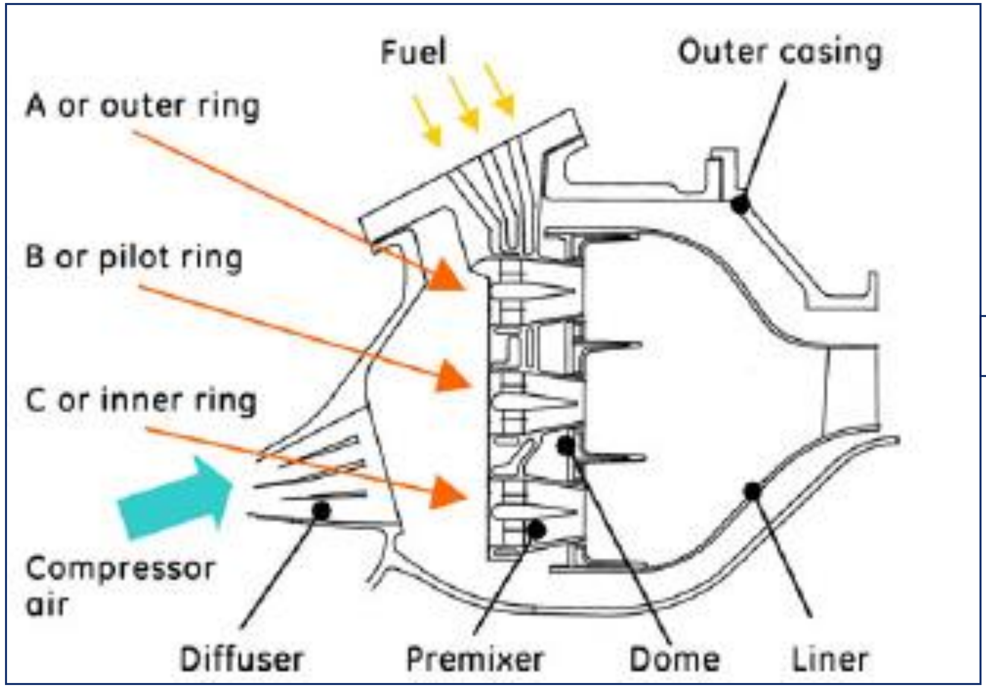
If $\lambda > 1$ --- **Air Fuel mixture is lean**

## DLE System:

## Approach to DLE system:

- ➢ Triple Annular Design
- ➢ Fuel & Air Staging ( Premix)
- ➢ Precise Flame Temperature control (Temperature monitoring is calculated with Algorithm, not actual temperature)

- **Lean Premixed Combustion Reduces NOx, CO and UHC Emissions**
- **NOx are Reduced**
  - Lowering Flame Temperature
    - Lean Combustion
    - Premixing to Eliminate "Hot Spots"
- **CO and UHC are Reduced**
  - Increasing Combustion Residence Time (Volume)
  - Combustor Design to Prevent Local Quenching




*DLE combustor – Triple Annular Design*

**Bulk Flame Temperature:**

- Bulk Flame Temperature is the average of flame temperature of the domes that are "supposed" to be burning (active domes)
- It is a calculated, not measured parameter.  Key inputs are:
  - Airflow of active domes
  - Total fuel flow
- The limits on Bulk flame temperature are TFL max - controlling NOx emissions.
- TFL min – Flame stability.
- The controller optimizes the flame temperature and operating within the range of TFL max & TFL min.

$$T_{flame} = f\,(\text{Air flow, Fuel flow, Fuel properties})$$

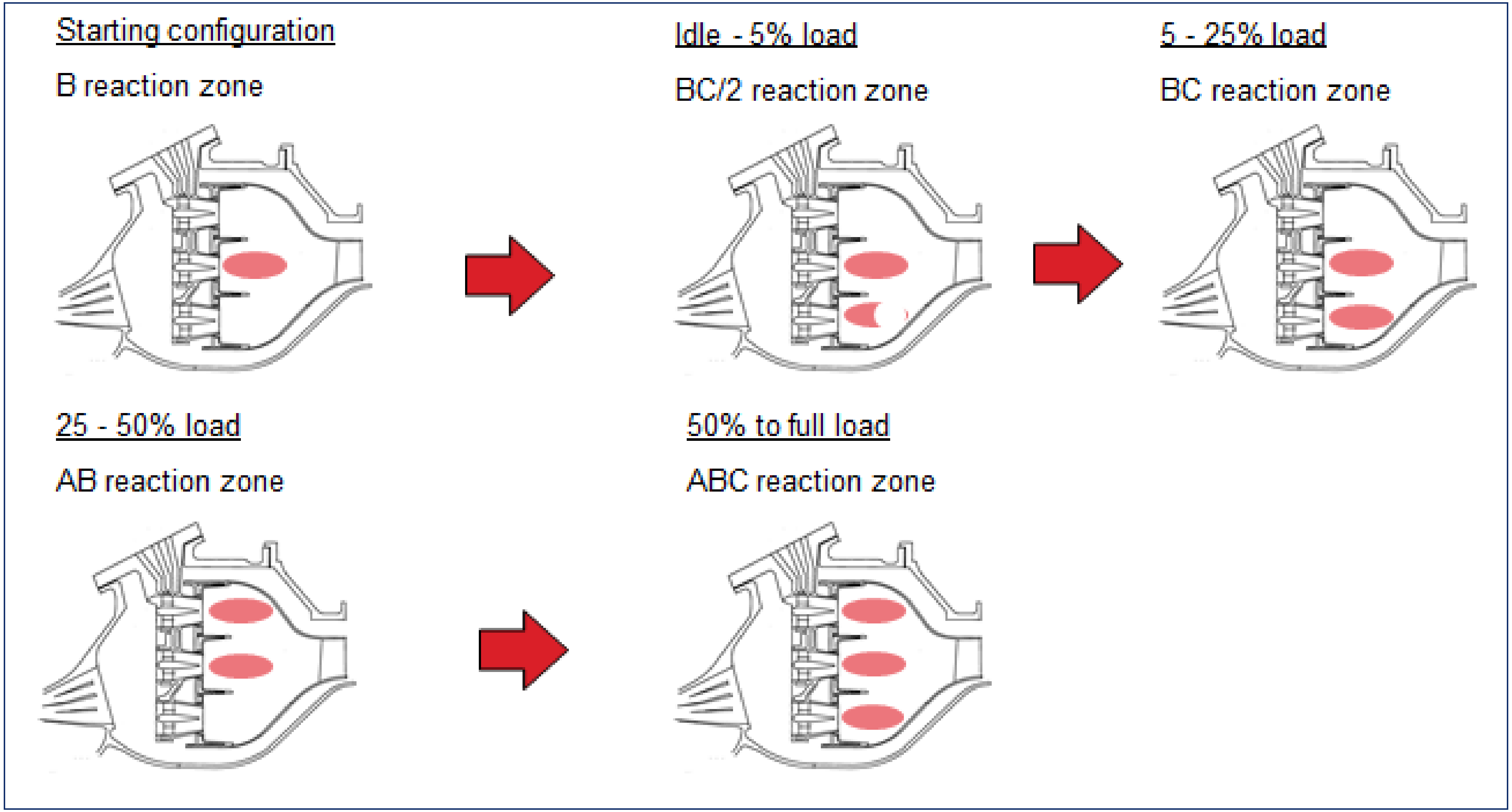
| Air flow | Fuel flow | Fuel properties |
|---|---|---|
| ↑ Model based | ↑ Measured (FMV) | ↑ Measured |

- Bulk Flame Temperature
  - Based on fuel & air to all burning zones
  - Drives air bleed control
  - Drives staging control

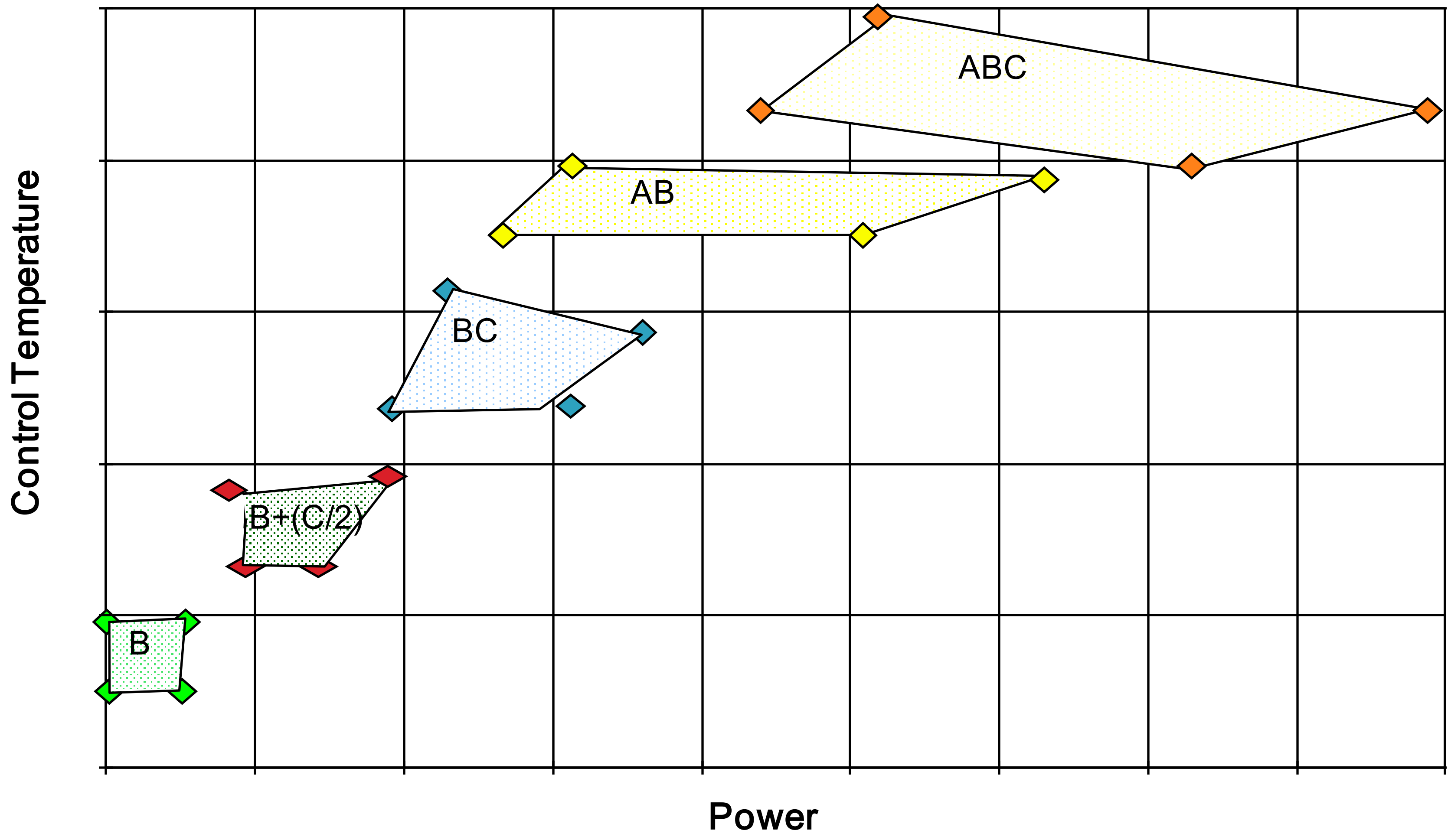
**Bleed control and staging**:

- In order to meet DLE emissions/combustor operability limits, bulk flame temperature needs to be relatively constant
  - Accomplished by changing combustor configuration and combustor airflow as power changes
- Combustor airflow changed by bleeding compressor - bulk flame temperature set by modulating overall compressor bleed
- TFLAME ~ FUEL FLOW / AIRFLOW IN COMBUSTOR
- Once bleeds are either full open or full closed, need to change combustor configuration to maintain bulk flame temperature within limits
- Stage up requirements are:
  - Bleeds fully closed and Flame temp is maximum
- Stage down requirements are:
  - Bleeds fully open and Flame temp is minimum

## DLE Burner Modes:



## DLE Combustor Operating Modes:



# DLE Combustor Mode Operating Details: