

Hydrocarbon Turboexpanders

Design and Operation



Turboexpanders Course Outline

- 1 Turboexpander General Information
- 2 Design Fundamentals
- 3 Auxiliaries
- 4 Turboexpander/Compressor Operation
- 5 Expander Testing
- 6 Magnetic Bearings
- 7 Turboexpander/Generator
- 8 Noise Control
- 9 Reliability / Maintenance

What is a Turboexpander?

- A turboexpander is a machine that continuously expands a fluid from a greater pressure to a lower pressure.
- Thereby producing:
 - Cooling
 - Shaft Power

When are Turboexpanders Used?

- Whenever there is sufficient pressure drop and mass flow to justify the economics of the installation.
 - **Gas streams** (pure, multi-component, or condensing)
 - **Liquid streams** (pure, multi-component, or flashing)
 - **Two phase streams** (“future development”)

Typical Turboexpander Processes

- Hydrocarbon Processing
 - Natural Gas Processing
 - LPG, Ethane Recovery/Rejection
 - Dew Point Control
 - Petrochemical
 - Ethylene Recovery
 - Refinery Off-Gas
 - Carbon Monoxide
 - MTBE

Typical Turboexpander Processes

LNG

- Peak Shaving

- New processes for base load plant

- Flashing Liquid Expanders

Power Recovery

- Pressure Letdown

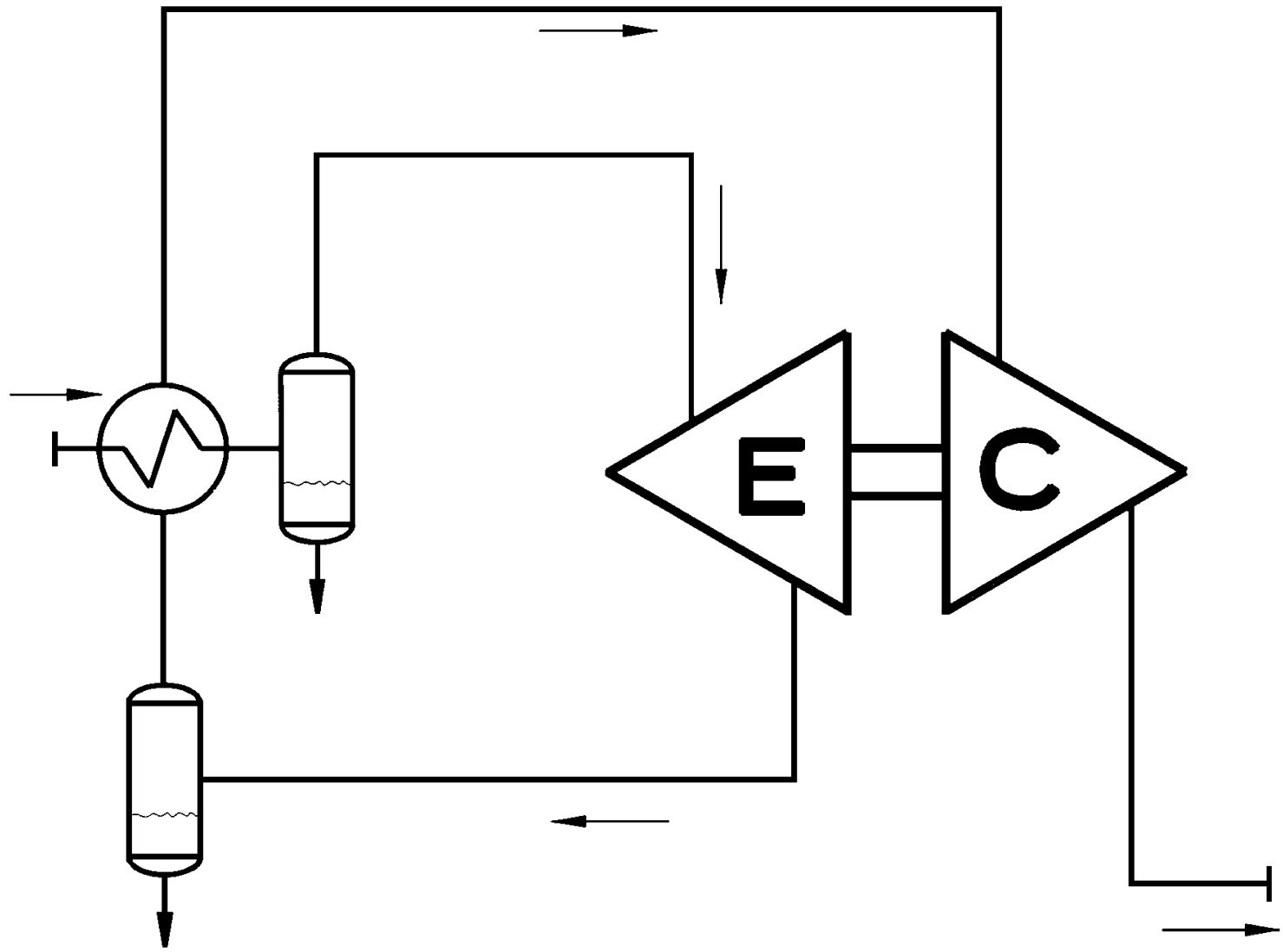
 - Fuel Gas

 - City Gate Station

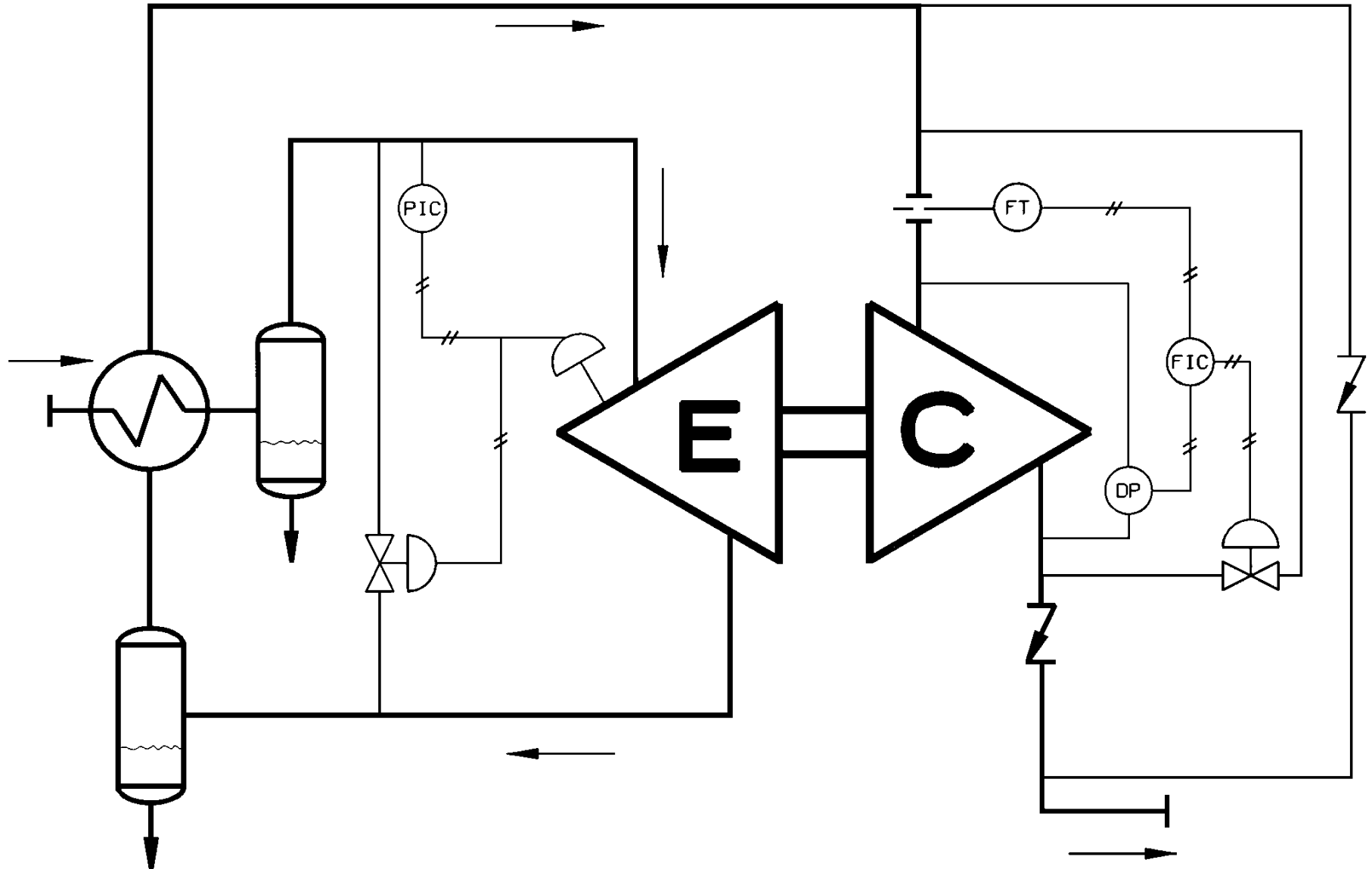
 - Storage Cavern

- Geothermal energy

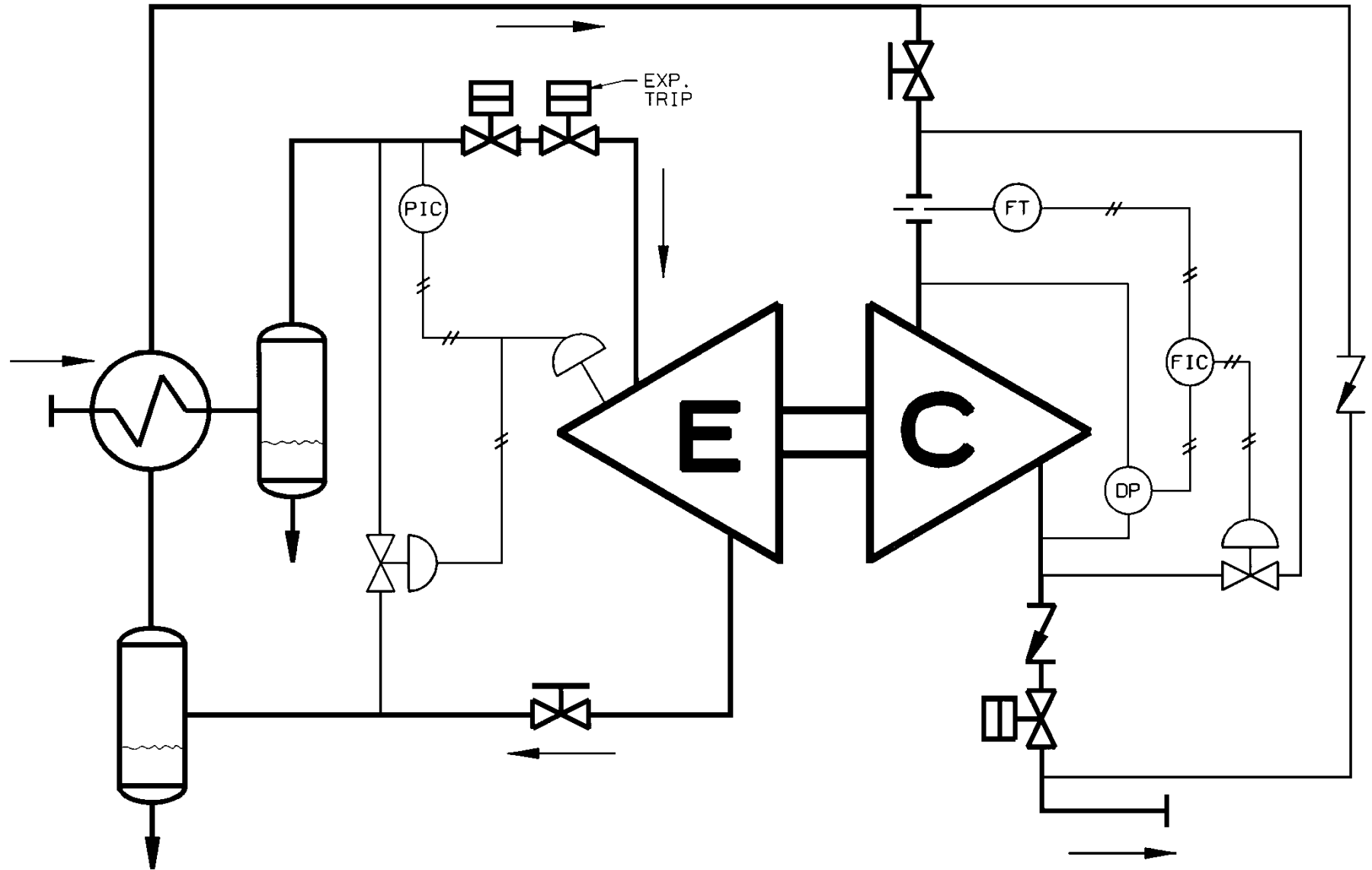
Typical Turboexpander Process



Typical Turboexpander Process



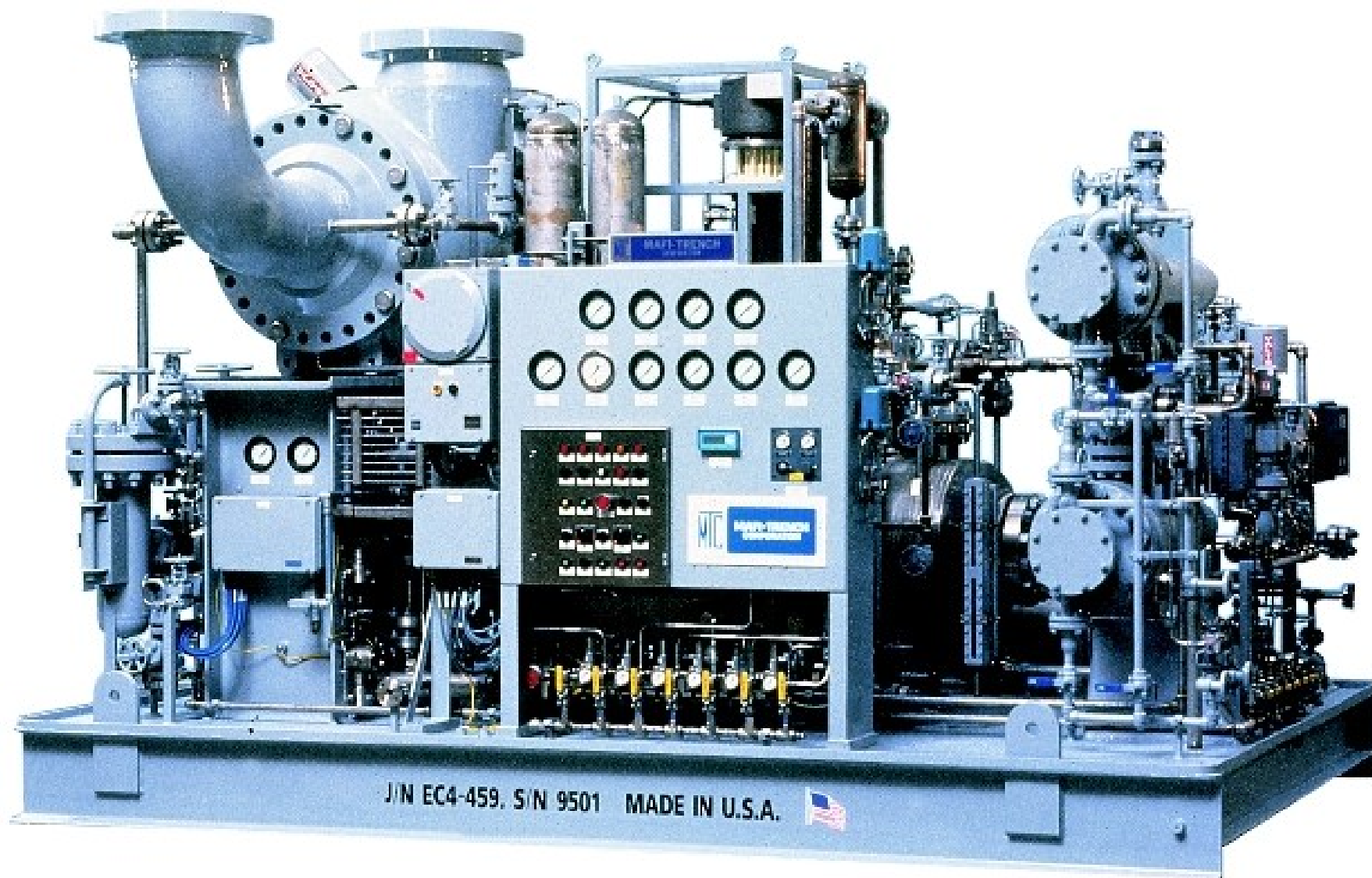
Typical Turboexpander Process



Typical Scope of Supply

- Expander/compressor
- Auxiliary Support Skid
- Controls & Instrumentation
- Factory Testing
- Expander Inlet Trip Valve
- Expander/compressor Inlet Screens
- Compressor Surge System
- Commissioning Spares
- Spare Rotating Assembly

Turboexpander Systems



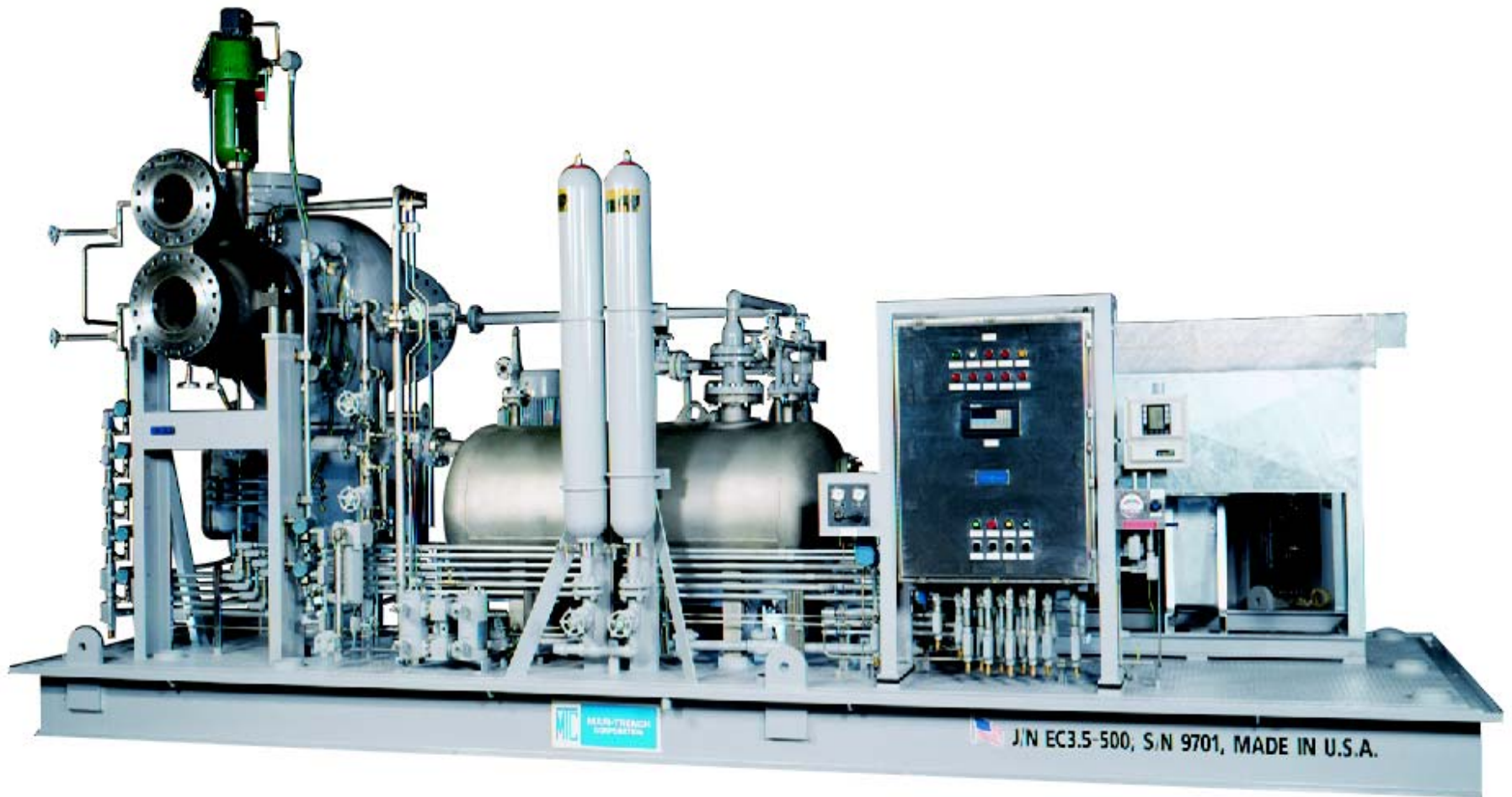
Offshore, sea water cooled, EC4 in dew point control service

Turboexpander Systems



Two EC3.5 operating in series for ethylene service

Turboexpander Systems



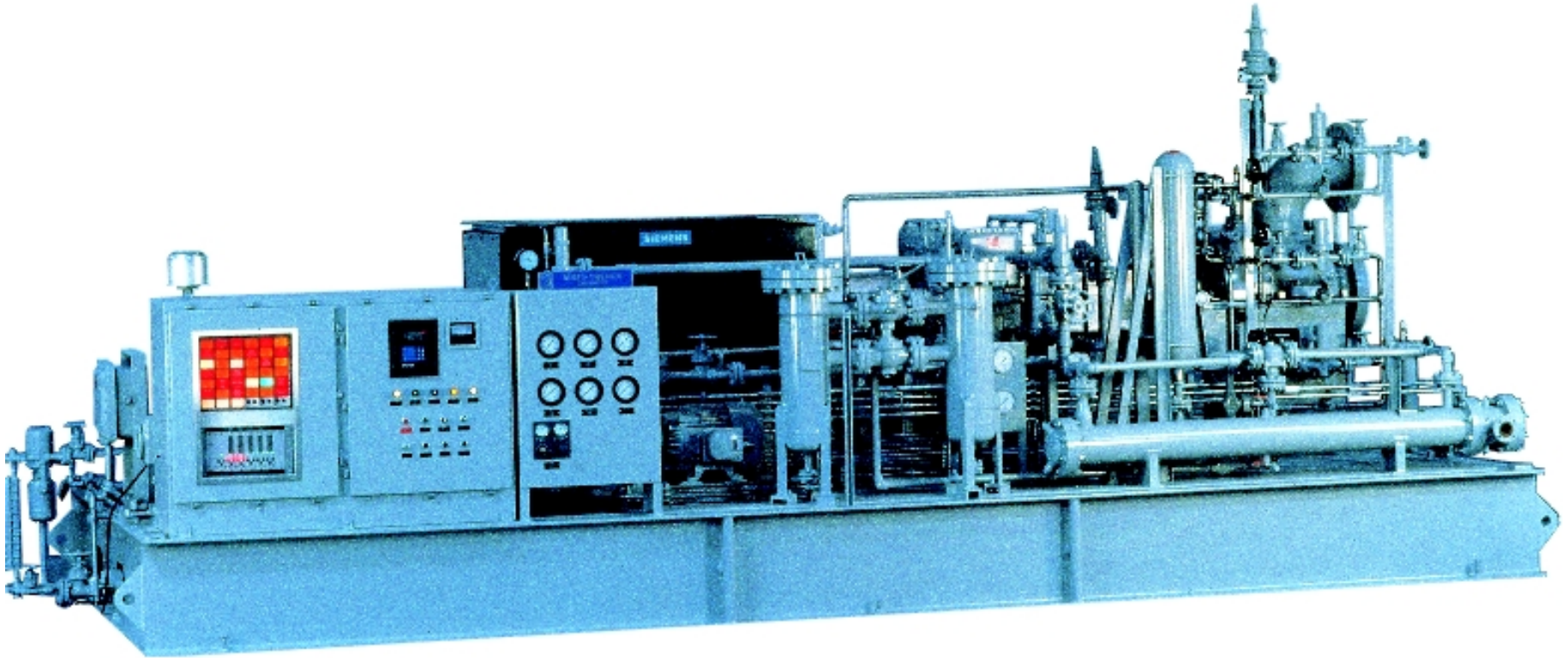
Air cooled, EC3.5 in LPG service

Turboexpander Systems



Magnetic bearing equipped EC3.5 in ethylene service

Turboexpander/Generator



Induction generator, parallel shaft gearbox, 2500 kW EG4

Turboexpander Sizing

Frame Size	Approx. max Power (kW)	Flange Size	
		Exp	Comp
Frame 1	200	3"/4"	6"/6"
Frame 2	1200	4"/6"	8"/8"
Frame 2.5	2000	6"/8"	10"/10"
Frame 3	3500	8"/10"	12"/12"
Frame 3.5	6000	10"/12"	18"/18"
Frame 4	8000	12"/14"	20"/18"
Frame 5	10000	20"/24"	24"/24"
Frame 6	18000	24"/30"	36"/36"

Applicable Codes & Standards

- Industry Standards
 - API 617
 - API 614
 - API 670
 - ANSI B31.3
- Corporate Standards
 - Shell DEP
 - ELF
 - Exxon IP
 - BP
 - Conoco
- International Standards
 - IEC
 - NEC
 - CSA, BASEEFA, PTB, LCIE, UL
 - ASME
 - BS5500
 - Stoomwezen, DPP, Alberta Boiler

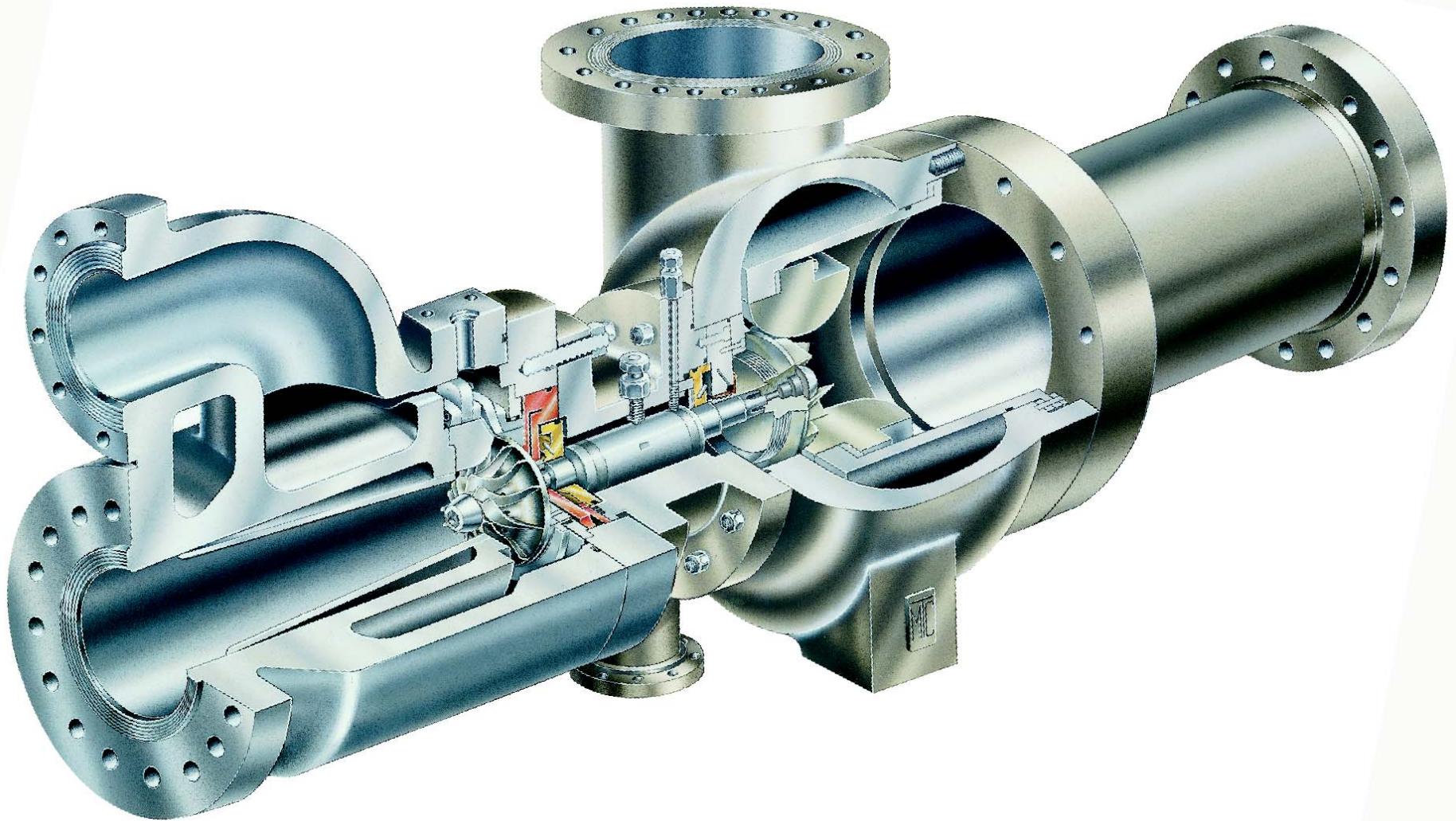
Design Considerations

- Location
 - Offshore/Onshore
 - Outdoor unprotected
 - Manned/Unmanned site
- Geography
 - Desert
 - Tropical
 - Ambient temperatures
- Hazardous Area
 - Division 1 / Zone 1
 - Division 2 / Zone 2

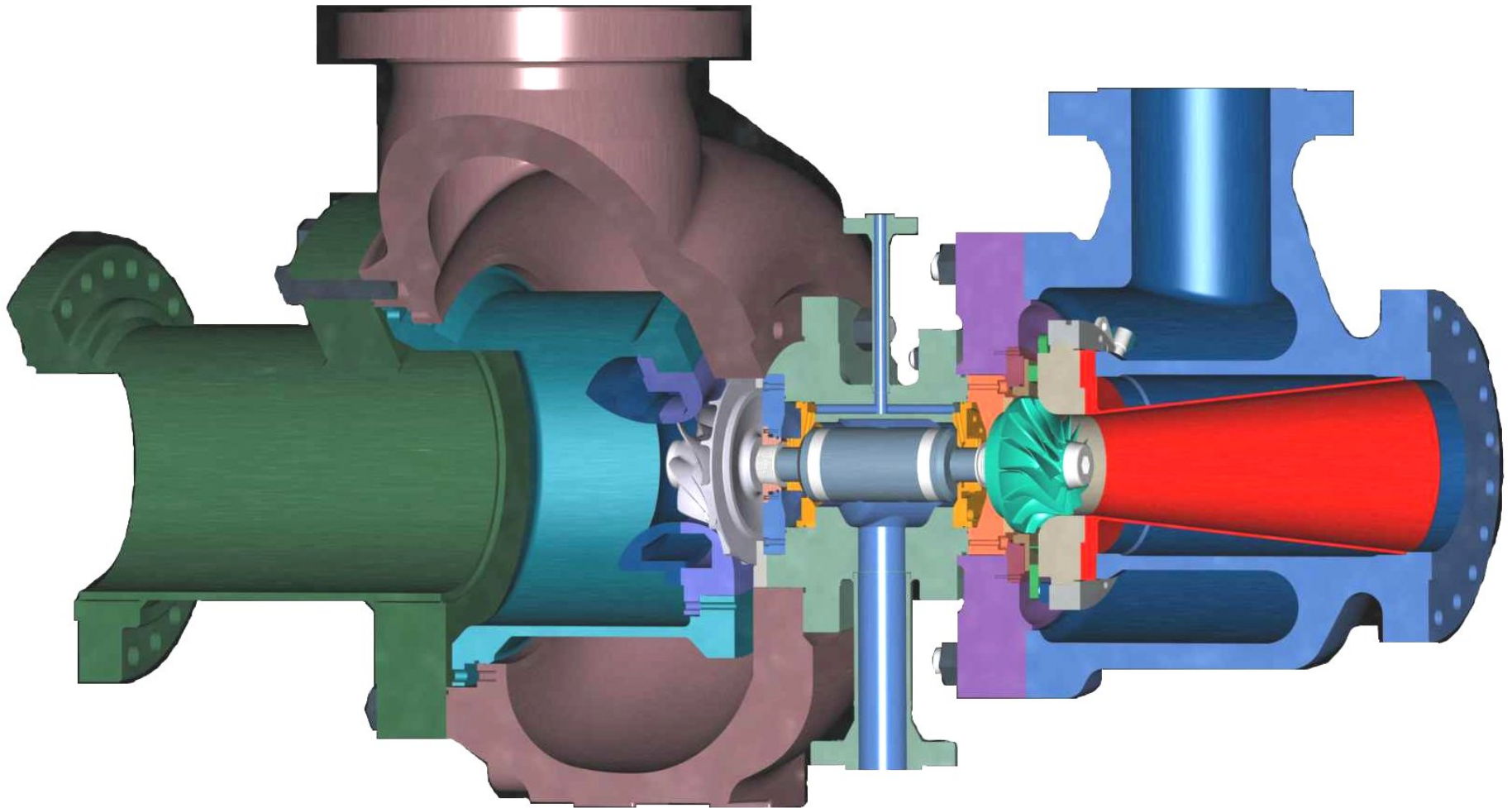
Design Considerations

- Materials of Construction
 - NACE requirements
 - Mercury
 - Design temperature
 - Corrosion resistance
- Design pressure
 - Flange Ratings
 - Relief Valve Settings

Hydrocarbon Turboexpanders



Design Features

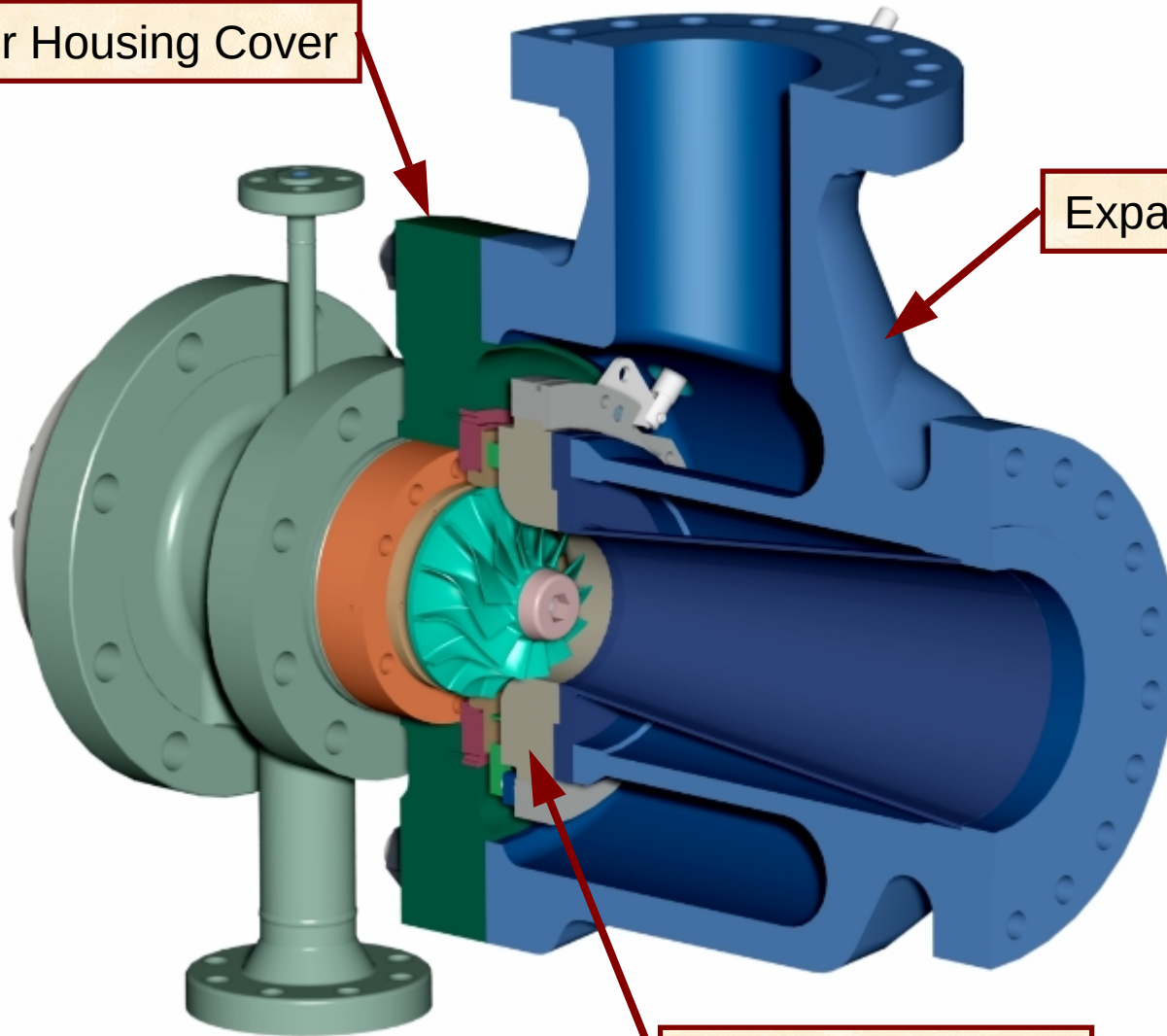


Expander Compressor Cross Section

Expander Housing Cover

Expander Housing

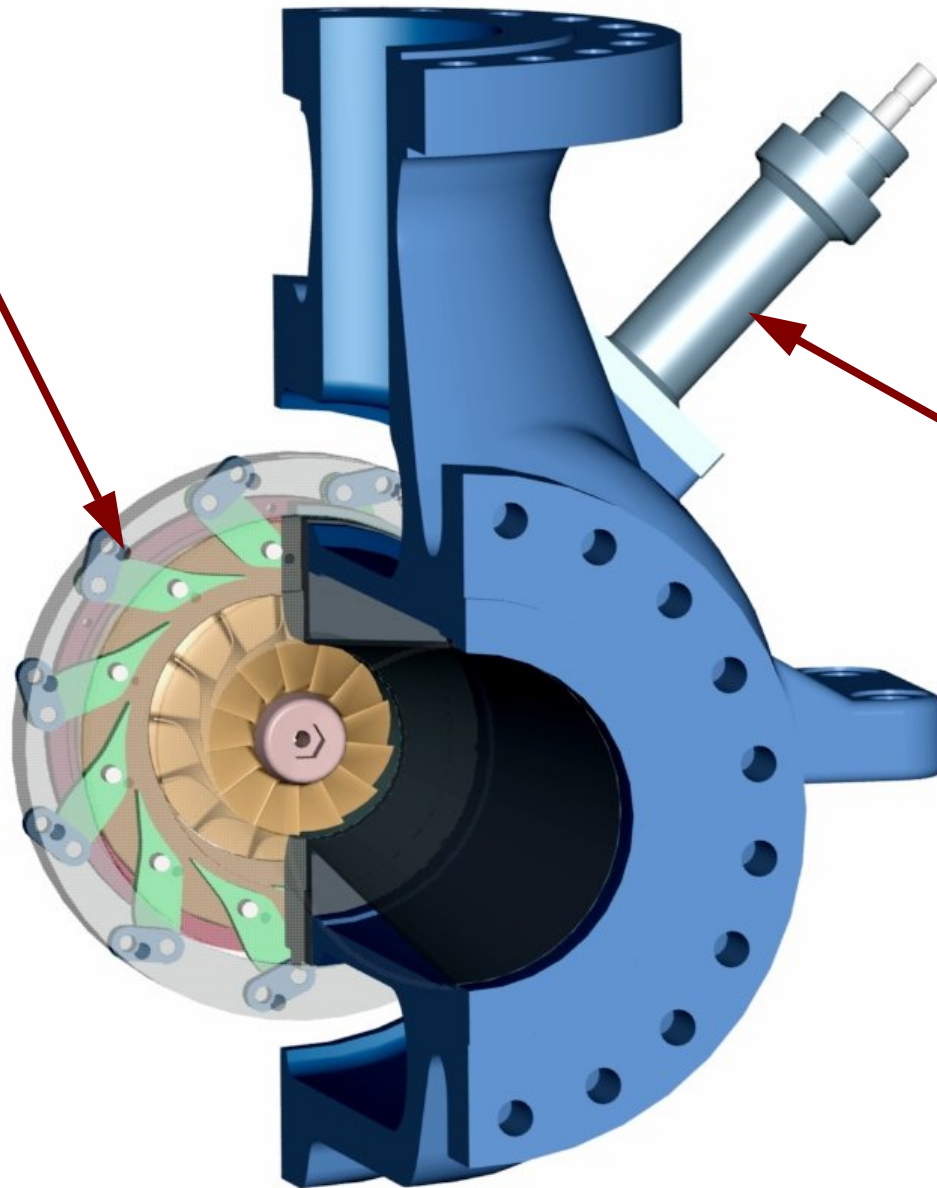
Expander Follower





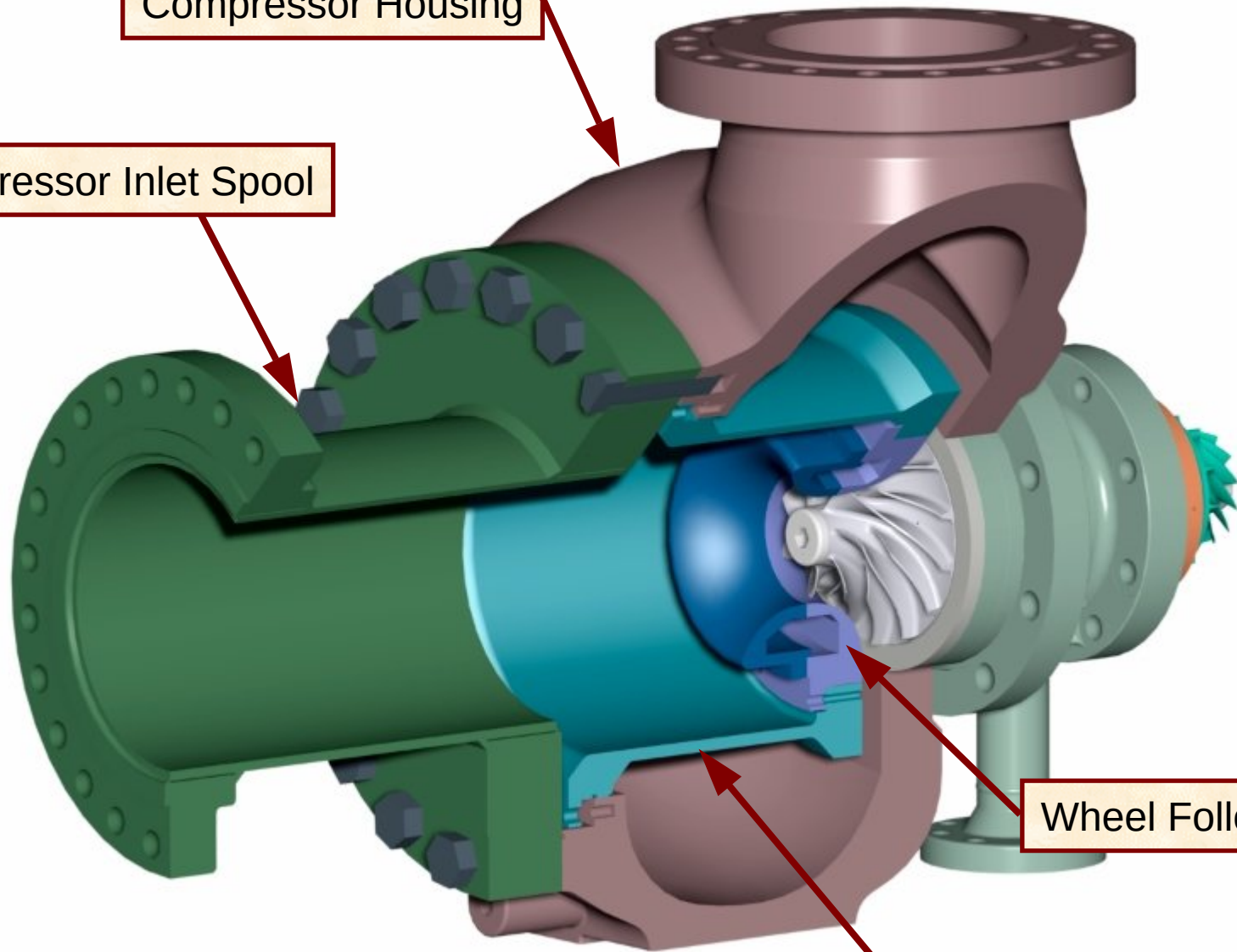
Inlet Guide Vane
Assembly

Inlet Guide Vane
Actuator



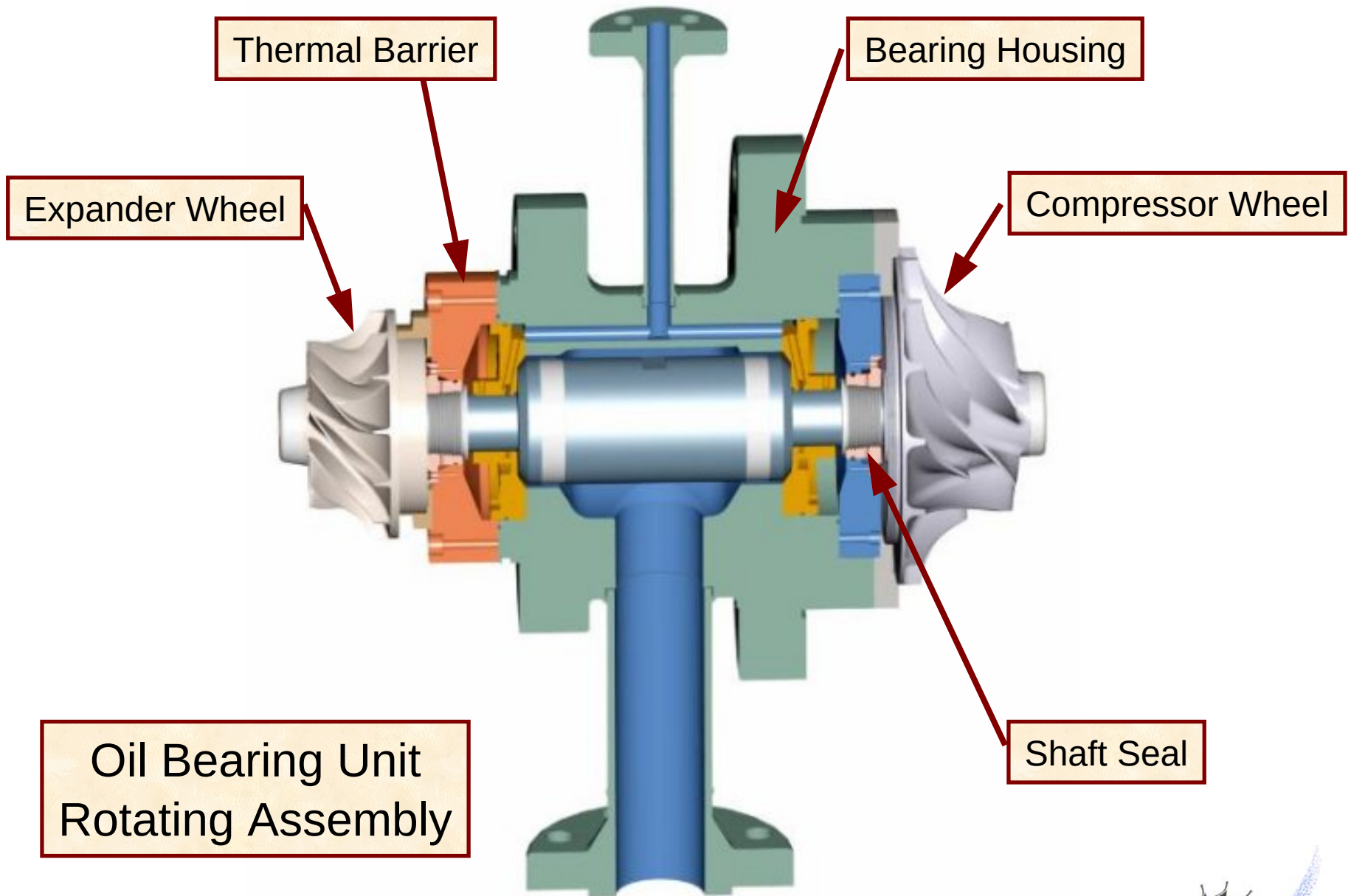
Compressor Housing

Compressor Inlet Spool

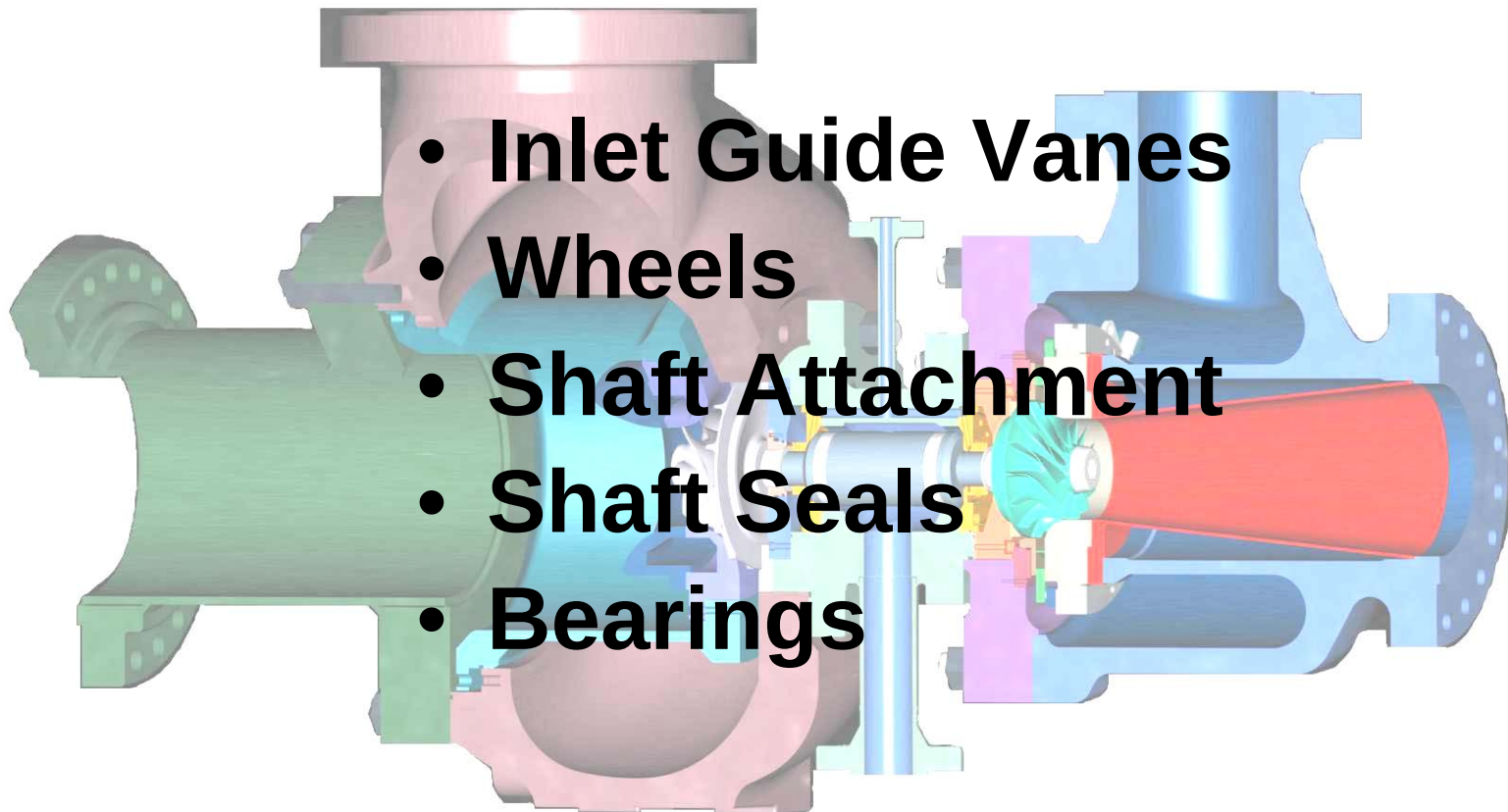


Wheel Follower

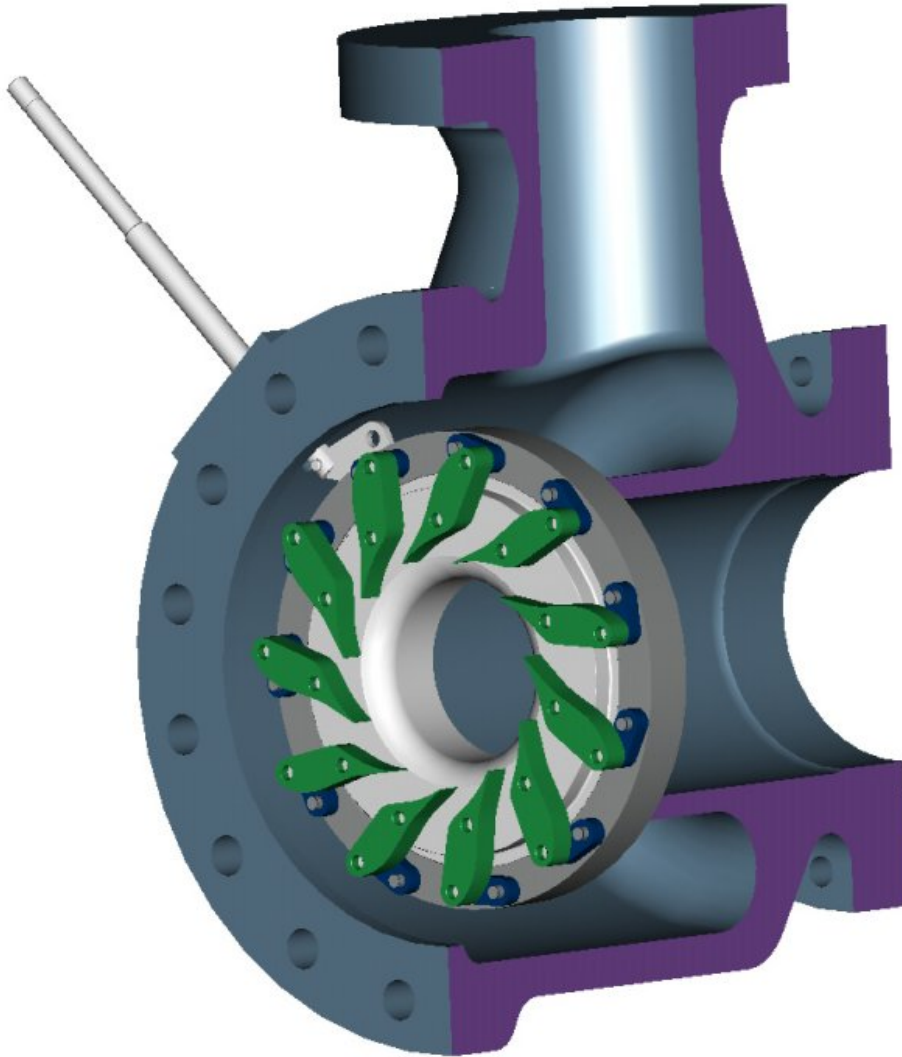
Diffuser Bracket



Turboexpander/compressor Design Features

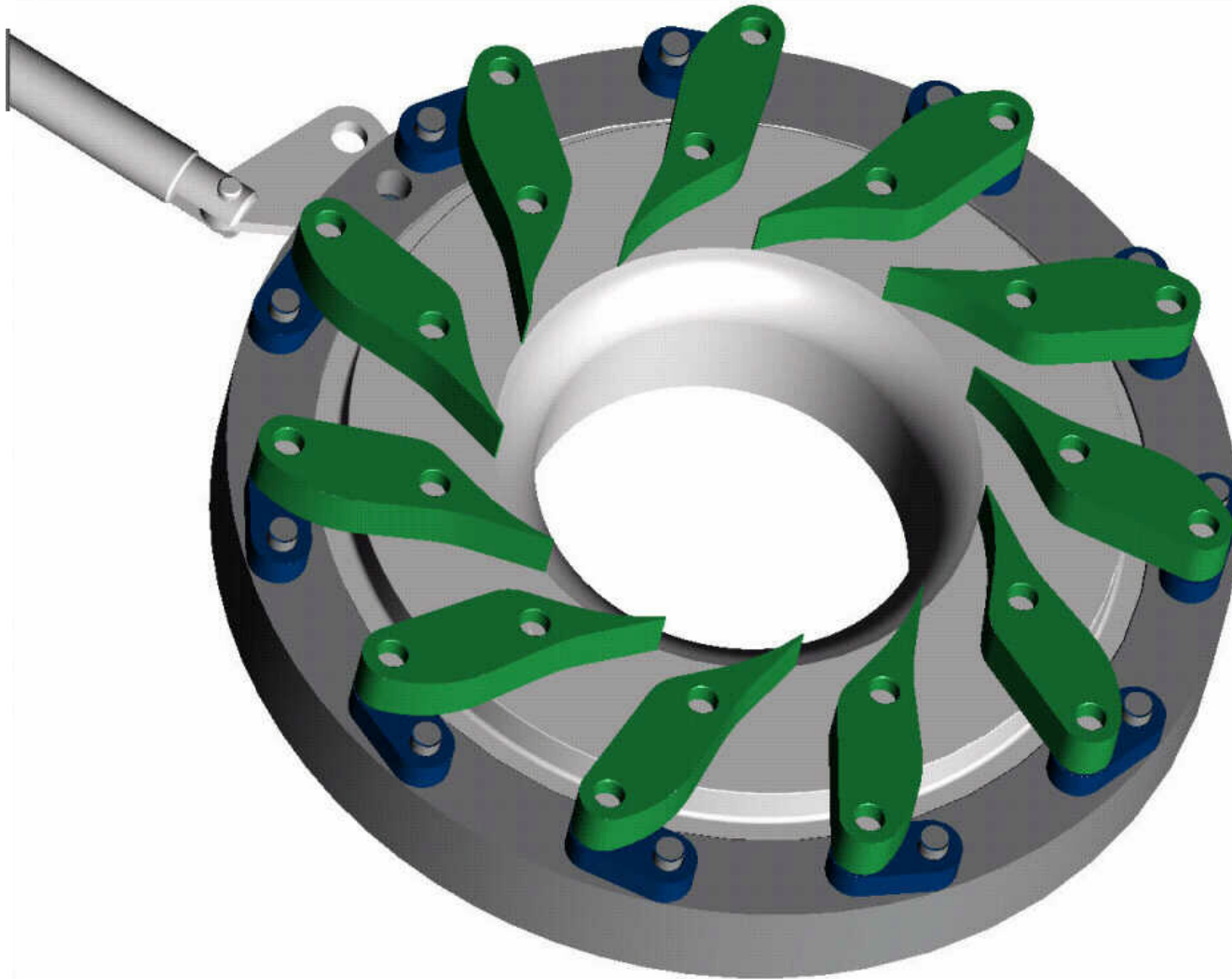


Expander Inlet Guide Vanes



- Custom designed
- 0-125% design flow
- Gall resistant
- Hardened materials to avoid erosion

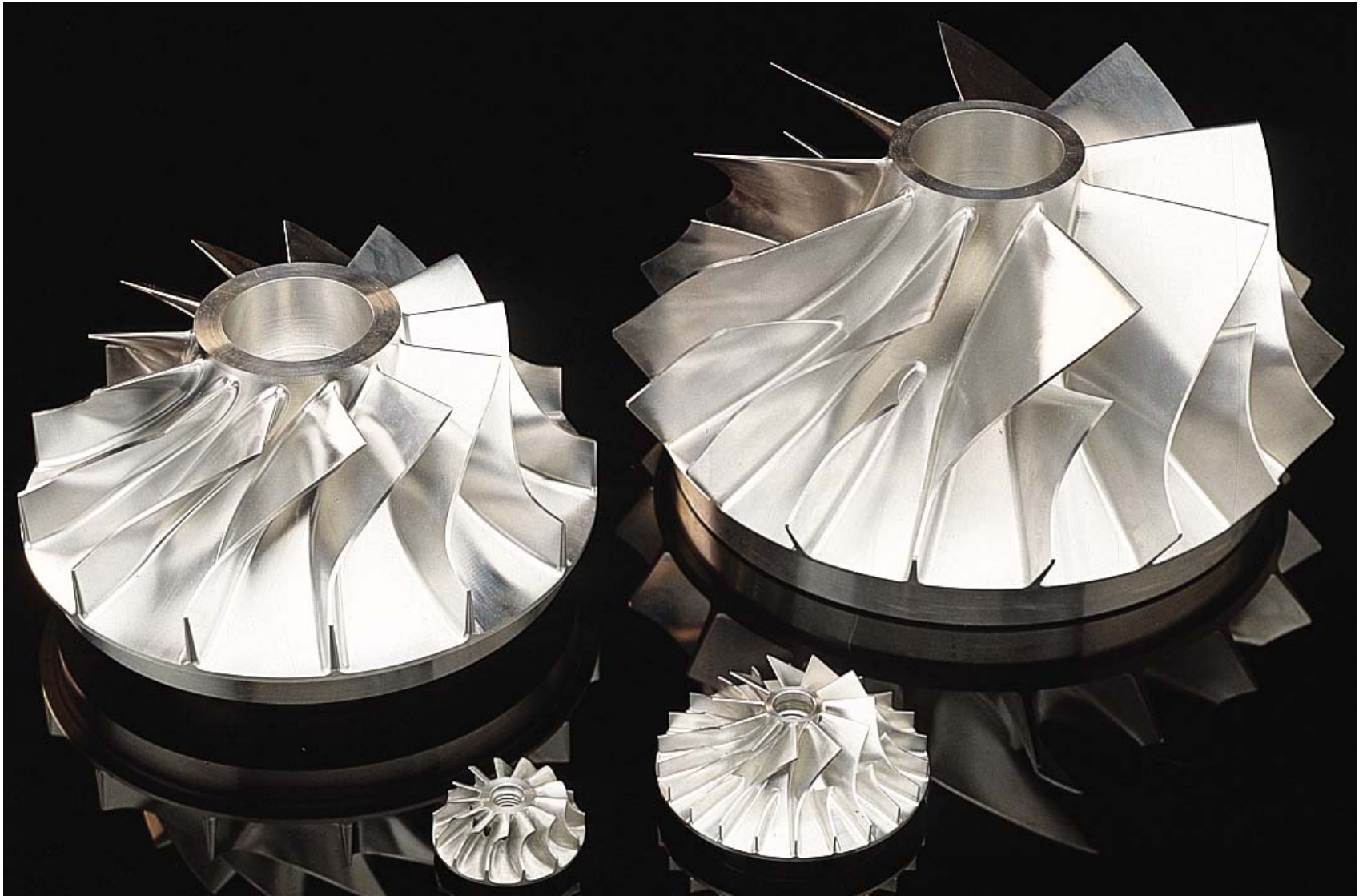
Expander Inlet Guide Vanes



Expander Inlet Guide Vanes

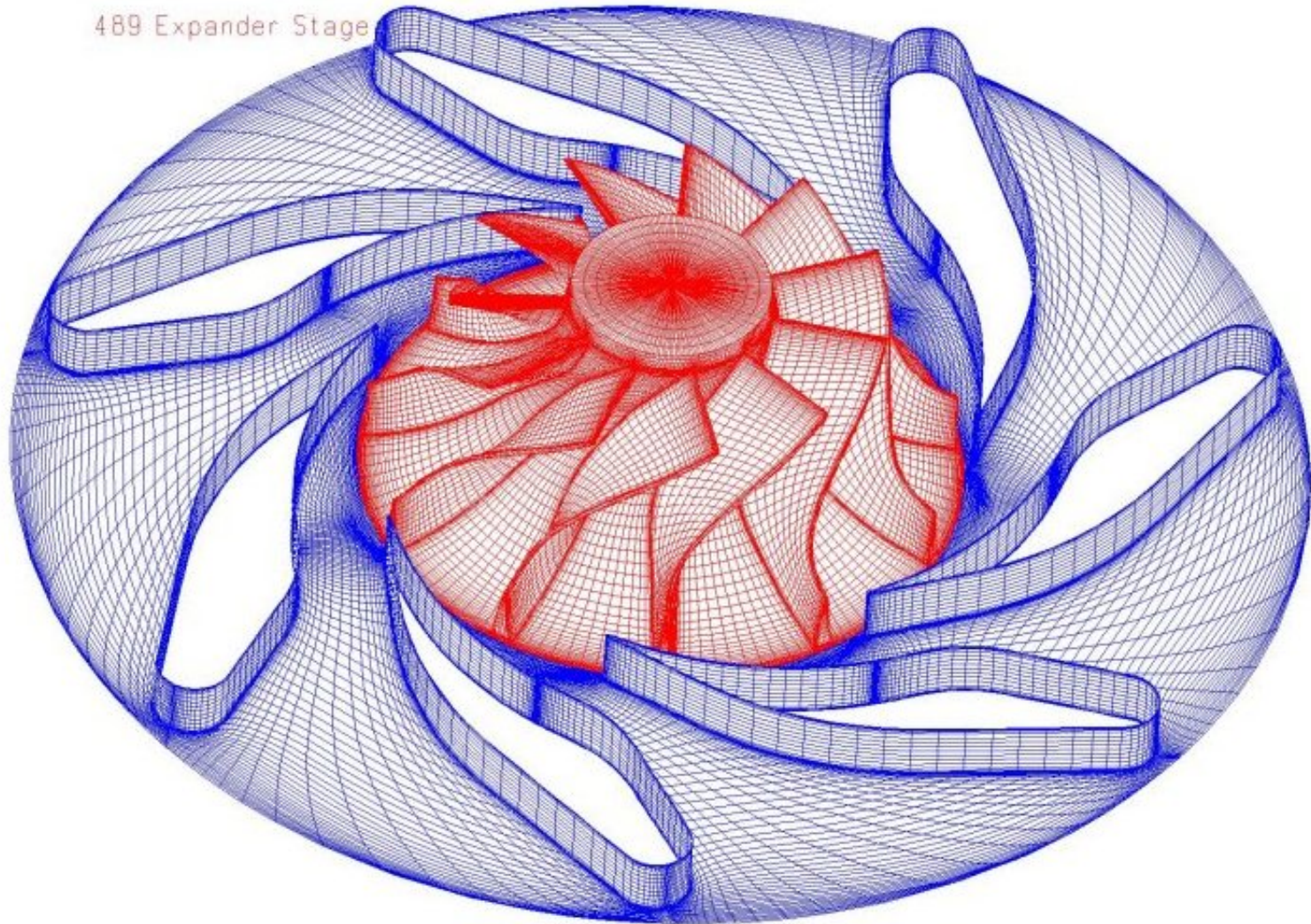


Expander / Compressor Wheels



Wheel Design

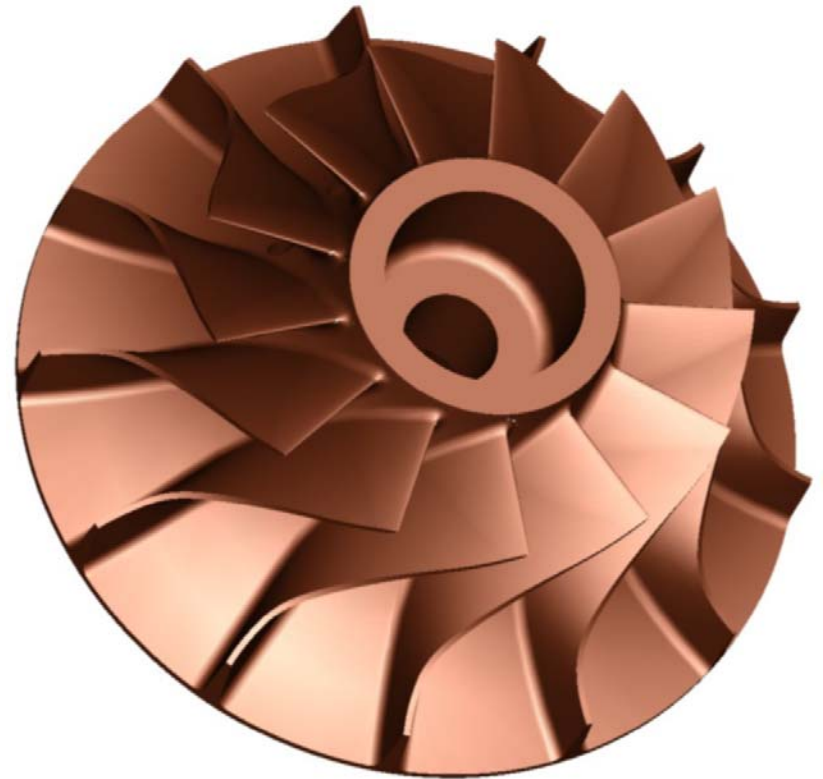
489 Expander Stage



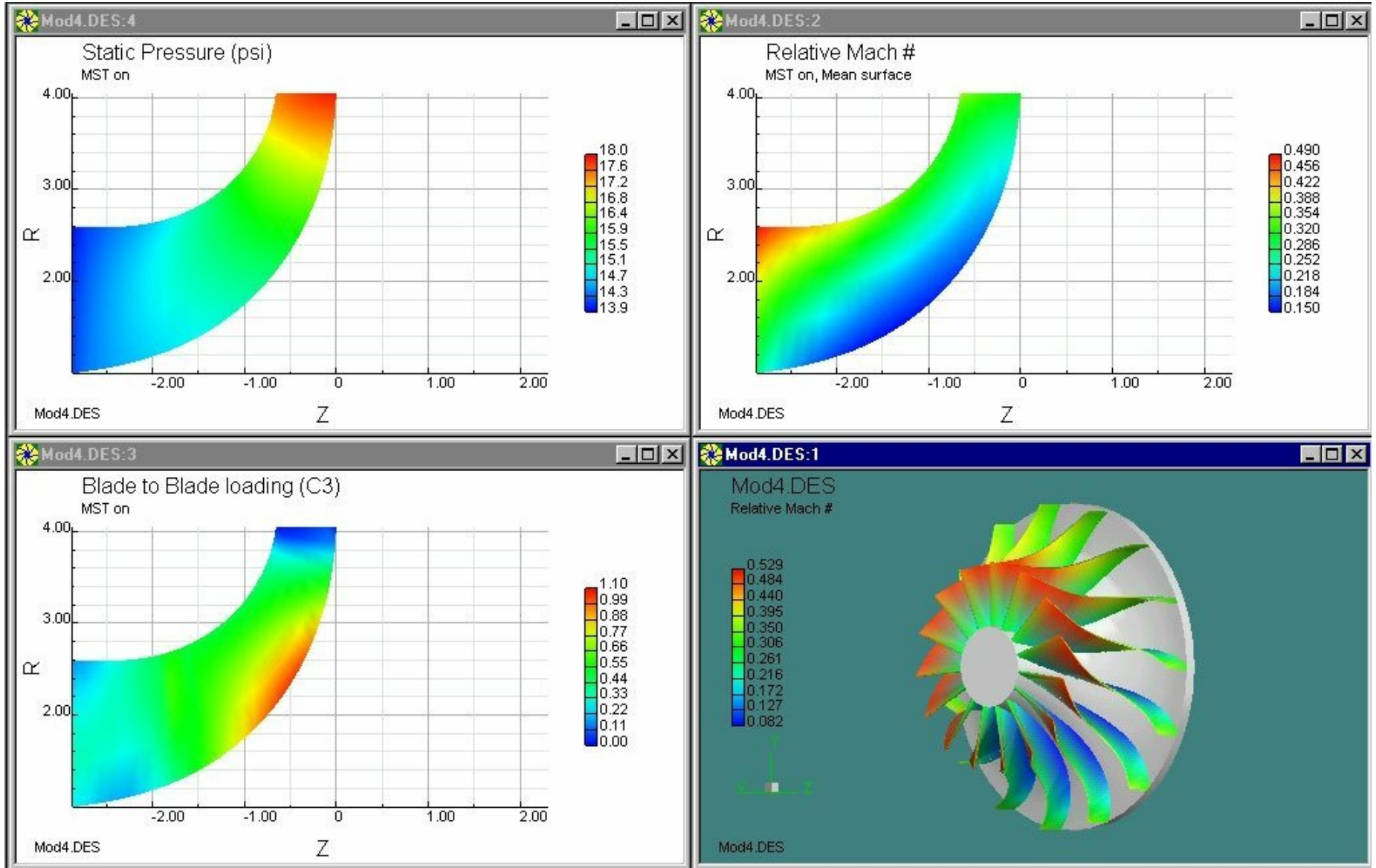
Wheel / IGV Mesh

Wheel Design

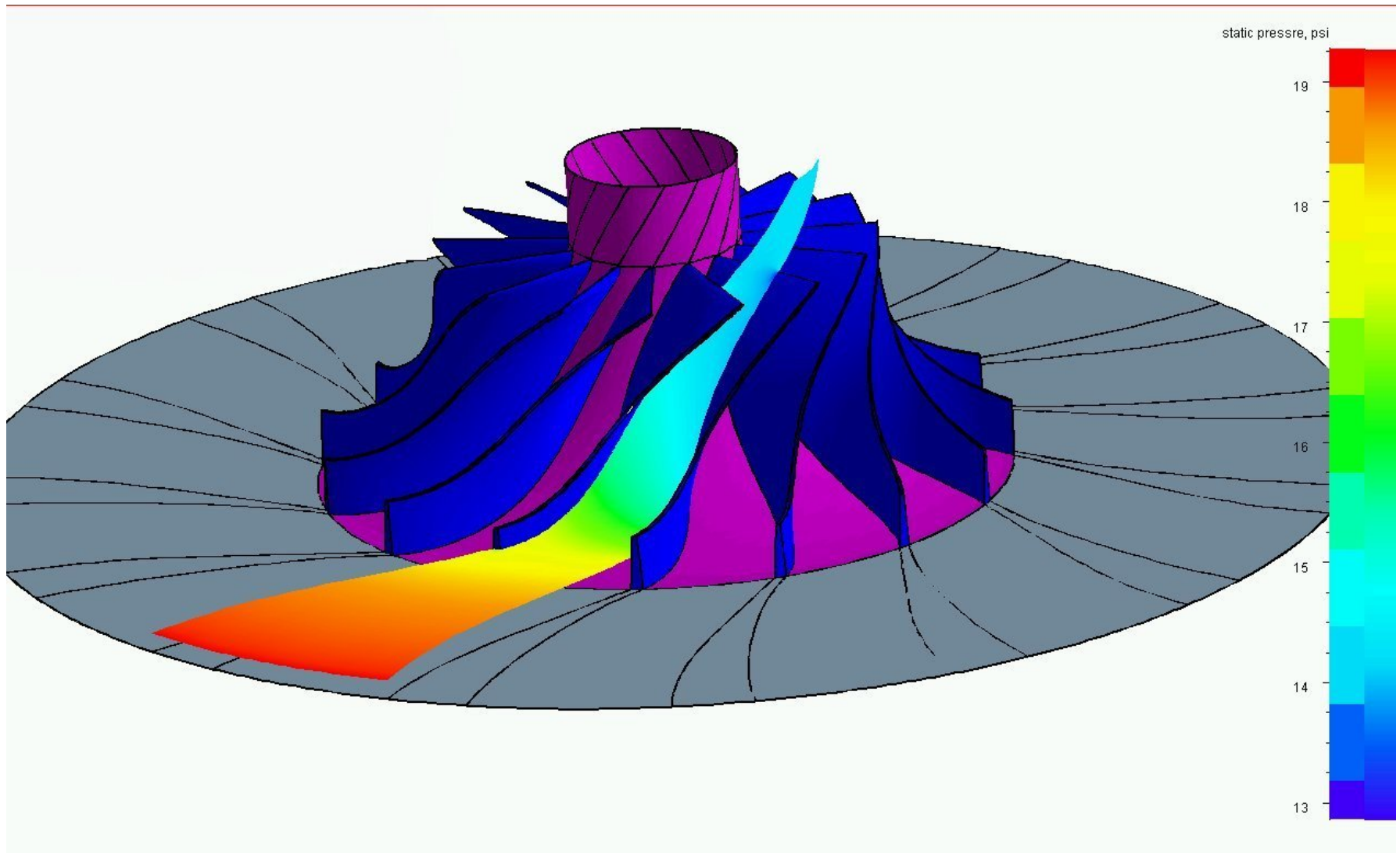
- Solid Modeling



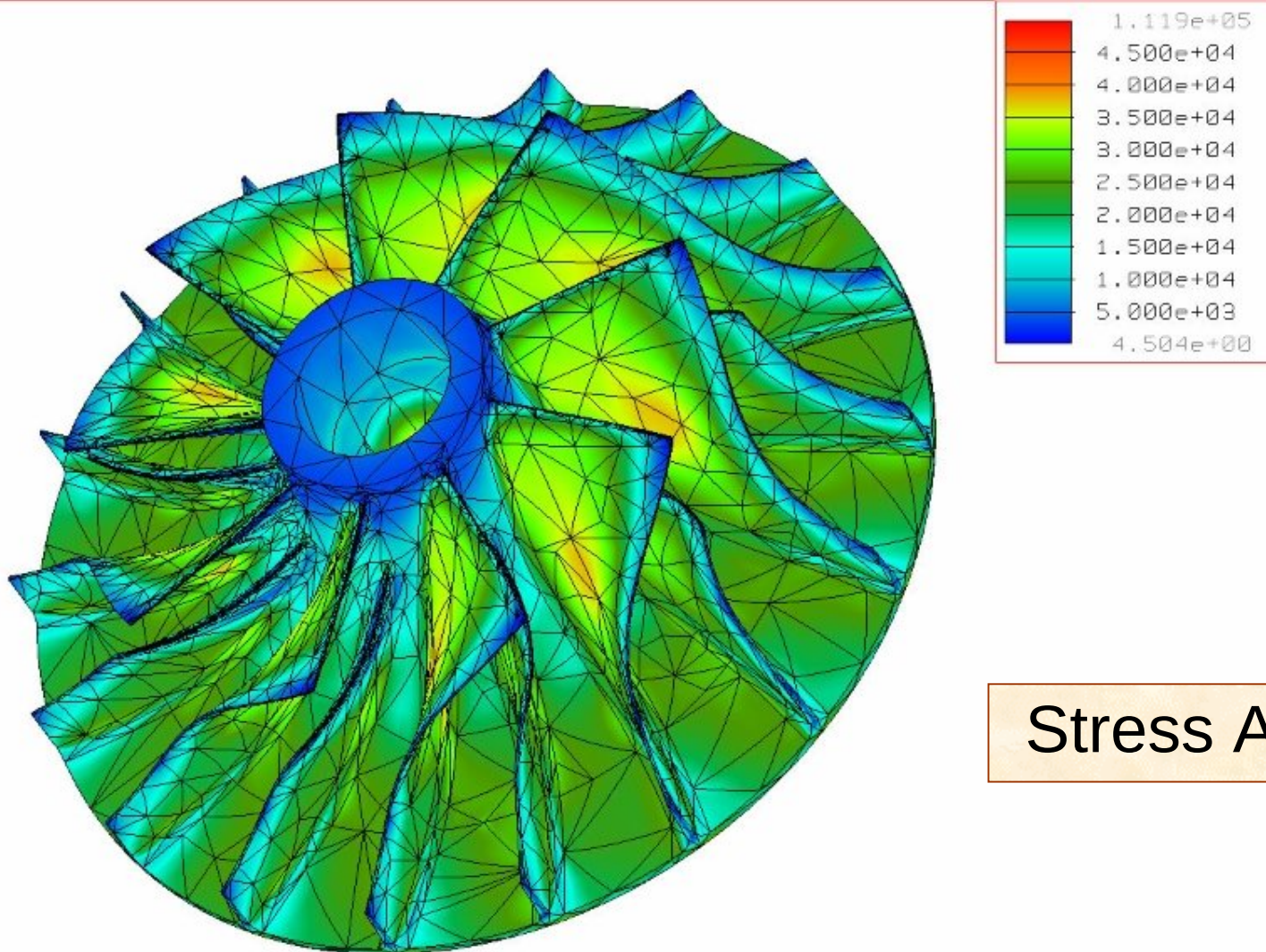
Compressor Design



Computational Fluid Dynamics (CFD)

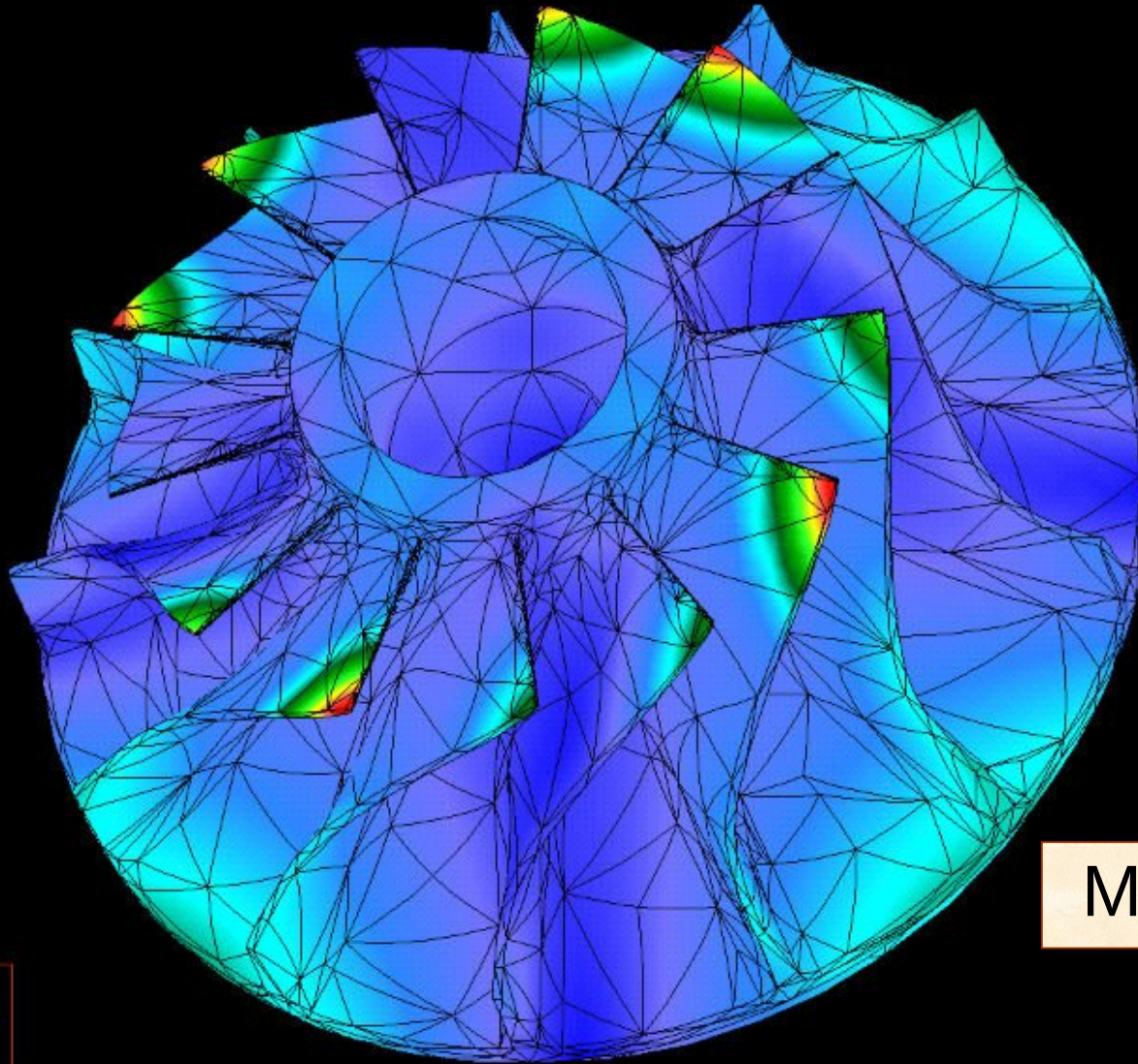


Finite Element Modeling (FEA)



Stress Analysis

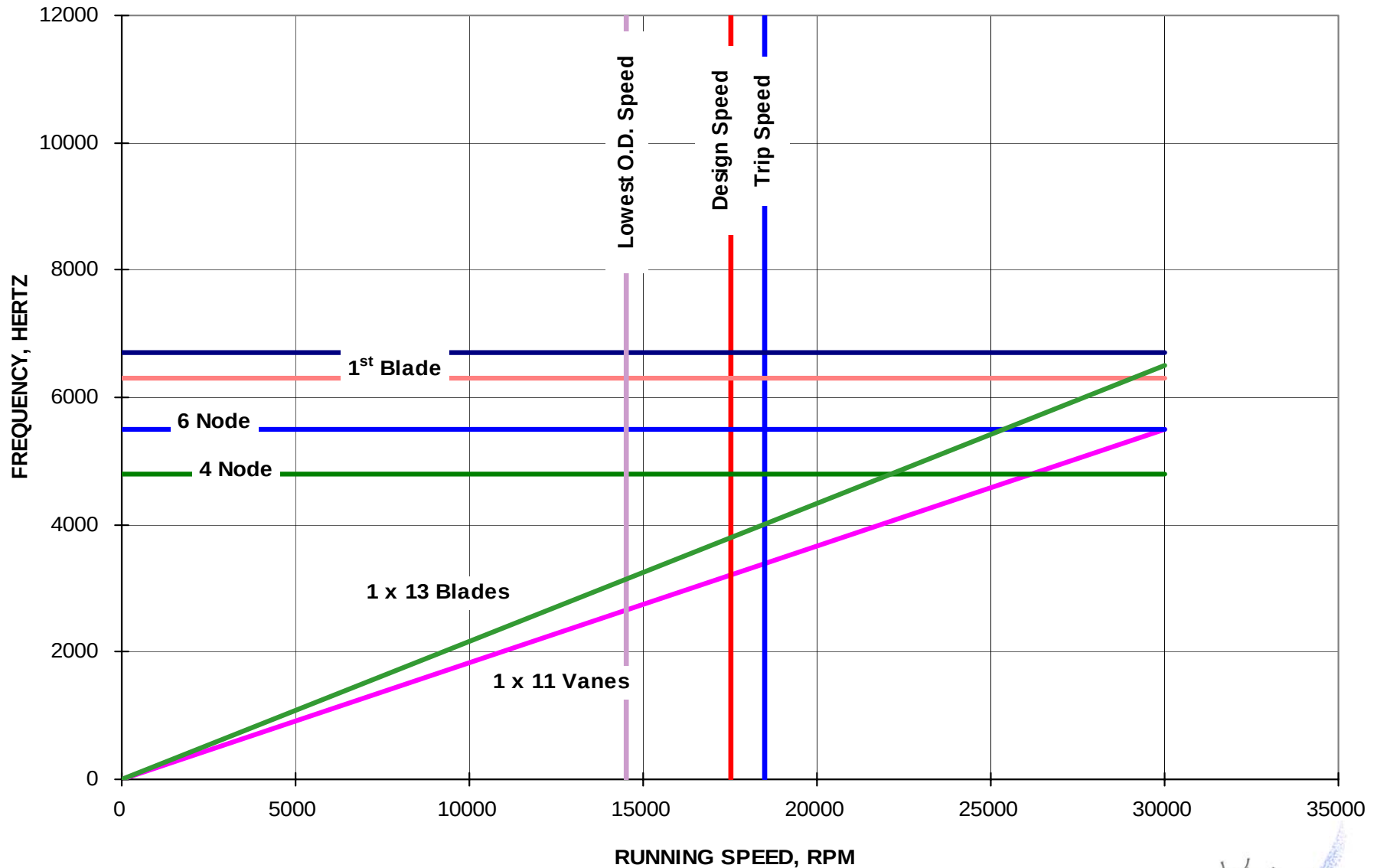
Finite Element Modeling



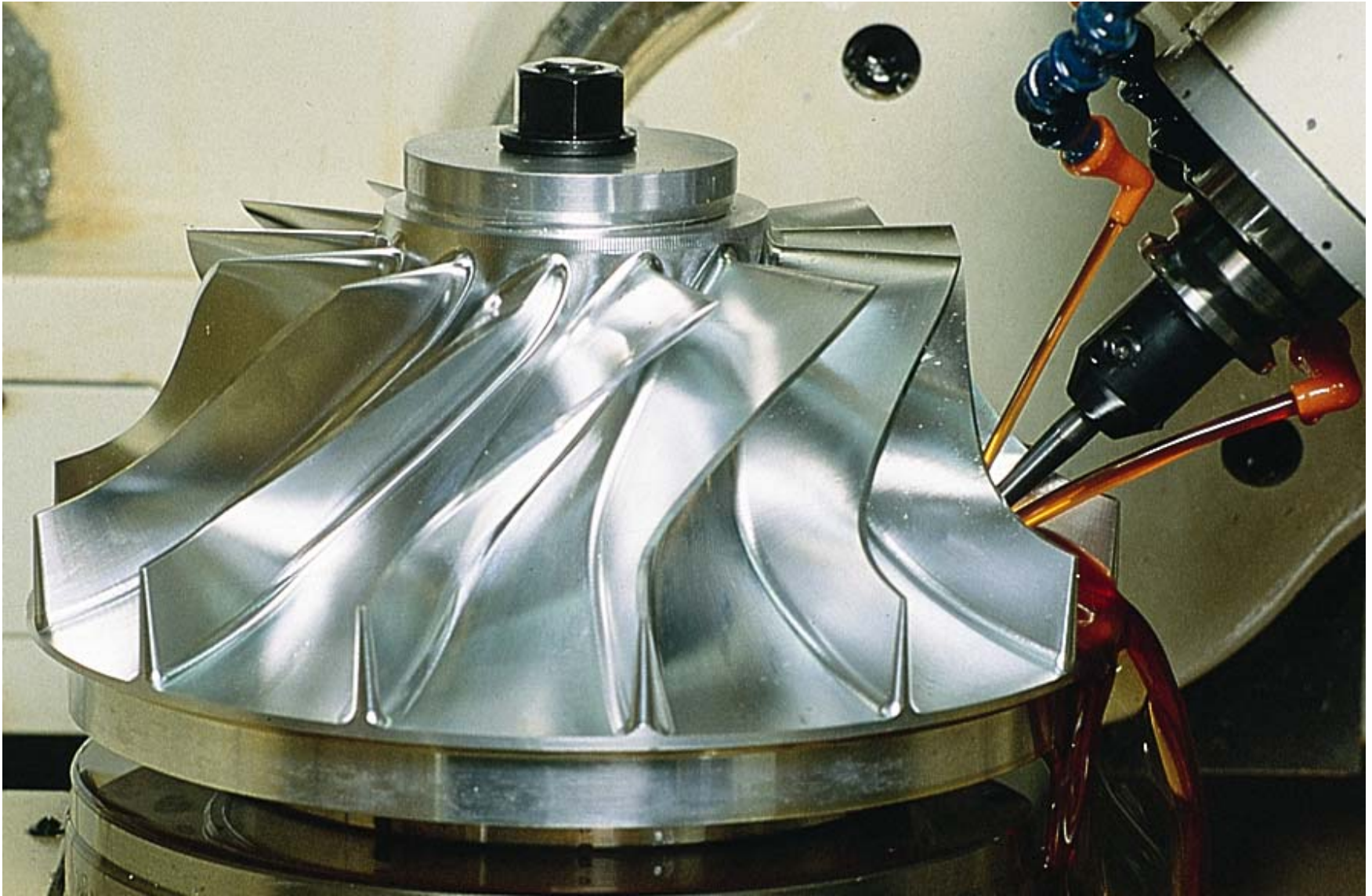
Modal Analysis



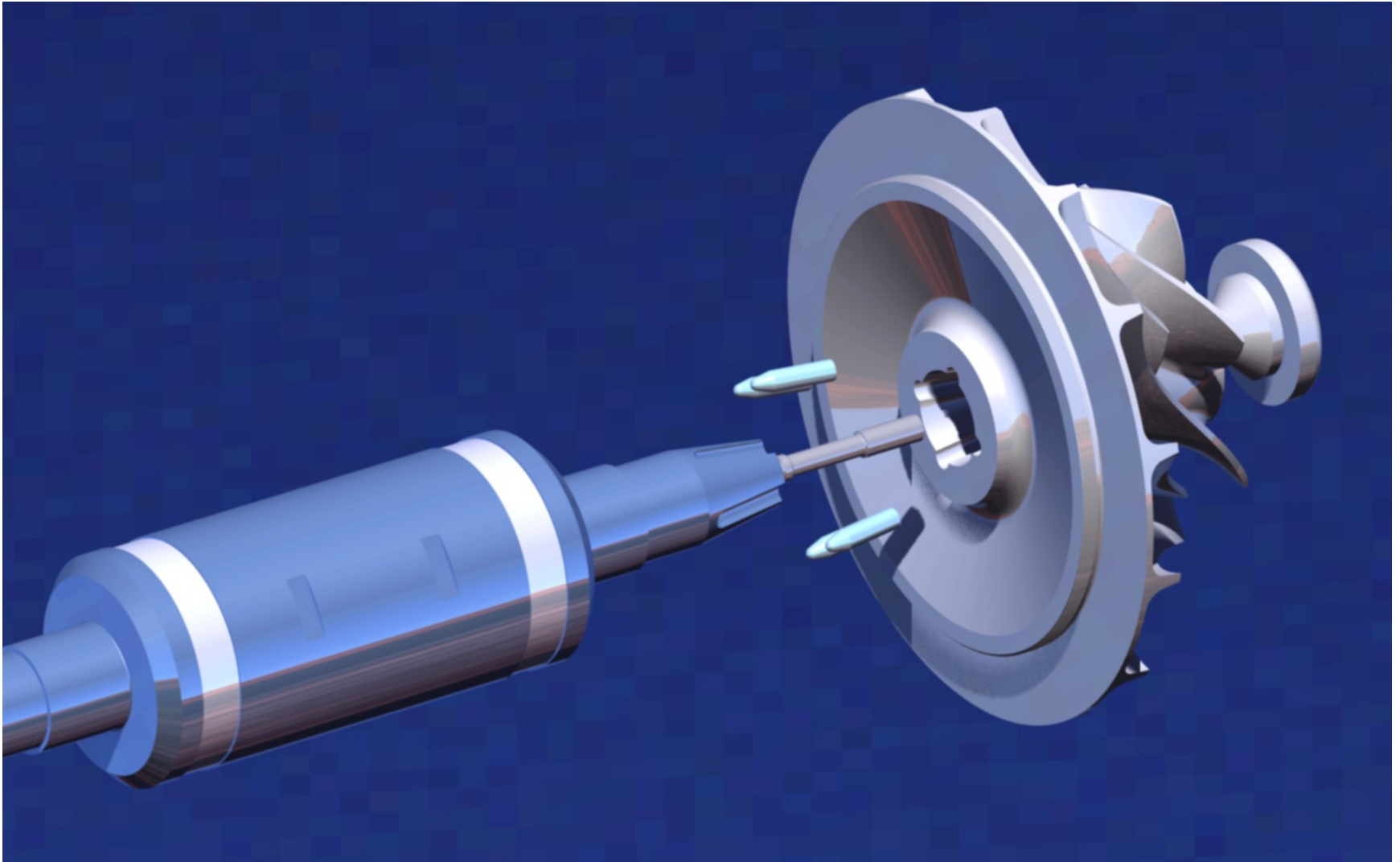
Typical Expander Campbell Diagram



Wheel Manufacture



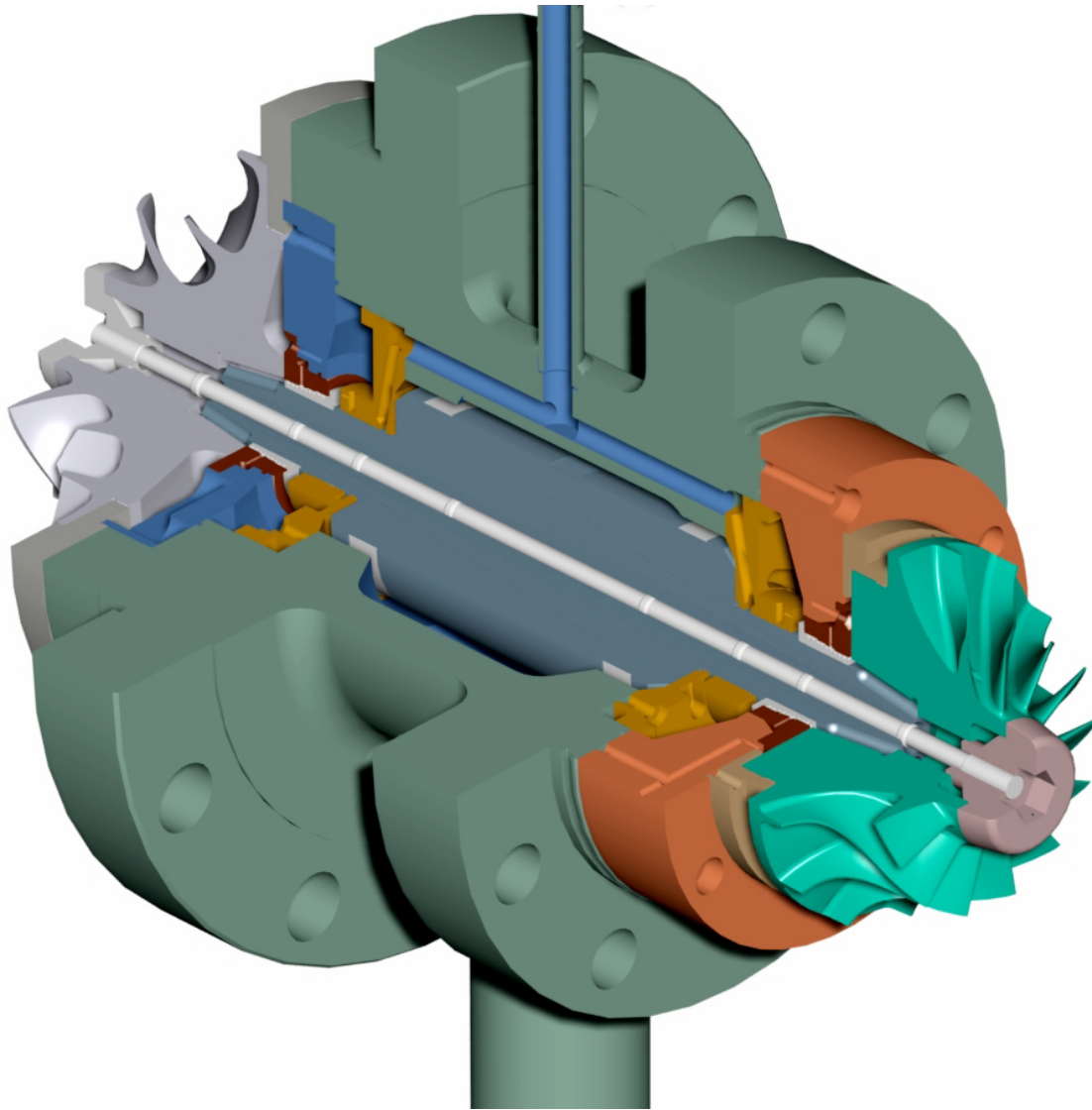
Shaft Attachment



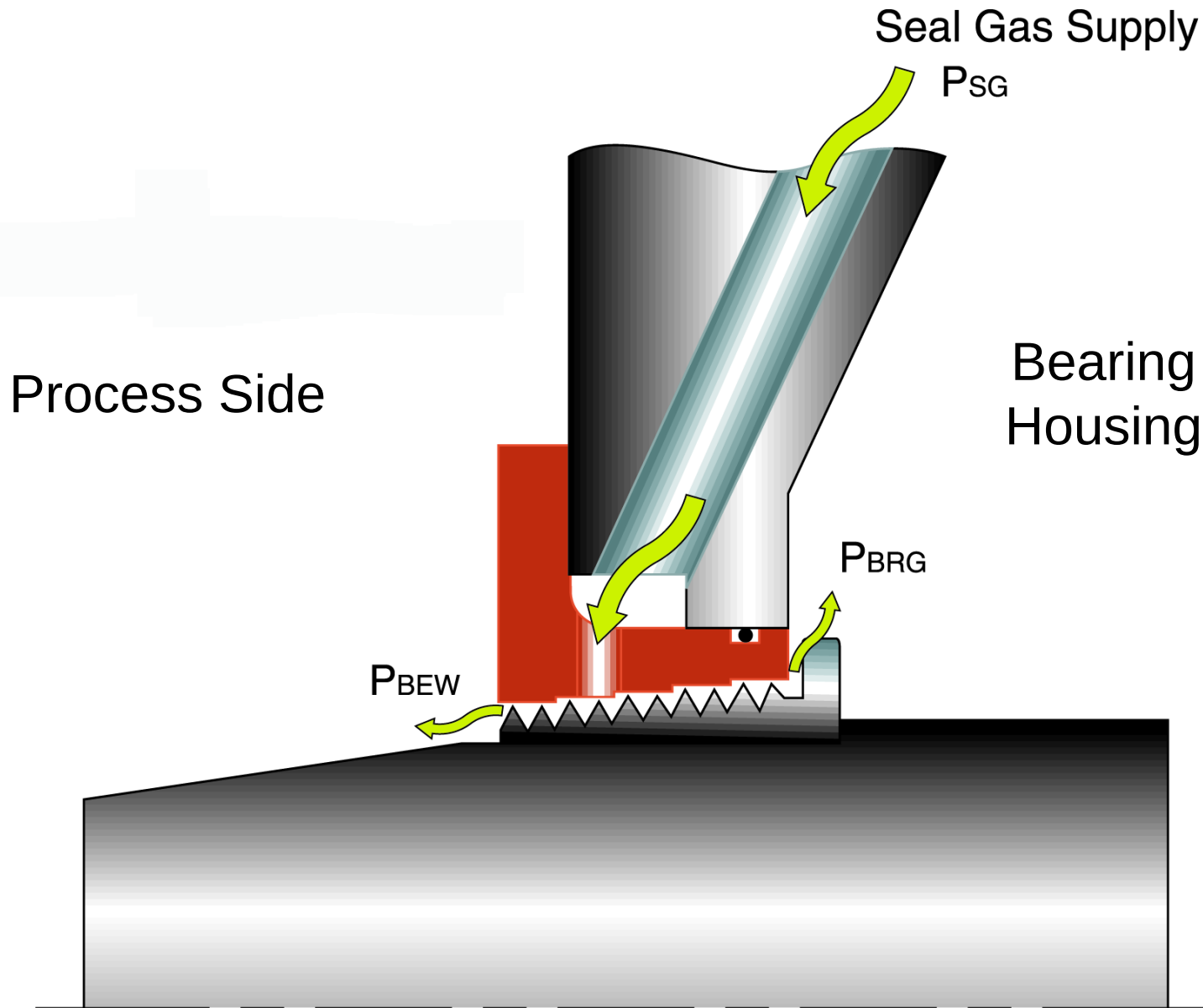
Shaft Attachment



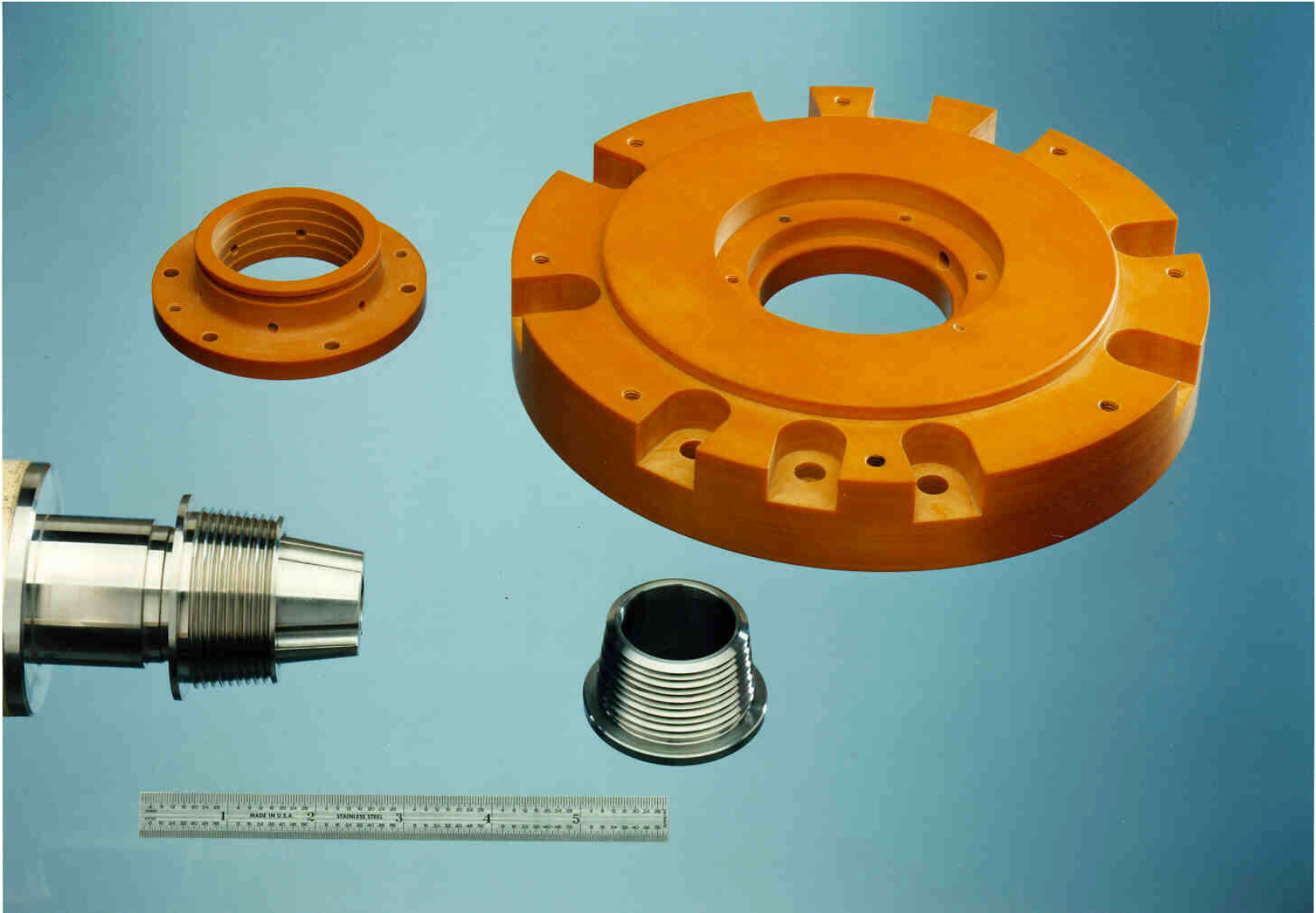
Shaft Attachment



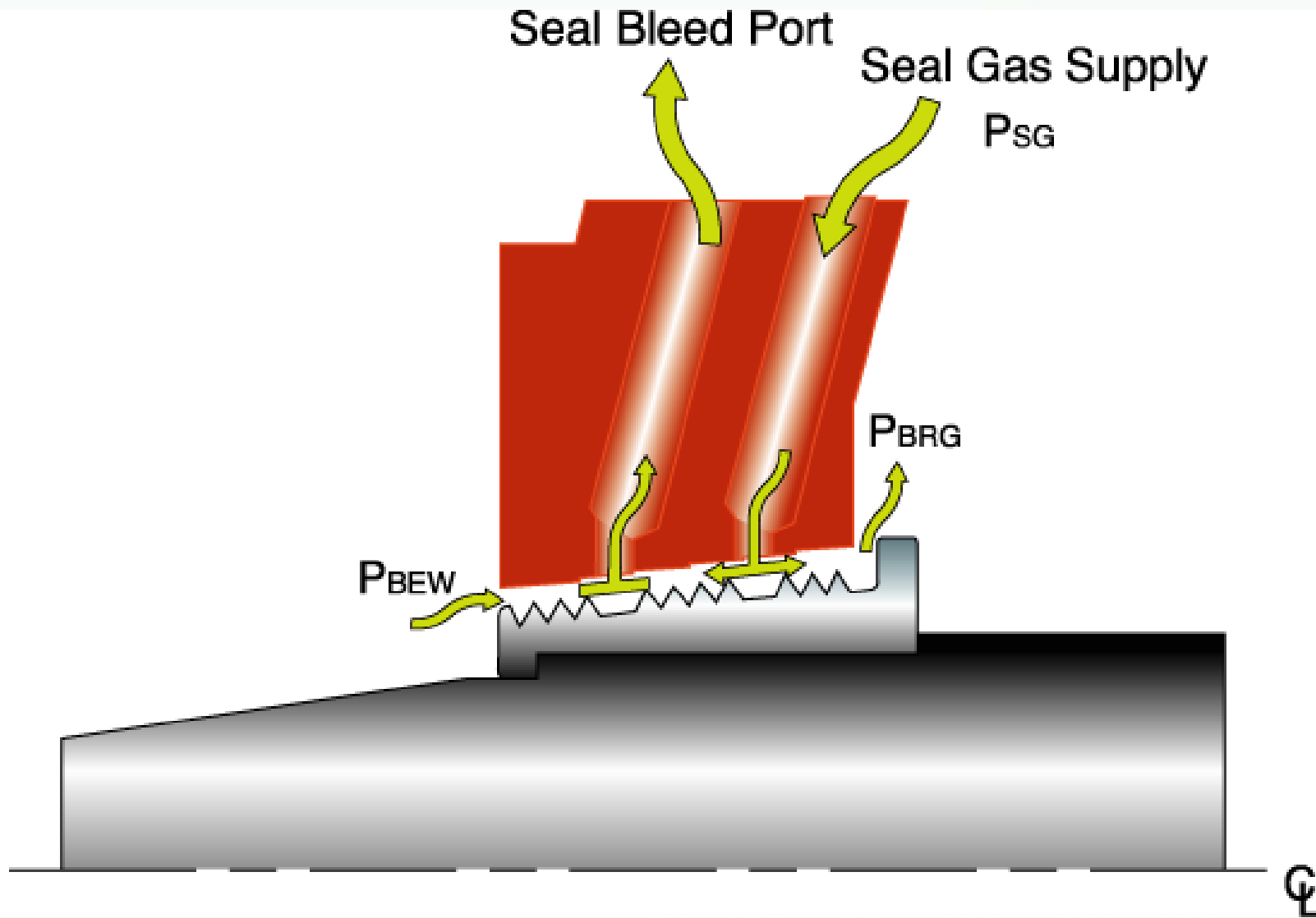
Single Port Labyrinth Seal



Shaft Seals

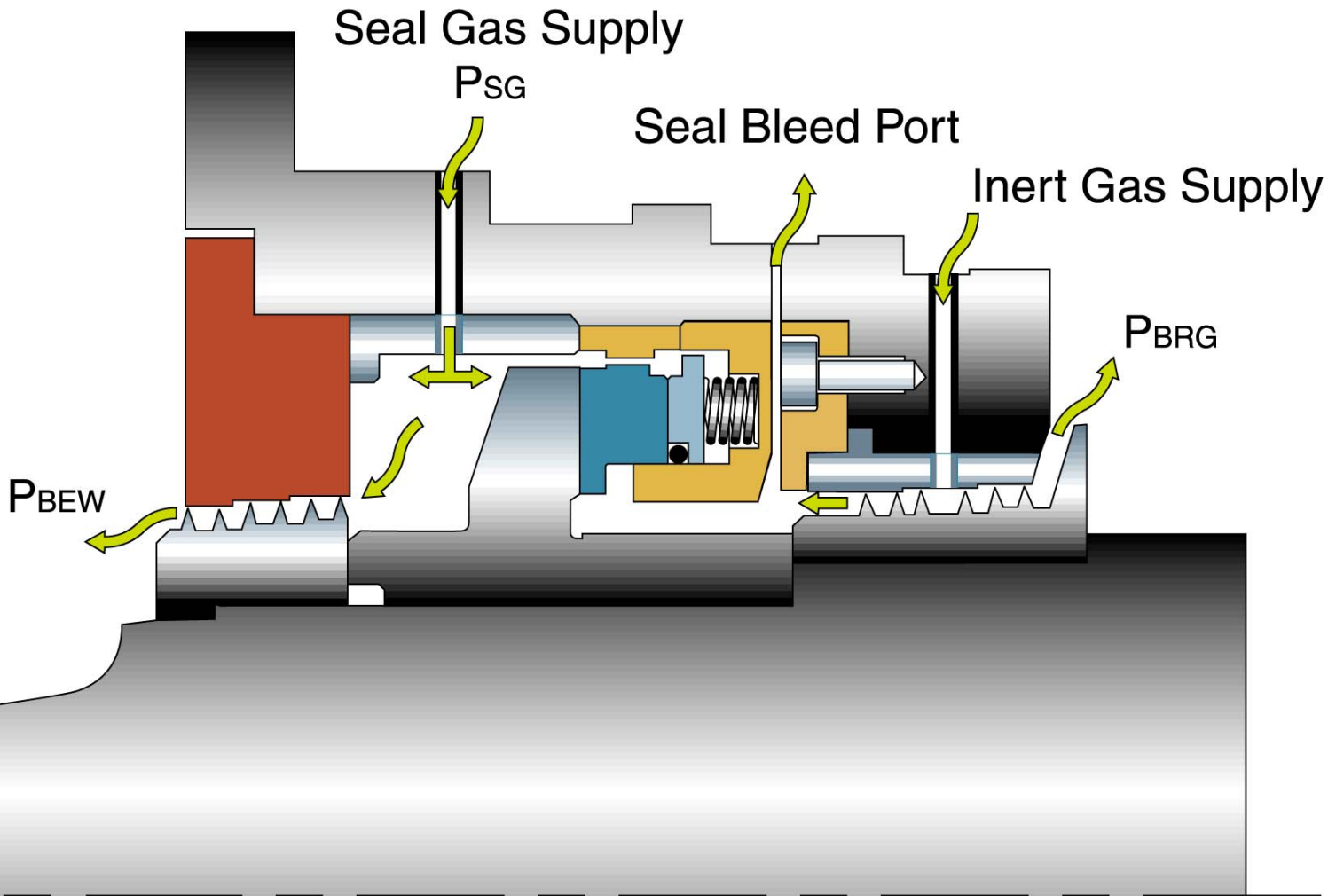


Two Port Labyrinth Seal



The diagram illustrates a cross-section of a gas seal assembly. A red, multi-lobed seal ring is mounted on a shaft. Three green arrows point into the seal from the top, labeled 'Seal Gas Supply' with pressure P_{SG} , 'Seal Bleed Port', and 'Buffer Gas Supply (N_2)'. At the bottom left, a green arrow points out from the seal, labeled P_{BEW} . At the bottom right, a green arrow points out from a port, labeled P_{BRG} . The shaft is shown in grey, and the housing is in black. A small 'C' symbol is at the bottom right.

Dry Gas Seal



Bearings

- Lube Oil or Active Magnetic
- Removable RTD's
- Oil Lubricated Radial: 3-lobe Sleeve or Tilt Pad
- Oil Lubricated Thrust: Tapered Land or Tilt Pad

Oil Lubricated Bearings



Fixed Bore Sleeve

Oil Lubricated Bearings



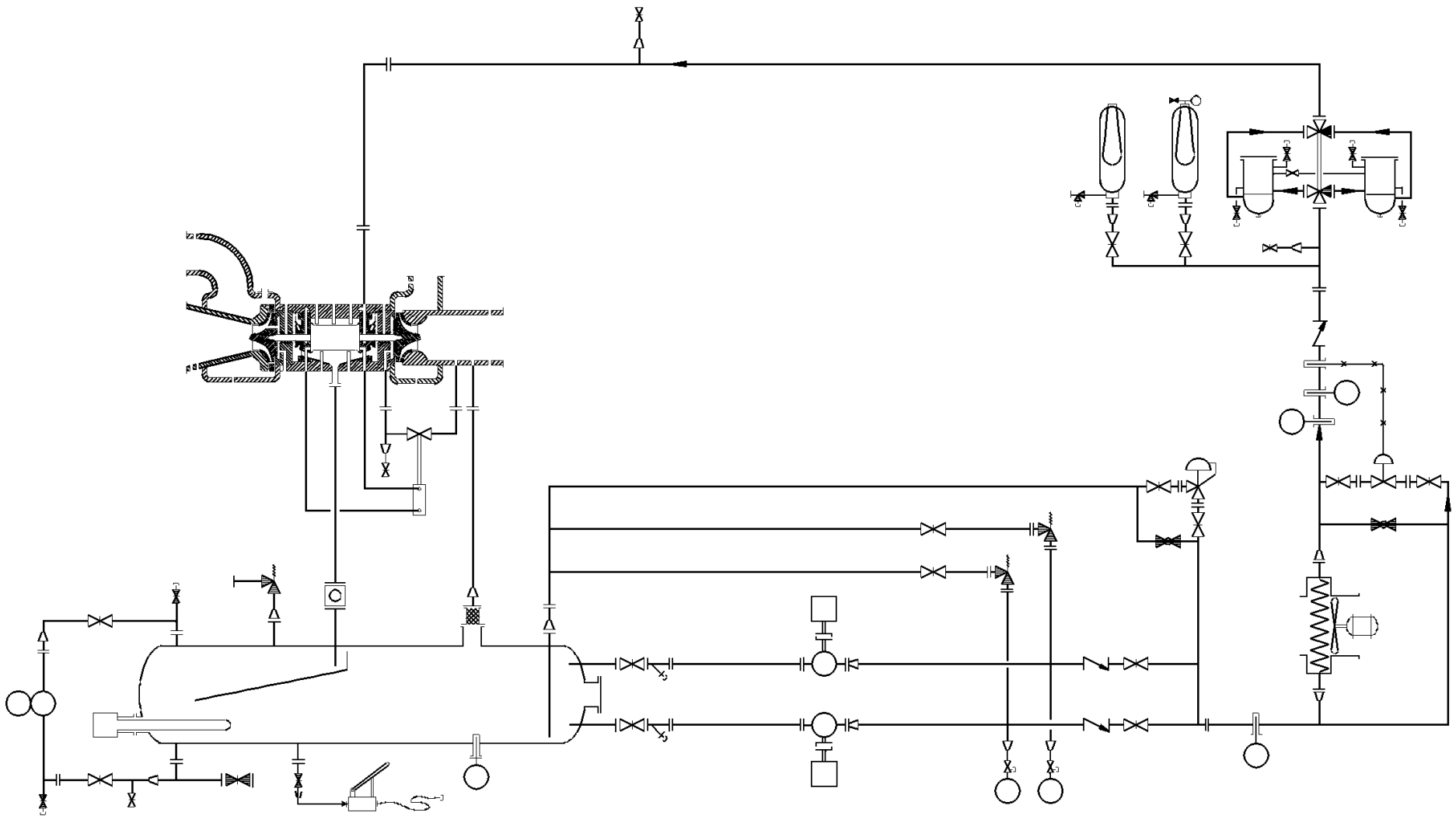
Tilting Pad

Turboexpander Auxiliaries

Lube Oil System

- Basic Design Features
 - Pressurized lube oil reservoir
 - Redundant filters, pumps, coolers as per API 614
 - Water or air-cooled lube oil coolers
 - Mounted on steel skid with expander

Turboexpander Auxiliaries



Lube Oil System Schematic

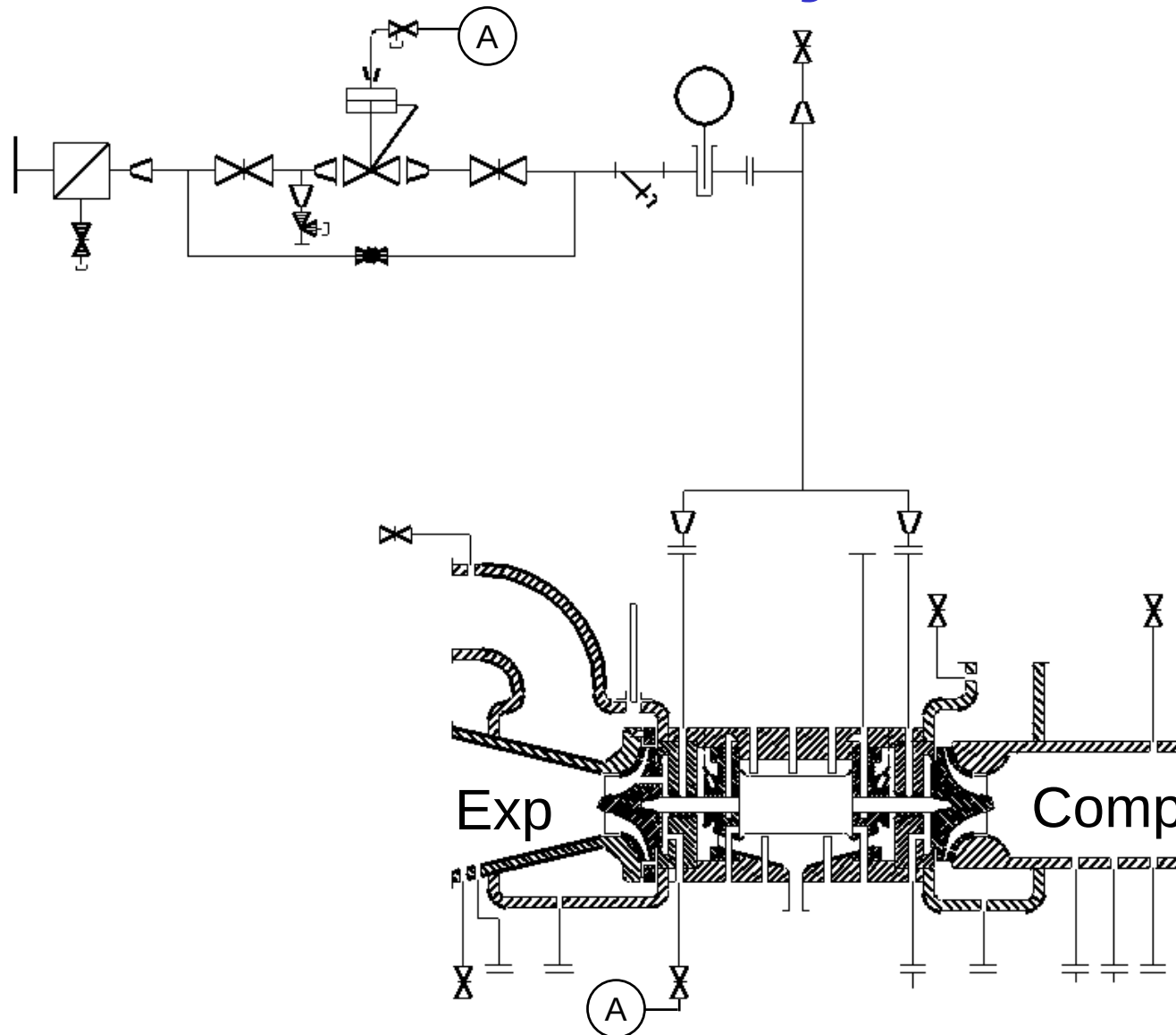
Turboexpander Auxiliaries

Seal Gas System

- Basic Design Details
 - Buffered Labyrinth System
 - 5 micron filtration
 - Pressure regulated off expander wheel
- Seal Gas Conditions
 - Warm, filtered, 20°C superheated
- Pre-conditioning
 - Heating
 - Liquid removal
 - Filtration

Turboexpander Auxiliaries

Seal Gas System



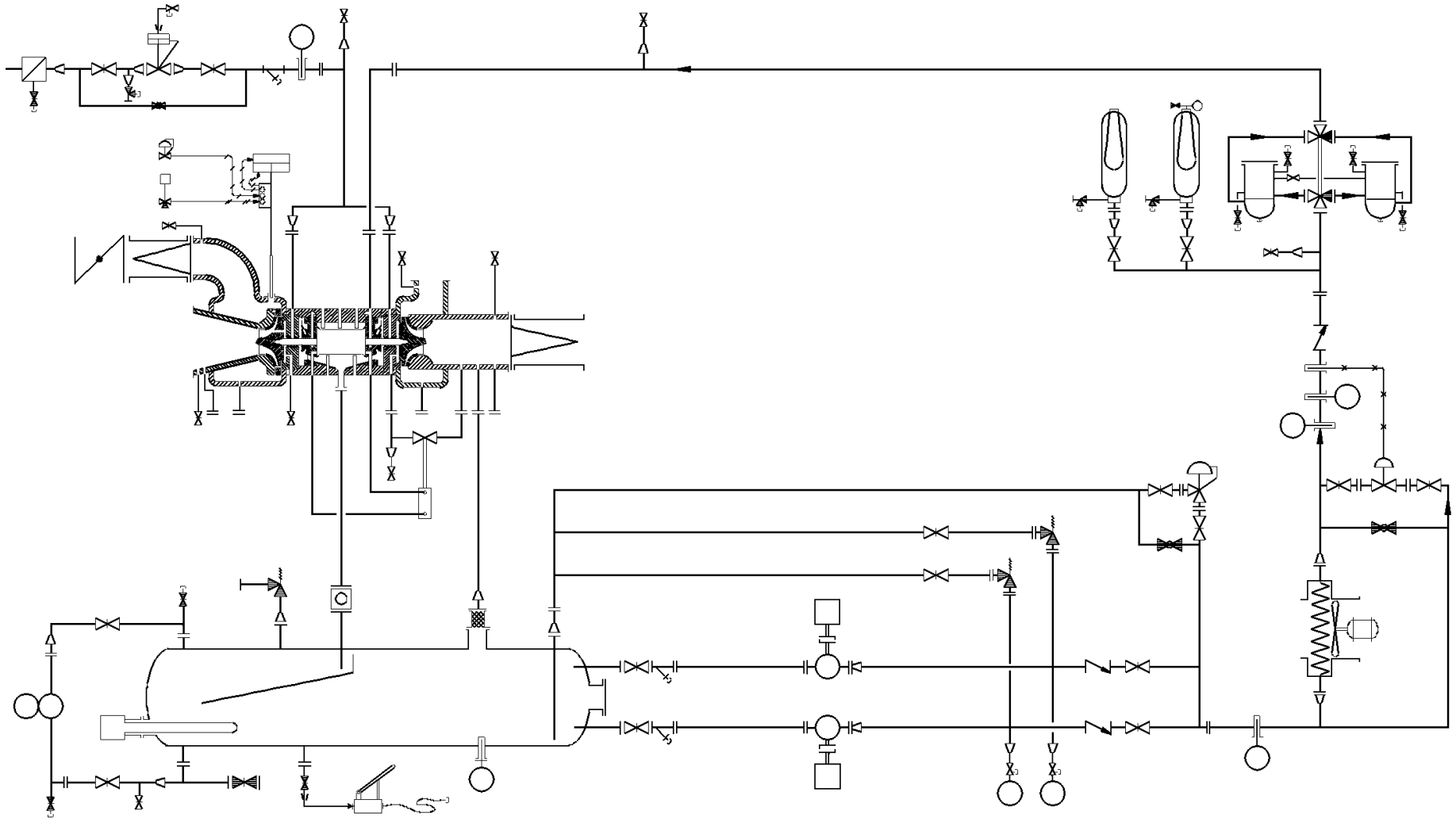
Turboexpander Auxiliaries

Lube Oil & Seal Gas Interaction

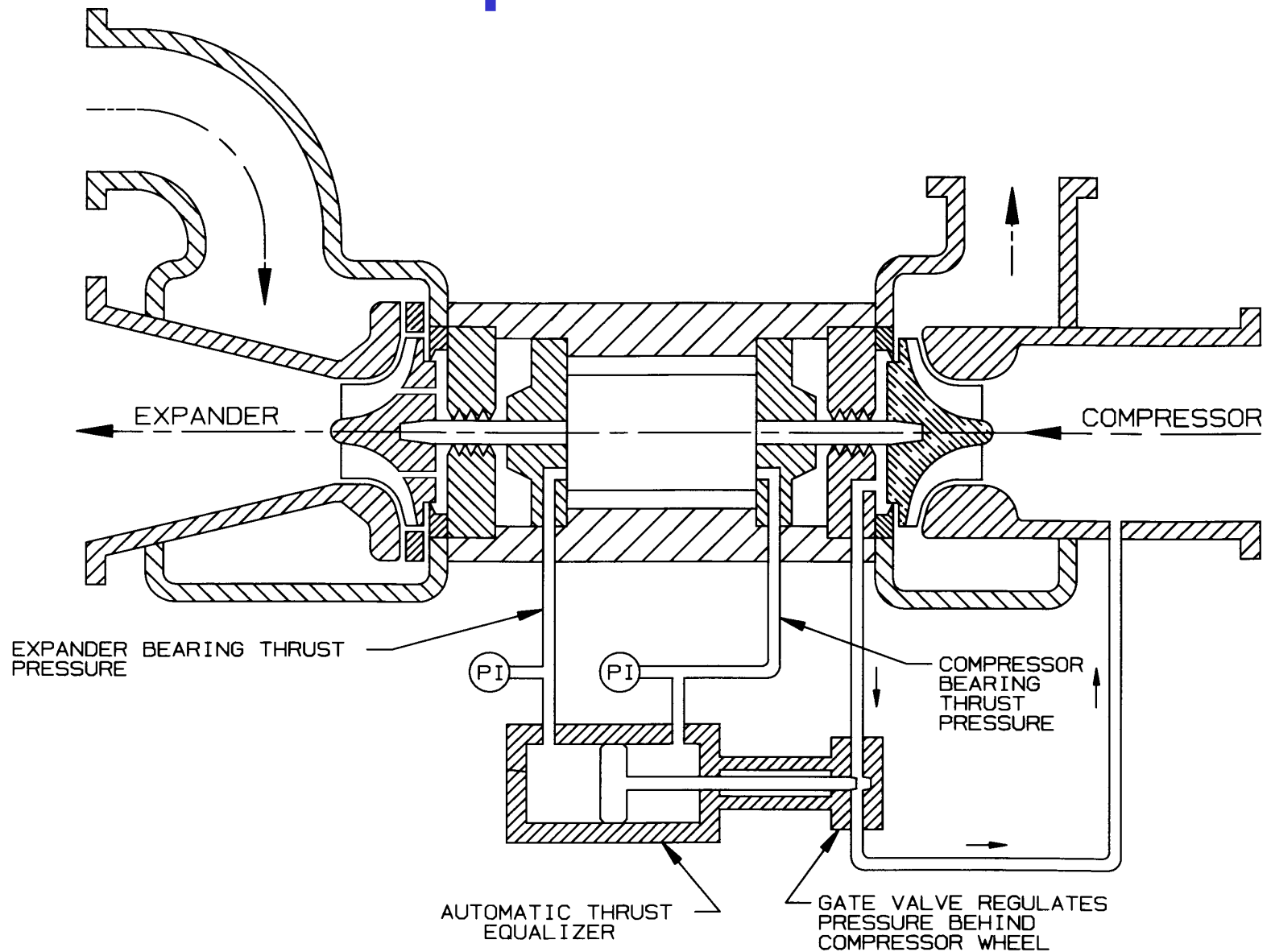
- Seal Gas: First On, Last Off
- Buffer gas required to separate process from lube oil
- Oil dilution considerations
- No loss of seal gas

Turboexpander Auxiliaries

Oil & Seal Gas Interaction

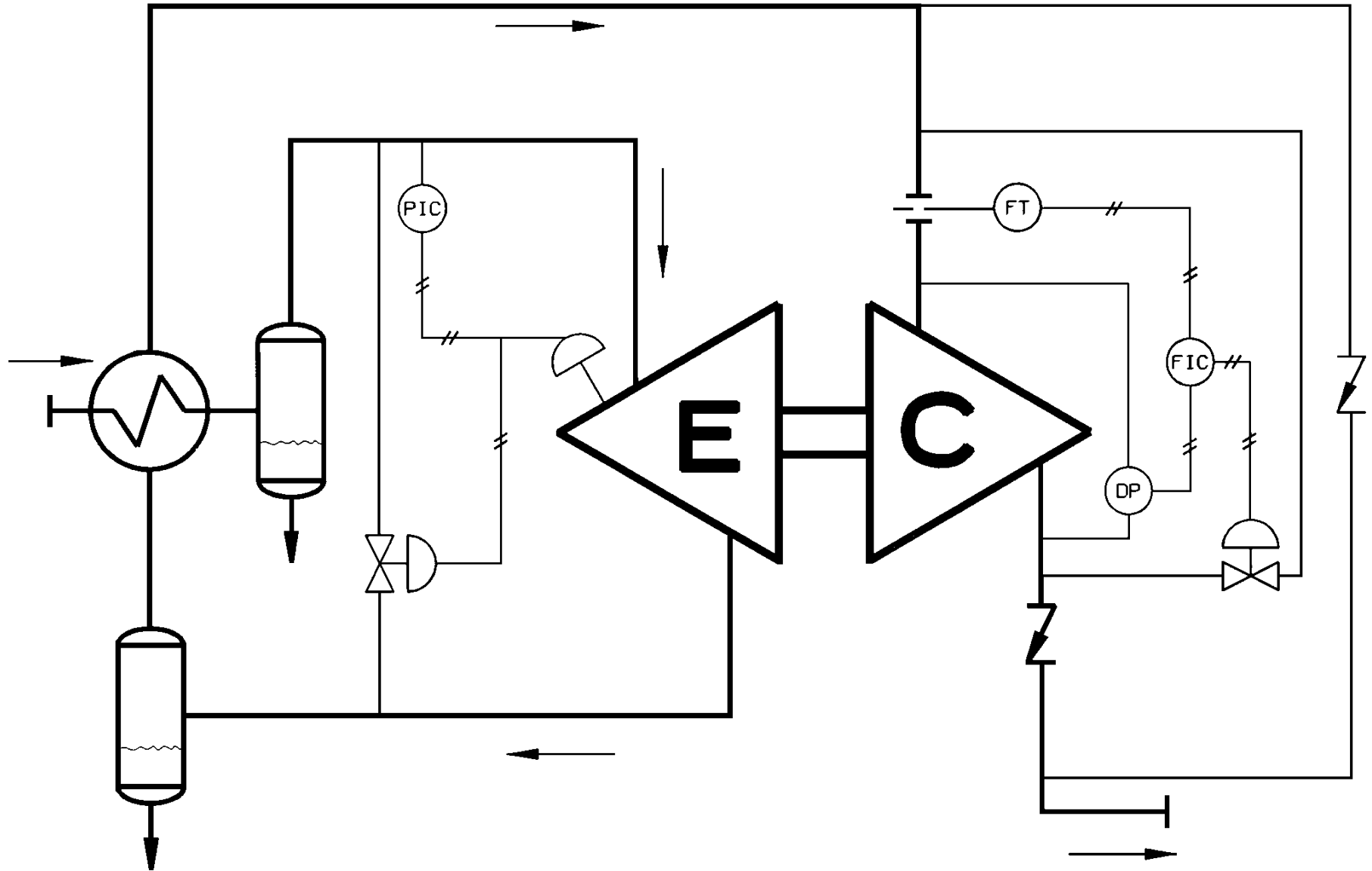


Turboexpander Auxiliaries



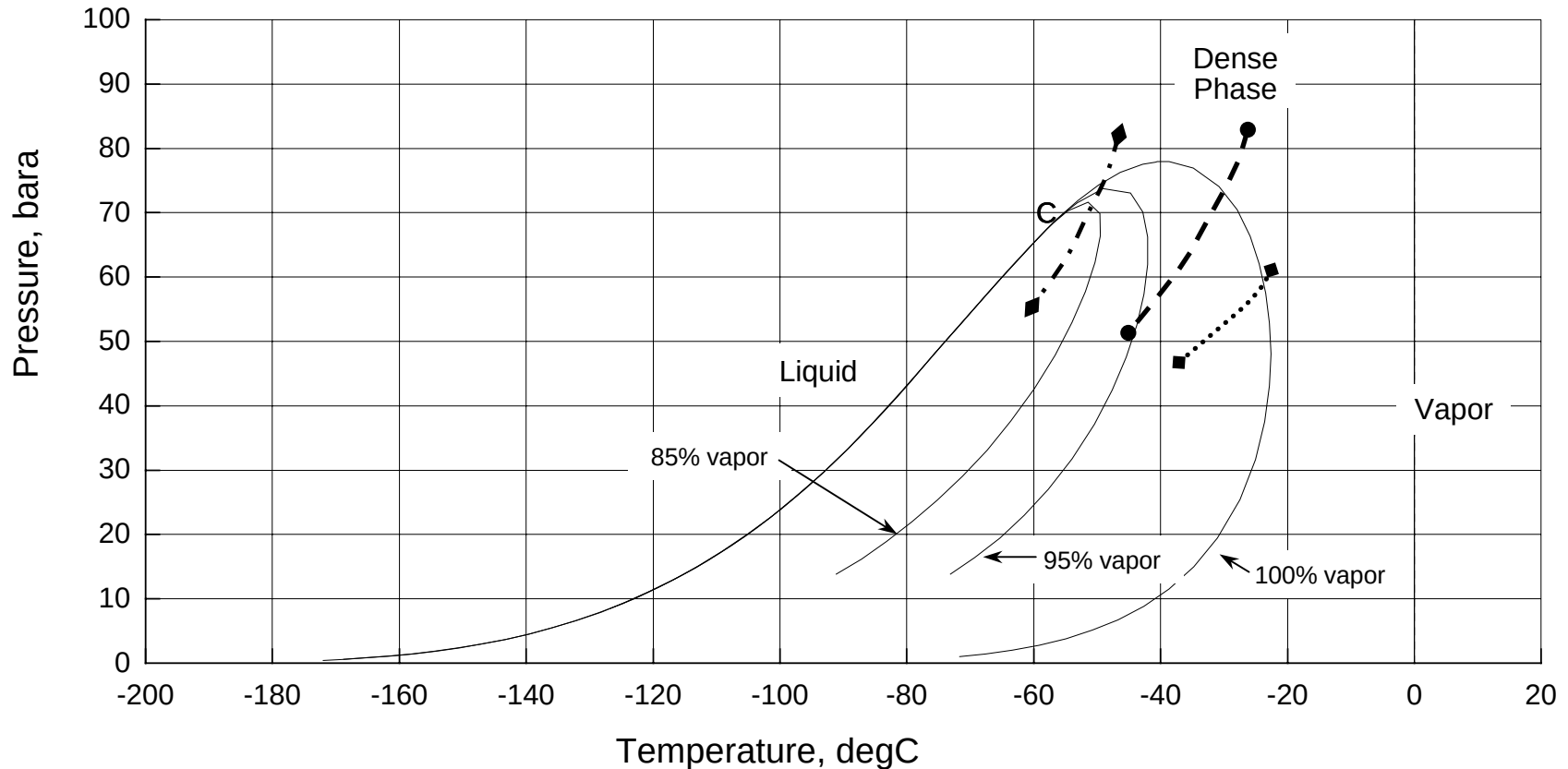
Automatic Thrust Equalizer System

Typical Turboexpander Process



Turboexpander/Compressor Operation

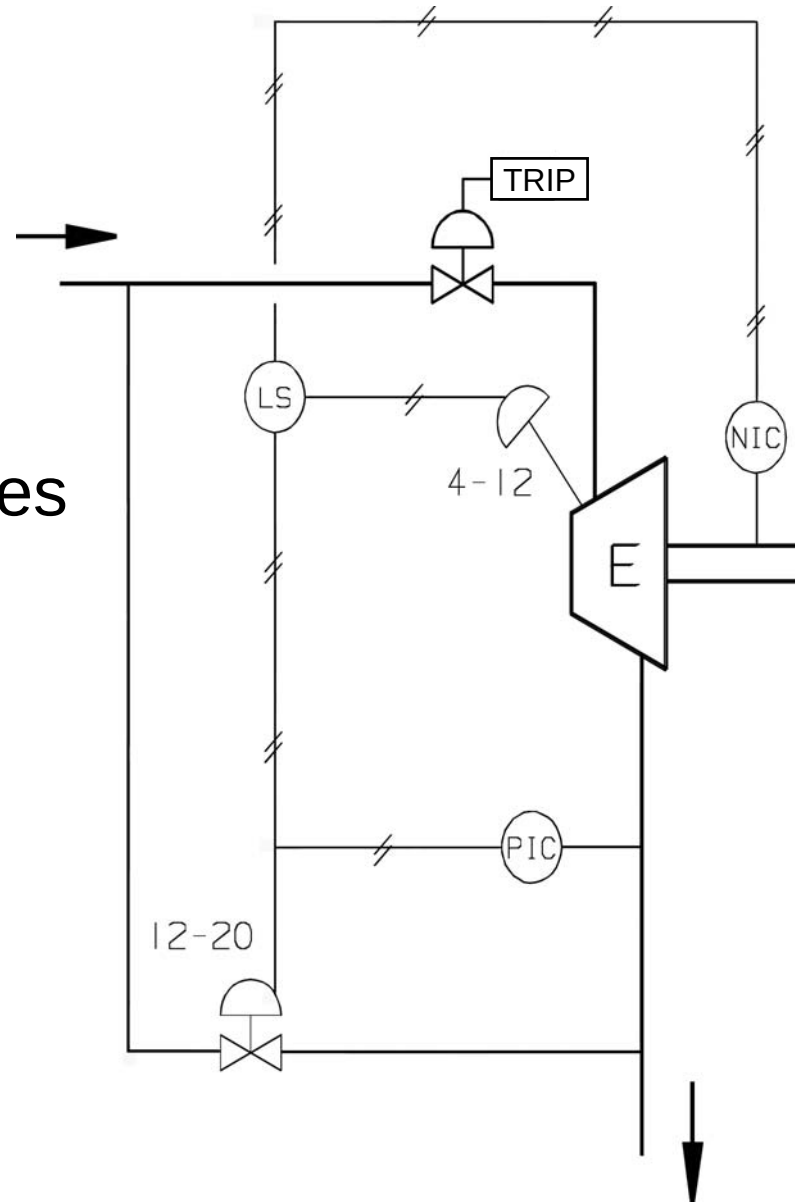
Typical Phase Envelope for Natural Gas



Turboexpander/Compressor Operation

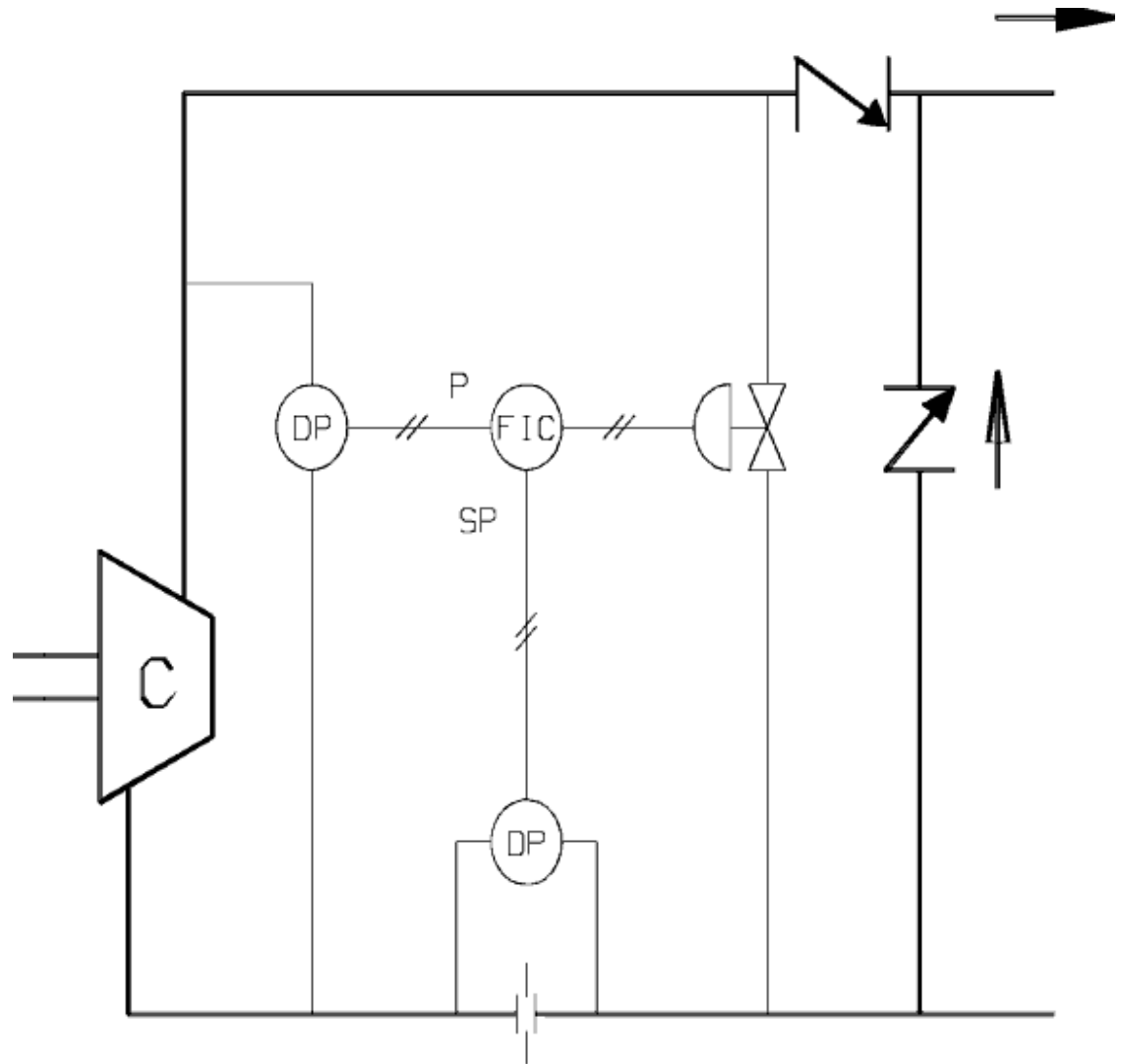
Expander Inlet Guide Vanes

- Split Range with J-T valve
- Speed Override (optional)

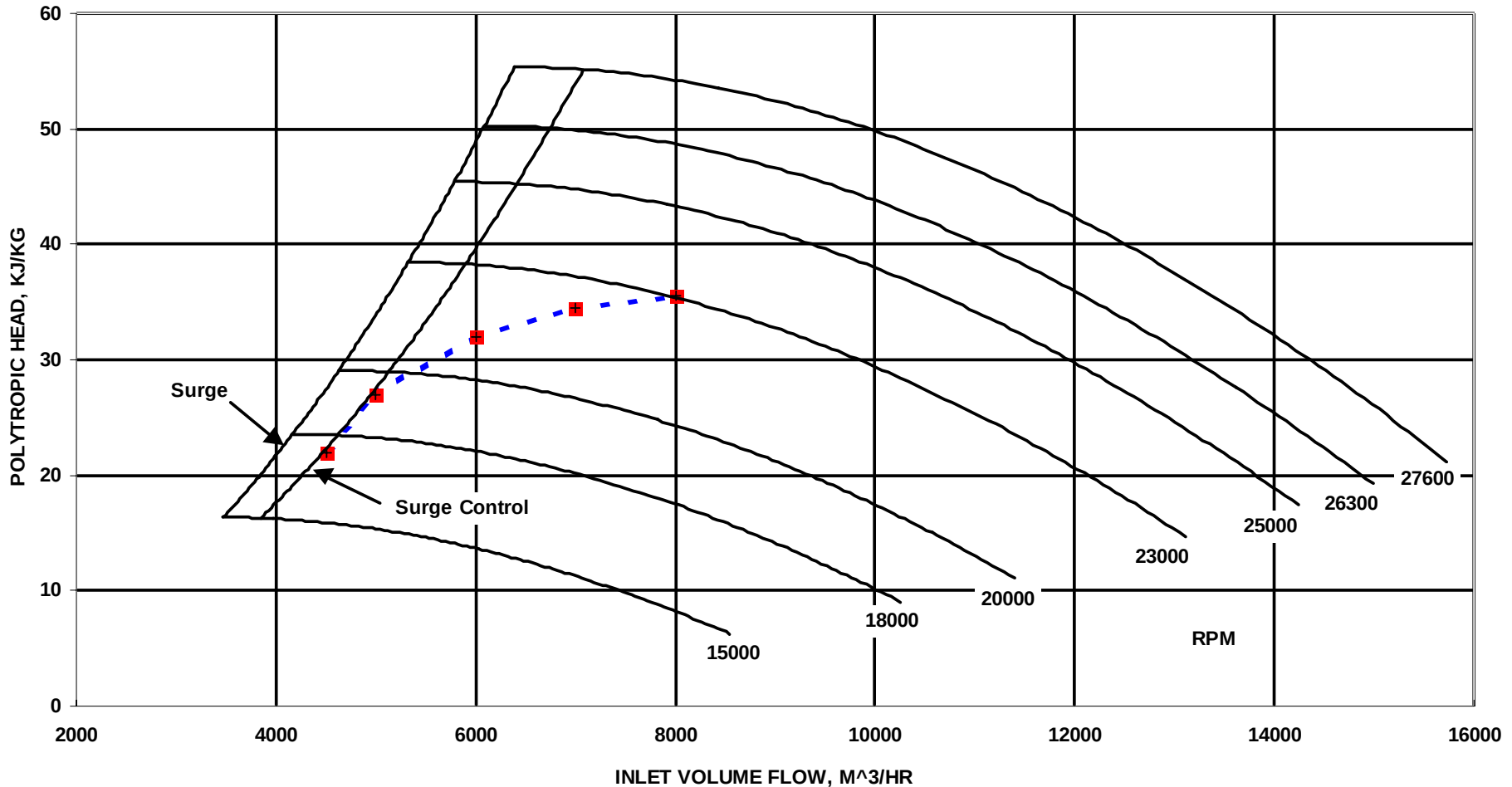


Turboexpander/Compressor Operation

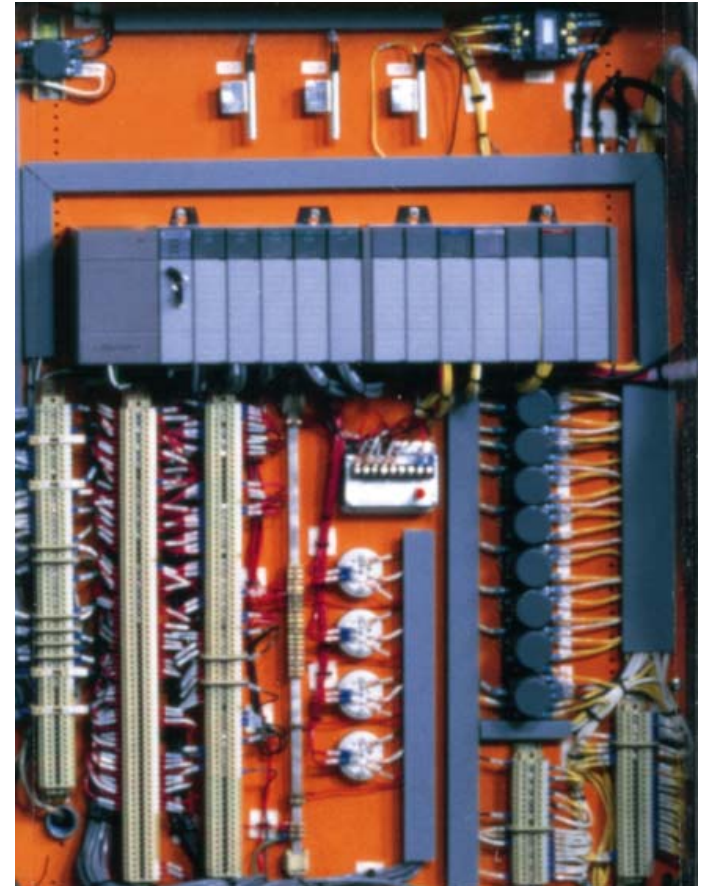
Surge Control
System



Typical Compressor Performance Map



Turboexpander Systems



Programmable Control & Instrumentation System (ProCIS)

Turboexpander Systems



Remote PLC panel with Video Display Unit

Turboexpander Factory Testing

Component

- Impeller overspeed
- Hydrotest Casings
- Shaft/Impeller balancing

System

- Lube Oil Functional
- Seal Gas Functional
- Instrumentation & Control Check

Turbomachinery

- Mechanical
- Performance
 - Expander
 - Compressor

Turboexpander Factory Testing

API 617 Mechanical Testing

- 4 hour run time @ MCS
- Slow roll
- 25% speed increments
- Trip speed verification



Turboexpander Factory Testing

ASME PTC-10 Class II Performance Testing

– Compressor

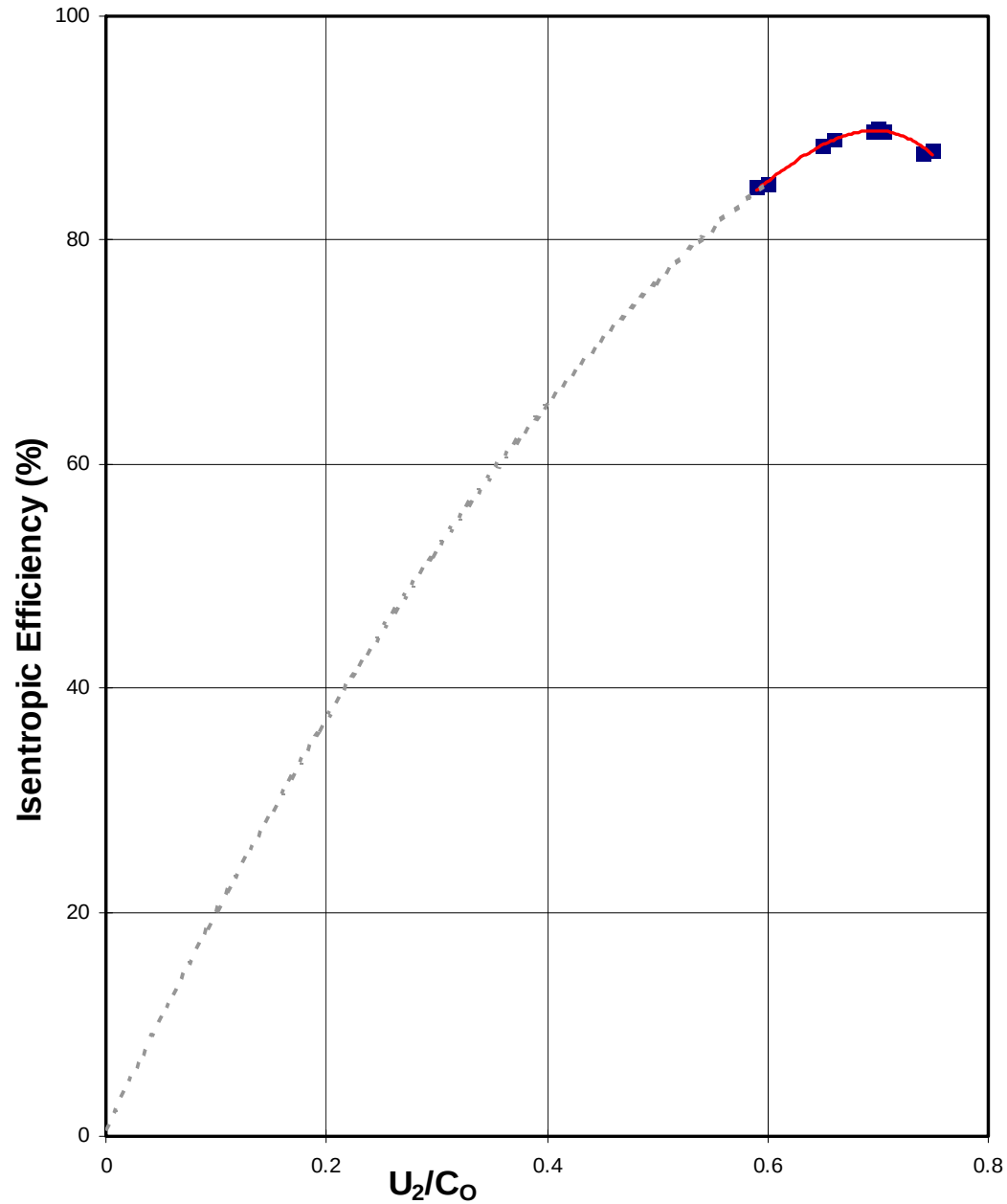
- Test on air
- Corrected speed
- Surge to stonewall

– Expander

- Test on air
- Range of u_2/c_0

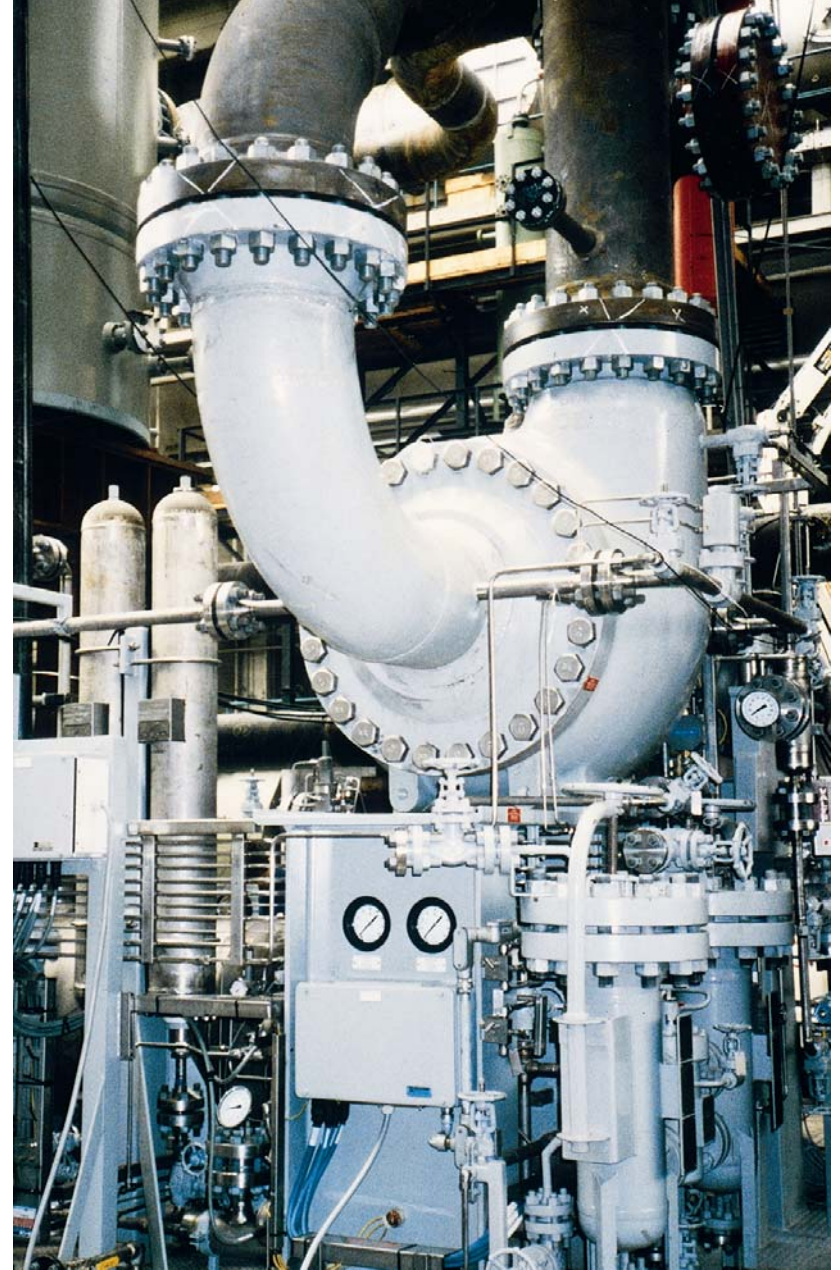


Typical Expander Performance Curve

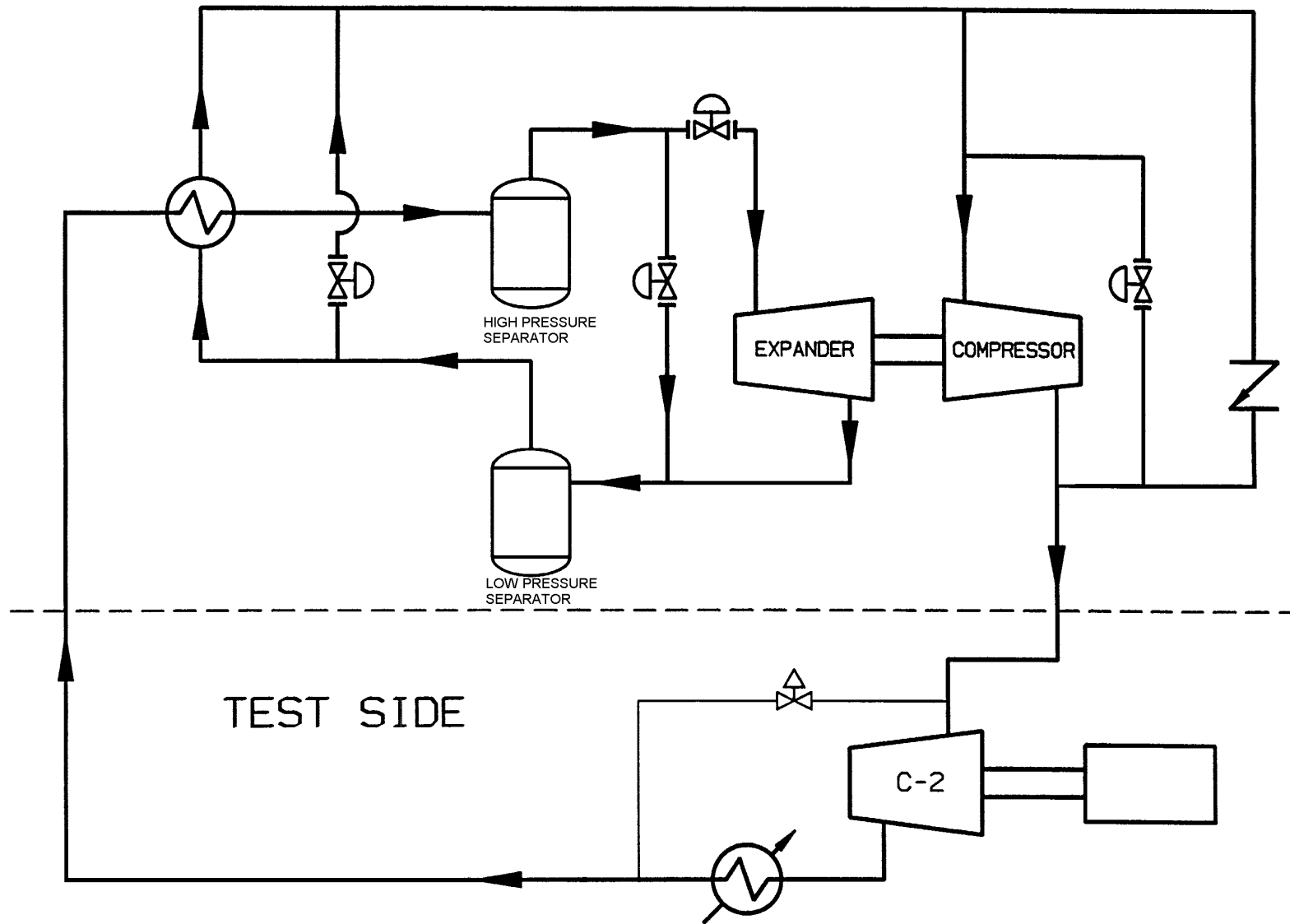


Full Power Full Pressure Testing

- Natural gas or inert gas
- Performed at indoor test facility in The Netherlands
- Test tailored to project requirements



Full Power Test Schematic



Magnetic Bearings

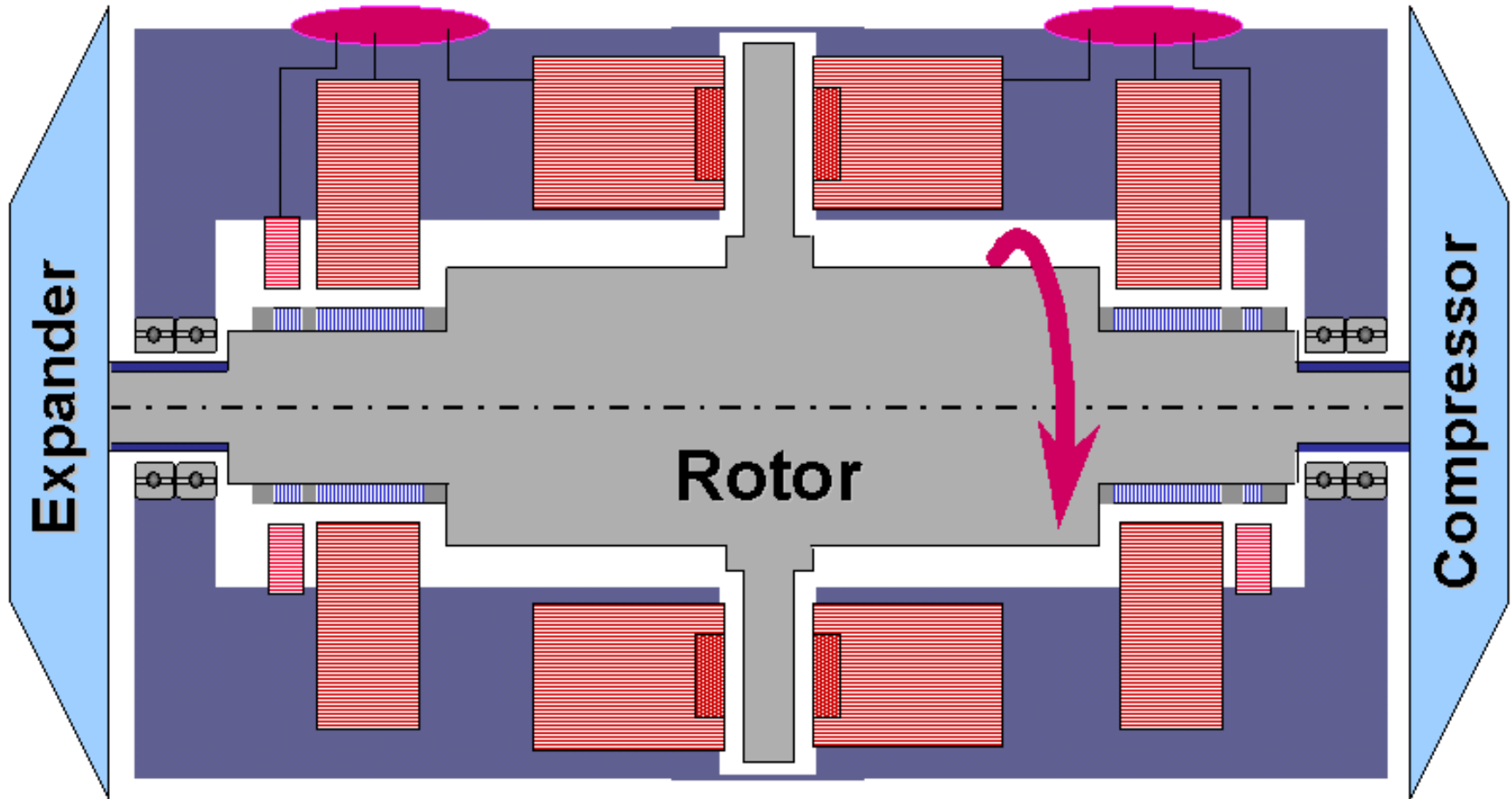


Magnetic bearing equipped EC3.5 in ethylene service

Magnetic Bearings

- Advantages
 - Eliminates oil
 - Low bearing losses
 - Smaller deck space
 - Lower weight
 - Reduced maintenance
 - Continuous monitoring of rotor parameters
- Ideal Applications
 - Ethylene Processes
 - Offshore Service
 - Environmentally sensitive locations
 - Life-Cycle Cost evaluated projects

Magnetic Bearings



Turboexpander Bearing Set

Electromagnets

i

i

Electromagnetic
Forces

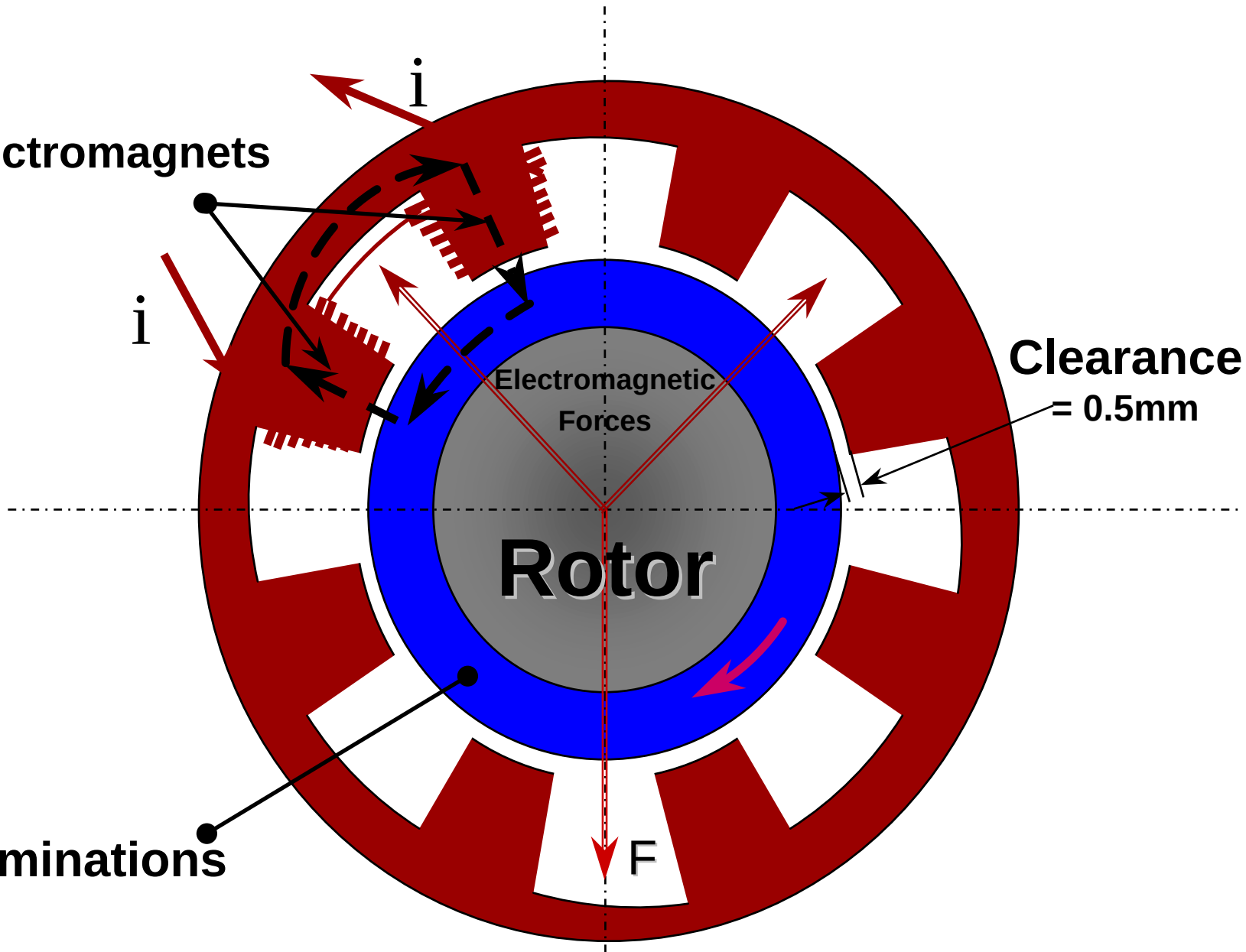
Clearance
= 0.5mm

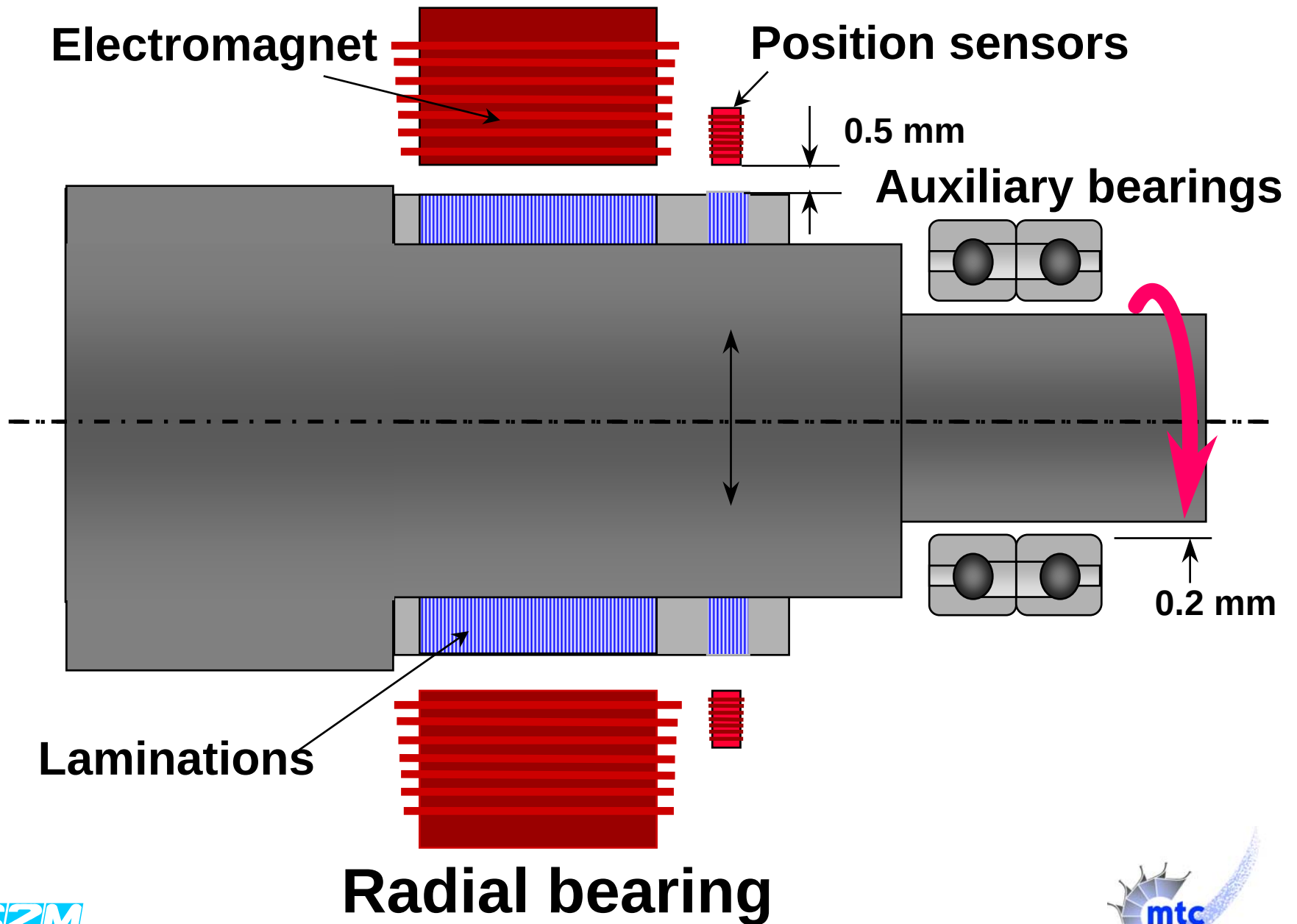
Rotor

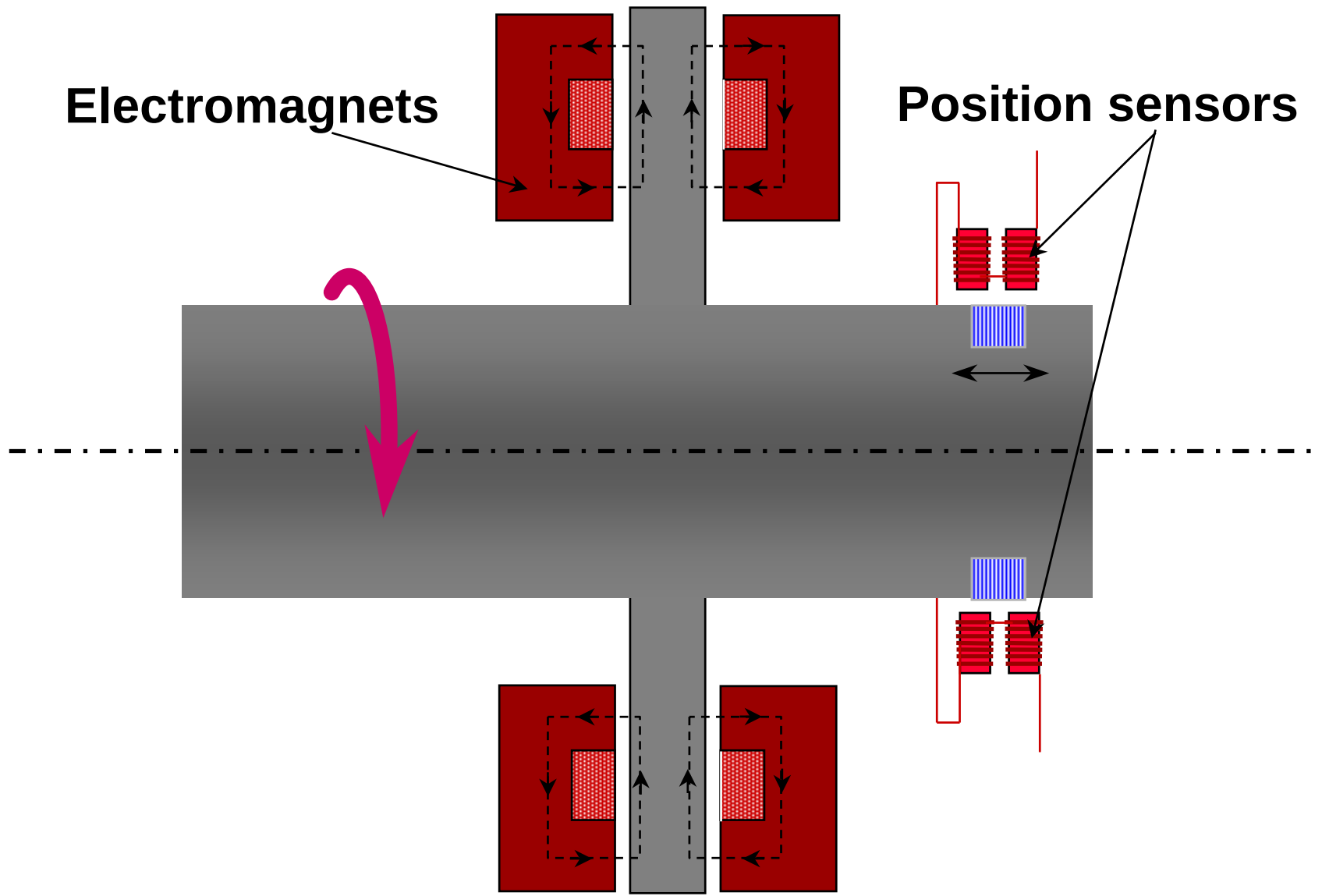
Laminations

F

Radial bearing





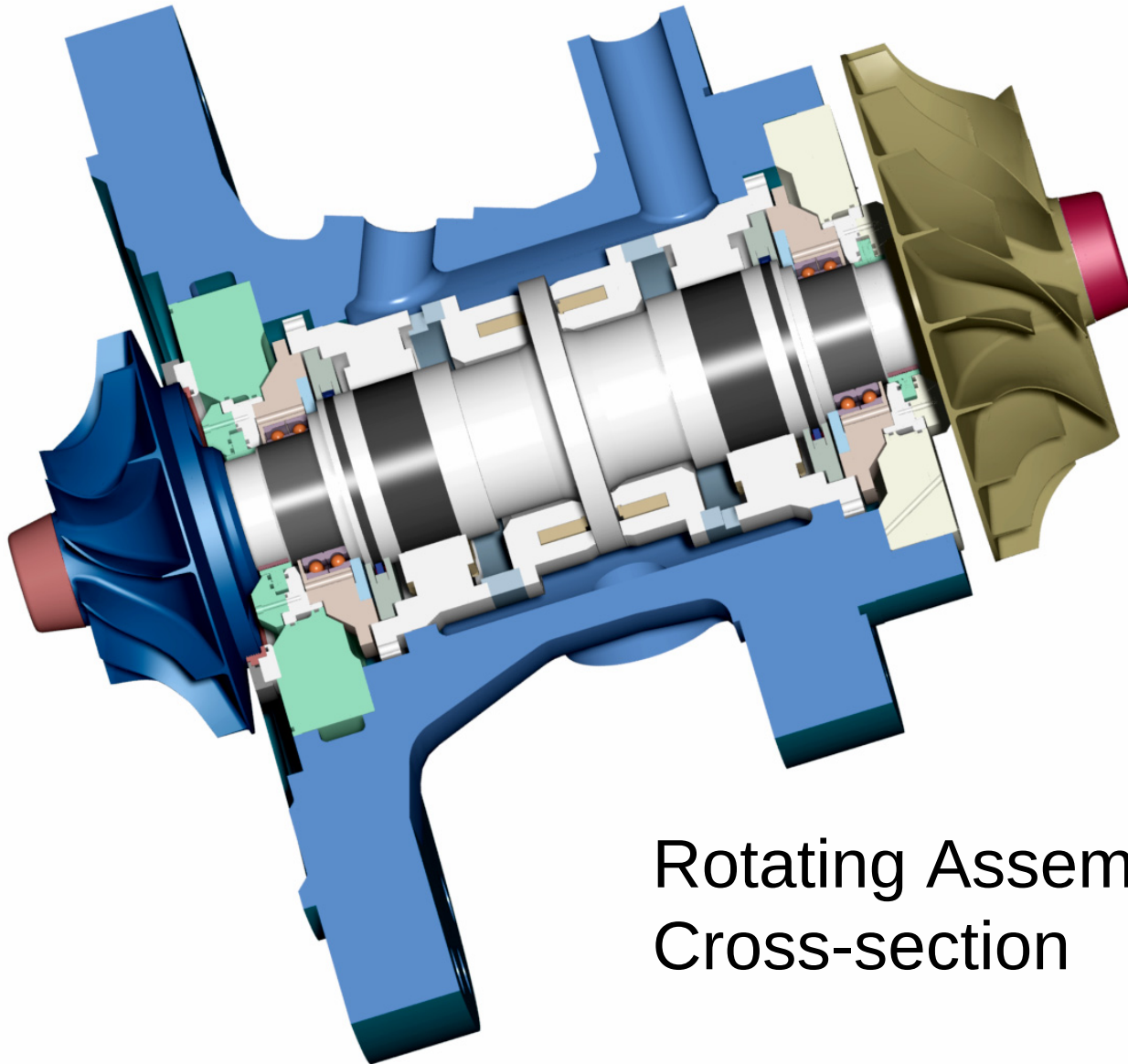


Electromagnets

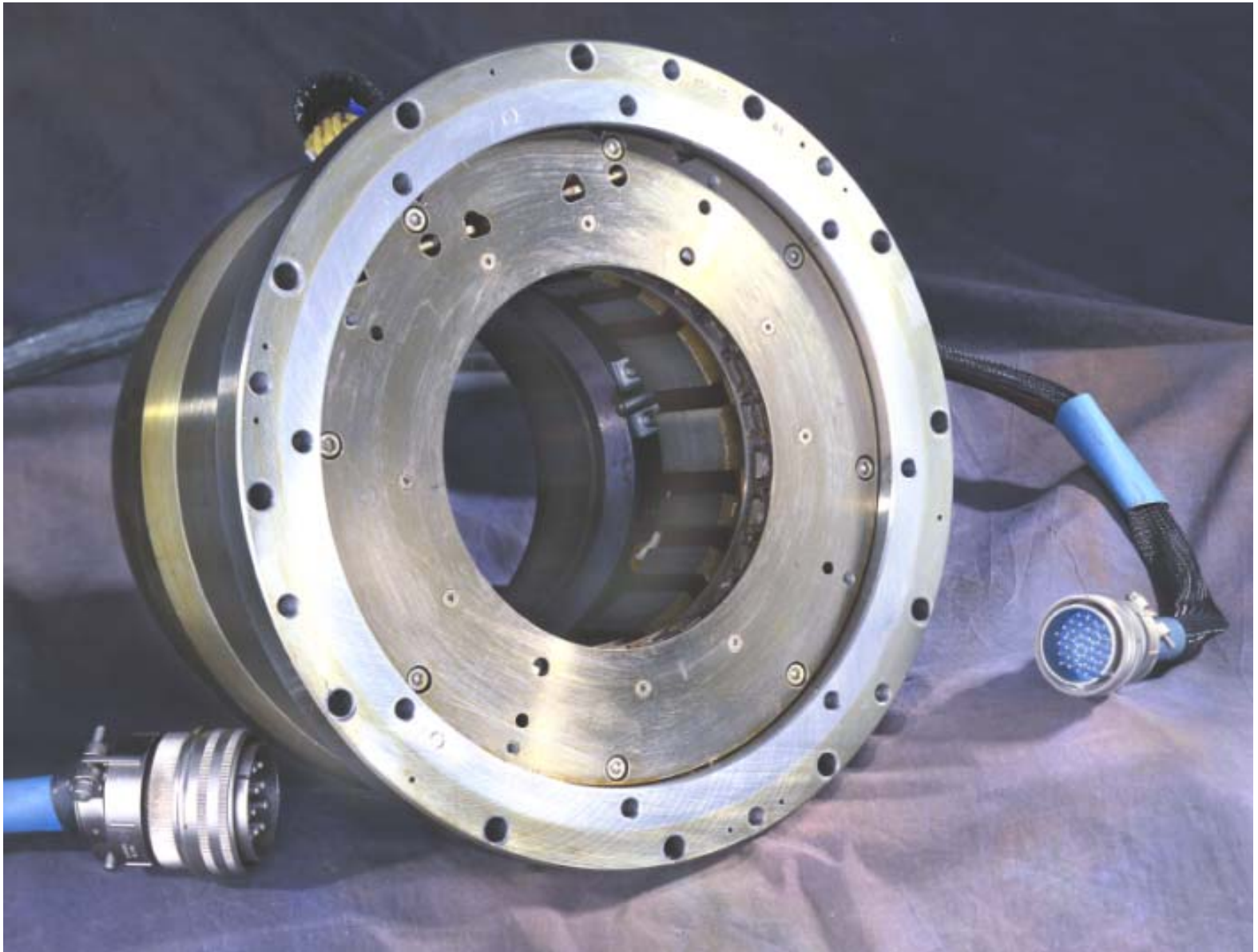
Position sensors

Axial bearing

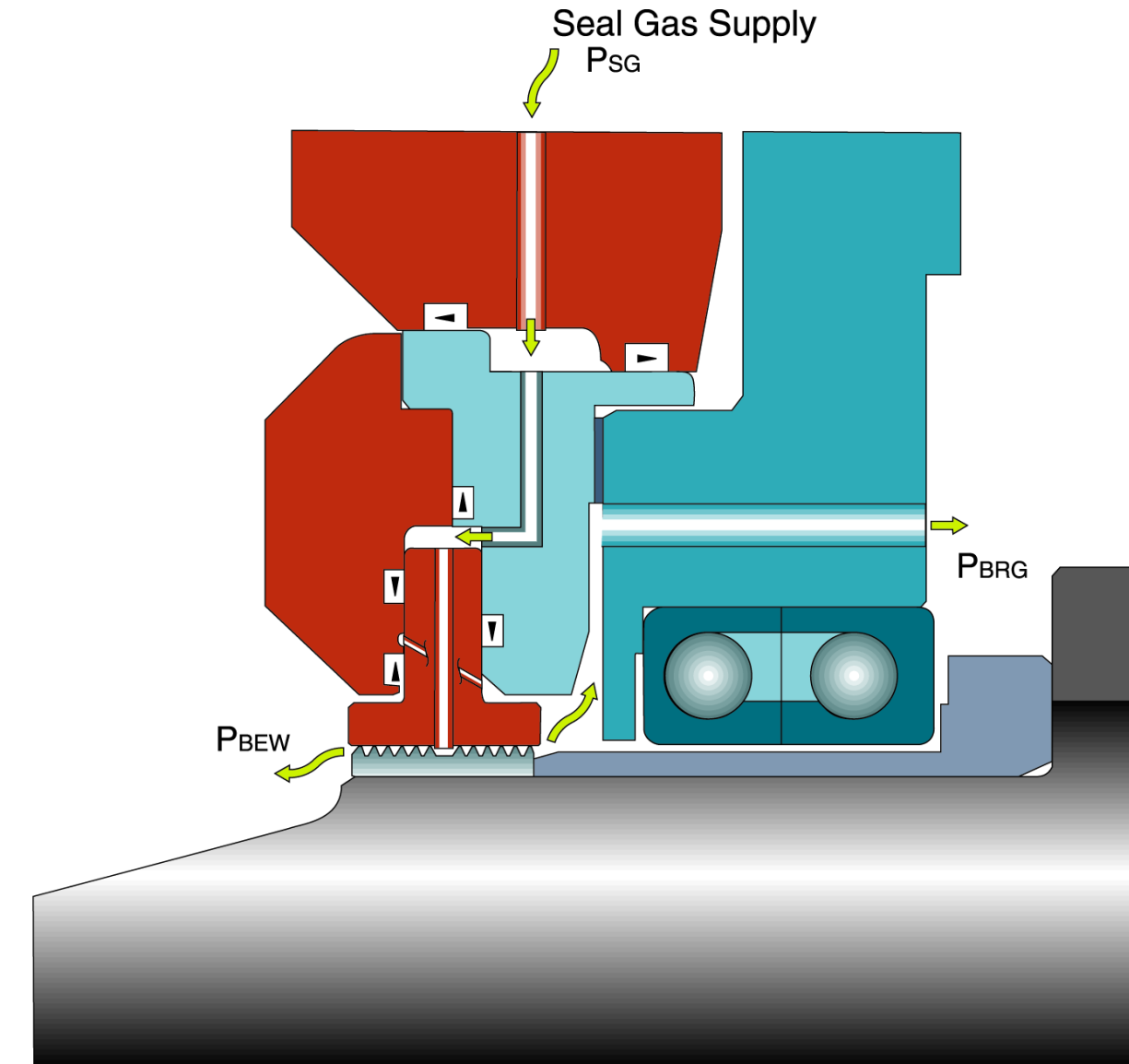
Magnetic Bearings



Rotating Assembly
Cross-section



Magnetic Bearing Floating Seal



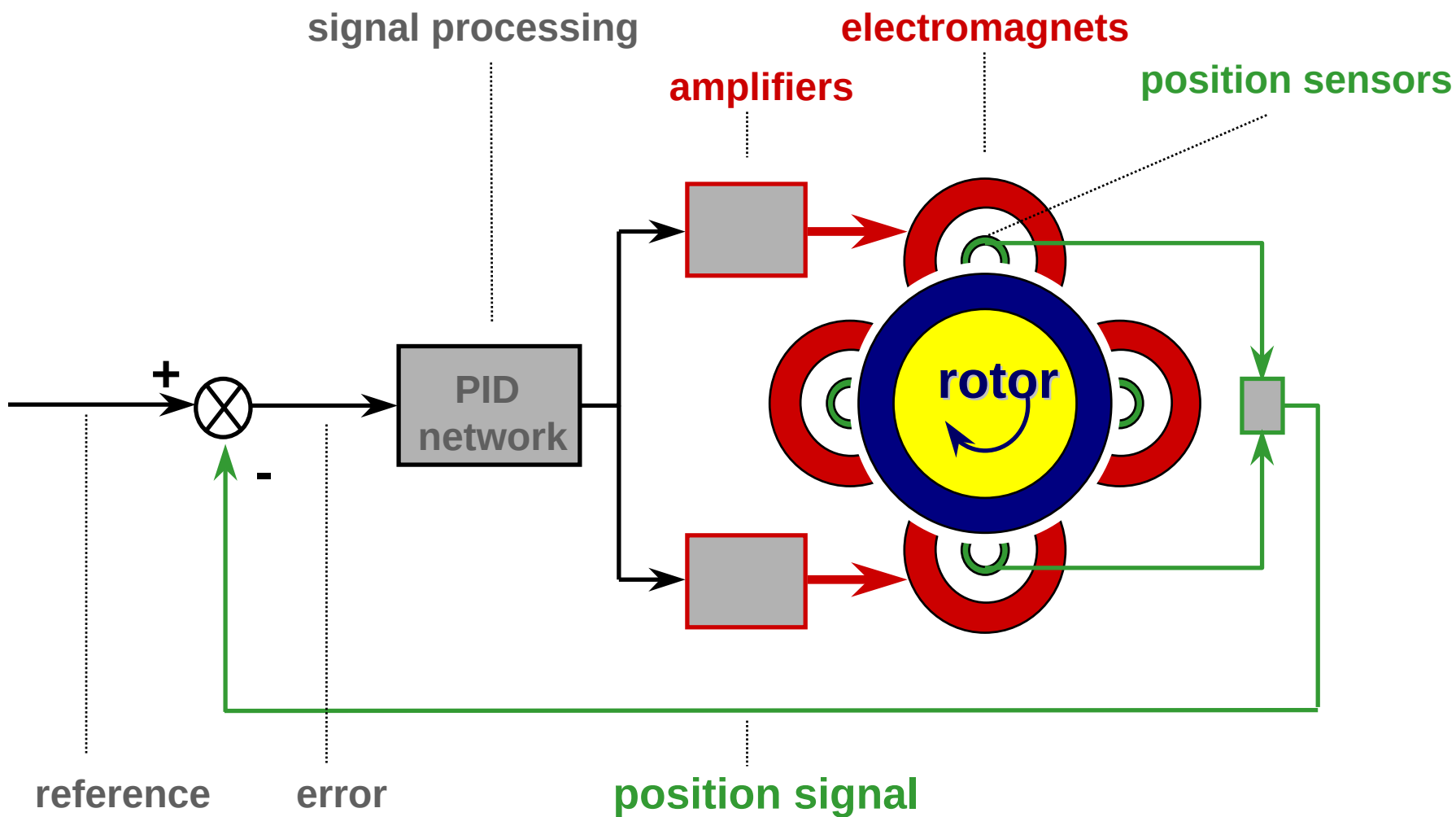


Auxiliary “Catcher” Bearing

Auxiliary Bearing Design

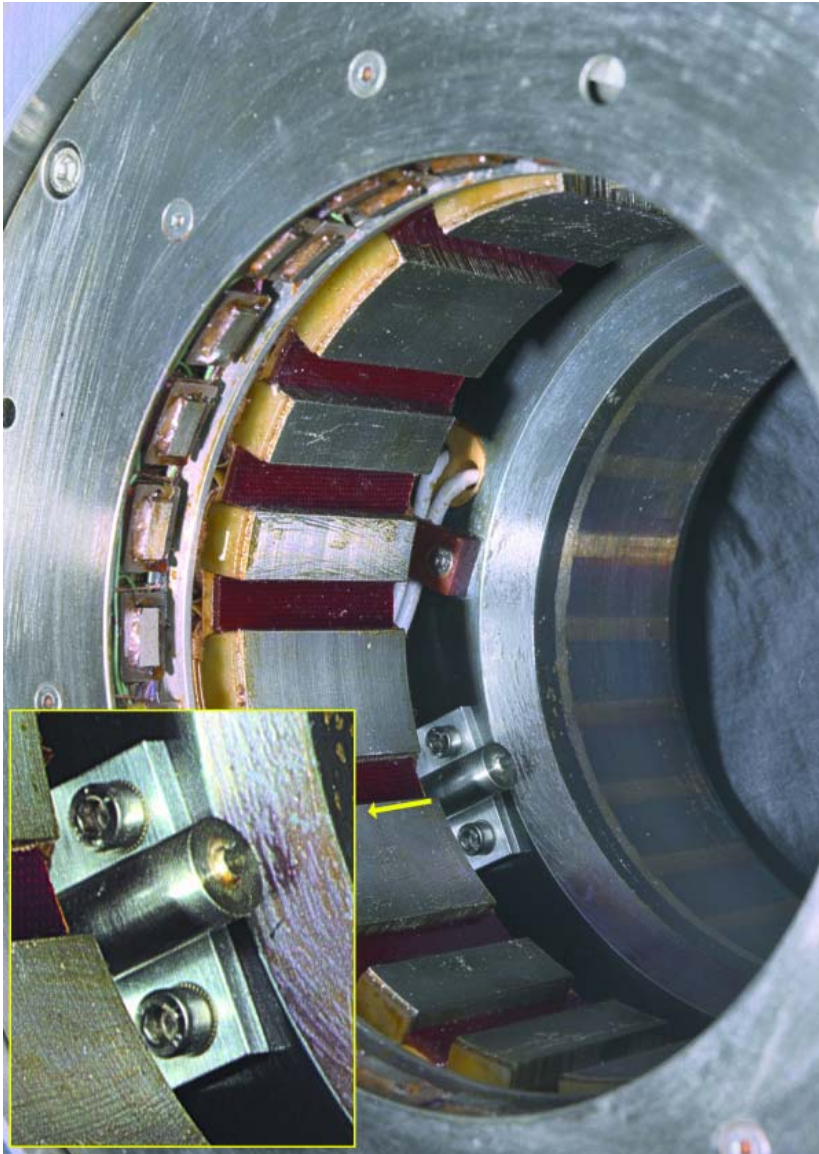


- Double angular contact
- Sized based on speed and diameter
- Ceramic Balls selected for maximum DN
- Borrelli Ribbon provides damping capability

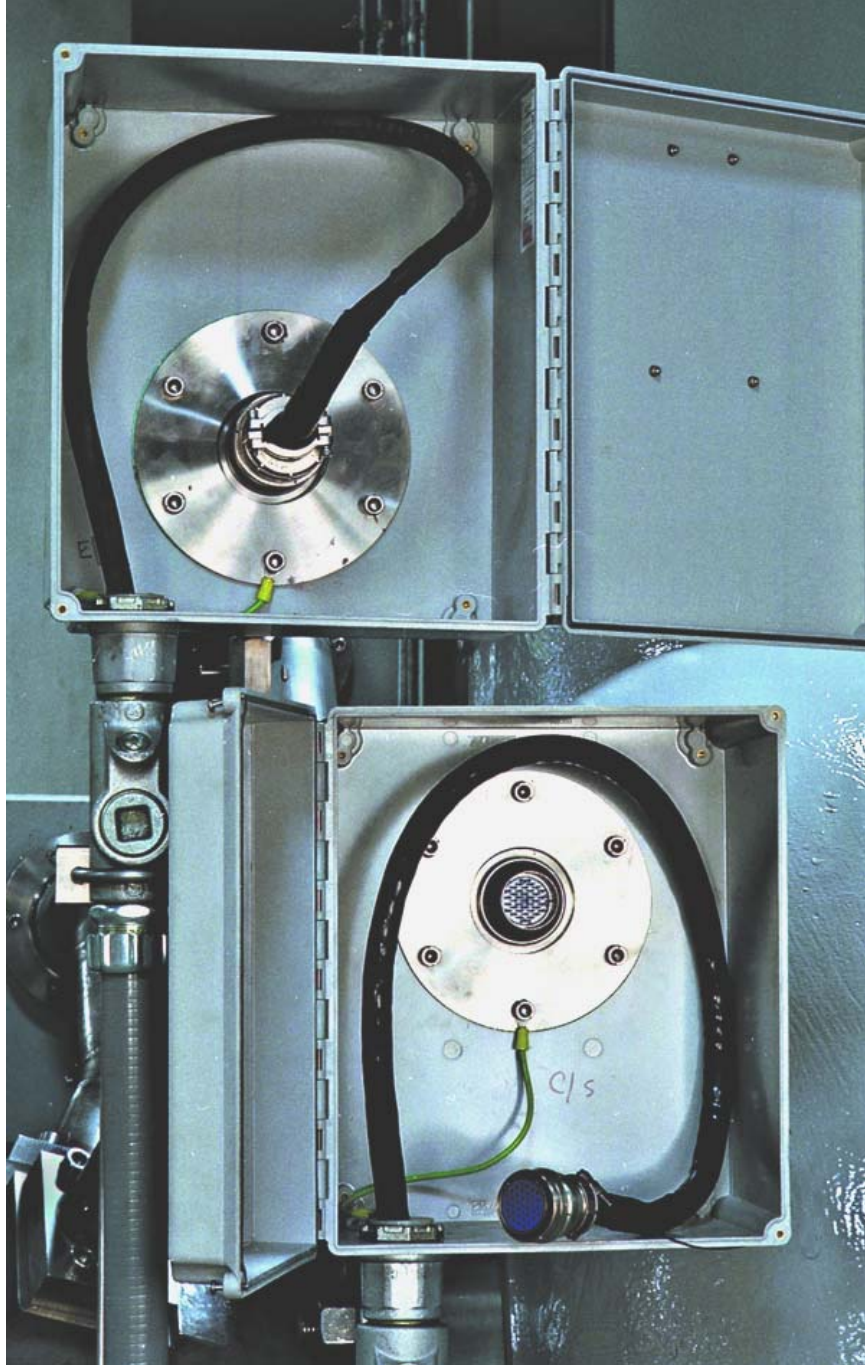


Control Loop

Magnetic Bearing Instrumentation

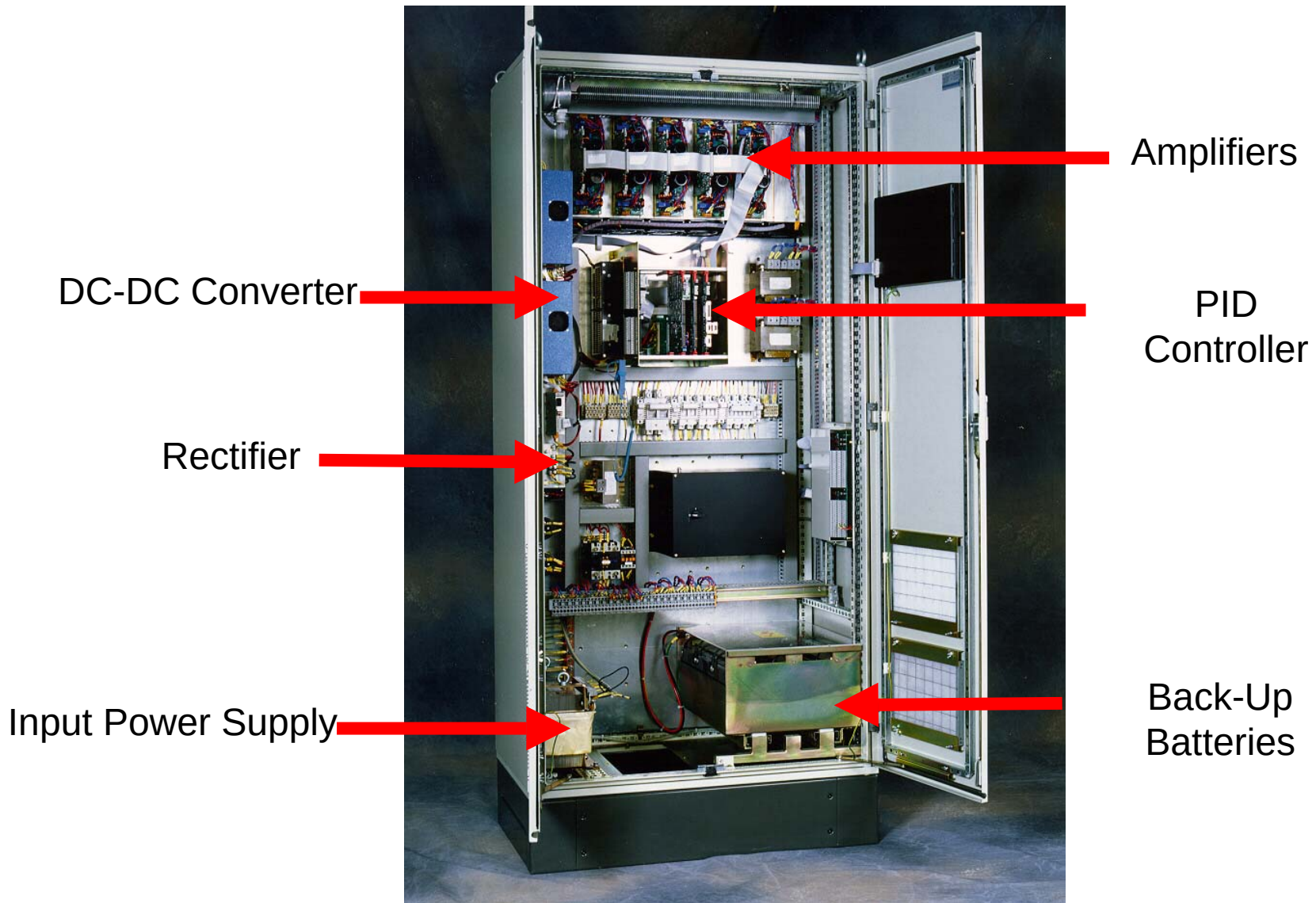


- Position Sensors: Functionally replaces radial vibration probes and axial position probes
- RTD's: Single Element, 2 per bearing
- Speed Probes: Up to 4 per machine can be supplied



Cable Pass-Thrus

- Provides 100% seal from pressurized housing
- Rated to 103 BarA
- Mounted in local junction box



Magnetic Bearing Control Cabinet

Magnetic Bearings

- Summary of data available from controller
 - Rotor position
 - Bearing temperature
 - Rotor speed
 - Vibration
 - Landing counter
 - Back-up battery condition
 - Individual current levels per amplifier

Alarms

09/10/97 15:40:53

Suspension **ON** Local/Remote **LOC** Suspension mode **ON** ABS **OFF** Battery test **OFF**

Rotation **OFF** Waiting **OFF** Rotation mode **OFF** Events **32** Battery test inhibition **ON**

S2M

Alarm Level 1	L2	Air pressure failure	Excess of current W2	Current V1	4.2 A	Current V3	4.2 A
Alarm Level 2		Water flow failure	Excess of current W3	Current V2	4.2 A	Current V4	4.2 A
Alarm Level 3		Speed sensor failure	Excess of current W4	Current W1	4.2 A	Current W3	4.2 A
AMB Common Trip		Top DSP speed failure	Excess of current Z1A	Current W2	4.2 A	Current W4	4.2 A
Events list half full		PLL DSP speed failure	Excess of current Z2A	Current Z1A	4.2 A	Current Z1B	0 A
Events list full		Extension rotor	Excess of current Z1B	Current Z2A	4.2 A	Current Z2B	0 A
DSP initialisation failure		Overspeed	Excess of current Z2B	Battery Voltage	72 V	Primary Cur 1	4 A
DSP 1 board failure		Power HV < mini	Surge failure V	Rectify Voltage	85 V	Primary Cur 2	4 A
DSP 2 board failure		Power HV > max	Surge failure W	TH AMP1	14 °C	TH AMP4	14 °C
DSP communication failure		Batt 1 Mod 1 cnx fail	Surge failure V24	TH AMP2	14 °C	TH AMP5	14 °C
Configuration default	L2	End of battery capacity	Surge failure W24	TH AMP3	14 °C	TH AMP6	14 °C
Temperature PT1 Input	L1	Battery 1 in use Mod 1	Surge failure Z	TH PT1	28 °C	TH PT3	28 °C
Temperature PT2 Input		Mains fuse failure	L2 Process Trip	TH PT2	28 °C	TH PT4	28 °C
Temperature PT3 Input		Amplifier failure V1	Position Sensor failure	Time Counter	22 H	Landing Cbr	24
Temperature PT4 Input		Amplifier failure V2	Battery 2 in use Mod 1	Speed	0 Rpm	ROT Extension	0 µm
Excess of temperature Mod		Amplifier failure V3	Battery 1 in use Mod 2	Position V1	3 µm	Unbalance V13	0 µm
Excess of position V		Amplifier failure V4	Battery 2 in use Mod 2	Position W1	5 µm	Unbalance W13	0 µm
Excess of position W		Amplifier failure W1	Speed too low	Position V2	4 µm	Unbalance V24	0 µm
Excess of position V24		Amplifier failure W2	BAT2 MOD1 cnx fail	Position W2	5 µm	Unbalance W24	0 µm
Excess of position W24		Amplifier failure W3	BAT1 MOD2 cnx fail	Position Z1	4 µm	Unbalance Z12	0 µm
Excess of position Z		Amplifier failure W4	BAT2 MOD2 cnx fail				
Excess of unbalance V		Amplifier failure Z1A	Battery test failure				
Excess of unbalance W		Amplifier failure Z2A					
Excess of unbalance V24		Amplifier failure Z1B					
Excess of unbalance W24		Amplifier failure Z2B					
Excess of unbalance Z		Excess of current V1					
L2 Cables not connected		Excess of current V2					
H.V. failure 300v		Excess of current V3					
Insulation failure		Excess of current V4					
Oscillator failure		Excess of current W1					

16:59:04

09/10/97

Alarm level 2

Landing counter

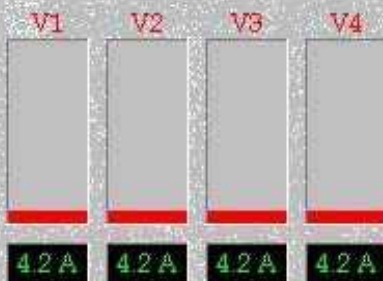
24

Number of events

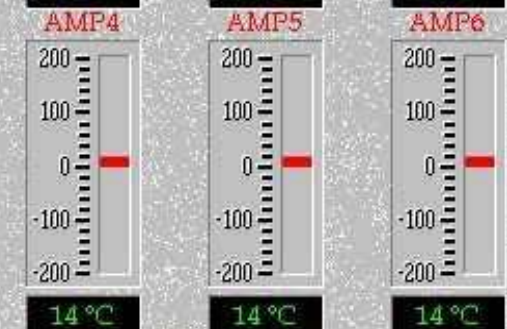
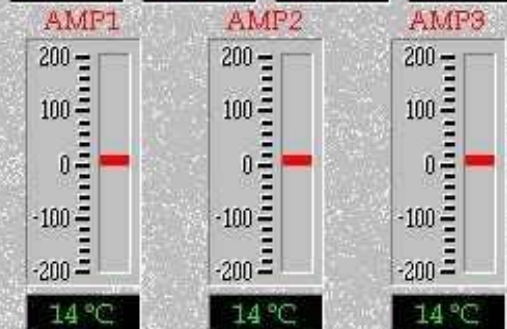
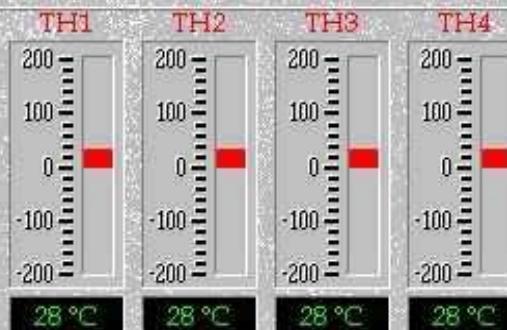
32



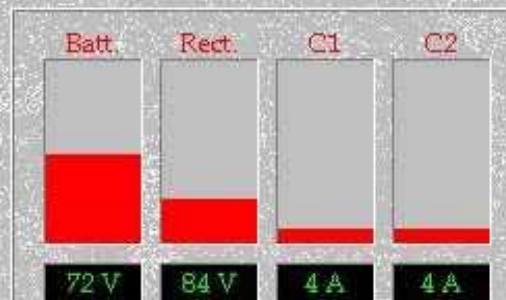
S2M



Currents



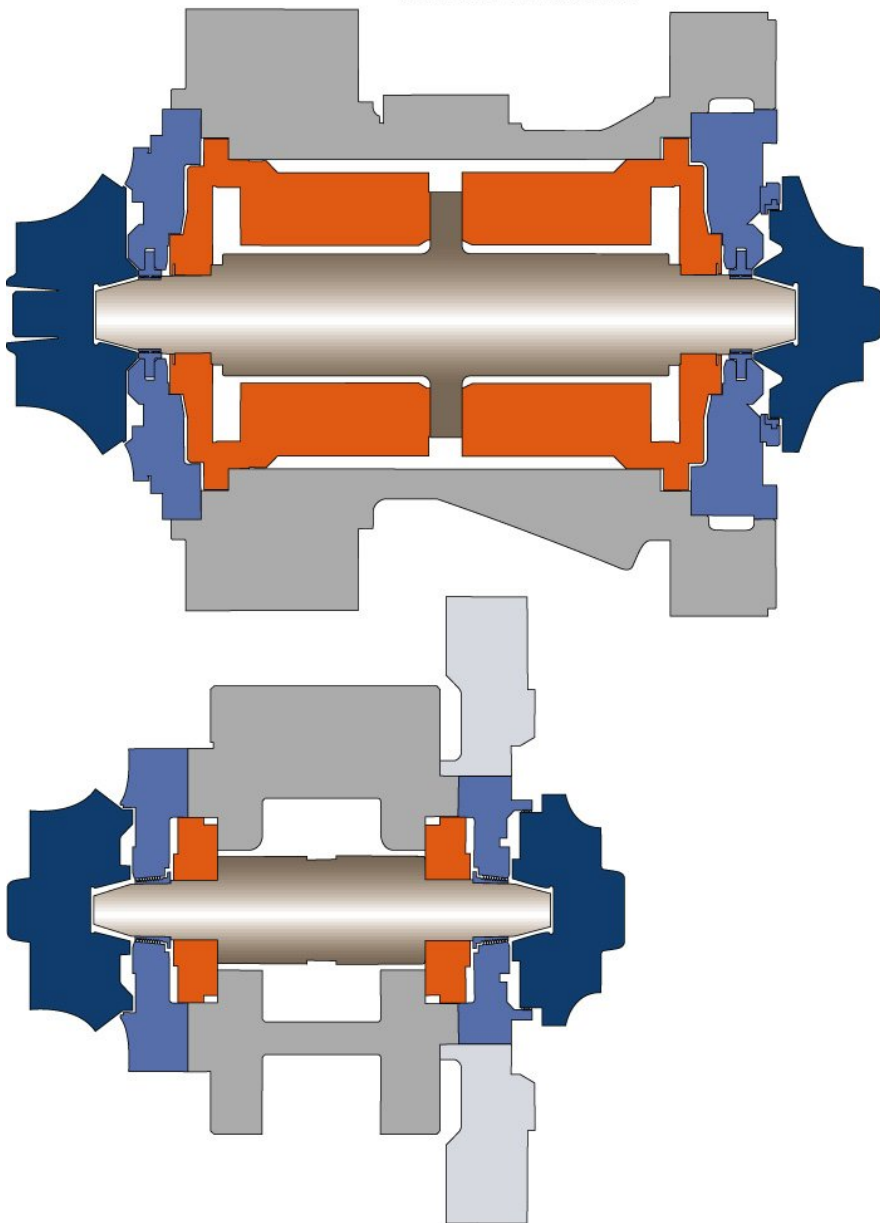
Temperatures



Time counter

23

OIL BEARING EXPANDER & MAGNETIC BEARING EXPANDER COMPARISONS



TYPICAL FRAME 3 PARAMETERS

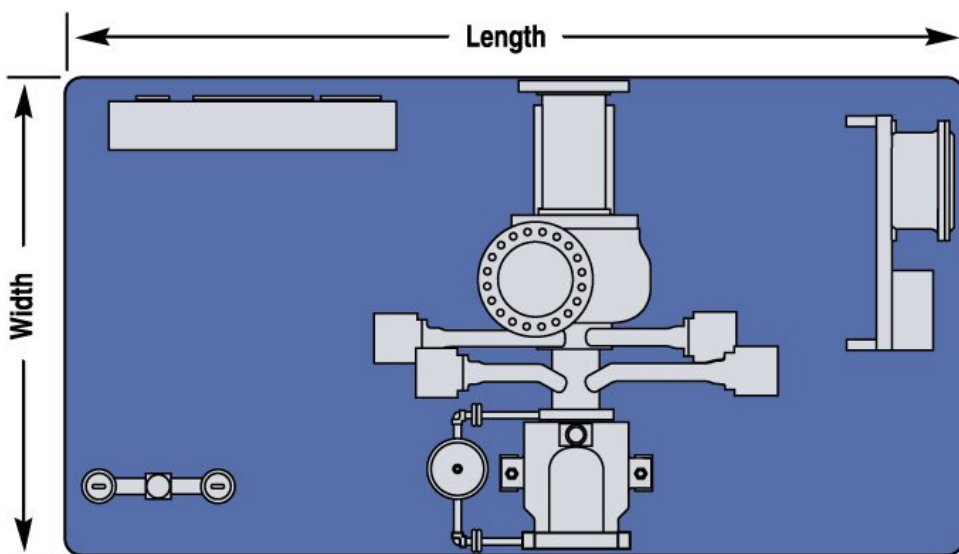
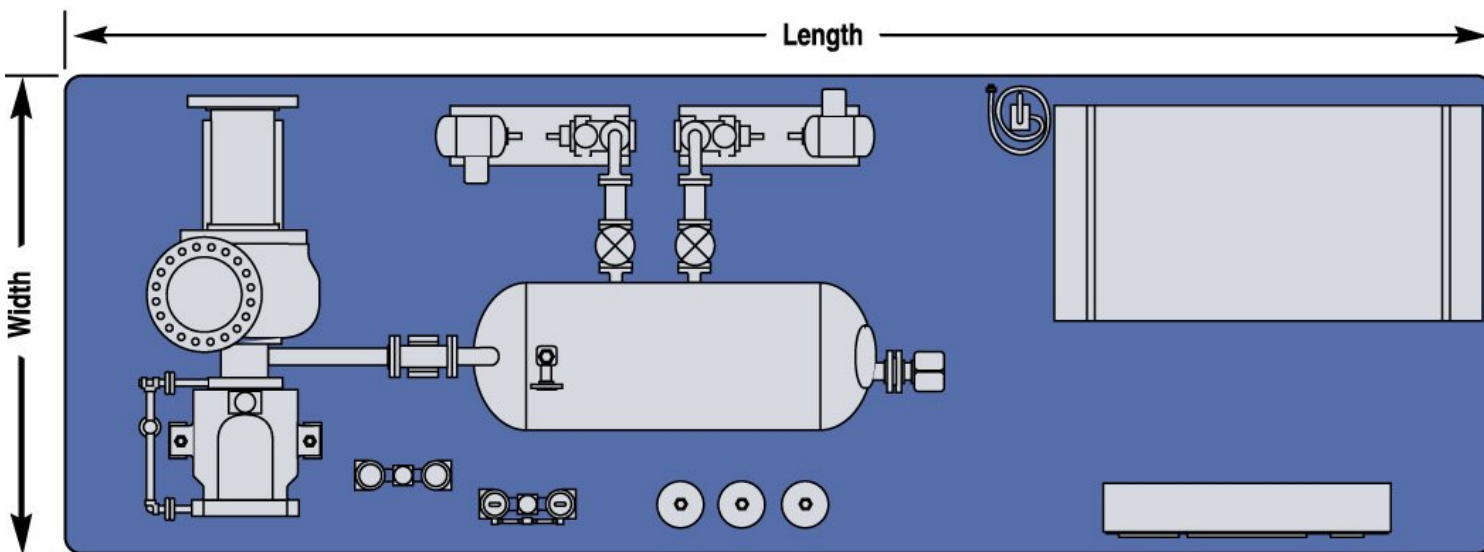
OIL BEARING EXPANDER

MAG. BEARING EXPANDER

Journal Diameter	2 in. (51mm)	4.3 in. (110 mm)
Rotor Weight	33 lb. (15kg)	104 lb. (47 kg)
Shaft Length	16 in. (400 mm)	25 in. (630 mm)
Thrust Area	7 in. ² (45 cm ²)	44 in. ² (280 cm ²)
Spare Rotating Assy. Wt.	650 lb. (300 kg)	2000 lb. (900 kg)

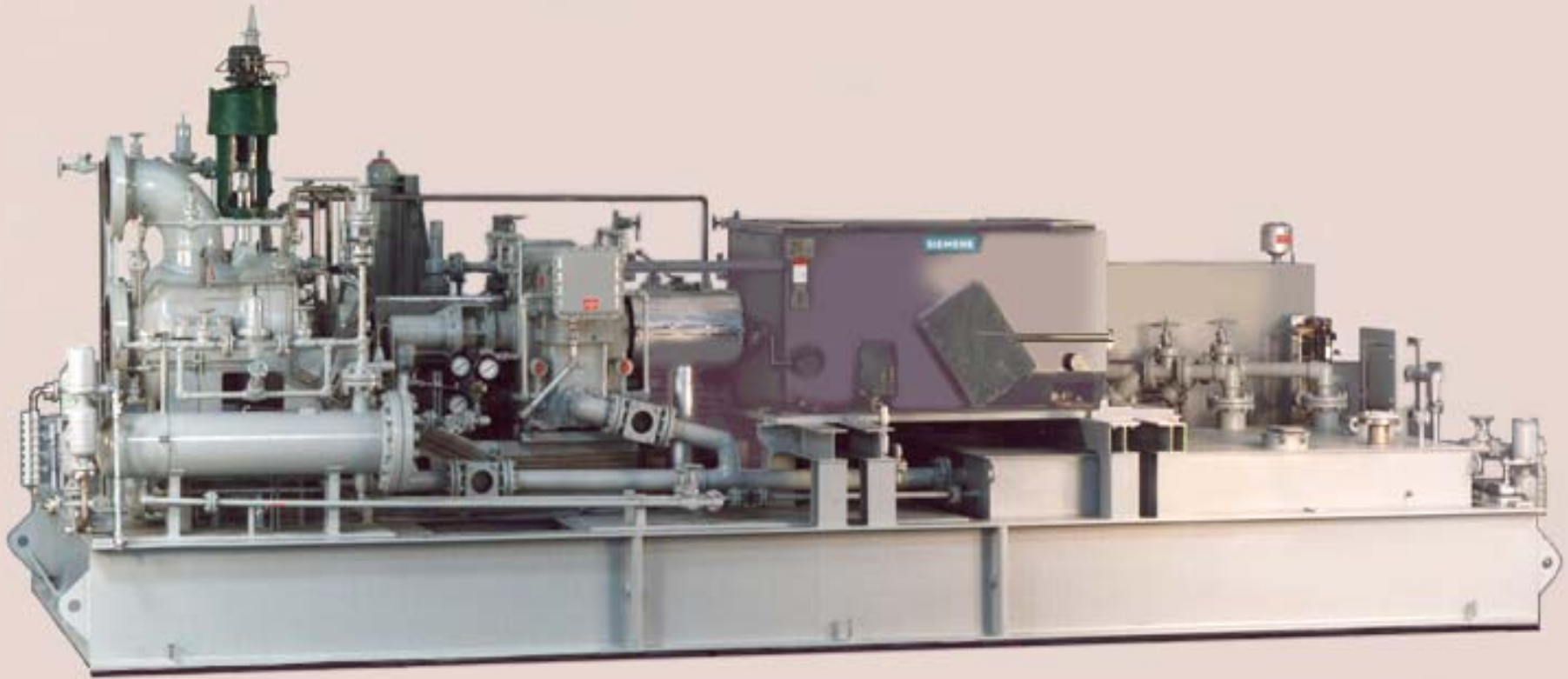
*Note: Data is for comparison of magnitudes.
Actual design values will vary.*

OIL BEARING & MAGNETIC BEARING EXPANDER SKID COMPARISONS



TYPICAL FRAME 3 PARAMETERS	OIL BEARING EXPANDER SKID	MAG. BEARING EXPANDER SKID
Length	24 ft. (7.4 m)	15 ft. (4.6 m)
Width	8 ft. (2.4 m)	8 ft. (2.4 m)
Weight	25,000 lb. (11,340 kg)	16,500 lb. (7500 kg)
<i>Note: Data is for comparison of magnitudes. Actual design values will vary.</i>		

Turboexpander/Generator

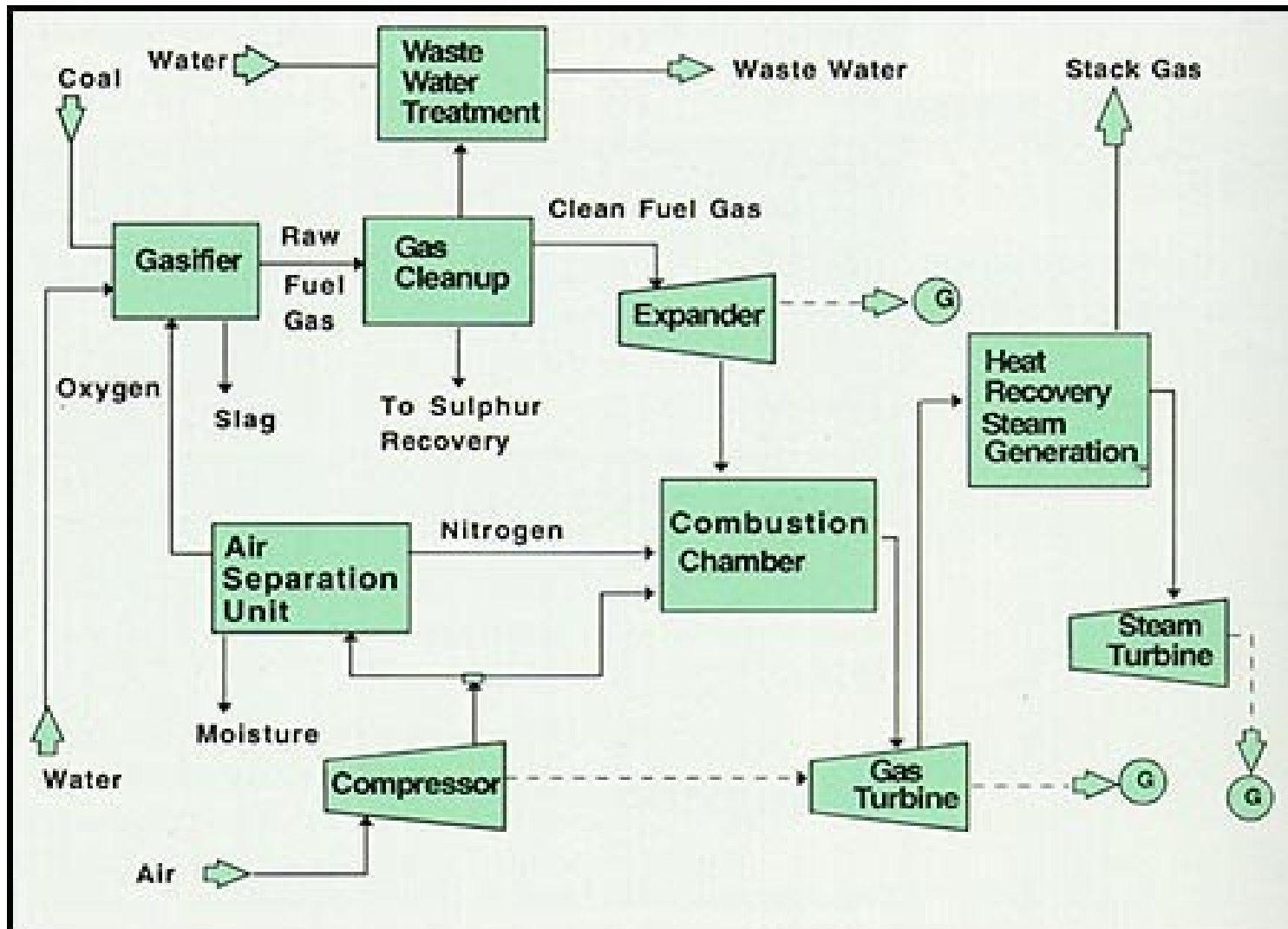


Induction generator, parallel shaft gearbox, 2500 kW EG4

Turboexpander/Generator

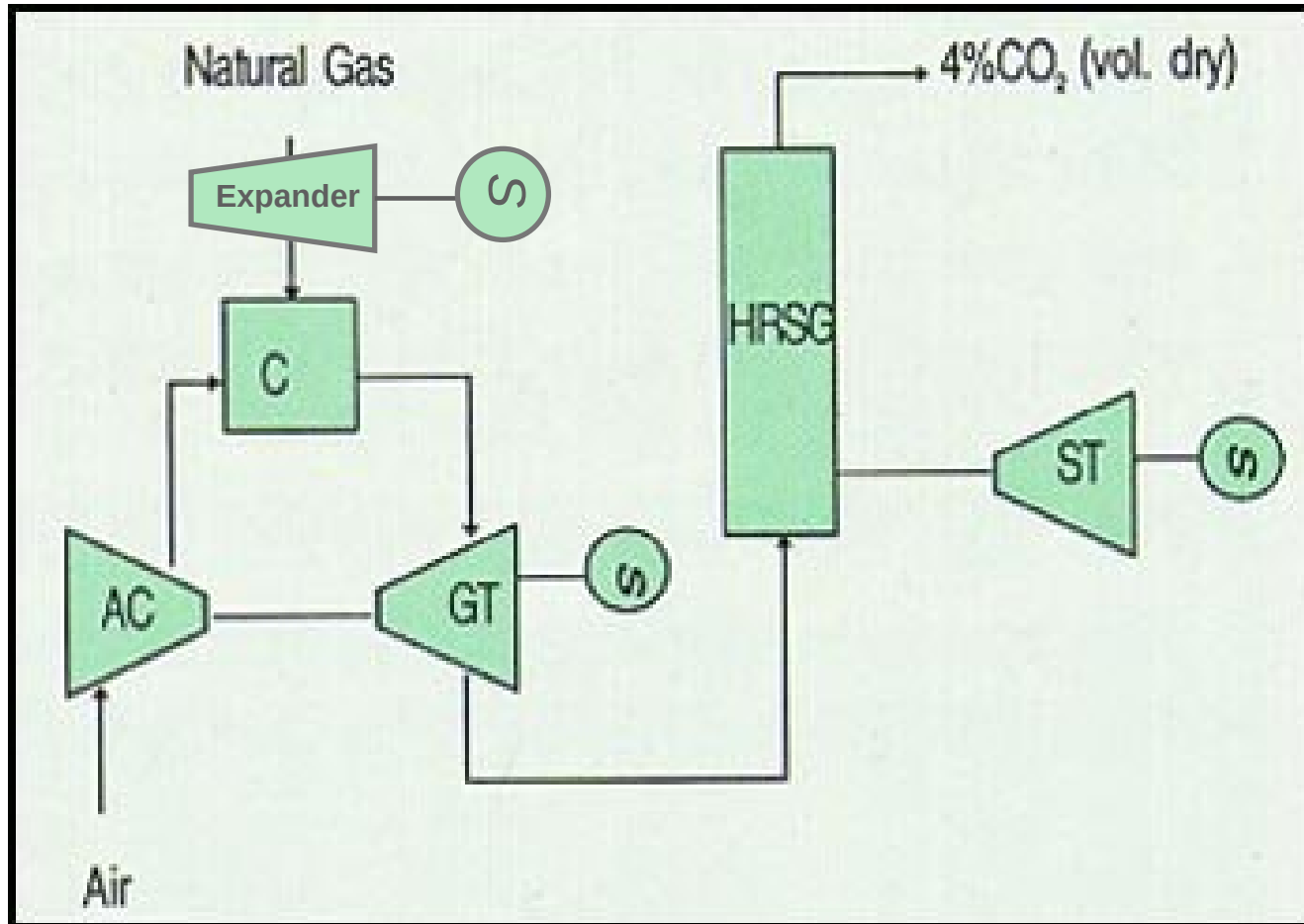
- Typical Applications
 - Pressure letdown
 - Rankine Cycle
- Speed reduction gearbox
 - Parallel Shaft
 - Integral
- Shaft Sealing Options
- Induction or synchronous generator

Turboexpander/Generator



Typical IGCC Application

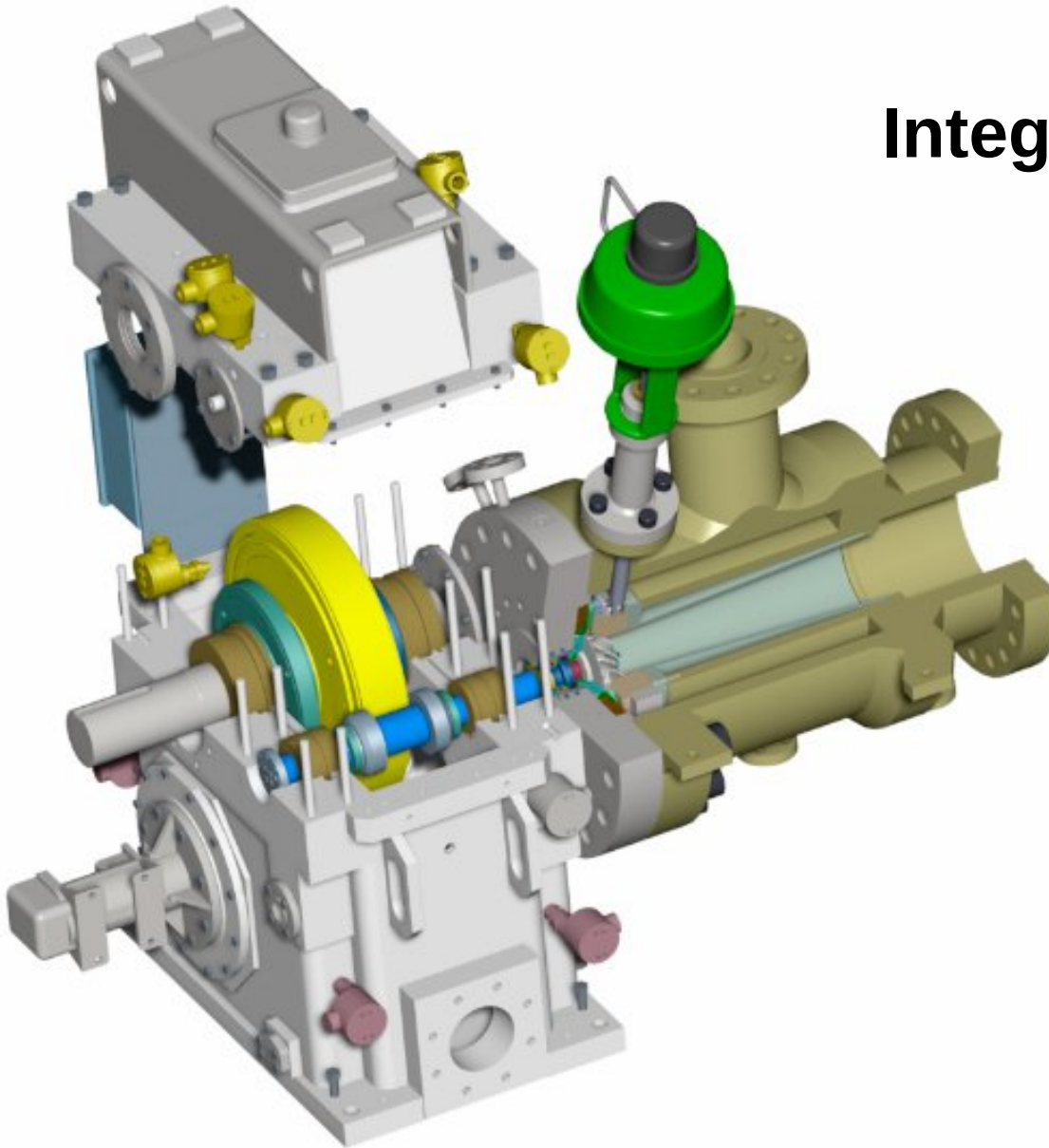
Turboexpander/Generator



Typical NGFCC Application

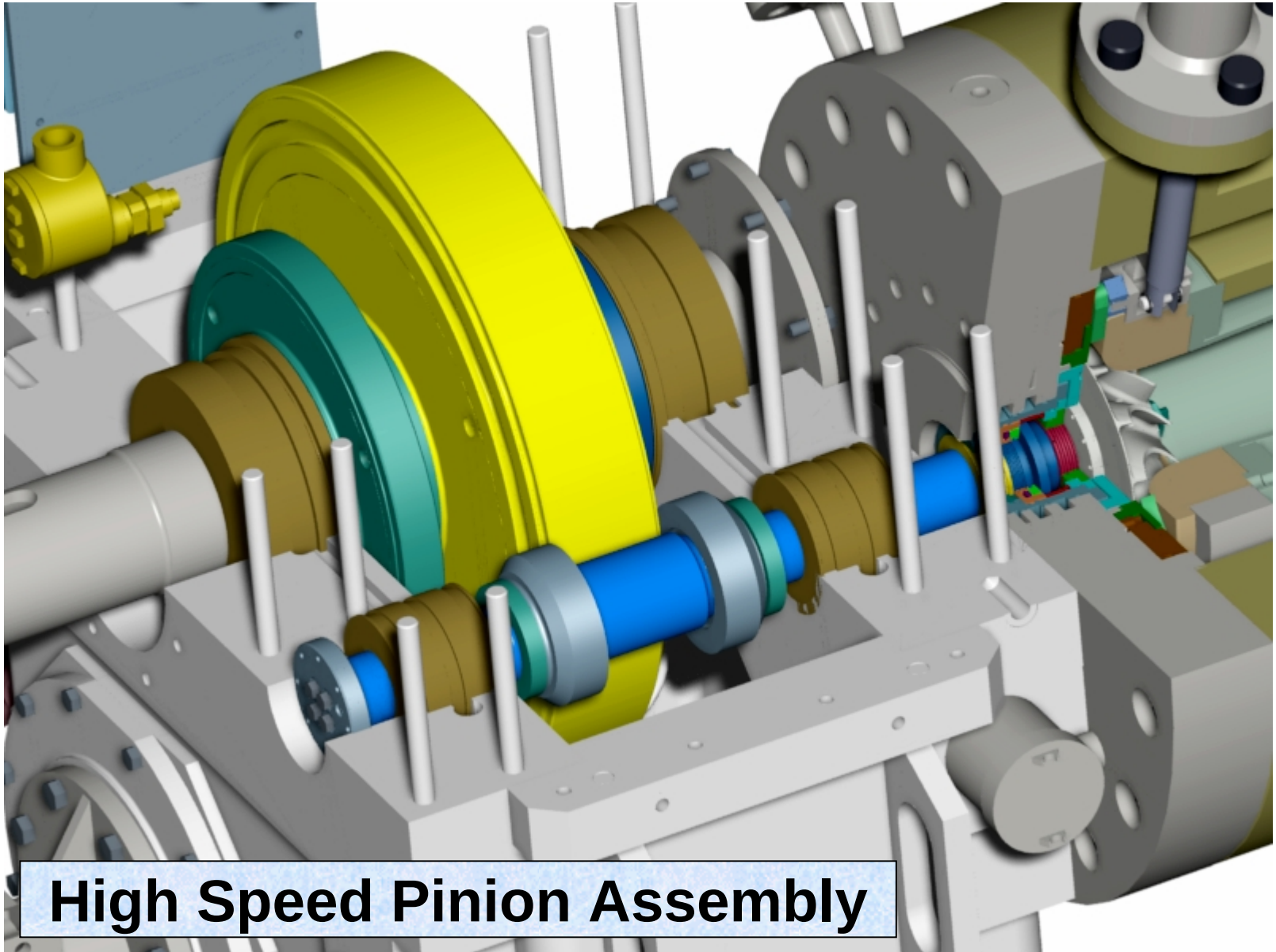
Turboexpander/Generator

Integral Gear Expander



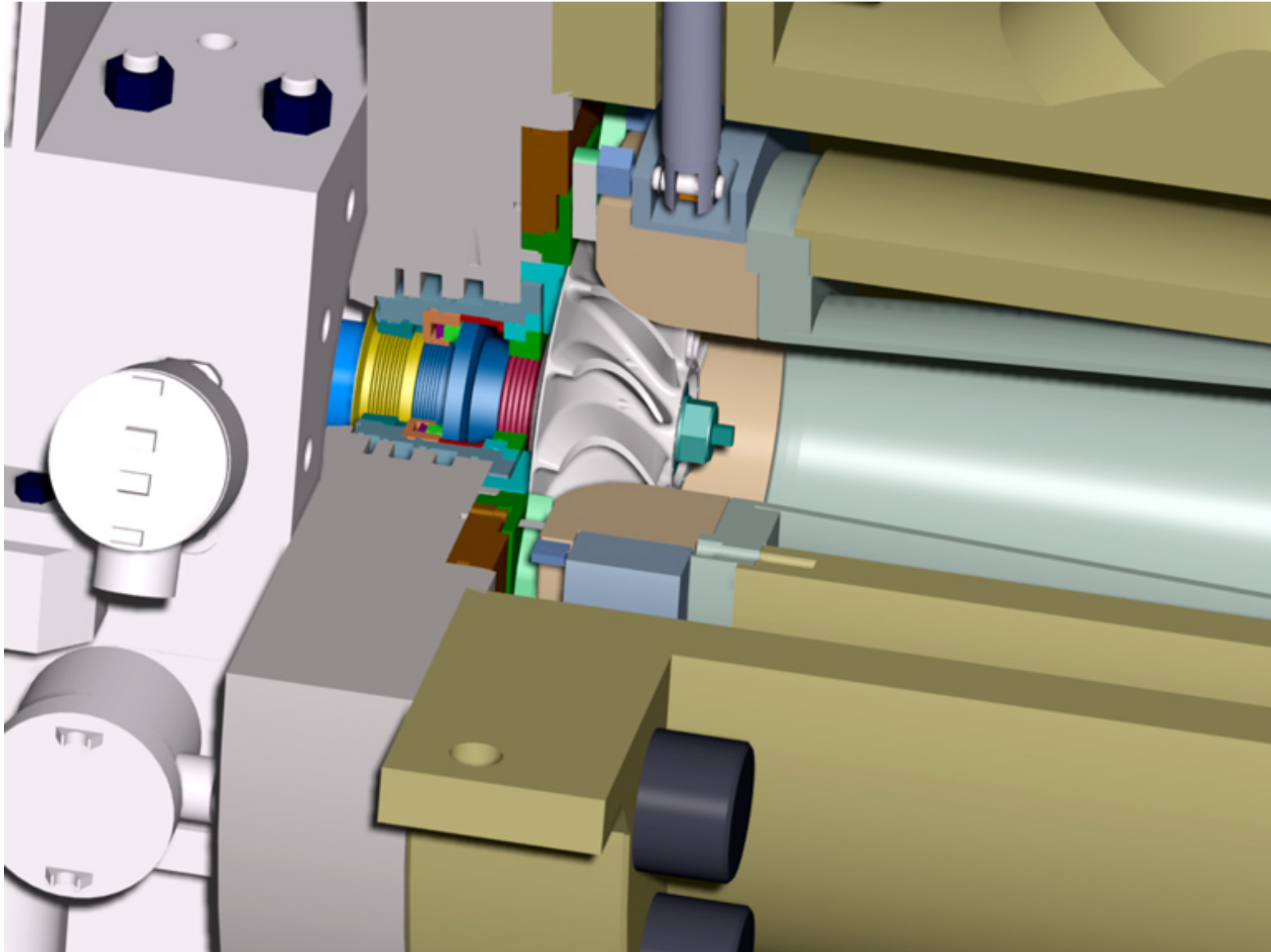
- Single Helical Gear
- Assorted shaft sealing methods
- Combined radial/thrust bearings on bull gear
- Can add additional impellers and pinions

Integral Gear Expander

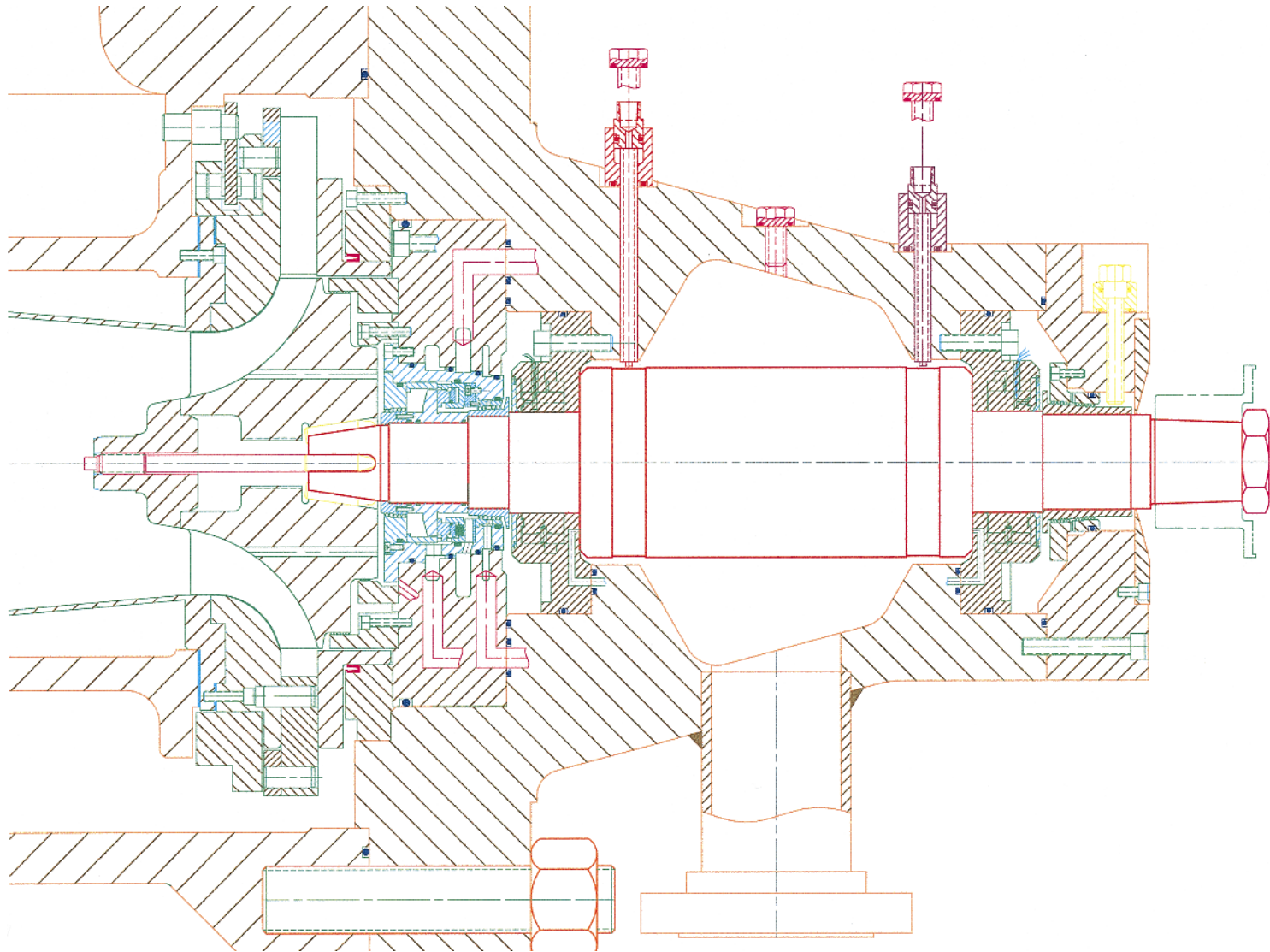


High Speed Pinion Assembly

Integral Gear Expander



Turboexpander/Generator



EG layout with single dry gas seal

Noise Control

- Acoustical Blankets
 - 15-25 dBA reduction in noise emanating from machine
- Pipeline Silencers
 - 20-35 dBA reduction in noise emitted into expander and compressor piping
 - Must allow for pressure loss

Reliability

- Reliability Centered Maintenance (RCM):
 - Maintenance system based on statistical data and experience.
- Condition Monitoring Recommended
 - What should be protected?
 - What should be trended?

Turboexpander Protection Recommendations

<i>Condition</i>	<i>Alarm</i>	<i>Trip</i>
<i>Overspeed</i>	Yes	Yes
<i>High Shaft Vibration</i>	Yes	Yes
<i>High Bearing Temperature</i>	Yes	Yes
<i>High Axial Thrust Pressure</i>	Yes	Yes
<i>Loss of Lube Oil Pressure</i>	Yes	Yes
<i>Loss of Seal Gas Pressure</i>	Yes	No *

* May be “Yes” for processes sensitive to oil contamination.

Turboexpander Condition Monitoring

Parameter	Trend Indication
Shaft Vibration	Imbalance, rotor damage, impeller wear, loose fits, surge, bearing damage, oil dilution or contamination.
Bearing Temperature	Oil system control malfunction, bearing damage, shaft seal damage.
Axial Thrust Pressure	Wheel seal damage, thrust balancing system malfunction.
Seal Gas Flow	Shaft seal damage.
Oil Viscosity (Optional)	Oil dilution or contamination.

Reliability/Maintenance

Health Care Maintenance Philosophy based on Condition Monitoring

- ① Pre-Commissioning and start-up
 - Initial stabilized operation
 - Service intervals defined
- ② Post commissioning through 5 years
 - Manufacturer's warranty expires
 - Long term operating characteristics defined
- ③ 6-30 years Service life
 - Time dependent failures
 - Overhaul/redesign service

Training

- MTC training programs:
 - 101: In-house training
 - 201: Site training
 - 301: Advanced training
- Certification programs
 - Maintenance
 - Operations
 - Safety

Refrigeration



The End Result



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