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

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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")

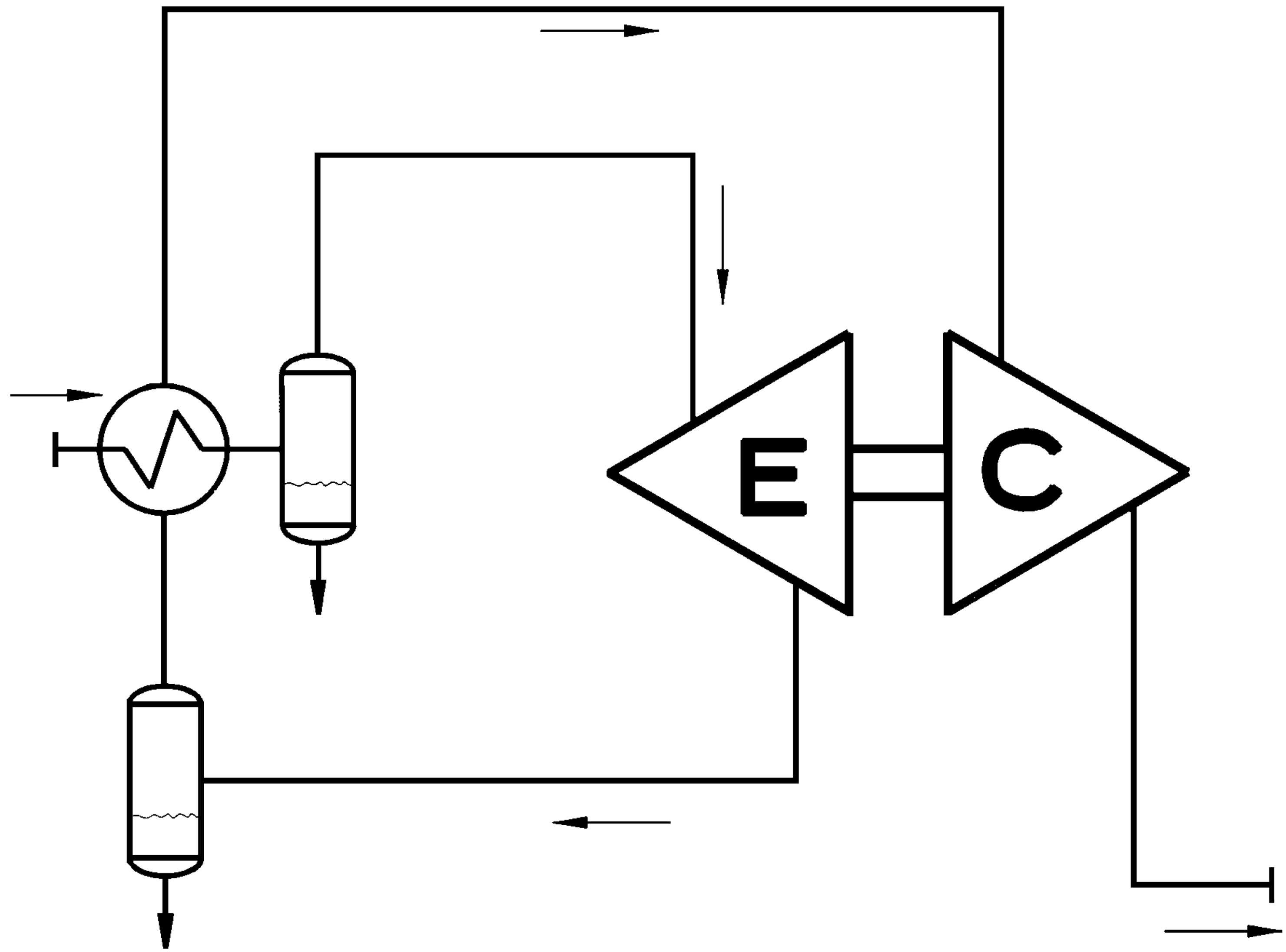
Typical Turboexpander Processes

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

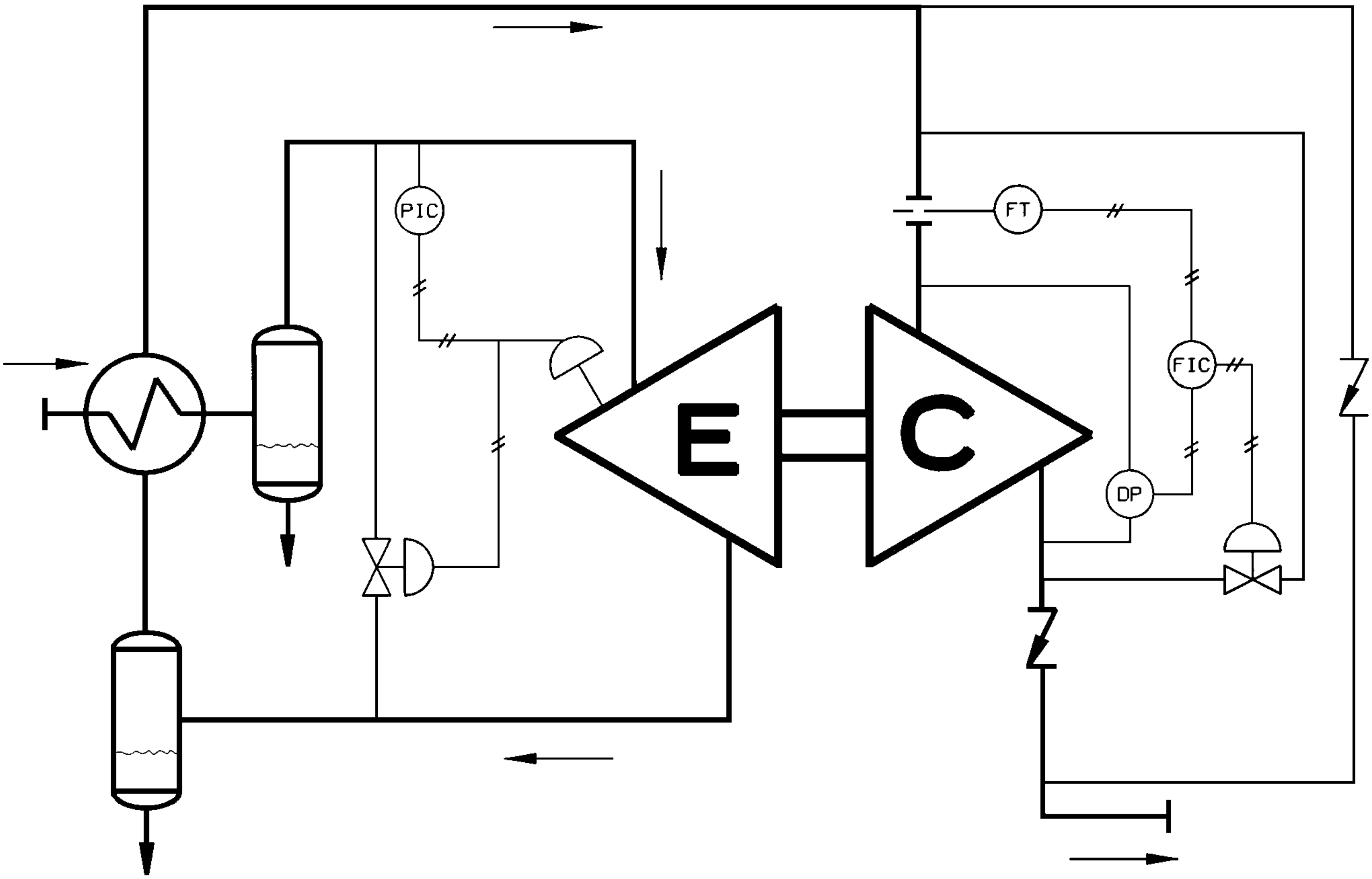
Typical Turboexpander Processes

- 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

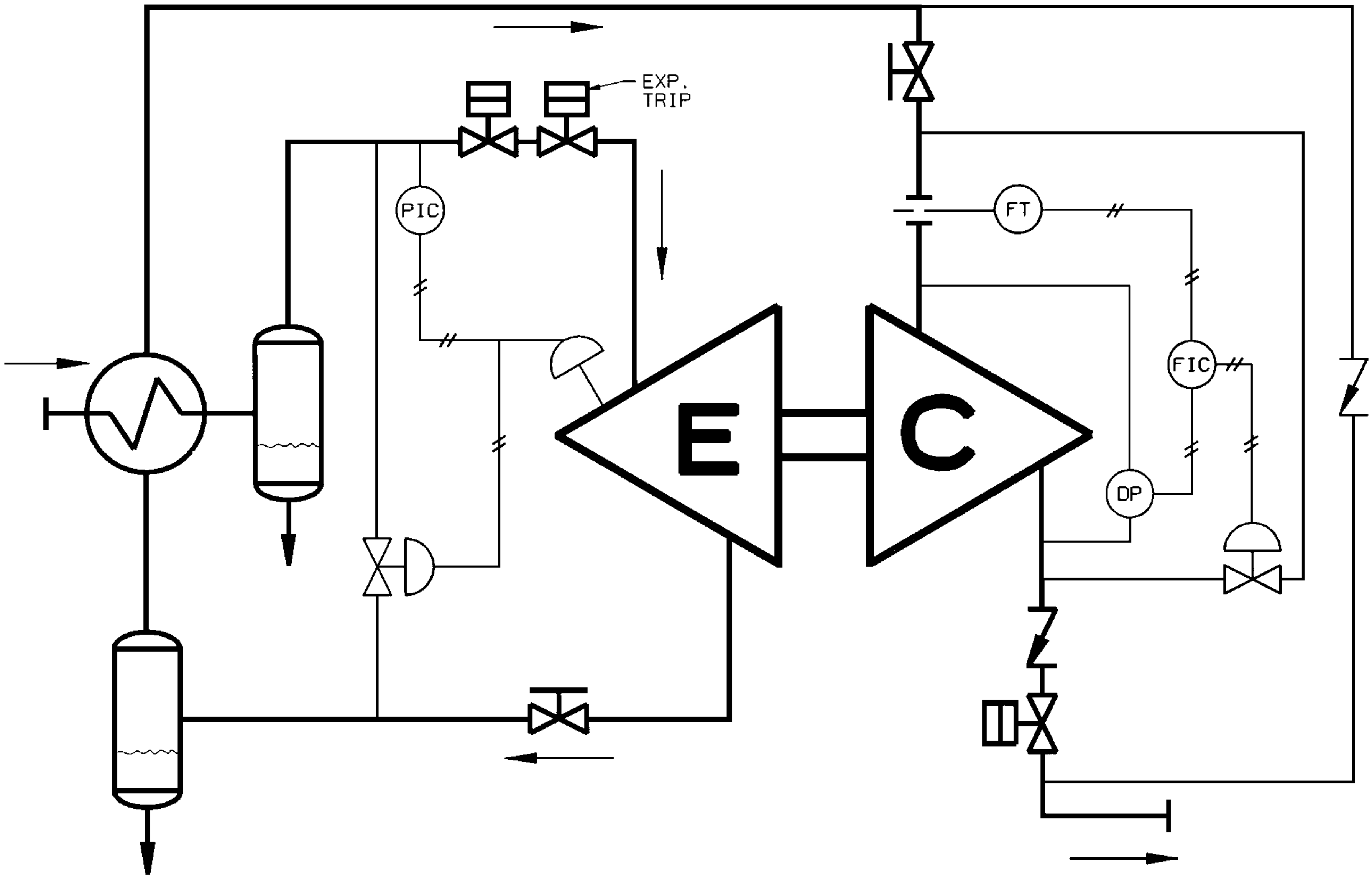
Typical Turboexpander Process



Typical Turboexpander Process



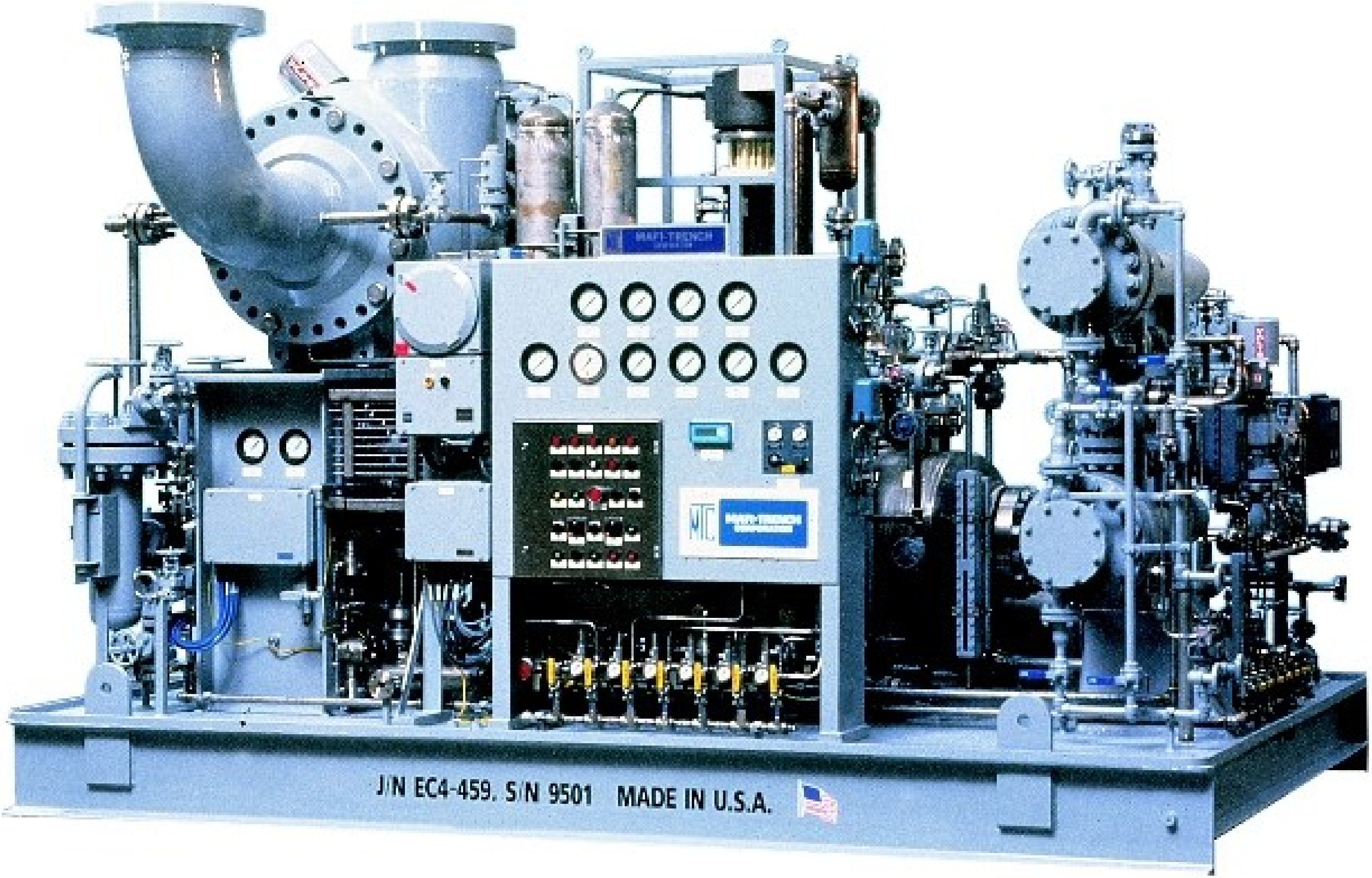
Typical Turboexpander Process



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

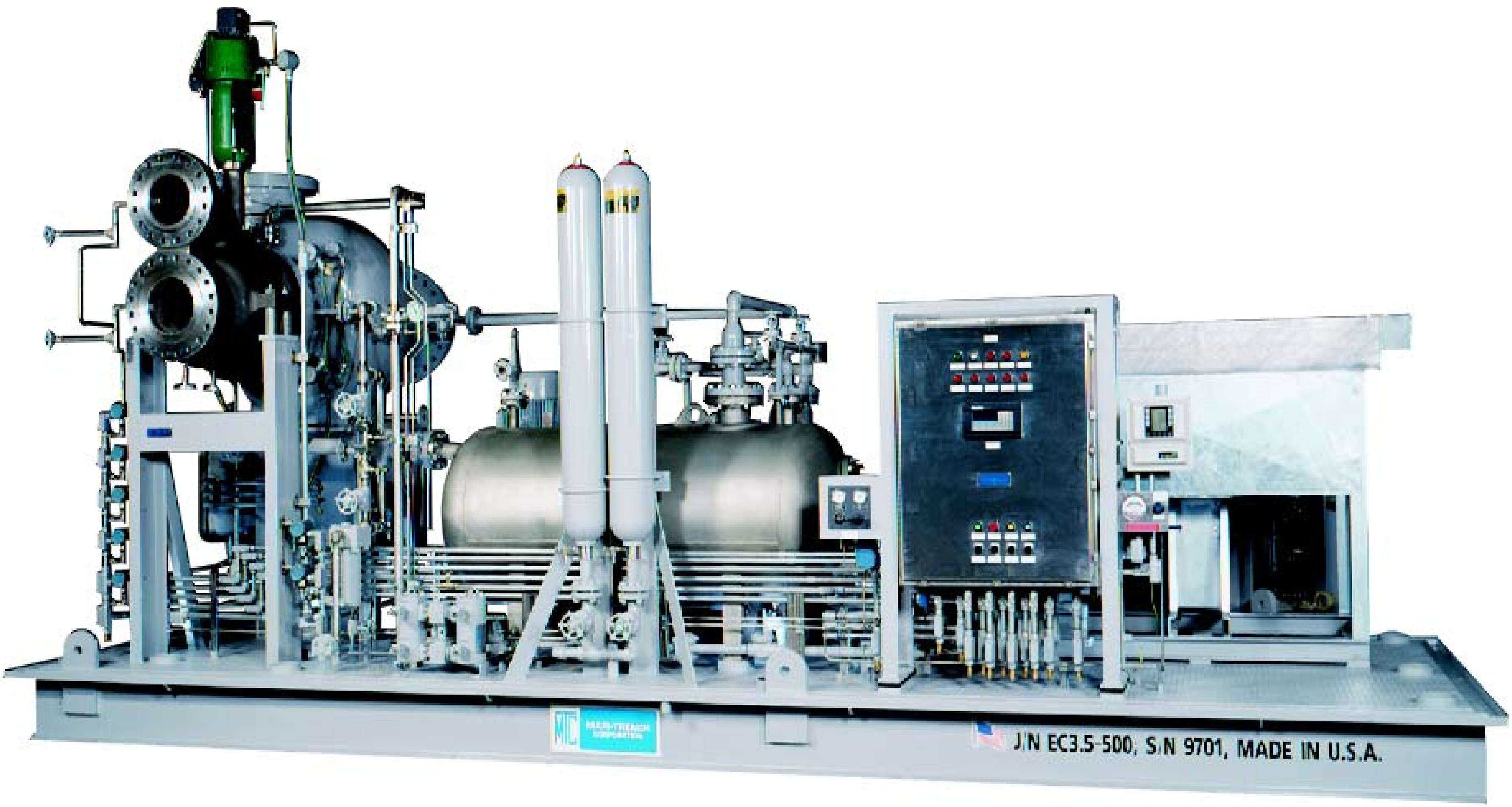


Offshore, sea water cooled, EC4 in dew point control service

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

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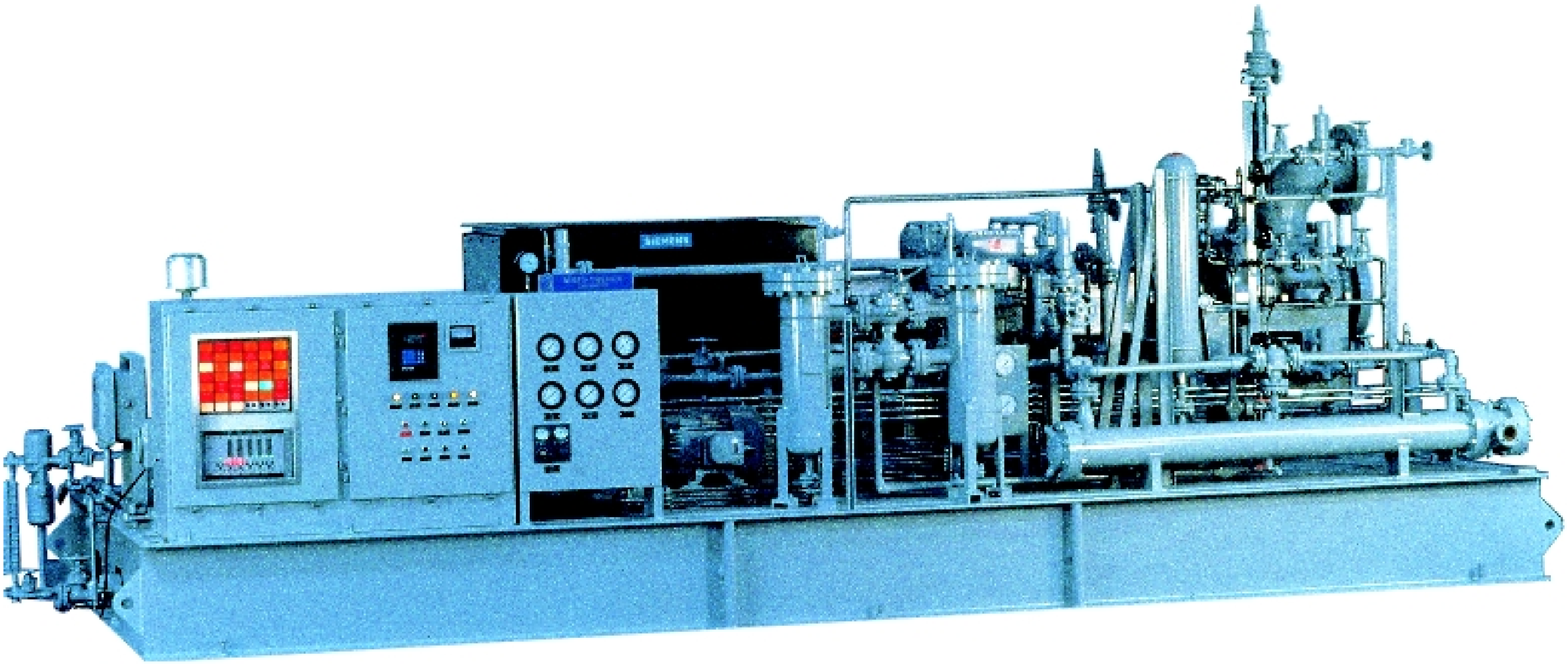
Turboexpander/Generator



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

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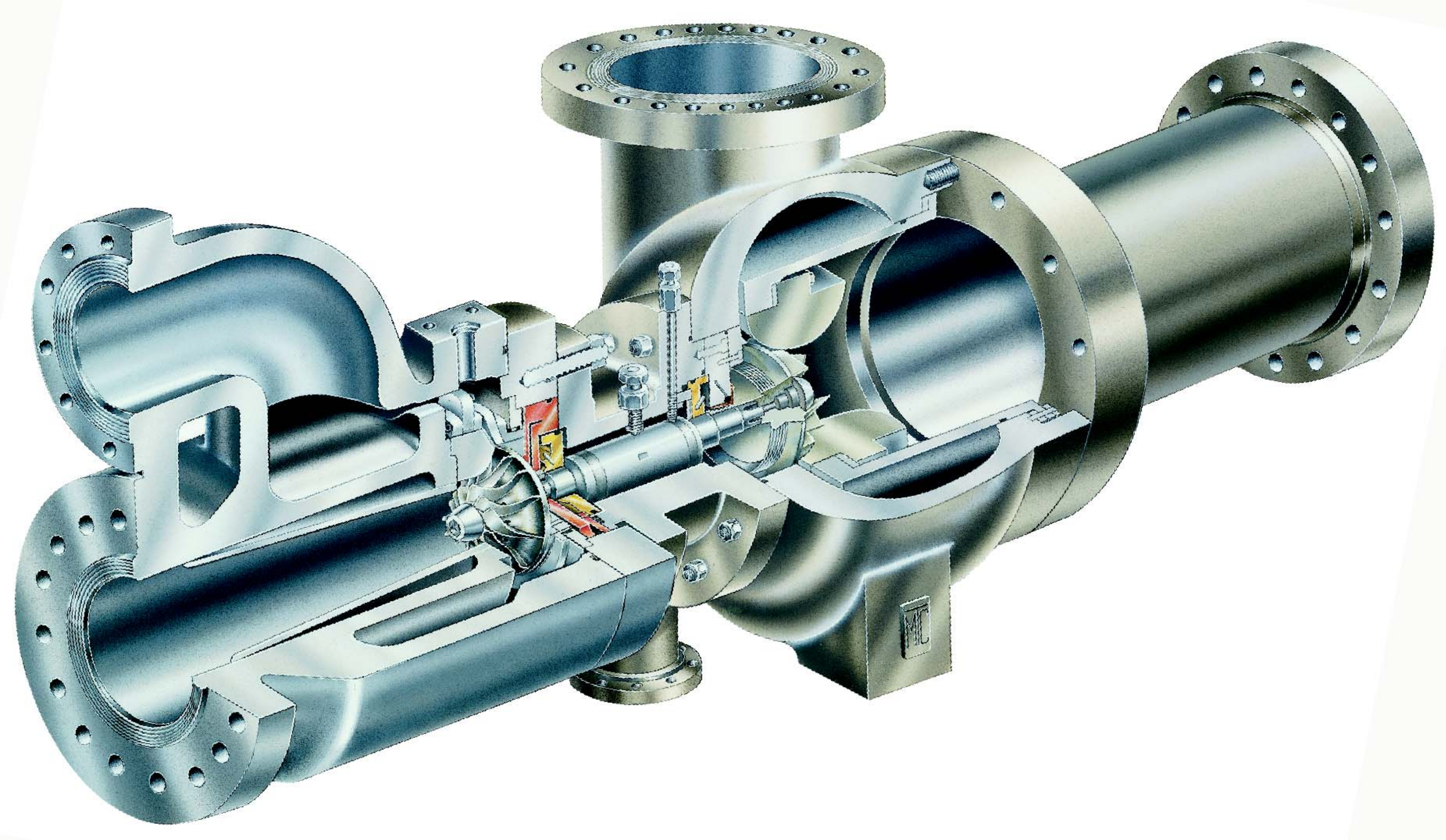
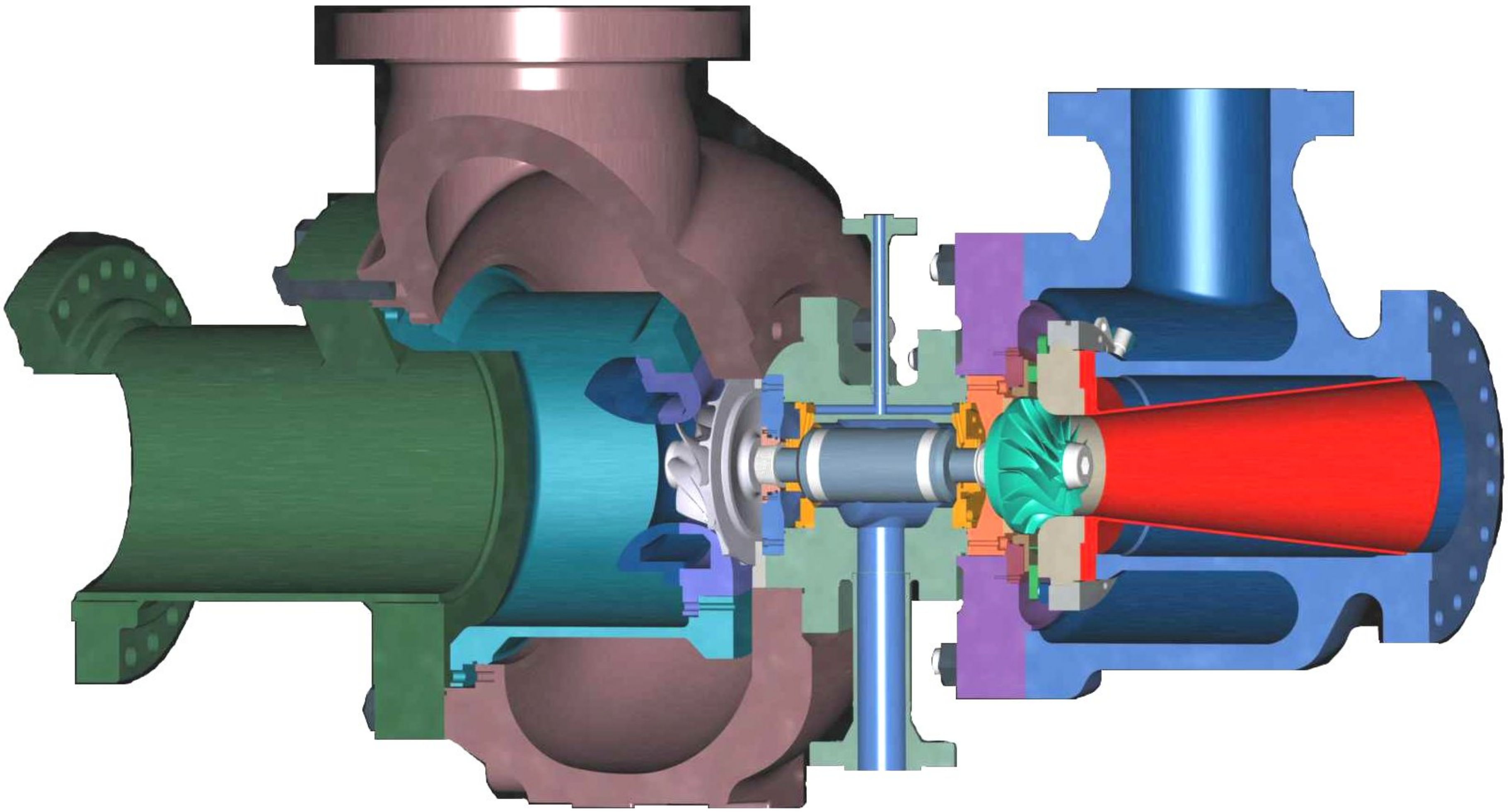
Hydrocarbon Turboexpanders



Design Features



Expander Compressor Cross Section

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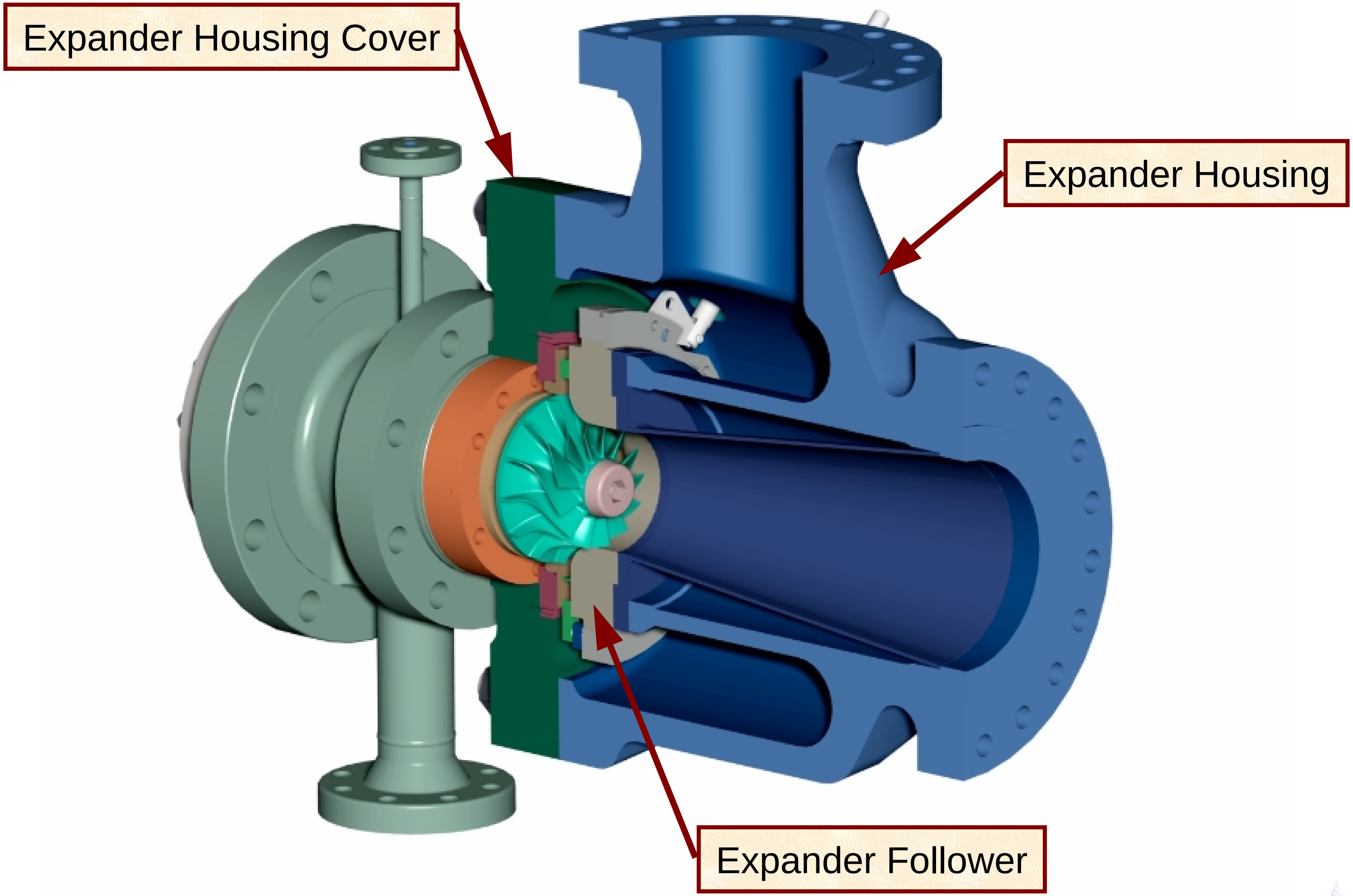

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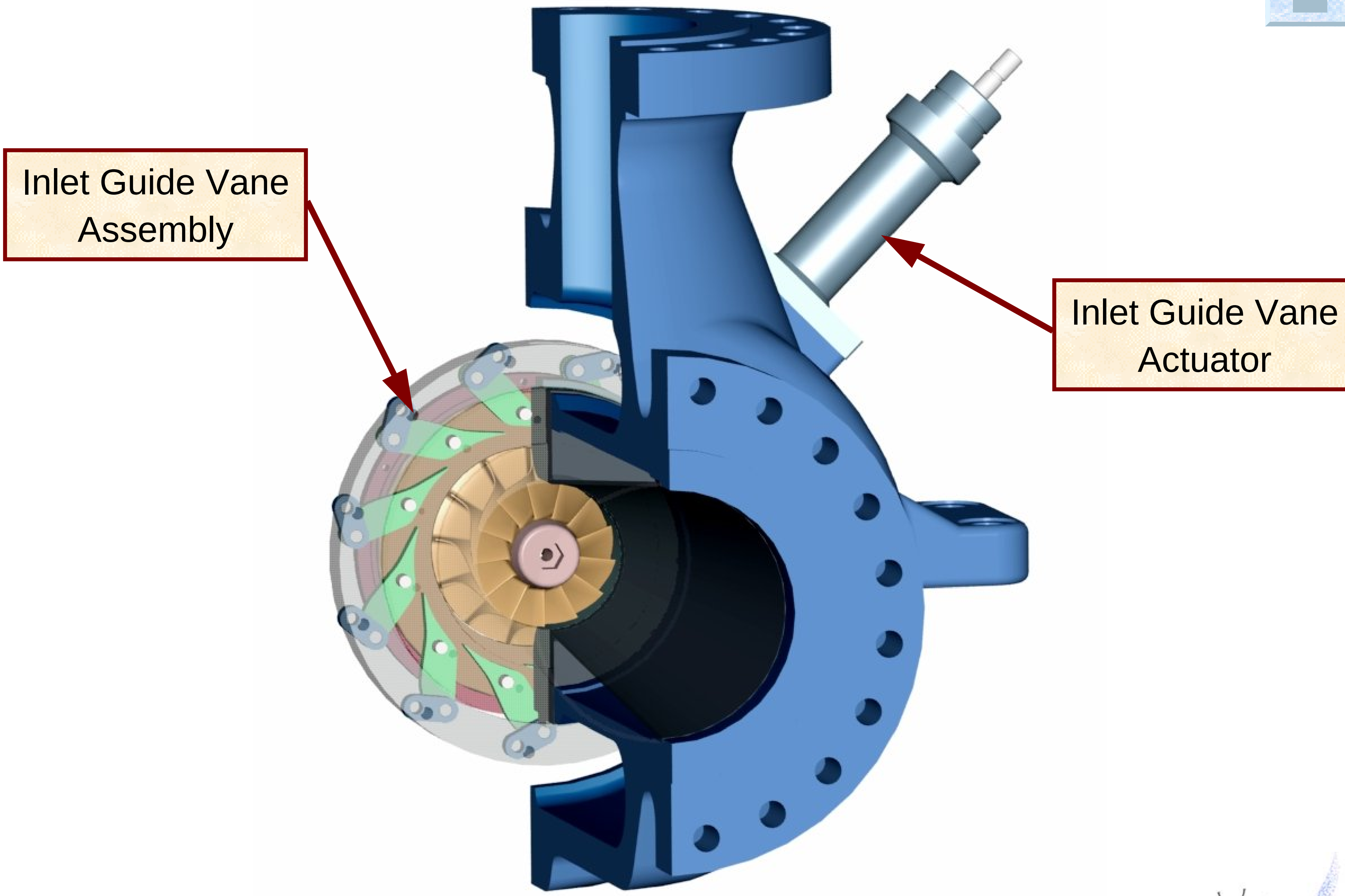
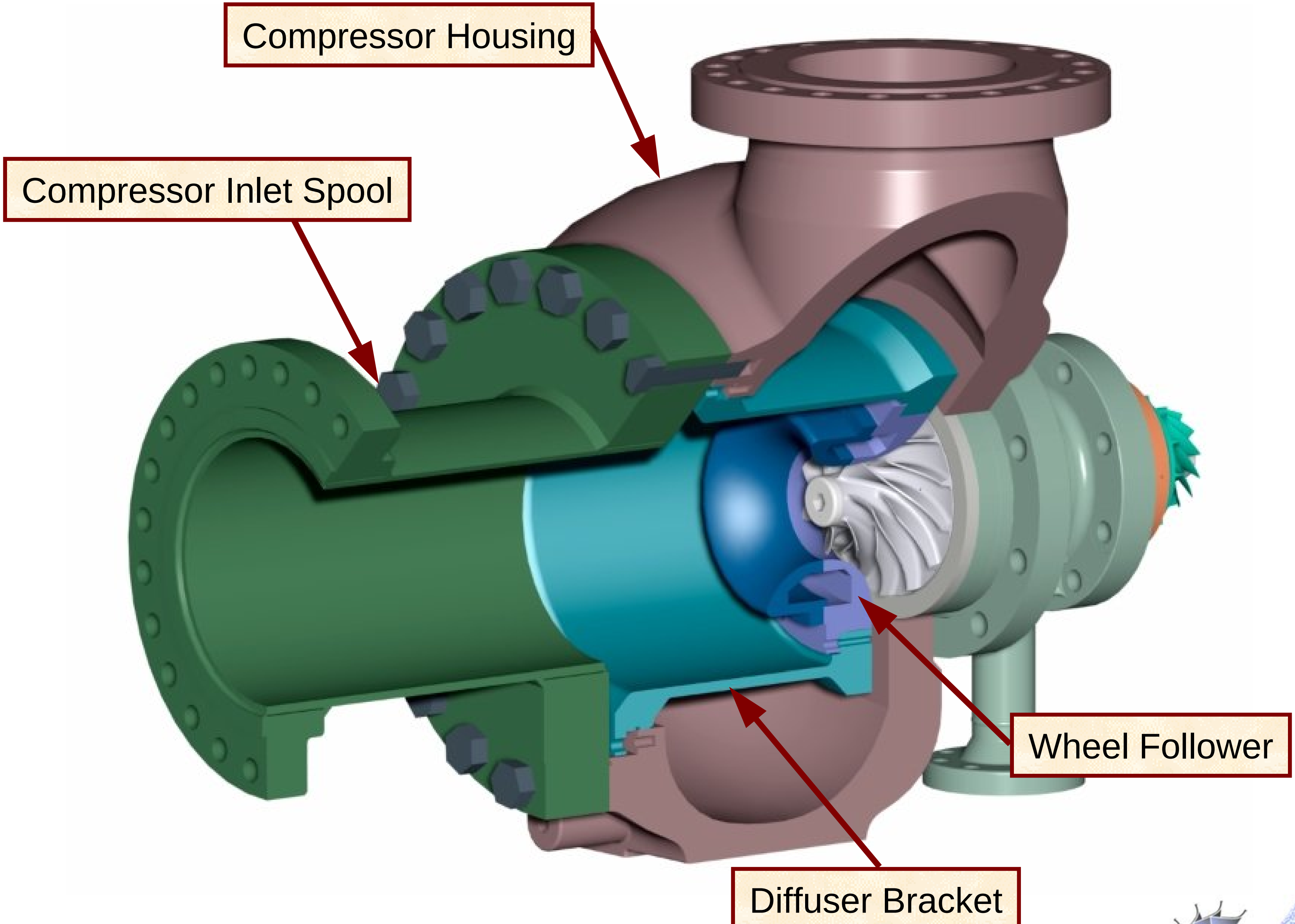
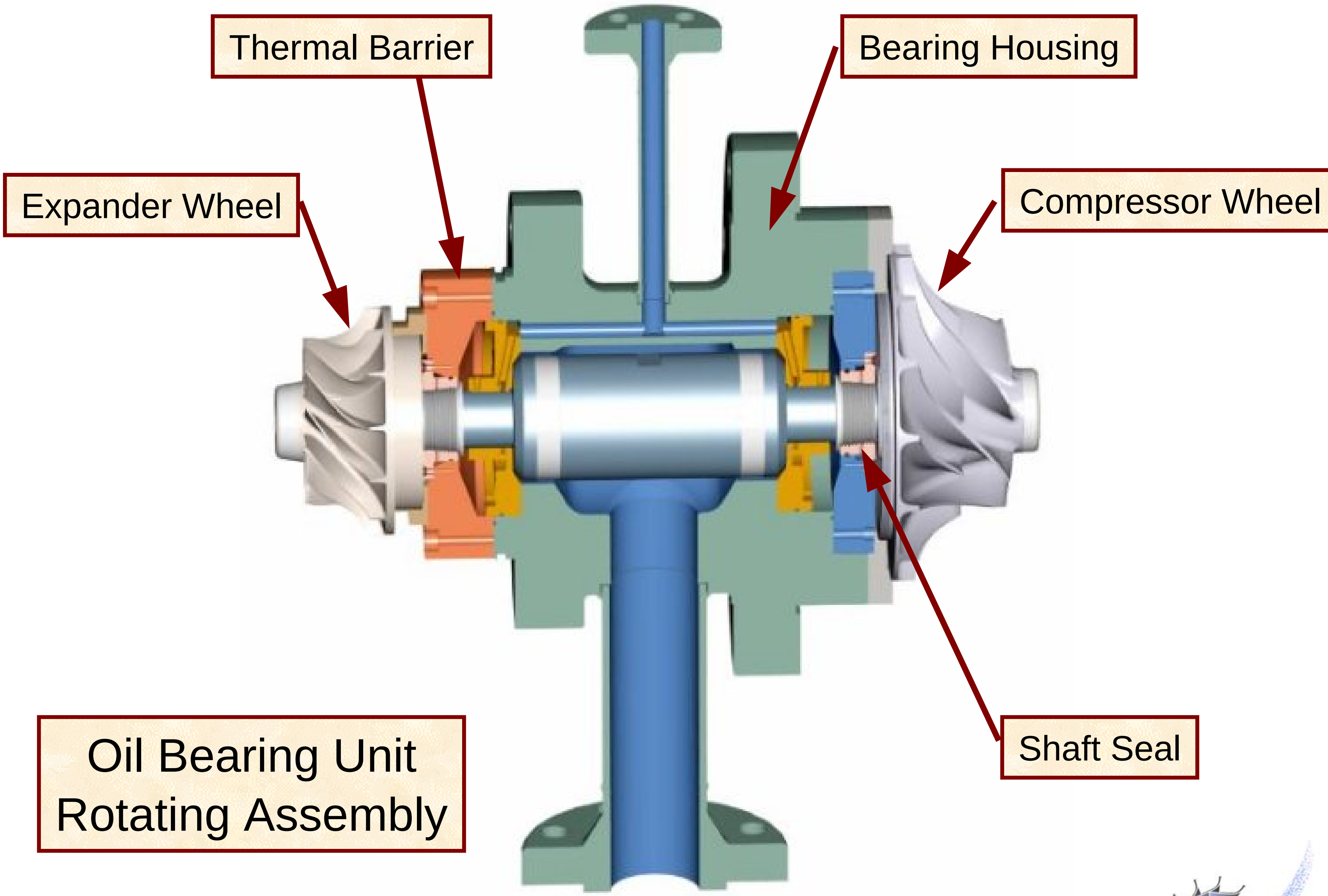
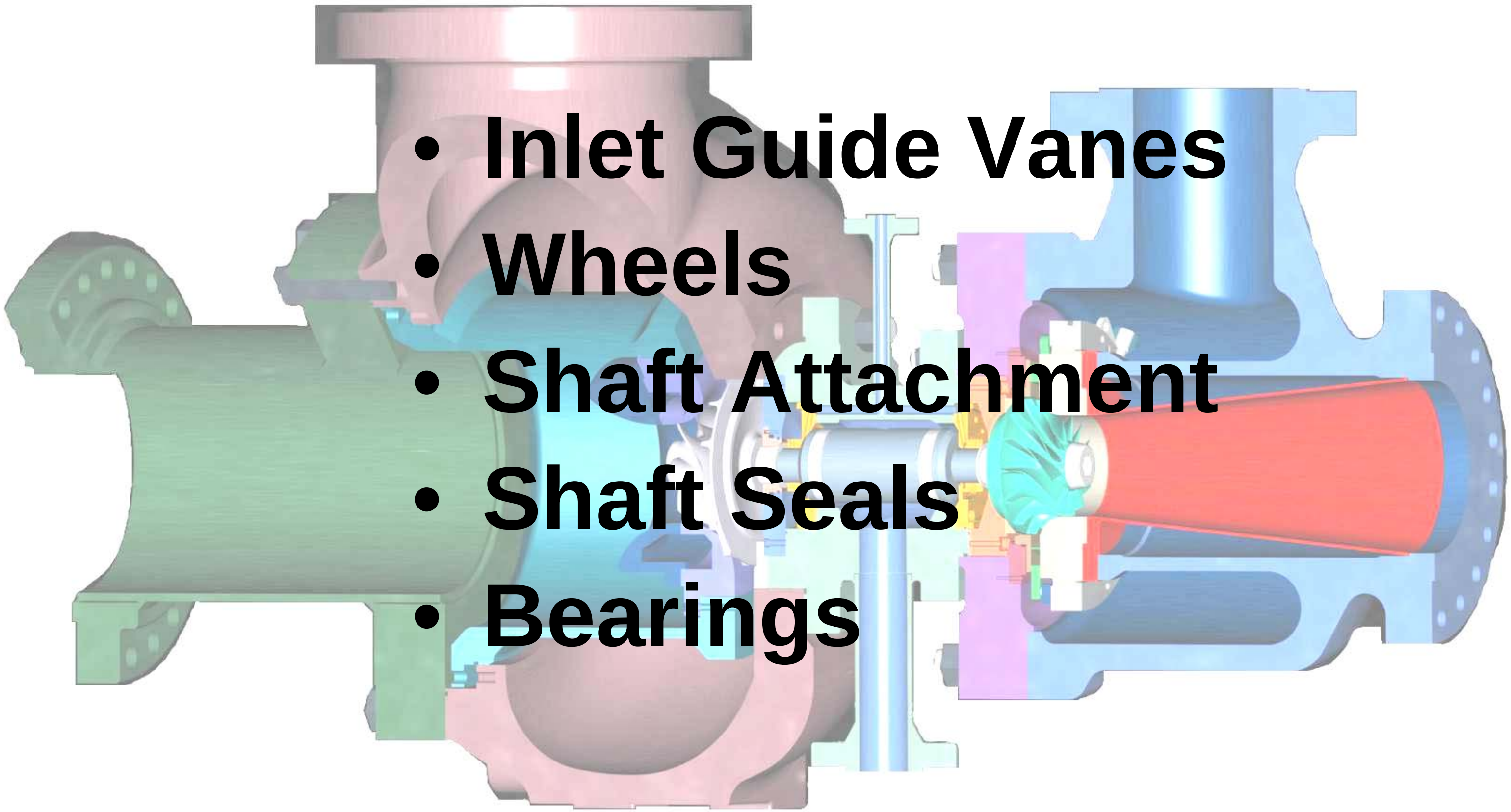

Inlet Guide Vane Assembly
Inlet Guide Vane Actuator


Compressor Housing
Compressor Inlet Spool
Wheel Follower
Diffuser Bracket



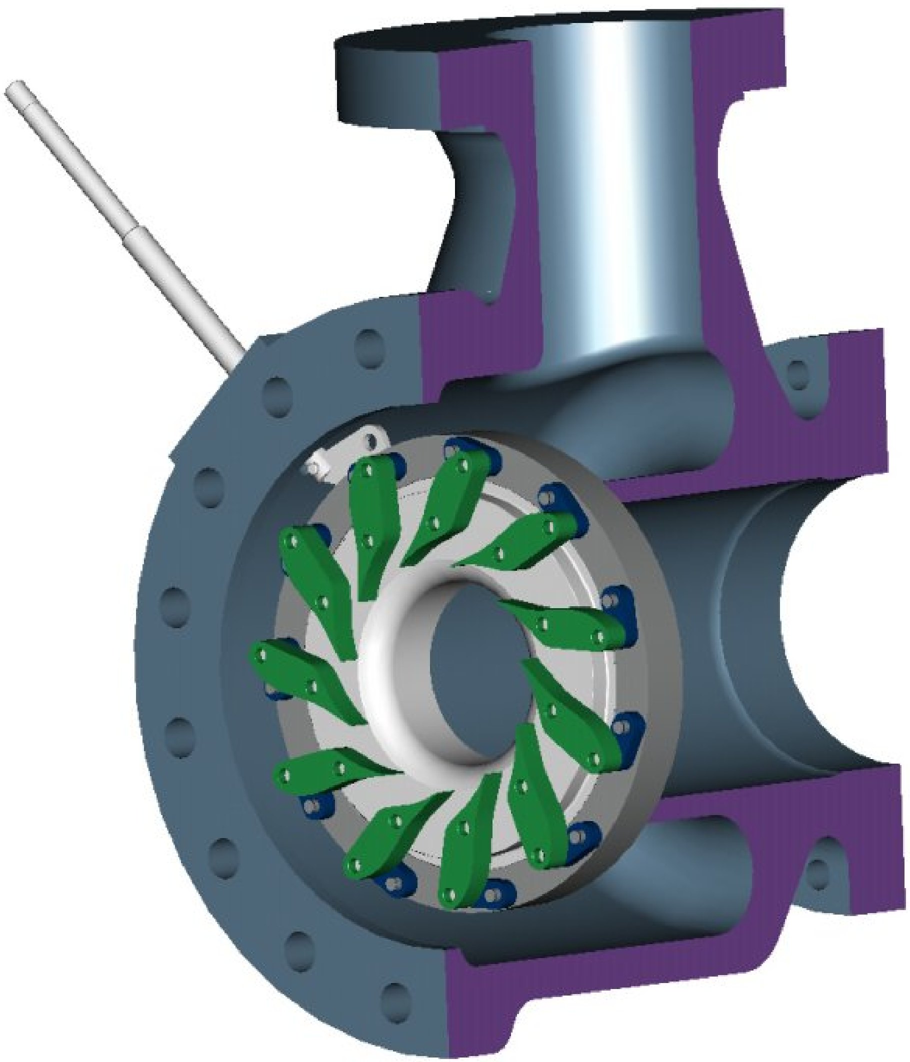
Oil Bearing Unit
Rotating Assembly

Turboexpander/compressor
Design Features



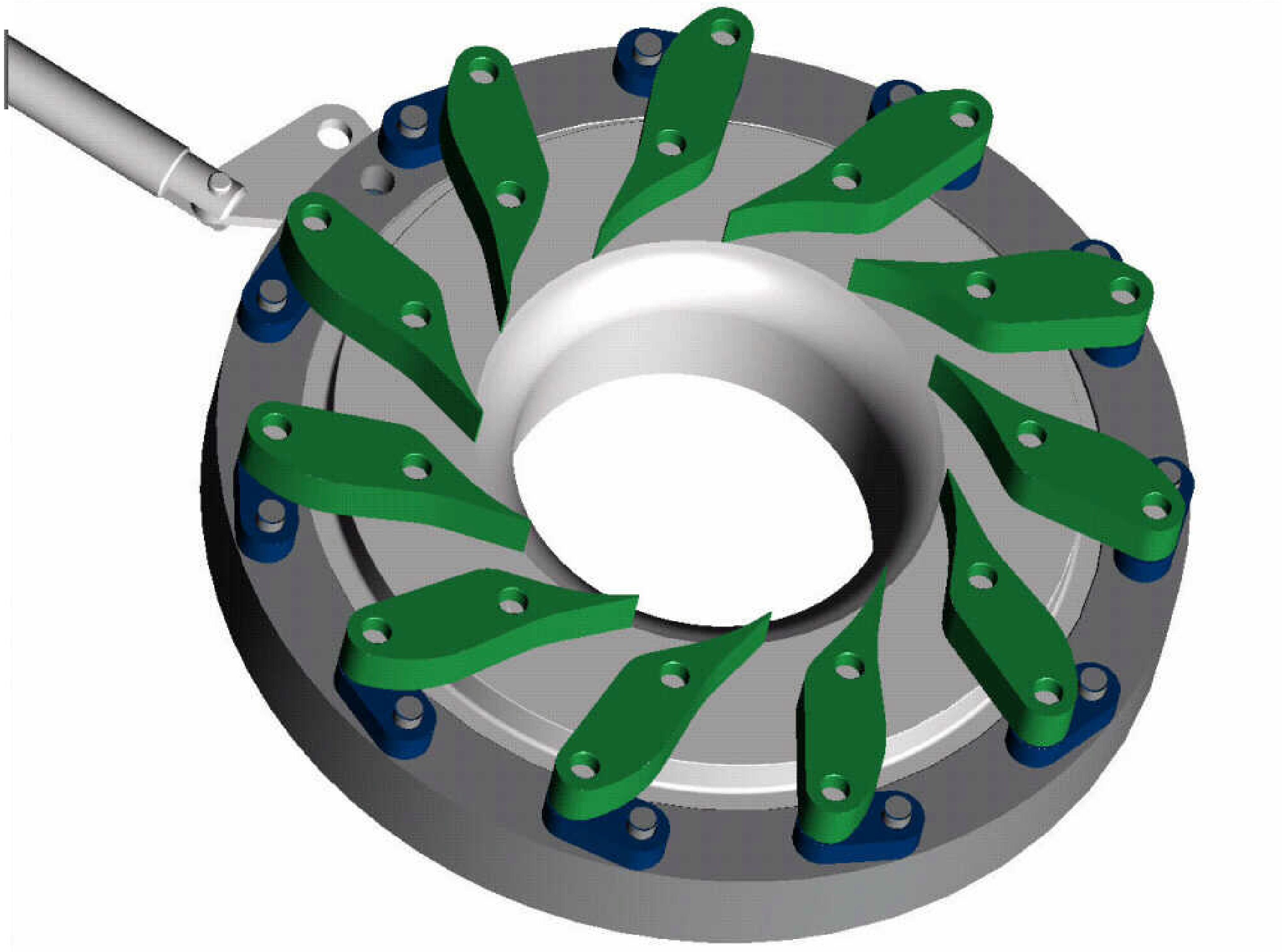
- Inlet Guide Vanes
- Wheels
- Shaft Attachment
- Shaft Seals
- Bearings

Expander Inlet Guide Vanes



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

Expander Inlet Guide Vanes



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Expander Inlet Guide Vanes

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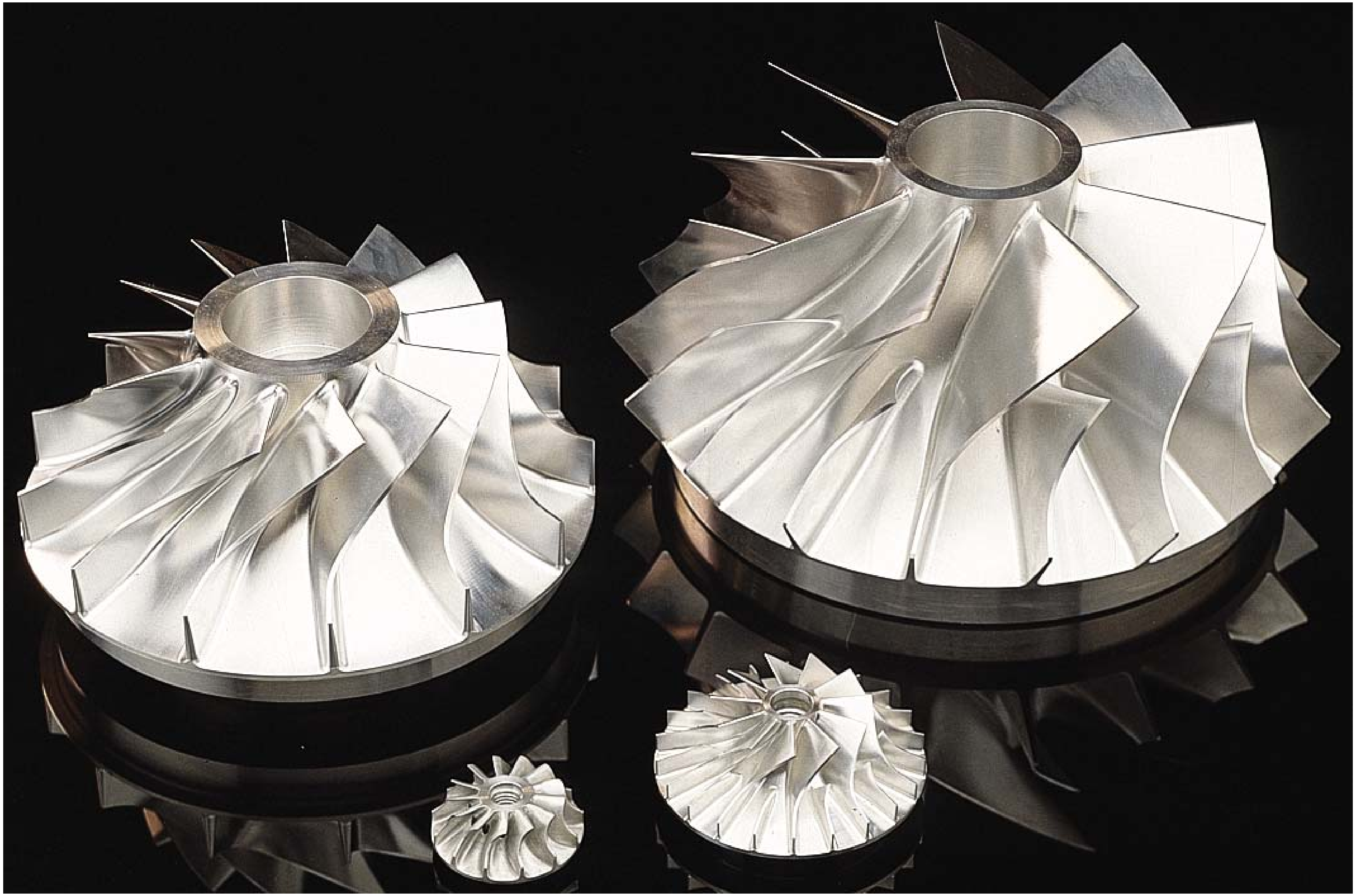
Expander / Compressor Wheels



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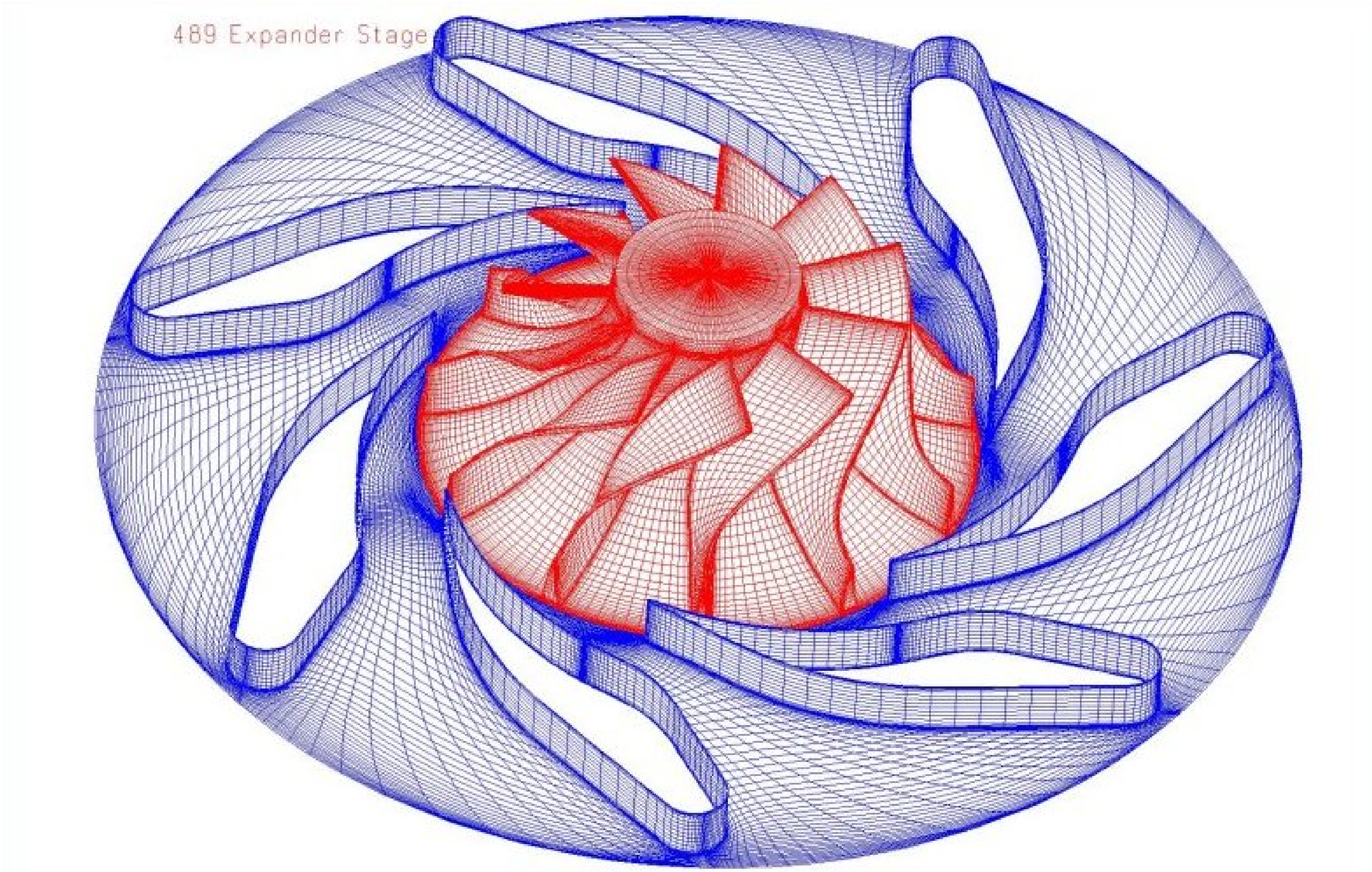
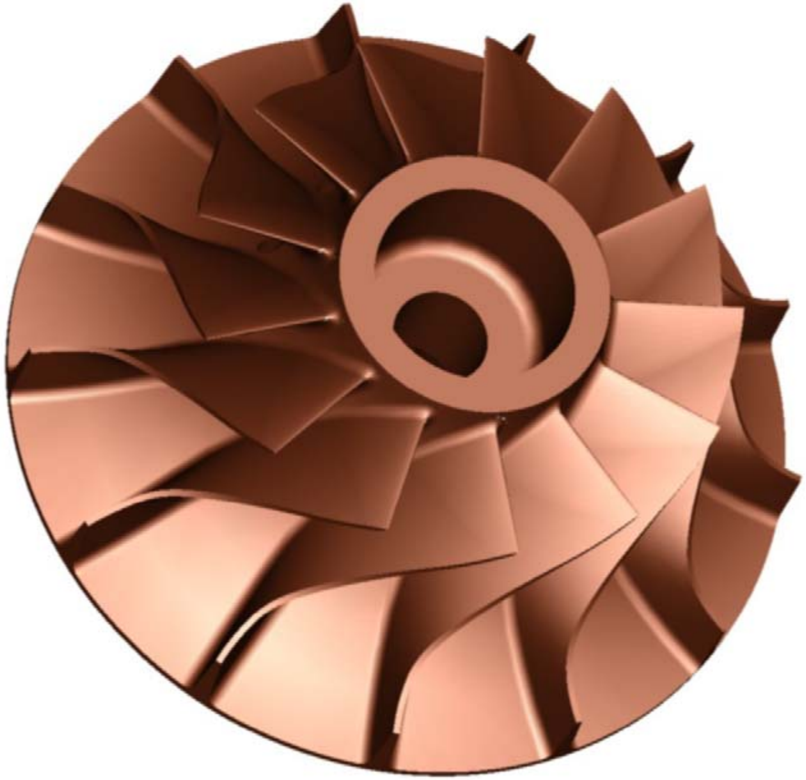
Wheel Design



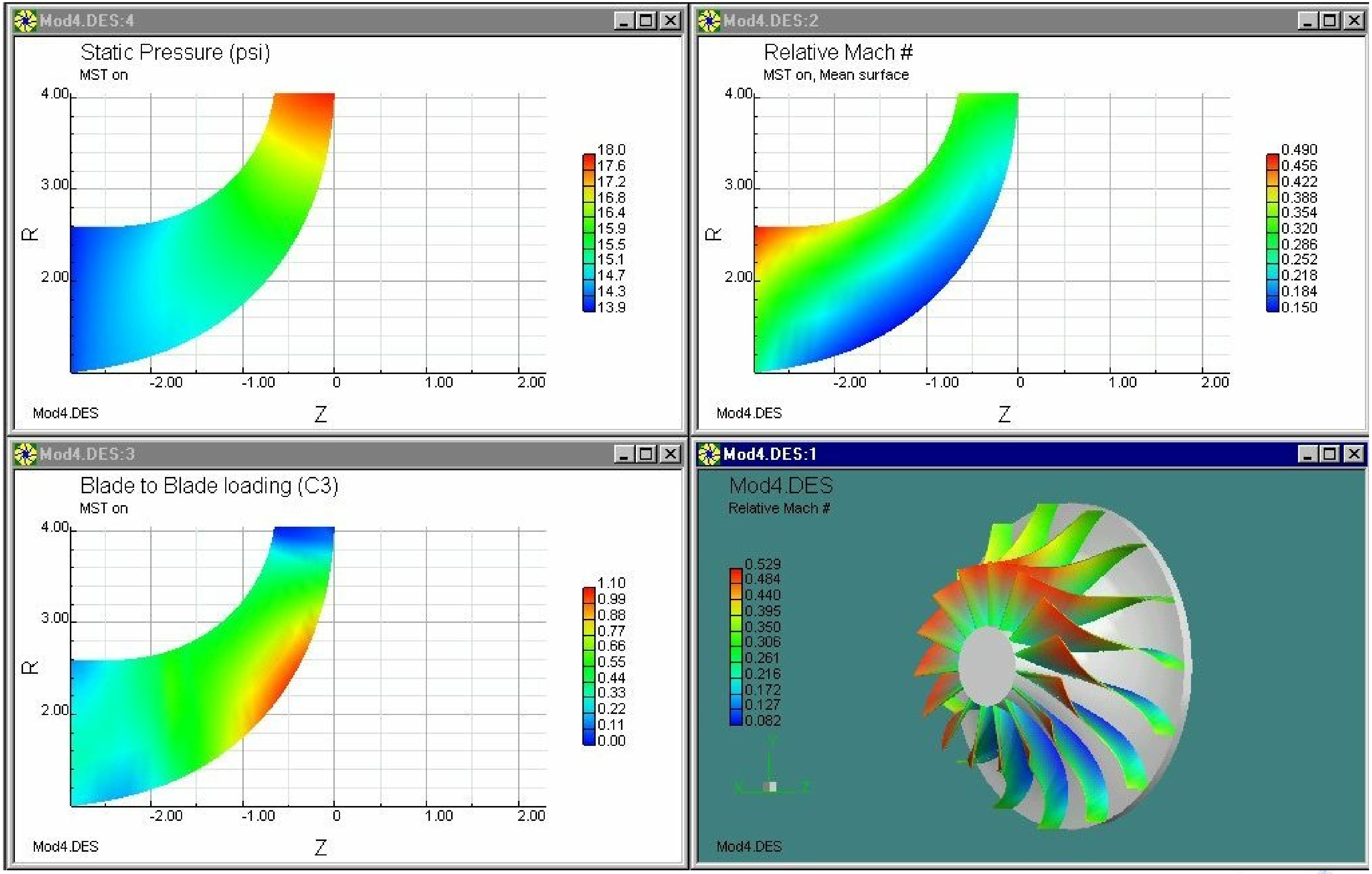
Wheel / IGV Mesh

Wheel Design

- Solid Modeling



Compressor Design



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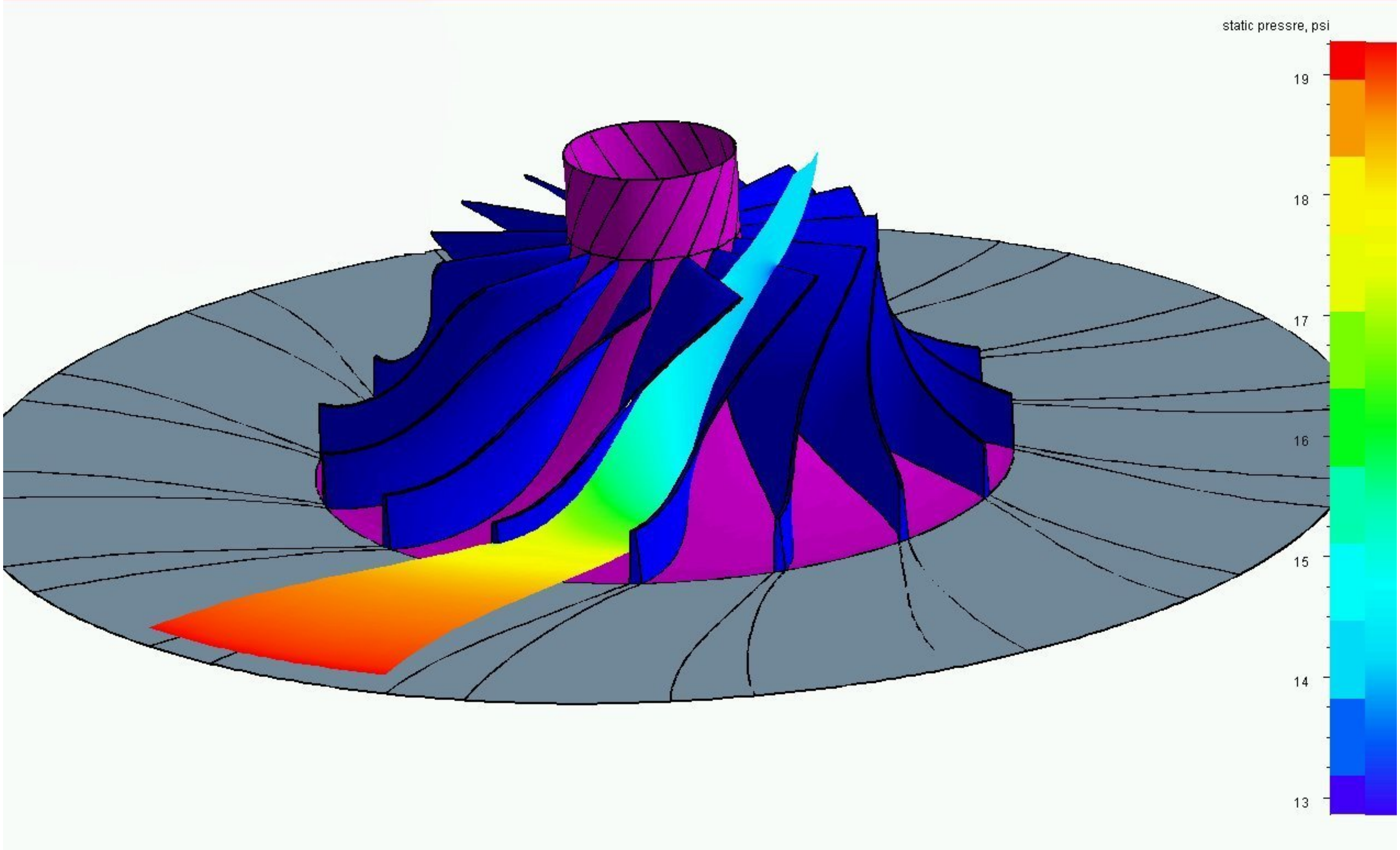
Computational Fluid Dynamics (CFD)



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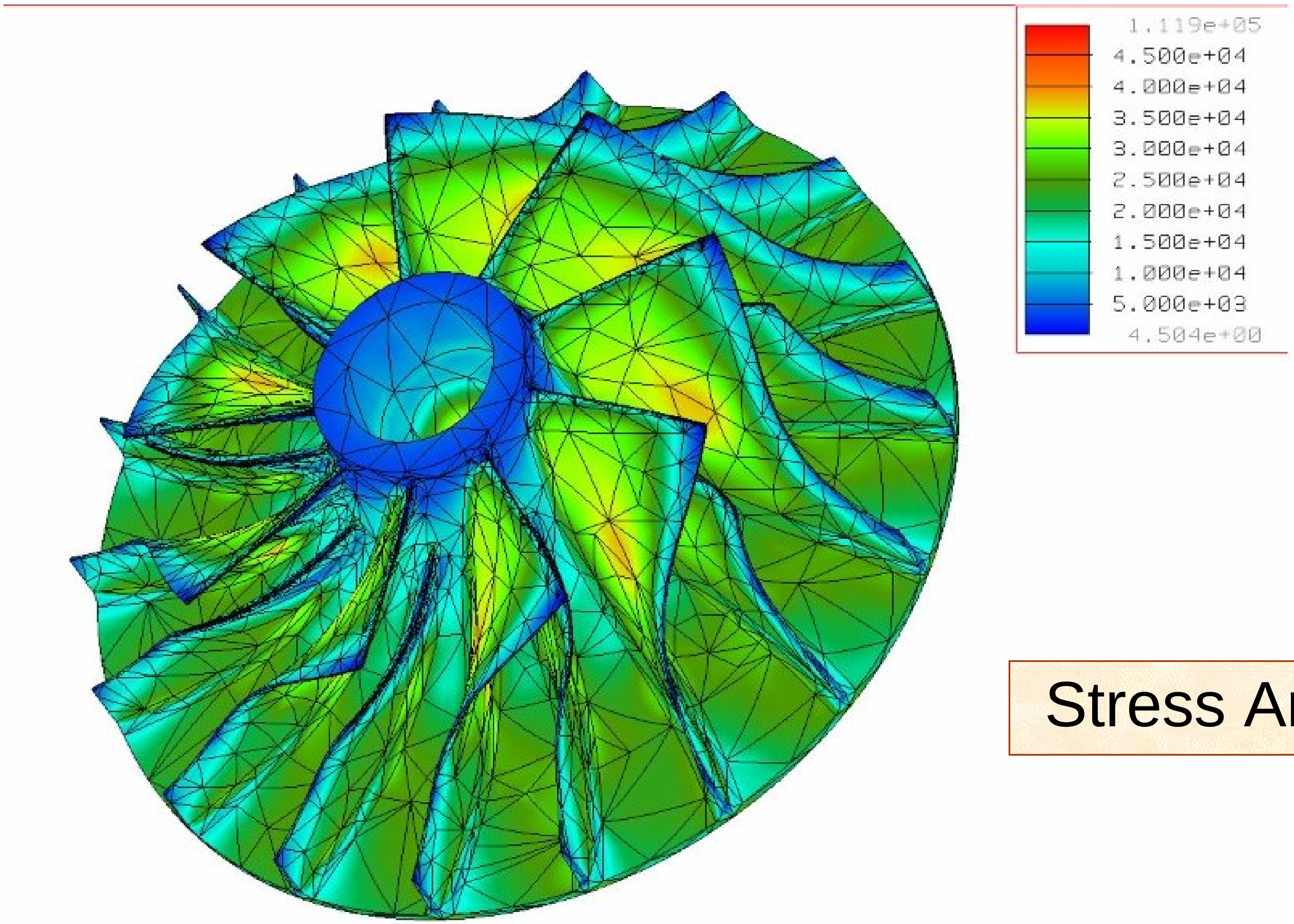
Finite Element Modeling (FEA)



Stress Analysis

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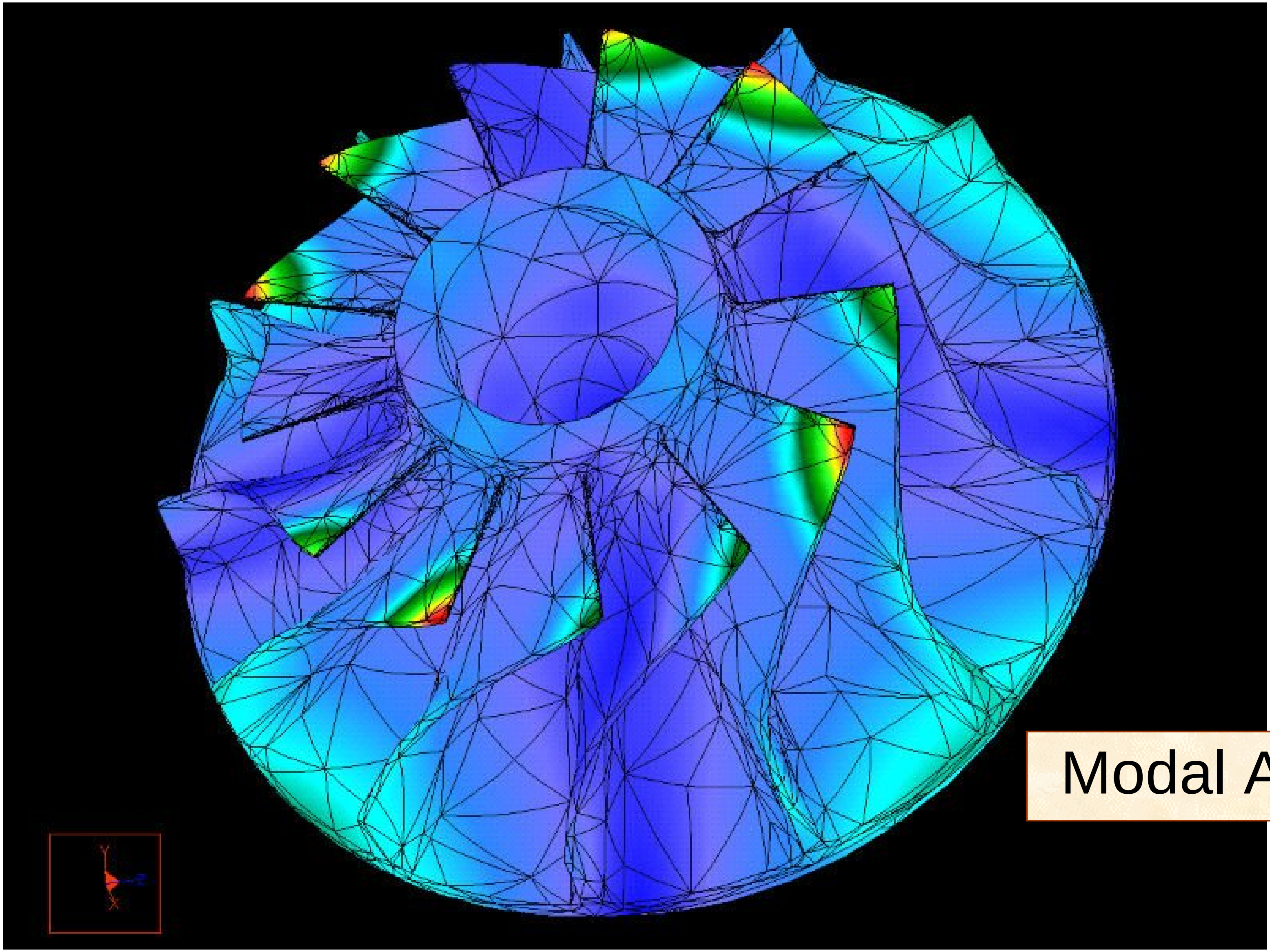
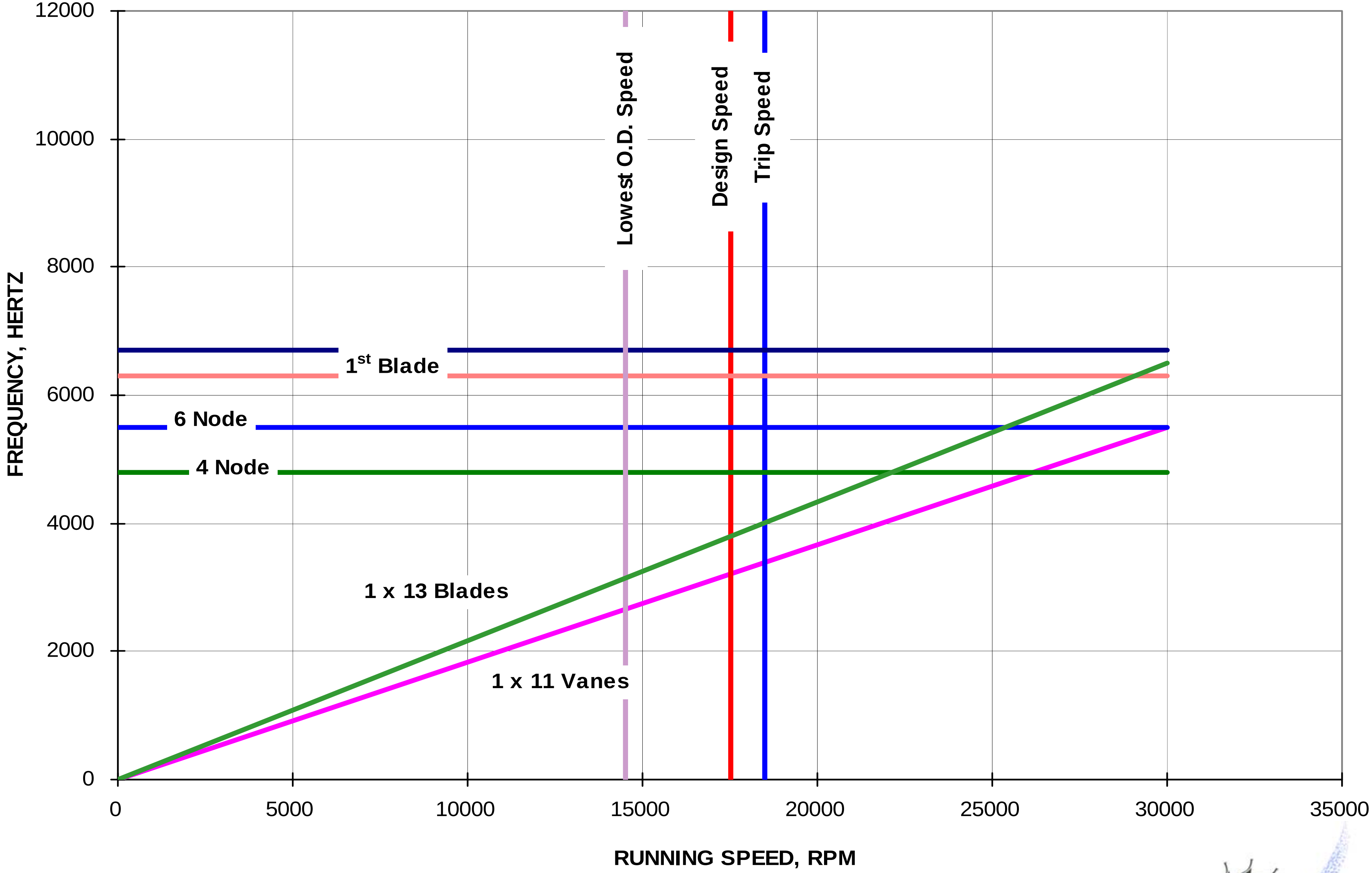
Finite Element Modeling

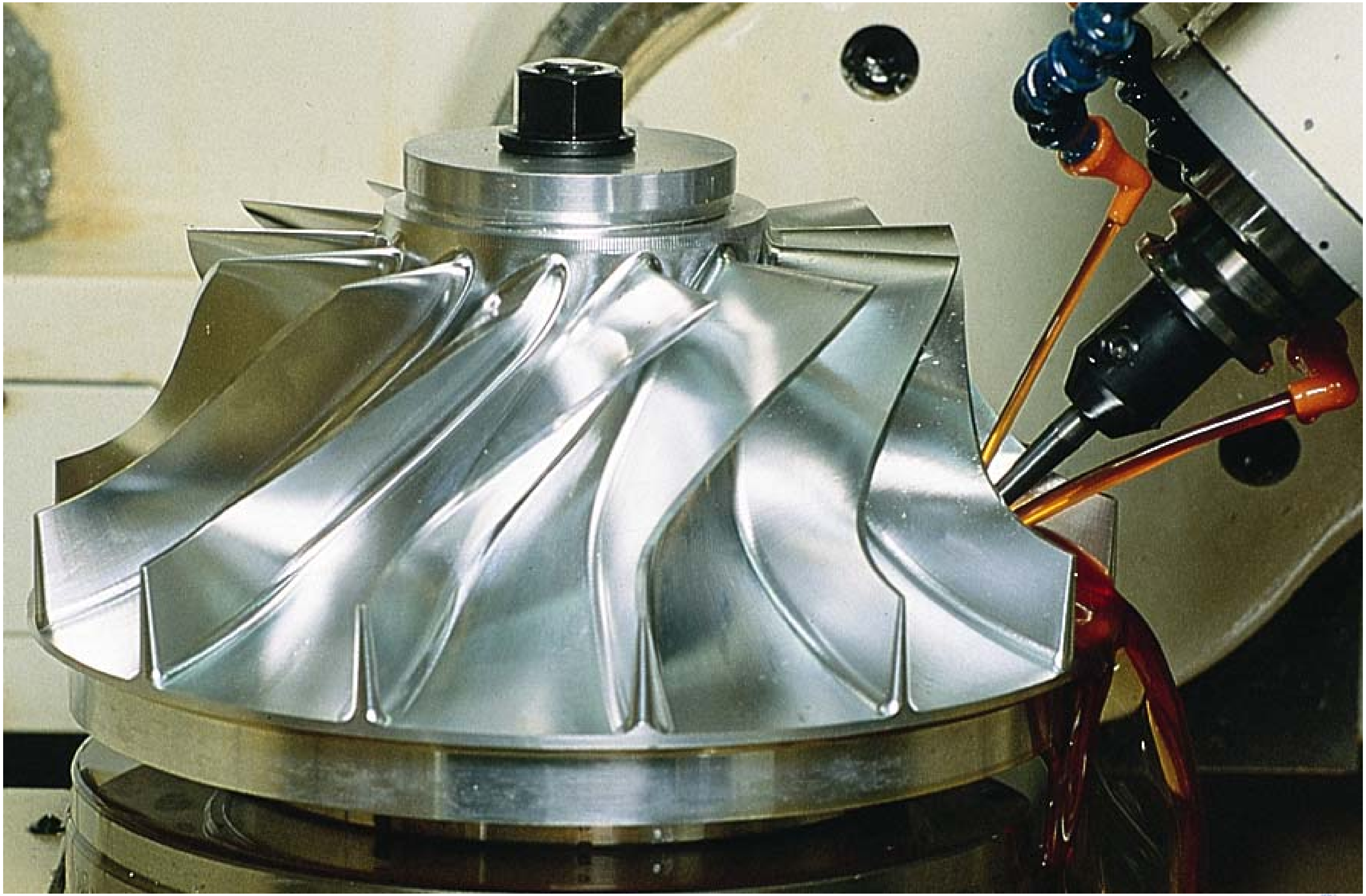


Modal Analysis

Typical Expander Campbell Diagram



Wheel Manufacture



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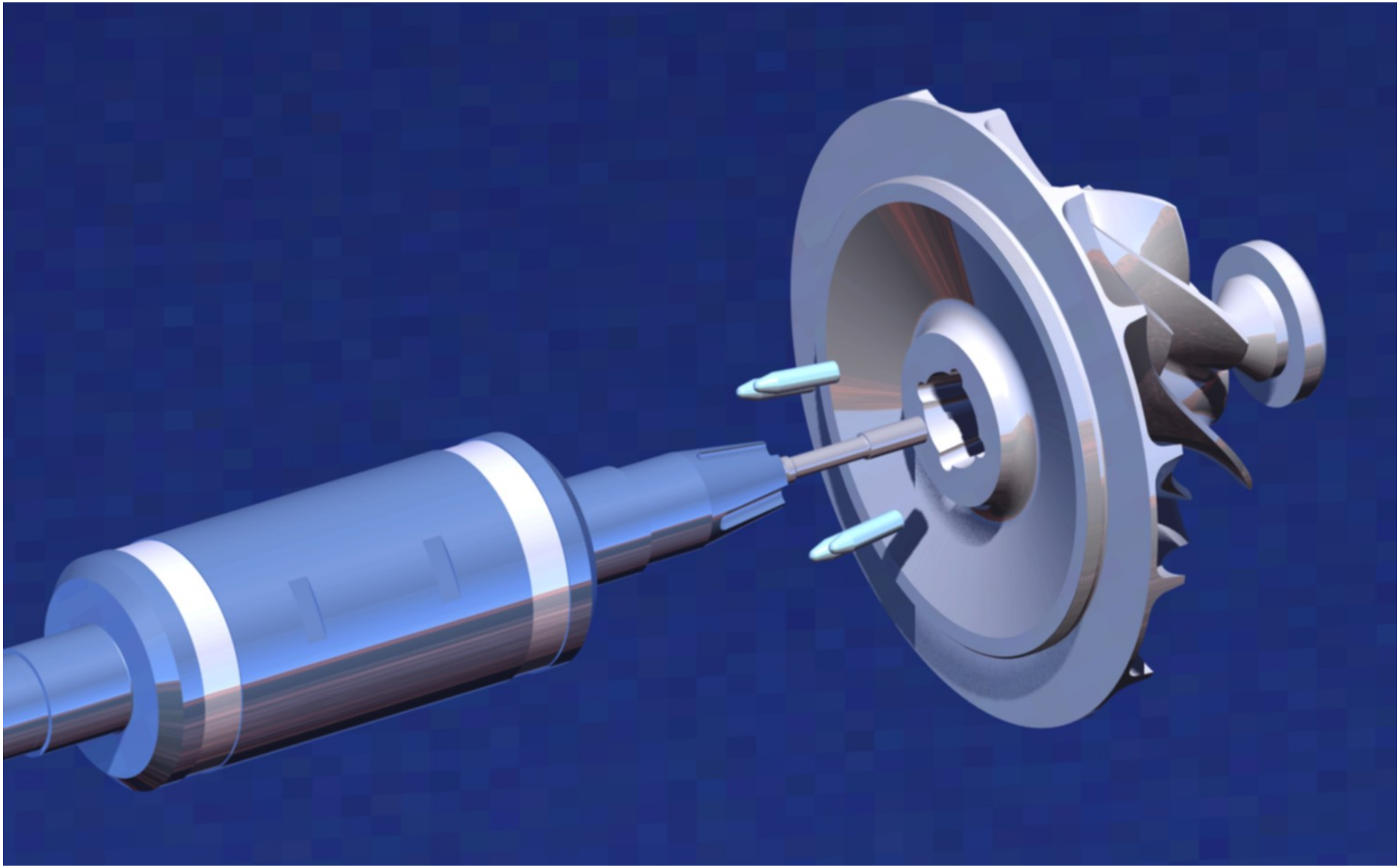
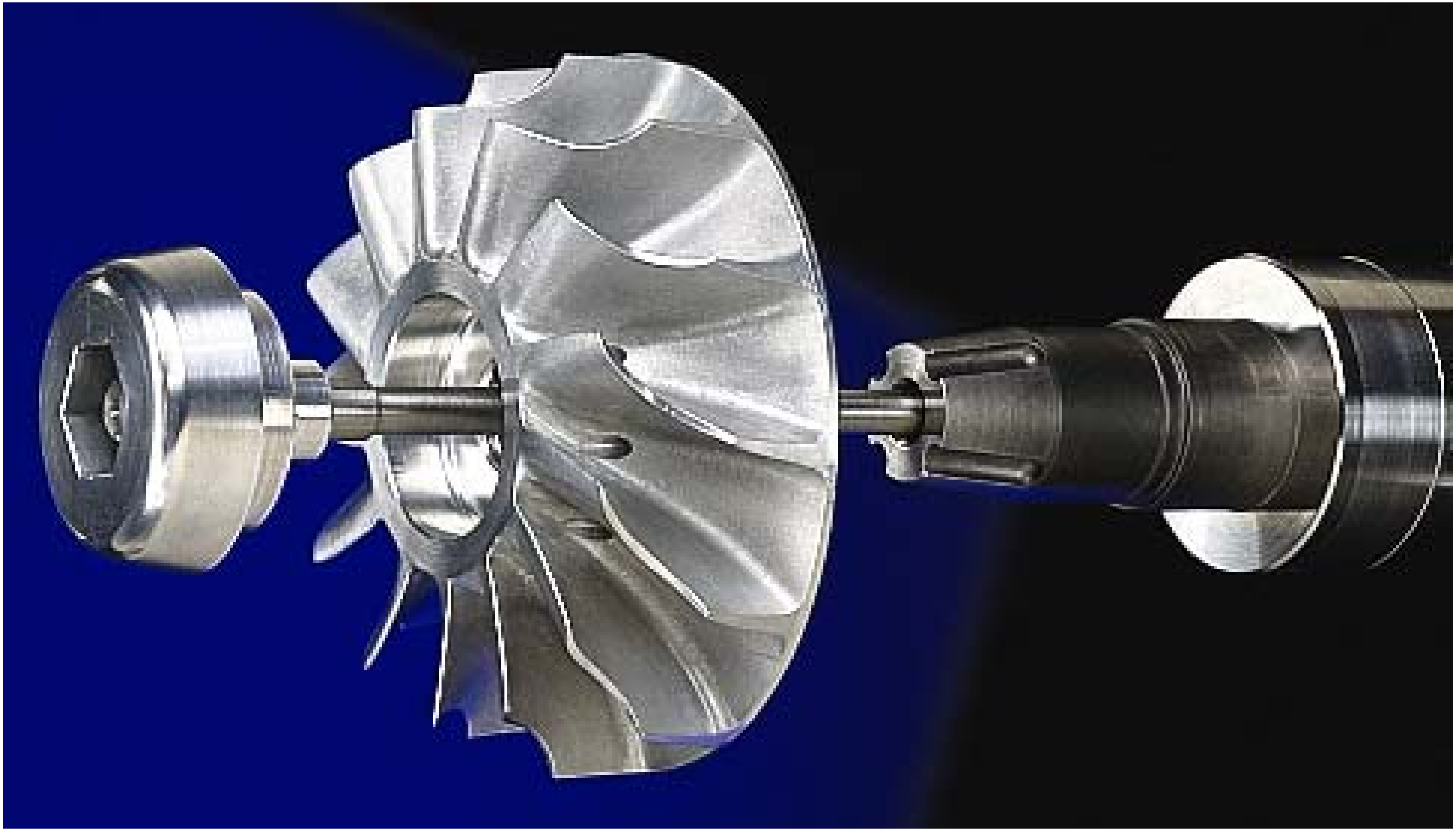
Shaft Attachment



Shaft Attachment



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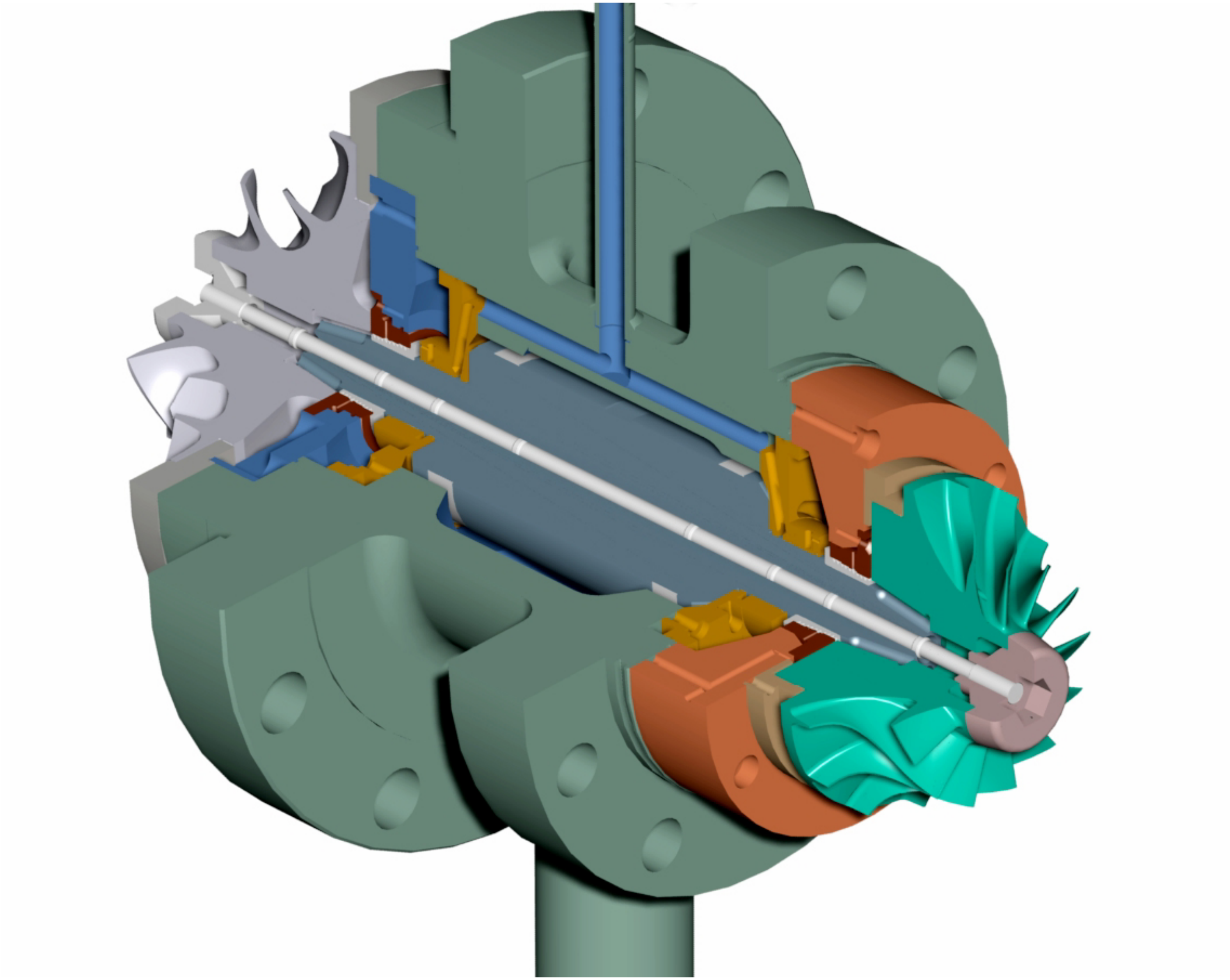
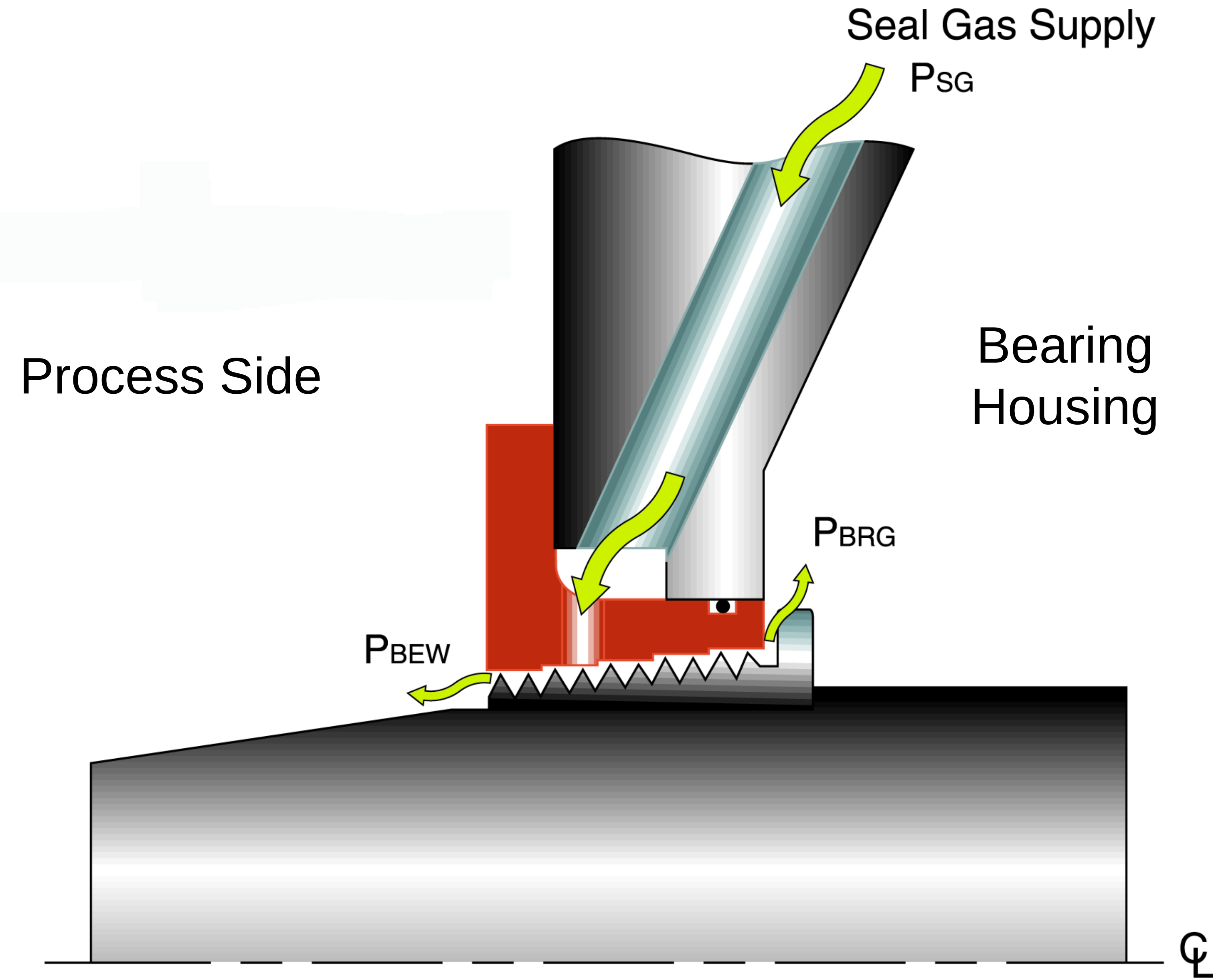
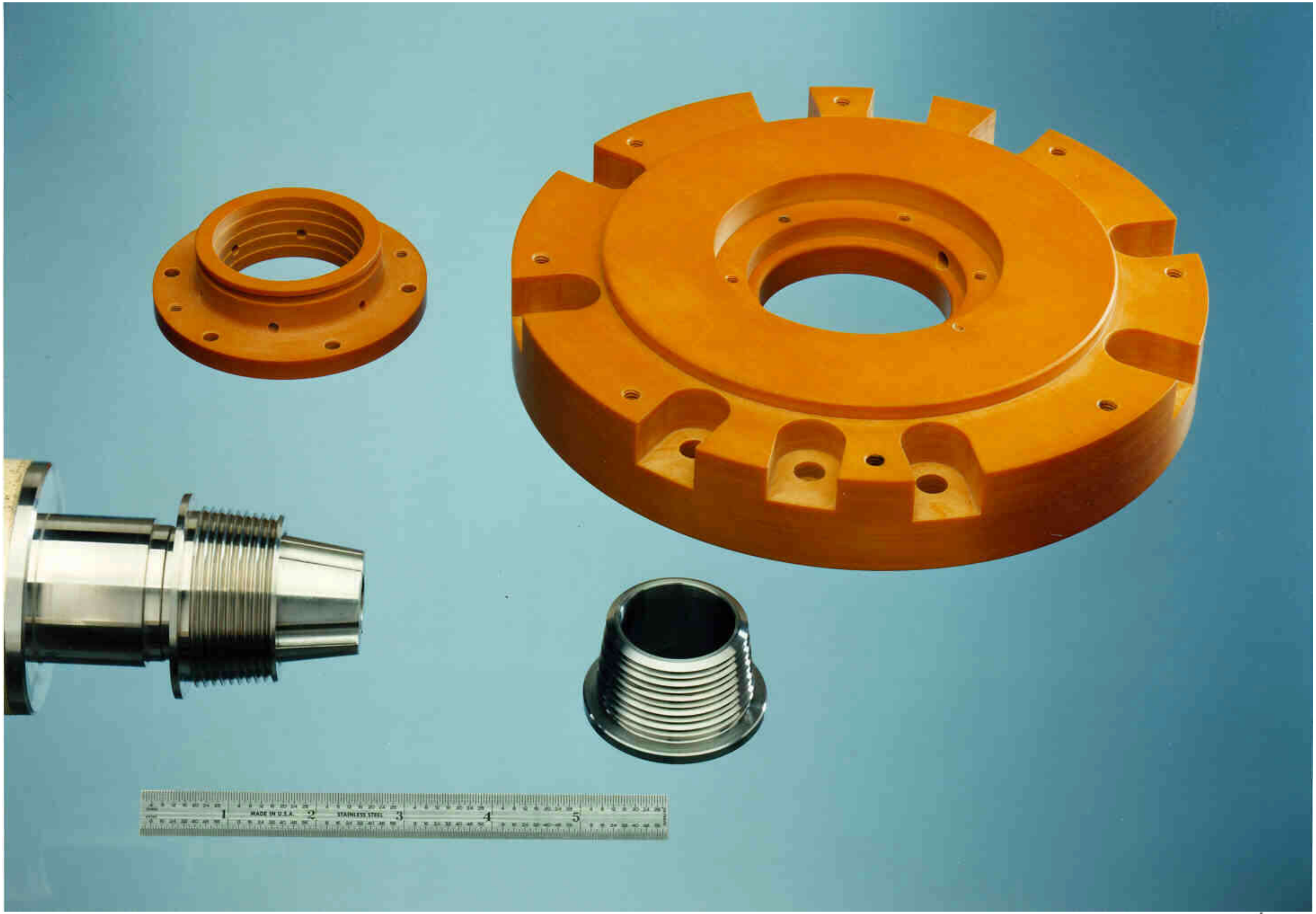
Shaft Attachment



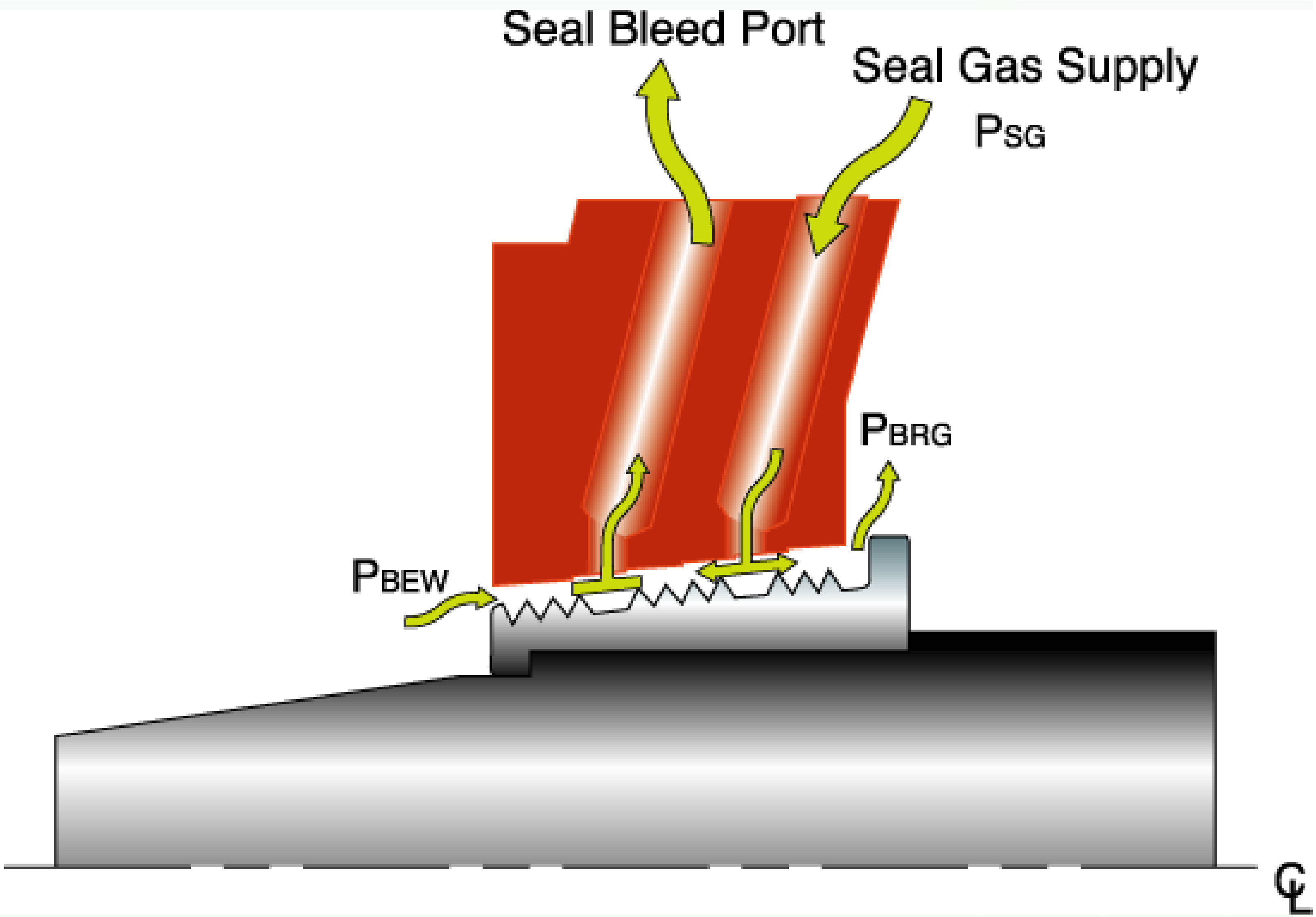
Single Port Labyrinth Seal



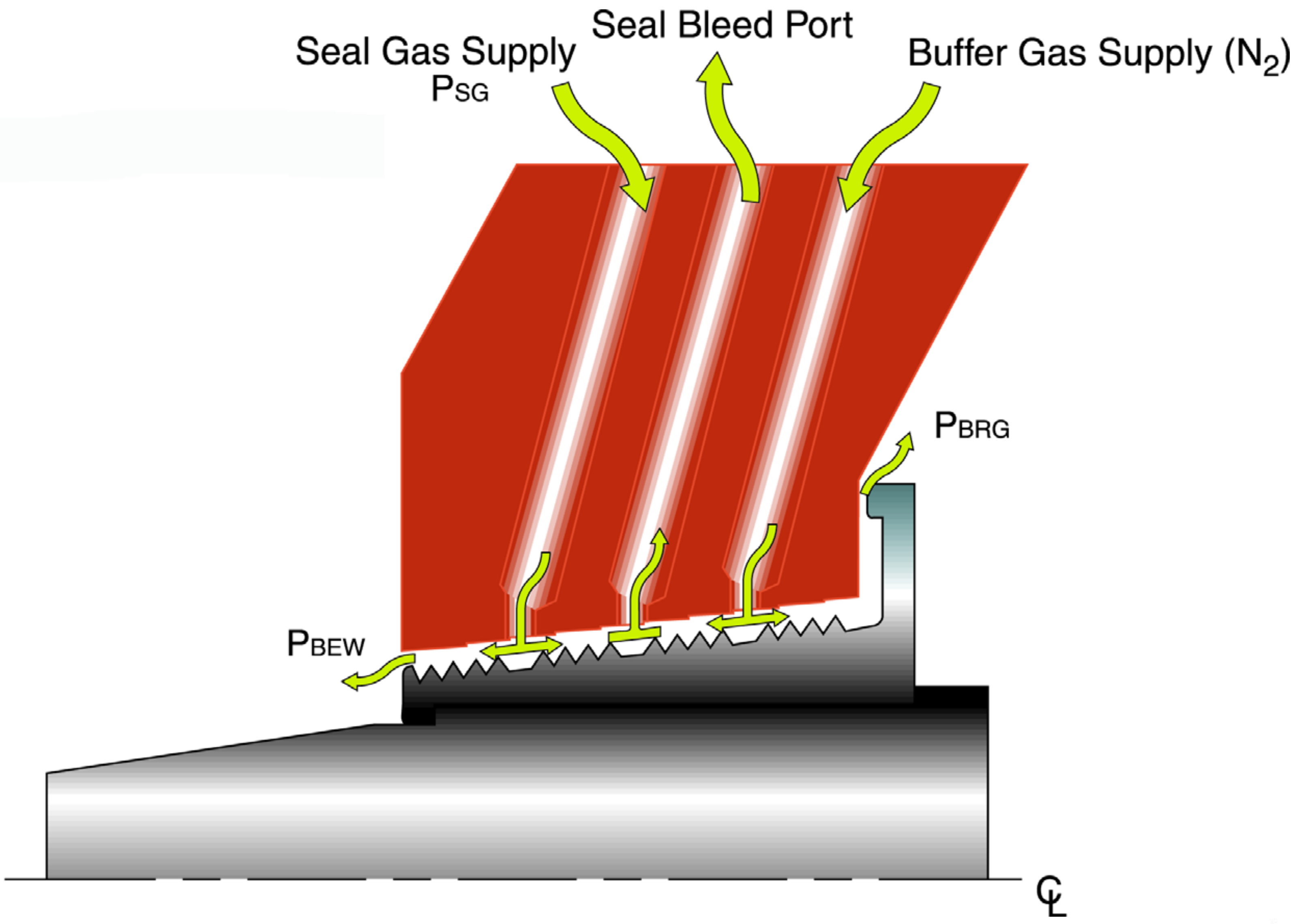
Shaft Seals



Two Port Labyrinth Seal



Three Port Labyrinth Seal



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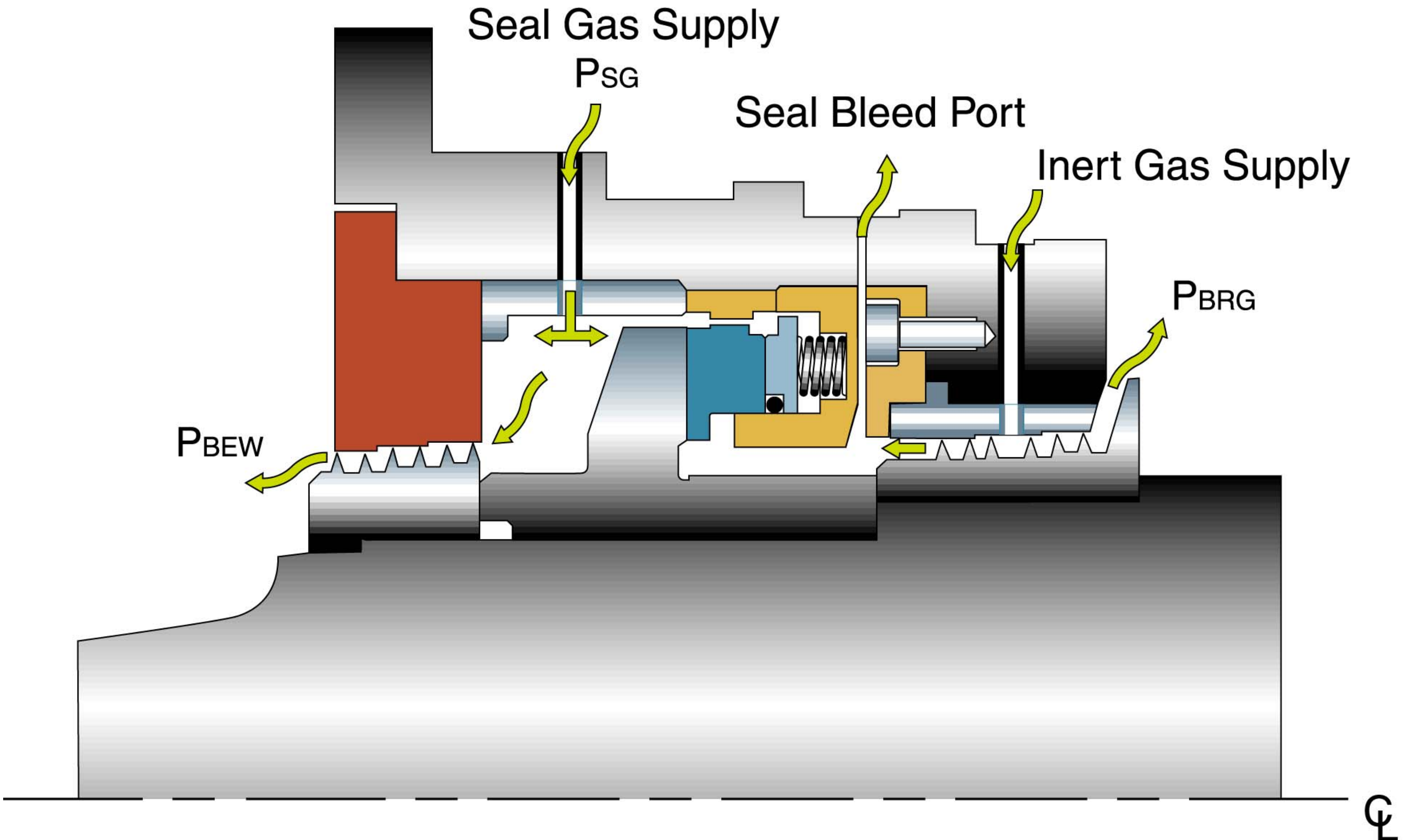
Dry Gas Seal

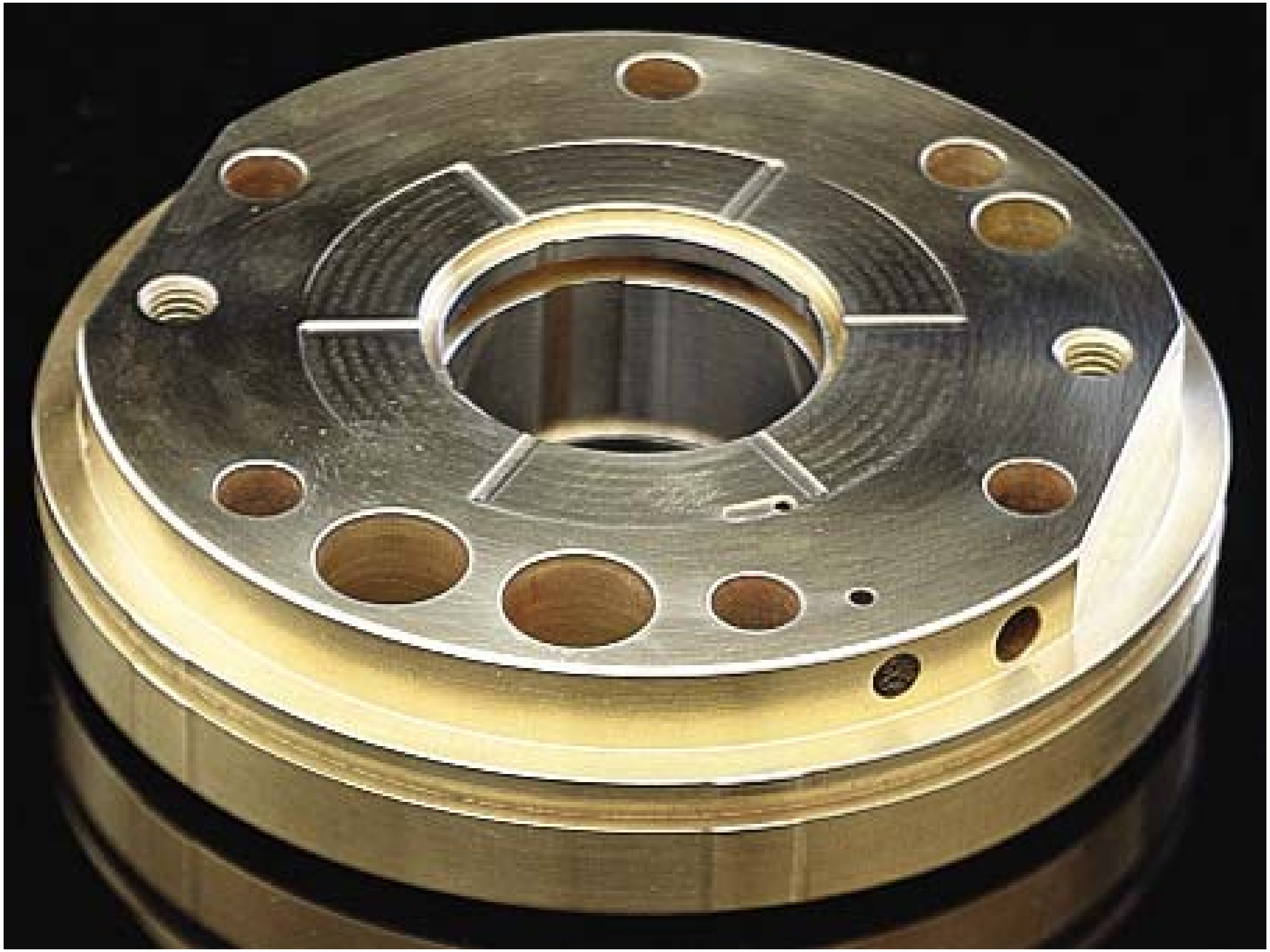


Seal Gas Supply
PSG
Seal Bleed Port
Inert Gas Supply
PBRG
PBEW
CL

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

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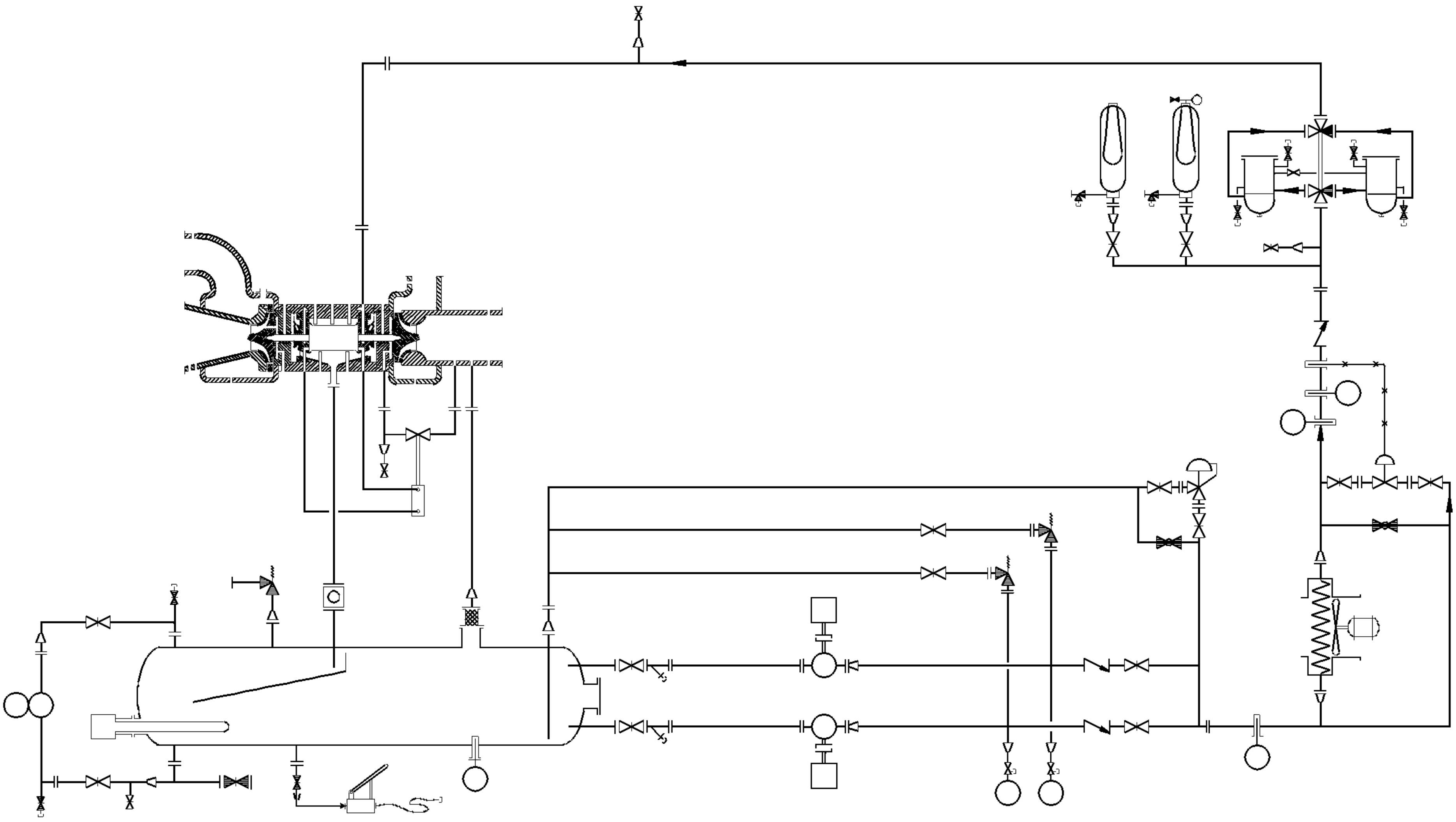
Turboexpander Auxiliaries



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, 20ºC superheated
- Pre-conditioning
  - Heating
  - Liquid removal
  - Filtration

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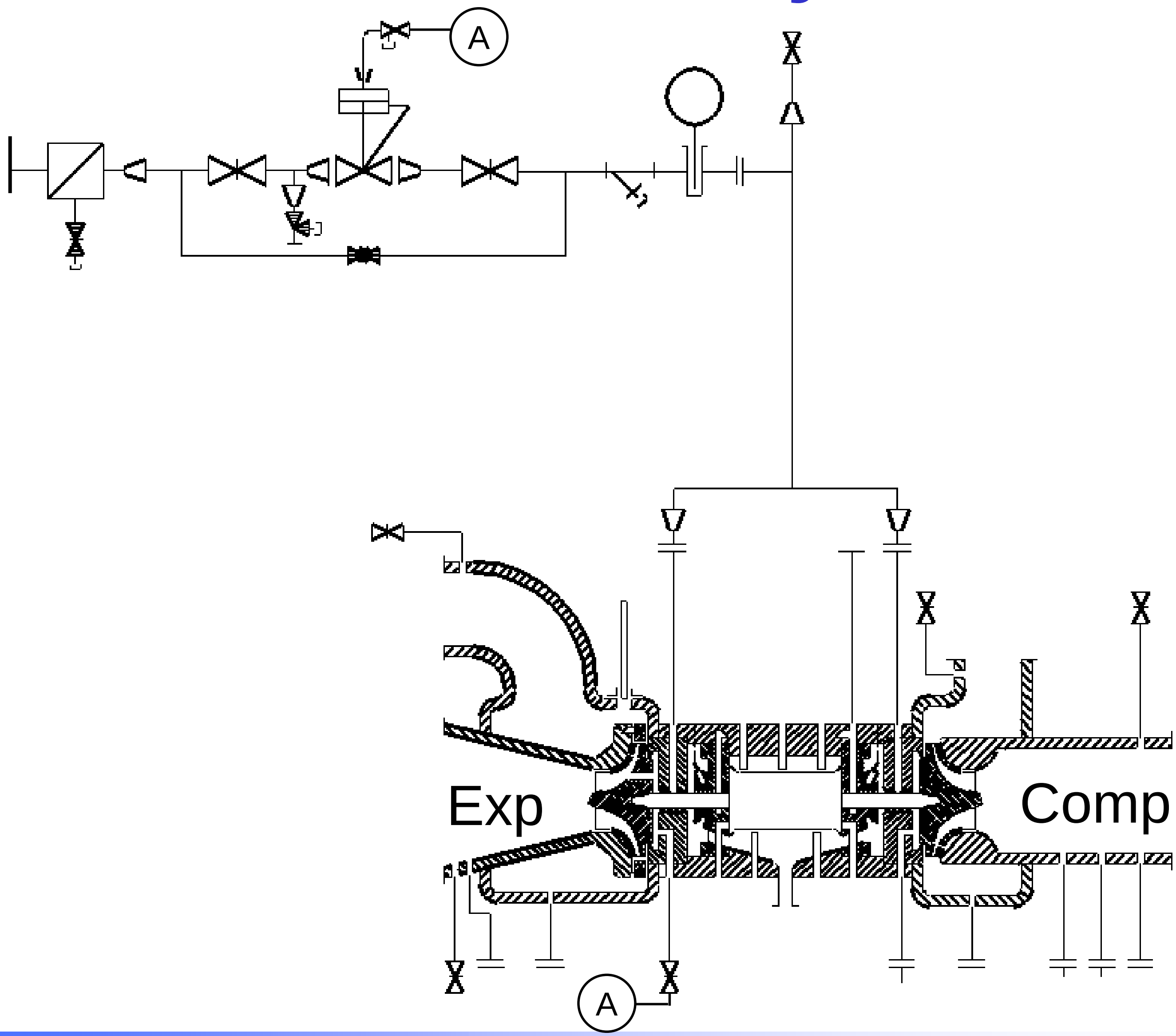
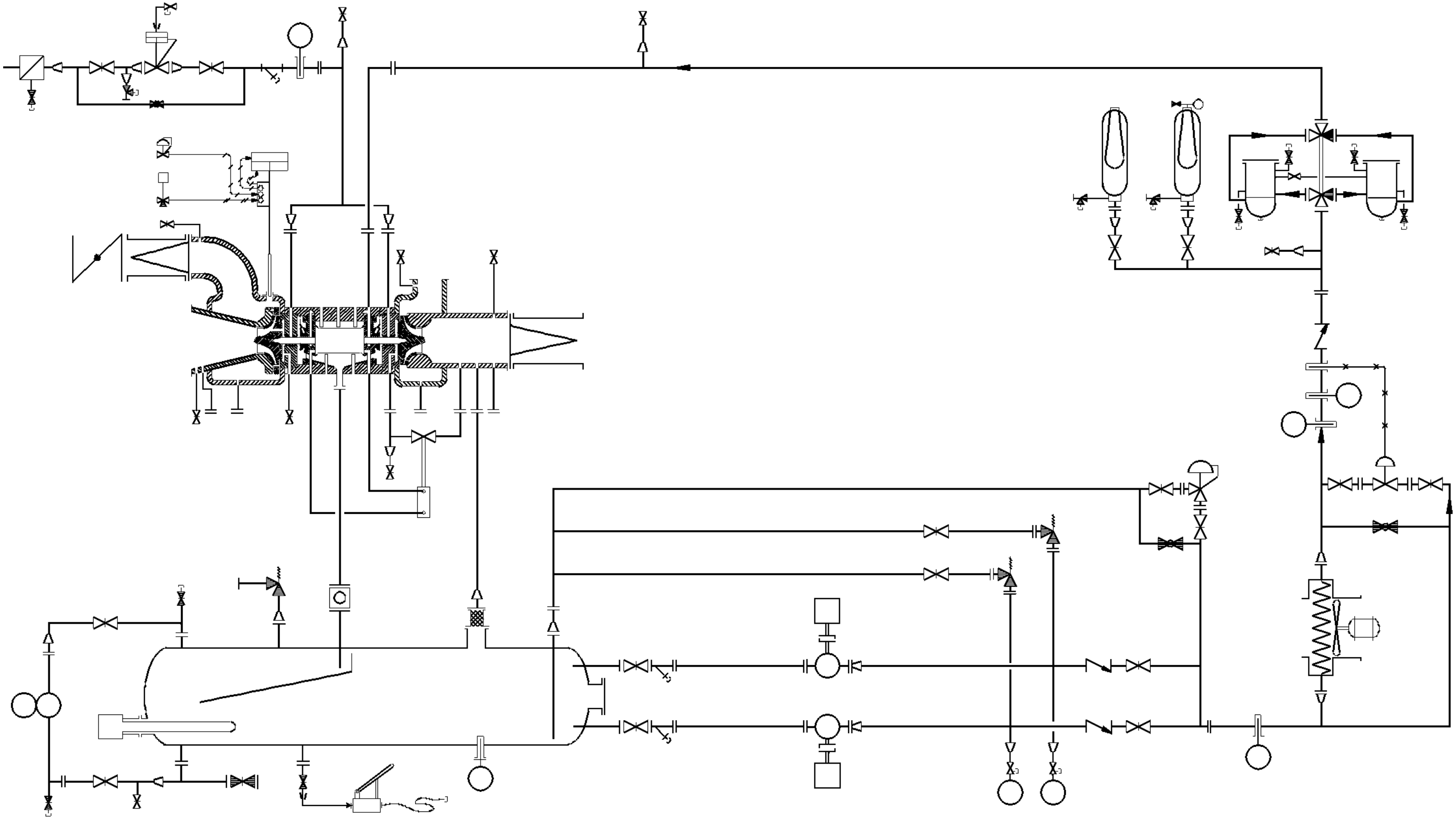
Turboexpander Auxiliaries
Seal Gas System



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



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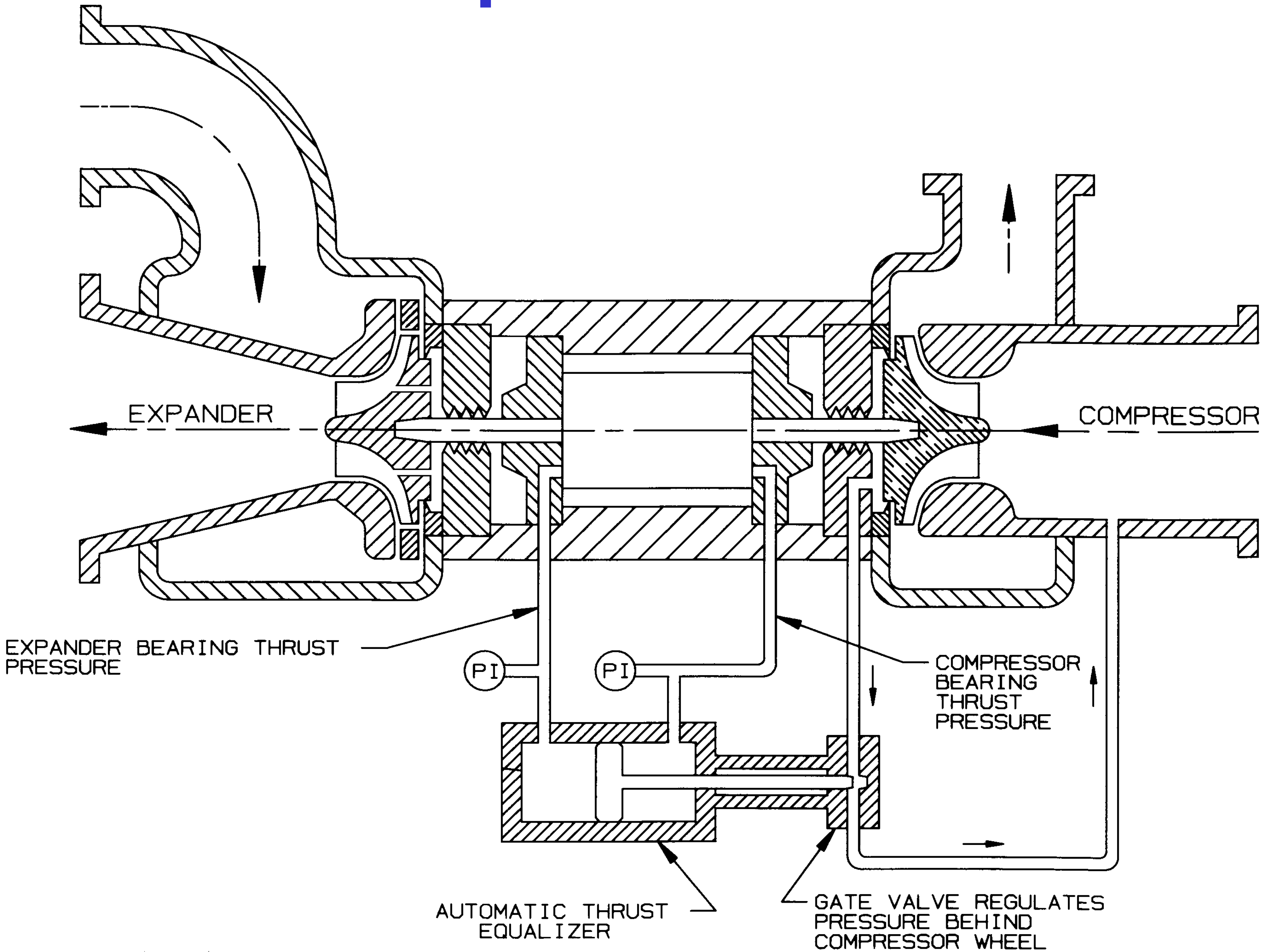
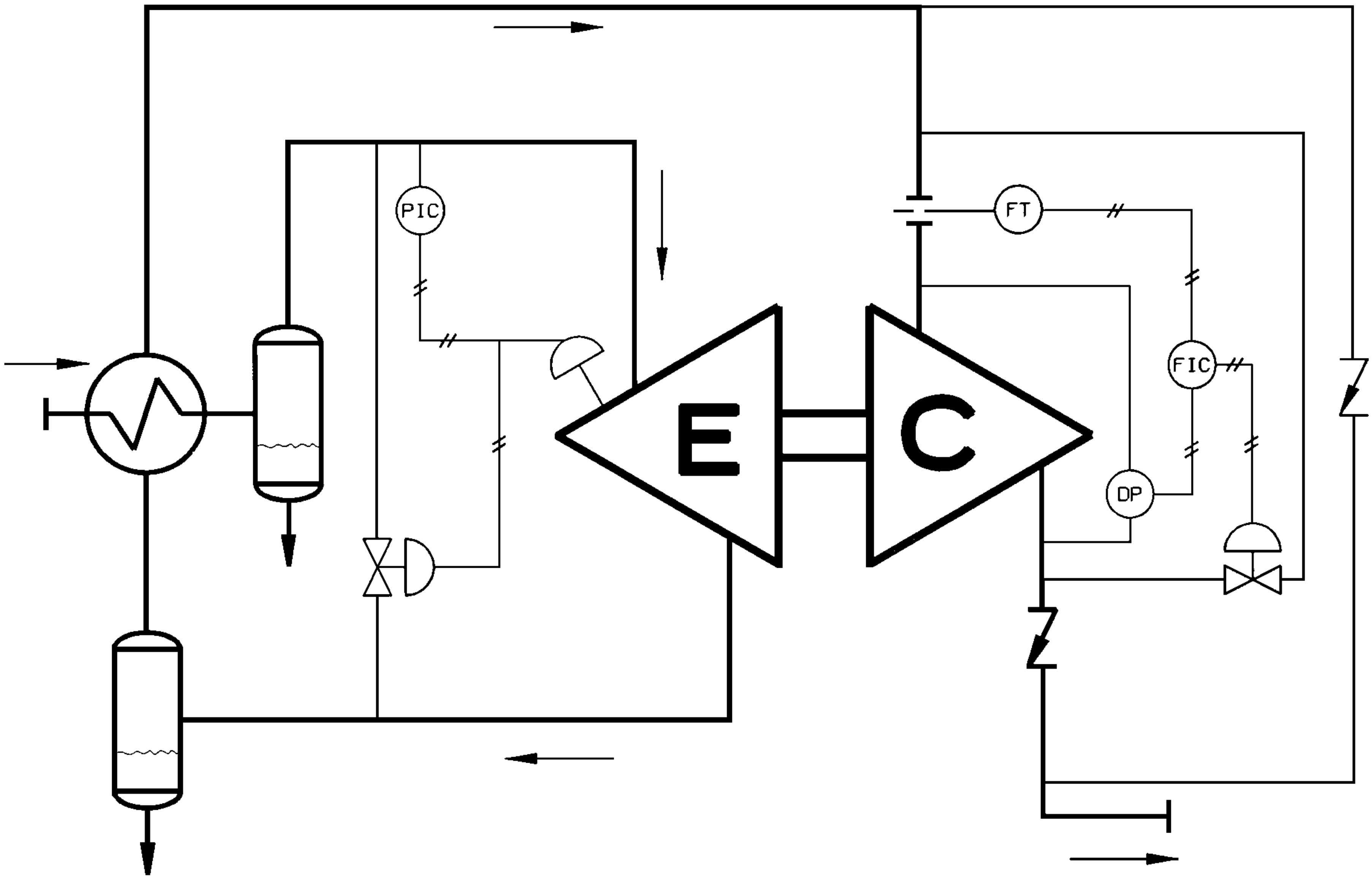
Turboexpander Auxiliaries

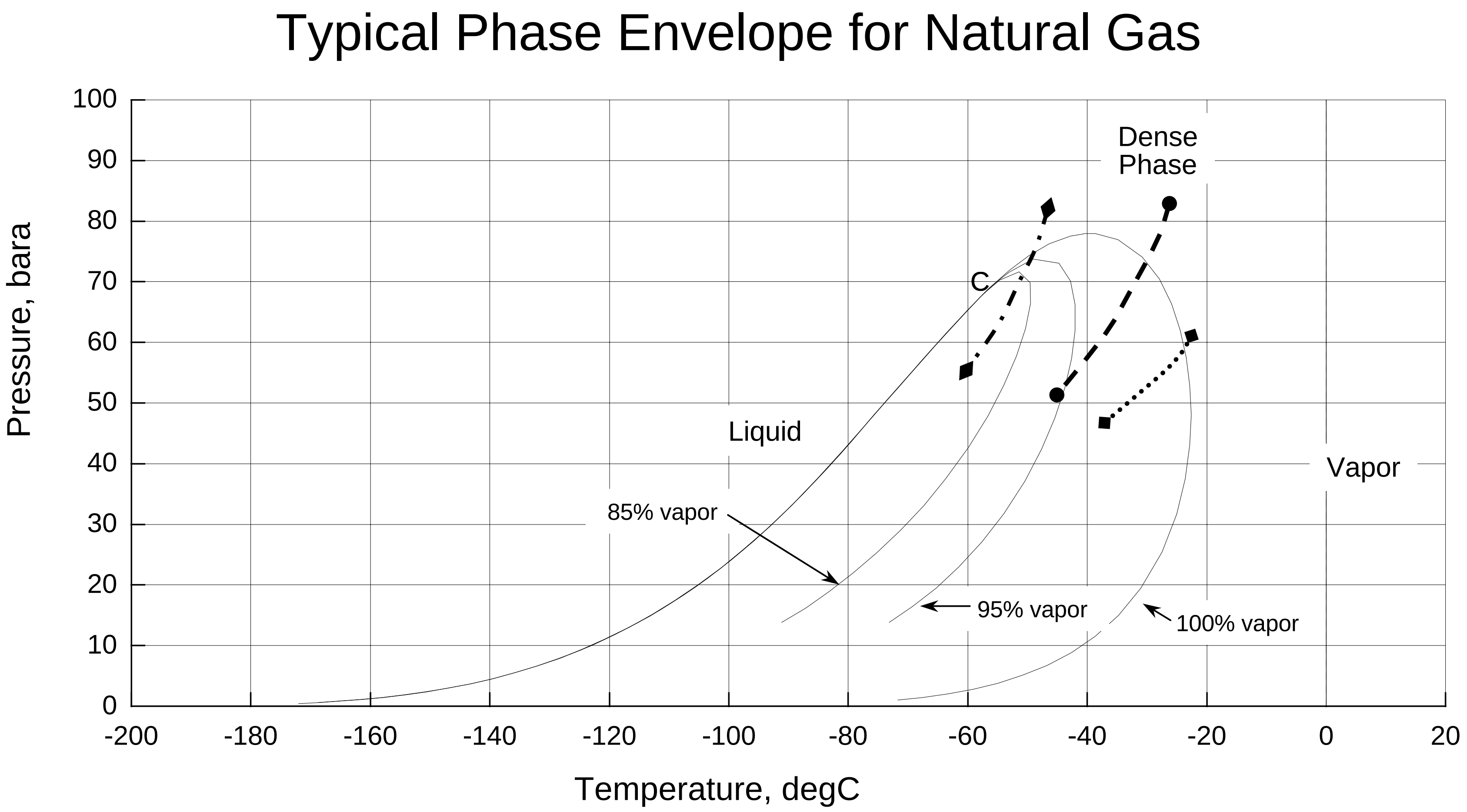


Automatic Thrust Equalizer System

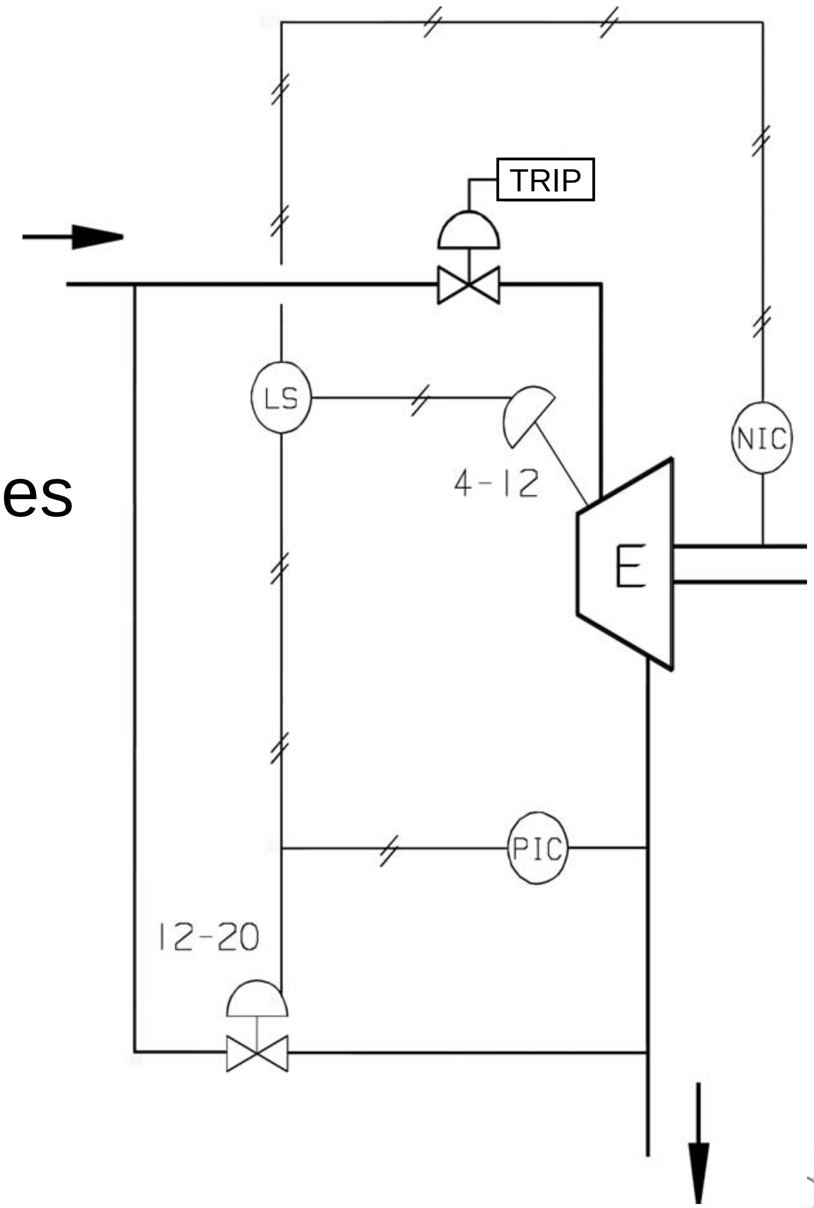
Typical Turboexpander Process



Turboexpander/Compressor Operation



Turboexpander/Compressor Operation

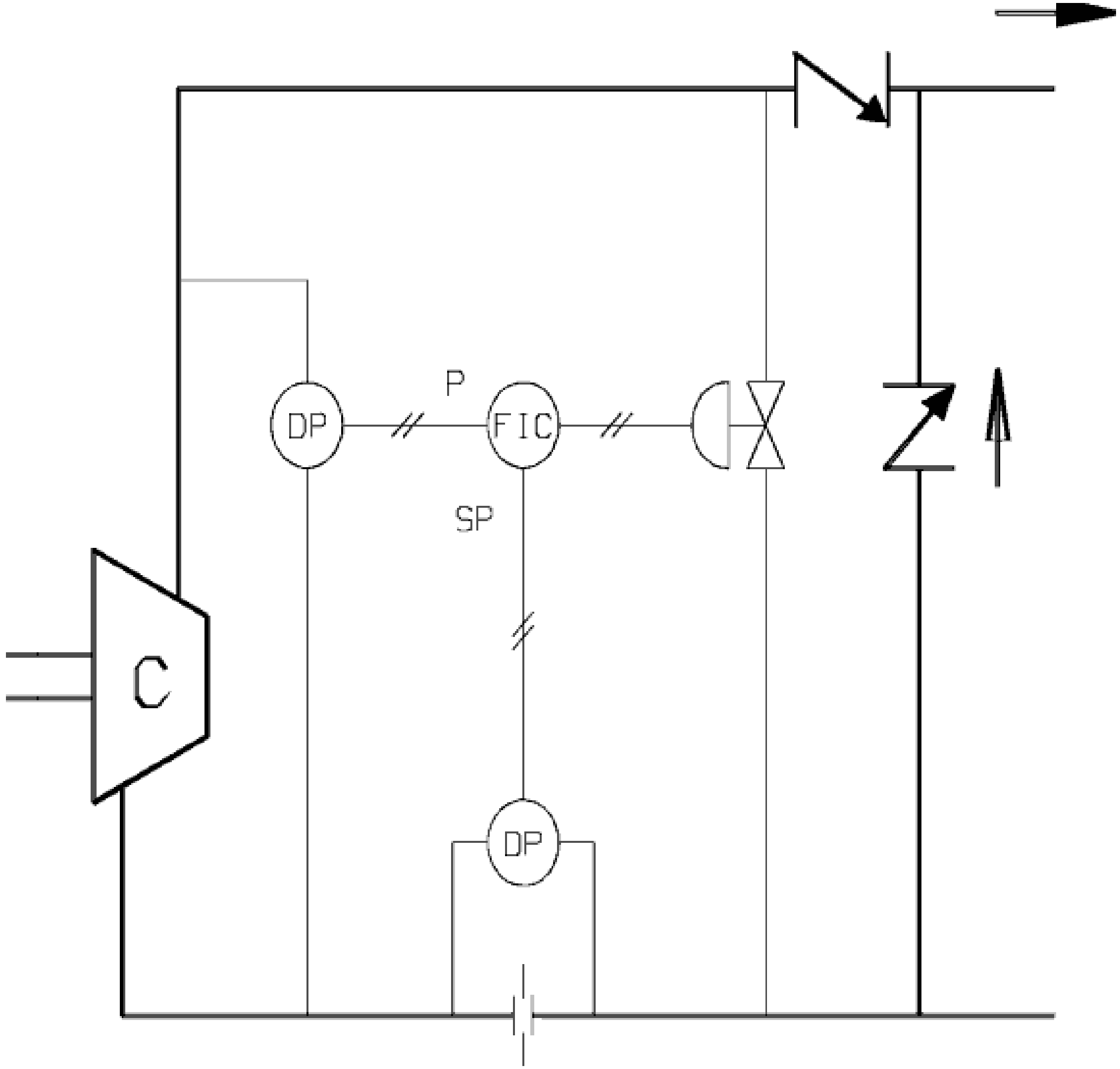


Expander Inlet Guide Vanes

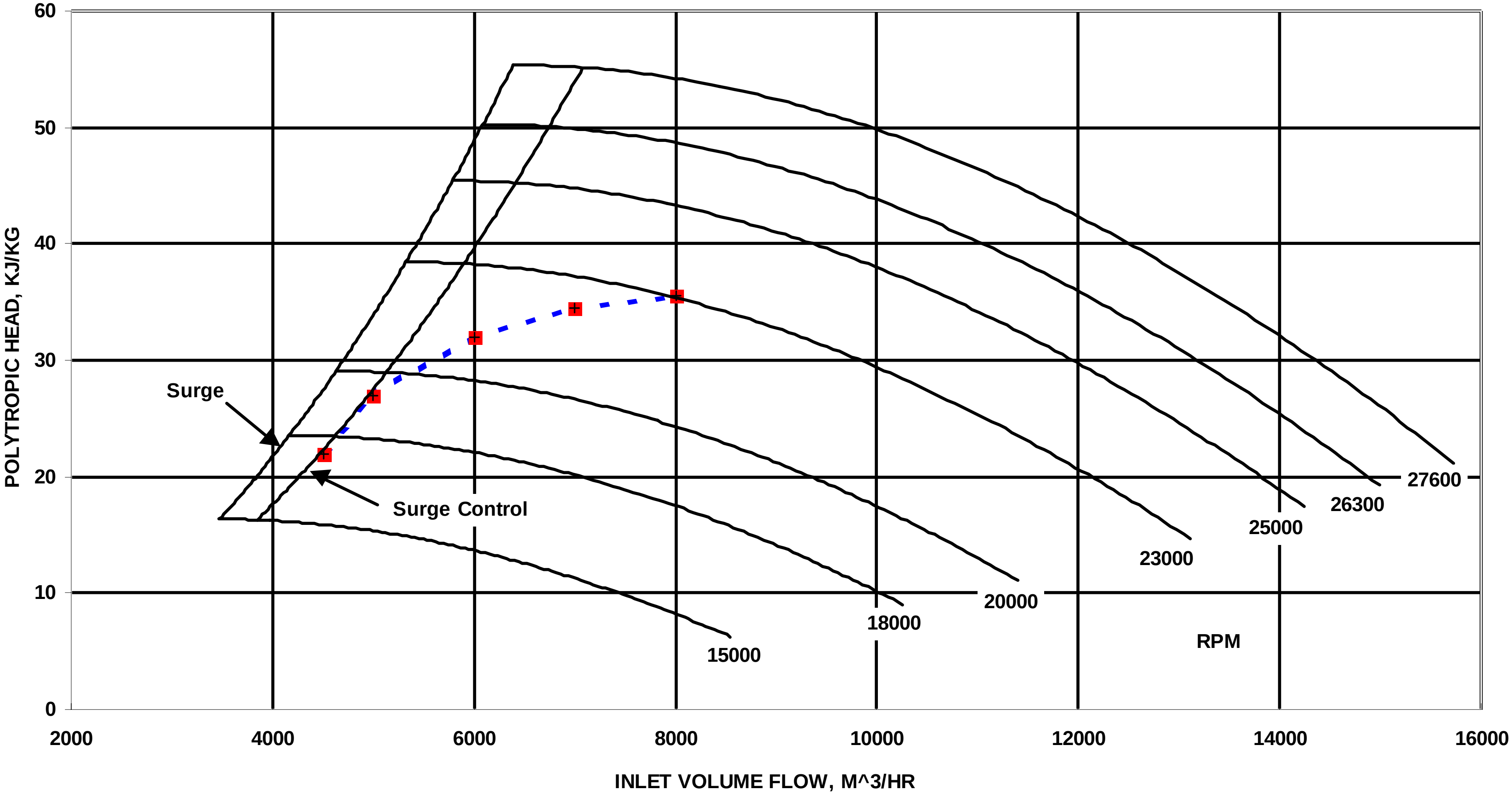
- Split Range with J-T valve
- Speed Override (optional)

Turboexpander/Compressor Operation

Surge Control System



Typical Compressor Performance Map



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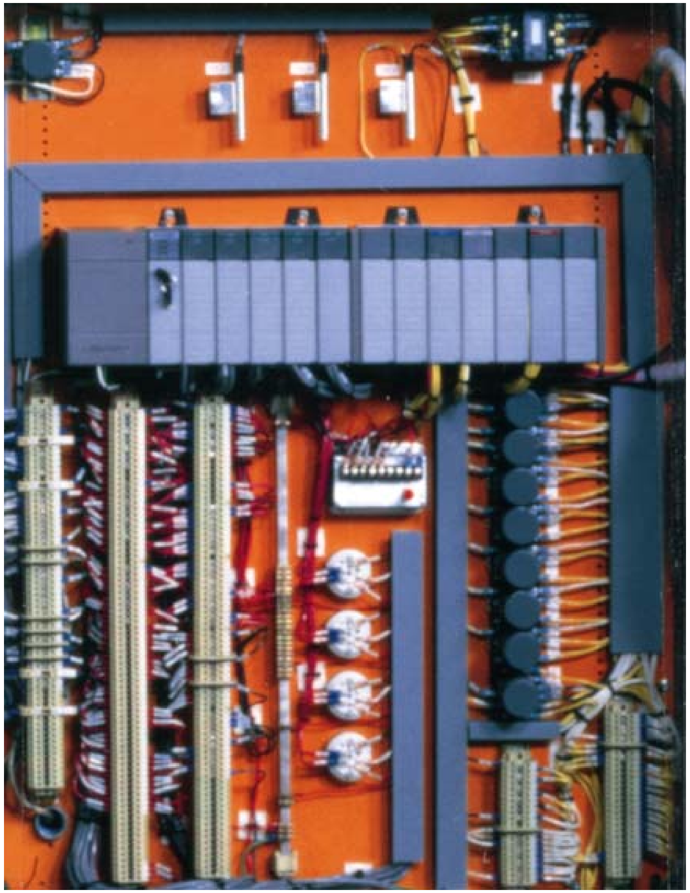
Turboexpander Systems



Programmable Control & Instrumentation System (ProCIS)

Turboexpander Systems

Remote PLC panel with Video Display Unit

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Turboexpander Factory Testing

Component

- Impeller overspeed
- Hydrotest Casings
- Shaft/Impeller balancing

Turbomachinery

- Mechanical
- Performance
  - Expander
  - Compressor

System

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

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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

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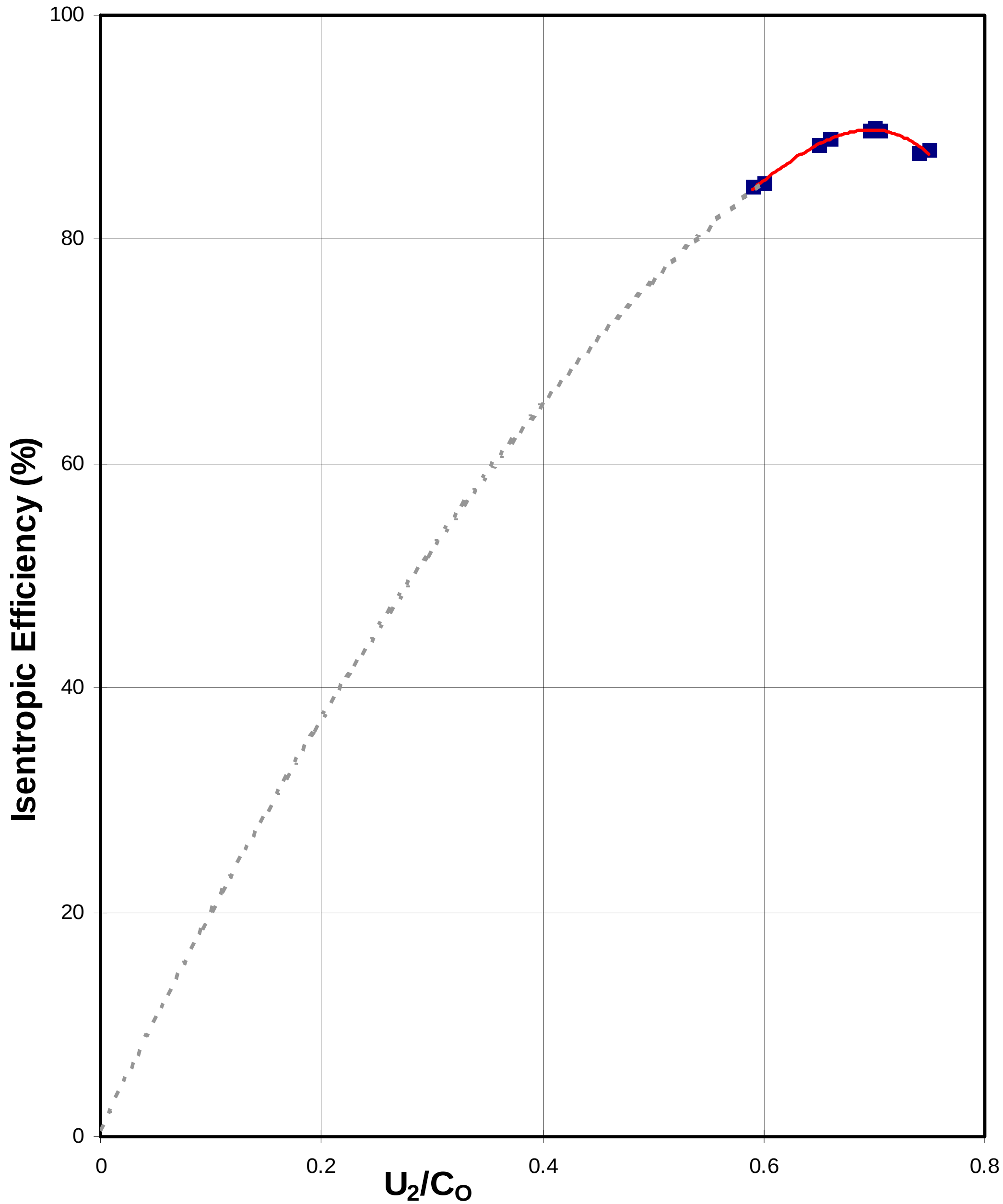
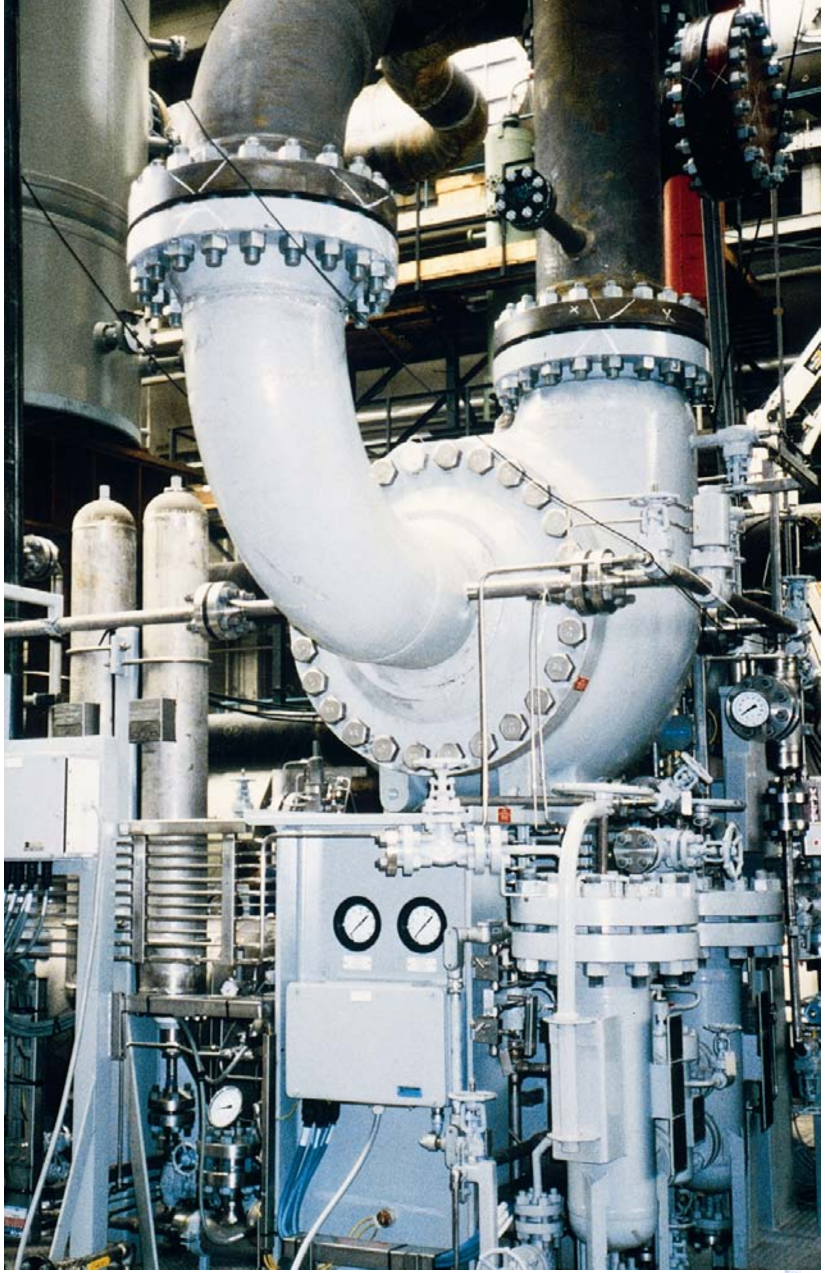
Typical Expander Performance Curve



Full Power Full Pressure Testing

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



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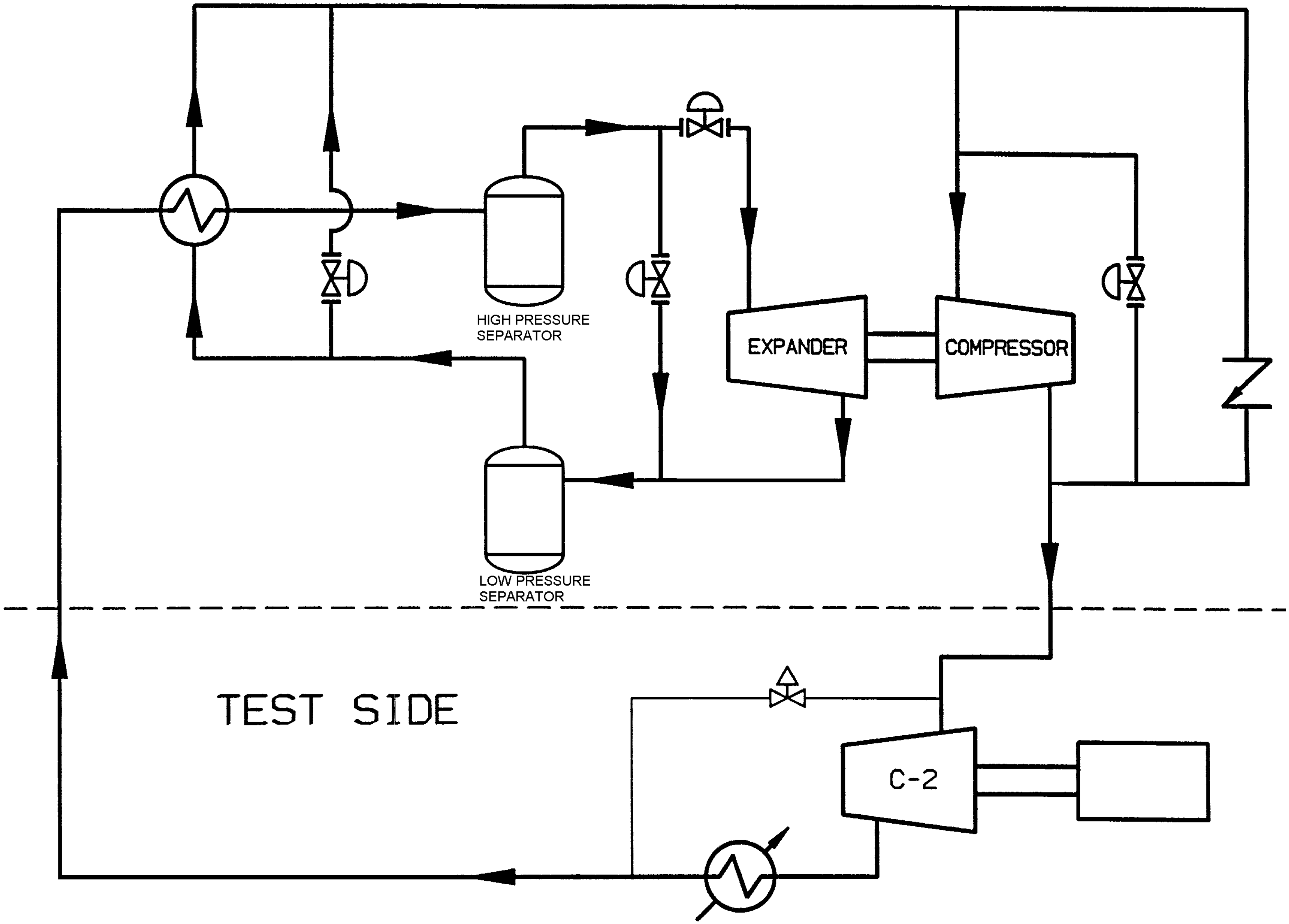
Full Power Test Schematic



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Magnetic Bearings

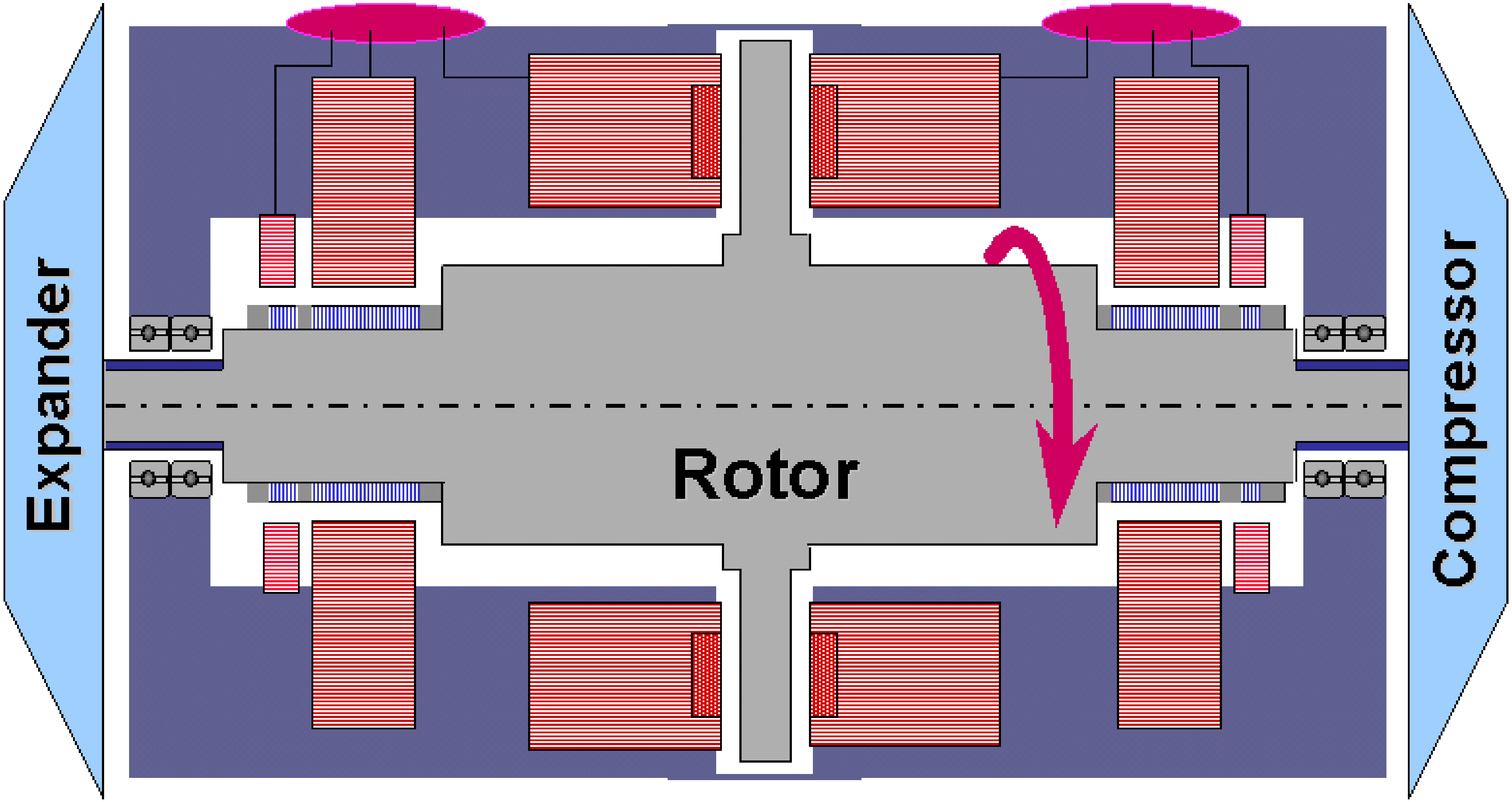
Magnetic bearing equipped EC3.5 in ethylene service

Magnetic Bearings

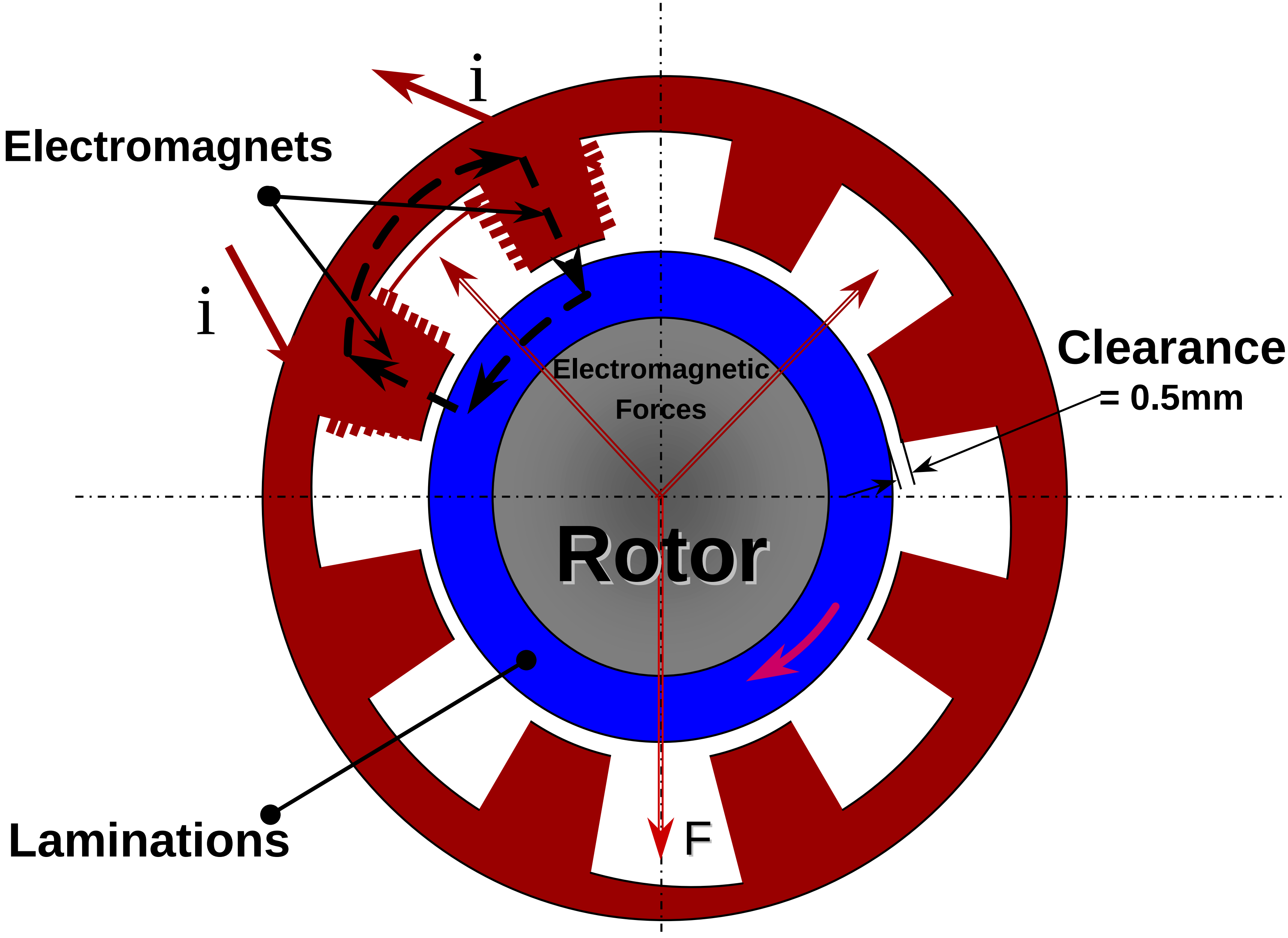
- Advantages
  - Eliminates oil
  - Low bearing losses
  - Smaller deck space
  - Lower weight
  - Reduced maintenance
  - Continuous monitoring of rotor parameters

- Ideal Applications
  - Ethylene Processes
  - Offshore Service
  - Environmentally sensitive locations
  - Life-Cycle Cost evaluated projects

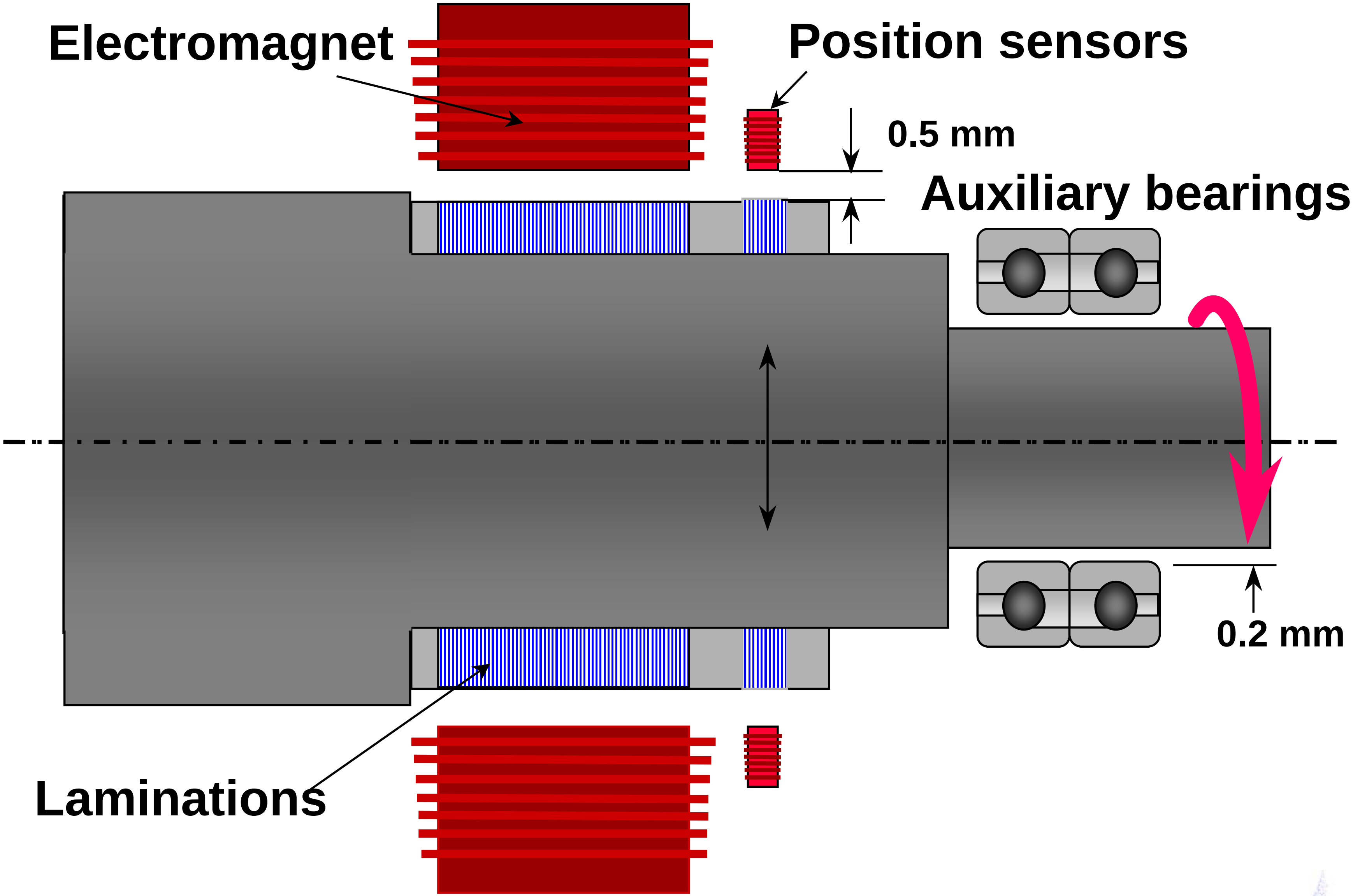
Magnetic Bearings



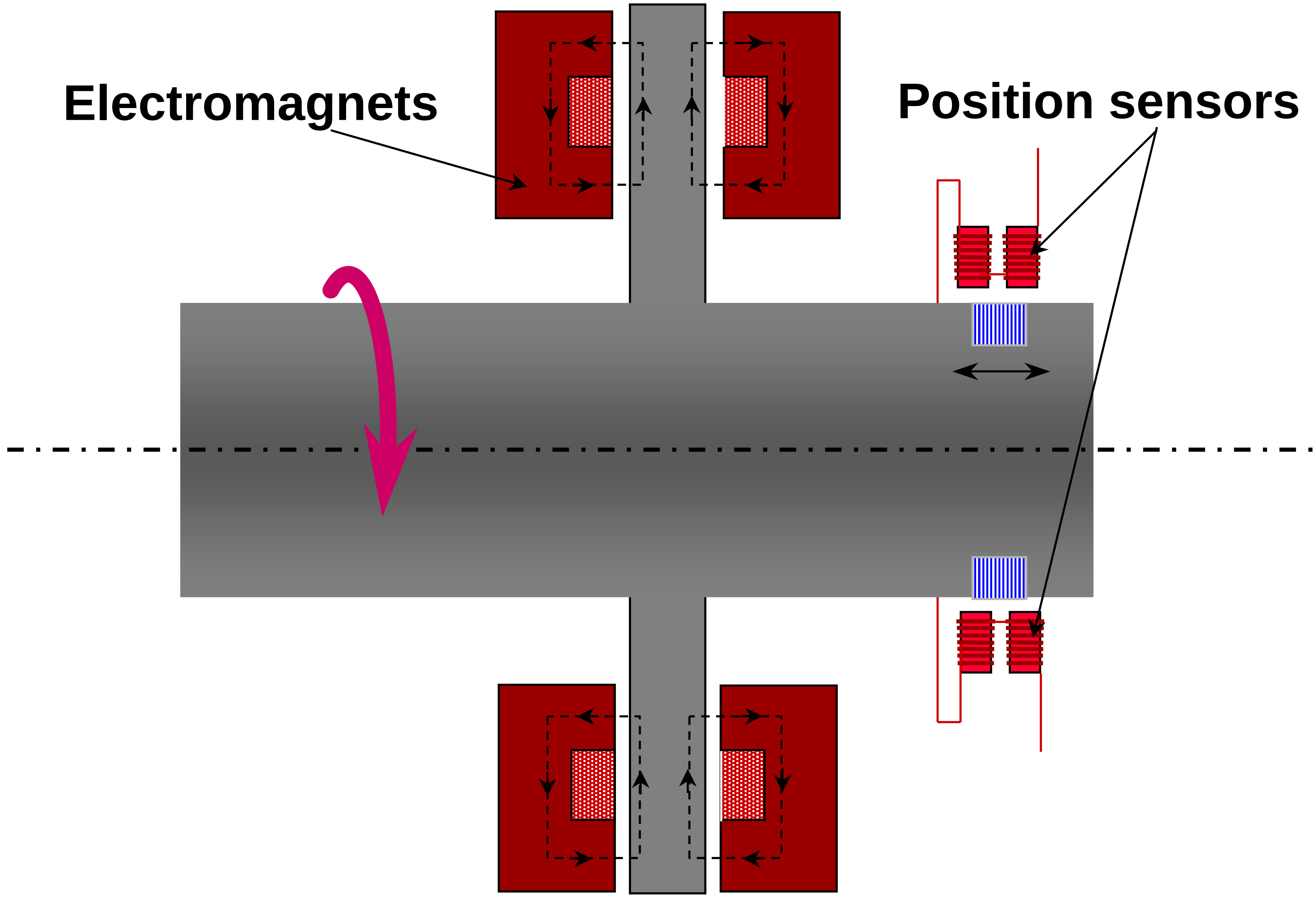
Turboexpander Bearing Set



Radial bearing

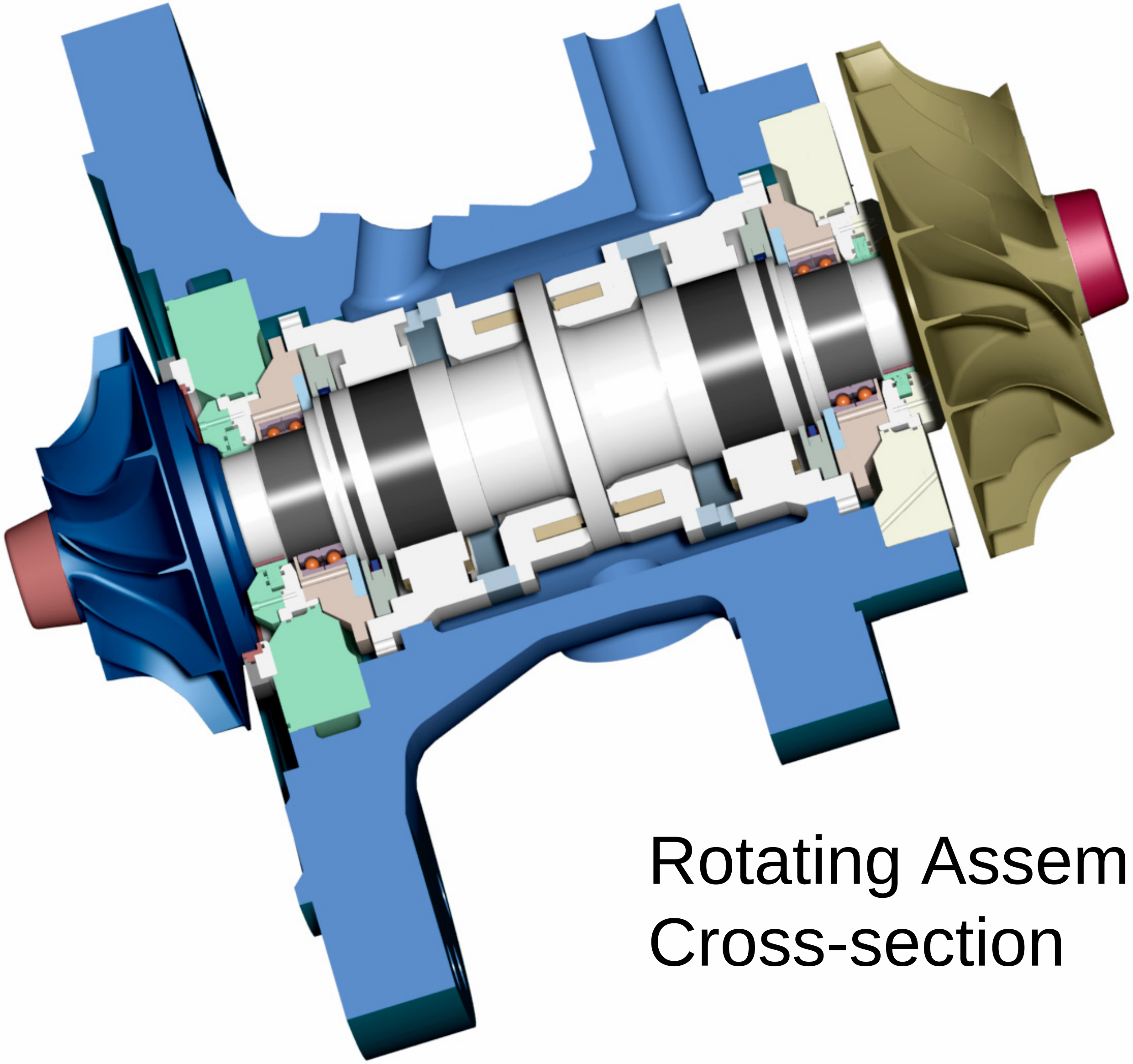


Radial bearing

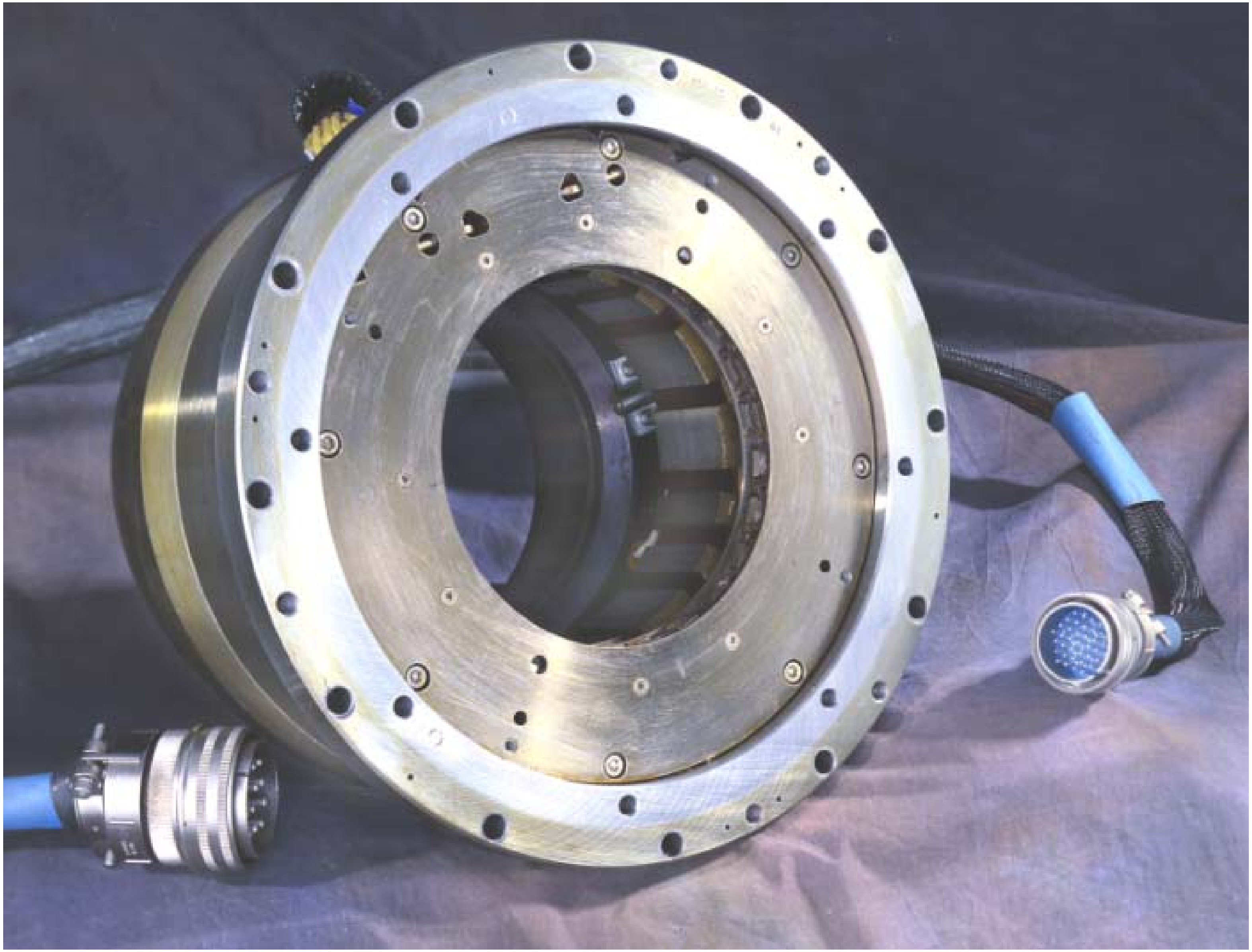


Axial bearing

Magnetic Bearings

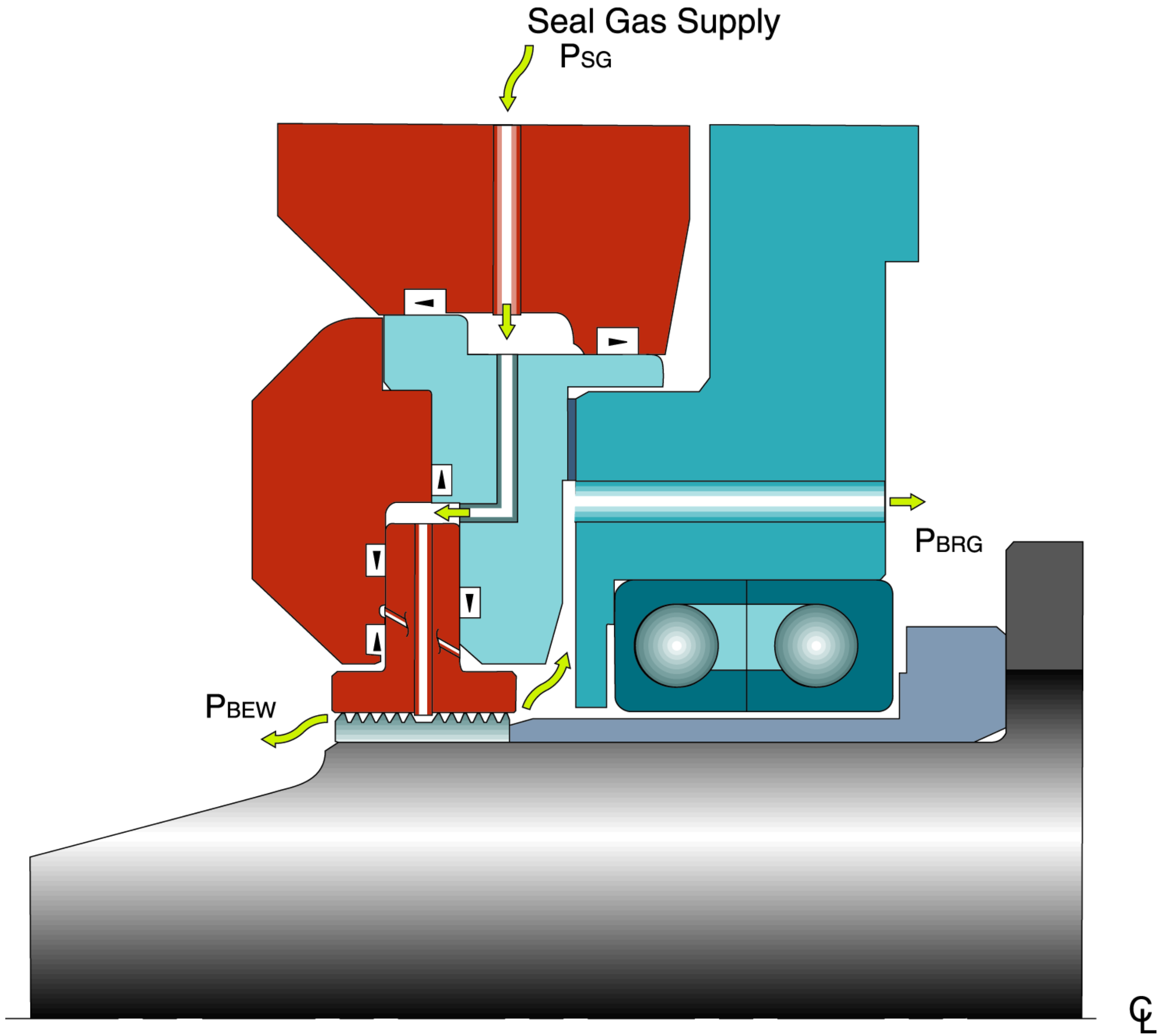


Rotating Assembly
Cross-section



Magnetic Bearing Assembly

Magnetic Bearing Floating Seal



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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

S2M

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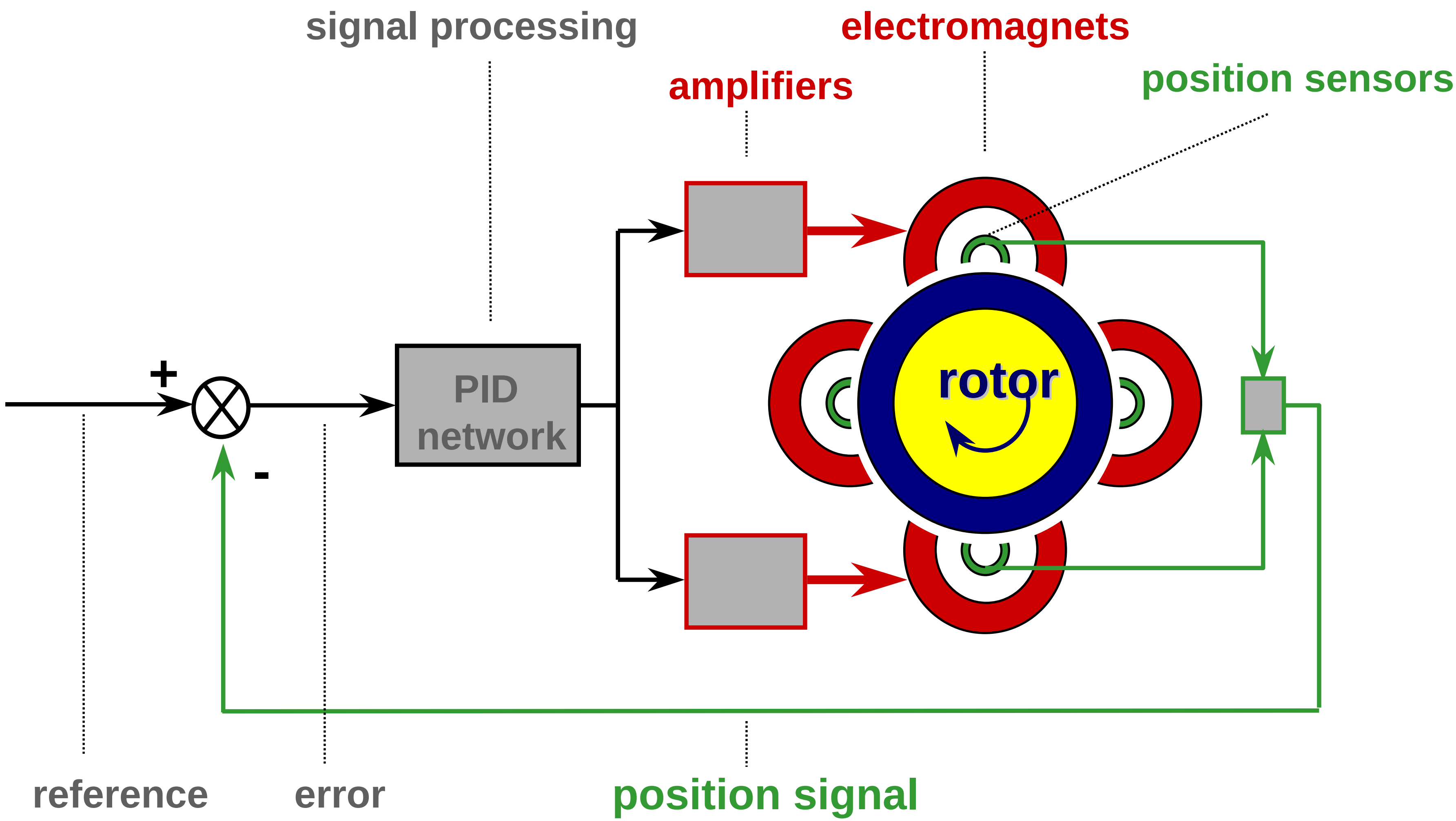
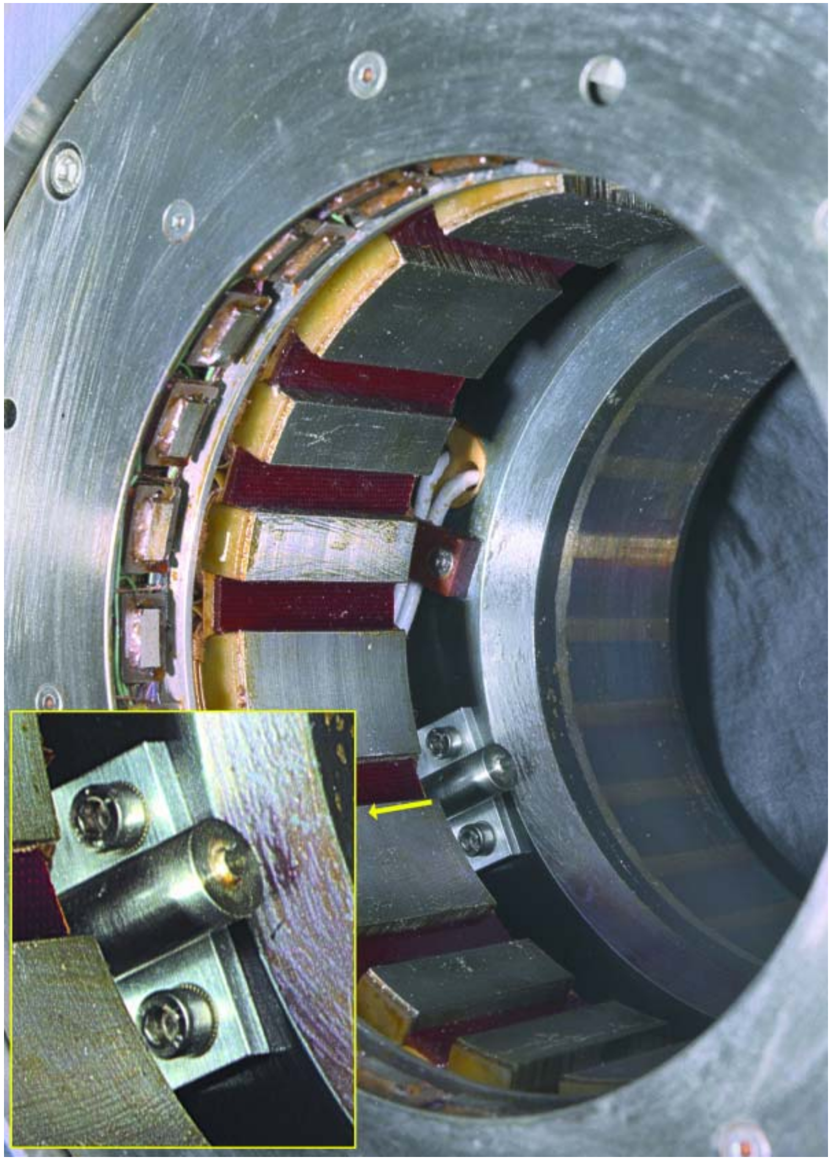
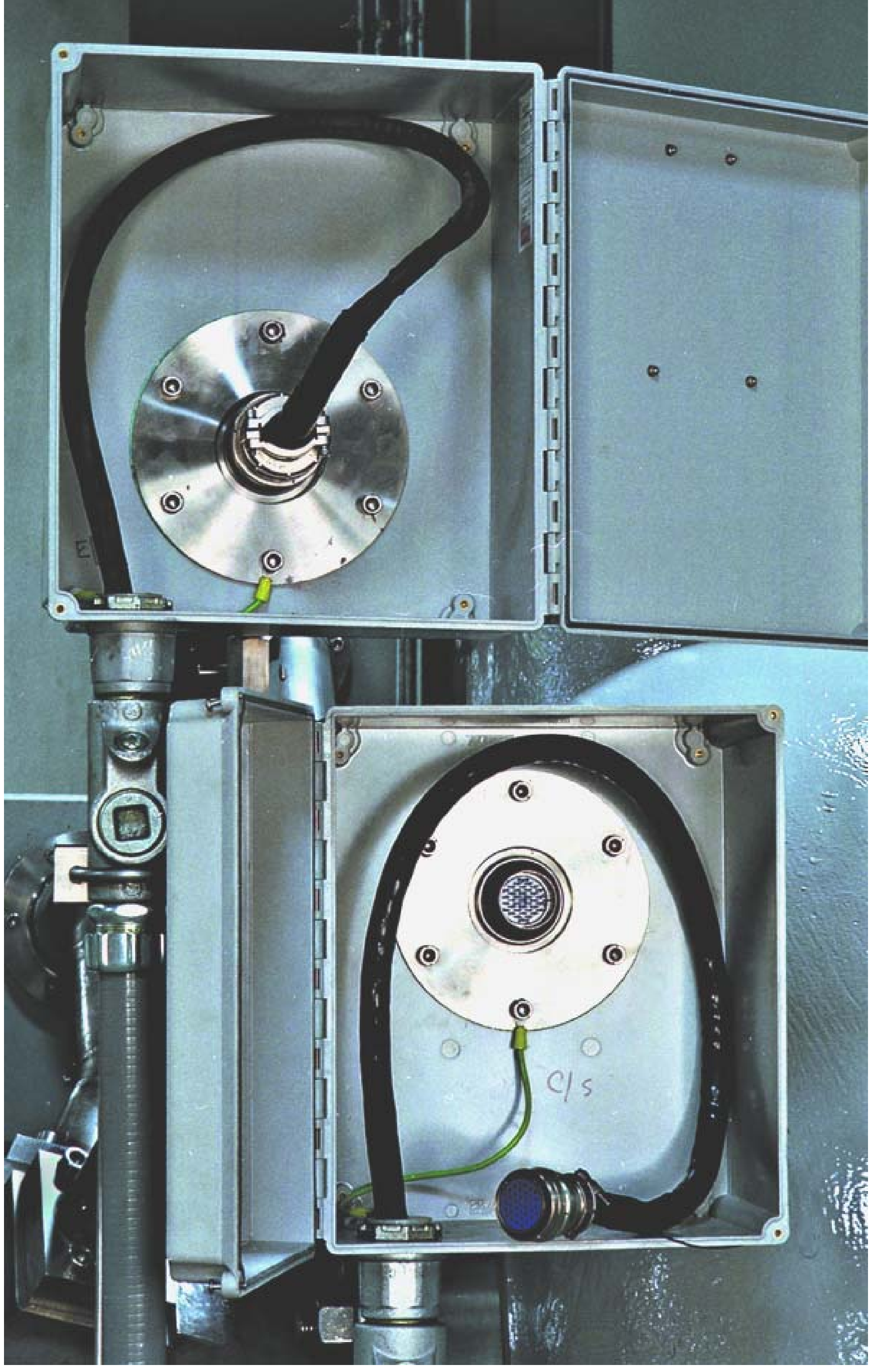


Control Loop

Magnetic Bearing Instrumentation

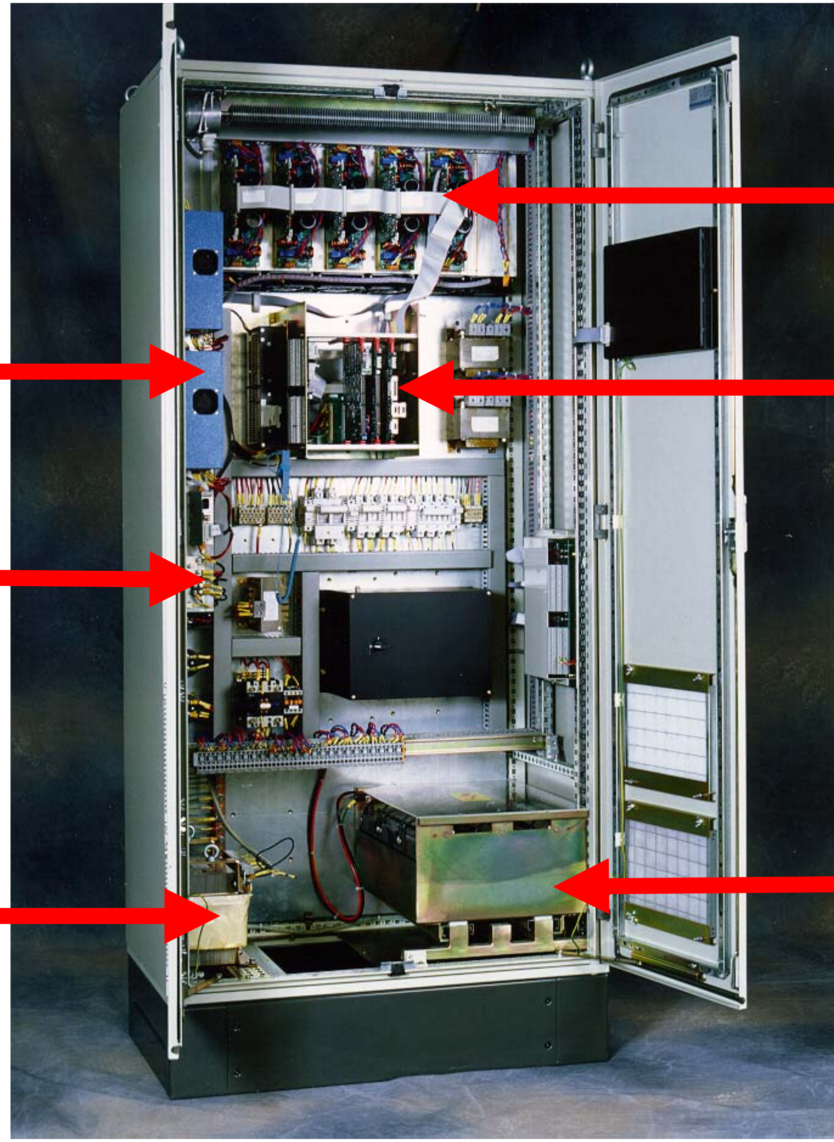


- Position Sensors: Functionally replaces radial vibration probes and axial position probes
- RTD's: Single Element, 2 per bearing
- Speed Probes: Up to 4 per machine can be supplied



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

S2M

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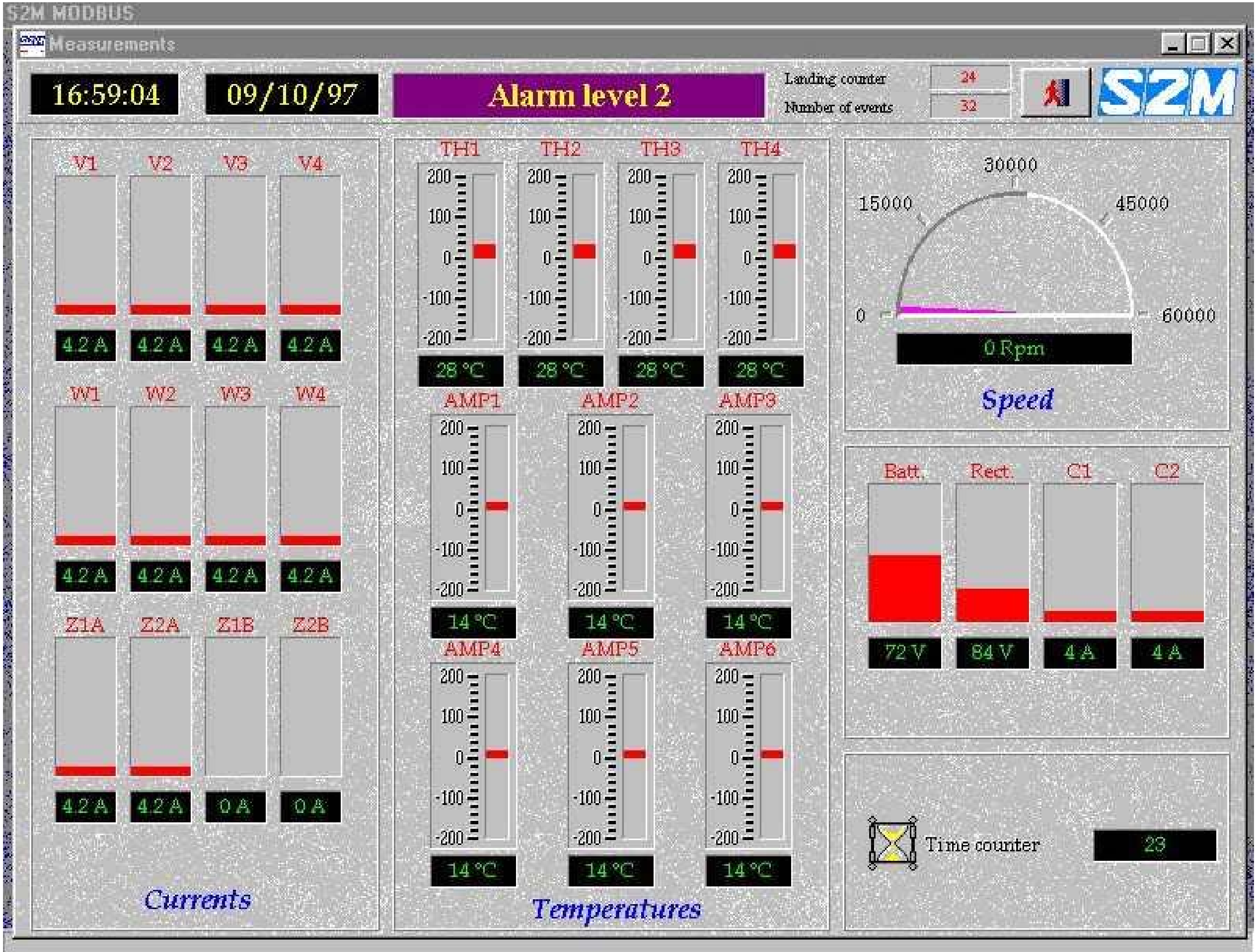

S2M

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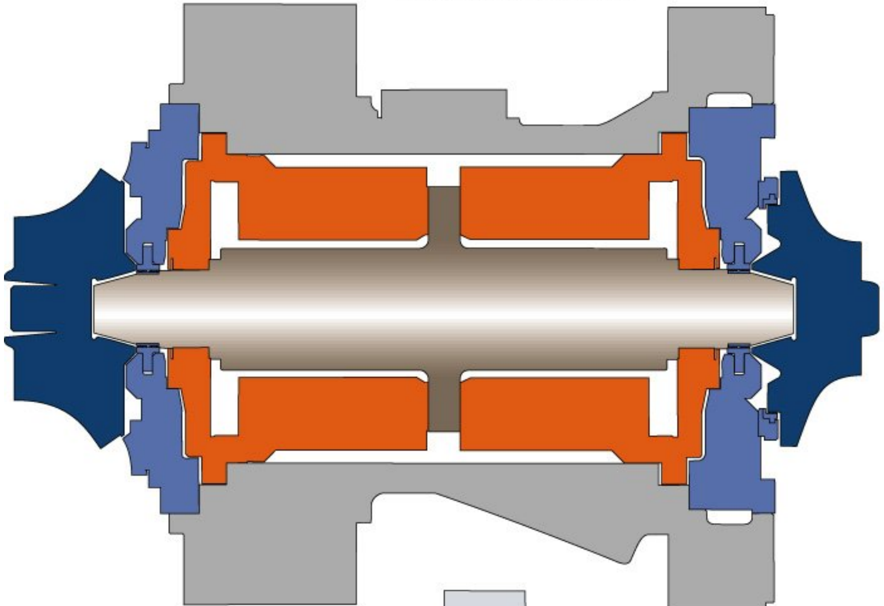
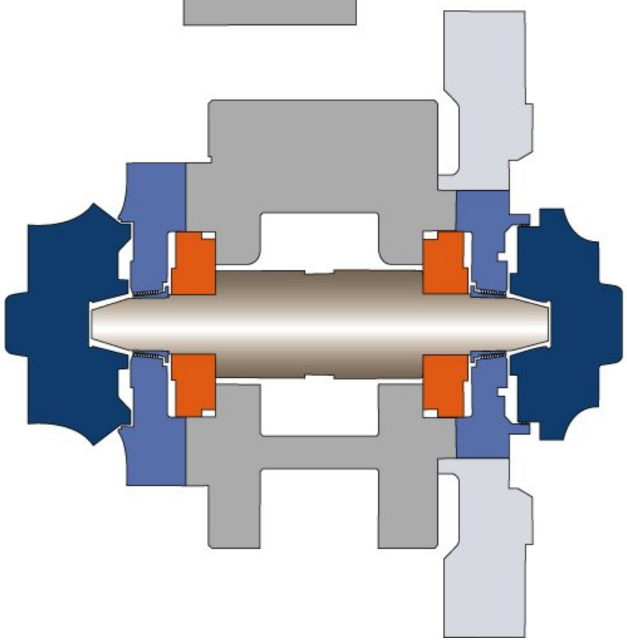
OIL BEARING EXPANDER & MAGNETIC BEARING EXPANDER COMPARISONS





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.

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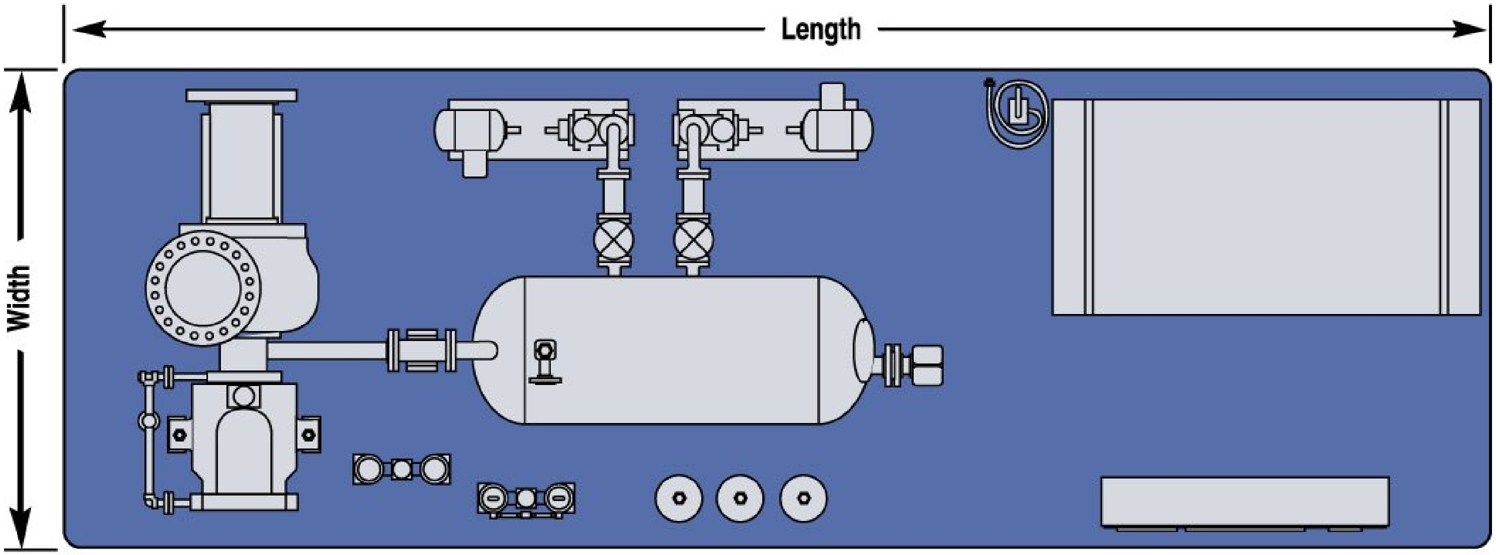
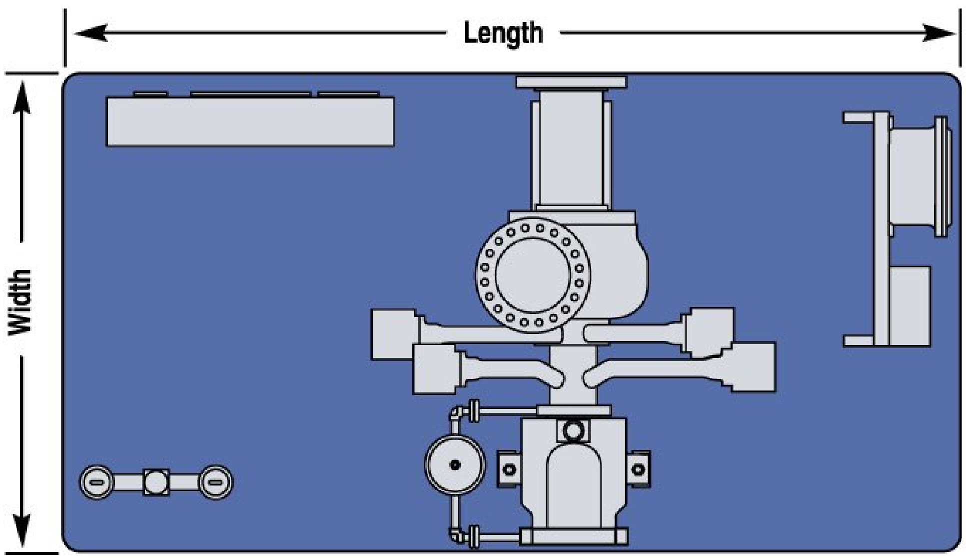
OIL BEARING & MAGNETIC BEARING EXPANDER SKID COMPARISONS

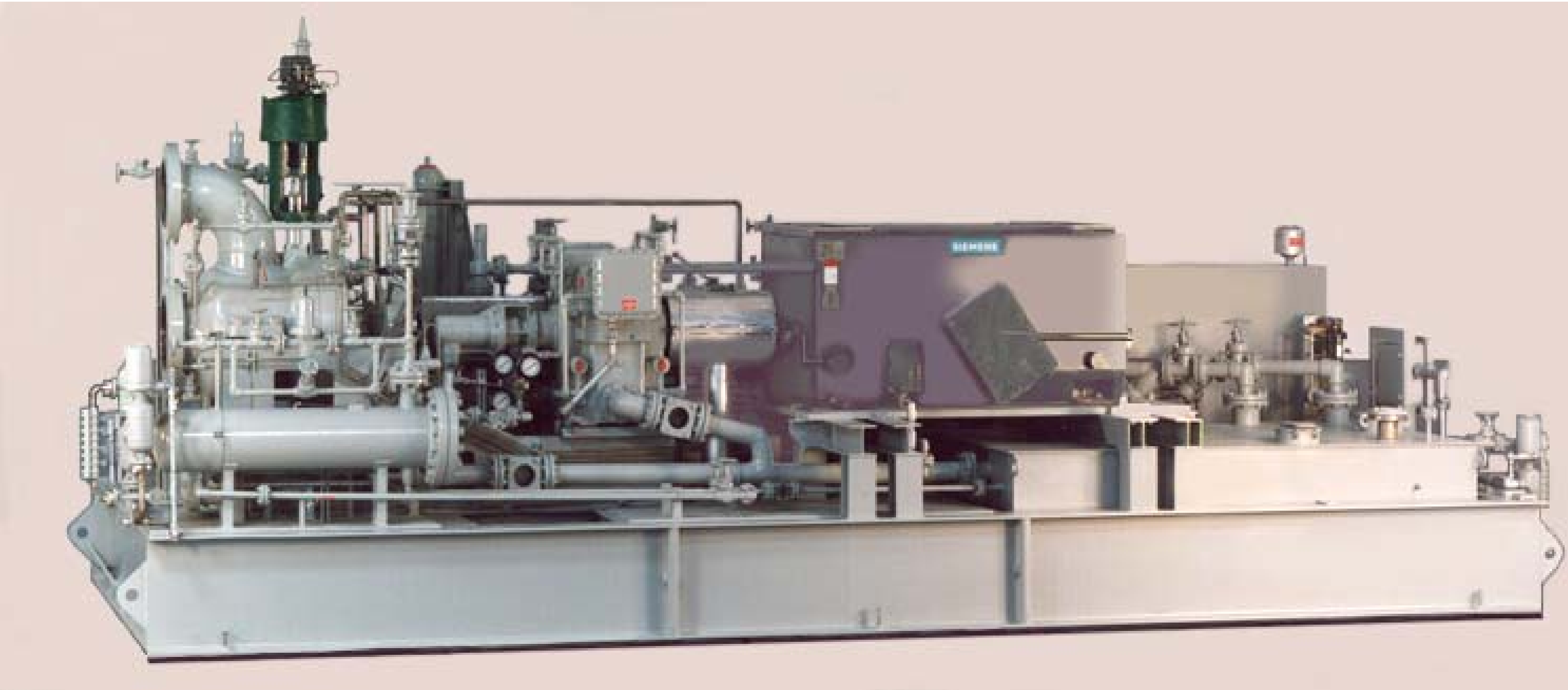




TYPICAL FRAME 3 PARAMETERS	OIL BEARING EXPANDER SKID	MAG. BEARING EXPANDER SKID
Length	24 ft. (7.4 m)	15 ft. (4.6 m)
Width	8 ft. (2.4 m)	8 ft. (2.4 m)
Weight	25,000 lb. (11,340 kg)	16,500 lb. (7500 kg)

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

Turboexpander/Generator



Induction generator, parallel shaft gearbox, 2500 kW EG4

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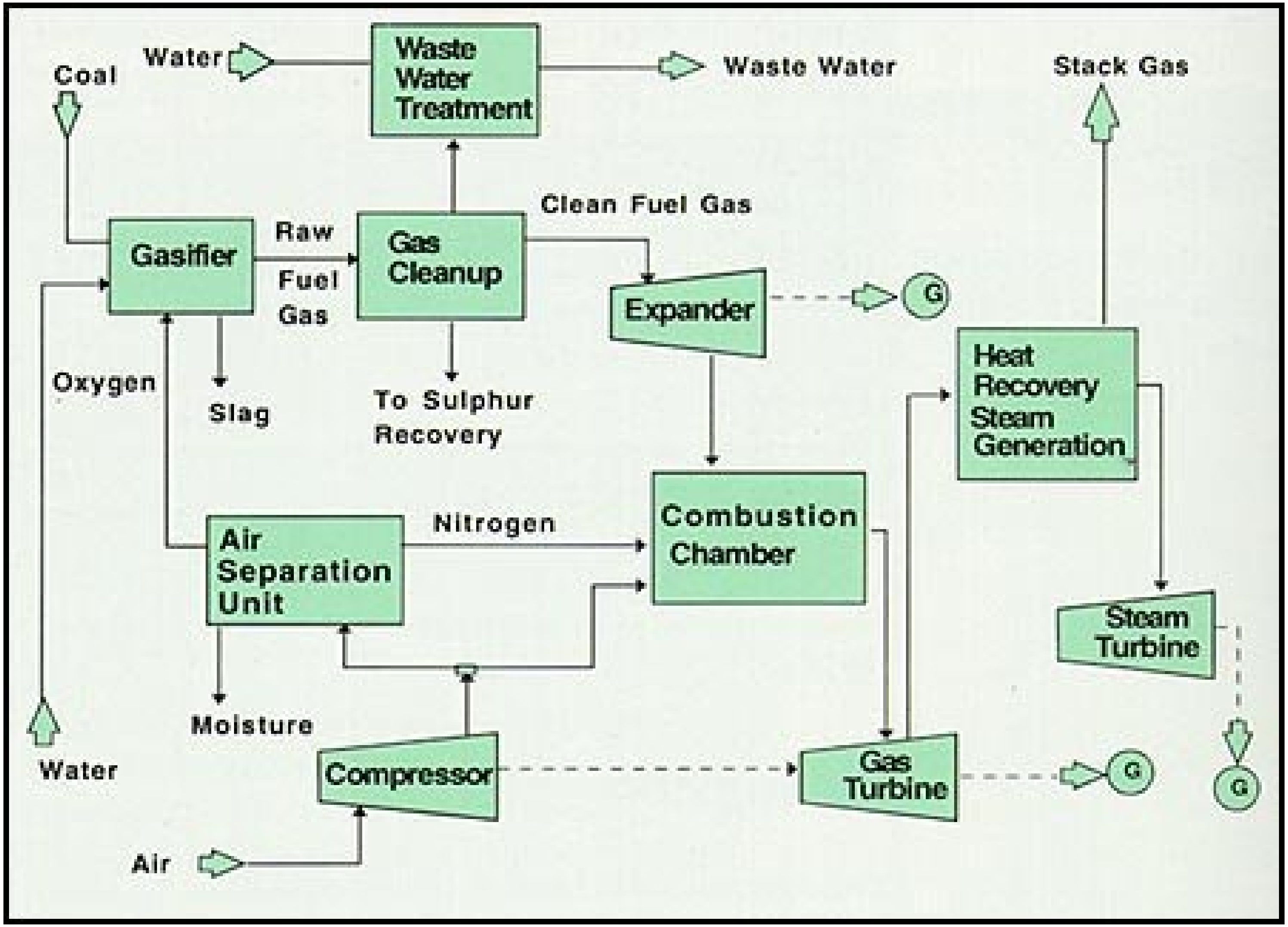
Turboexpander/Generator

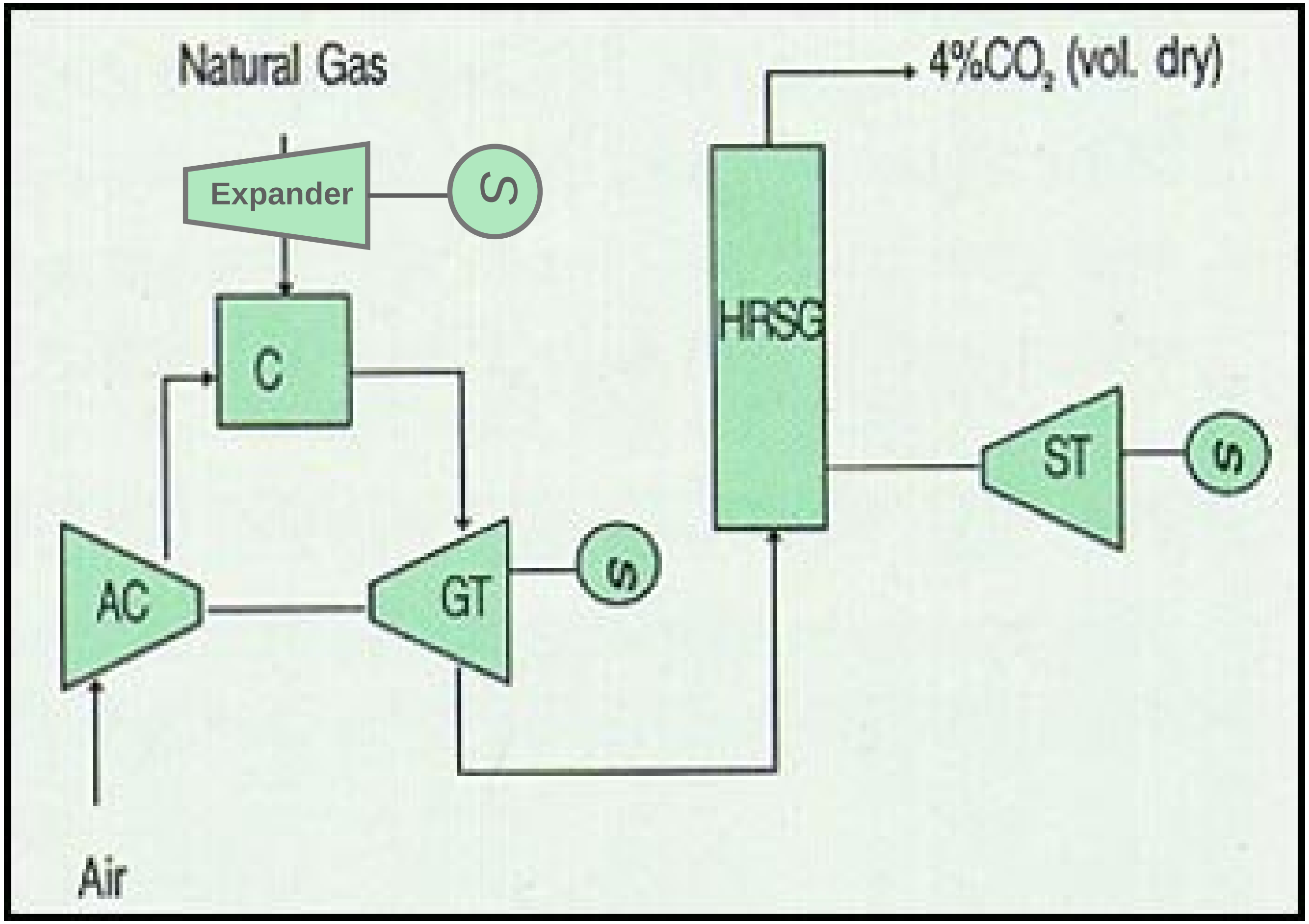
- Typical Applications
  - Pressure letdown
  - Rankine Cycle
- Speed reduction gearbox
  - Parallel Shaft
  - Integral
- Shaft Sealing Options
- Induction or synchronous generator

Turboexpander/Generator



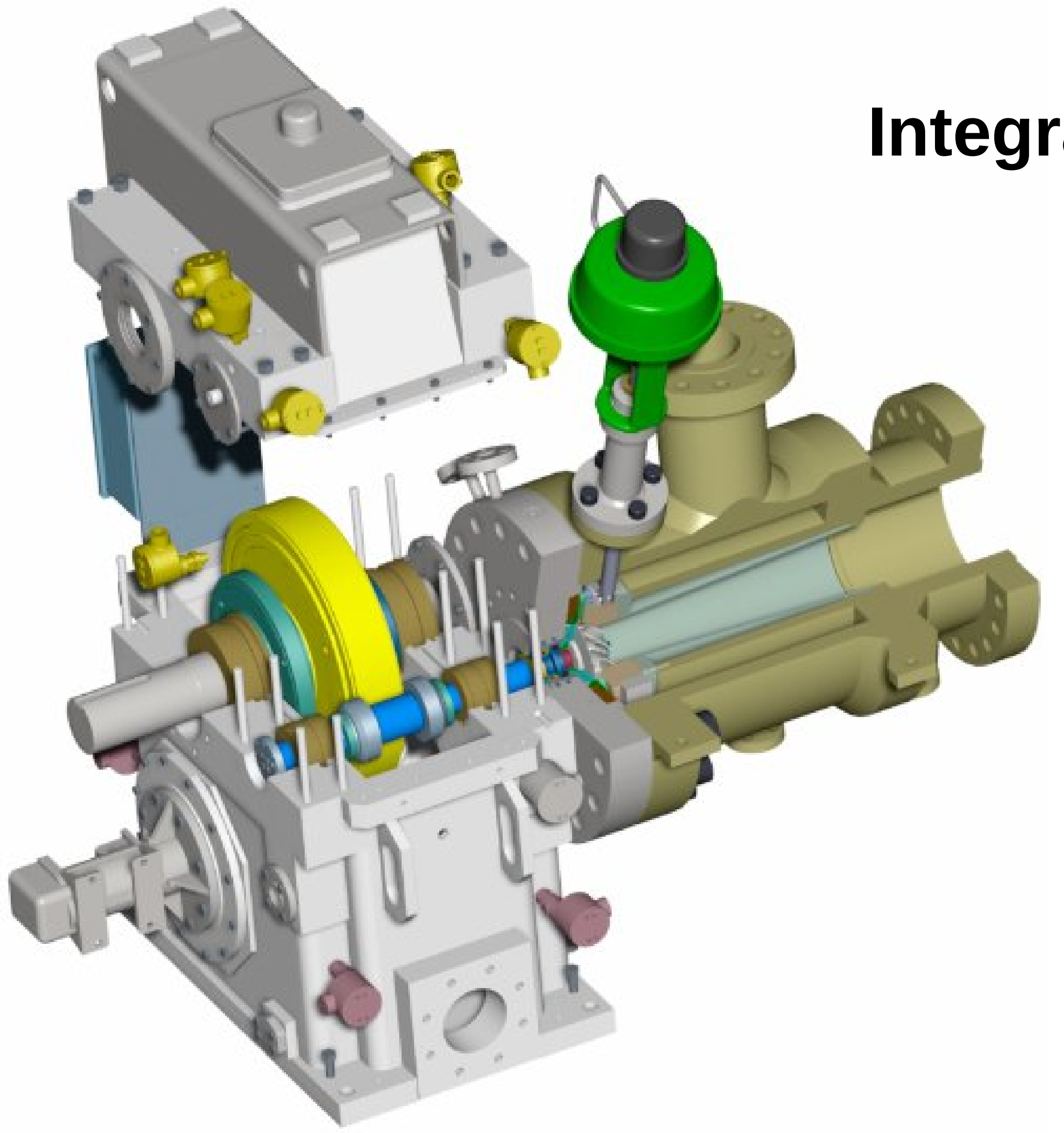
Typical IGCC Application

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

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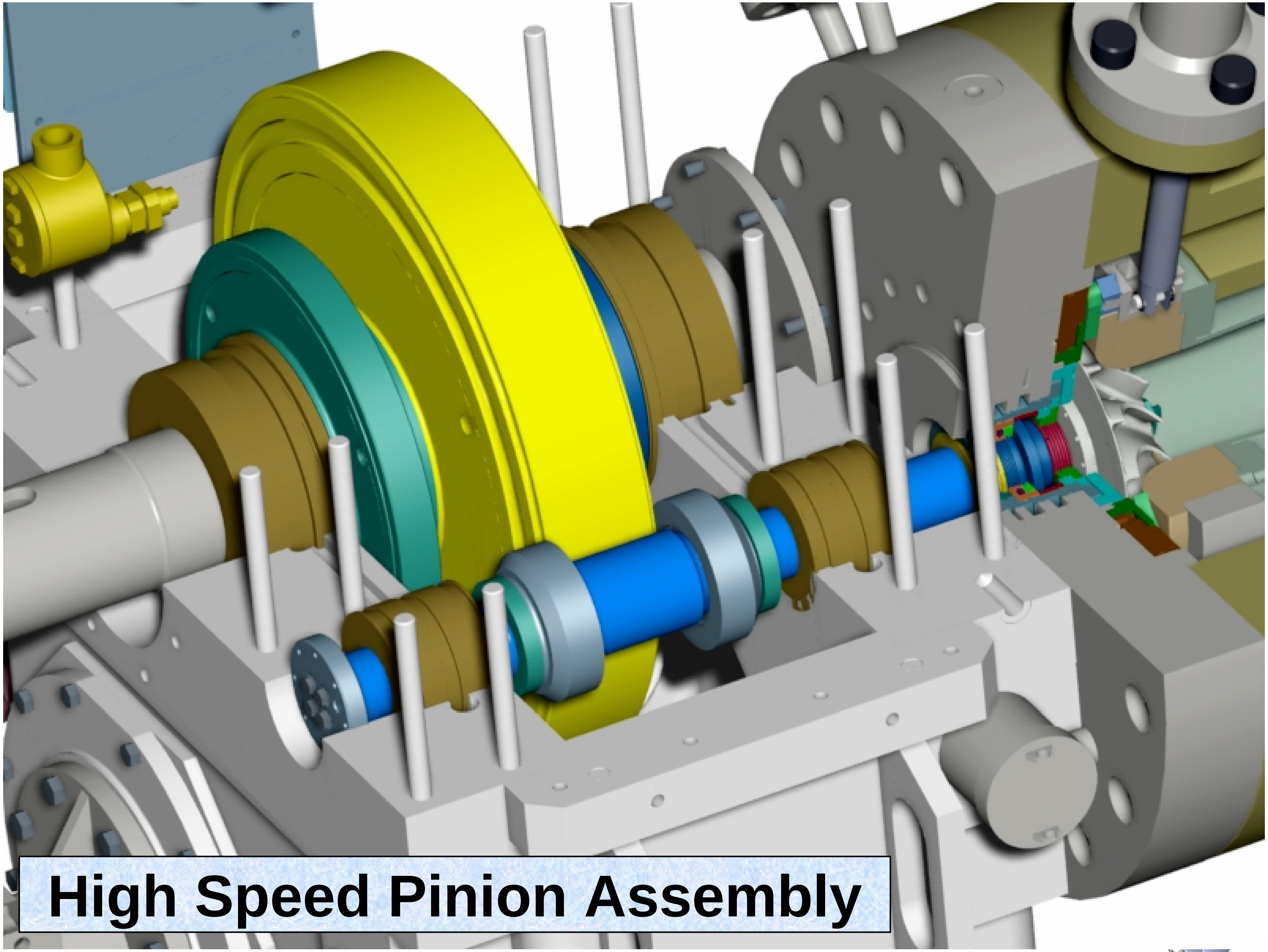
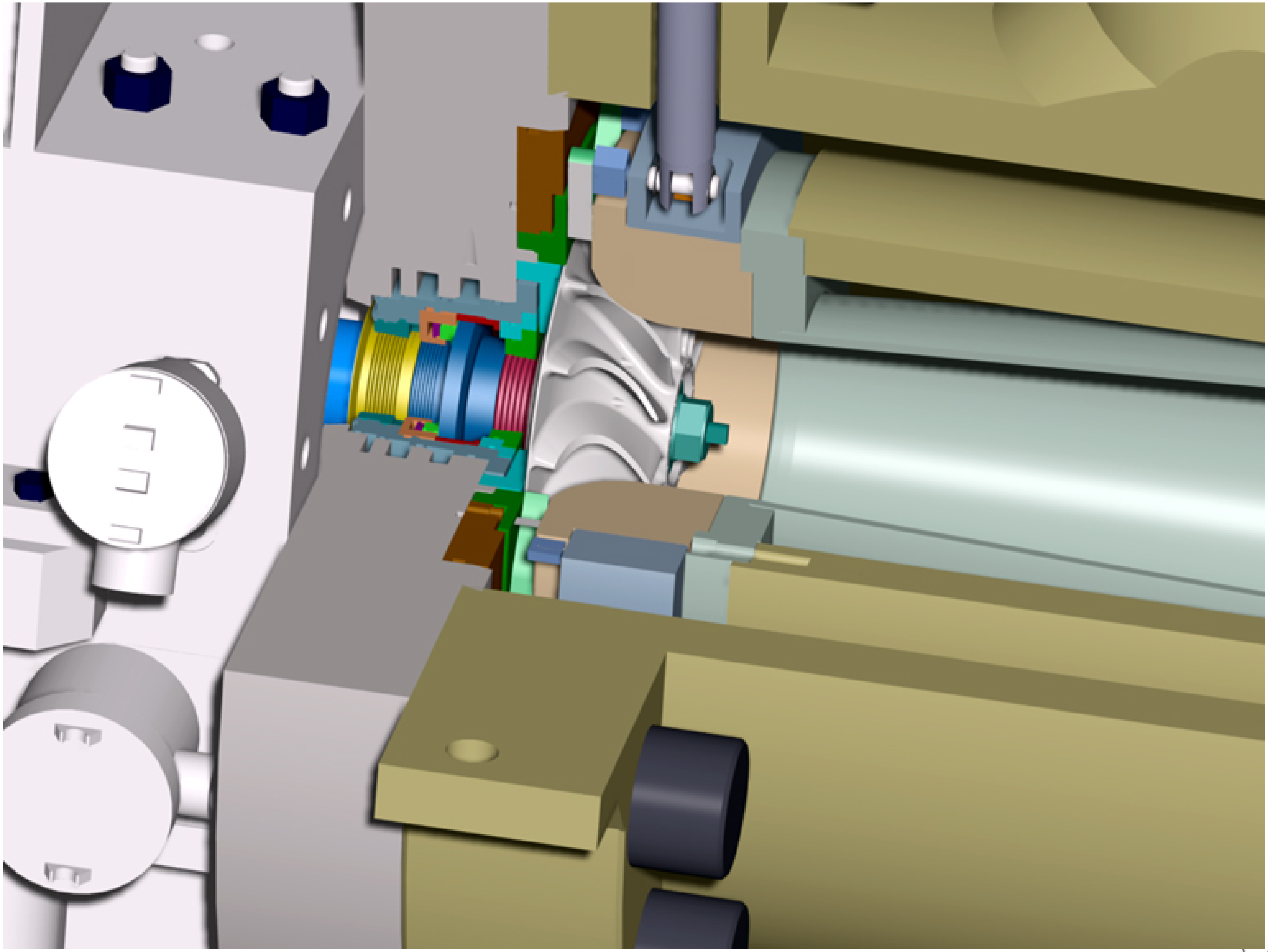
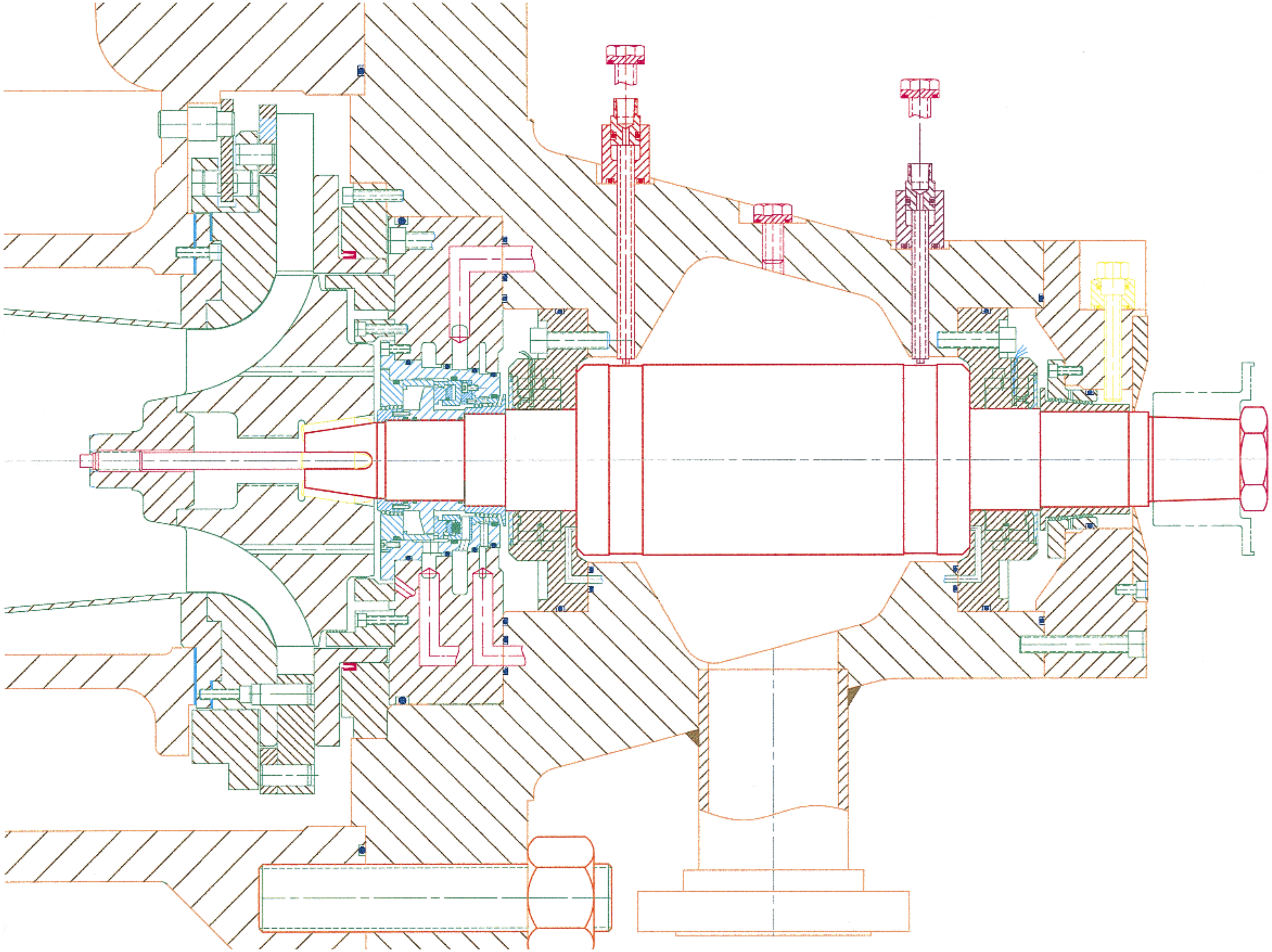
Integral Gear Expander



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

Condition	Alarm	Trip
Overspeed	Yes	Yes
High Shaft Vibration	Yes	Yes
High Bearing Temperature	Yes	Yes
High Axial Thrust Pressure	Yes	Yes
Loss of Lube Oil Pressure	Yes	Yes
Loss of Seal Gas Pressure	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.

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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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