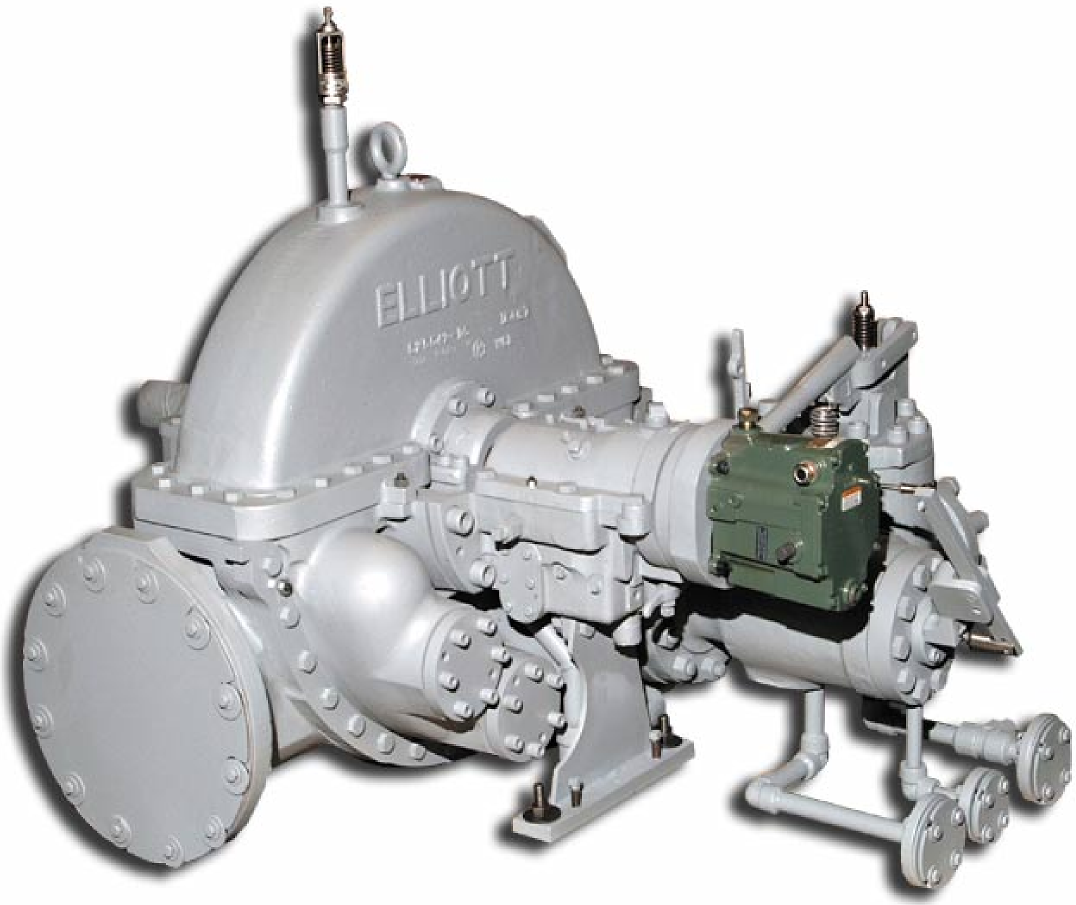
Selecting Steam Turbines for Pump Drives



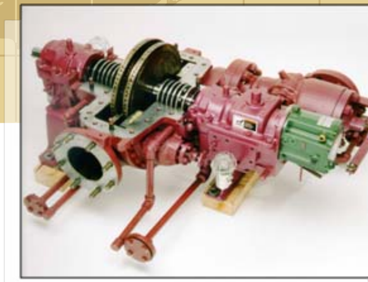
Dave Scott

Ramco Energy Products Ltd

Wayne Adams

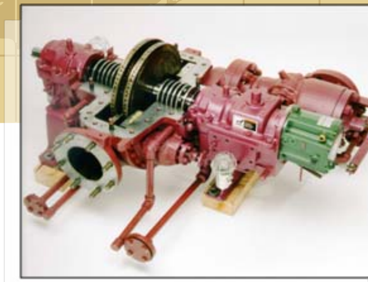
J.W. Adams & Assoc. Inc

Calgary Pump Symposium
November 13,2009

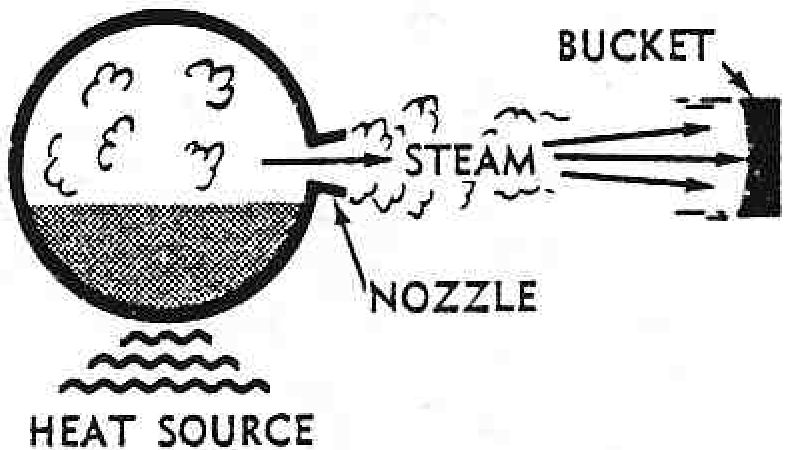


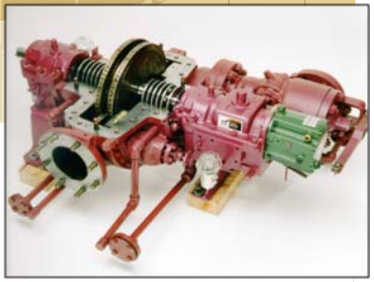
What is a Steam Turbine?

A Steam Turbine is an energy conversion device. It extracts heat energy from steam and converts it to velocity, or kinetic energy. The velocity energy, in turn, is used to produce rotary motion or useable shaft power.



What is a Steam Turbine?

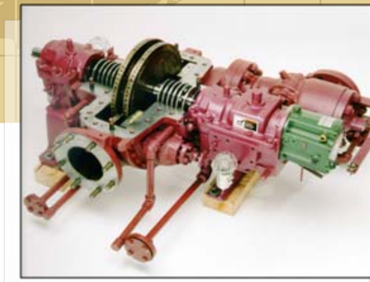




Steam Cycle Terms

Non- Condensing:

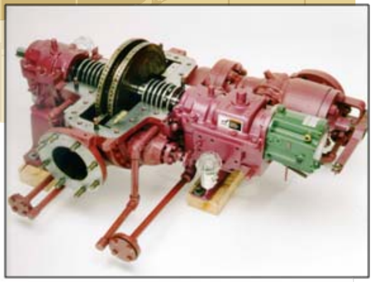
"Non-condensing" cycle is used when the turbine exhaust pressure is above atmospheric (14.7 psia). The exhaust steam energy is usually utilized in the plant process (resulting in a high "Steam-Cycle" efficiency).



Steam Cycle Terms

<u>Condensing:</u>

"Condensing" cycle is used when the turbine exhausts to a pressure lower that atmospheric (usually to a steam condenser). The steam is cooled in the condenser (by water or air cooling) and the resulting condensate is pumped back to the boiler. Condensing "Steam Cycle" efficiencies are usually very low since most of the exhaust steam energy is lost to the cooling medium and not recovered.



Steam Cycle Terms

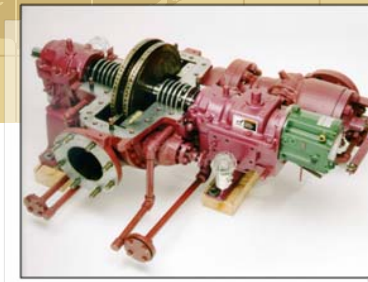
Steam Rates:

Theoretical Steam Rate (TSR) is based on "isentropic" turbine performance [no losses] or 100% efficiency.

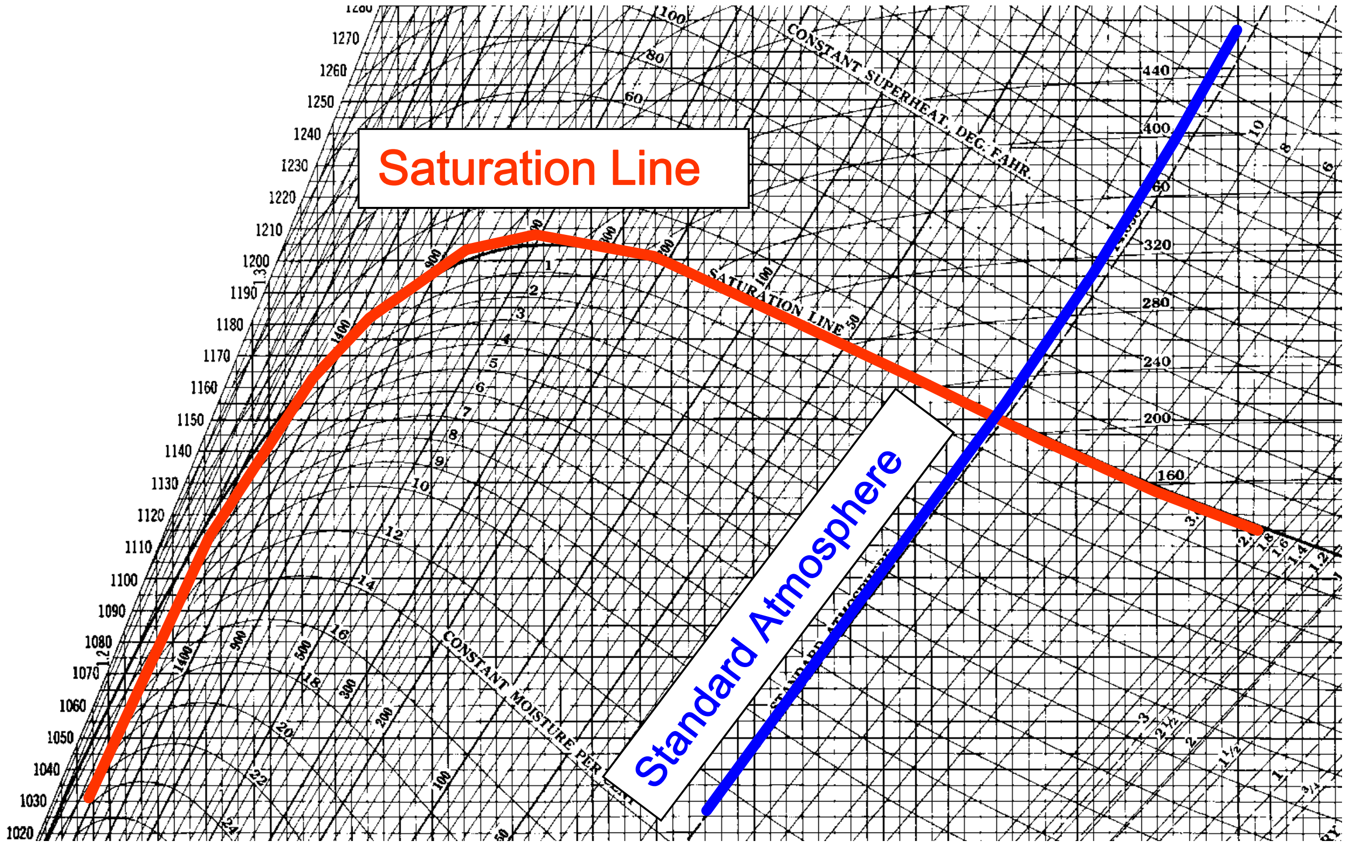
Actual Steam Rate (ASR) reflects turbine efficiency and is expressed in the same terms as the TSR. Lower ASR’s are indicative of higher turbine efficiencies.

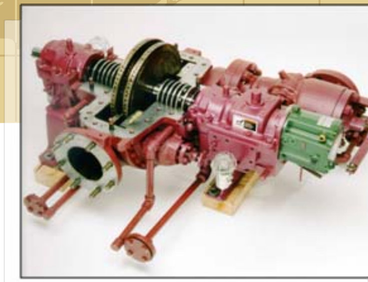
Larger wheel sizes are often more efficient. Smaller wheels have lower windage losses and can be more efficient at low horsepowers than large wheels.

Typical single-stage turbine efficiencies range between 30 - 50%. Standard multistage turbine efficiencies range between 60 - 70%. Engineered multistage turbine efficiencies range between 70 - 80%.

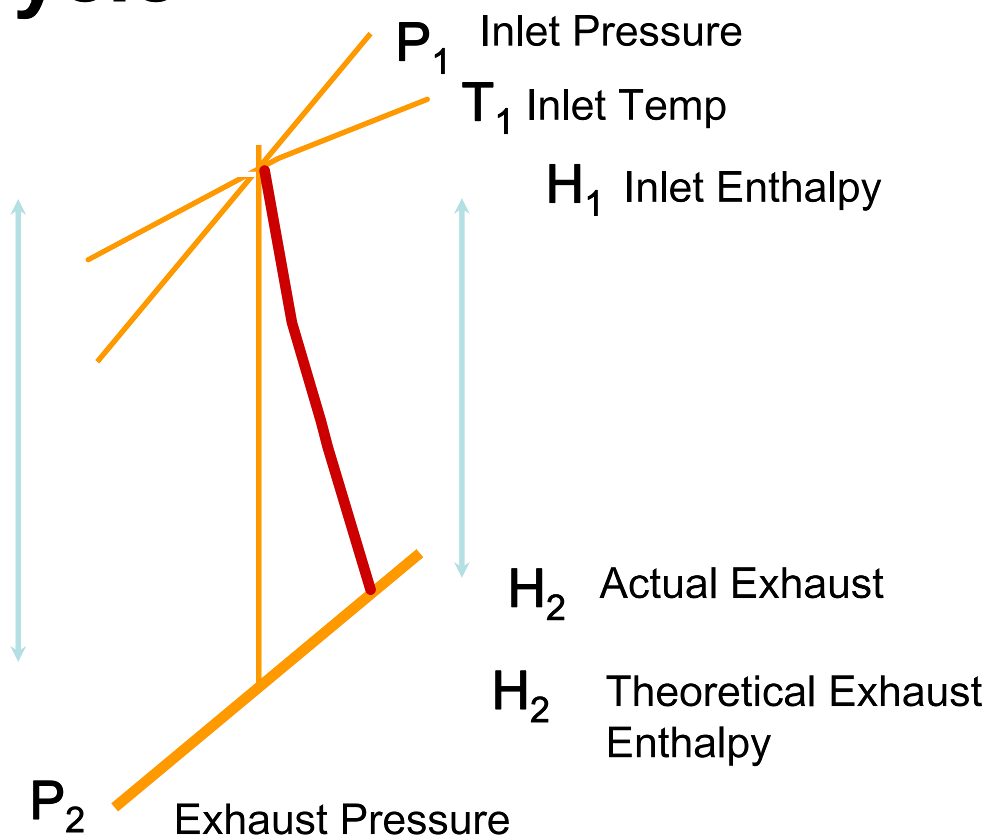


Mollier Diagram





Steam Cycle

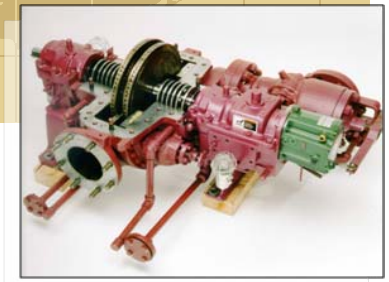

P_1 Inlet Pressure
T_1 Inlet Temp
H_1 Inlet Enthalpy
H_2 Actual Exhaust
H_2 Theoretical Exhaust Enthalpy
P_2 Exhaust Pressure

Outline

- Why Steam Turbines?
- Steam Turbine construction
- Specifications
- Steam Turbine selection

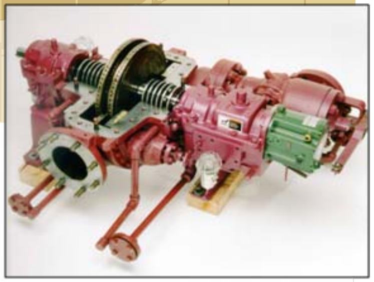
Steam Turbines as Prime Movers

- Prime movers are required as a drive for pumps, fans, blowers, generators, compressors, etc.
- Steam turbine drivers are prime movers that convert the thermal energy of steam into mechanical energy through the rotation of a shaft.



Steam Turbines Applications

- Pumps
- Generator Drives
- Compressors
- Fans
- Blowers
- Paper Mills
- Sugar Mills
- Palm Oil Mills



Advantages of Steam Turbine Drives

- High horsepower in a small package.
- Variable/optimal speed capability.
- Usually directly connected to driven equipment.
- Non Sparking - explosion proof.
- High starting torque capability.
- Will not stall or trip on overload.
- Can operate independently of plant electrical system.
- Quick start capability.

Why Steam Turbines?

Why Steam Turbines?
Variable Speeds

	Design speed	Maximum Continuous speed	Minimum speed
Simple governors	100%	105%	85%
Advanced governors	100%	105%	65% or more

Why Steam Turbines?
Speed Capability

Typical pump speeds:

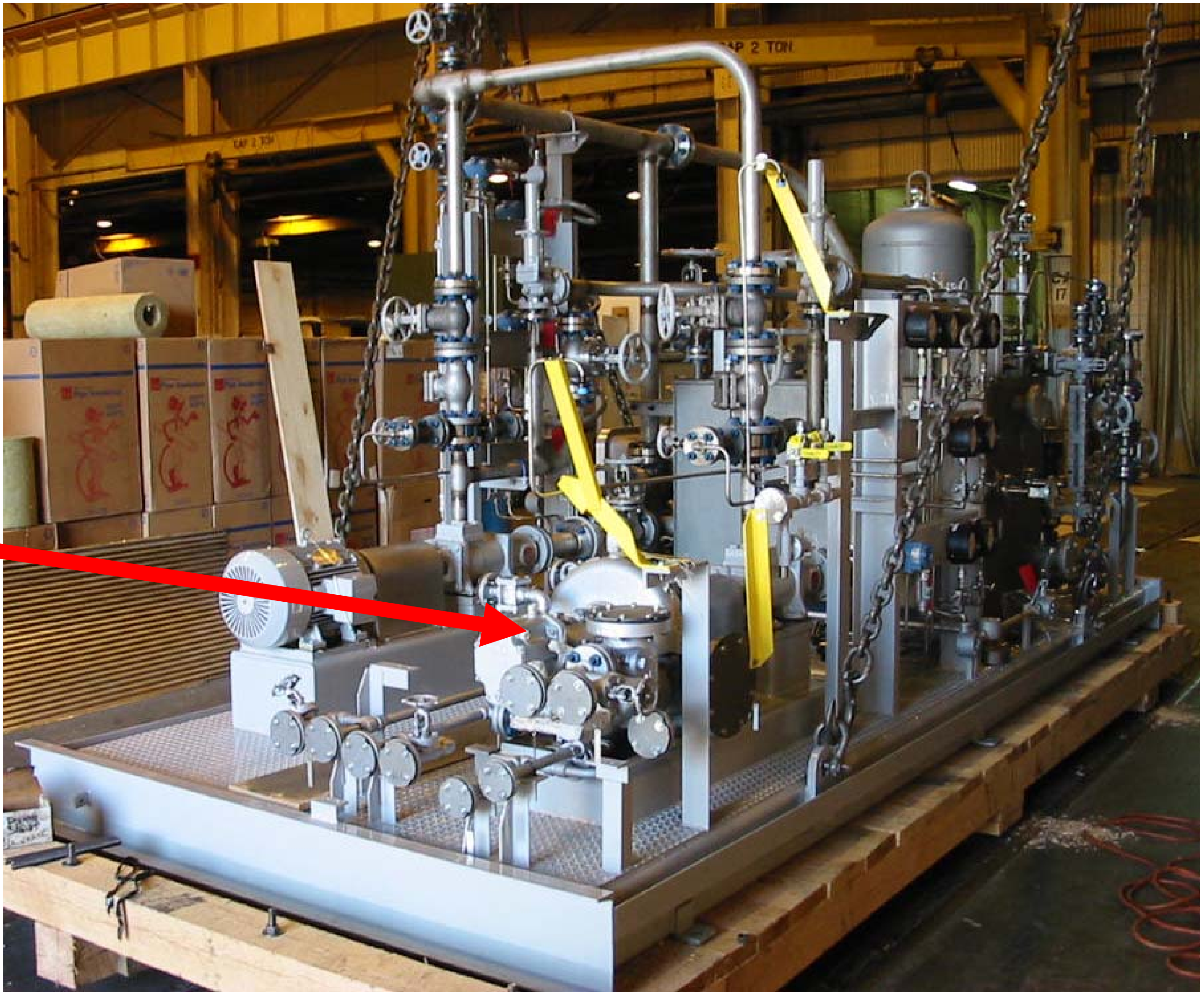
1500, 1800, 3000, 3600 RPM

Maximum speeds -To 12000 RPM

(and more)

Why Steam Turbines?

Quick Starting



Why Steam Turbines?
Availability of Steam

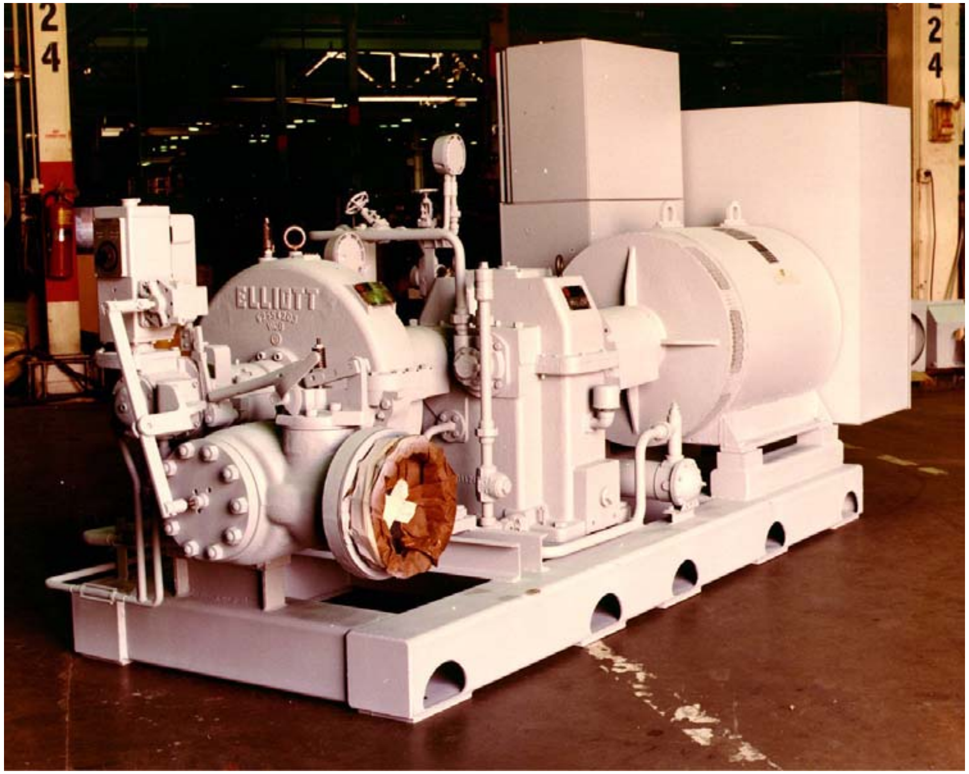
Exothermic processes

Why Steam Turbines?

Electrical Power Alternatives

Critical duties - power not required to operate a steam turbine

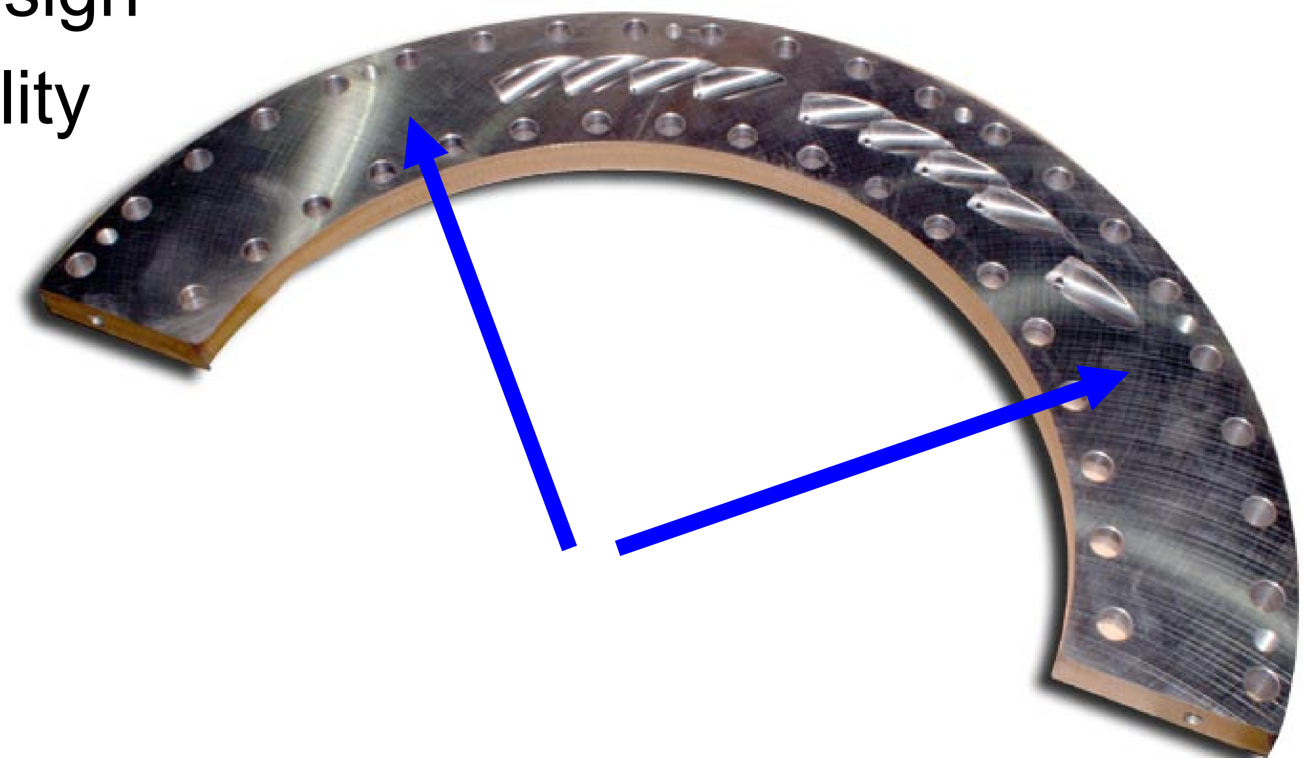
Generate power when power is not available



Why Steam Turbines?
Flexibility

Variety of duties, common design

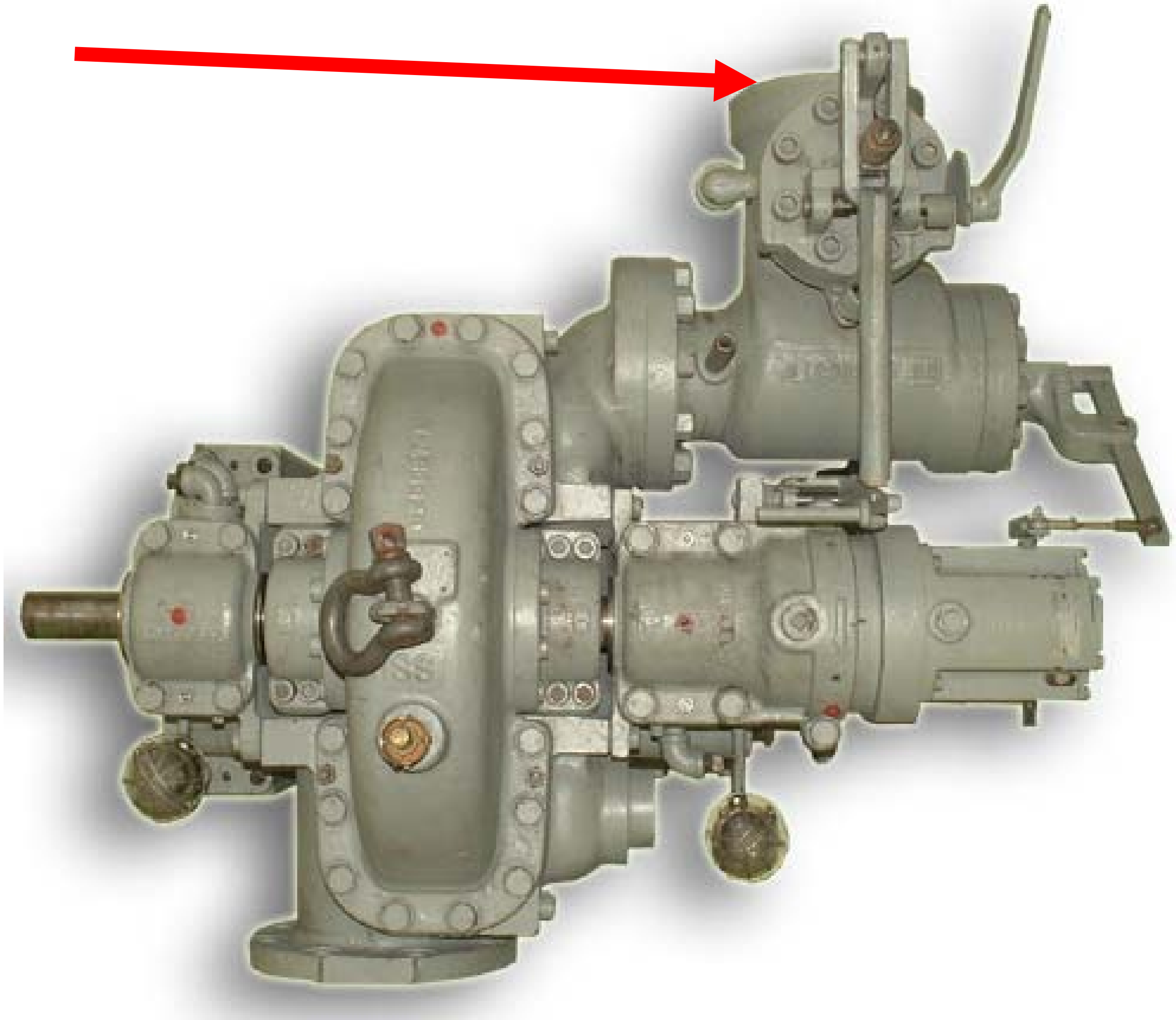
Upgradeability



Steam Turbine Construction

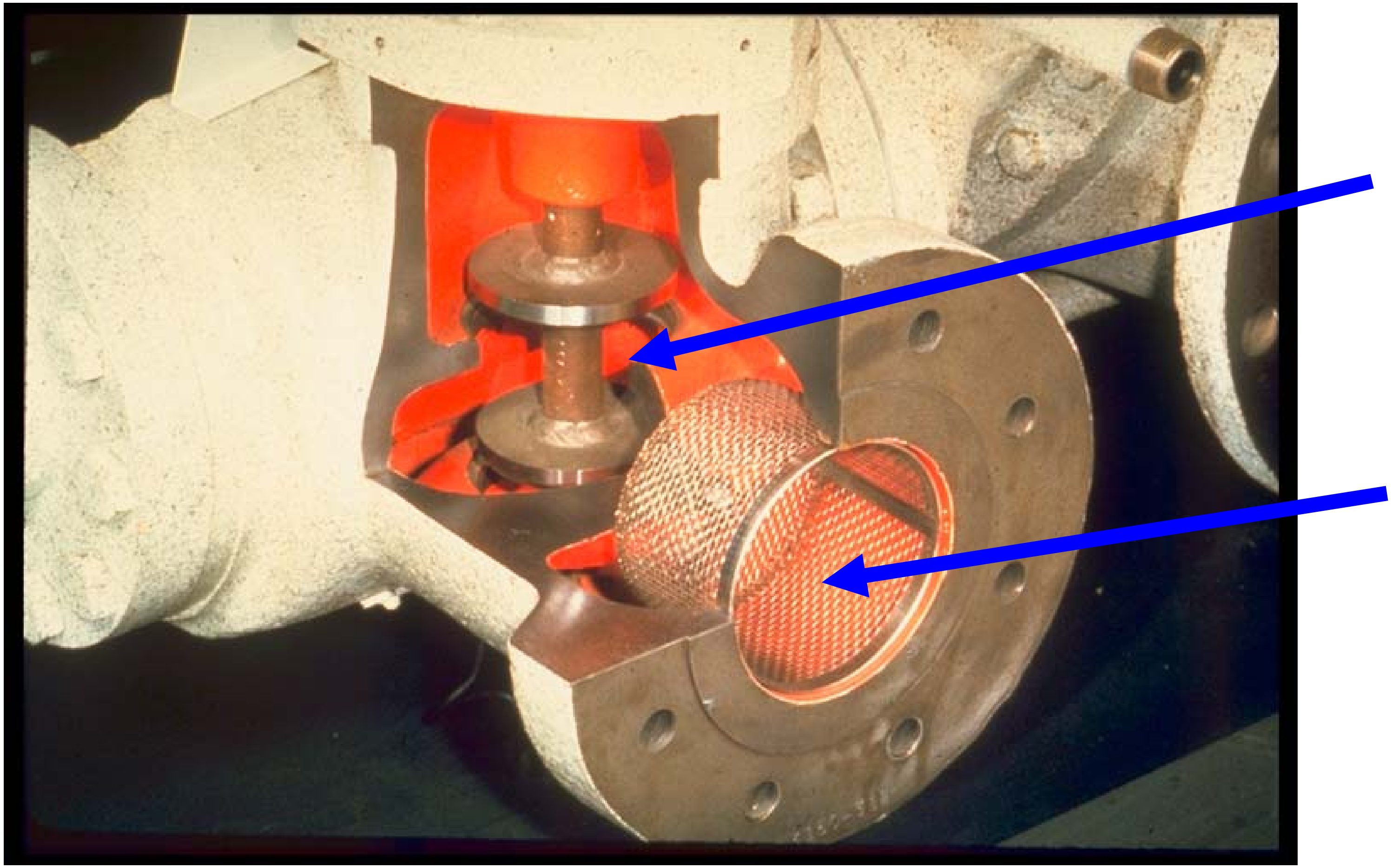
Steam Turbine Construction

Follow the Steam



Steam Turbine Construction

Inlet



Trip Valve Types

Venturi Trip - single seated and piloted. Normally actuated through springs and linkages but also can be used in conjunction with bellows assemblies for low/air pressure trip functions. No throttling capability.

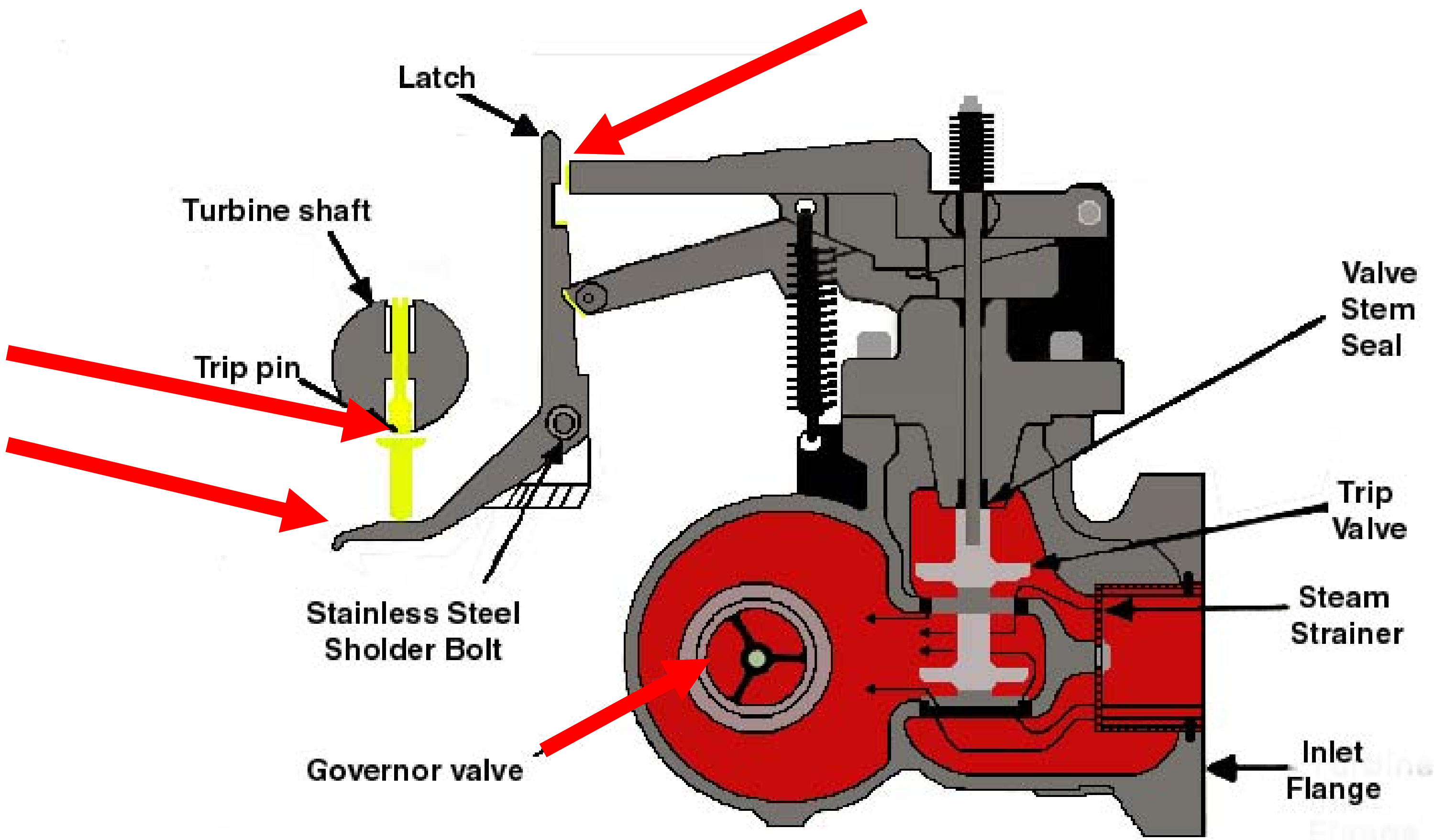
Built-in T &T Valve - The trip and governor valve are housed in the same inlet casing.

Separate T & T Valve - just as the name implies, it is separate from the turbine. Oil operated or latch type.

Steam Turbine Construction

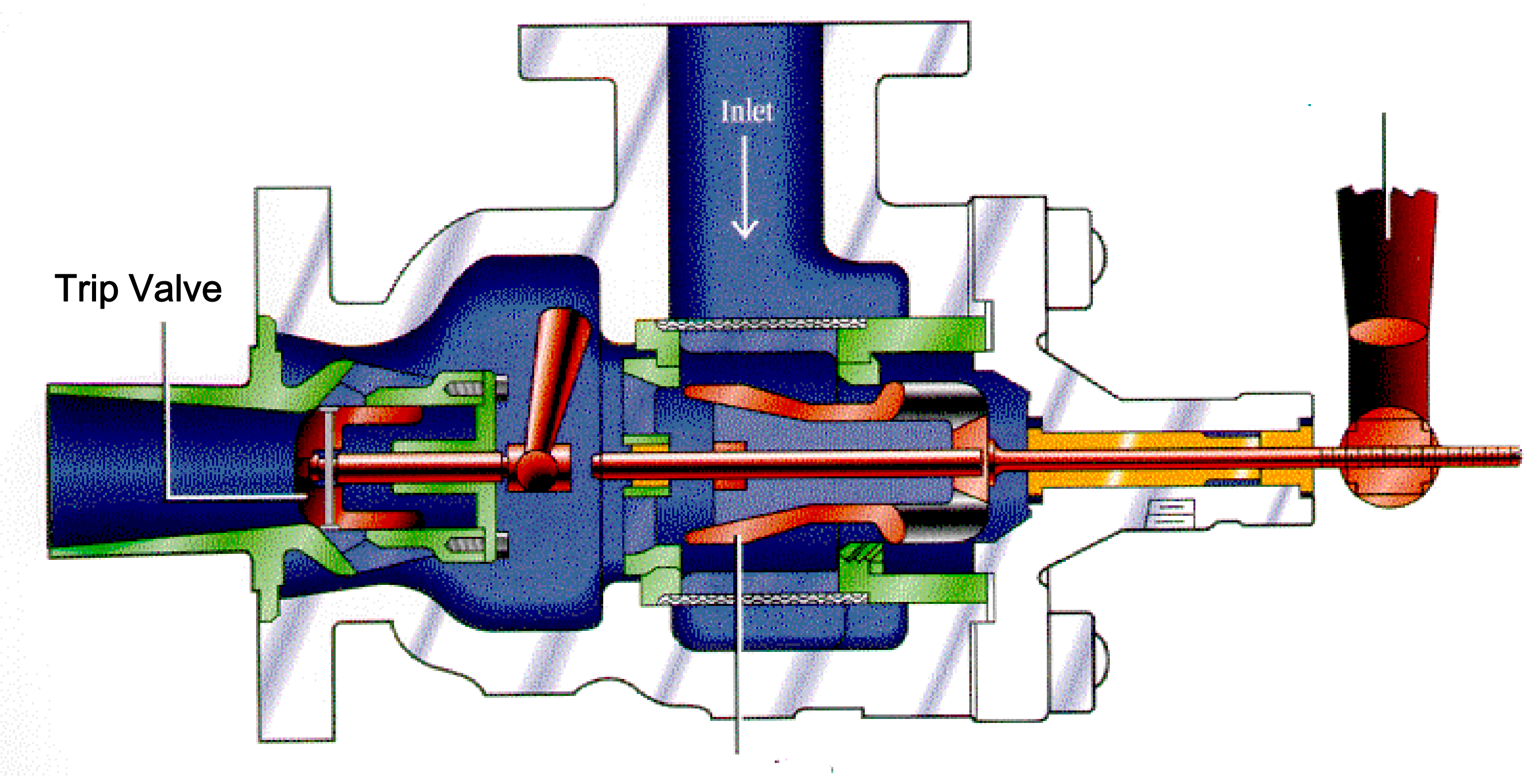
Steam Chest

OVERSPEED TRIP AND GOVERNOR VALVE

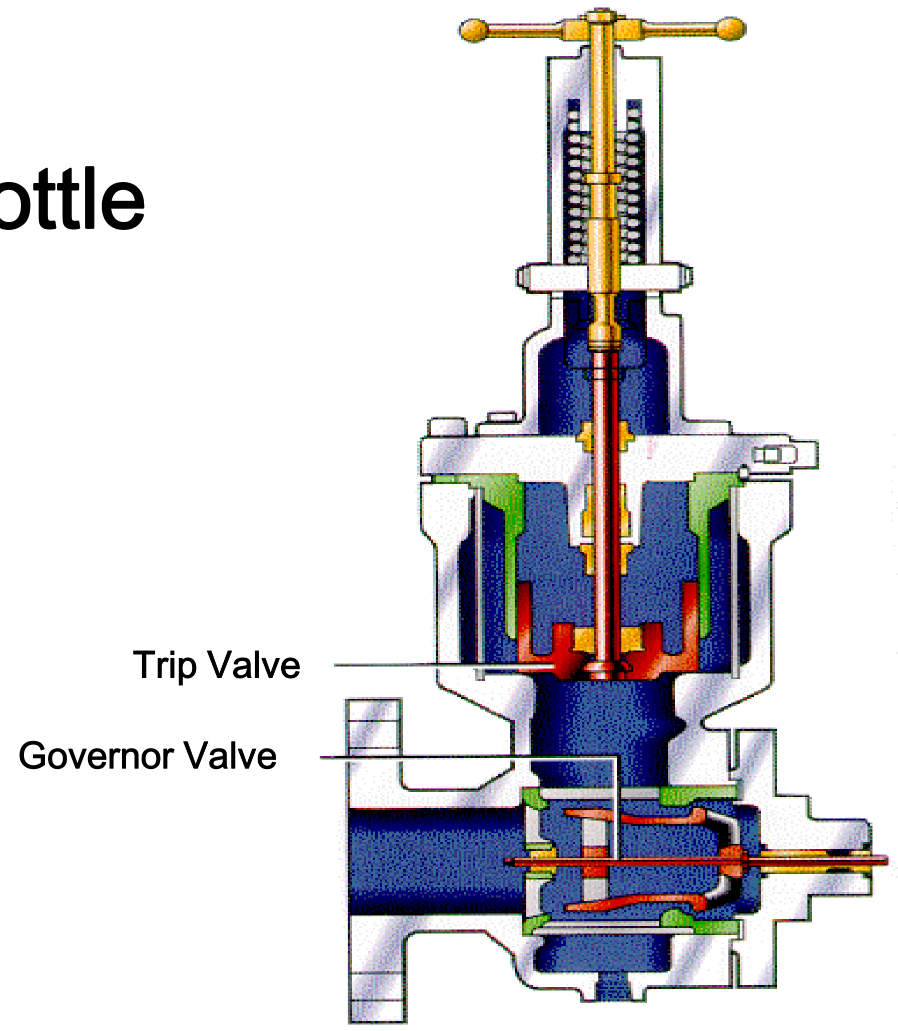


Steam Turbine Design - Components

Single Governor Valve & Venturi Trip



Trip &Throttle Valve



Steam Turbine Design - Components

Rotor

- Curtis 2 row wheel is standard but 1 Rateau wheel is available for high speed applications.
- Single profiled disc with 2 rows of blades shrunk and keyed on to shaft is standard. Solid rotor construction is available for certain applications and API 612 machines.

Steam Turbine Design - Components

Blades / Buckets

Turbine blades (buckets) are normally 403 stainless steel

Lower stressed blades are made from stock drawn to foil shape. (Drawn Blades)

Steam Turbine Design - Components

Blades / Buckets

Drawn Blades:

- Machined from extruded airfoil shaped stock.
- Cut to length, tenon and root machined.
- Packer piece (spacer) between each blade.
- Wedge/block locking piece at rim insertion point.

Steam Turbine Design - Components

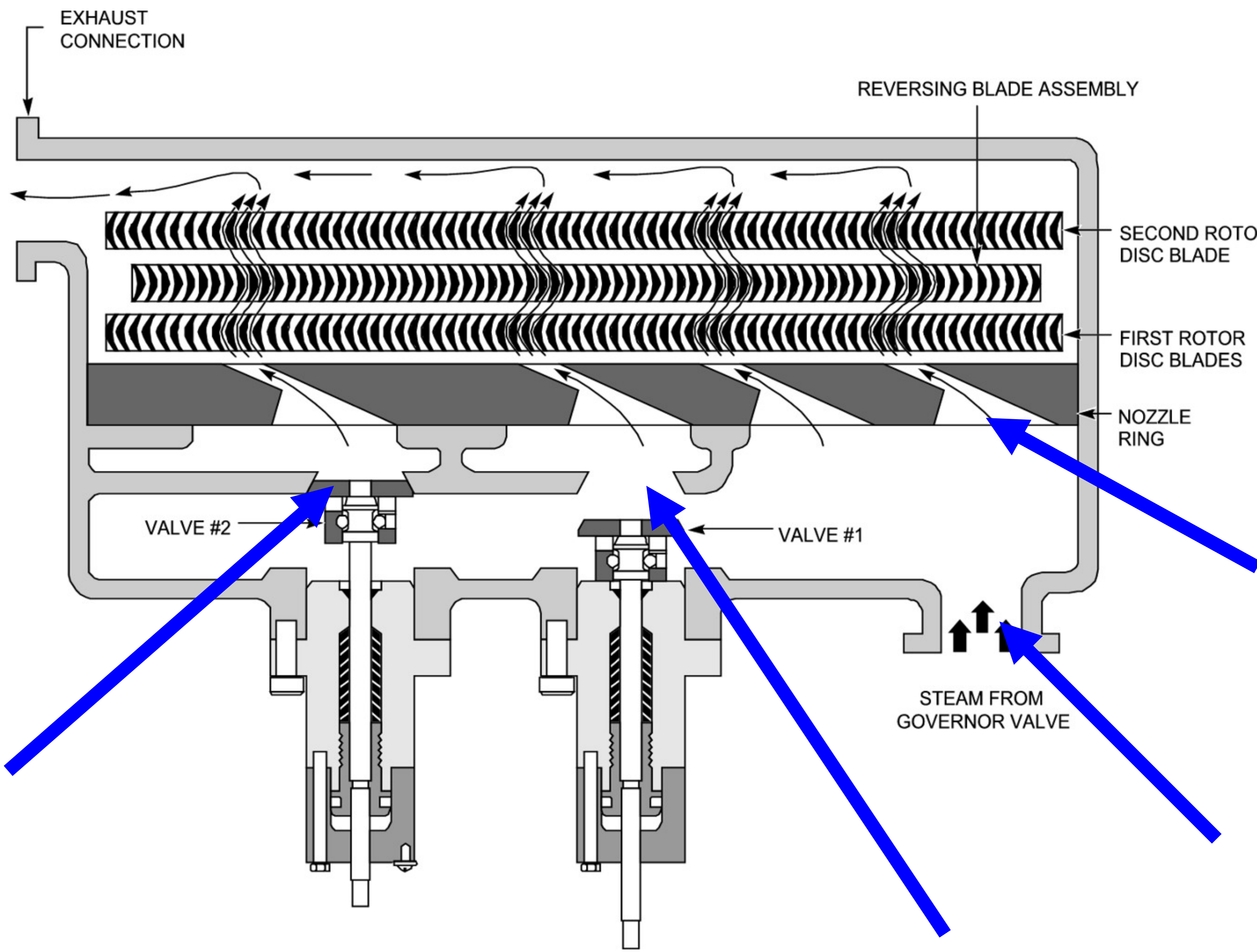
Blades / Buckets

Milled Blades:

- As horsepower and speeds increase, stronger blades are needed. Also better shapes for efficiency.
- Milled blades are machined from a rectangular piece of bar stock and are more expensive to produce because of the machining steps involved.
- Milled blades do not require a packer piece between each blade.
- Wedge/block locking piece at rim insertion point.

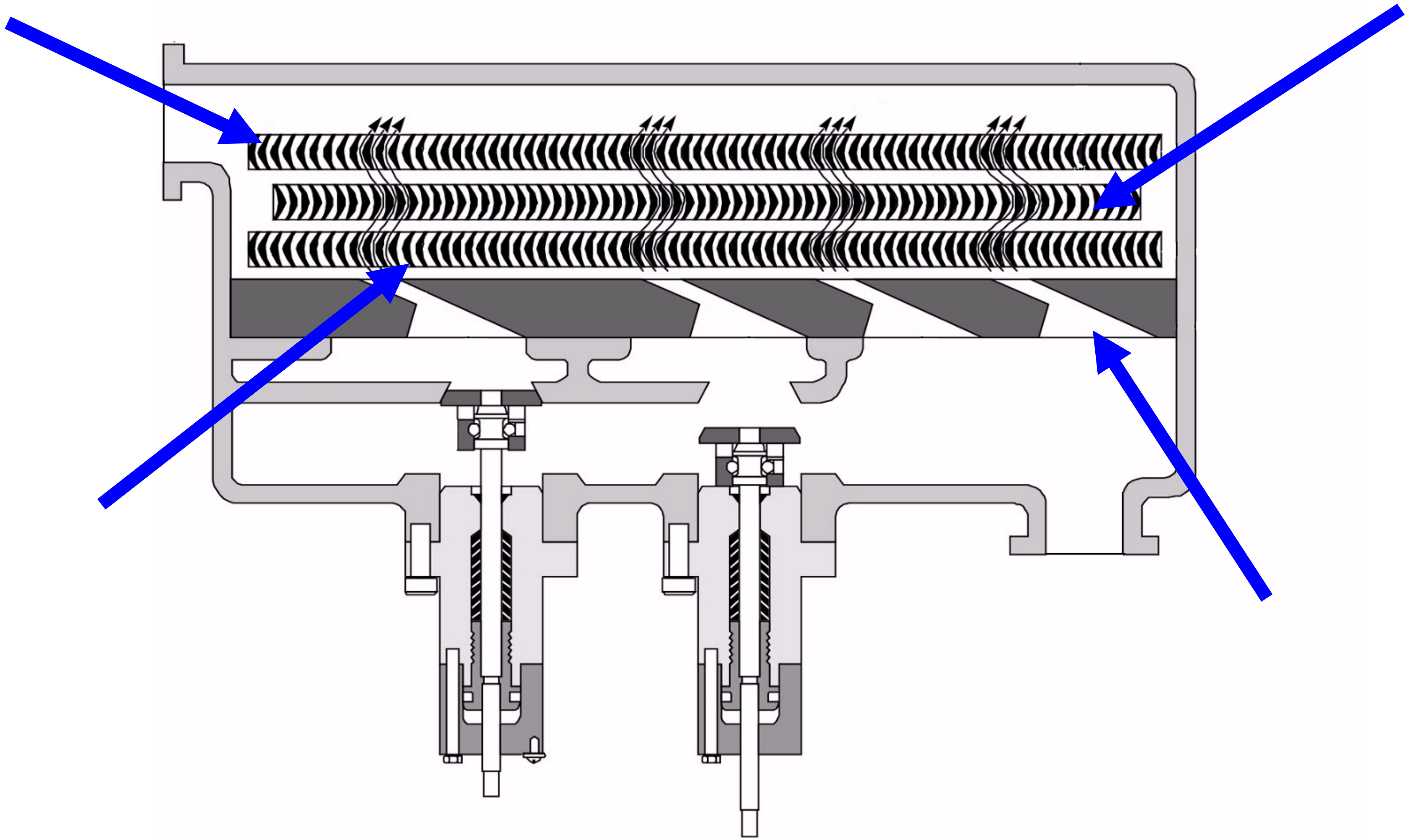
Steam Turbine Construction

Steam End

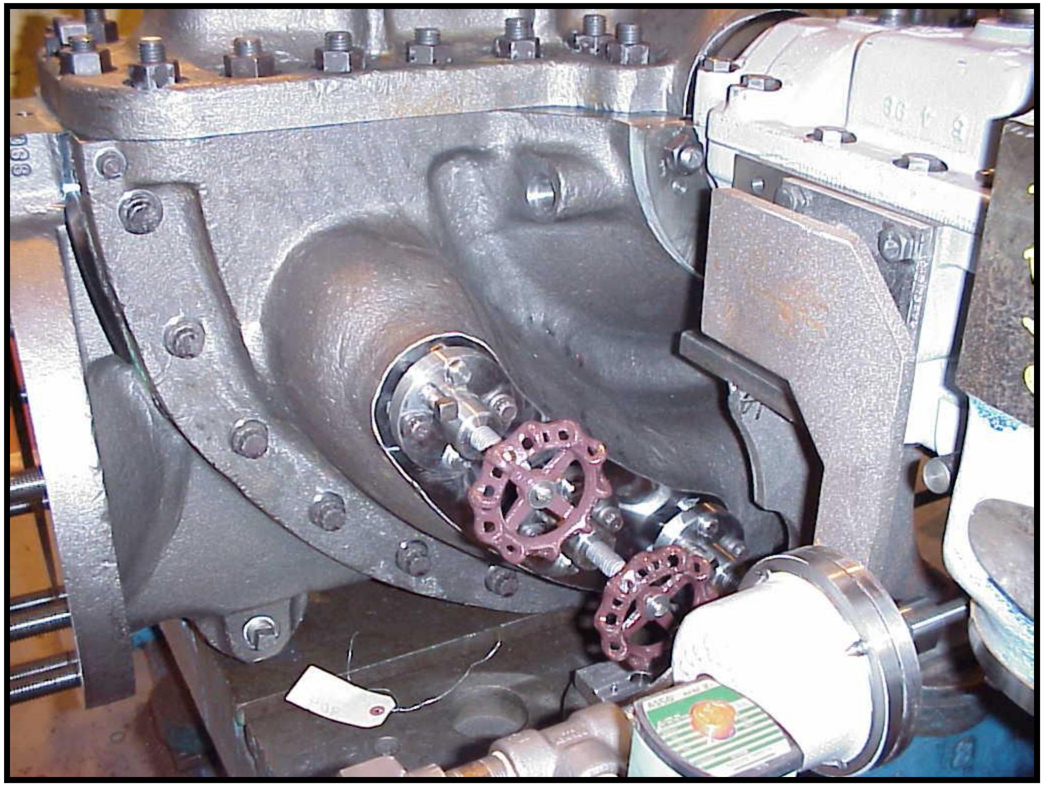


Steam Turbine Construction

Steam End



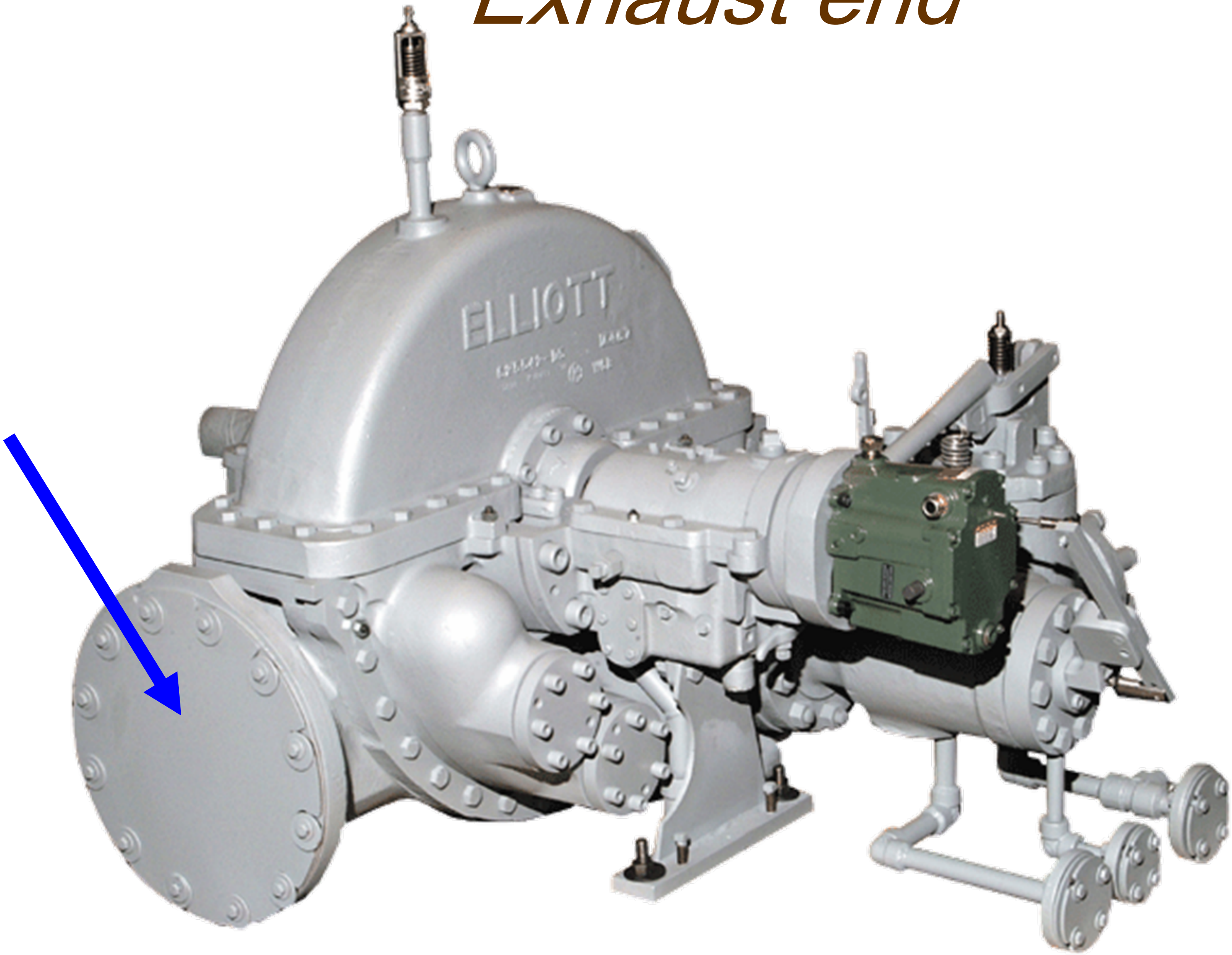
Steam Turbine Design - Components



Manual Handvalves

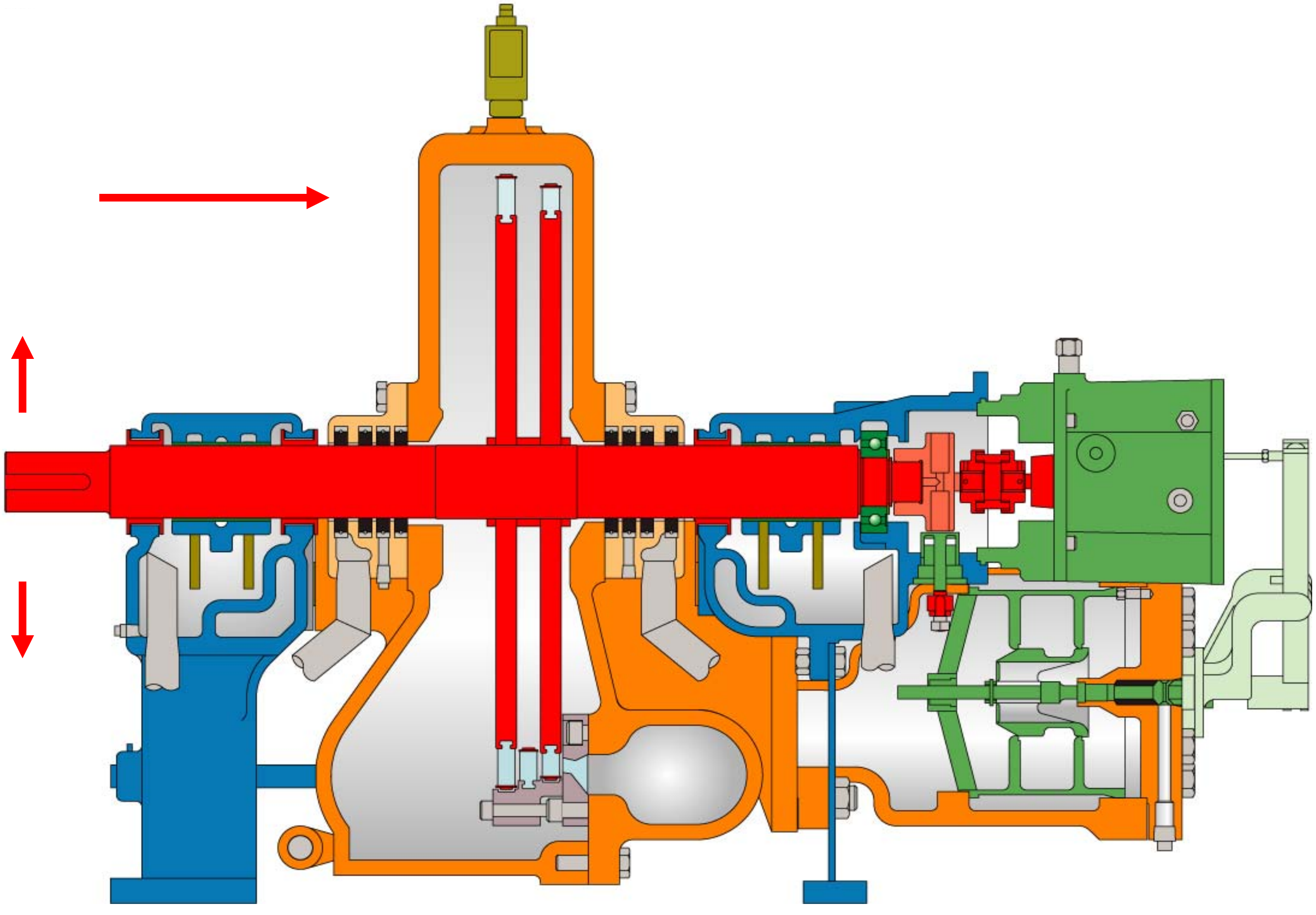
Steam Turbine Construction

Exhaust end



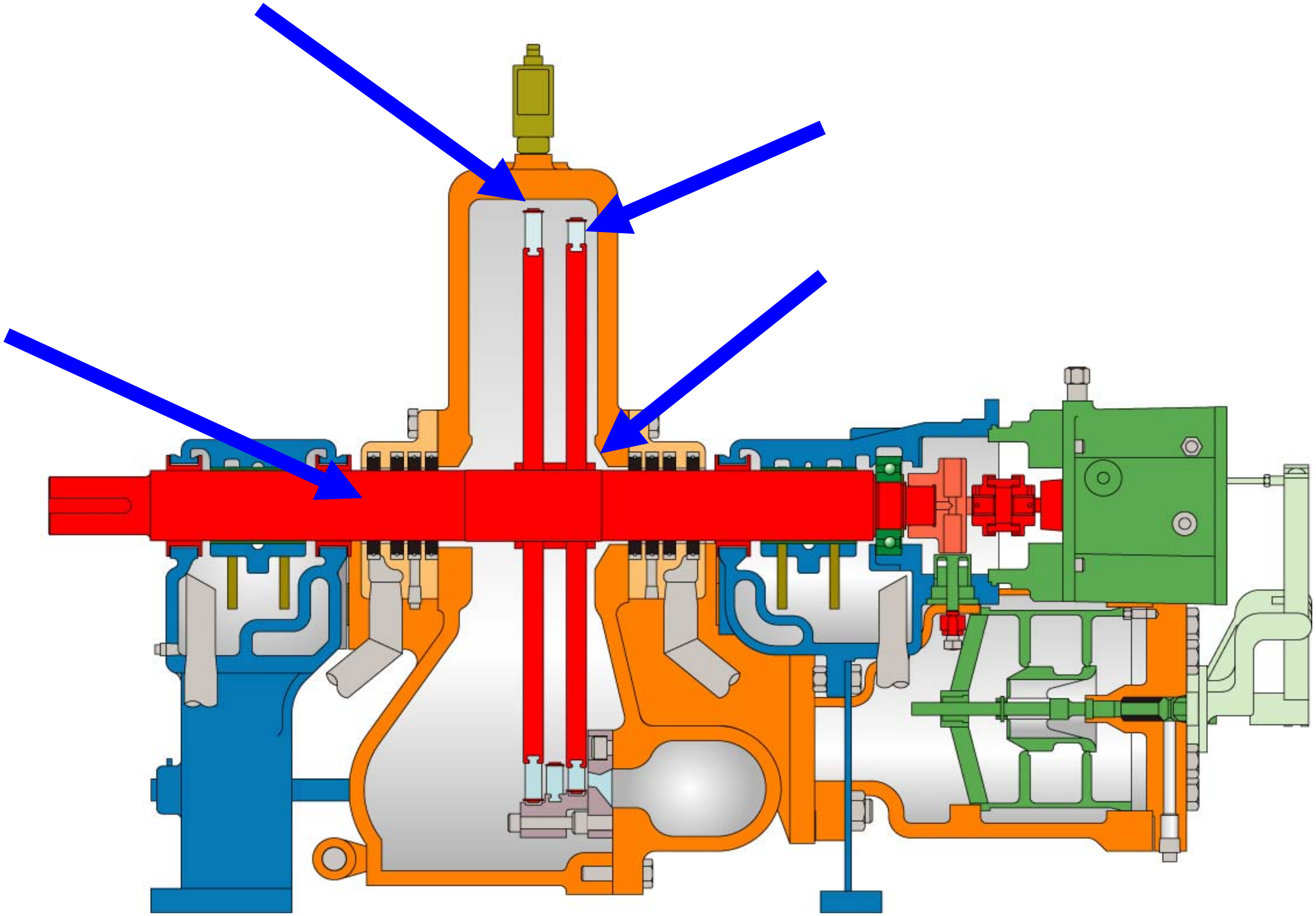
Steam Turbine Construction

Casing Support



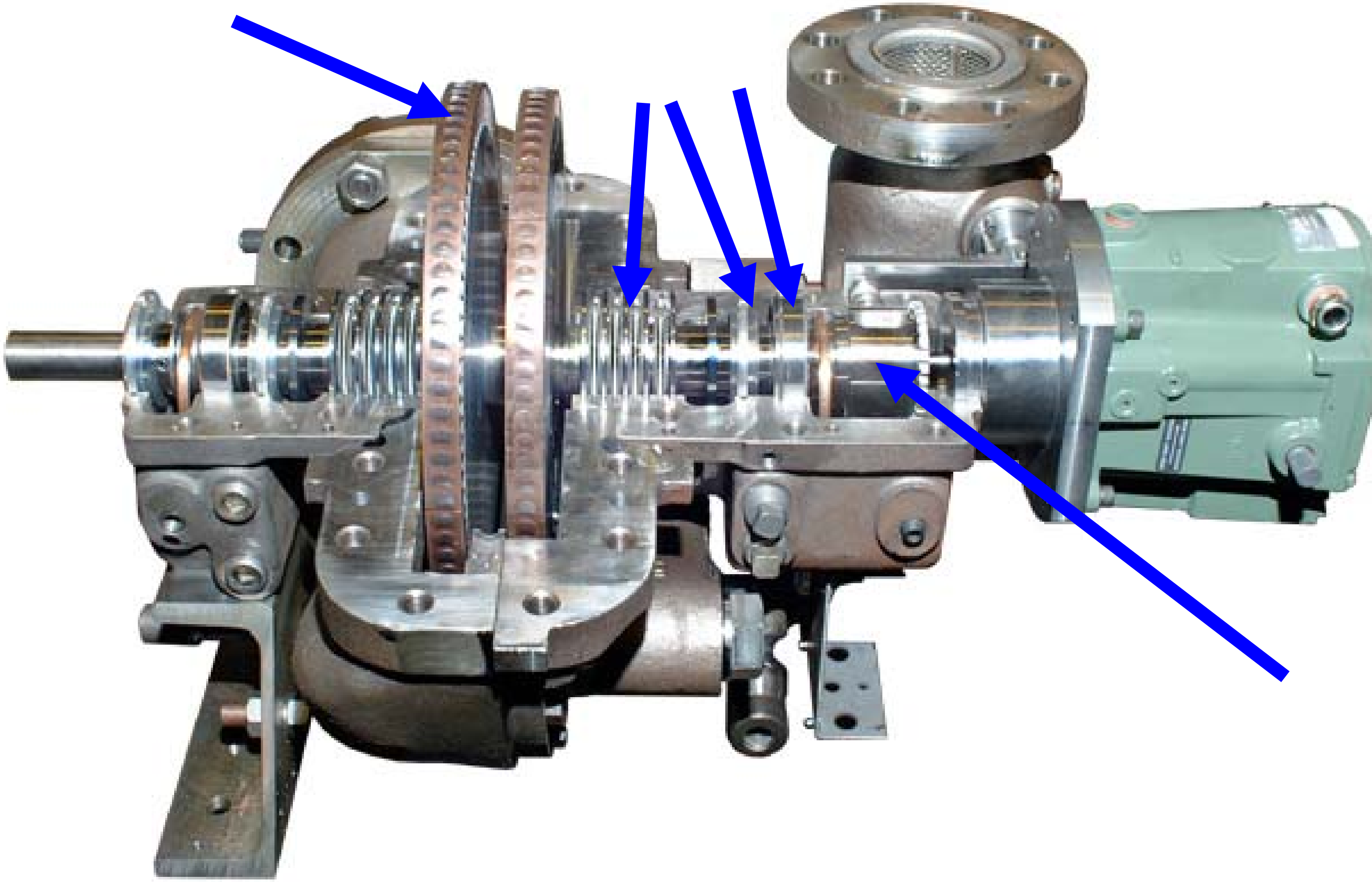
Steam Turbine Construction

Rotor



Steam Turbine Construction

Rotor



Steam Turbine Design - Components

Bearing Housings

SST bearing housings are cast separate from the casing and are bolted on to the casing during assembly. They are cast with integral cooling water passages for lube oil cooling and are horizontally split to allow bearing removal with the rotor and casing in place. The following NON-STANDARD options are available:

Steel material

INPRO seals

Air purge connections

Oil mist connections

Steam Turbine Construction

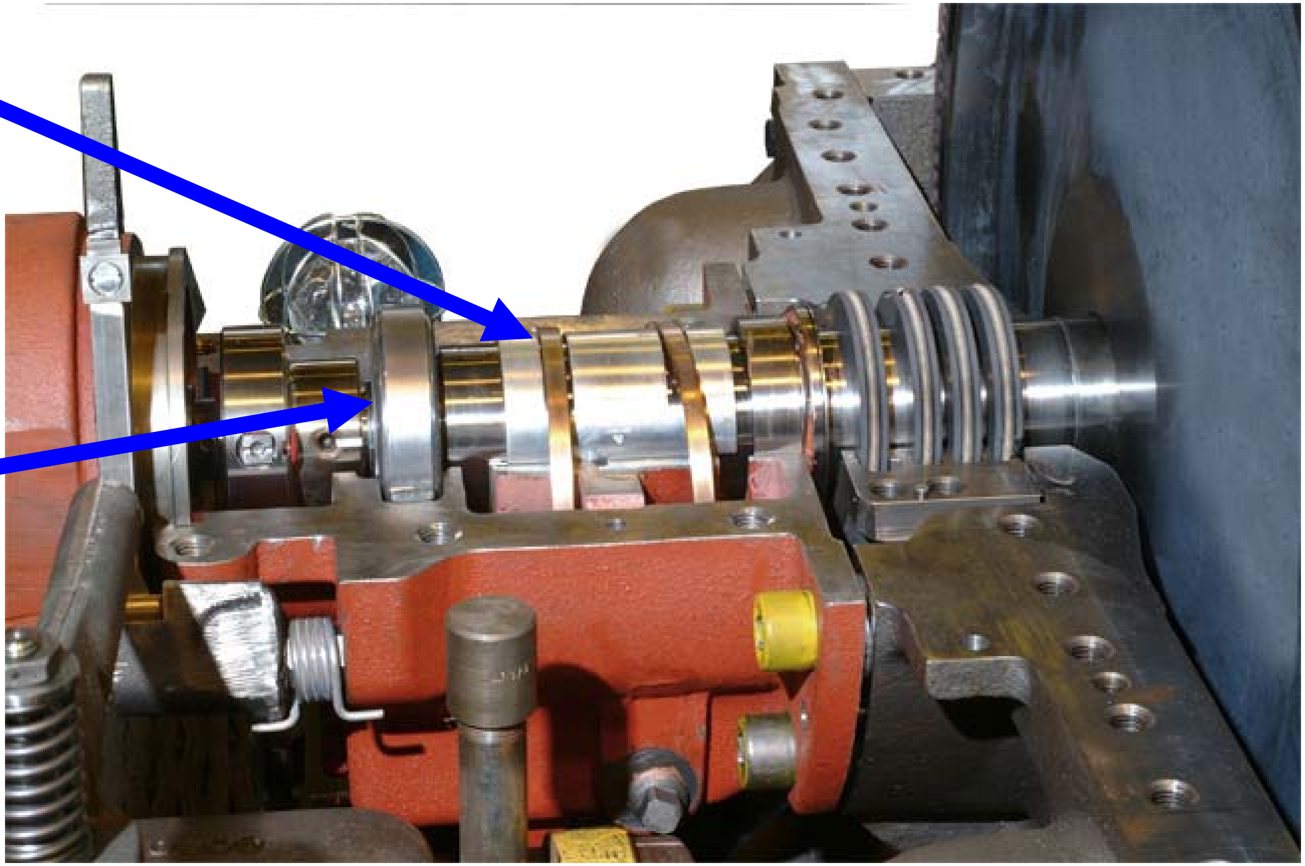
Bearings

Journal bearings

- Sleeve, ball

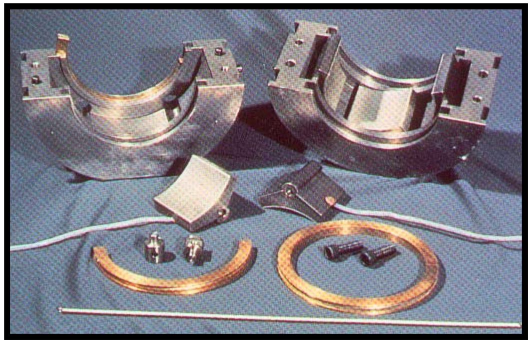
Thrust bearing

- Rotor locating ball
- Tilting pad



Steam Turbine Design - Components

Turbine Bearings



The Journal Bearings support the turbine rotor.

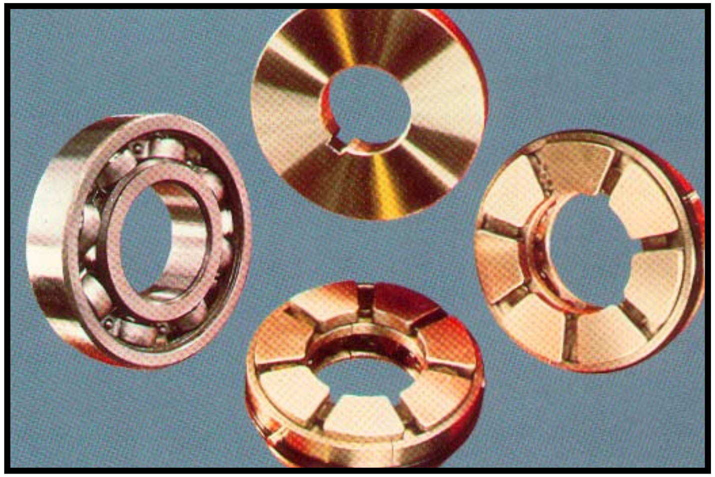
<u>Two types</u>

Sleeve type bearings

Tilt-pad type bearings

Note: Ball radial bearings have been supplied on some turbines for ExxonMobil.

Turbine Bearings



The Thrust Bearing locates the turbine rotor in relation to the nozzle ring.

Two types

Ball type thrust bearings

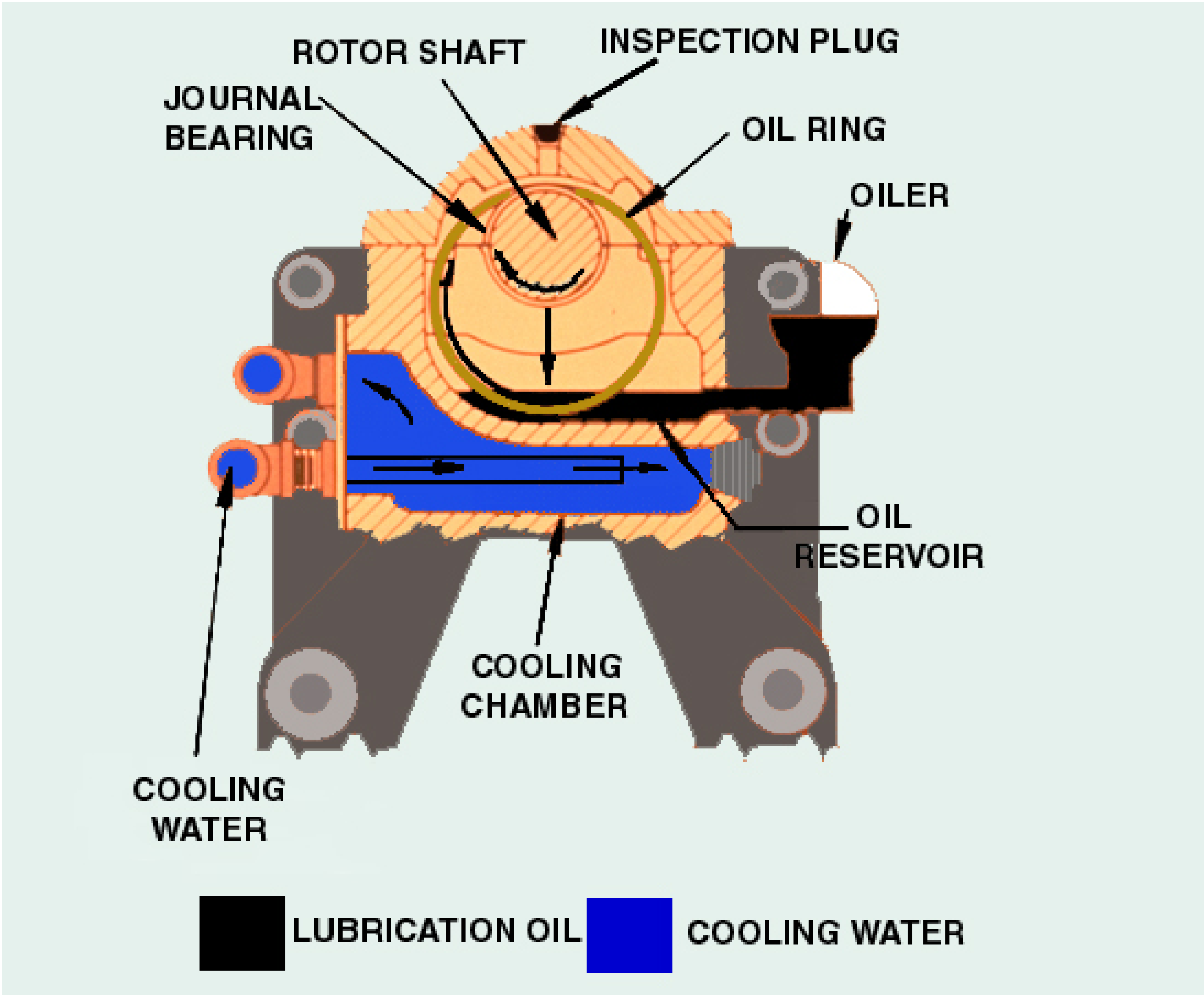
3311XR (Simple Bearing Case)(MRC)

9310 - U (Hi-Cap Bearing Case) (MRC)

Tilt-pad type bearings - Glacier

Steam Turbine Construction

Ring-Oiled Bearings



Steam Turbine Construction
When Pressure Lubrication?

- Higher speeds
- Tilt-pad thrust bearing
- High exhaust temperatures
- Needed for other items
  - Trip and Throttle valve
  - Gear

Steam Turbine Design - Components

Lubrication

Options:

- “SP” circulating oil system (non - pressurized)
  - Saddle pump with oil tank, level indicator, carbon steel interconnecting tubing and sight flow indicator. Cooler and filter available as options.
- F.F. lube feed and drain manifolds
- Complete F.F. lube system

Lubrication

All standard ball thrust bearing applications are ring oiled unless :

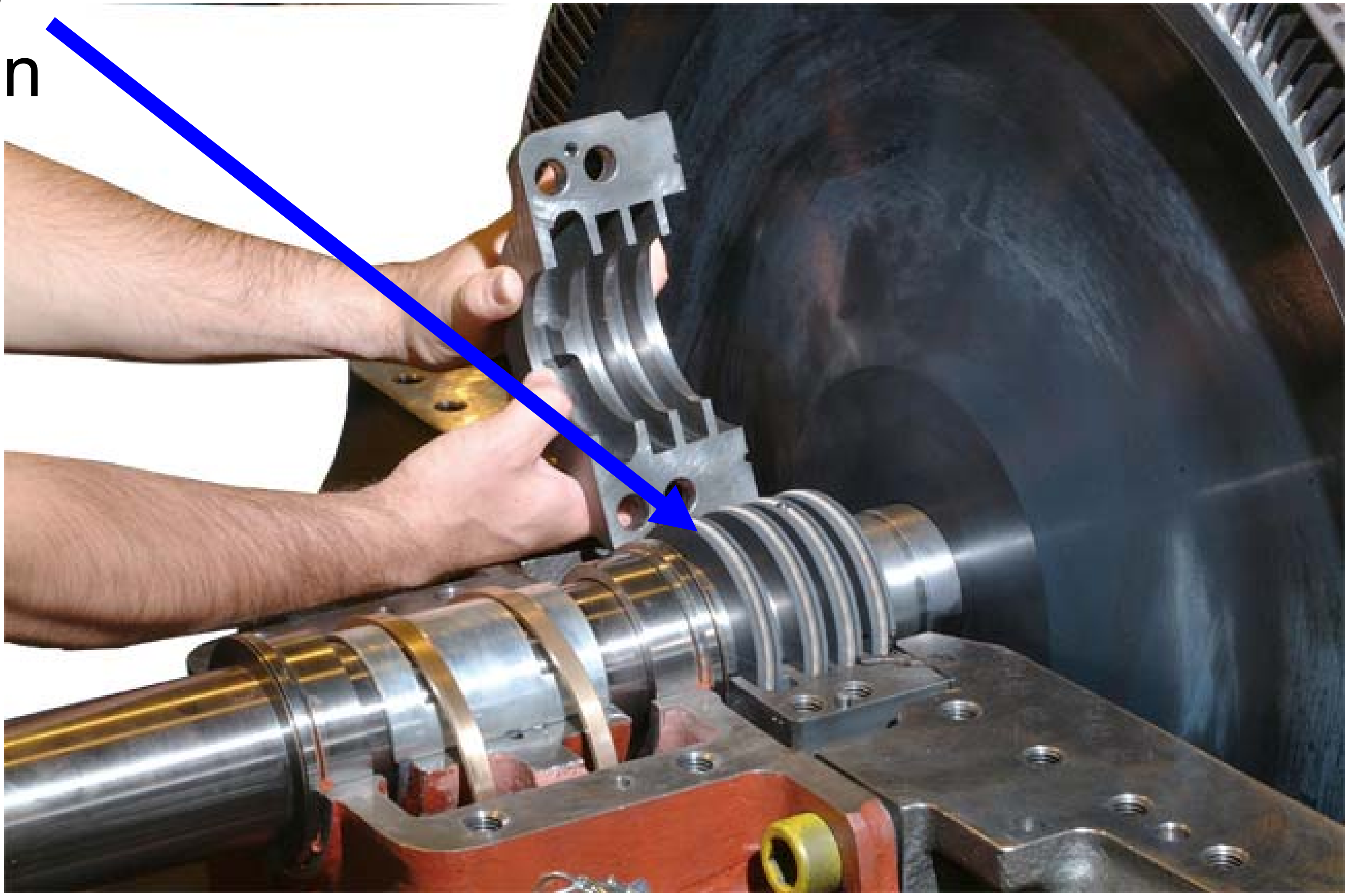
- Turbine speed is over 5000 RPM
- Limits on allowable Exhaust temperature are exceeded.

All 9310-U (oversize ball thrust) and tilt-pad thrust bearing applications require a force feed lube oil system.

Steam Turbine Construction

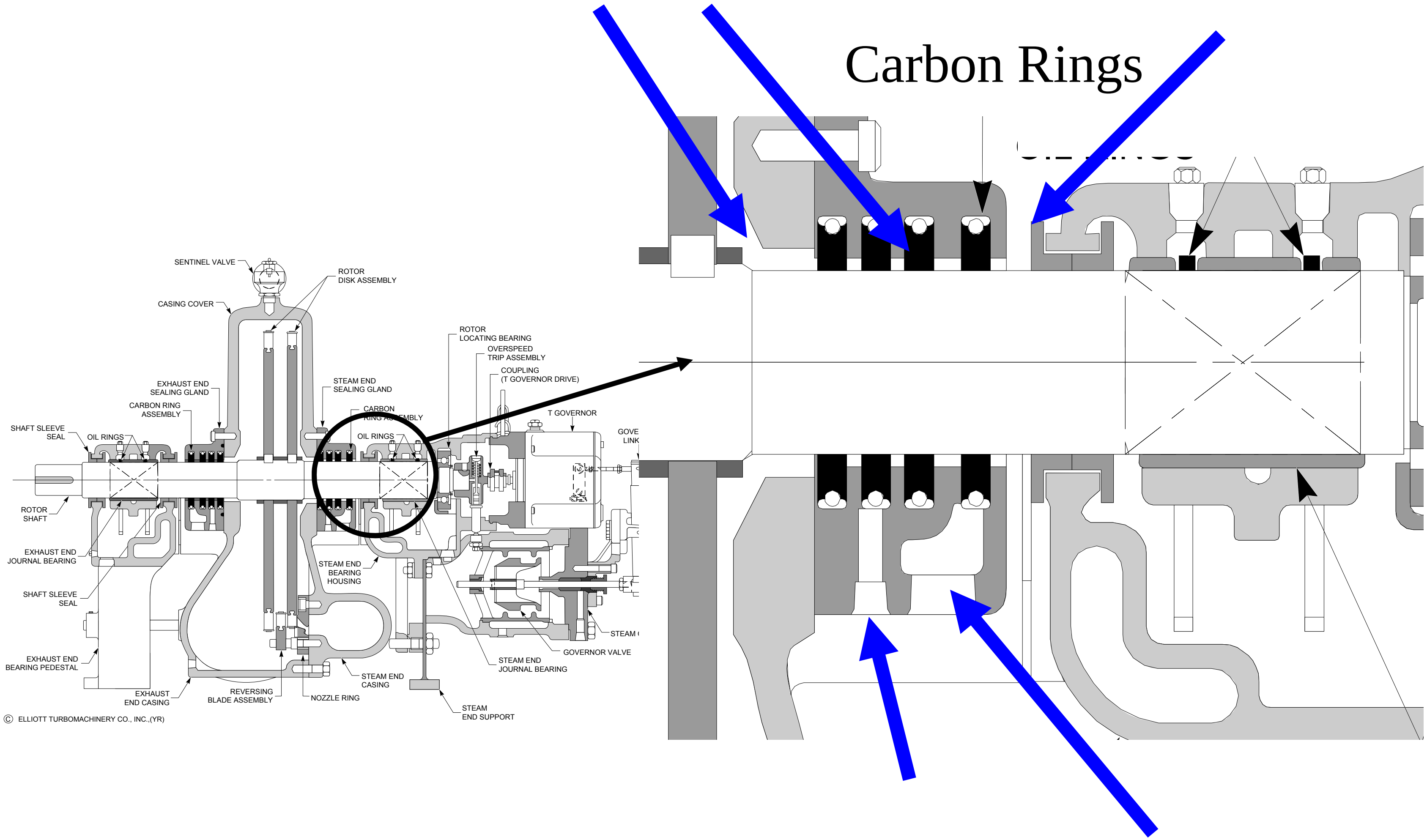
Shaft Seals

Carbon rings most common



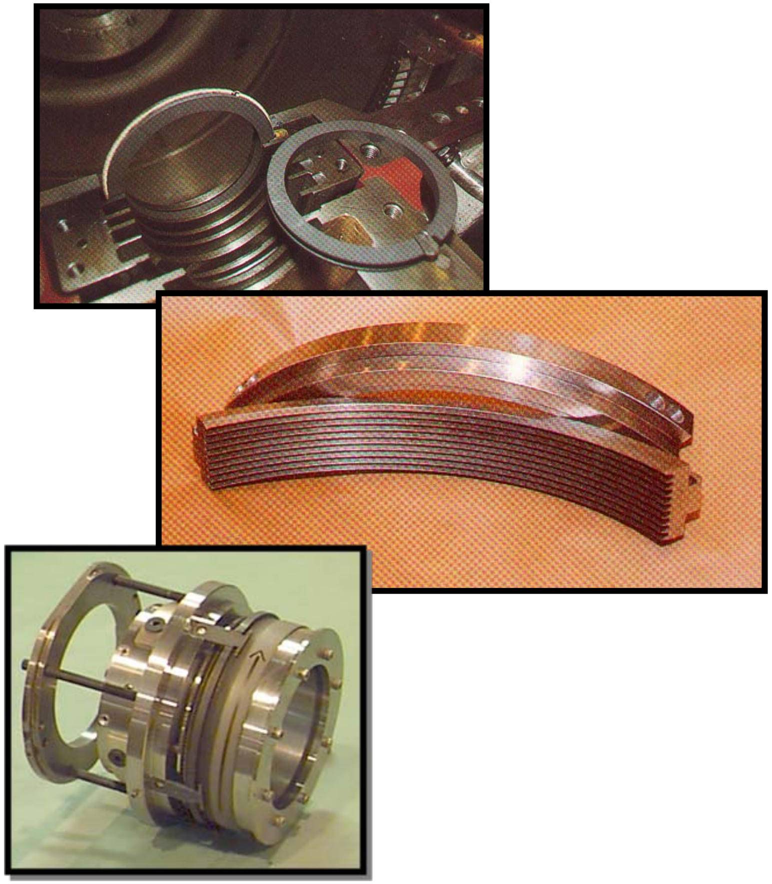
Steam Turbine Construction

Seal Leakage



Steam Turbine Design - Components

Turbine Seals



Seals prevent steam from leaking out of the casing along the turbine shaft, and potentially contaminating the bearing oil.

Three types

Carbon Ring

Labyrinth

Mechanical

Steam Turbine Construction

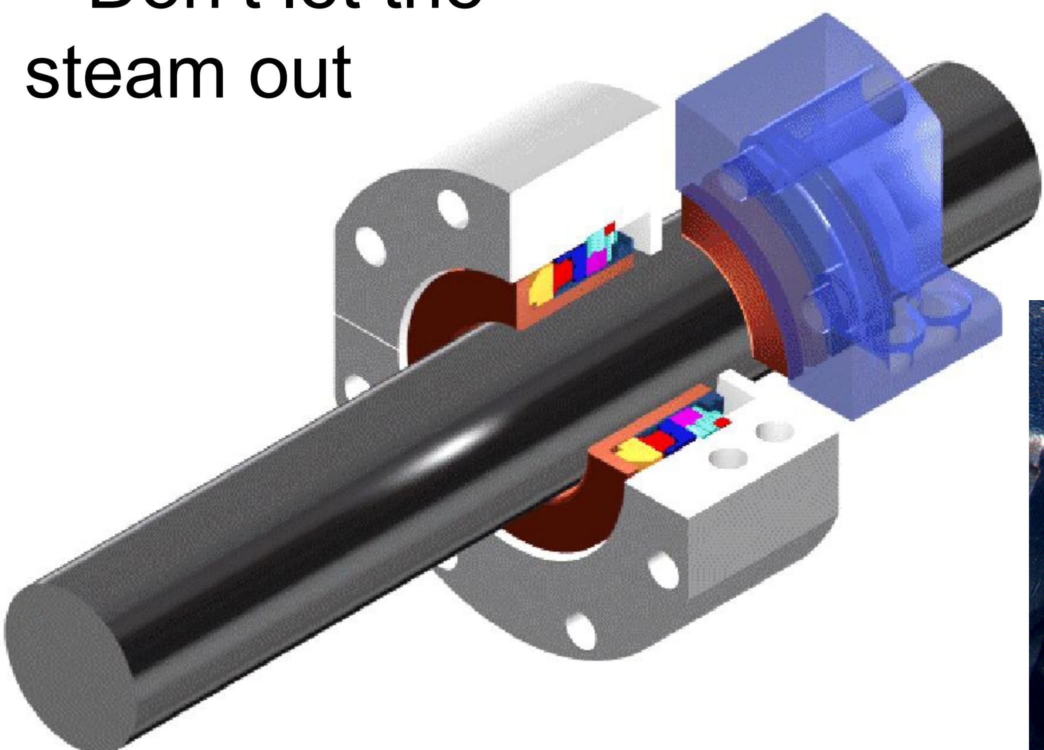
Seal Alternatives

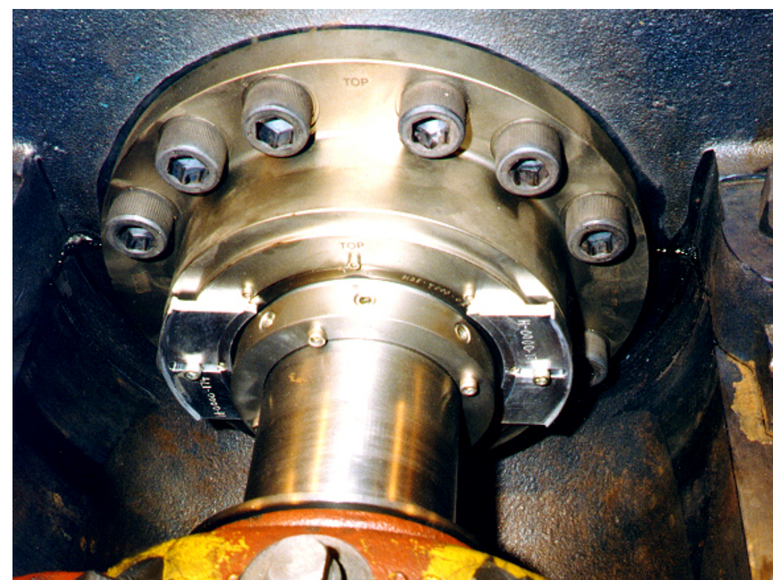
Gas Face Seal
– Don’t let the
steam out

Water accumulation

Growth

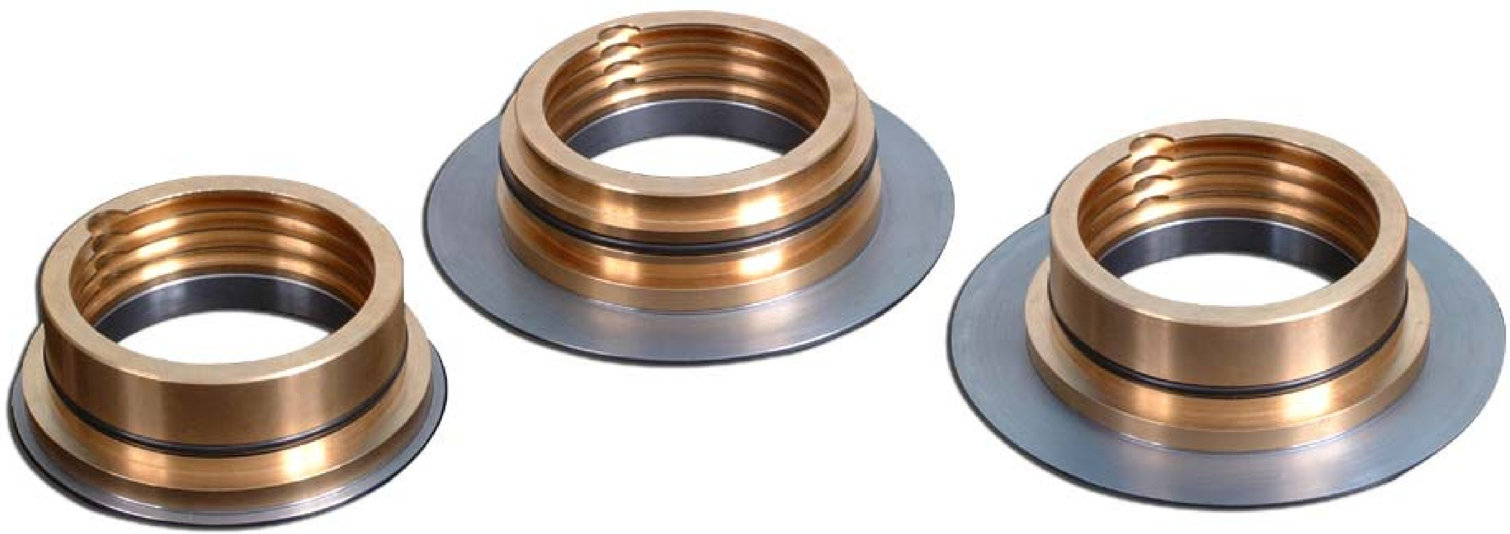
Cost





Bearing Isolators

Keep the oil in and
the steam out



Steam Turbine Construction

Controls – Speed definitions

Class of Governing System	Maximum Speed Regulation %	Maximum Speed Variation %	Maximum Speed Rise %
A	10	0.75	13
B	6	0.50	7
C	4	0.25	7
D	0.50	0.25	7

Governors

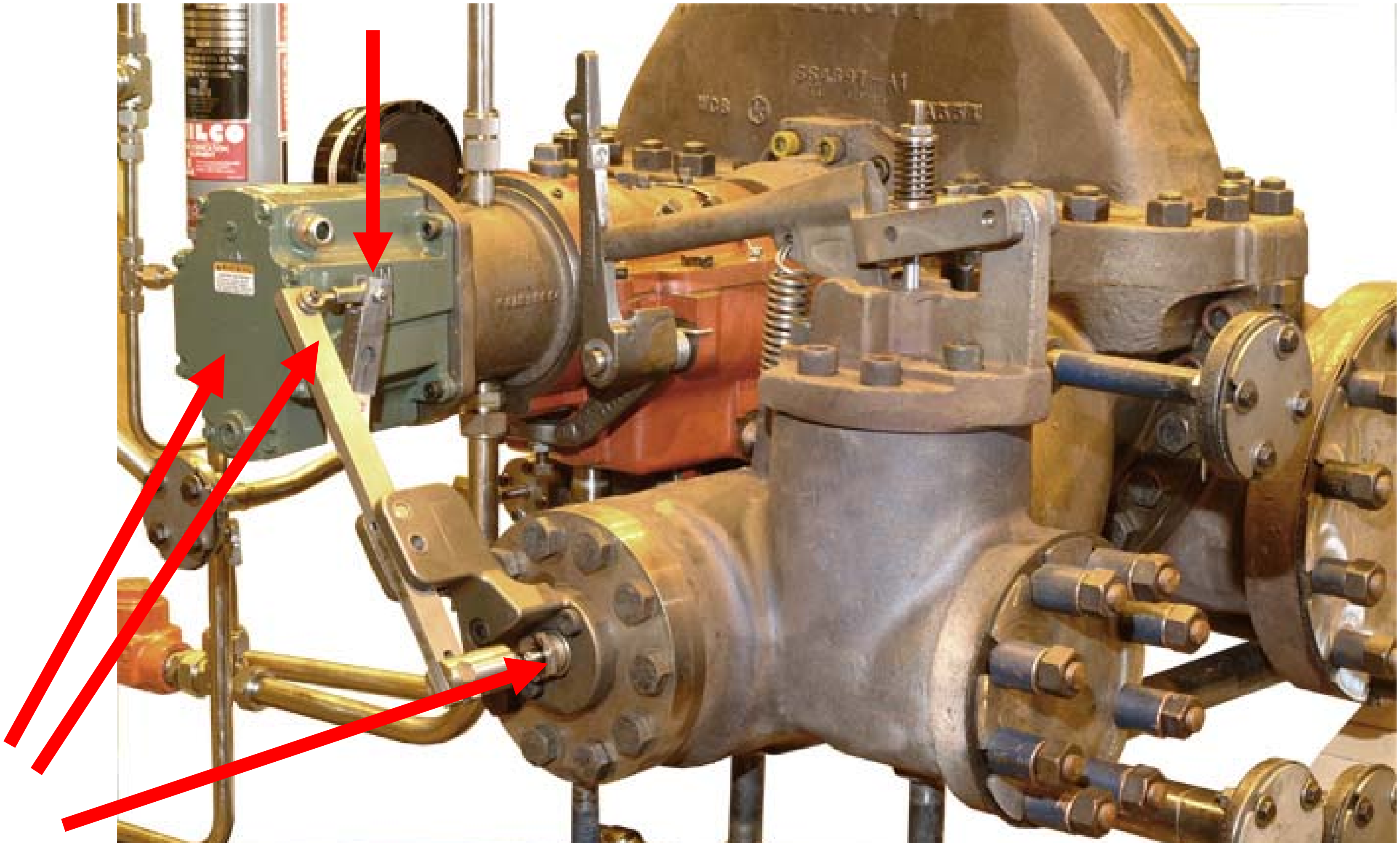
The standard governor is the Woodward TG-13.

The following mechanical-hydraulic governors are available:

- TG-13L
- PG-D
- PG-PL
- UG-10
- UG-40

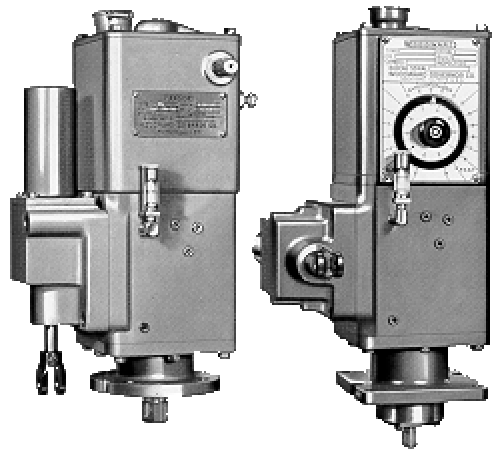
Steam Turbine Construction

Controls – Mechanical-Hydraulic

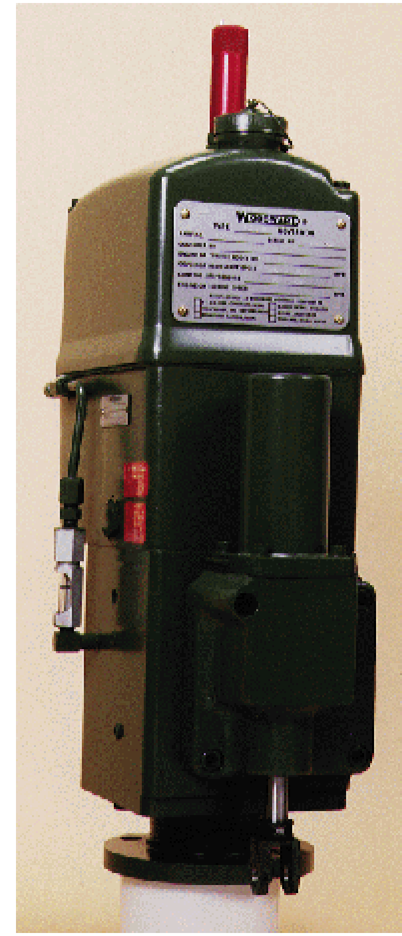


TG -13

PG-D



PG-PL



UG- 8 & 10

UG-40

Governors

The following electronic governors are available:

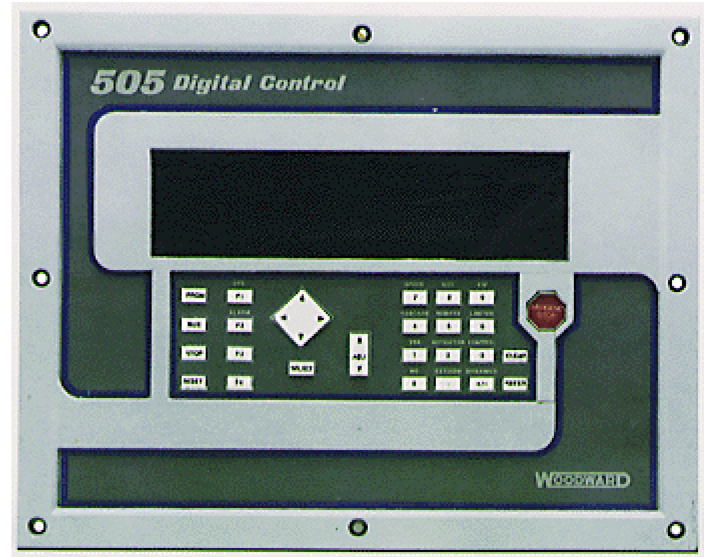
- Woodward Peak 150
- Woodward 505
- Tri-Sen TS-110
- Tri-Sen TS-310
- Dynalco

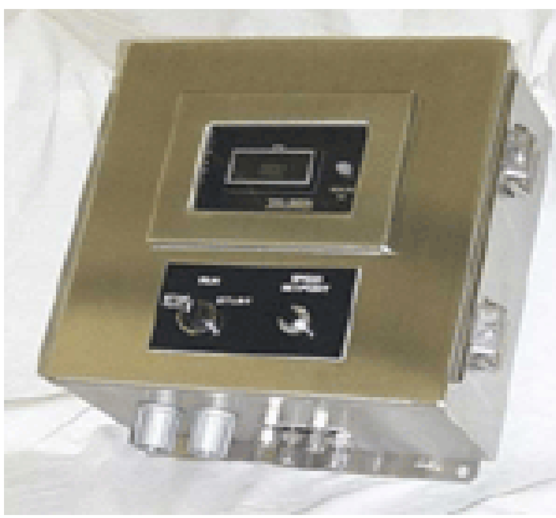
Actuators - Fisher, Valtek and Woodward

- Pneumatic and hydraulic

Peak 150

505

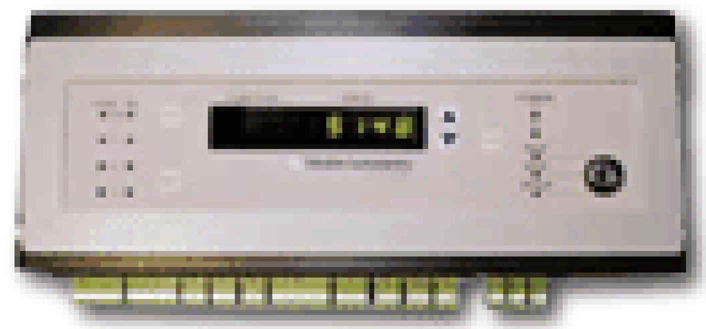




TS 110

TS 310

Woodward ProTech 203



Triconex TurboSentry

Steam Turbine Construction
Controls - Electronic

Control components considerations -

- Reliable
- Versatile
- Remote signal
- Redundant trip

Steam Turbine Selection When to use a Multistage Turbine

- Larger exhausts needed than available on single stage turbines (typically condensing)
- Steam rate improvement
- Power too high for single stage turbine

Steam Turbine Selection

Multistage Comparison

	Steam rate at normal	Annual cost of steam (millions)
Normal power Plus 10%	51.2	$1.58
Min/Max design with Hand Valves	54.6	$1.68
Min/Max design without Hand Valves	58.7	$1.81
Multistage	40	$1.23

Steam Turbine Specifications

Steam Turbine Specifications

- NEMA SM23
  - Controls
  - Velocity limits
  - Piping loads
  - Excursions
  - Purity
- API 611 General Purpose
- API 612 Special Purpose

Mechanical Differences

API 611

- Cast iron bearing housing
- Sleeve journal bearings
- Ball or tilt-pad thrust bearing
- Carbon ring steam seals
- Keyed shaft
- Nema A or D governor

API 612

- Steel bearing housing
- Sleeve or tilt-pad journal bearings
- Tilt-pad thrust bearing
- Labyrinth end seals
- Nema D governor
- Oil operated T&T valve
- 2 out of 3 voting electronic trip
- No mechanical trip
- Casing field rotor balance provision
- Rotor shafts must be degaussed

Standard Testing

API 611

- 1-hour uninterrupted mechanical test
- Measure Oil Temperature (IN)
- Measure Oil Pressure (IN)
- Measure Steam Pressure
  - Inlet and Exhaust
- Measure Steam Temperature
  - Inlet and Exhaust
- Standard Rotor Balance

API 612

- 4-hour uninterrupted mechanical test
- Rotor Dynamics Testing
  - Amplitude vs. Frequency
  - Amplitude vs. Speed
  - Phase Angle vs. Speed
  - Prove Lateral Critical (N/A for stiff shaft rotors)
- Measure Oil Temperature (IN / OUT)
- Measure Oil Pressure (IN / OUT)
- Measure Oil Flow
- Measure Steam Pressure
  - Inlet and Exhaust
- Measure Steam Temperature
  - Inlet and Exhaust
- Check rotor unbalance response (if coupling is furnished by Elliott)
- Incremental Rotor Balance

Standard Documentation

API 611

- Willans Line (Performance Curve)
- API-611 Data Sheets

API 612

- Willans Line (Performance Curve)
- API-612 Data Sheets
- Rotor Response Analysis (Lateral)
- Campbell / Goodman Diagrams

Steam Turbine Selection

Steam Turbine Selection

Data Required

- Musts
  - Inlet pressure
  - Inlet temperature
  - Exhaust pressure
  - Power required (sometimes flow available)
  - Speed of driven equipment

Steam Turbine Selection
Data Required - Additional

- Driven equipment
- Control required (NEMA)
- Operational considerations
- Steam consumption information

API 611 Data Sheet

GENERAL-PURPOSE STEAM TURBINE
DATA SHEET
U.S. CUSTOMARY UNITS

JOB NO. ______ ITEM NO. ______
PURCHASE ORDER NO. ______
SPECIFICATION NO. ______
REVISION NO. 0 DATE ______
PAGE 1 OF 3 BY DCM - ELLIOTT

APPLICABLE TO: ○ PROPOSAL ○ PURCHASE ○ AS BUILT
FOR ______ UNIT ______
SITE ______ NO. REQUIRED ______
SERVICE ______ DRIVEN EQUIPMENT ______
MANUFACTURER ELLIOTT MODEL ______ SERIAL NO. ______

NOTE: ○ INDICATES INFORMATION COMPLETED BY PURCH □ BY MANUFACTURER ⃞ BY MFGR IF NOT BY PURCH

○ OPERATING CONDITIONS			□ PERFORMANCE		
OPERATING POINT	POWER, BHP	SPEED, RPM	OPERATING POINT/ STEAM CONDITION	NO. HAND VALVES OPEN (5.4.1.5)	STEAM RATE, LBS/HP-HR
NORMAL			NORMAL/NORMAL (CERTIFIED SR)	X	
RATED			RATED/NORMAL		
OTHER (4.1.4)			(1) MIN. INLET - MAX EXHAUST		
○ DUTY, SITE AND UTILITY DATA					

API 611 Data Sheet

17 ○ SLOW ROLL REQ. (4.10.4) ○ HAND VALVES REQ. (5.4.1.5)

18 DUTY ○ CONTINUOUS ○ STANDBY

19 ○ UNATTENDED AUTO START (4.1.6)

20 LOCATION (4.1.14) ○ INDOOR ○ HEATED ○ UNHEATED

21 ○ OUTDOOR ○ ROOF ○ W/O ROOF

22 AMBIENT TEMP., °F: MIN. ______ MAX ______

23 UNUSUAL CONDITIONS ○ DUST ○ SALT ATMOSPHERE

24 (4.1.14) ○ OTHER ______

25 ELECT. AREA (4.1.13) CLASS ______ GROUP ______ DIV ______

26 ○ NON-HAZARDOUS

27 CONTROL POWER V ______ PH. ______ HZ ______

28 AUX. MOTORS V ______ PH. ______ HZ ______

29 COOLING WATER PRESS, PSIG ______ D P PSI ______

30 TEMP ______ FLOW, GPM ______ D T °F: ______

31 ALLOW. SOUND PRESS LEVEL (4.1.12) ______ dBA @ ______ FT

32 ○ STEAM CONDITIONS

33		MAX	NORMAL	MIN.
	INLET PRESS, PSIG			
34	INLET TEMP, °F			
35	EXHAUST PRESS (PSIG)(IN. HGA)			
36	○ STEAM CONTAMINANTS (4.11.1.7)			

API-611 OTHER ______

CONSTRUCTION

TURBINE TYPE ○ HORIZ ○ VERTICAL

NO STAGES ______ WHEEL DIA., IN. ______

ROTOR: ☐ BUILT UP ☐ SOLID ☐ OVERHUNG

☐ BETWEEN BRGS

BLADING ☐ 2 ROW ☐ 3 ROW ☐ RE-ENTRY

CASING SPLIT ☐ AXIAL ☐ RADIAL

CASING SUPPORT ☐ CENTERLINE ☐ FOOT

○ VERT. JACKSCREWS (4.2.13)

VERTICAL TURBINE FLANGE

○ NEMA "P" BASE ○ OTHER (4.4.9) ______

TRIP VALVE ☐ INTEGRAL ☐ SEPARATE

INTERSTAGE SEALS ☐ LABYRINTH ☐ CARBON

END SEALS ☐ CARBON RING, NO/BOX ______

☐ LABYRINTH ☐ MATERIAL ______

☐ MECHANICAL ☐ MFR ______

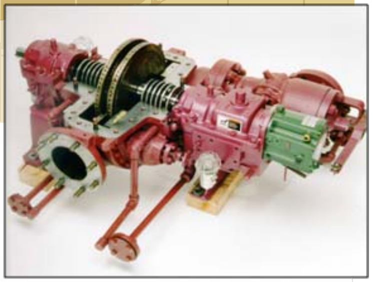
TYPE RADIAL BEARINGS (4.9.1) ______

TYPE THRUST BEARING (4.9.2) ______

API 611 Data Sheet

37	**TURBINE DATA**	☐ CALCULATED THRUST LOAD ______ PSI (4.9.15)
38	☐ ALLOW SPEEDS, RPM, MAX ______ MIN ______	☐ BEARING MFGR's ULTIMATE RATING ______ PSI
39	☐ MAX CONT SPEED, RPM (3.1.10) ______	THRUST COLLAR (4.9.10.2) ☐ REPLACEABLE ☐ INTEGRAL ☐ NONE
40	☐ TRIP SPEED, RPM ______ BLADE TIP VEL, FPS ______	◯ LUBE OIL VISCOSITY (4.10.3) ISO GRADE ______
41	☐ FIRST CRITICAL SPEED, RPM (4.8.2.1) ______	LUBRICATION ◯ RING OILED ◯ PRESSURE ◯ GREASE
42	☐ EXH. TEM °F ______ NORMAL ______ NO LOAD	OIL MIST (4.9.19)
43	☐ POTENTIAL MAX POWER, BHP (3.1.20) ______	◯ PURGE OIL MIST ◯ PURE OIL MIST
44	☐ MAX. NOZZLE STEAM FLOW, LBS/HR ______	◯ BEARING HOUSING OILER TYPE ______
45	ROTATION FACING GOVERNOR END ◯ CCW ◯ CW	
46	◯ DRIVEN EQUIPMENT THRUST, LBS (4.9.11) ______	
47	(VERTICAL TURBINE) (4.9.3)	
48	◯ WATER PIPING FURN. BY ◯ VENDOR ◯ OTHERS	
49	◯ OIL PIPING FURN. BY ◯ VENDOR ◯ OTHERS	
50		

CASING DESIGN	**INLET**	**EXHAUST**
MAX. ALLOW. PRESS, PSIG		
MAX ALLOW. TEMP, °F		
HYDRO TEST PRESS., PSIG		



Factors that affect Turbine Performance

<u>Steam Conditions</u>

More "available energy" means lower steam flow to produce power.

<u>Horsepower & RPM</u>

In general, higher HP & RPM turbines are more efficient.

<u>Frame Size</u>

Number of stages.

Stage pitch diameters.

<u>Inlet & Exhaust Losses</u>

Minimized by keeping velocities within reasonable limits.

Steam Turbine Selection

Steam Rate = Flow/Power or TSR/η

TSR – theoretical steam rate = Δh_{is}/Constant

Steam Turbine Selection

Power Calculation

Power = (Flow) (H_{is}) (η) / 2545 - HP losses

In English units:

Power = horsepower

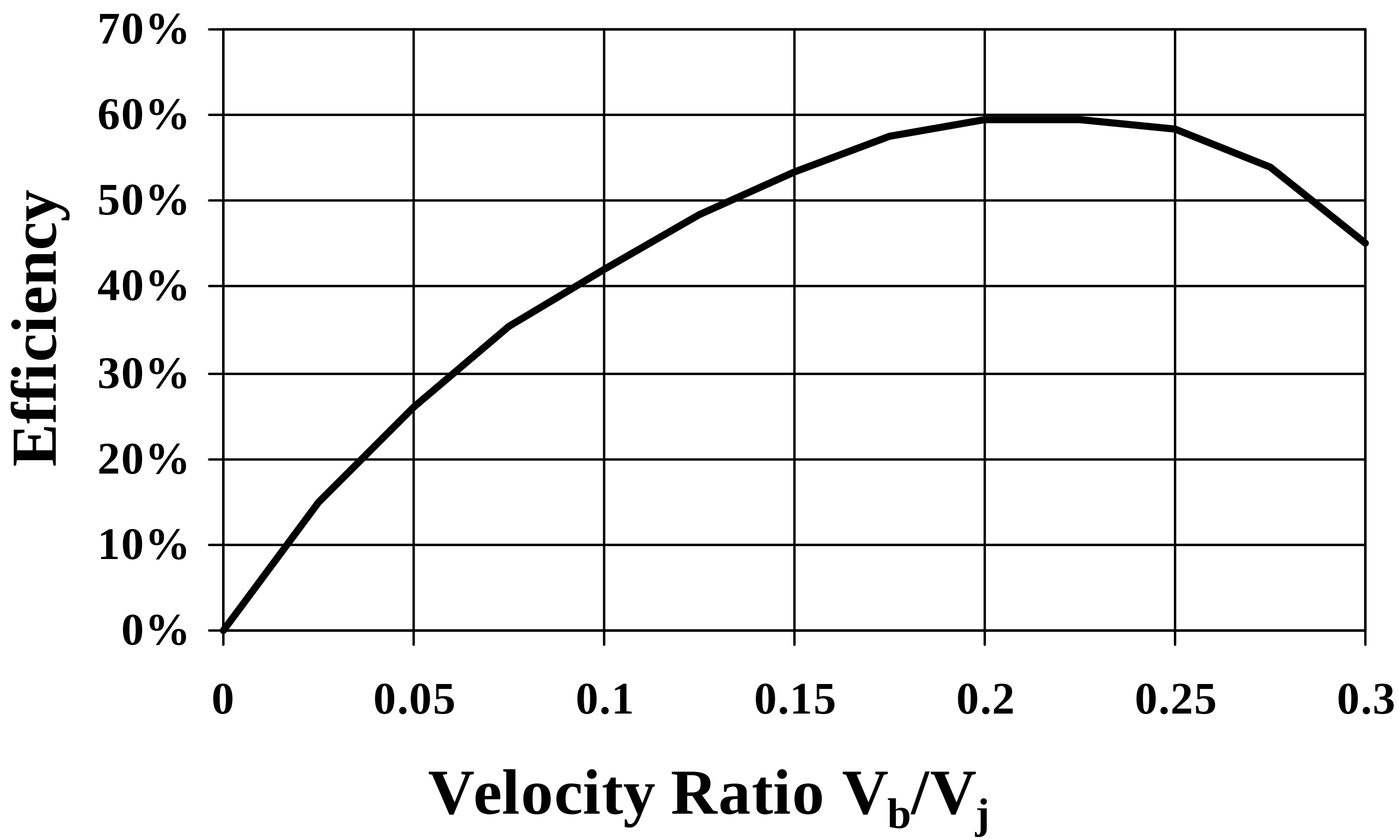
H_{is} = Isentropic BTU per pound

η = efficiency

Flow = Pounds per hour

Steam Turbine Selection

Typical Efficiency



Where V_b = Bucket Velocity = π(Stage Diameter)(Speed) / K

And V_j = Steam Jet Velocity = $\sqrt{2g_cJ(\Delta H_{is})}$

Steam Turbine Selection Example

- 770 Horsepower @ 3600 RPM
- 600 psig/700 Deg. F/150 PSIG
- 847 maximum Horsepower

Steam Turbine Selection Design Checks

Inlet and Exhaust velocities

	Non – Condensing feet/second	Condensing feet per second
Inlet	175	175
Exhaust	250	450

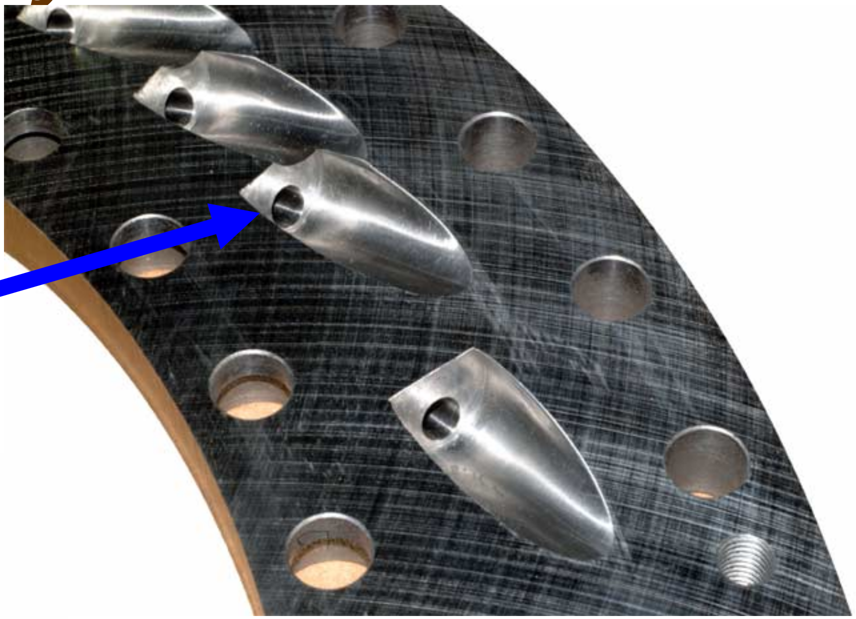
Steam Turbine Selection Design Checks
Mechanical Limits

- Shaft end torque
- Blade stresses (Goodman diagram)
- Blade frequencies (Campbell Diagram)
- Speed limits
  - Blades, Shrouds, Disks, Critical speed

Steam Turbine Selection Design Checks

Aerodynamics

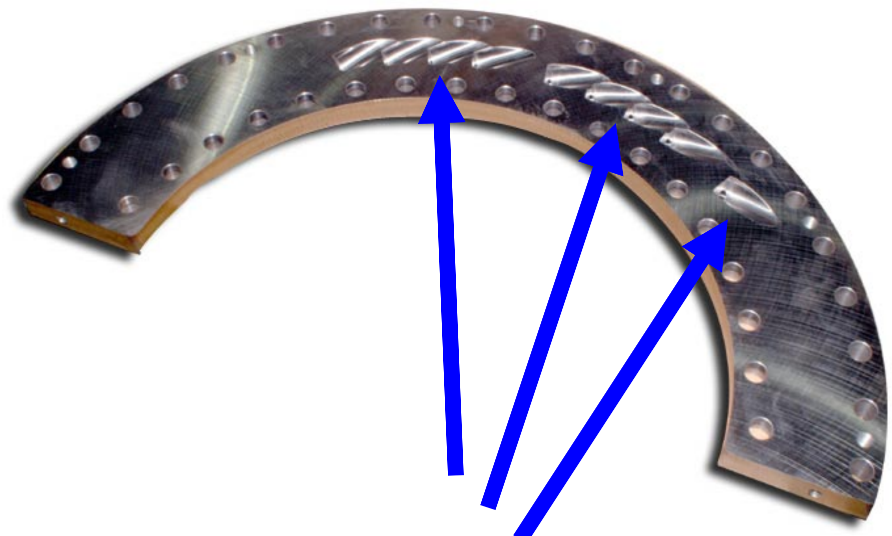
Pressure ratio across the stage determines ideal nozzle expansion ratio – ratio of exit area to throat area



Steam Turbine Selection
Nozzle Configuration

Steam flow divided by critical flow determines nozzle area required

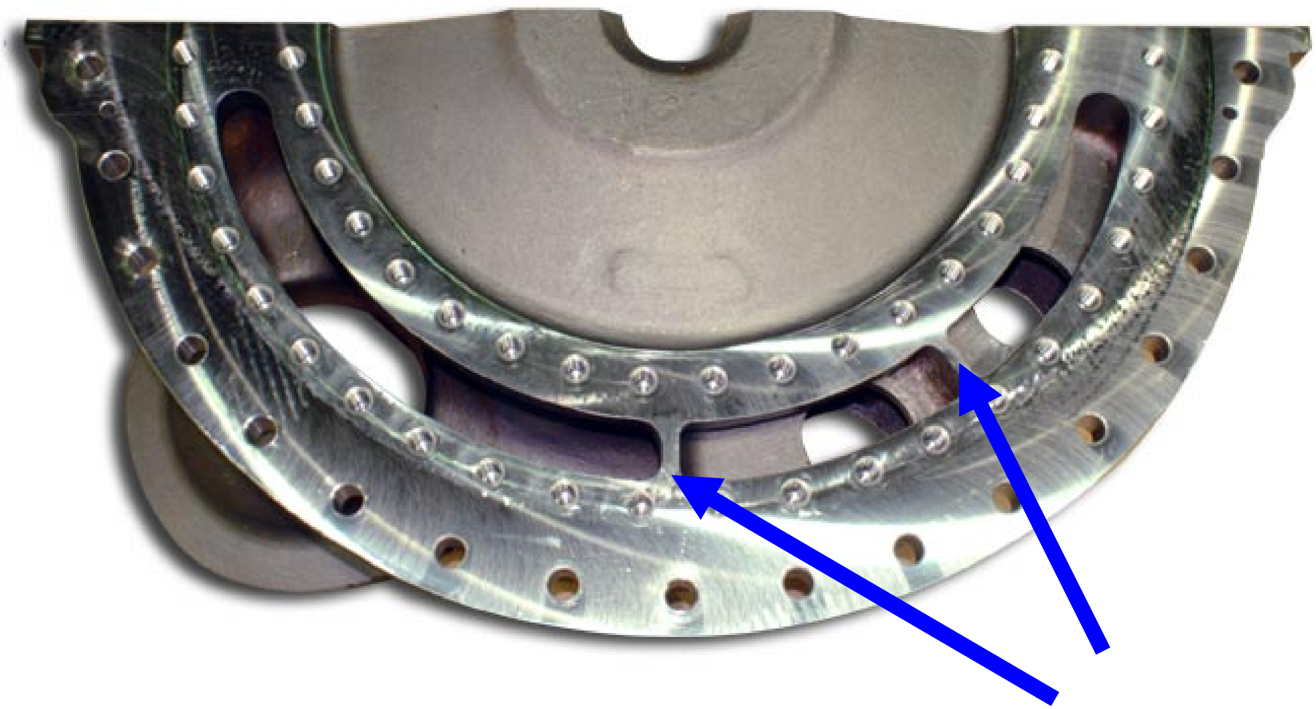
Nozzle area required divided by the nozzle throat area determines the number of nozzles



Nozzles are arranged to accommodate the hand valve ports ribs

Nozzle Ports

Nozzles are arranged to accommodate the hand valve ports, ribs



Steam Turbine Selection

Results Comparison

	Steam rate at normal	Annual cost of steam (millions)
Normal power Plus 10%	51.2	$1.58
Min/Max design with Hand Valves	54.6	$1.68
Min/Max design without Hand Valves	58.7	$1.81

Steam Turbine Design - Components

Instrumentation

Following instrumentation available:

- Thermocouples or RTDs
- Radial vibration probes
- Axial position probes
- Keyphasor
- Vibraswitch
- Accelerometer

Leakoffs & Drains (Typical)

Leakoffs to Open Drain

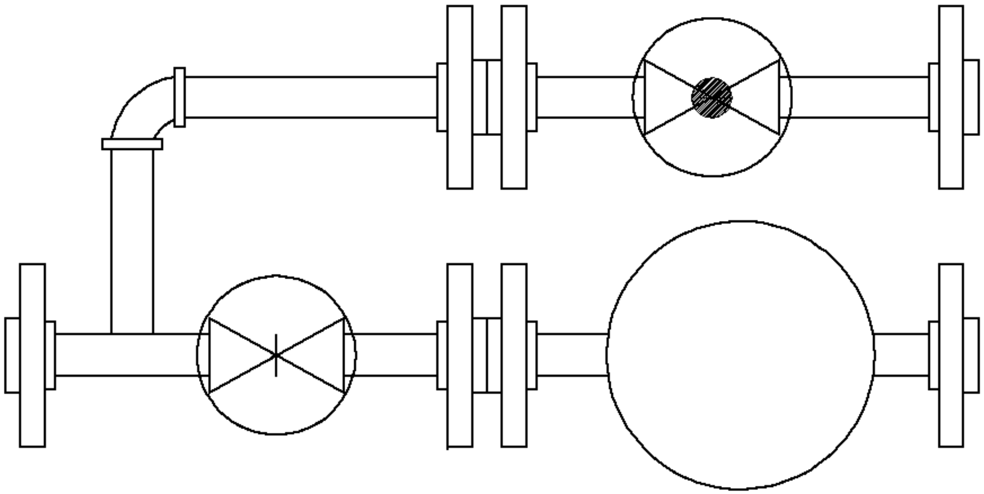
•2 packing case
•1 trip valve stem
•1 governor valve stem

Open Drains with Suitable Valve

•1 turbine case drain
•1below the seat drain (steam chest)
•1above the seat drain (steam chest)

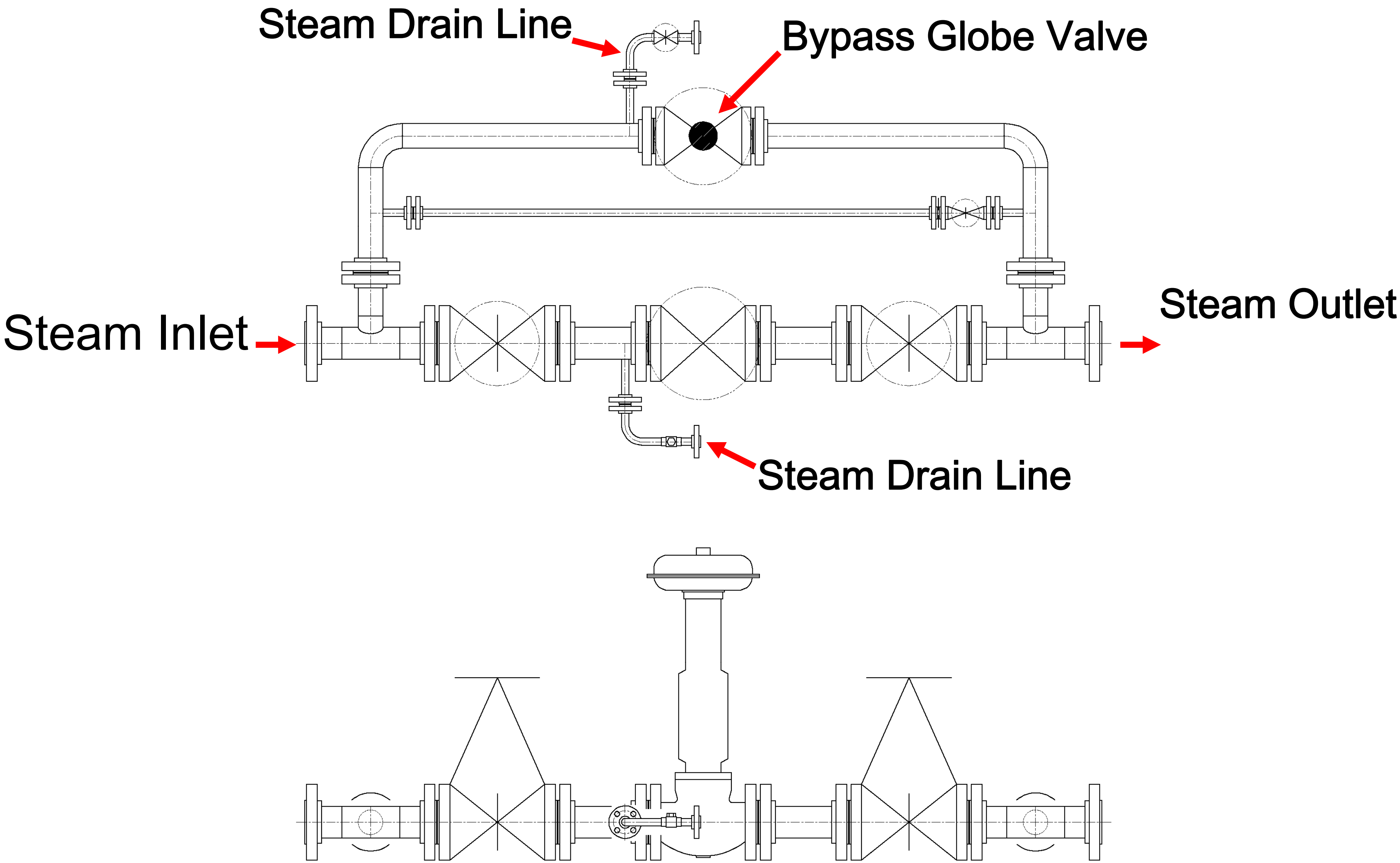
Steam Traps

- Spirax Sarco
  - TD-52 or TD-62 (based on temperatures)
- Located on turbine drain lines



Steam Turbines

Auto Start



Steam Turbine Design - Components

Accessories

Following accessories are available:

- Low oil / air pressure trip
- Solenoid trip arrangement
- Alarm & trip switches
- Tachometers (digital, externally powered or self-powered)
- 2 out of 3 voting overspeed trip arrangement
- Gaugeboards with gauges and tachometer mounted
- Soleplate or baseplate (turbine alone or with gear/generator)

Steam Turbine Design - Components

Accessories

- Valved casing drain connections
- Seal steam piping
  - Manual system
  - Automatic system
- Gland condenser options - standard & TEMA C
- Automatic steam traps
- Couplings
- Optical alignment flats & tooling balls

Steam Turbine Design - Components

Accessories

- Material certifications
  - BOM
  - Material certs on major castings
  - Certificate of compliance
- Miscellaneous tests
  - API 612
  - M & E runout check

Software - Drawings, Lists and Data

Main equipment outline (General Arrangement)

Section drawings - normally contained in IOM

Parts Lists - normally contained in IOM

Lube schematics - furnished when FF lube system supplied

Electrical schematics - supplied when several electrical devices and instrumentation is furnished

Instruction manuals - CD plus 1 hard copy. Hard copy shipped with turbine

Software - Drawings, Lists and Data

Optional drawings and data submittals available at extra cost:

- **Combined outline - all major equipment on one drawing**
- **As-built section drawings**
- **P & I diagram**
- **Performance curves**
- **Campbell & Goodman diagrams**
- **Critical speed analysis**
- **Torsional data and or analysis**
- **Report on balance machine sensitivity - API**
- **API Appendix requirements**

Steam Turbine Selection Conclusions

- Pump OEMs – don’t over-specify the power
- Contractors – Use realistic min/max conditions
- Users – Use the Hand valves!!!

Summary

- Steam turbines are a reliable and flexible driver for pumps
- Construction allows long term reliability
- Specifying appropriate operating conditions can save significant amounts of money