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Steam Turbine Upgrades: The Key to Optimizing Overall Plant Cycle Performance

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Steam turbine Applied Technology .

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Effective Uprates Come in Many Forms

- **Component Upgrades** for :
  - Improved Turbine Efficiency
  - Unit / Component Reliability
  - Increased operating times between outages.
- **Turbine Uprates** to Support Overall Plant Optimizations
  - Review overall plant thermal cycle
  - Identify any changes in Plant Process Requirements
  - Review Overall Turbine Capability to Accommodate Anticipated Process Changes;
    - Revised Section flows / Pressures / Stage loadings
    - Boiler / Condenser/ Generator Capability
    - Minimize off Peak operation / Optimize Section performance.

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Effective overall cycle optimization often requires accommodating a wide range of OEM equipment

Impulse

- GE
- MHI
- W Industrial
- Delaval
- Toshiba
- Thermodyn
- Allen
- Shin Nippon
- ABB
- Ansaldo Industrial
- Elliot

- Franco Tosi
- Hitachi
- Metro Vickers
- Skoda
- BHEL
- Bellis
- DR
- Worthington
- IR
- TurboDyne
- Peter Brotherhood
- Terry
- Murray
- Coppus

Reaction

- Siemens
- Parsons
- W Utility
- Nuovo Pignone
- Fuji
- Allis Chalmers
- Alstom
- Ansaldo Utility
- Escher Weiss
- Man
- BHEL

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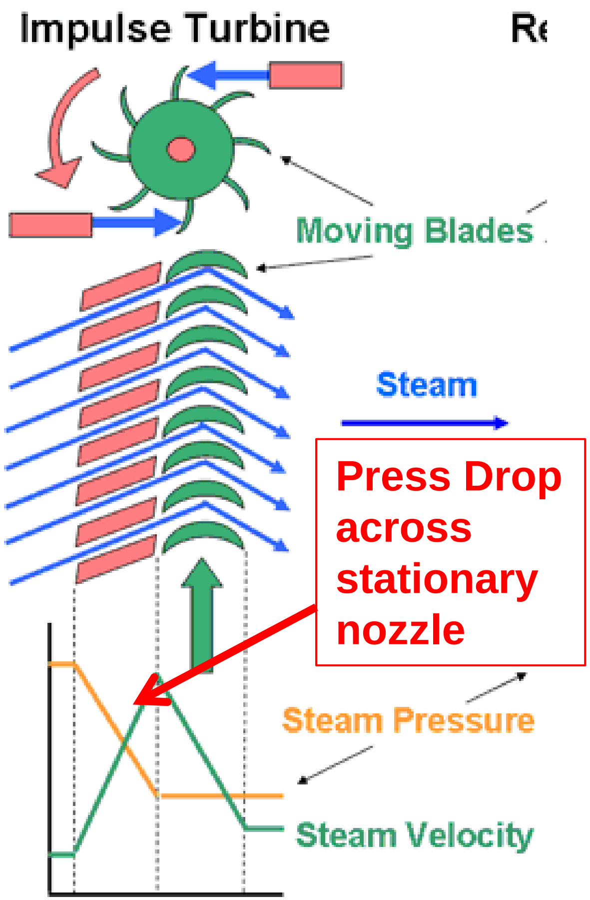
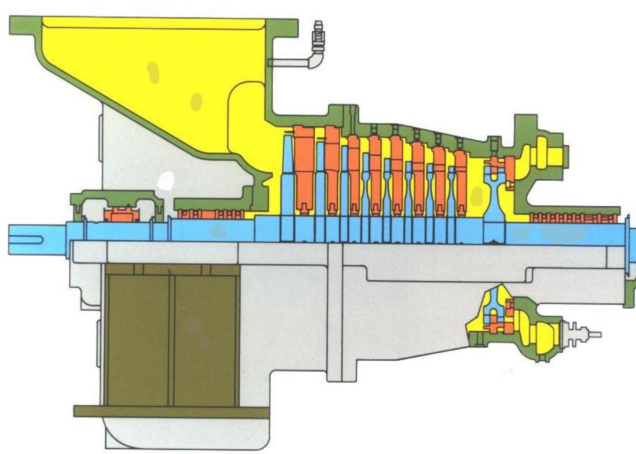
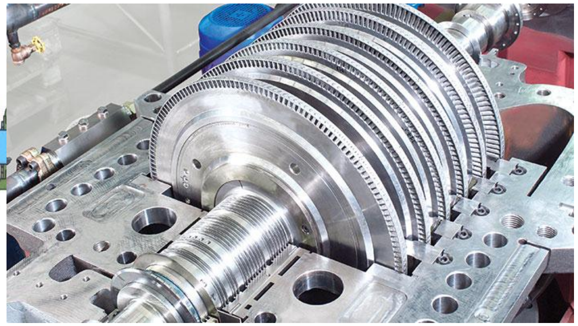
Impulse Turbine Design

- Impulse
  - Steam accelerated by pressure drop across stationary components
  - Pressure drop limited to stationary components.
  - High velocity steam impinges on rotating blades creating torque
  - Most common US design due to rugged construction and reliability







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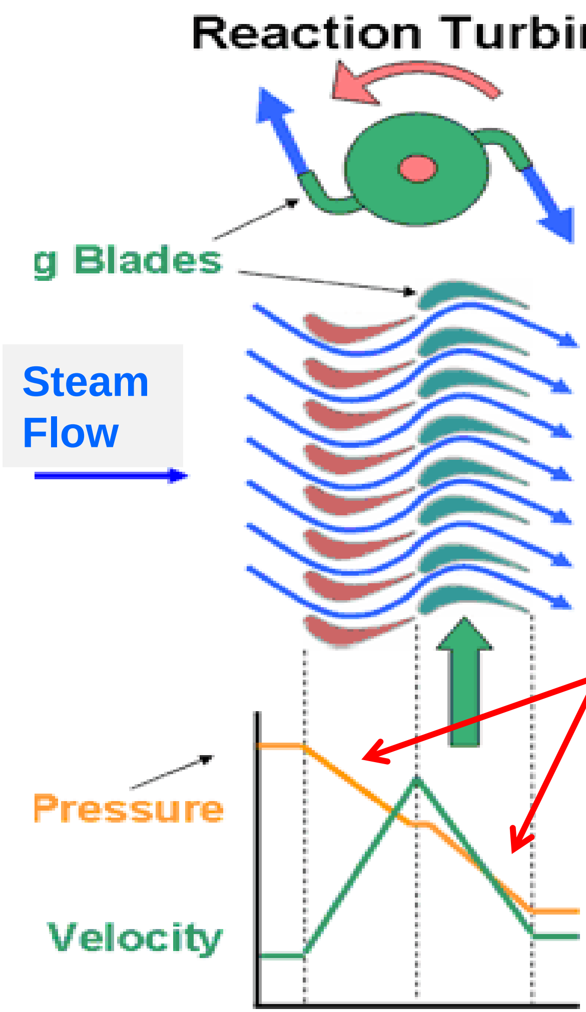
Reaction Turbine Design Methodology



Press drop taken across both nozzle and rotating blade

Reaction

- Stage pressure drop occurs equally across stationary and rotating components.
- Lower pressure ratios across each stage
- Results in twice as many stages for given energy range.
- Lower steam velocities, results in lower losses and higher theoretical performance
- Drum rotor construction / Less physically robust design.
- Requires balance piston to counteract stage thrust.

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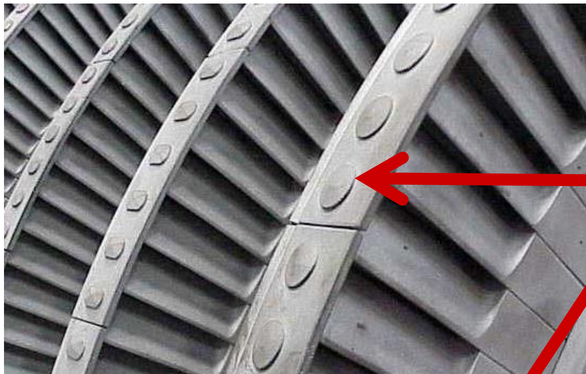
Typical Component / Reliability Upgrades

◆ Modernization of Obsolete / Unreliable Blade Designs



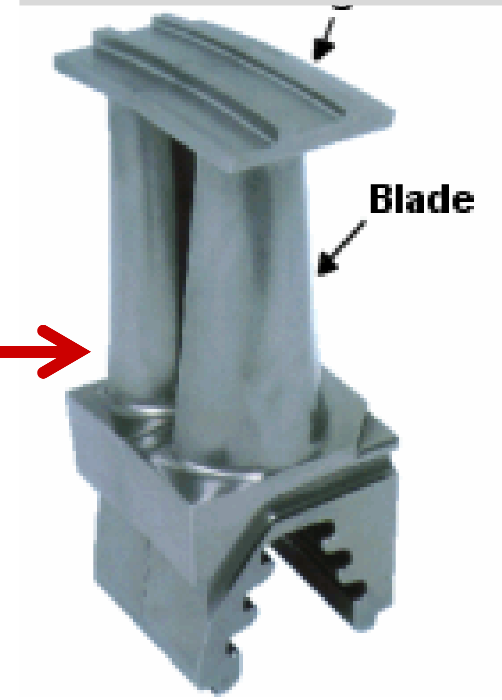
From

- Mechanically attached (Peened) shrouds
- Constant profile vanes
- Short band groups
- Thru-Penetration tie wires
- 1960 Design standard

To :

- Optimized aerodynamic vane
- Continuously coupled integral tip shroud.
- Improved Dovetail /Fastener (as required)

Continuously coupled integral cover.



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Typical Reliability Upgrade Opportunity

From :

- Obsolete constant cross section vane
- Hard peened tenons
- Short band groups
- Through drilled tie-wire
- Stress concentration at tie-wire penetration
- Challenging wet and corrosive operating environment

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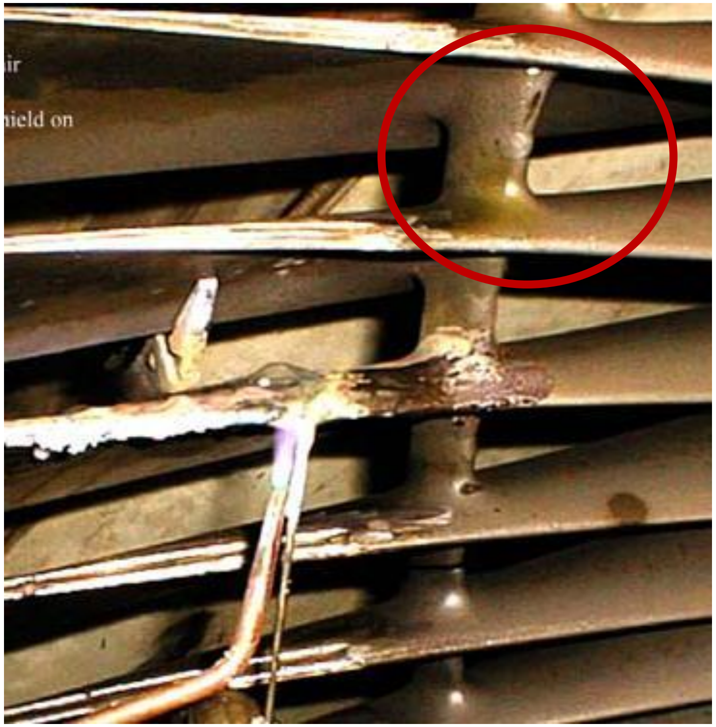
Typical Tall Blade Modernizations

Original Design

- Rigid / Brazed Lashing lugs & tie wires
- Reduced damping
- Repetitive maintenance



Fully Modernized design

- Integral (not through drilled) mid-span lugs
- Inserted (loose)mid-span couplings for increased damping and vibration suppression.

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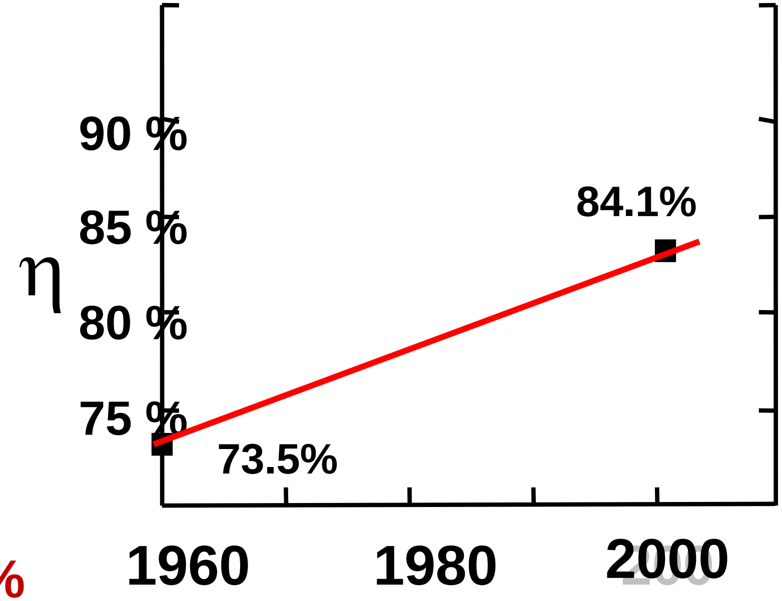
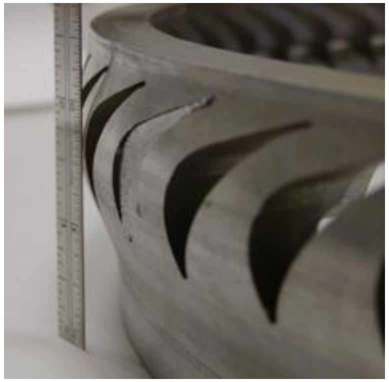
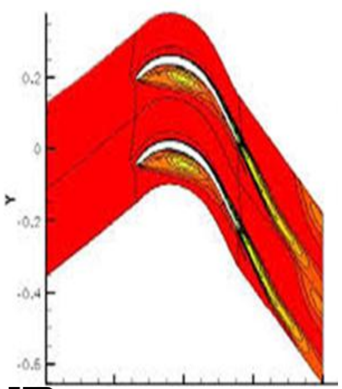
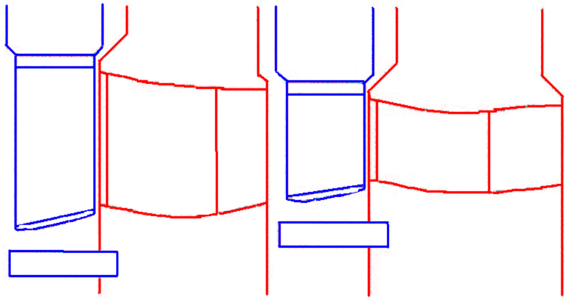
Performance Improvements Summary

Design Feature	% GAIN
Stationary Blades	0.5-0.75
Profiled End Wall	1.0-1.5
Rotating Blades	0.5-0.75
Steam Path Surface Finish	0.5-3.0
Brush Packing	0.5-1.0
Throttling Losses	1.0-2.0
Stage Leakage Control	0.25-1.0
TOTAL	**4.25 - 10.0 %**









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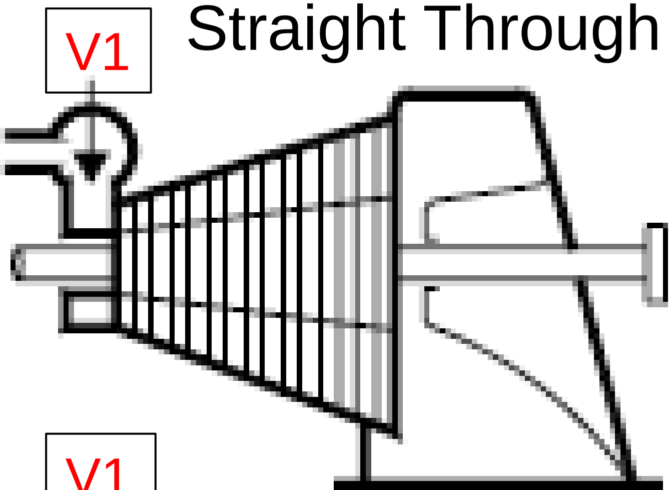
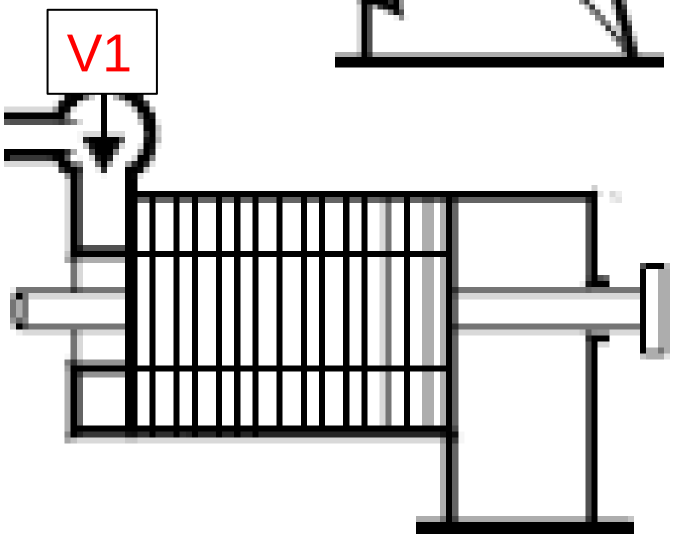
Steam Turbine Types & Opportunities

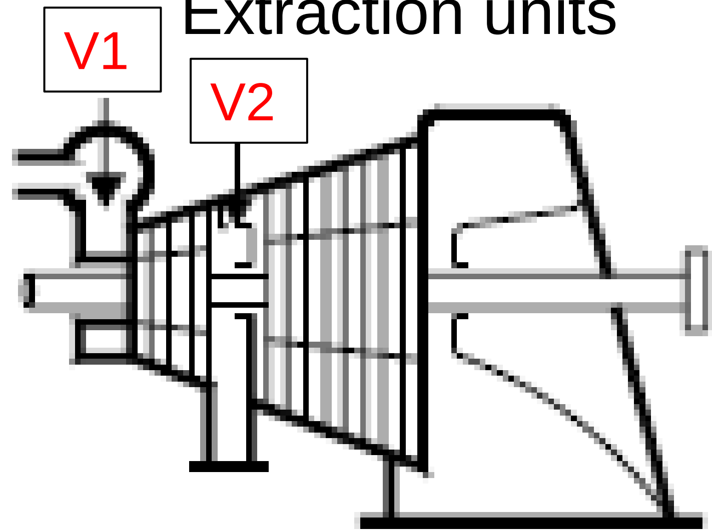
Straight Through units

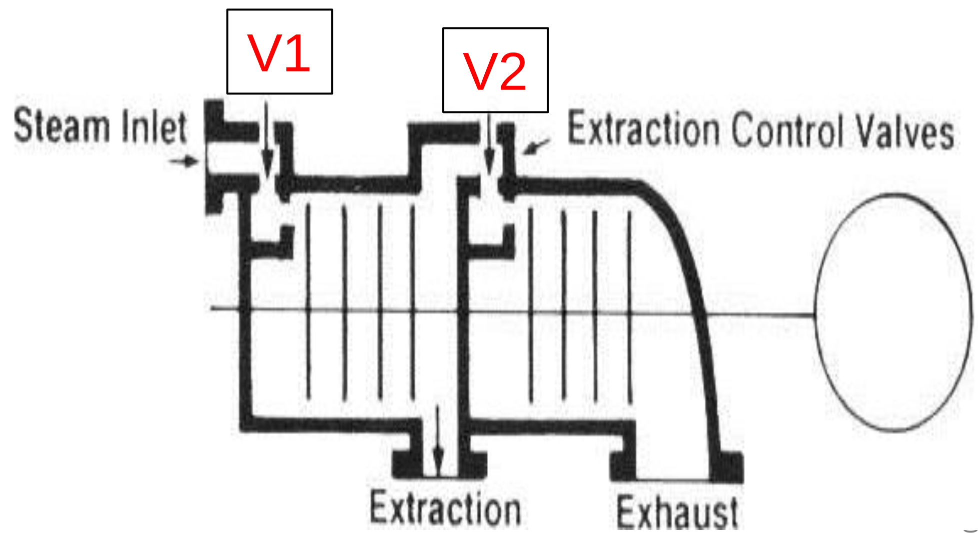




- Changes in inlet Flow / power/ efficiency
- Add extract or admission
- Convert to non- condensing

Extraction units

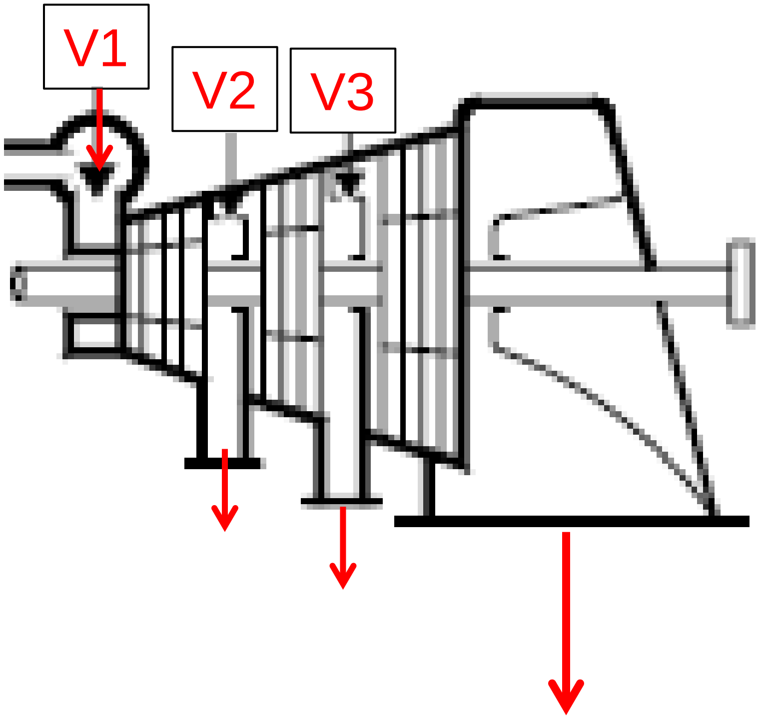




Multiple options for Changes in inlet / extract flow / pressure & output

Steam Turbine Types & Opportunities

- Double auto extraction condensing (DAXC)
  - Changes in extraction pressures
  - Changes in section flows
  - Eliminate need to PRV of steam for process
  - Changes typically driven by revised process requirements
  - Common Paper Mill / Refinery Configuration



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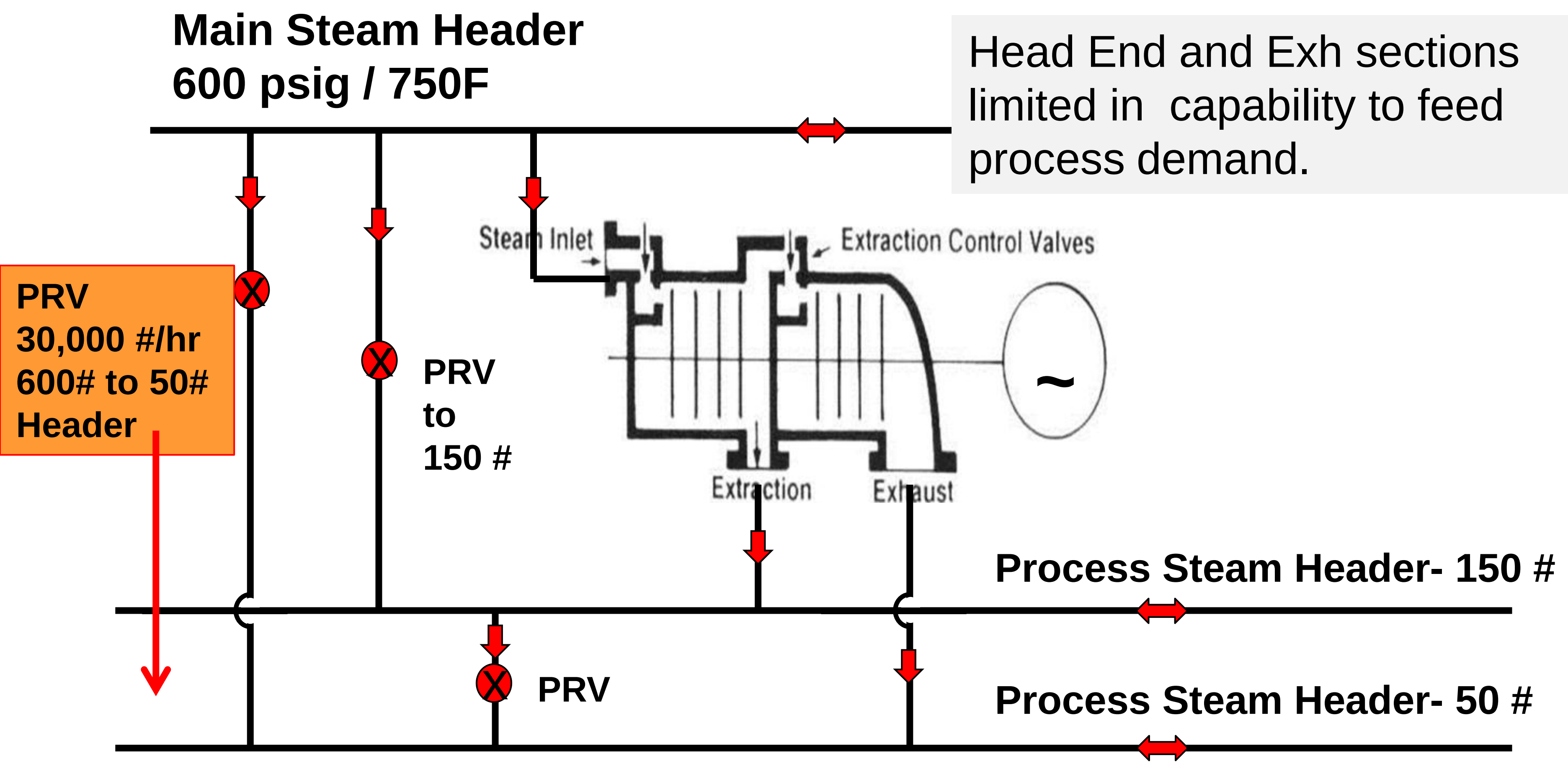
Typical Industrial Cycle Optimization



- Customer PRV 30,000 #/hr 600# steam to 50 psig to feed process
- Benefits not apparent as process requirements satisfied
- **Power Gain = + 1.45 MW / Estimated cost savings = $900 K / year**

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Optimizing Turbine Sections

- **Turbines originally designed by specification to provide:**
  - Maximum capability at nameplate/max-rating
  - Optimum efficiency at “Guarantee” point
  - AE’s always provide additional flow capacity to account for degradation and compressor margin, API 612 requirement

- **But turbine sections must also accommodate:**
  - All maximum and minimum swings in section flow and pressure
  - Variable summer and winter process demands
  - Specified power and section flow requirements
  - Need for supplemental PRV steam for process use
  - Provide optimum performance at “normal” operating point

As a result many turbine sections actually operate at significantly off peak design flow and efficiency

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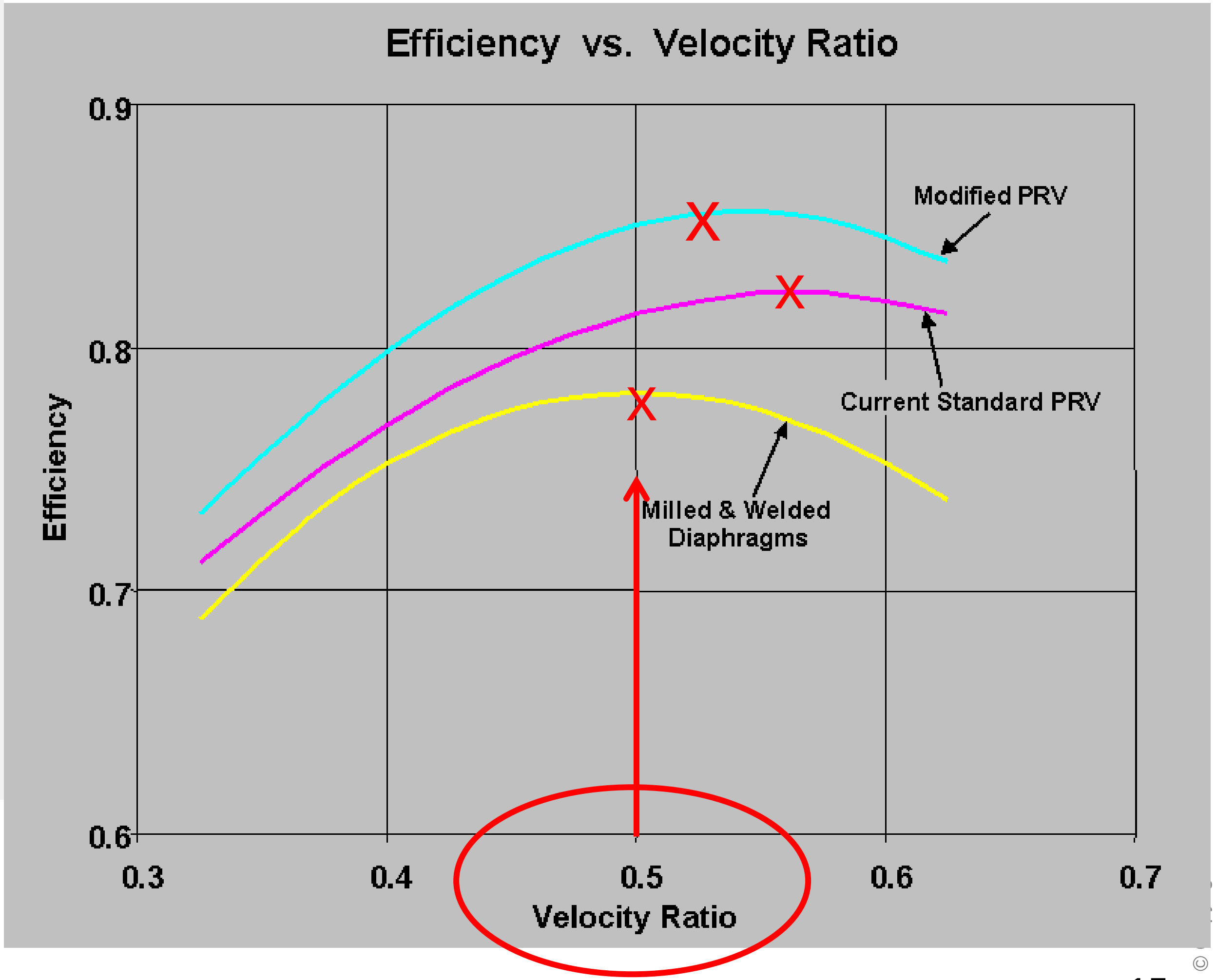
The Key Thermodynamic Design Parameter.

Velocity Ratio

W/Vo = Wheel Speed / Steam Jet Velocity

Key Characteristics

- Max Eff @ turbine design point
- Efficiency Max when Wheel speed =½ Steam Jet Velocity
- W/Vo directly Influenced by off-design section flows.
- Efficiency reduced when operated off peak.



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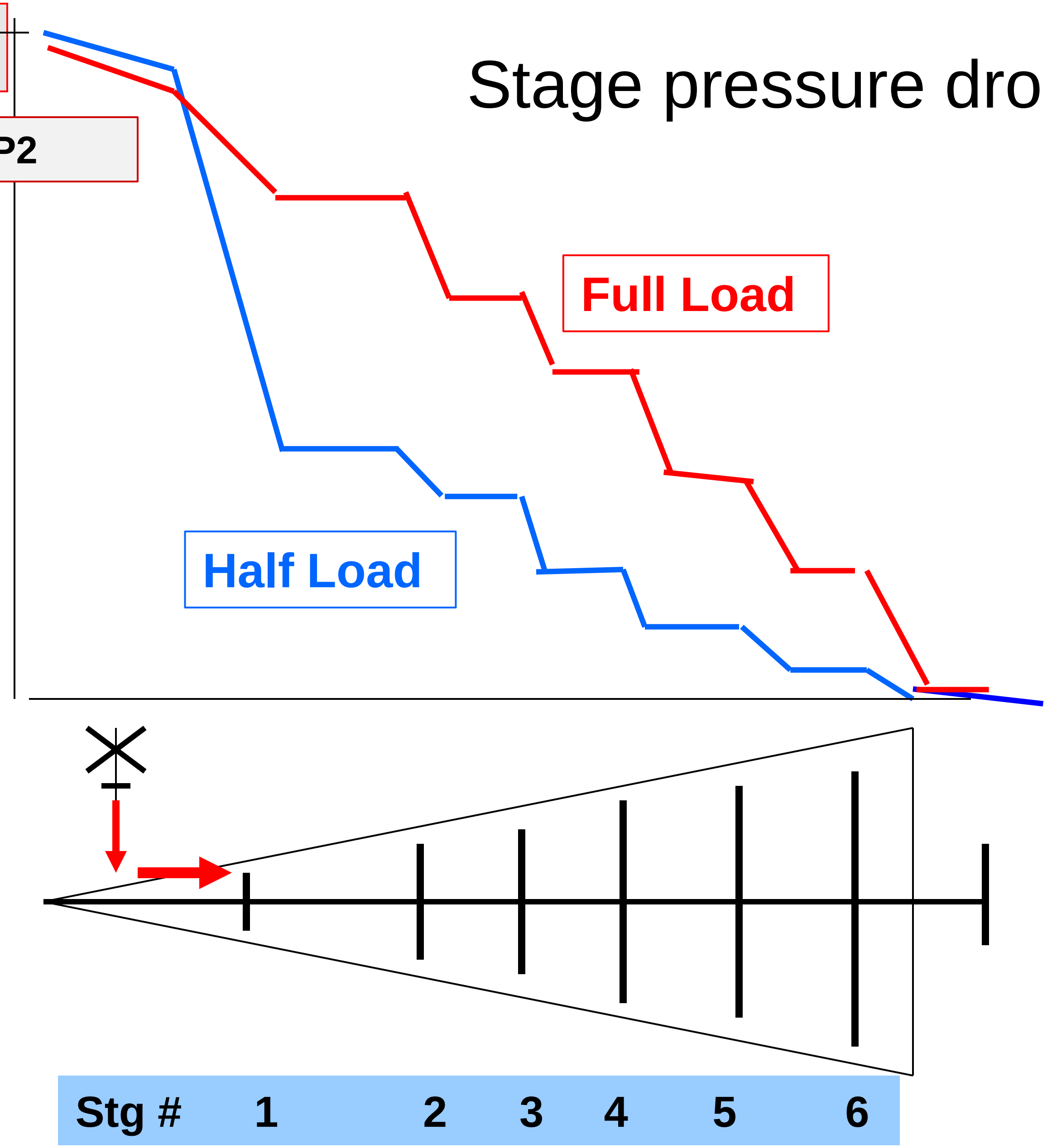
Stage loading characteristics @ part load operation.

Inlet Press **1250 #**

Stage P1/P2

Unit design
250 K#/hr inlet
Straight condensing

Operation @ Half load
125 K #/hr inlet - Cond.



Impact on operation

- **Increased Stg # 1 loading**
- **Stgs 2-6 starved for flow**
- **Off peak performance on Stg #1 & Stgs 2-6**
- **Losses and potential heating issues on Exhaust stages @ low flows .**

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Ex - Optimization For Part Load Operation

- **Problem :** Turbine operating @ part load / well below design Conditions.
- **Result** Significant efficiency loss
- **Solution:** De-rate individual turbine section or entire steam path to fit new cycle requirements
- **Example**
  - Turbine running @ 20% design throttle flow.
  - Original efficiency = 80%. Efficiency @ 20% throttle flow = 40%.
  - Inlet = 900 psig / 900-F/ Exhaust - 50 psig.
  - Original max flow = 1,200 K#/hr / new flow is 240 K #/hr
  - Purchased Power costs $.07/kw-hr
  - De-rated unit can achieve Approx. 70 + % overall efficiency
  - Output at 40% efficiency = **3,980 kW's**
  - Output @ 70% efficiency = **6,964 kW's** (Post Rerate)
  - Power Gain from Re-Rate **= 2,984 KW**
  - **Savings = $1,835,000 /year**

Seemingly insignificant changes can often yield surprisingly large benefits!

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Typical Single Auto Extraction Cond (SAXC)

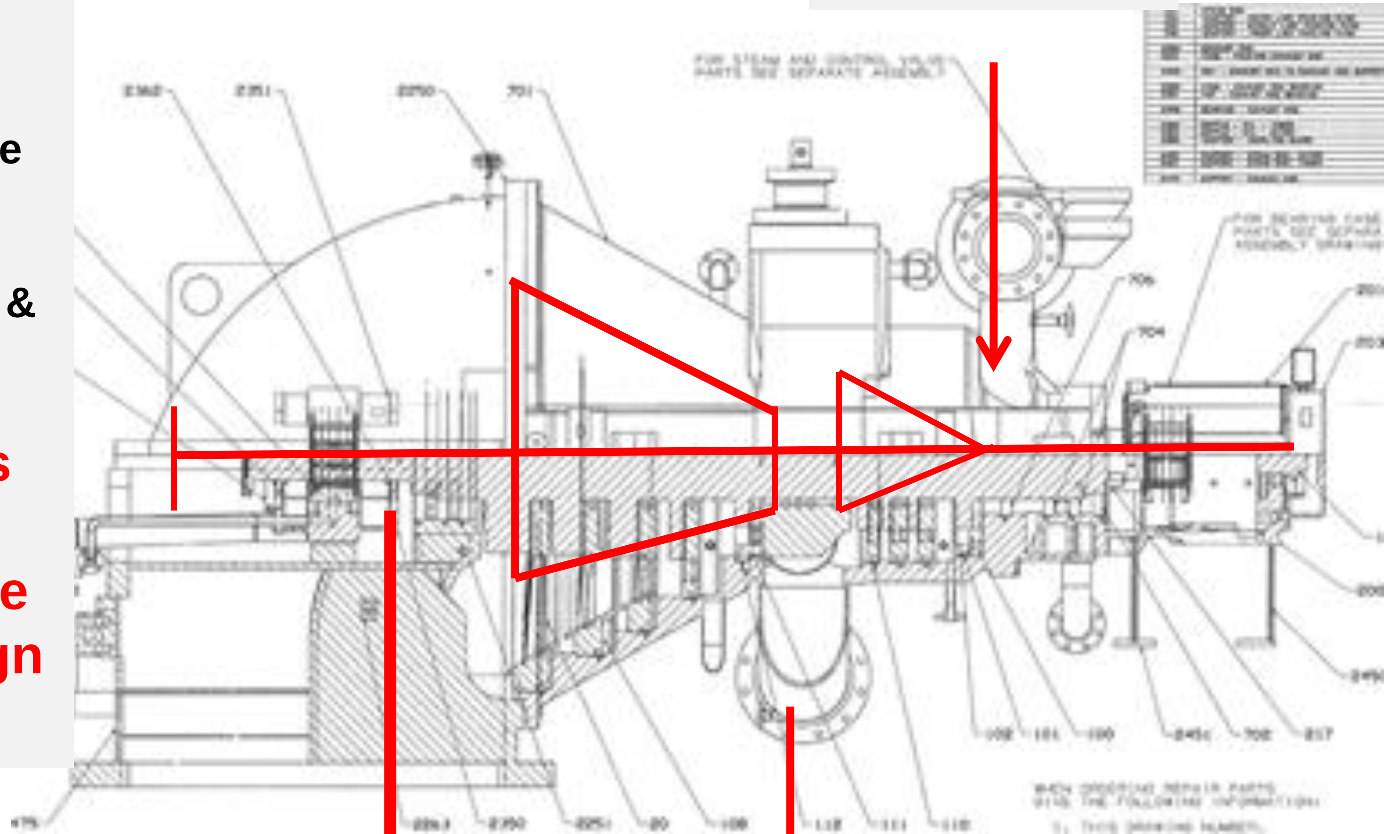
Head end section sized for maximum inlet and extract flow

Head End must accommodate full range of required inlet flows

Exhaust sized for max & min condensing flow

Individual sections often run at significant variance from original design limits

1250 # inlet



Condensing Exh

650 # Extract to Process

Part Load Operation - Auto Extraction Turbine

Inlet Press **1250 #**

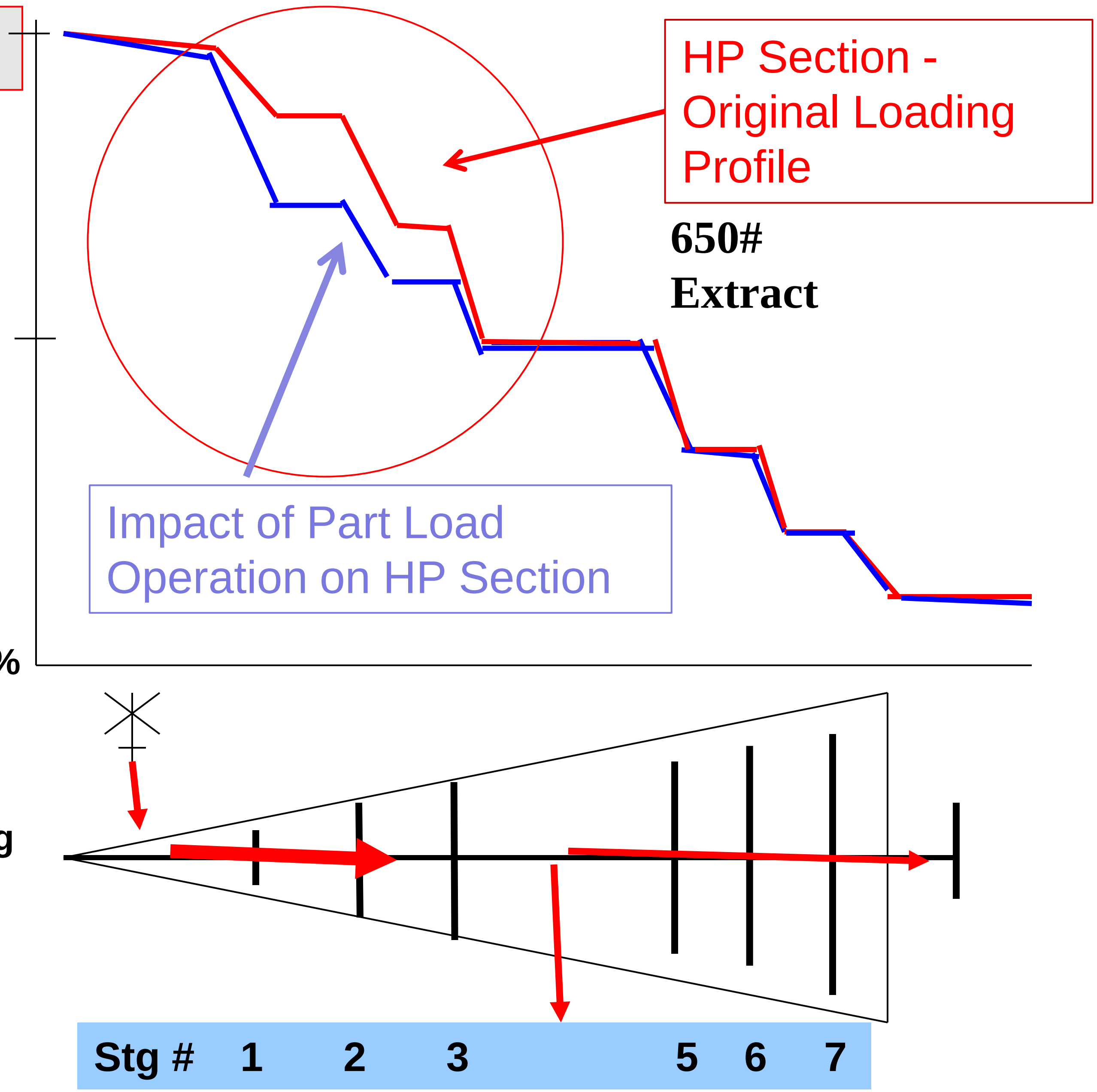
Stage pressure drop

Unit design
250 K#/hr inlet
100 K #/hr Extract @ 650#
Max Exh flow = 150 K #/hr

When run @ Zero Extract
150 K #/hr inlet
150 K #/hr Exh

Impact on operation

- **Head end running at 60% Design flow.**
- **Result = off peak HP section Efficiency**
- **Increased Stg #1 loading**
- **Loss of overall MW output**



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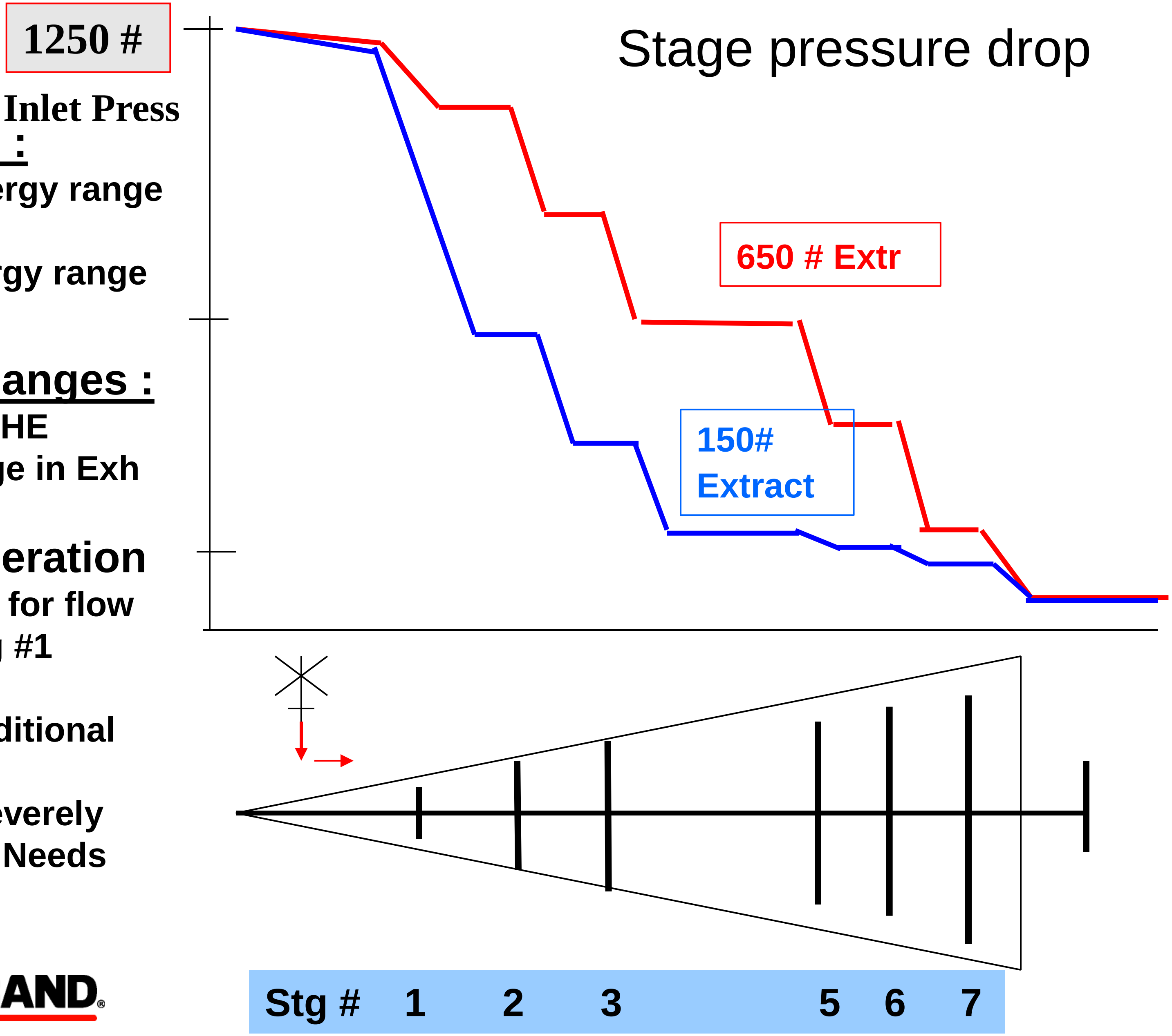
Impact of Changes in Extract Pressure on Section Loading



Observations :

- Increased energy range on head end
- Reduced energy range on Exhaust

Required Changes :

- Add stage to HE
- Remove stage in Exh

Impact on operation

- HE oversized for flow
- Increased stg #1 loading
- HE Needs additional stage
- LP section severely undersized . Needs fewer stages

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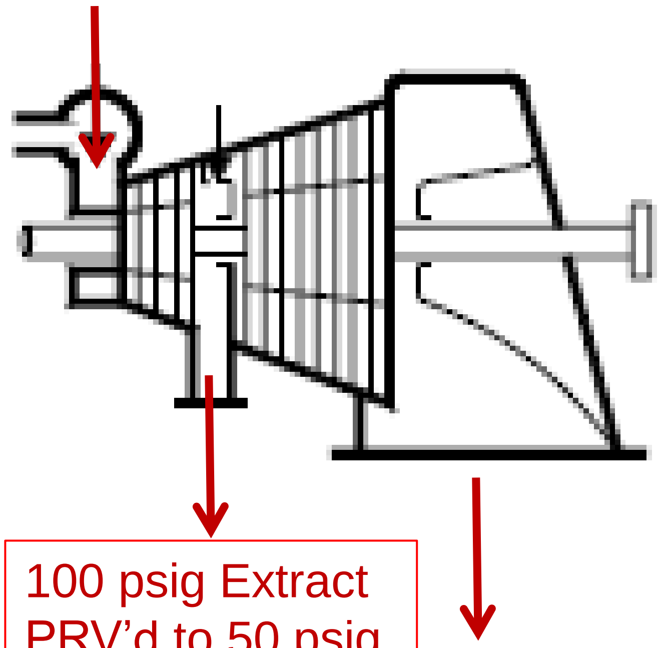
Typical Revamp Scenario-Cycle Change

- **Single-Auto-Extract-Condensing unit (SAXC)**
- **Process changes require change in extraction pressure from 100 to 50 psig**
- **Process demand currently satisfied by PRV of 200,000 #/hr of 100 psig steam to 50 psig level**
- **Loss of flow through turbine HP section results in loss of 2,700 KW output**
- **Assume Electricity valued $.07 cent per kw-hr.**



100 psig Extract PRV’d to 50 psig to support process demand

Potential Economic Benefit = <u>$ 1.6M/year</u>

Seemingly insignificant changes can often yield surprisingly large benefits!

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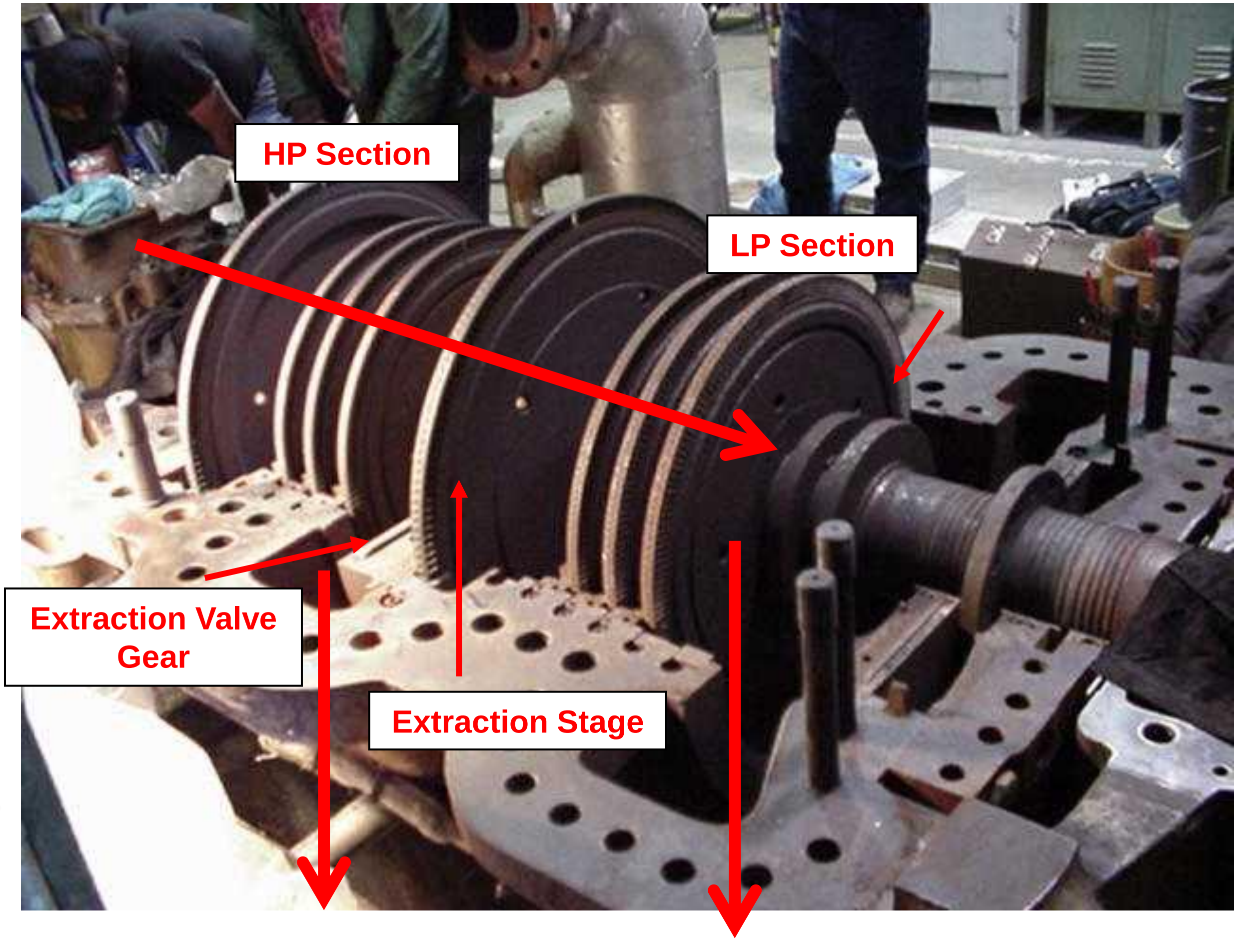
Ex-   Impact of Eliminating Extraction

Define Objective:

- 5 MW GE -SAXNC
- Change in plant process eliminates need for extraction steam
- Loss of extraction flow results <u>loss of available MW output.</u>
- LP section unable to pass additional flow required to make up for MW shortfall.



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Current Turbine Section Flow Limits

Unit capability as shown on Original Extraction Map

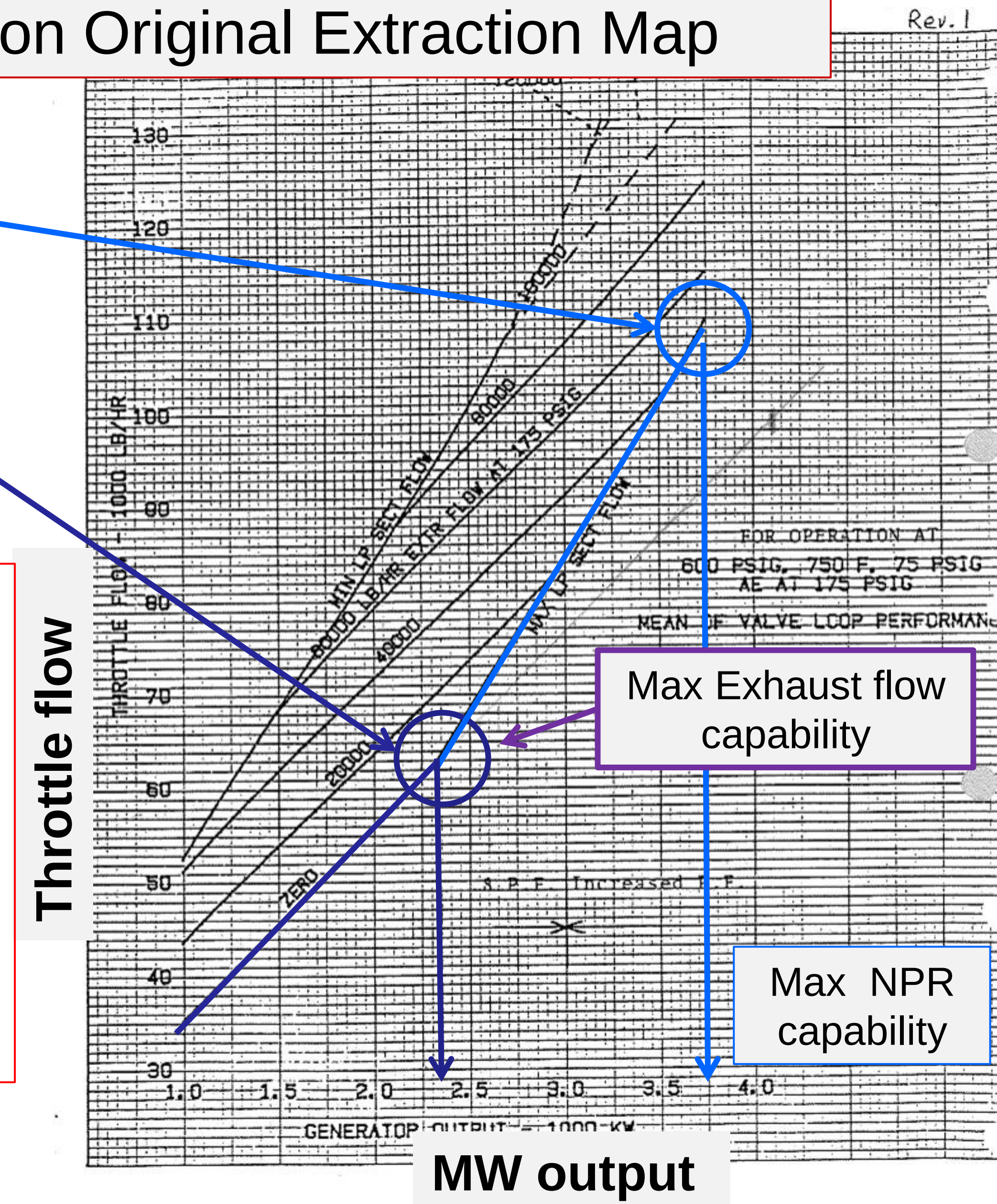
Max capability w:
- Max Exh flow
- And 50K #/hr Extract
- 3.75 MW

Max capability w/ Zero Extract flow
- 2.35 MW

Change in plant process eliminated need for extract flow

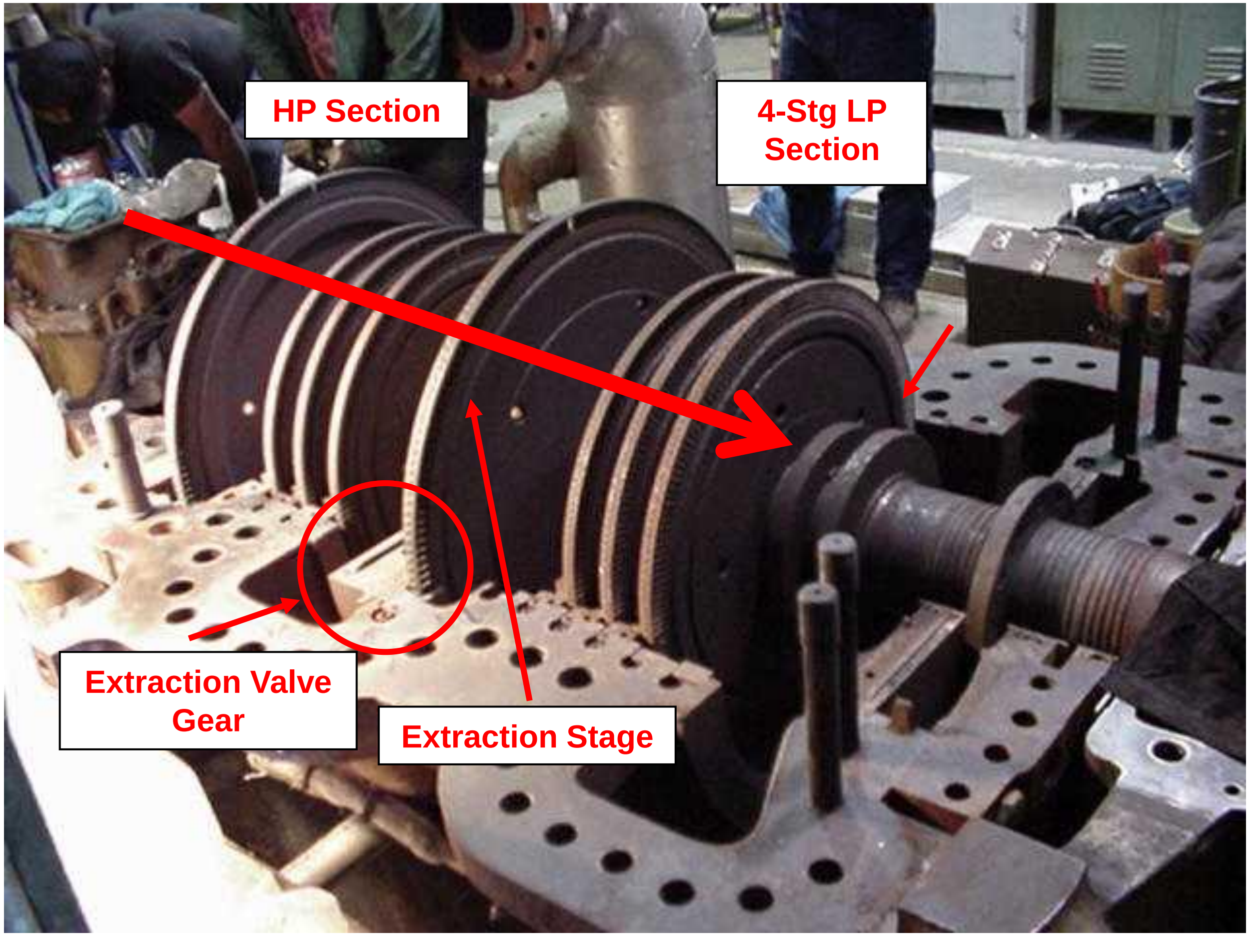
Boiler capacity available & process requires additional MW output.

Max Cond output = 2.35 MW



Observations on Unit limitations:

- Extraction valve gear restricts flow capability to the LP section.
- Pressure @ Stg # 5 no longer limited by Extraction
- LP stages 5-8 under-sized for HP flow capability.
- Straight Non-Condensing operation without flow path changes results in loss of MW output.



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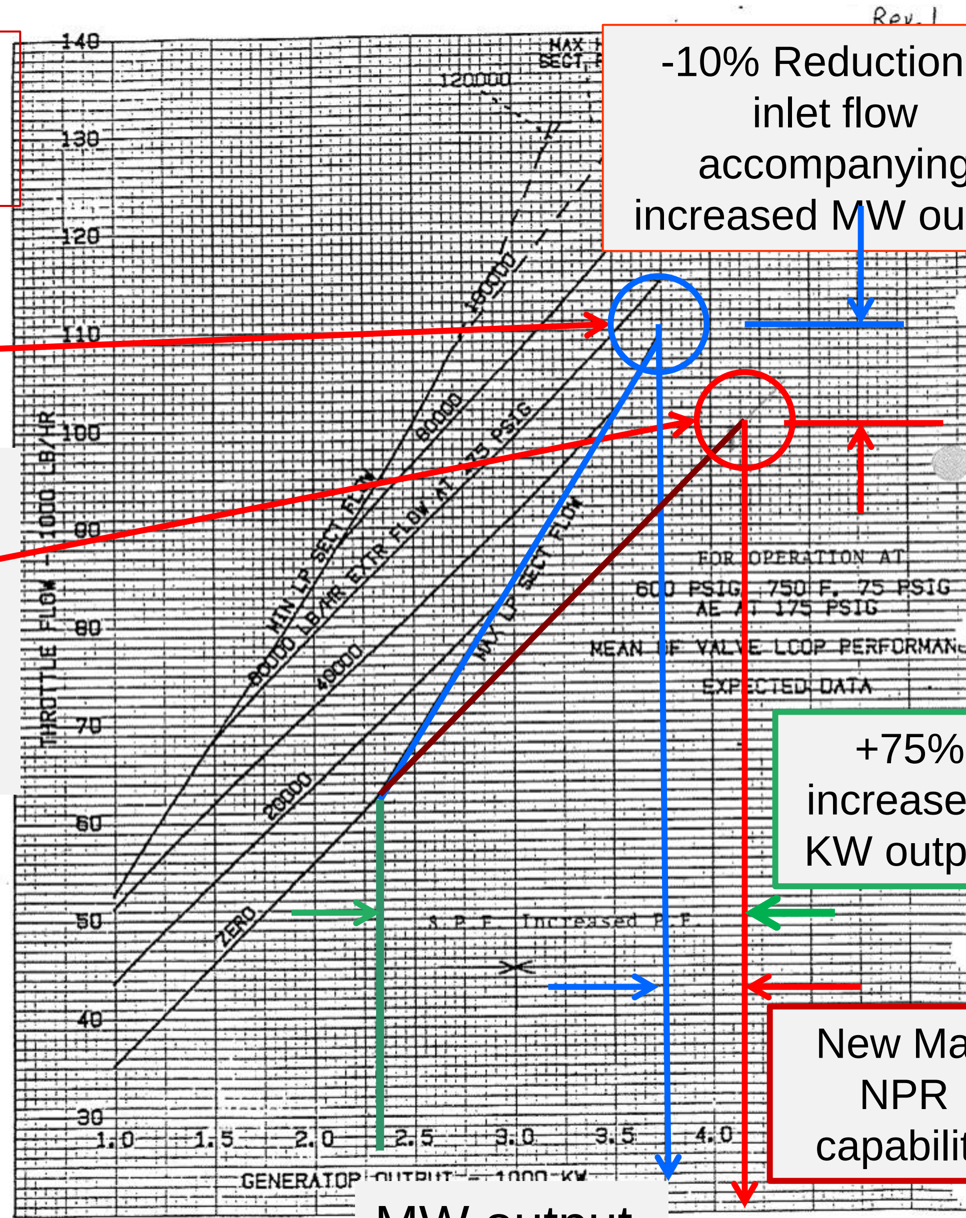
Uprate Changes & Benefits

Post Uprate Performance @ new operating conditions

Original Max MW output required additional 50K #/hr Extract flow

New capability as reconfigured for Straight-Condensing operation.

Throttle flow



-10% Reduction in inlet flow accompanying increased MW output

+75% increase in KW output.

New Max NPR capability

MW output

SC Output capacity increased from:

- 2.35 MW to 4.15 MW (+75%)
- @ 10% less inlet flow
- & limited hardware changes.
- Eliminated need to vent Extract steam to generate needed MW.

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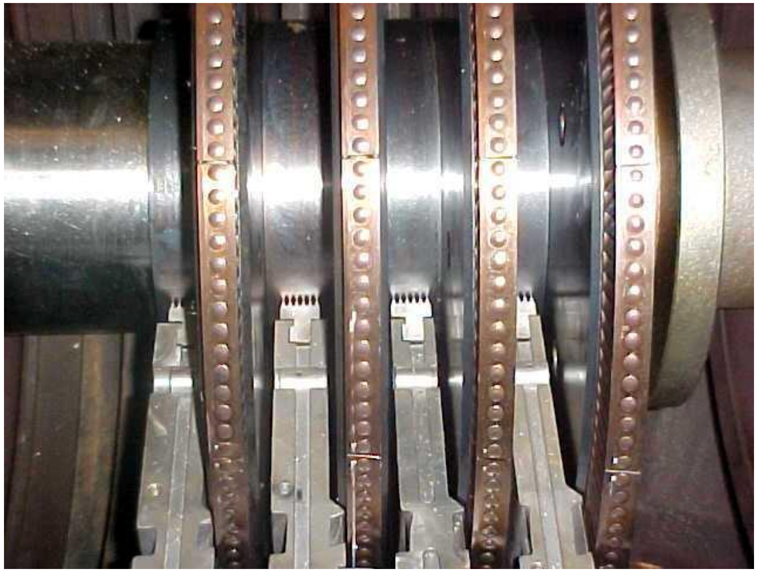
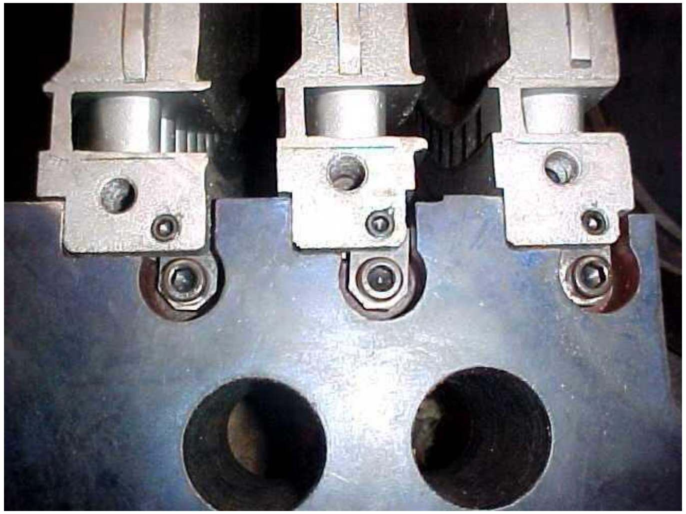
LP Rerate Modifications

- LP Section Modifications:
  - New forged wheels with high performance blades
  - New high efficiency diaphragms
  - Blank Casing Extraction Ports
  - Remove Extraction valve gear
  - Low leakage Inter-stage & gland seal labyrinths



Net Benefit

- Increased :
  - L.P section flow capability,
  - Efficiency,
  - MW output.



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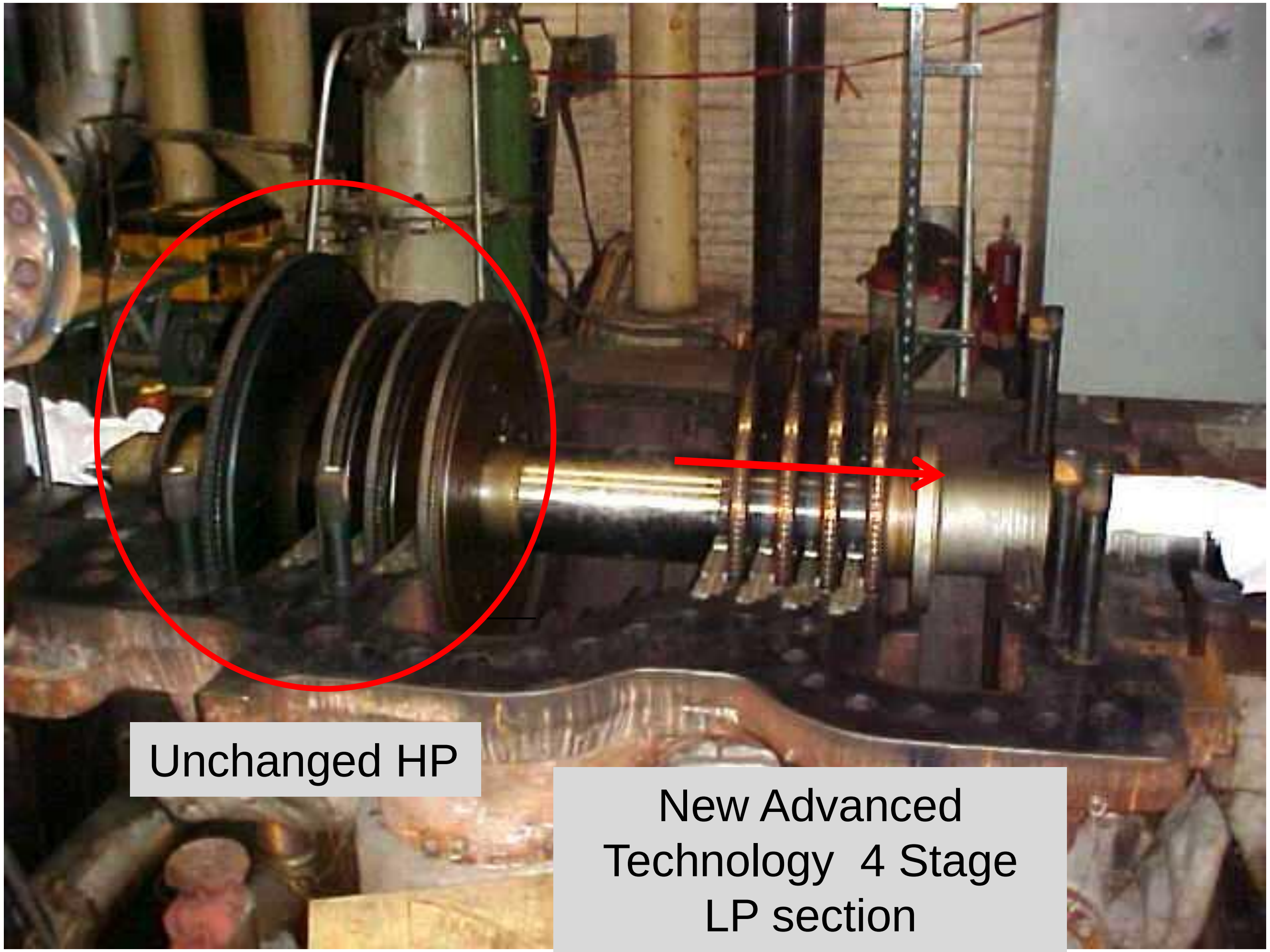
Post Uprate Steam Path configuration

Revamp Solution:

- Convert unit to straight through Non-Condensing operation
- Remove Extraction
  - Nozzle box
  - Valve gear
  - Reduces losses
  - Simplifies controls

New LP staging to Increase :

- Efficiency
- Flow capability
- MW Output



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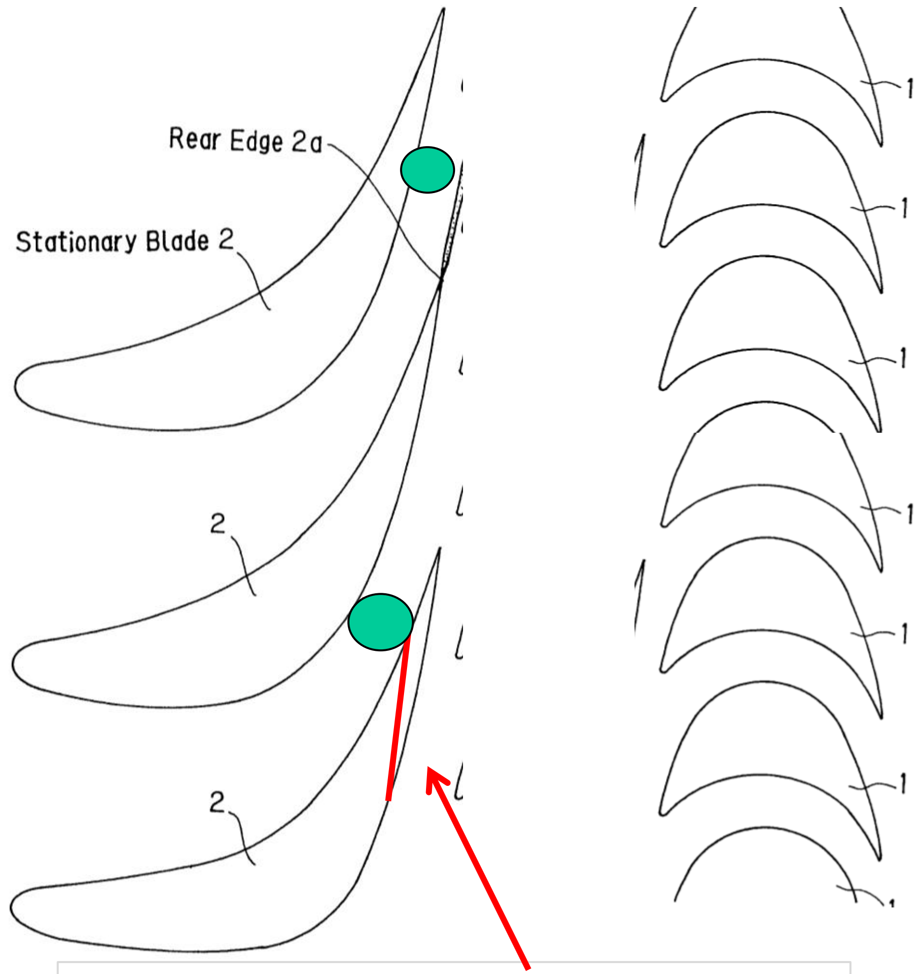
Reduced scope rerate options

Limited Increases in flow passing capability possible with minor changes.

- Modify diaphragm flow passing area by grinding
- Increase d flow capability with some limited reduction in performance.
- Mods typically implemented as a short term fix during outage, with follow up optimization
  .



Reconfigured nozzle exit edge.

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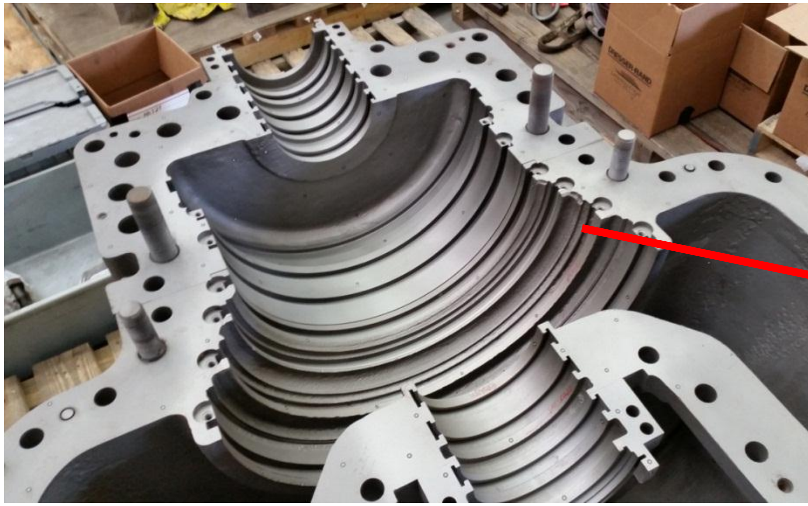
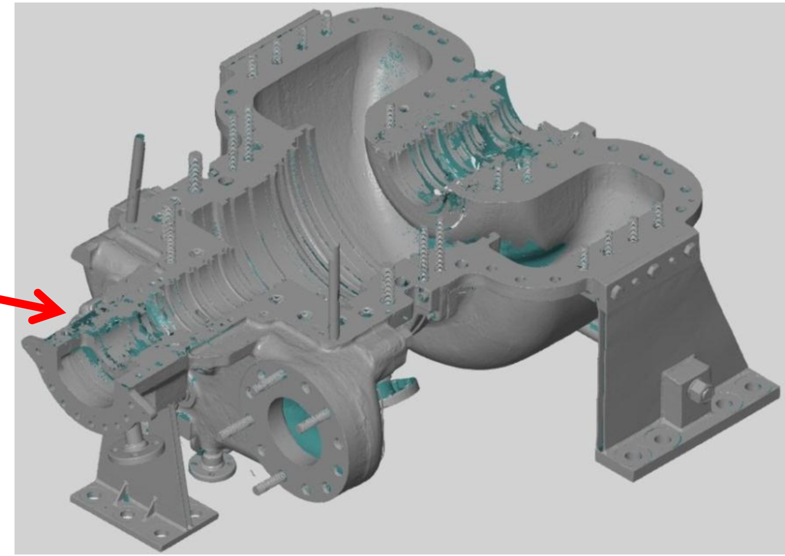
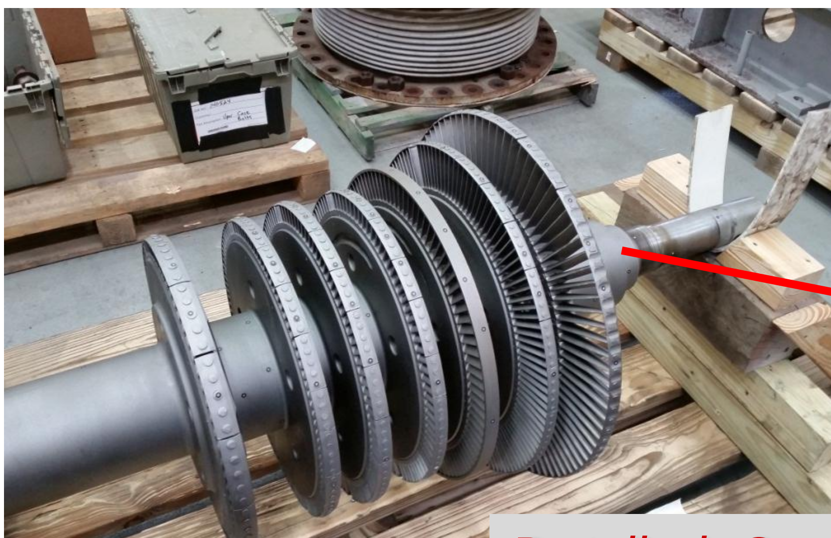
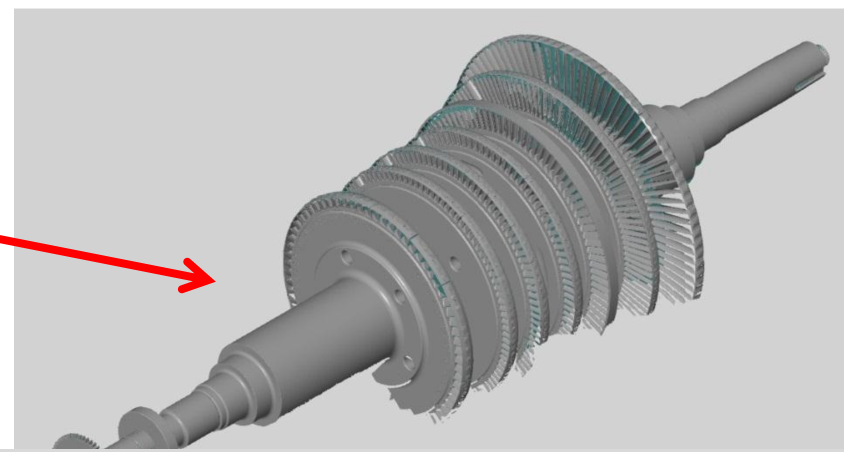
Advanced optical scanning technology can provide critical data despite limited access to original design records.









Detailed Casing & Rotor Scans can be completed on site with minimum impact on outage schedule

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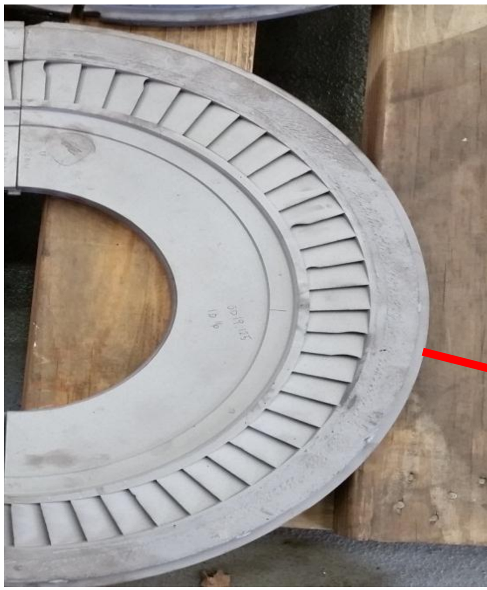
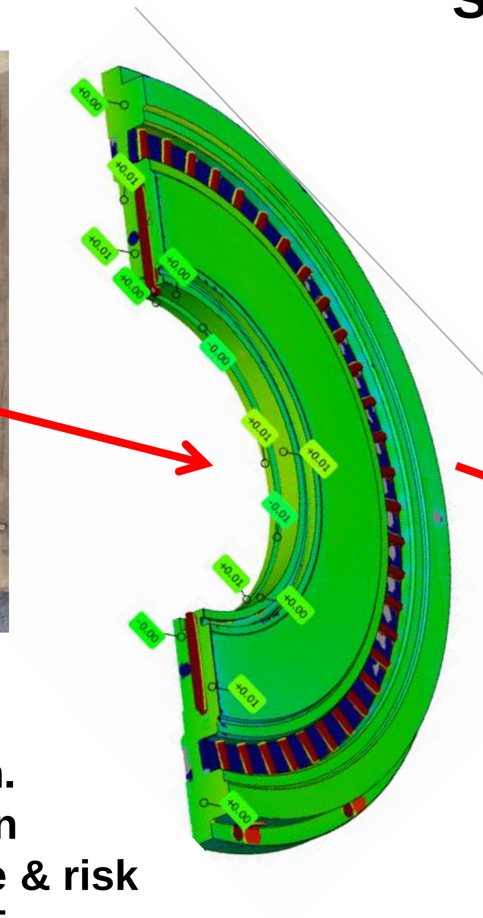
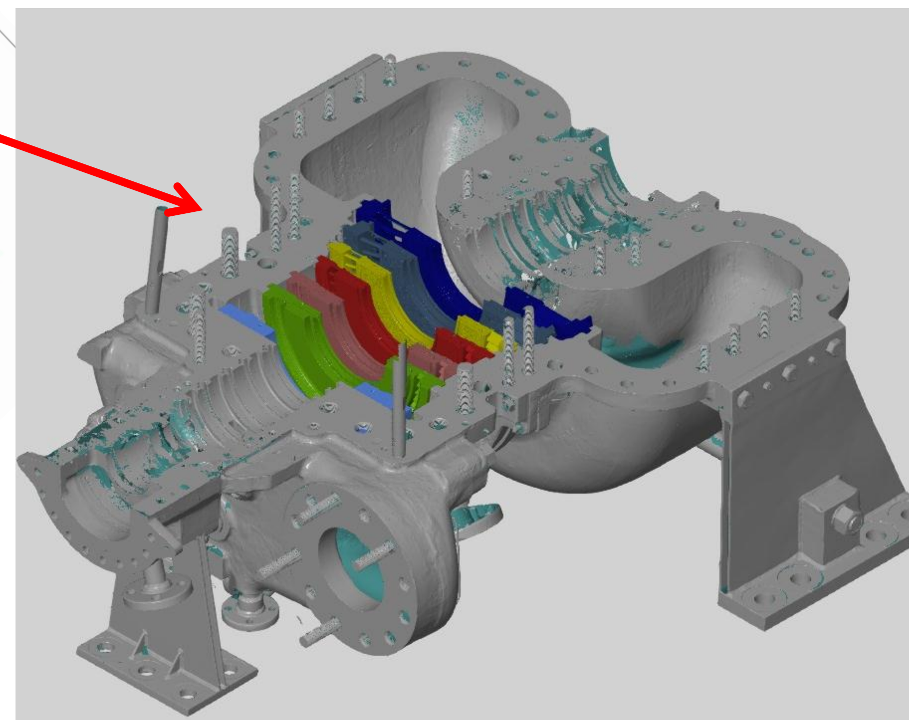
3-D models can be used to analyze and Verify Critical Component Assembly & Interfaces,

Solid models applied to support:

- Dimensional verification
- Detailed stress analysis
- Short cycle / flexible mfg.







- ➢ **Identify potential limitations w/ design.**
- ➢ **Facilitate installation**
- ➢ **Reduce outage cycle & risk**
- ➢ **Confirm revamp design prior to installation**

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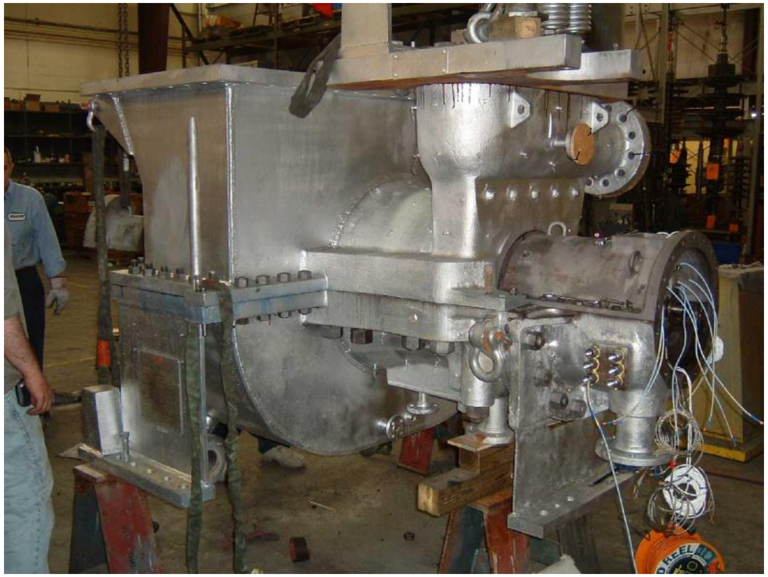
Reapplied Turbines Can = Excellent Value

- Non-Reheat units have near unlimited service life w/ proper inspection and upgrade.
- Steam Path measurement can identify potential uprate options.
- Cost effective modifications often possible to accommodate new service conditions.
- Older units often more robust than modern designs.
- New units less than 50MW often Geared vs Direct coupled TG sets.



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Benefits of Uprate vs New Unit

- **Reduced delivery cycle – 30wks vs 12-18 months**
- **Reduced initial Capital Investment / Cost.**
- **Typically Installed during normal turbine outage.**
- **Minimizes BOP / Foundation changes and Installation costs**
  - **These can be 3-10X the cost of comparable revamp**
- **Minimum power interruption / delayed installation**
- **Uprated units w/ modern Steam path components can deliver comparable new Unit performance @ significantly reduced cost**
- **Assured of a Proven Reliable Design.**
- **New unit start up delays can extend installation time**
- **New 30-60 MW Turbines are often less rugged - High Speed Geared sets.**

Uprates Typically Far More Cost Effective Than a New Replacement Turbine

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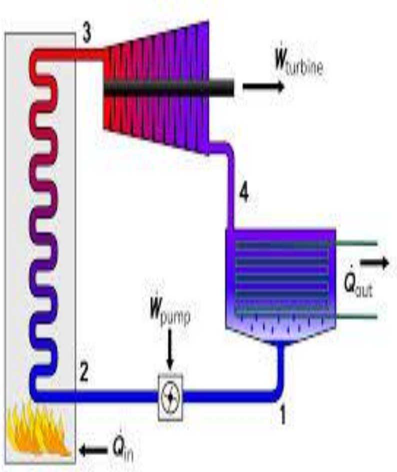
Tailoring Turbine Uprates to Enhance Overall Cycle Efficiency

Optimizing Cycle Efficiency is the most Significant Optimization Opportunity.

Cost Effective Revamps Not Always Obvious

- **Impact of Off-Optimum operation seldom recognized**
- **Customers experts on their process but not always on turbine design.**
- **OEM's typically concerned with their equipment / not overall cycle benefits.**



Significant Optimization Opportunities Include:

- **Optimizing the turbine to fit the cycle**
- **Resizing turbine section flow to meet cycle demands.**
- **Adding Extractions / removing process and cycle bottlenecks**
- **Reconciling original design and actual operating conditions.**
- **Fully understanding turbine's role in cycle and unit operation**
- **Compensating for loss in MW output due to Addition of Emissions Equip**

Optimizing Overall Plant Performance Requires a Focus on Both Cycle and Individual Turbine Efficiency.

Common Misconceptions about Turbine Uprates

- They are always complex
- That they are prohibitively expensive
- They cannot be accommodated during a normal turbine outage
- Paybacks are difficult to commercially justify
- They require major balance of plant changes.

Turbine Uprates are often overlooked in cycle optimization studies, and can represent a cost effective way to significantly improve overall system performance, and reliability.

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Thanks For Your Attention !

- Questions ?

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