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

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

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<th>Impulse</th>
<th>Reaction</th>
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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.
Reaction Turbine Design Methodology

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.

Press drop taken across both nozzle and rotating blade
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)
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
**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

<table>
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<tr>
<th>Design Feature</th>
<th>% GAIN</th>
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<tr>
<td>Stationary Blades</td>
<td>0.5-0.75</td>
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<tr>
<td>Profiled End Wall</td>
<td>1.0-1.5</td>
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<tr>
<td>Rotating Blades</td>
<td>0.5-0.75</td>
</tr>
<tr>
<td>Steam Path Surface Finish</td>
<td>0.5-3.0</td>
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<td>Brush Packing</td>
<td>0.5-1.0</td>
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<tr>
<td>Throttling Losses</td>
<td>1.0-2.0</td>
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<tr>
<td>Stage Leakage Control</td>
<td>0.25-1.0</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>4.25 - 10.0 %</strong></td>
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![Graph showing % efficiency improvement over years](chart.png)
Steam Turbine Types & Opportunities

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

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
Typical Industrial Cycle Optimization

Main Steam Header
600 psig / 750F

PRV
30,000 #/hr
600# to 50# Header

PRV
600# to 50# Header

PRV to 150 #

Steam Inlet

Extraction Control Valves

Exhaust

Process Steam Header- 150 #

Process Steam Header- 50 #

Head End and Exh sections limited in capability to feed process demand.

- 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
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
The Key Thermodynamic Design Parameter.

Velocity Ratio

\[ W/Vo = \text{Wheel Speed} \div \text{Steam Jet Velocity} \]

Key Characteristics

- Max Eff @ turbine design point
- Efficiency Max when Wheel speed = \( \frac{1}{2} \) Steam Jet Velocity
- \( W/Vo \) directly influenced by off-design section flows.
- Efficiency reduced when operated off peak.
Stage loading characteristics @ part load operation.

Inlet Press 1250 #

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.

Stage pressure drop

Stage P1/P2

Full Load

Half Load

Stg # 1 2 3 4 5 6
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!
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

1250 # inlet

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

**HP Section - Original Loading Profile**

**650# Extract**

**Impact of Part Load Operation on HP Section**

**Stg #**: 1 2 3 5 6 7

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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
**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.

Potential Economic Benefit = $1.6M/year

Seemingly insignificant changes can often yield surprisingly large benefits!
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 in loss of available MW output.
- LP section unable to pass additional flow required to make up for MW shortfall.
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

Max Exhaust flow capability
Max NPR capability
Throttle flow
MW output
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 undersized for HP flow capability.
- Straight Non-Condensing operation without flow path changes results in loss of MW output.
Post Uprate Performance @ new operating conditions

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

New capability as reconfigured for Straight-Condensing operation.

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.

+75% increase in KW output.

-10% Reduction in inlet flow accompanying increased MW output

New Max NPR capability
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.
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

Unchanged HP
New Advanced Technology 4 Stage LP section
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.
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.
3-D models can be used to analyze and Verify Critical Component Assembly & Interfaces.

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

Solid models applied to support:
- Dimensional verification
- Detailed stress analysis
- Short cycle / flexible mfg.
Reapplied Turbines Can = Excellent Value

- Non-Reheat units have near unlimited service life with 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.
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
Tailoring Turbine Upgrades 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.
Thanks For Your Attention!

◆ Questions?