REINHOLD ENVIRONMENTAL Ltd.

2012 NOx-Combustion Round Table & Expo Presentation

February 13-14, 2012, in Columbus, OH / Hosted by AEP

Tangential Firing Systems and NOx Tuning

2012 NOx-Combustion Roundtable

Jim Jordan

Columbus, Ohio 2/13/12

POWER | ALSTOM

Agenda

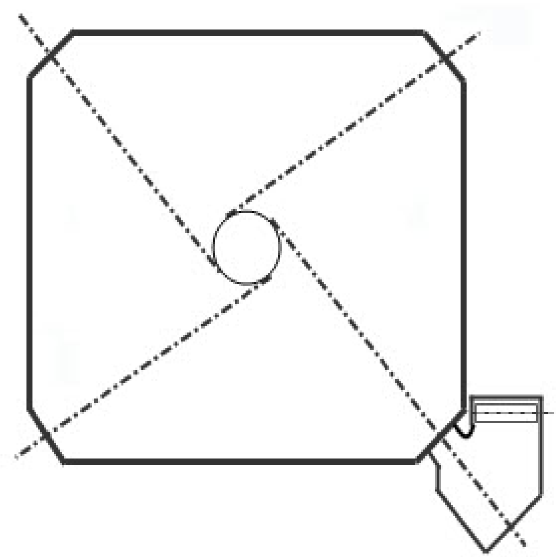
Topic 1	Conventional Tangential Firing Systems
Topic 2	Low NOx Tangential Firing Systems
Topic 3	NOx Tuning - Tangential Firing System
	Questions

Tangential Firing

- **General Points**
  - In operation since 1927
  - Single flame envelope concept – all fuel and air streams interact to form a common “fireball” mixture
  - “The furnace is the burner” and mechanical turbulence is sustained throughout the furnace
  - T-fired combustion is inherently lower NOx as compared to wall fired units due to lower temperatures in the firing zone

Conventional Tangential Firing System

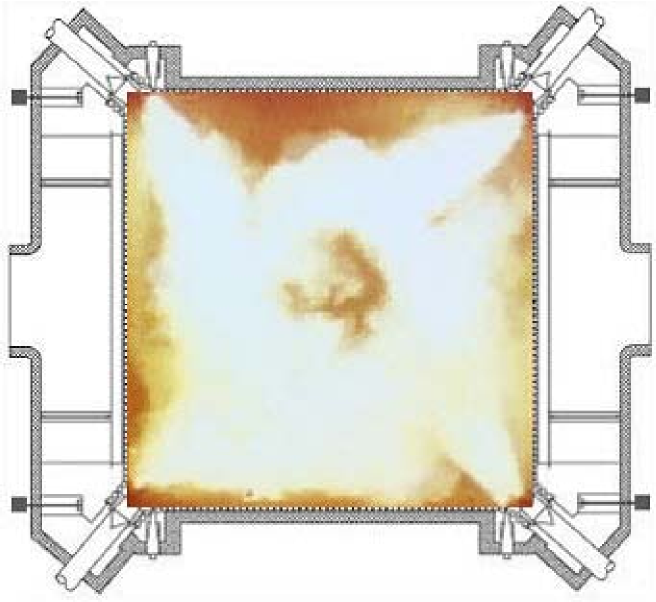
- **Basic Features**
  - The fuel and air is introduced at the corners of the furnace
  - The fuel and air streams are aimed tangent to a circle in the center of the furnace
  - Corner windboxes incorporate a series of vertically stacked air and fuel compartments and nozzle tips
  - Combustion air to each windbox compartment is controlled by a louver type damper



Conventional Tangential Firing System

ALSTOM

- **Single Flame Envelope**
  - Impingement on the laterally adjacent air and fuel streams promote bulk mixing
  - Long diffusion flames result in flame body having a cyclone-like rotation that fills the furnace
  - The furnace becomes the burner
    - Minimizes a need for stringent balancing of the fuel and air distribution at each of the nozzle tips



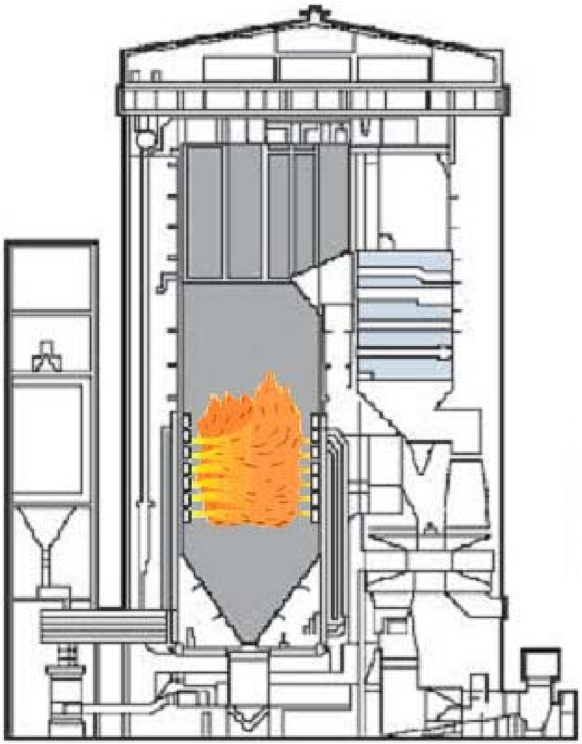
fireball_17.avi

“The furnace is the burner”

Conventional Tangential Firing System

ALSTOM

- **Fuel Admission**
  - Pulverized coal from each pulverizer is admitted to the furnace on an elevation basis
  - An additional pulverizer is put into service as load demand increases
    - Typically starting with the lower elevations of fuel and progressing upward

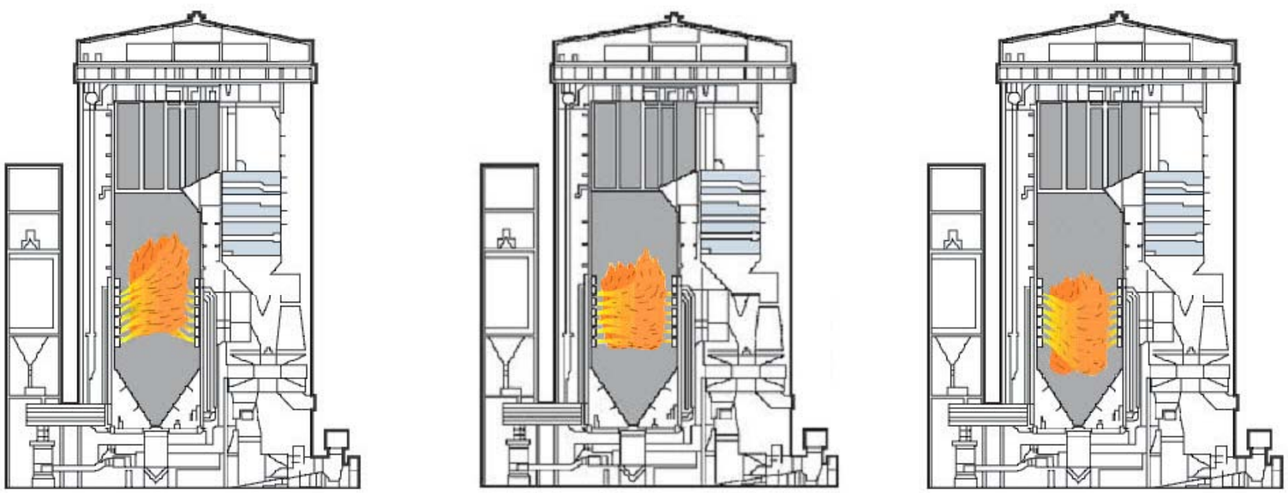


“Coal is fired on an elevation basis”

Conventional Tangential Firing System

ALSTOM

- **Tilting Tangential Firing**
  - Position of the "fireball" can be adjusted up/down which will affect the heat absorption in the furnace waterwalls
    - Thus affecting the temperature of gases leaving the furnace
    - Which ultimately affects the SH and RH steam temperatures

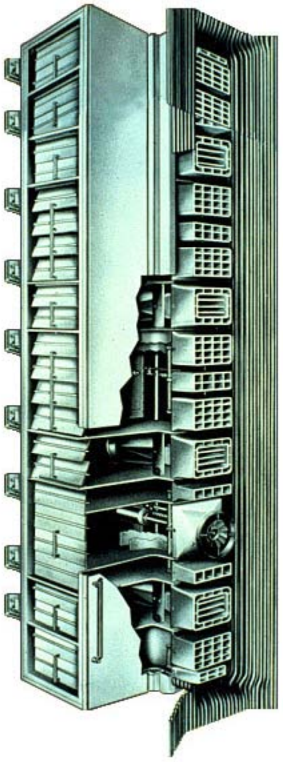


Nozzle Tilts -UP   Nozzle Tilts – HORIZONTAL   Nozzle Tilts - DOWN

Conventional Tangential Firing System

ALSTOM

- **Windboxes**
  - Different designs depending on the age of the unit, fuels fired and size of the unit
  - Separate horizontal compartments for the admission of fuel and air into the furnace
  - Windbox is part of a system, including:
    - Coal transport piping
    - Secondary air connecting ducts
    - Furnace buckstays (structural component)
    - Bent tubes forming the furnace waterwall opening

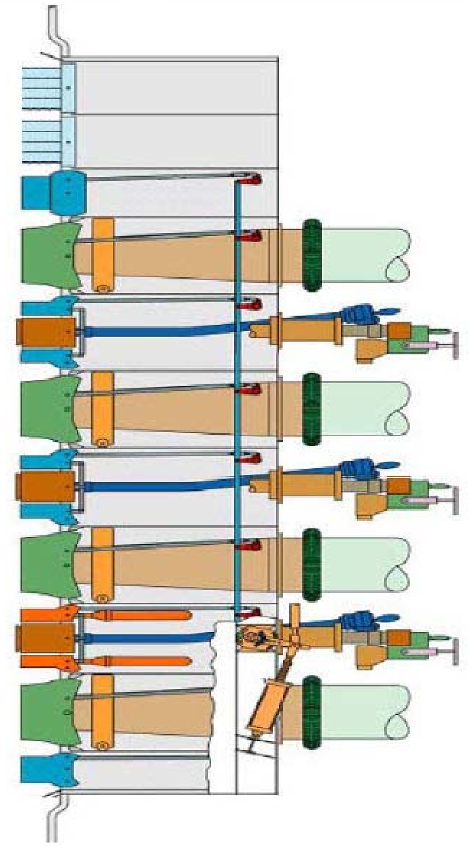


"Part of a System"

Conventional Tangential Firing System

ALSTOM

- **Windbox Secondary Airflow**
  - Originates from the Forced Draft Fan(s)
  - Preheated by the air heater
  - Distributed to corner windboxes through ducting system
  - Divided up into horizontal compartments in the windboxes
    - **Fuel Air** – at fuel nozzle elevations
    - **Auxiliary Air** – in-between fuel elevations
    - **Overfire Air** – at top of the windbox
      - Since about 1971

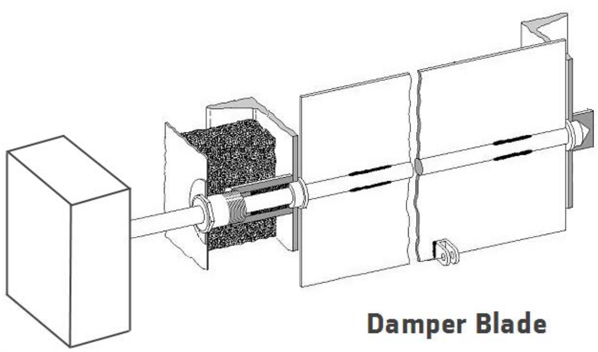


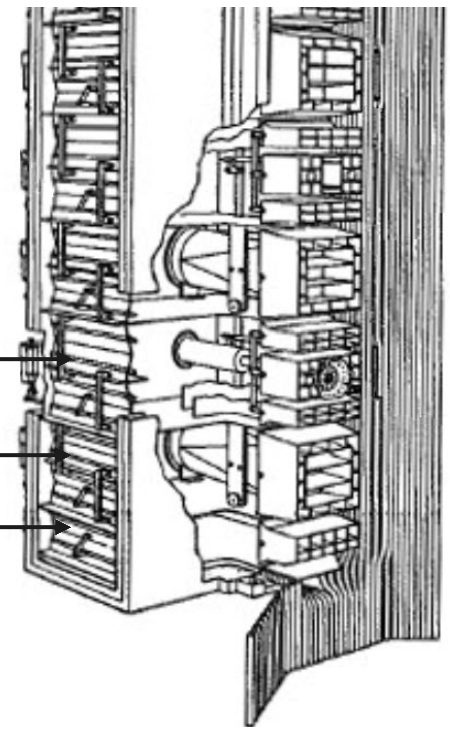
"Layers of Air and Fuel"

Conventional Tangential Firing System

ALSTOM

- **Modulating Secondary Air Dampers**
  - Louver dampers at entrance into each of the Fuel and Air windbox compartments
  - Size and quantity of damper louvers for each compartment designed accordingly
  - Amount of SA to each compartment is regulated by a damper drive





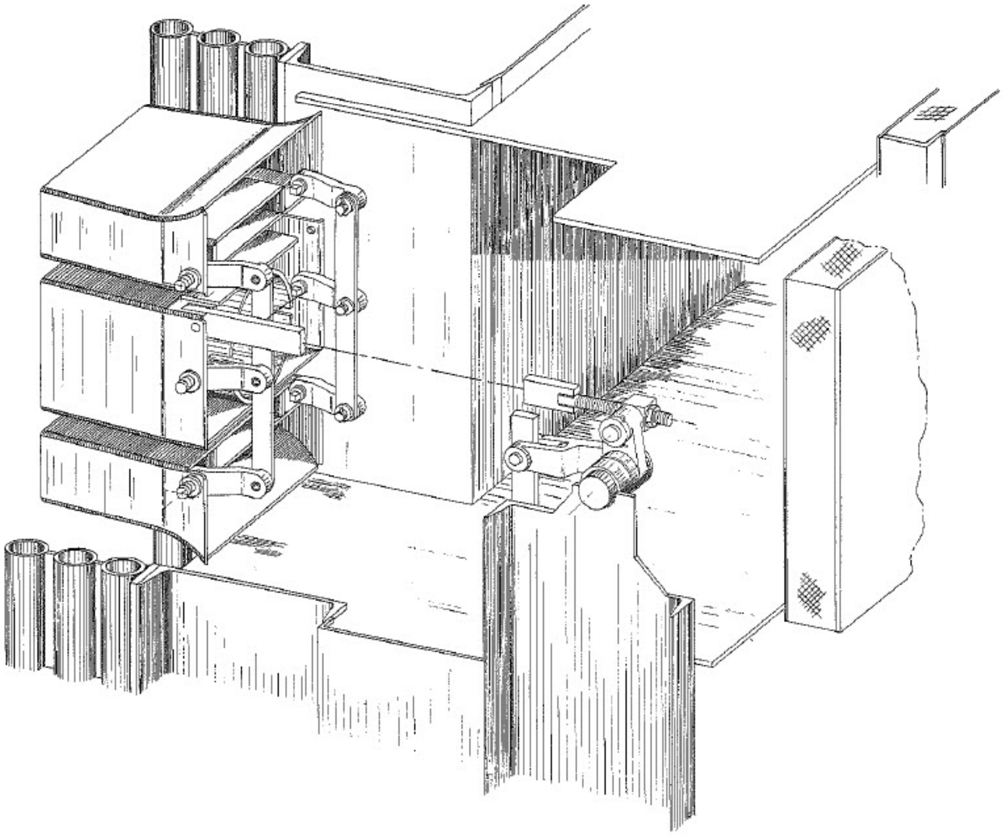
*** *Dependant on whether oil gun***

"Air Distribution Control"

Conventional Tangential Firing System

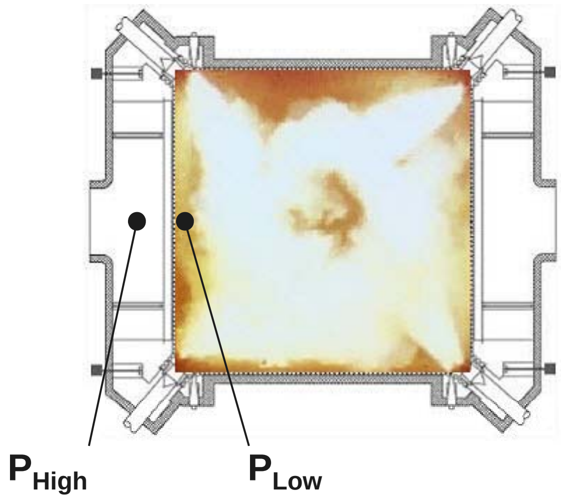
ALSTOM

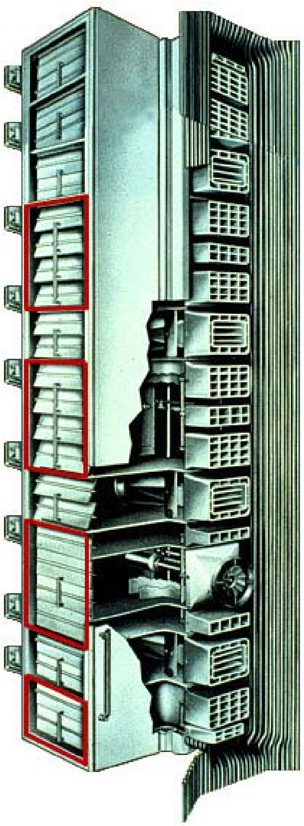
- **Windbox - Air Nozzle Compartment**
  - Adjustable Air Nozzle Tips



Conventional Tangential Firing System

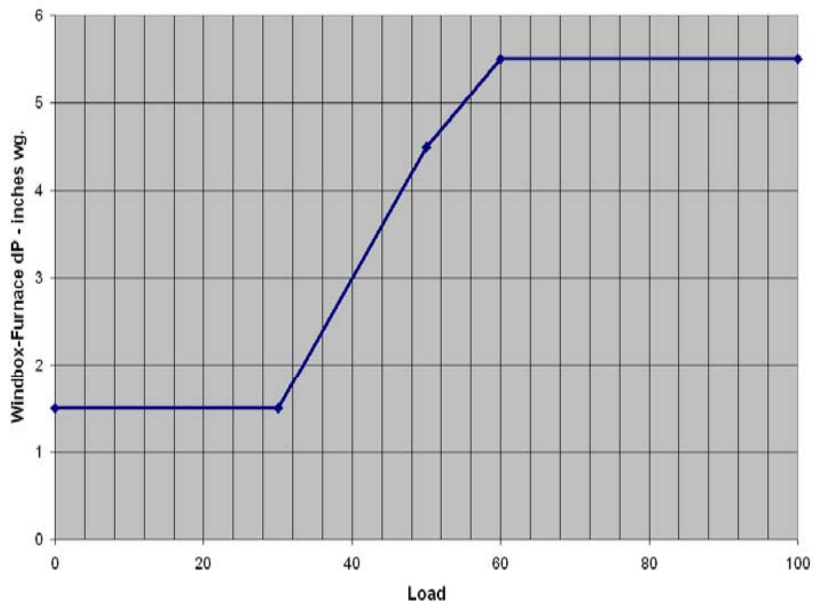
- **Auxiliary Air Dampers at Air Nozzle Compartments**
  - For control of Windbox-to-Furnace differential pressure
    - Driving force to assure distribution of secondary air to the fuel nozzles on the elevations in-service and adjacent air nozzle tips
    - Affects air velocity through nozzle tips which affects the jet penetration and rate of furnace mixing





Conventional Tangential Firing System

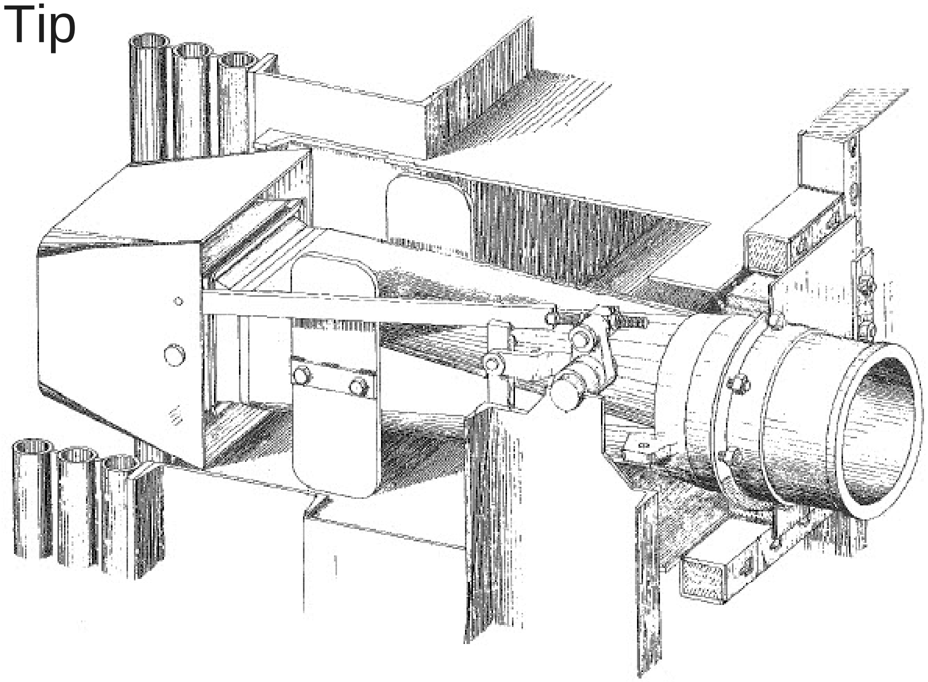
- **Control of Windbox-to-Furnace delta-P**
  - Auxiliary Air dampers modulate on automatic control to maintain Windbox-to-Furnace differential pressure
  - Follows a control curve vs. Load
    - Curve will be unit specific
    - Lower dP at the low loads
      - Less furnace turbulence
    - Higher dP at the high loads
      - More furnace turbulence



Example of Curve

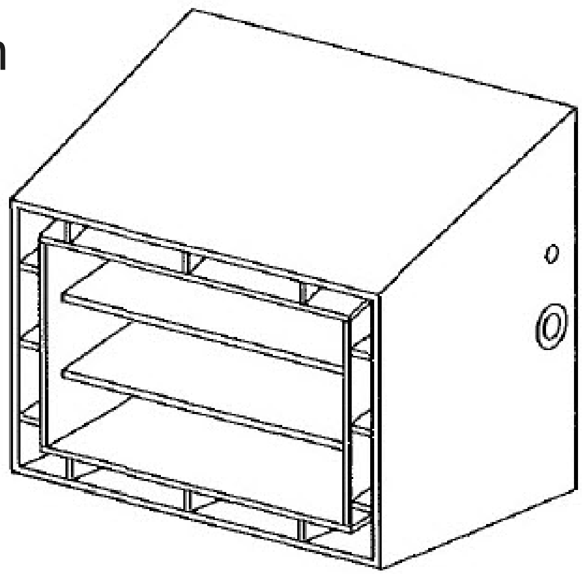
Conventional Tangential Firing System

- **Windbox - Coal Nozzle Compartment**
  - Coal nozzle assembly
    - Directs the pulverized coal and transport air into furnace
    - Stationary Coal Nozzle
    - Adjustable Coal Nozzle Tip



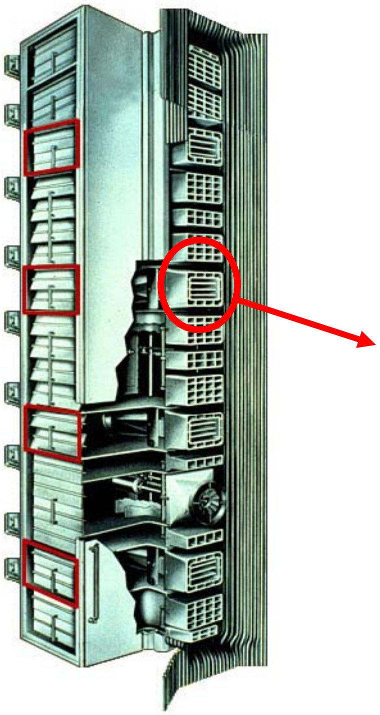
Conventional Tangential Firing System

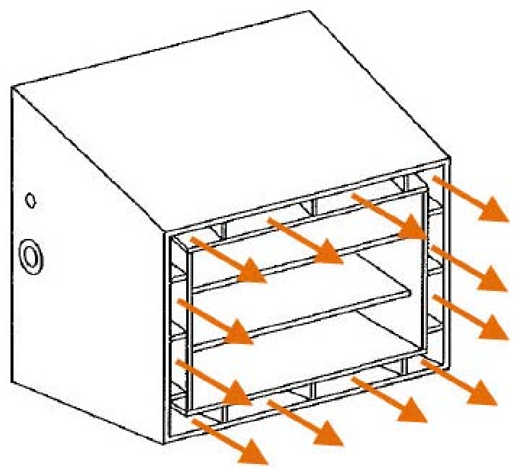
- **Adjustable Coal Nozzle Tip**
  - Size and configuration influences …
    - Initial air/fuel mixing and early stages of combustion of the pulverized coal
    - Potential of ash pluggage and deposition on the nozzle tip
    - Flame stability at the nozzle tip
    - Potential of cracking and over-heating
  - Inner Shroud
    - Primary Air & Pulverized Coal
  - Outer Shroud
    - Fuel Air around perimeter



Conventional Tangential Firing System

- **Fuel Air Dampers**
  - Regulate amount of secondary air admitted around periphery of coal nozzle tips
  - Controls ignition point at the coal nozzle tips





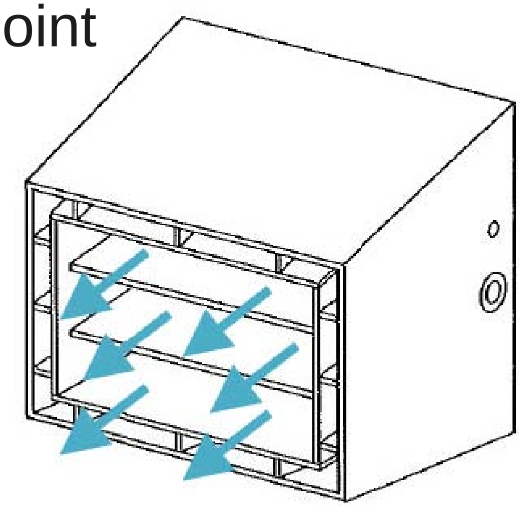
Conventional Tangential Firing System

- **Control of Fuel Air Dampers**
  - Automated control that typically follows a control curve vs. Coal Feeder Speed
    - Unit specific, with coal and firing conditions

Example of Curve

Conventional Tangential Firing System

- **Primary Air**
  - Purpose – dry and transport the pulverized coal from the pulverizers to the furnace
  - Quantity depends on pulverizer size, coal piping I.D. and coal fired
  - Exit velocity at nozzle tips affects ignition point
  - Not controlled at the windboxes
    - Controlled by the milling system

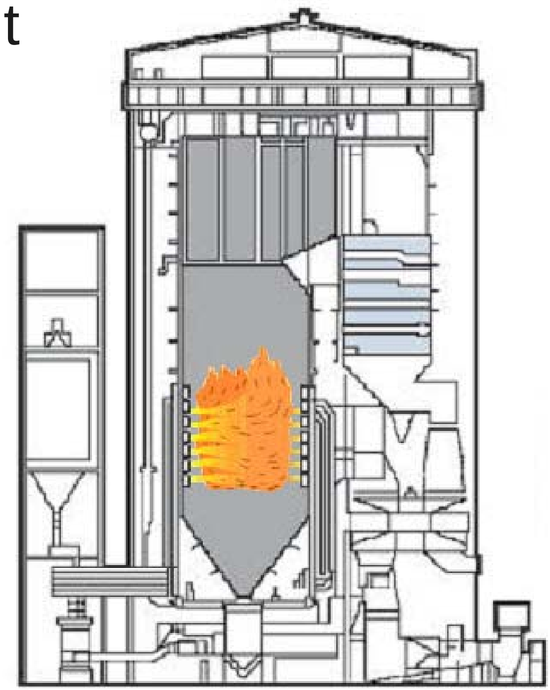


"First air to touch the pulverized coal"

Conventional Tangential Firing System

ALSTOM

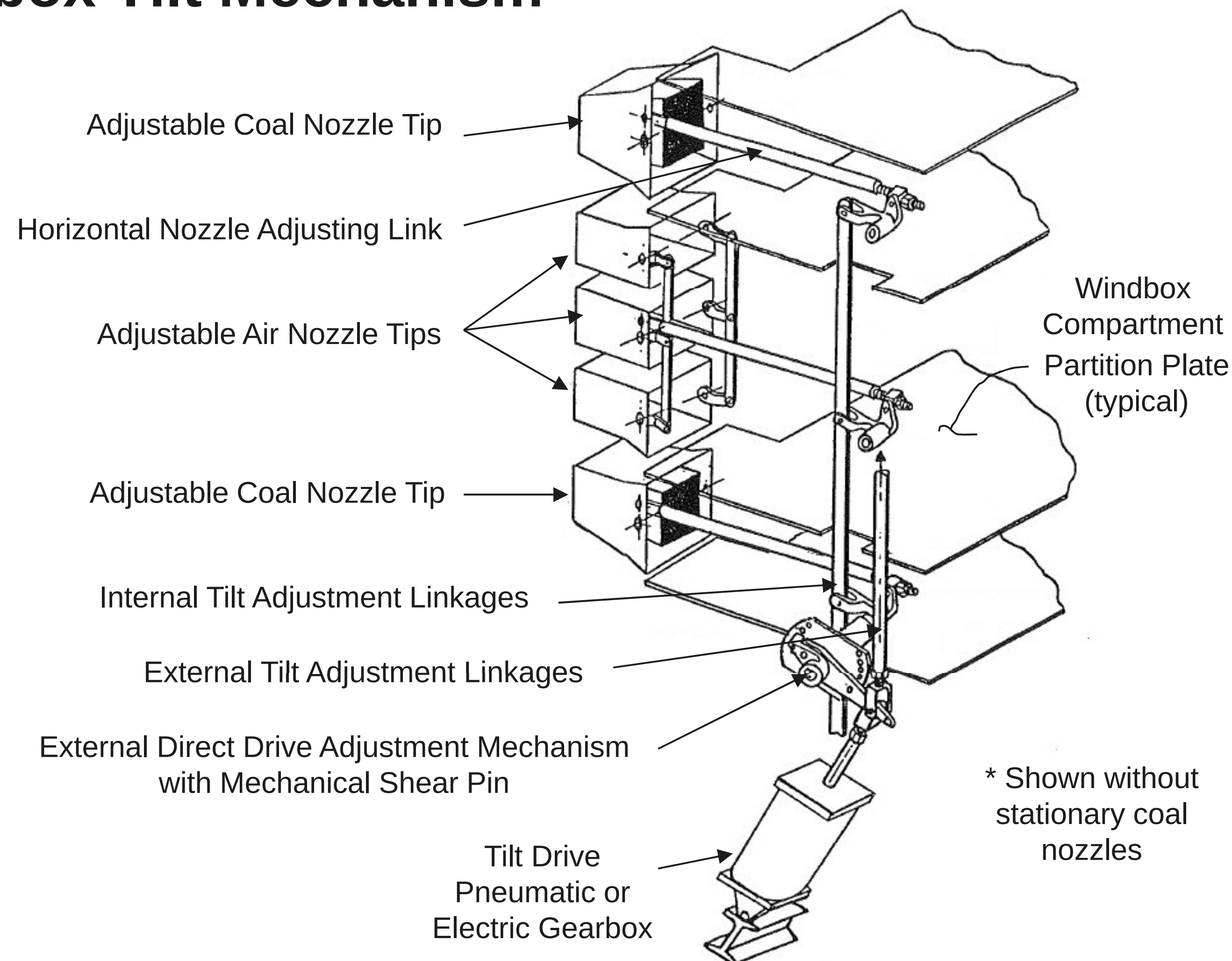
- **Main Windbox Tilts**
  - Each corner windbox has its own tilt drive
  - All air and fuel nozzle tips in a corner tilt together +/-30º
  - All corners typically tilt in unison



"For steam temperature control"

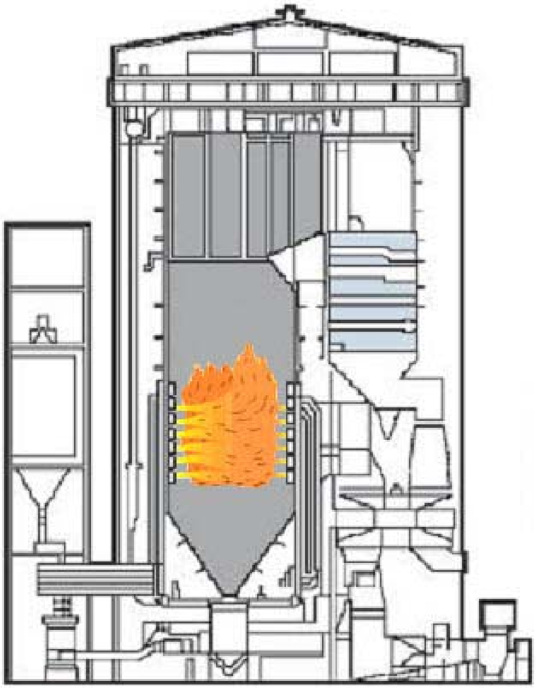
Conventional Tangential Firing System

- **Main Windbox Tilt Mechanism**



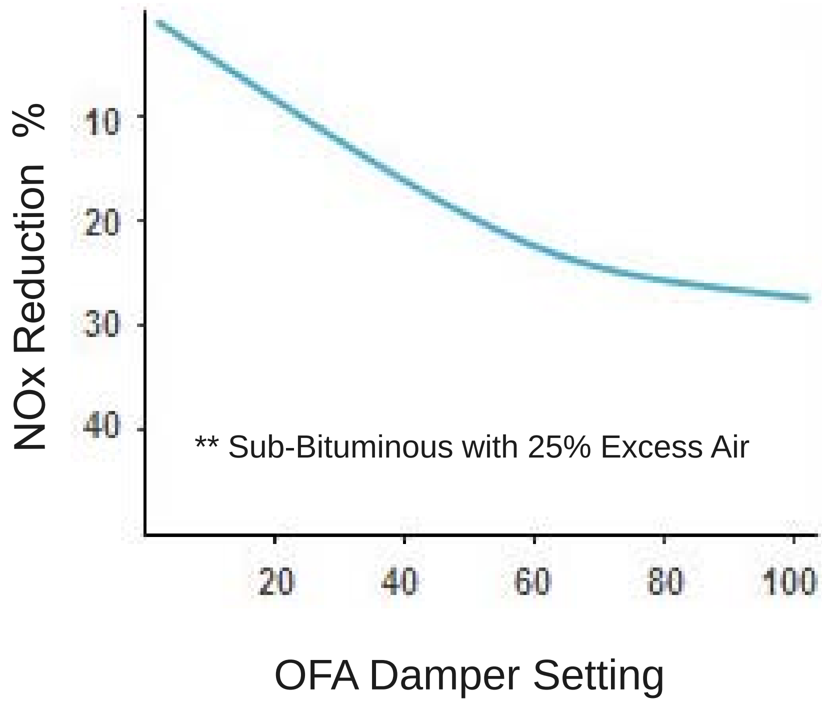
Conventional Tangential Firing System

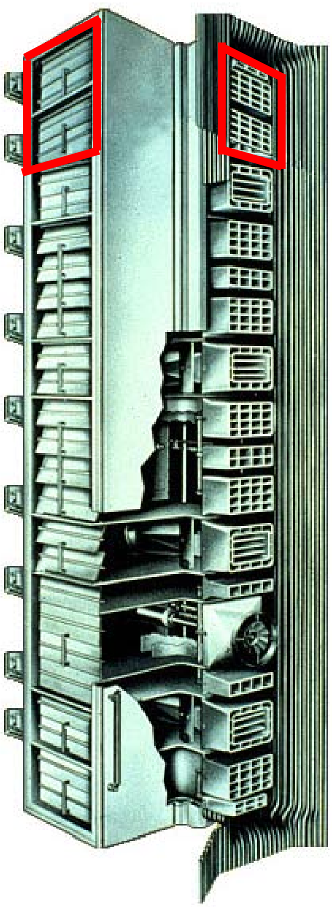
- **NOx Emissions**
  - Prior to 1990, large tangentially fired pulverized-coal fired boilers had NOx emissions between 0.4 to 0.7 $lbs/10^6$ Btu heat input
    - Dependant on
      - Heat release rates
      - Furnace size and geometry
      - Fuel properties
      - Firing system and residence time
      - Boiler operation



Conventional Tangential Firing System

- **Effect of OFA admission on NOx**
  - Approximately 15% of total air to OFA
  - Resulted in 20% to 30% NOx reduction

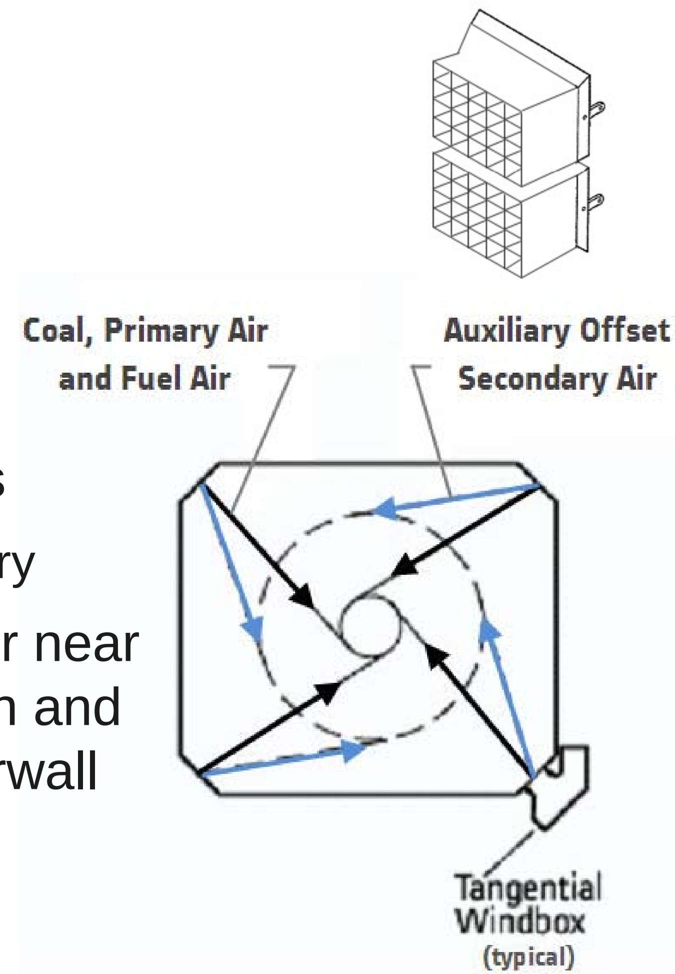




Low NOx Tangential Firing Systems

ALSTOM

- **Concentric Firing System**
  - LNCFS™ developed in 1980
  - Early designs had <u>fixed</u> horizontally off-set Air nozzles
    - Delays entrainment of secondary air into the coal and primary air streams
      - Reduces the local firing stoichiometry
    - Concentrated oxygen boundary layer near furnace walls reduces ash deposition and tenacity and can help to inhibit waterwall wastage corrosion

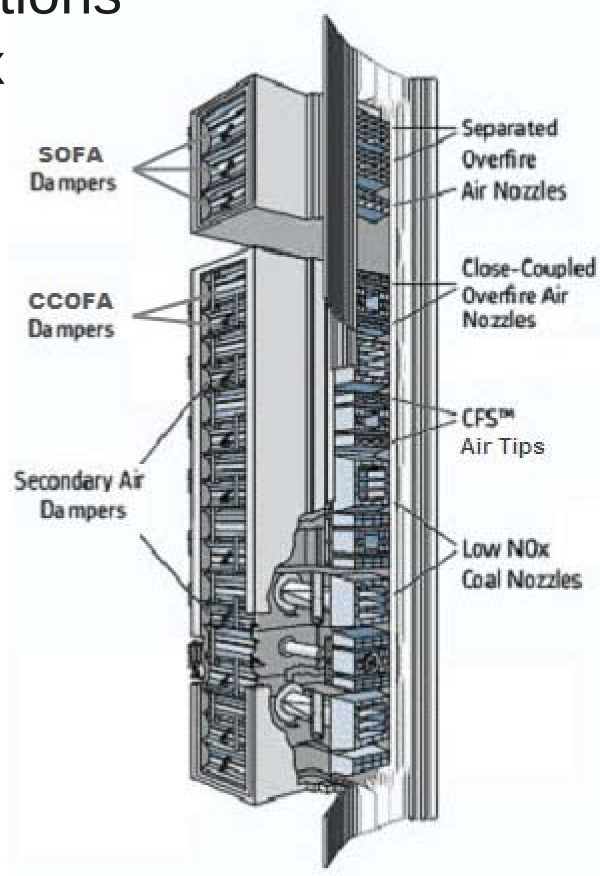


"Horizontal air staging"

Low NOx Tangential Firing Systems

ALSTOM

- **Low NOx Concentric Firing System**
  - Since 1990 there have been advancements in the LNCFS™ with several configurations available depended on amount of NOx control required
  - Designs incorporate
    - Bulk furnace staging
      - Close-coupled overfire air (CCOFA)
      - Separated overfire air (SOFA)
    - Local combustion air staging
      - Off-set air nozzles (CFS™)
    - Early controlled coal devolatilization
      - Low NOx coal nozzle tips



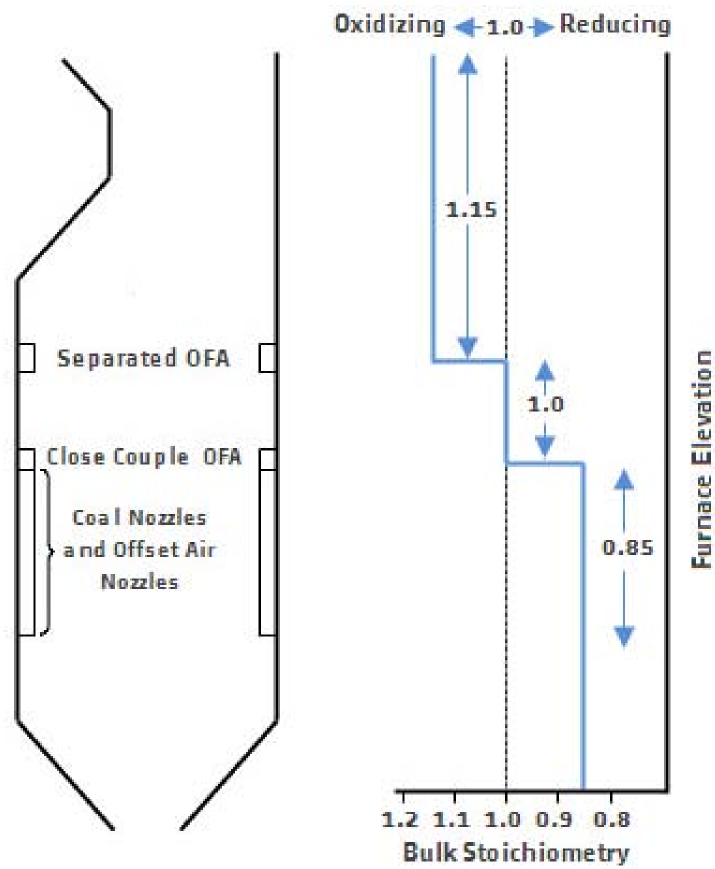
Low NOx Tangential Firing Systems

- **NOx Emissions**
  - Today, depending on the unit design/geometry and fuel fired, modified tangential fired pulverizer-coal firing systems can achieve NOx in the range of 0.09 to 0.22 lb/ $lbs/10^6$ Btu
    - Lower values achieved on tall furnace firing PRB
    - Higher values on shorter furnaces firing a bituminous coal
  - These values are achieved by using:
    - Precise control of furnace stoichiometry
    - Concentric firing via CFS™ air nozzle tips
    - Initial combustion process control

Low NOx Tangential Firing Systems

ALSTOM

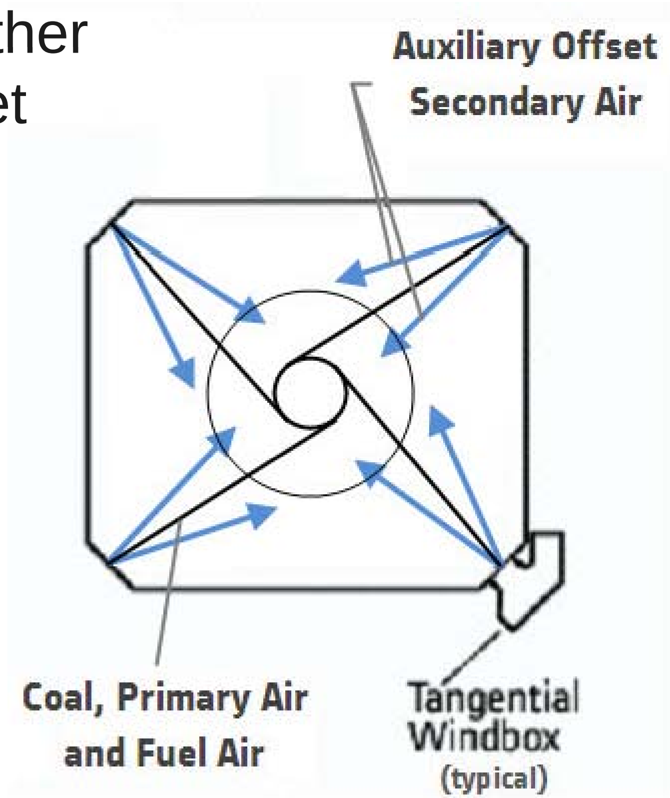
- **NOx Reduction with Bulk Staging**
  - Combustion air is redistributed
    - Main Windbox
    - CCOFA
    - SOFA
  - Reduces available oxygen during the critical early phase of combustion and maximizes time at sub or near stoichiometric conditions
  - Minimal oxygen combined with early fuel ignition and rapid devolitilization contributes to reducing NOx



Low NOx Tangential Firing Systems

ALSTOM

- **Concentric Firing System**
  - Auxiliary Air nozzle tips may have either a fixed or adjustable horizontal off-set
    - With off-set +/- 12.5º or 15º dependant on specific design
  - CCOFA nozzle tips may also have either a fixed or adjustable off-set
    - Provides flexibility during tuning to maximize mixing during the burn-out process to reduce CO



"Horizontal Air Staging"

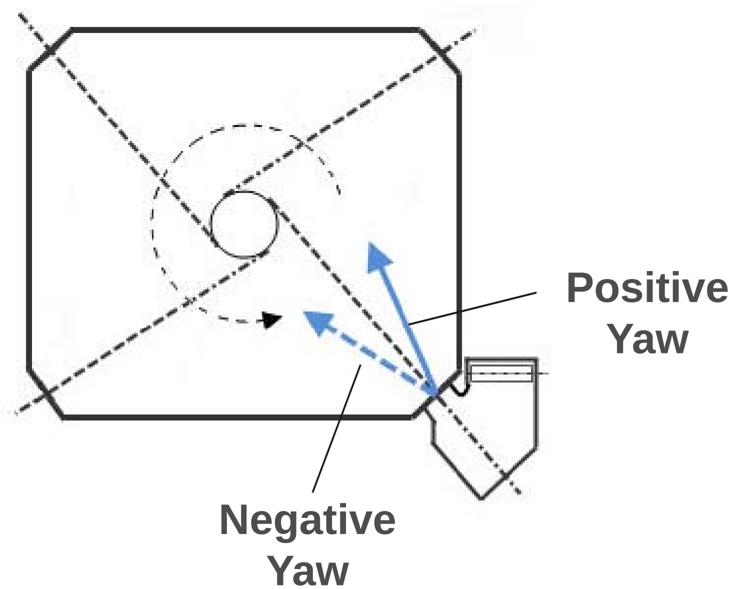
Low NOx Tangential Firing Systems

ALSTOM

- **Positive & Negative Yaw on Air Nozzle Tips**
  - Positive Yaw
    - Off-set is with fireball rotation
  - Negative Yaw
    - Off-set is against fireball rotation

NOTE:

- Alstom does not recommend negative yaw settings on CFS™ air nozzles in the firing zone

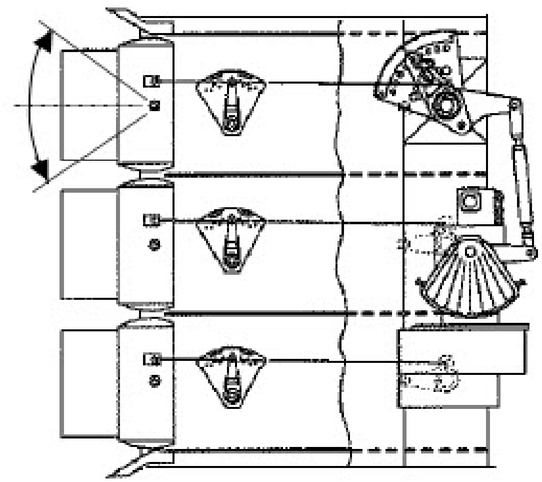


"Direction of Horizontal Air Staging"

Low NOx Tangential Firing Systems

ALSTOM

- **SOFA Windboxes**
  - Stages combustion process by redistributing 25-30% of the secondary air above the main firing zone
  - Each corner has a tilt drive for nozzle tips
  - Multiple air nozzle tips with adjustable horizontal yaw and tilt capability
    - Provides for fine tuning the mixing process to maximize combustion efficiency, control NOx, CO and steam temperatures
  - Each air nozzle compartment has a louver type damper for control



Low NOx Tangential Firing Systems

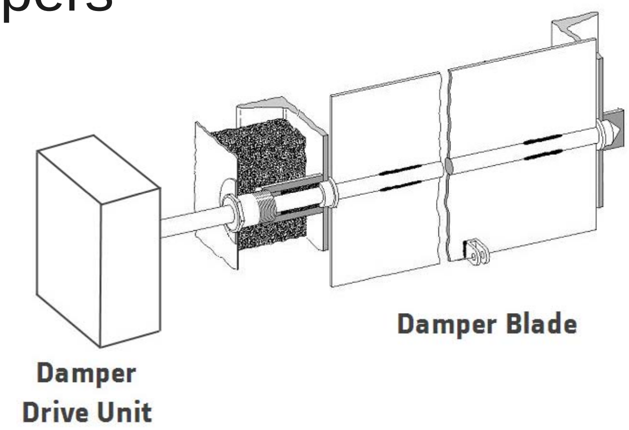
- **Burner Tilts**
  - Continue to be used for steam temperature control
  - Modified tilt range: air nozzles +/-30º and fuel +/-20º
  - Some units set up with bias capabilities between corners
    - Can help to control O_2 splits, SH / RH temperatures and CO
  - Some units set-up with an auto stroking sequence every X-hours to help keep the tilts freed up
    - *Caution:* Limit auto stroking of the tilts to 1-corner at a time so as to minimize NOx and temperature excursions

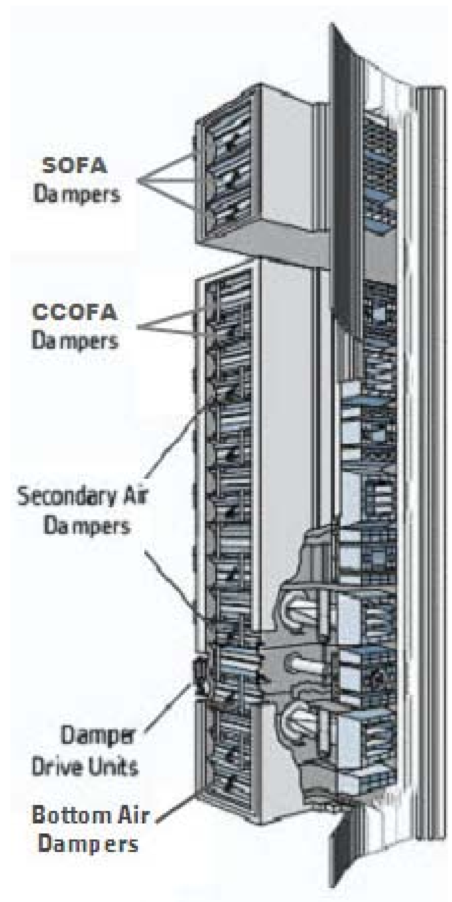
Low NOx Tangential Firing Systems

- **SOFA Tilts**
  - Nozzle tips have +/-30º tilt range
  - Some units have manual tilts and others have tilt actuators
  - Control schemes: Manual or remote that follows burner tilts with a ratio bias, follows a load curve, or manual control
  - Biasing corner tilts can help to control O_2 splits, SH / RH temperatures and CO

Low NOx Tangential Firing Systems

- **Dampers on LNCFS™**
  - Windbox Secondary Air Dampers
    - Auxiliary Air Dampers
    - Bottom Air Dampers
    - Fuel Air Dampers
  - Windbox CCOFA Dampers
  - SOFA Dampers

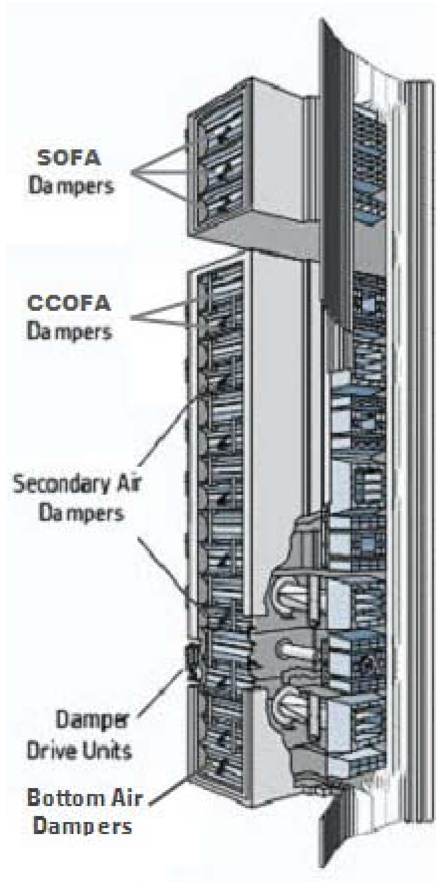




Low NOx Tangential Firing Systems

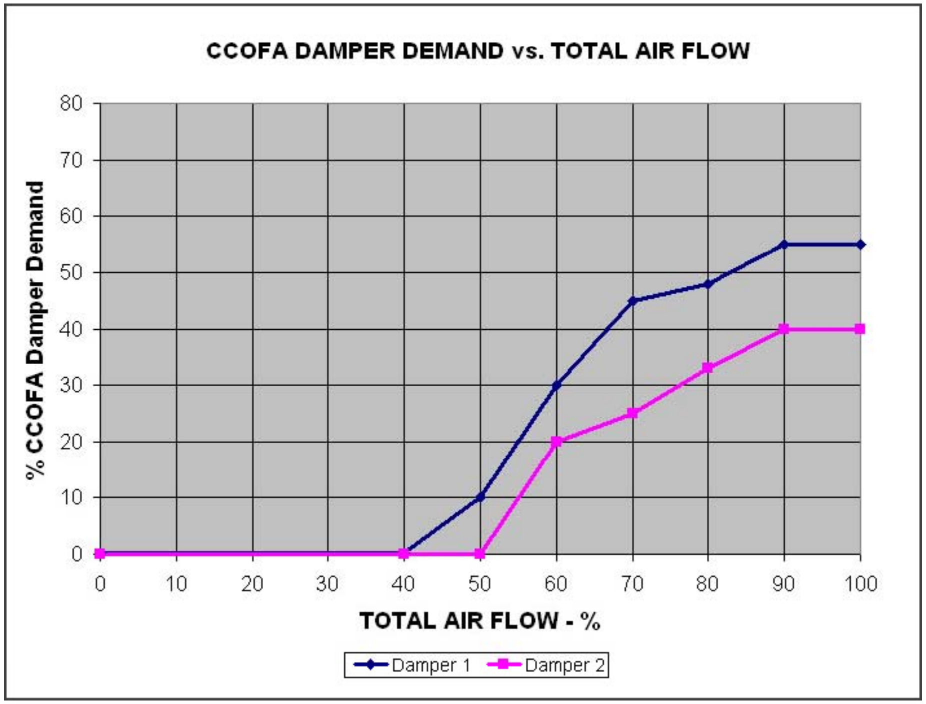
ALSTOM

- **Windbox Secondary Air Dampers**
  - Auxiliary Air Dampers
    - Function same as with conventional T-Firing
    - Damper sizing modified to ensure control with less air being admitted at this elevation
    - Controls often modified to provide separate control for Bottom Air Dampers
  - Fuel Air Dampers
    - Function same as with conventional T-Firing
    - Control curve typically modified from that of a conventional T-firing

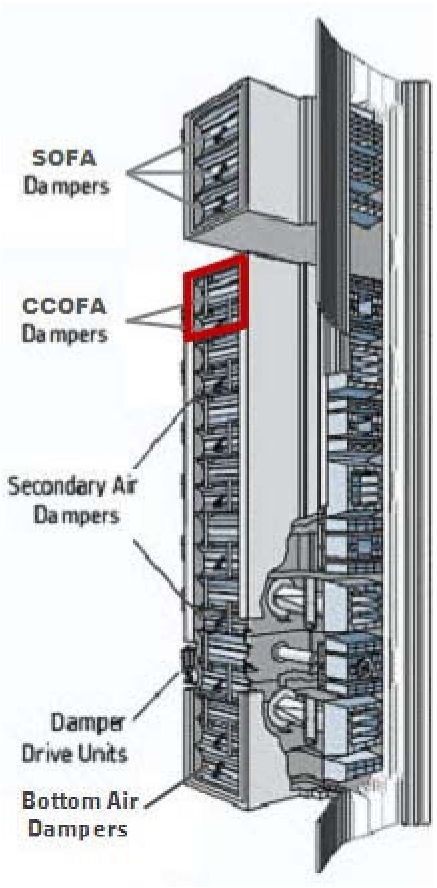


Low NOx Tangential Firing Systems

- **CCOFA Dampers**
  - Typically follow a control curve vs. Total Air
    - Specific curve will vary depending on unit

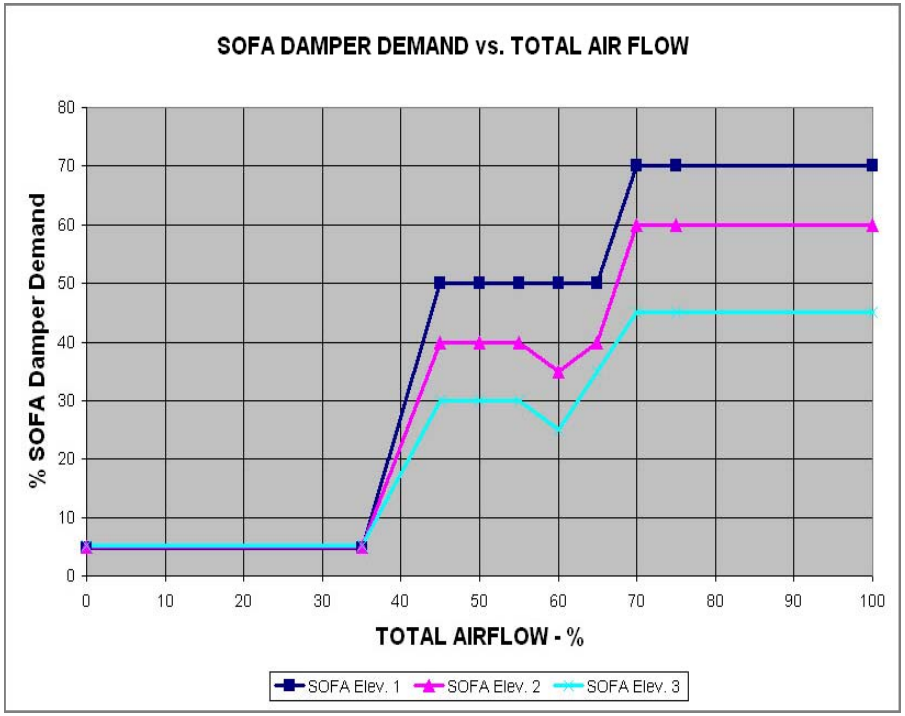


Example of Curve

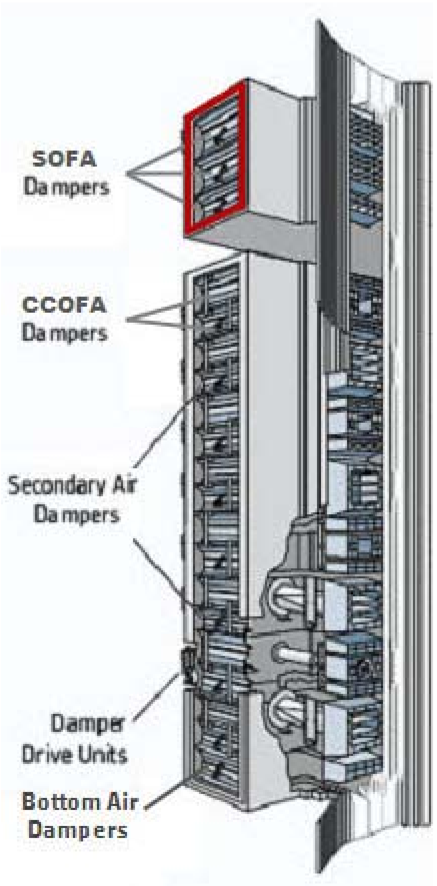


Low NOx Tangential Firing Systems

- **SOFA Dampers**
  - Typically follow a control curve vs. Total Air
    - Specific curve will vary depending on unit



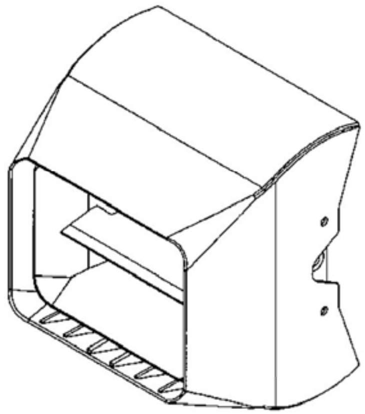
Example of Curve

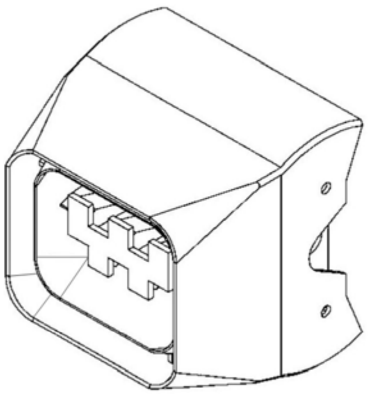


Low NOx Tangential Firing Systems

ALSTOM

- **Low NOx Coal Nozzle Tips**
  - Design is bulbous and aero dynamic
    - Decreases turbulence that causes recirculation and deposition of ash on nozzle surfaces
    - Provides for better air flow control through range of tilt movement
  - Design provides for …
    - Flame front control at the exit of the nozzle tip to achieve early fuel ignition and rapid devolatilization of the coal
    - Improved flame stability

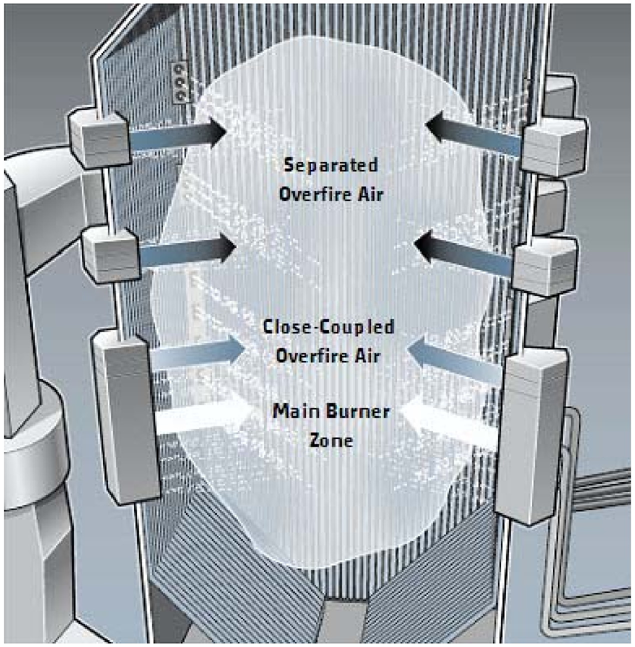




Low NOx Tangential Firing Systems

ALSTOM

- **TFS 2000™**
  - Developed in 1992
  - Combines the previous technologies Alstom used to control NOx
    - Staging OFA / SOFA
    - Concentric secondary air
    - Horizontal yaw control of SOFA
    - Flame Front Control Coal Nozzle Tips
    - Includes finer coal pulverization that allows for more aggressive staging
      - less than 1% on 50 mesh
      - +75% through 200 mesh



TFS 2000 Low NOx.AVI

"Our most aggressive in-furnace emission control system"

NOx Tuning - Tangential Firing Systems

- **When is NOx Tuning likely to be Performed**
  - Following the initial installation of a new low NOx system
  - Unauthorized changes have been made to the LNCFS™
  - Changes to emissions regulations
  - Upgrades to the DCS control system
  - Fuel changes

NOx Tuning - Tangential Firing Systems

- **NOx Tuning Considerations**
  - Boiler load needs to be stable
  - Define load points for the tuning
  - Boiler operating conditions for optimum NOx will be different from what the operators are accustomed to
  - Pulverizers capable of making desired coal fineness and have reasonable control of Primary airflow
  - Identify constraints
    - Minimum steam temperatures
    - Allowable CO emissions
    - Minimum windbox damper positions
    - Existing equipment issues
    - Available time

NOx Tuning - Tangential Firing Systems

ALSTOM

- **Operating Variables that Effect NOx and CO**
  - Boiler Load
  - Flue gas excess oxygen
  - Air flow to SOFA
  - Air flow to CCOFA
  - bias in OFA between corners
  - Main windbox tilts
  - SOFA tilts
  - bias between Burner/SOFA tilts
  - Windbox-to-furnace delta-P
  - Fuel Air dampers
  - Yaw positions on CFS™ tips
  - Yaw positions on CCOFA
  - Yaw positions on SOFA tips
  - Primary Air flow
  - Mills in-service
  - Sootblowing practices

“Many variables to consider”

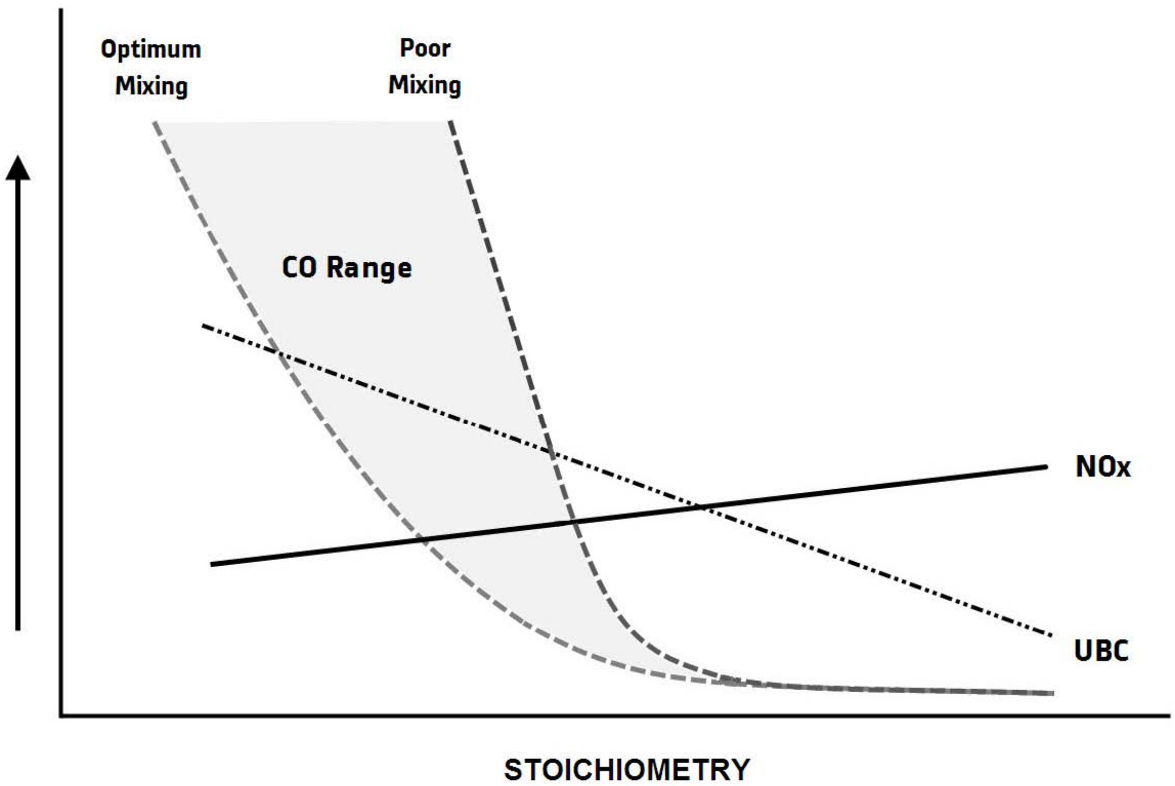
NOx Tuning - Tangential Firing Systems

- **Operating Parameters Commonly Tested**
  - Evaluate effects on NOx, CO and UBC in fly ash:
    - SOFA and CCOFA damper positions
    - SOFA, CCOFA and CFS™ yaw positions on nozzle tips
    - SOFA and main burner tilt positions
    - Fuel air damper positions
    - Flue gas excess air
    - Windbox-to-furnace differential pressure
    - Mills in service

"Strong actors"

NOx Tuning - Tangential Firing Systems

- **Typical Trends for NOx, CO and UBC**

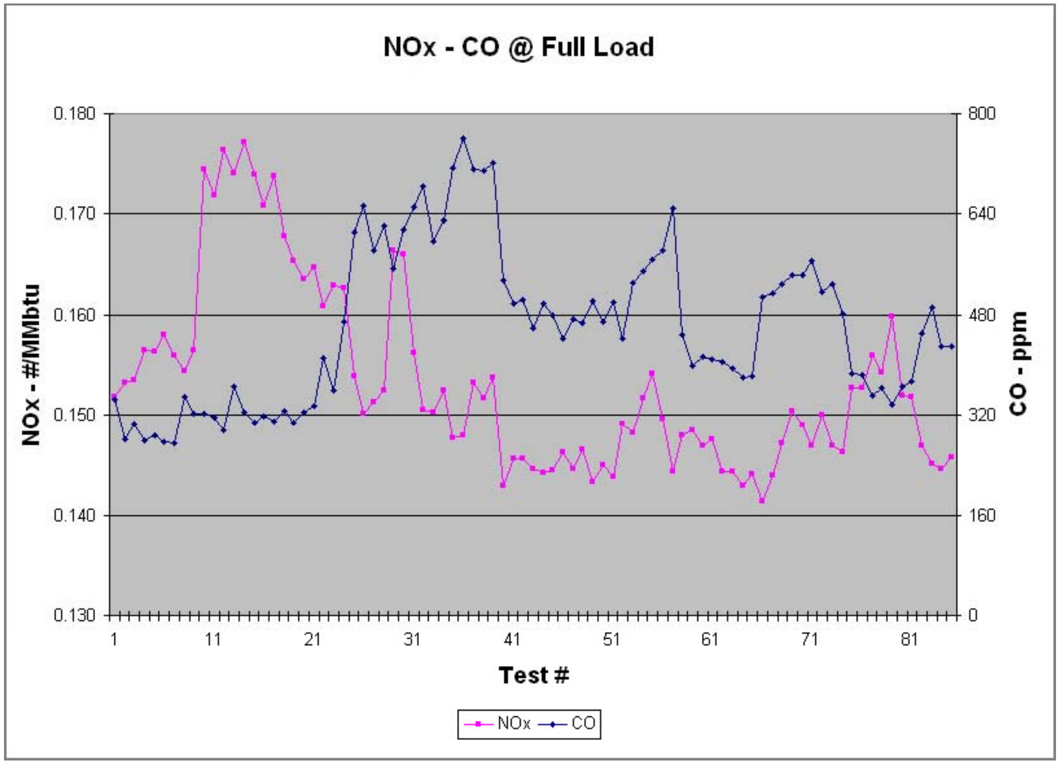


"There are trade-offs"

NOx Tuning - Tangential Firing System

ALSTOM

- **Some Adjustments Help and some Don't**



"Make small iterative changes and be patient"

NOx Tuning - Tangential Firing Systems

- **Conditions that Helped to Reduce NOx**
  - Amount of staging air to SOFA
  - Maintaining separation between burner and SOFA tilts
  - Achieving stable airflow
  - Lower operating excess air
    - Constraints – increases CO, increases furnace slagging and reduces SH and RH steam temperatures
  - Optimizing the use of Primary Air
    - Either quantity of pulverizers in-service or individual airflows
  - Reducing air infiltration into the furnace and backpass
  - Maintaining cleanliness of furnace walls

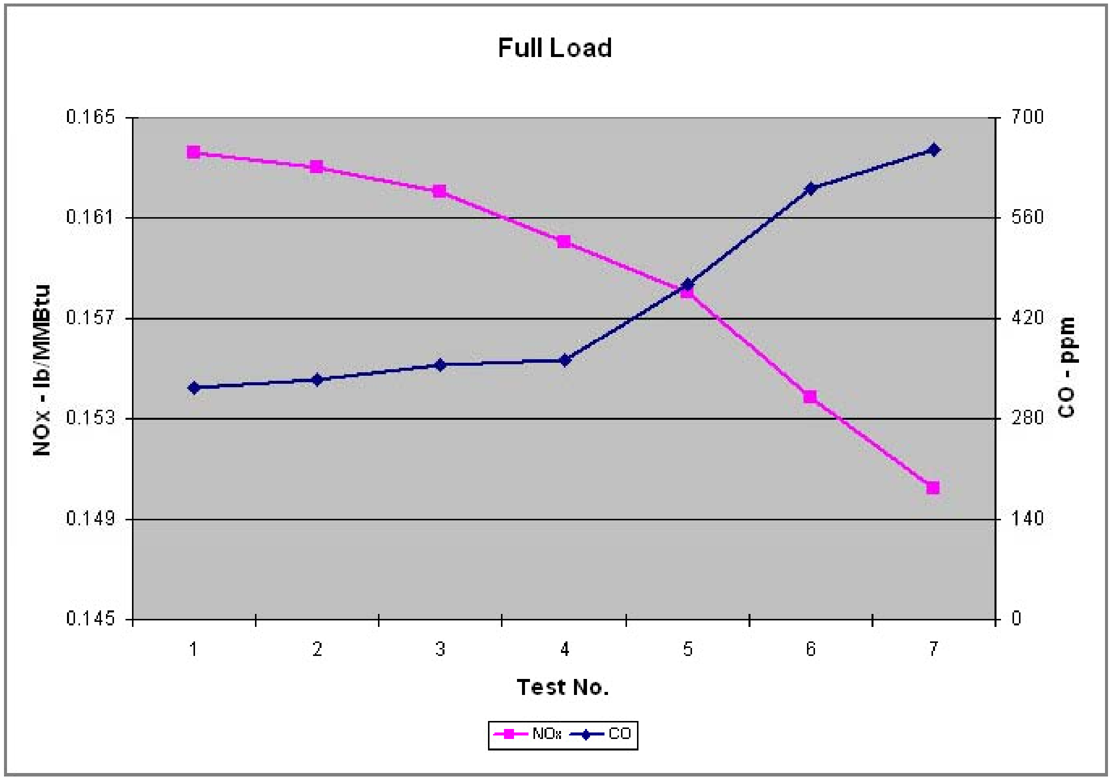
NOx Tuning - Tangential Firing Systems

ALSTOM

- **Conditions that Hindered Reducing NOx**
  - Degrading fuel quality (BTU's)
  - Over-staging
  - Unstable airflow
    - Swings in furnace draft due to limitations on ID or FD fans
    - Swings in turbine throttle pressure due to control issues
  - In-operable SOFA & windbox secondary air dampers
  - A burner corner or SOFA corner tilt out of position
    - Can affect both NOx and O_2
  - High mill airflows

NOx Tuning - Tangential Firing Systems

- **Inverse Nature of NOx and CO**
  - Actual test results



NOx Tuning - Tangential Firing Systems

- **Conditions that Resulted in High CO**
  - Low excess air
  - Poor mixing of the fuel and air
    - Low Windbox-to-Furnace differential pressure
  - Over-staging
  - In-operable SOFA & windbox secondary air dampers
  - In-operable yaw adjustment on CFS™ or SOFA air nozzle
  - Operating with raised burner tilts
  - A burner corner corner tilt out of position
  - Biasing Fuel Air dampers in corners can help reduce CO

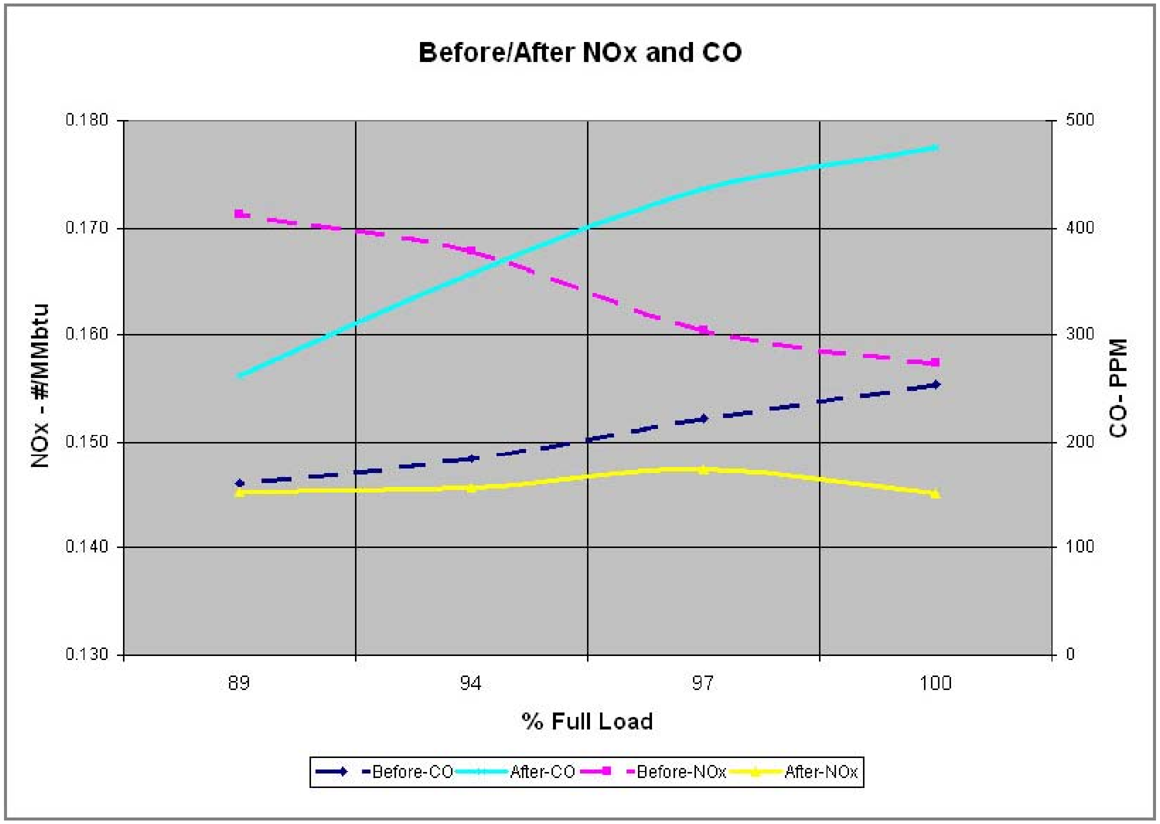
NOx Tuning - Tangential Firing System

- **Refine Control Curves Based on Tuning Results**
  - O_2 vs. Load
  - Windbox/Furnace differential pressure vs. Load
  - SOFA Dampers vs. Total Air Flow
  - CCOFA Dampers vs. Total Air Flow
  - Fuel Air Dampers vs. Feeder Speed

"Curves are different for each unit"

NOx Tuning - Tangential Firing System

- **Results of Tuning**



"Goal was to reduce NOx at expense of CO"

NOx Tuning - Tangential Firing System

- **Some Lessons Learned from NOx Tuning**

1. Upfront planning pays big dividends
   - Evaluate equipment functionality and perform calibrations
2. Develop a detailed test plan
   - Set-up a matrix with combinations of selected test variables
3. Teamwork and Communications are essential
   - Ensure everyone knows their role in the tuning effort
   - Insure operators understand the planned test conditions and they buy into making the necessary changes

NOx Tuning - Tangential Firing System

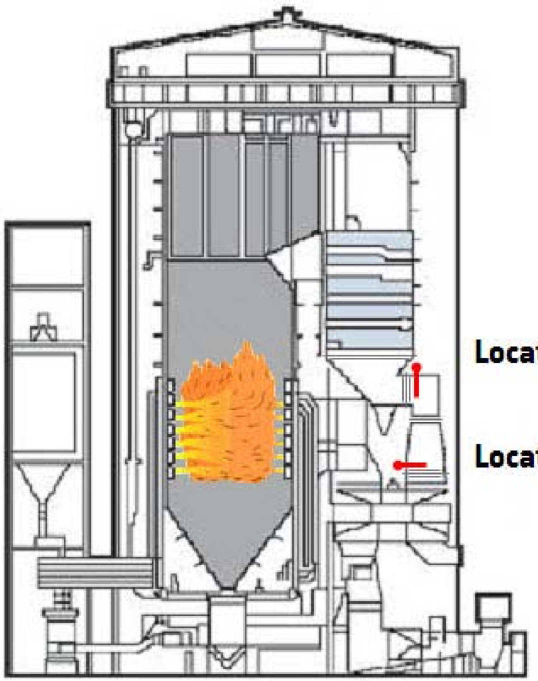
ALSTOM

- **Lessons Learned from NOx Tuning (continued)**

4. Utilize capabilities of plant's DSC and data historian
   - Set-up and monitor trends, including: Unit load, NOx, CO, O_2 (average) and Total Airflow
   - Set-up historian to collect data that will be used to generate graphs for the analysis of the tested variables
5. Ensure the tilts and dampers are functional and working properly from the control room
   - A single in-operative tilt or damper will affect NOx, CO and O_2 between the furnaces
6. Ensure all O_2 probes, NOx and CO instrumentation are calibrated

NOx Tuning – Lessons Learned

- **Case in Point - Oxygen Probes**
  - Measured O_2 in flue gases needs to be representative
    - Probes at optimum location
    - Probes of sufficient length
    - Sufficient quantity of probes
  - Properly calibrated
  - Avoid air infiltration upstream

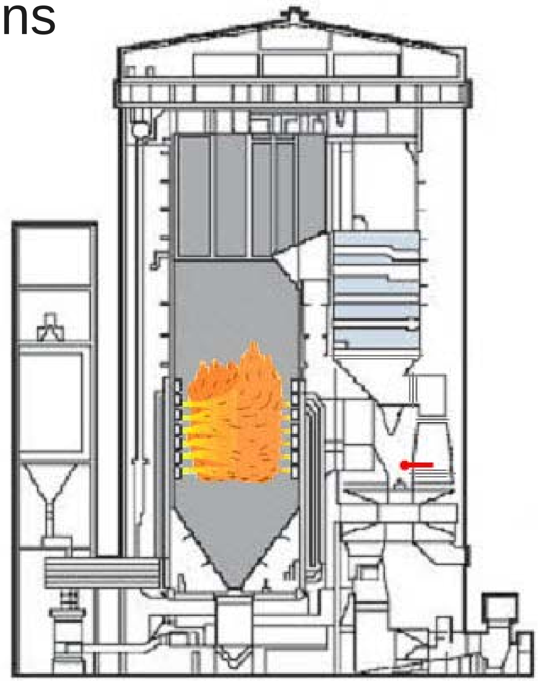


"Plant's O_2 probes are key to successful tuning"

NOx Tuning – Lessons Learned

ALSTOM

- **Points of Possible Air Infiltration**
  - Excessive leakage at closed windbox dampers
  - Damaged bottom ash seal trough curtains
  - Boiler access doors
  - Furnace observation ports
  - Seals at sootblower
  - Boiler and penthouse casing leaks
  - Damaged expansion joints in gas ducting upstream of the O_2 probes



"Probes don't distinguish where O_2 is coming from"

NOx Tuning - Tangential Firing System

- **Lessons Learned from NOx Tuning (continued)**

7. Change 1-test variable at a time
   - Otherwise it will be difficult to characterize the tested variables
8. Make small changes to the set-points and be patient
   - Allow sufficient time for unit to settle out
9. Maintain a log of set-point changes and resultant operations
   - Otherwise by days end you'll never remember all the details

NOx Tuning - Tangential Firing System

- **Lessons Learned from NOx Tuning (continued)**

10. During the tuning, make inspections to ensure dampers on the main and SOFA windboxes continue to be functional
    - A single in-operative damper will affect results
11. Make inspections of the furnace conditions
    - Monitor ignition points at the coal nozzle tips
    - Cleanliness of waterwalls affects NOx generated in furnace
    - Color/appearance can give clues as to areas of CO
12. Always verify operating conditions are repeatability with the re-adjusted tuning parameters

Questions

www.alstom.com/power

POWER | ALSTOM