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Boiler Design Considerations for Cycling Operations

by

P. J. Hunt
Manager, Boiler Design Engineering
RILEY POWER INC.
a Babcock Power Inc. company
(formerly Riley Stoker Corporation)

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BOILER DESIGN CONSIDERATIONS FOR CYCLING UNITS

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P. J. HUNT, Manager
Boiler Design Engineering

RILEY STOKER CORPORATION
WORCESTER, MASSACHUSETTS

INTRODUCTION

New boiler specifications are demanding much greater flexibility in unit designs than has been required in years past. It has become common for nuclear installations and large fossil fired boilers (above 700 MW) to be base loaded and smaller fossil fired units to take demand swings and surges. This generally means that most units below 700 MW bid today are specified for cycling service.

At this point, some clarification should be made on definitions. Quite often, cycling and peaking units have been used interchangeably; however, in fact, their designs and their operating characteristics are much different.

Peaking units are essentially base loaded boilers which have been designed conservatively enough that changes from normal steam cycle conditions to maximize generator output at the expense of higher cycle heat rates can be achieved. Typically this type of "peak" output would occur for short durations during the day probably only Monday through Friday. The cycle conditions most often altered to the boiler would be

- Higher steam flow
- Higher steam pressure
- Lower feedwater temperature

On the other hand, cycling boilers are very distinctive in their design in that the rigorous demands placed on their operating characteristics, via daily shut downs and startups and rapid load responses, make their overall design extremely complex and should include a great deal of conservatism.

Cycling boilers are generally always designed for variable pressure operation throughout the load range. By operating at variable or reduced pressure at lower boiler loads, the turbine governor valves can be left open longer and not be throttled, thus maintaining high steam temperatures to the HP turbine chest over the load range. Superheat and reheat steam temperature will also be maximized from the boiler at lower operating pressures and loads. Figure 1 shows the effect on superheat and reheat when comparing variable pressure operation on a cycling unit with typical constant pressure control of a non-cycling designed boiler.

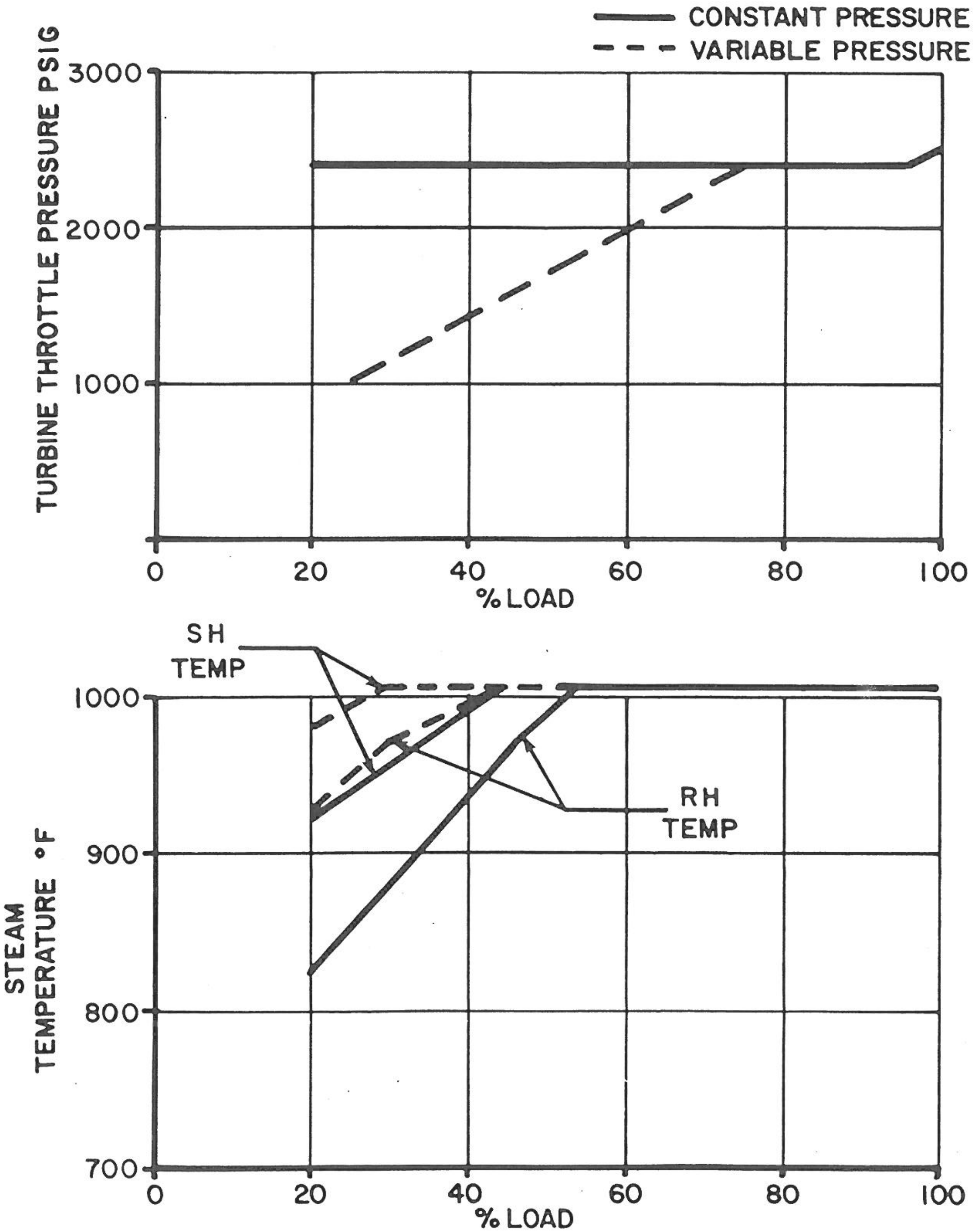

Figure 1 Effect of Variable Pressure Operation on Steam Temperature

A boiler-turbine relationship is one of slave to master. The turbine or system master is a lower tolerance, higher degree of design sophistication than is the boiler. The key to a sound cycling boiler-turbine system design is to minimize large temperature differences within the components and thus keep cyclic stresses to as low a value as possible. Large temperature differences are prevented from occurring in the turbine through

- Special boiler design parameters and considerations that allow fast load and temperature response.
- External piping valves and control systems which provide smooth temperature matching of incoming steam and turbine components.
- Strict boiler operational criteria which, using sound and extensive monitoring instrumentation, protect both boiler and turbine from exceeding their design limitations.

This paper will now discuss specifics of these three areas of key consideration in cycling boiler design.

BOILER DESIGN CONSIDERATIONS

Operational Definition

The essential requirement to the boiler design is a thorough understanding of the specific cycling duty of the system. The thermal and mechanical design of any practical boiler design is possible when a clear and concise definition of the operational characteristics is known.

Riley Stoker approaches this criteria by generating "histograms" which are temperature and pressure cycle descriptions of all key boiler components. Four major components of the structure for which this is performed are:

- the drum
- superheater outlet header
- reheater outlet header
- feedwater nozzles

Figure 2 shows a typical histogram of a steam drum developed for one of Riley's recent cycling boiler contracts. As can be seen on this diagram, all cyclic stress related criteria are identified on a pressure temperature scale with the number of cycles expected for each over the life of the boiler.

The key to the overall sound stress analysis evaluation of the boiler pressure parts is a thorough, complete and representative histogram of the particular pressure part component.

Superheater Design

The most rapid startup designed cycling boilers utilize all drainable superheater surface. The drainable circuitry allows for draining of condensed water within the elements after shutdown. Some cycling boilers do have non-drainable superheater elements, but much care must be taken during unit starts that all condensate has been boiled from the tubes to prevent flow blockage when unit firing rate and load are ramped. Figures 3, 4, and 5 show recent Riley contracts for cycling service.

Figure 3 is Wisconsin Electric Power, Units #1 and #2 at Pleasant Prairie Station. The units are coal-fired and employ all drainable superheater surface.

Figure 4 is Dairyland Power Unit #6 at Alma, Wisconsin. It, too, is coal-fired, but non-drainable superheater surface was selected.

Figure 5 is a gas and oil fired cycling design for the National Electricity Board of the States of Malaya, Port Klang Power Station, Units #1 and #2. Drainable superheater surface was used for this design.

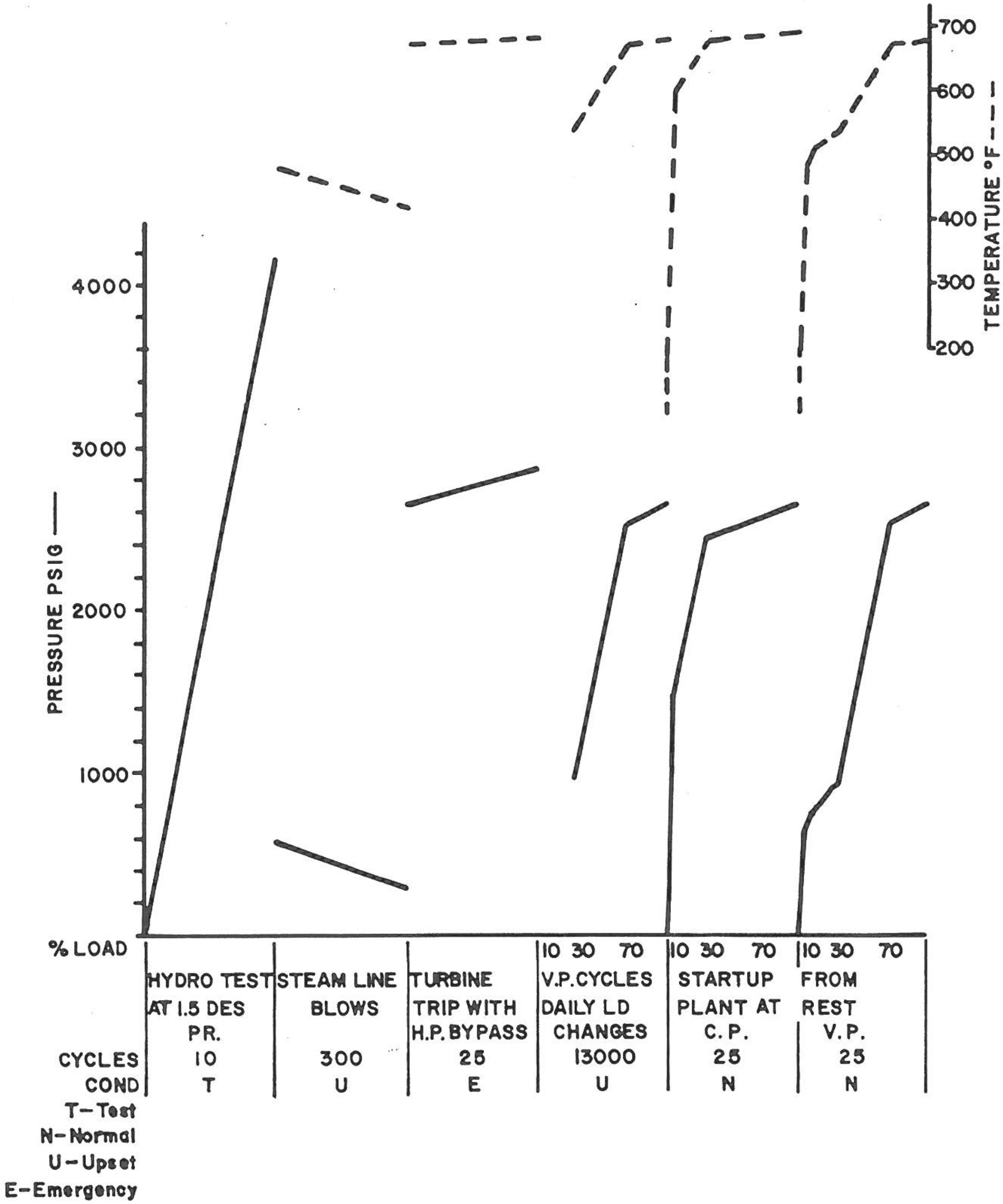

Figure 2 Drum Histogram

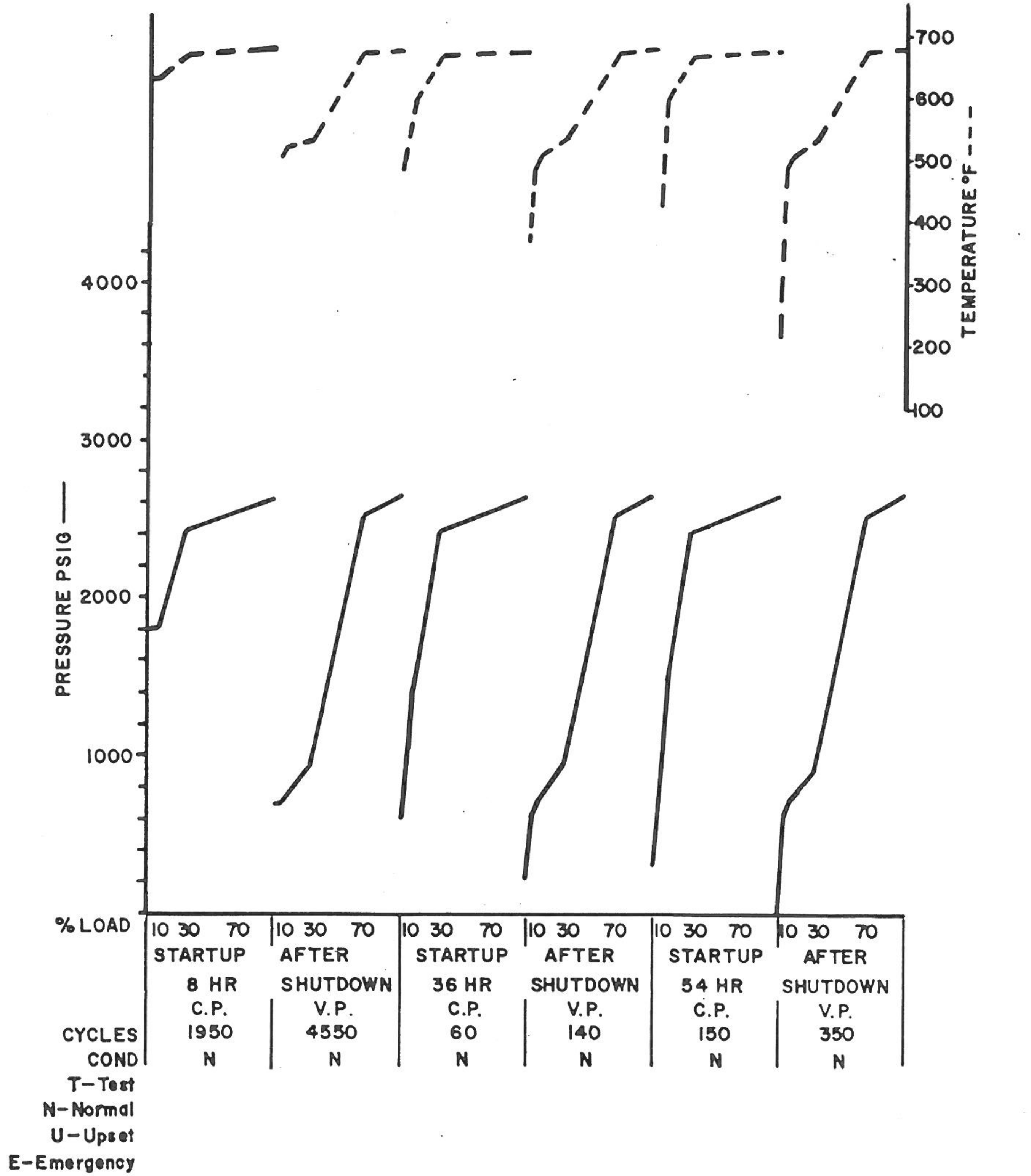

Figure 2 Drum Histogram (continued)

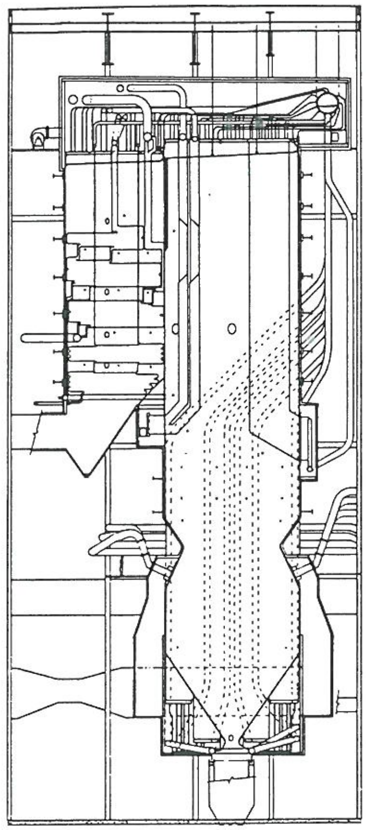

Figure 3   Wisconsin Electric Cross-section

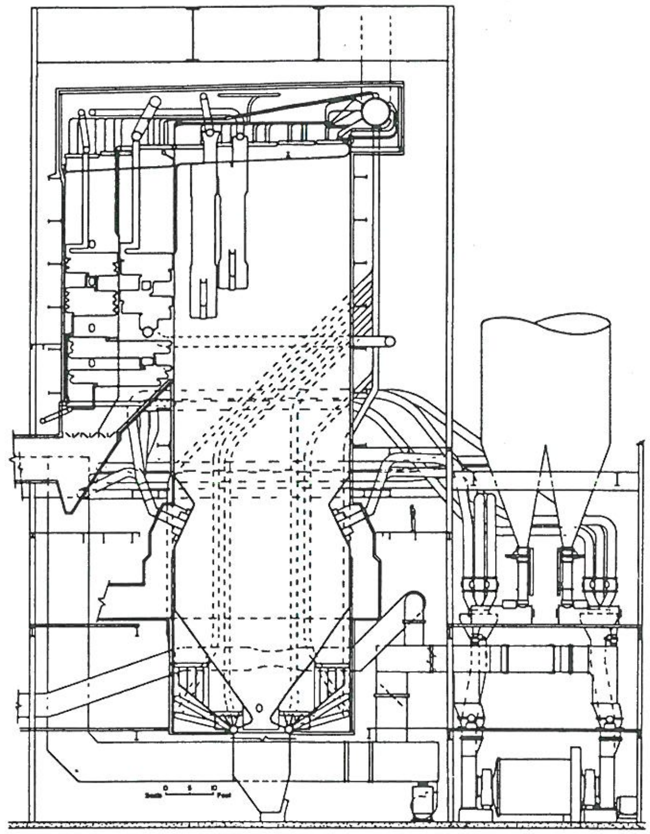

Figure 4   Dairyland Power Cross-section

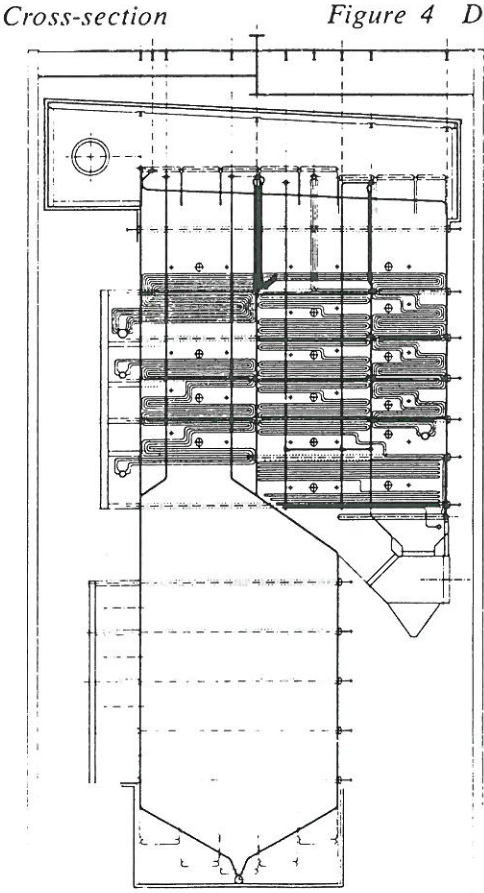

Figure 5   Port Klang Cross-section

Steam Mass Flows

Cycling unit designs generally use 15-20% higher steam velocities, with associated higher pressure drops, in superheaters and reheaters than conventional base loaded units. The higher velocities help to ensure greater metal cooling and the greater pressure drop provides positive tube-to-tube flow distribution particularly at low loads and during rapid ramping.

Metal Selection

Metal selection techniques for cycling boilers are much more complex than in base loaded boiler designs. For base loaded units, control point and maximum continuous ratings under steady state conditions govern the material selection (type and thickness).

Cycling boilers must be scrutinized under load and pressure ramping modes, using transient mathematical computerized techniques that calculate tube metal temperatures under overfiring conditions necessary in a ramp where saturation temperatures may vary up to 400°F/hour over a short time span.

This lengthy and elaborate calculation and modeling technique will pinpoint material requirements for all pressure part circuitry to meet the particular cycling demands of a given customer.

Drum Design

In general, boilers that are designed for cycling service will have larger steam drums than base loaded units. This allows larger volumes of water storage in the drum which helps to minimize level change impact under rapid downward load and pressure ramping.

Another important feature of drum design is maintaining low temperature differentials between the top and bottom of the drum which serves to minimize cyclic stress.

Where pressure and load ramping introduces saturation temperature change rates above 200°F/hr., a drum internal baffle arrangement is adapted as shown in Figure 6. Unlike more conventional boiler drum

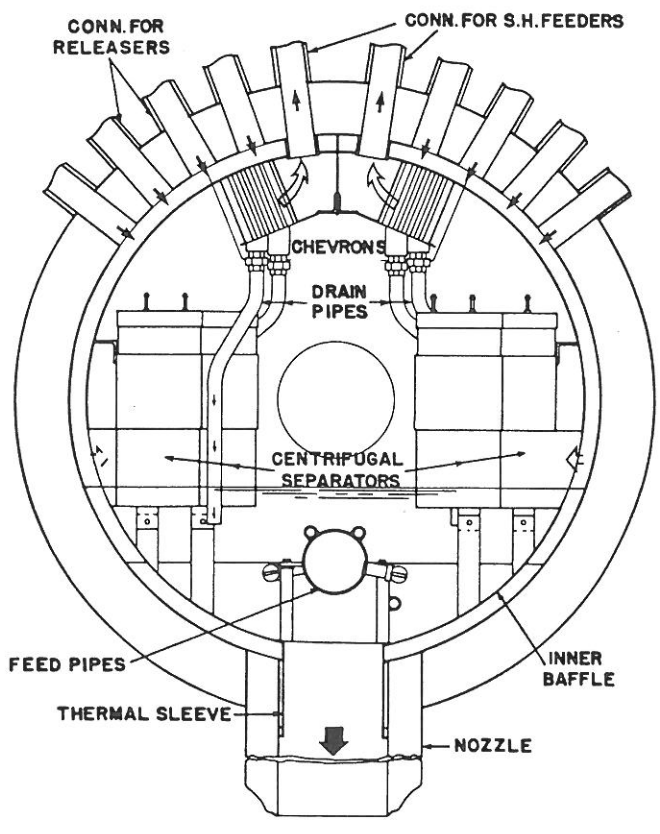

Figure 6 Inner Baffle Drum Design

designs where releasers enter the steam drum along the lower half of the drum, the internal baffle arrangement introduces the steam emulsion near the drum top forcing it to flow downwards along the drum periphery to the steam separator inlet. By forcing the steam emulsion along the entire inside circumference of the drum, near equal film coefficients are maintained top to bottom, minimizing metal temperature differences.

This design drum is being used on our Port Klang contract.

Spray Systems

Superheater and reheater spray systems on cycling boilers have double the quantity capability of non-cycling boiler designs. This greater spray margin gives more control flexibility for limiting boiler tube metal temperatures and even provides better turbine temperature matching capability under startup or ramping conditions.

Superheater and reheater spray systems also are provided with multivalve control capability so that under circumstances of flow or firing forced imbalances on the steam side, the spray system will selectively overspray the high side temperature condition balancing final pipe and header temperatures.

Mechanical Flexibility

The arduous cycling duty of the boiler demands a rigorous review of all areas of the design subjected to differential expansion. The following are particularly sensitive areas of flexibility design review:

- Economizer, superheater and reheater penetrations through water wall surface
- Superheater and reheater header location and feed tubing circuitry between the last penetration point and the header
- Windbox, penthouse, ductwork attachments and overall casing design

EXTERNAL SYSTEM DESIGN CONSIDERATIONS

Economizer Protection

During startups, the feedwater system is closed during warming and early pressure rising. Under these circumstances, it is common for stagnant feedwater in the economizer to begin steaming and to cause disruptions when releasing into the drum reservoir. Metal temperatures also become high in the economizer tubes, and when cold feedwater is again introduced to the economizer, thermal shocking of the tubes occurs.

Two methods of eliminating this phenomena are recommended with cycling units:

1. A small by-pass around the main feed control system to trickle feed feedwater to the economizer and maintain circulation, and
2. A recirculation connection from a main downcomer to the economizer inlet. This allows the downcomer static head to force circulation through the economizer tubing.

Blowdown System

During rapid startups, the drum water volume increases rapidly during pressure ramps and firing. Control of drum swell is critical to maintain a smooth and rapid startup. A Control Room-activated blowdown system from several downcomers along the length of the drum is recommended on cycling units to help relieve and control large drum water level swells.

Superheater By-pass

A startup system employed on some cycling boilers is the superheater by-pass as shown schematically in

Figure 7. This by-pass system dumps part of the main steam flow directly to the condenser while allowing the remainder to pass through the entire superheater exiting at a higher temperature than would occur if total flow had passed through the superheater. This then allows quicker final steam-to-turbine temperature matching than is experienced on a more conventional boiler without this system.

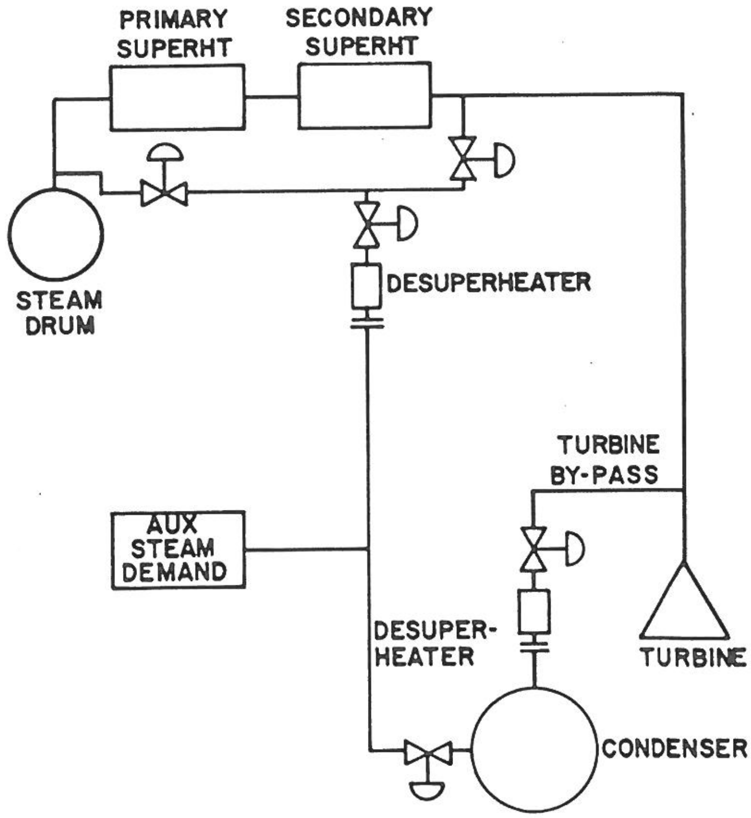

Figure 7 Superheater and Turbine By-pass

Variable Pressure with Pressure Reducing Valves

An uncommon method of operating at variable pressure at the turbine but with full pressure on the boiler is shown schematically in Figure 8. This system reduces the cyclic stresses on the boiler drum developed under normal variable pressure operation, as the drum operates at a fairly constant pressure throughout the load range with the reduced pressure at the turbine being achieved with pressure reducing valves. Although benefitting the boiler and turbine with constant and variable pressure operating capabilities

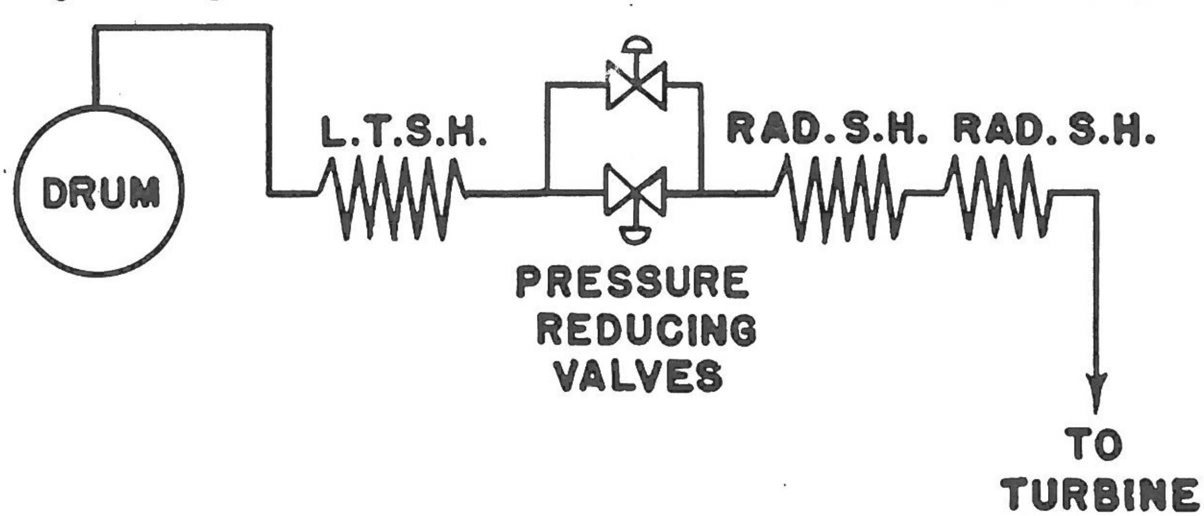

Figure 8 Variable Pressure Operation with Pressure Reducing Valving

respectively, this system does have the disadvantage of maintaining high boiler feed-pump power over the load range because of significant valve pressure drop.

Full Turbine By-pass

The full turbine by-pass system, often referred to as the European By-pass System, is a complex network of valving and circuitry which gives great flexibility to a cycling boiler/turbine system design. The full turbine by-pass system is shown in Figure 9.

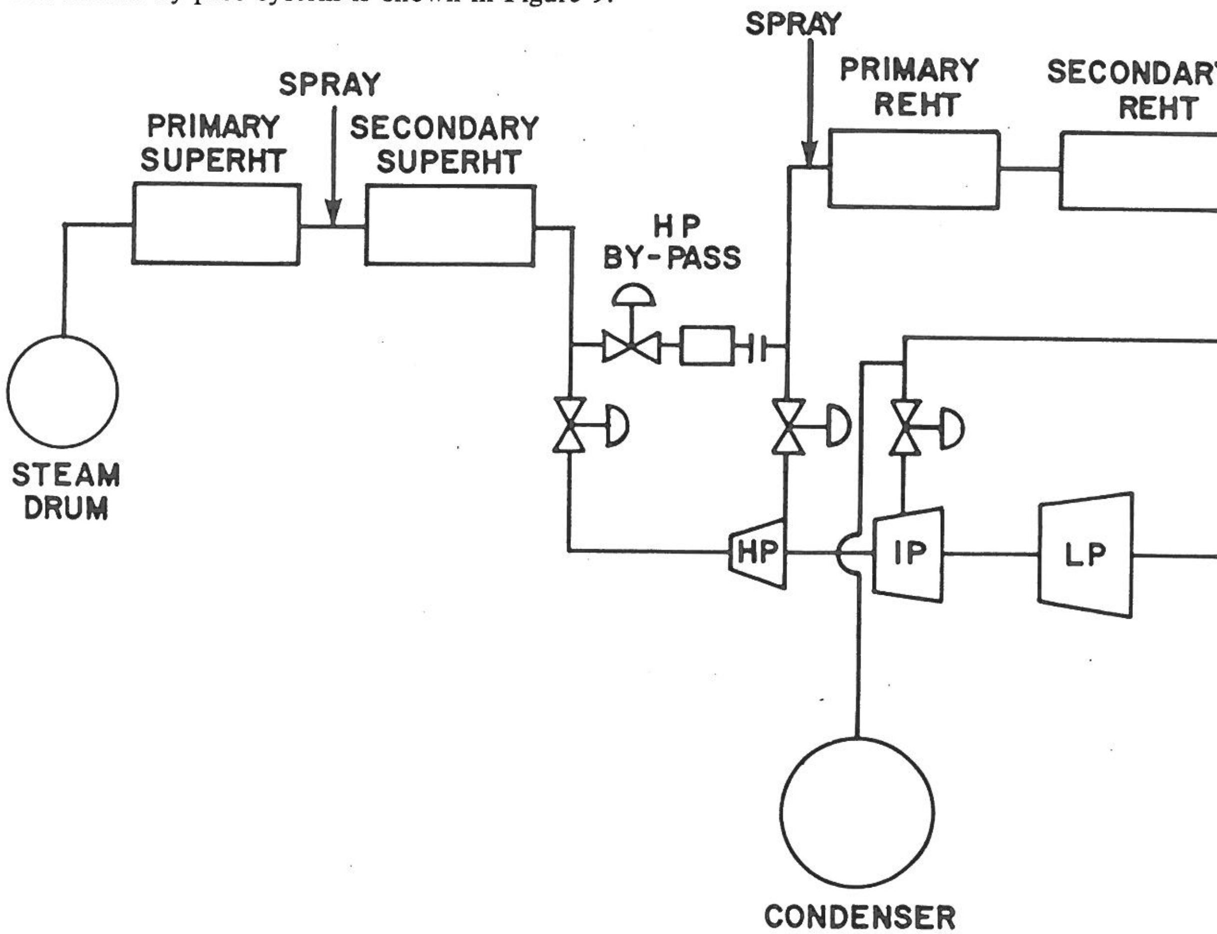

Figure 9 Full Turbine By-pass

This system has the unique capability of:

- Unlimited turbine temperature matching capabilities
- Positive reheater cooling protection at all loads
- Depending on the size of the system components, it allows the boiler to operate continuously from 60 to 100% of MCR after the turbine has been tripped.

A full turbine by-pass sized at 60% of MCR has been designed for the Port Klang unit.

OPERATIONAL DESIGN CONSIDERATIONS

Pressure Raising Rate

When ramping pressure of a cycling designed boiler, the rate of saturation temperature change allowed should not exceed the design criteria. Depending upon the contract, this value may vary between 200 and 400°F/hr. Figure 10 shows a typical coal fired boiler cold startup curve with a 200°F/hr. rate of saturation temperature change.

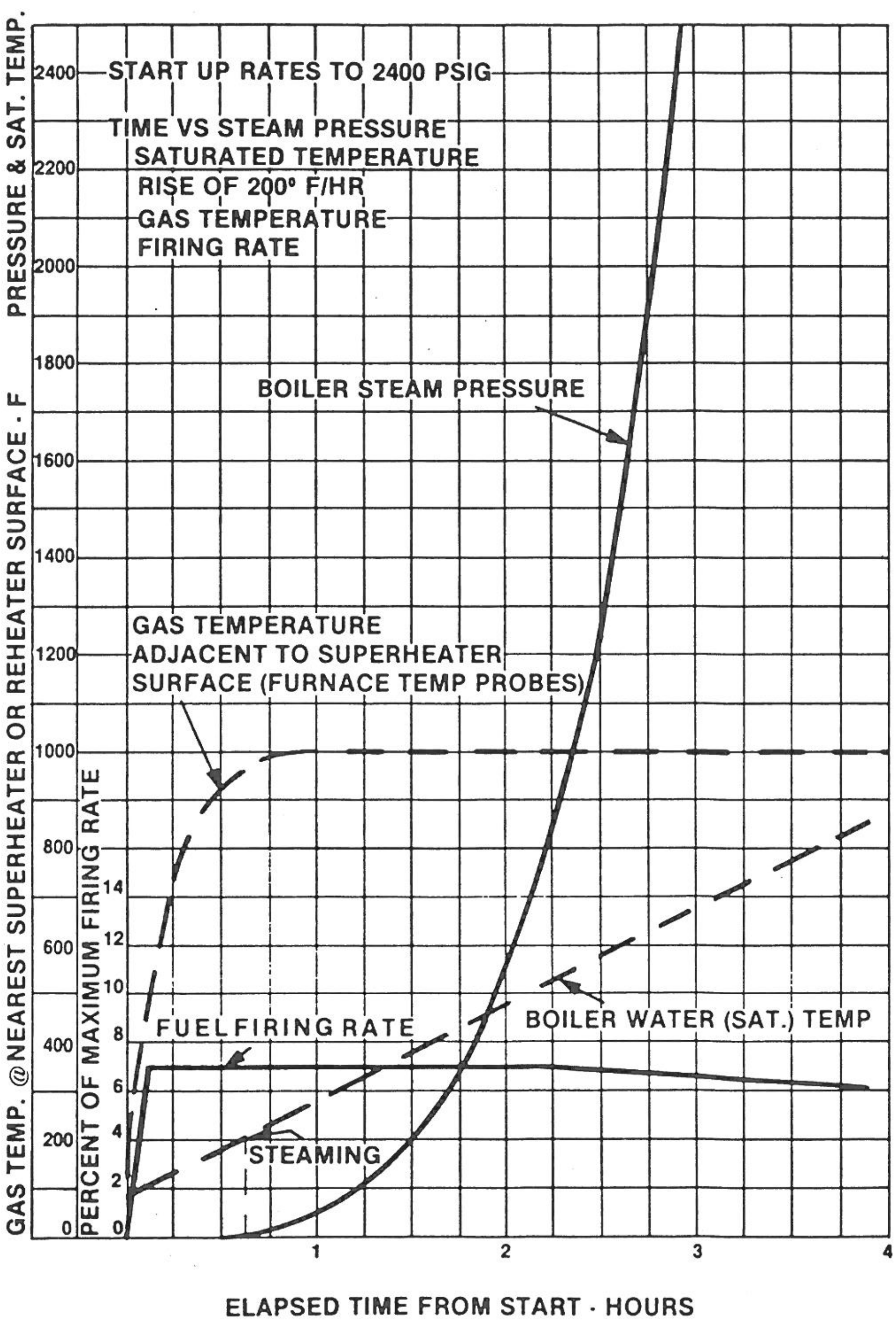

Figure 10 Cold Startup

Drum Temperature Differentials

On pressure and load ramping circumstances, top and bottom drum differentials are monitored. These values must not exceed 150°F when heating and 100°F when cooling during unit operation.

Firing Rate – Furnace Gas Temperatures

Furnace gas temperature measuring probes must be furnished and utilized on all unit startups. Until adequate superheater and reheater tube cooling is achieved, the gas temperature entering the first section of superheater surface must not exceed 1000°F.

Tube/Header Metal Limits

Tube and header temperatures for all pressure part sections must be monitored in the control room. During any cycling operation, tube and header temperature limits must not be violated, as significant reduction in metal life can occur or, in some cases, if the incident is severe enough, actual tube failures may result.

Load Ramping

Allowable load ramping criteria is set by the design of the particular contract. Typically, coal fired cycling units such as Wisconsin Electric Power are designed for 5%/minute at constant pressure, and 3%/minute under variable pressure. Whatever design ramping rate is specified for a given contract, boiler operators should strive to be at or below that rate during all cycling service.

Drum Level Control

Drum level is extremely sensitive during rapid load and pressure ramps. It is important, however, to restrict the ramping in such a manner to maintain water level fluctuations in the drum to ± 3 inches.

SUMMARY

This paper has addressed three important boiler design related considerations for the design of modern cycling boilers. Those considerations are unique to the boiler itself, external to it and the means it's ultimately operated under.

Modern boiler contracts will all be capable of great flexibility of operation. External proven systems such as the full turbine by-pass will enhance boiler flexibility even more.

From a boiler designer's standpoint, great flexibility can be designed too, but it's of utmost importance to define realistic boiler operating life patterns, as the basis for the design.

And, finally, once the boiler design criteria have been established, it's up to operations to perform within the limitations of the design.