

## Summary of Boiler Series Talk given by Dick Thomas

### Introduction

The topic of Dick's talk given on August 9<sup>th</sup> was smokeboxes. He started by explaining that the function of the front-end system or smokebox is to create a draft so that the products of combustion are drawn through the flues and firetubes, discharged into the atmosphere, and fresh air drawn in under the grate. The vacuum induced is maximum (about 20 inches of water) at the blast pipe and diminishes in the smokebox, the flues and firetubes, the firebox, and the ash pan. Even though the vacuum is only about ½ inch of water at the ashpan it's sufficient to produce the high combustion rate required.

Using a cross sectional view of the smokebox, Dick listed the major components contained therein as:

1. Exhaust connections from the cylinder
2. Exhaust stand pipe
3. Exhaust nozzle
4. Stack.

The first two items are necessary, but the nozzle and stack are the really important components. They make up what is generically known as a steam jet pump or ejector. These devices are not only found in locomotive front ends, but also in vacuum brake systems, process evaporators in sugar mills, conveying systems, and the like. The steam feedwater injector is a first cousin to the steam ejector.

Of course, there are other items in the smokebox such as front-end throttles, superheater elements, and spark arresting screens, but Dick did not cover them in this talk.

Dick then described the four components as follows:

1. There are two schools of thought on how to connect the exhaust pipes from the cylinders to the blast pipe. One group feels it's important to direct the exhaust upward via a curved elbow into the blast pipe to prevent the exhaust from going directly across to the other cylinder. The second group feels there is no noticeable difference in performance between the two arrangements so go with the simple tee since it's easy to make. Sometimes a small concession is made for separation by putting a simple baffle in the center of the tee.
2. The exhaust stand provides the path for the exhaust steam from the cylinders to the nozzle. Since some experimenting with nozzle shapes will necessary, the nozzle connection should be made for easy replacement.
3. The two important parameters of the nozzle are its diameter and the shape of the bore.
4. The stack (or technically the venturi) is another component that evokes a spirited discussion. Should the bore be straight or tapered? Should the bottom be a straight bore, conical, or curved out like a trumpet bell. Important dimensions of the stack include length, choke diameter, shape of bore (tapered or not) and distance above the nozzle.

Dick pointed out that early engine designers tried a variety of schemes from double venturi tubes (petticoat pipes) to adjustable nozzles in an attempt to get the maximum steaming performance. However, in the end, fixed components of a single nozzle and venturi prevailed. There was some investigation of multi-ported nozzles and even there, the simpler designs were better.

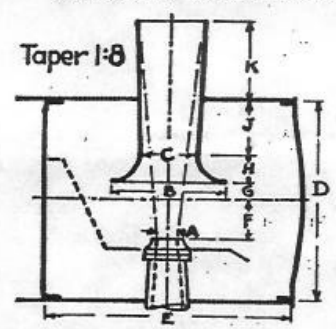
Wide ranges of opinions and empirical design formulae have appeared in the model engineering press regarding how to design a front end. Most are based on some aspects of full size practice. For example, in the USA the Association of American Railroads, The Pennsylvania Railroad, and Purdue University worked together to produce in 1902 what became known as the Master Mechanic's Front end. In the UK a good reference is E. S. Cox's *British Railways Standard Steam Locomotives*.

The determination of answers to the above problems or questions depends on the interest and inclination of the builder. If you are comfortable with technical reading, number crunching, and experimental analysis then have a crack at designing your own front end. Otherwise, stick to published designs, but if you do and problems arise, you may have to do some adjusting of the smokebox components.

Published Relationships

Dick showed several outline drawings of smokeboxes to illustrate the many different schemes that are available to the builder. He focused on the Master Mechanic's version shown below.

**MASTER MECHANICS' FRONT END - 1902**



1. Make K and F as large as possible.
2.  $C = 0.21D + 0.16F$ .
3.  $B = 2C$  or  $= 0.5D$ .
4.  $J + H = 0.32D$ .
5.  $H = 0.22D$ .
6.  $G = 0.18D$ .

From Loco.Cyc.-1925

	B	C	F	G
High	.47D	.29D	.25D	.15D
Low	.36D	.23D	.12D	.07D
Avg.	.42D	.25D	.16D	.09D

From Other Sources:

7.  $A(\text{diam}) = 0.25 \text{ cyl. diam.}$
8.  $A(\text{area}) = \frac{\text{Grate Area}}{200}$   
both in square inches.
9.  $F + G = C$ , about.
10.  $F + G = \frac{1}{4} \pm 1/8 D$

The design procedure using the Master Mechanic's Front End will be explained via proposed layout for a 1 1/2" Mikado.

Start with the known or given information. In this case:  $D = 8$ ,  $K = 3.5$ .

Grate Area = 67.5 square inches, Flue Area = 7.4 square inches.

Calculations:  $F = .16D = .16 \times 8 = 1.3$   
 $C = .21D + .16F = .21 \times 8 + .16 \times 1.3 = 1.9$   
 $B = .5D = 2C = 2 \times 1.9 = 3.8$   
 $J + H = .32D = .32 \times 8 = 2.6$   
 $H = .22D = .22 \times 8 = 1.6$   
 $G = .18D = .18 \times 8 = 1.4$   
 $A_1 = .25$  of the Cylinder Diameter  
 $A_1 = .25 \times 2.25 = .56$   
 $A_2 = 1/200^{\text{th}}$  of the Grate Area  
 $A_2 = 67.5/200 = .34$  (seems low)

From other sources:

$C = .25$  of Flue Area =  $.25 \times 7.4 = 1.9$  (right on, but maybe a coincidence!)  
 $C = .24$  times the square root of the Grate Area =  $.24 \times 8.21 = 2.0$  (pretty good)  
 $A = .25C = .25 \times 1.9 = .48$  (Pretty good)  
 $F + G = 2.3C = 2.3 \times 1.9 = 4.4$  (F+G from above is 2.7. Way off.)  
 $B = 1.9C = 1.9 \times 1.9 = 3.6$  (Pretty good)

This is a very approximate method as can be seen by variation in results. While there is agreement among some parameters, others are inconsistent. Clearly, some experimentation will be in order. For example, although two different sources give the nozzle bore to be about .50, maybe the .34 value will work better. If nothing else at least doing the arithmetic will give the builder the range of values that the construction should accommodate.

Slap some paper on your drawing board (or turn your CAD system) and layout the above smokebox assuming steam issues from the nozzle at an included angle of 16°. Would you cut metal to that layout?

#### Alignment Procedure

Dick recommended the construction of an alignment rod made to fit in the nozzle bore and extending upward into the stack. Two disks are fitted tightly into the stack bore and drilled for the alignment rod. When all pieces are coaxial the rod should slide easily. Based on full size practice, which required accuracy to 1/16, model practice requires accuracy to about .007.

#### Conclusion

Dick concluded his talk with the customary question-answer period and mentioned that the talk was part one of a two-part presentation. Dick's second talk will cover the experimental phase of constructing a smokebox. Many thanks to Dick for his well illustrated and informative presentation.

## Summary of Boiler Series talk given by John Lisherness

### Steel Boiler Construction

#### 1. Materials

Boiler shell is conveniently made from standard wall steel pipe (A106 or A53). A local supplier is Pacific Pipe in Oakland. Special sizes are available in 1020 hotroll tube with 3/8 wall, but it's very expensive.

Use A285 or A36 hot roll for steel plate and hot roll 1020 steel bar. Minimum thickness is 1/4 inch, but use 5/16 if using threaded stay bolts. For larger boilers, use 3/8 thick plate for flue sheets. Local supplier for plate steel is Ryerson Steel in Emeryville.

#### 1. Design Overview:

Boiler outline should follow general size and shape of prototype. Simplify where possible. Avoid using combustion chamber, siphons, etc.

A boiler with conical courses can be made by splitting the pipe lengthwise, tapering with a heavy press brake, then trimming and re-welding. All that can be avoided by making a straight barrel and adding rings to support lagging. The smokebox is easily made by using the same pipe as used for the shell. The boiler and smokebox can then be joined with an inner ring.

Water legs should be on the wide side for best circulation and ease of cleaning. The mud ring can be made from 5/8 half-round hot roll steel which makes preparation for welding much easier. Use washout plugs at all 4 corners of mudring to facilitate boiler washing.

Three are main types of staybolts. The first is threaded at each end. After installation the ends are peened over or welded. The second type is pipe threaded on inside and welded on the outside. It's useful where inside access is limited. The third type of stay bolt is welded on both sides. To prepare the inside of the firebox for welding, use a back countersink. One advantage of the threaded stay bolt is its ability to hold the inner and outer wrapper sheets in alignment.

Crown girders easier to use than staybolts. With girder stays, the downward force on the crown sheet is transferred to the mudring. A curved top crown sheet is stronger than a flat top and less likely to be damaged should the water level fall.

Don't forget to make the firebox door big enough to be able to roll the back end of the fire tubes and install grates, etc. It's recommended that copper fire tubes be used and rolled into the flue sheets.

Layout tube holes with enough clearance to be able to use a tube rolling tool inside the firebox.

Hollow through stays useful for passing small pipes through the boiler. Use schedule 80 pipe.

Openings for water inlets and water glass, etc. can be 1/8" pipe thread tapped directly into the outer shell as needed provided the plate is at least 5/16" thick. For larger fittings or thinner plates, use a bushing or half coupling welded in.

Decide on the type of throttle to be used and make provisions in the boiler accordingly. Throttles inside boiler don't get overheated, but are hard to service. On the other hand, smokebox throttles are accessible, but must be able to withstand the heat and grime.

Finally, the boiler design should take into account that distortion and shrinkage from welding will occur.

## 2. Fabrication Methods:

Boiler pieces can be cut out with oxyacetylene, plasma, or saw. What follows next is a lot of very dirty work grinding to clean up edges and beveling in preparation for welding. Proper weld preparation is essential. Use a needle scaler to remove all trace of flux.

Welding methods include TIG for tacking pieces together and for stay bolts, and stick welding for the remainder of the joints. MIG welding with the newer, flux cored wires might be worth examining for boiler work.

Electrodes for boiler welding include E6010 for groove butt and fillet welds in all positions with excellent penetration, E6012 for instances of poor fit up, and E7018 for a highly restrained joint. For serious boiler work a good direct current power supply with a current rating of at least 300 amps is necessary. Don't try to fool around with small AC home maintenance welders. If you are determined to weld a boiler yourself, sign up for a welding class (or several) at your community college. Read every article on welding miniature boilers that have appeared recently in the hobby magazines. Get some good textbooks and learn about welding by reading and doing. If you feel uneasy about the actual welding, prepare the pieces and have a professional do the welding.

Most important, pay attention to safety warning regarding welding hazards. Don't risk injury.

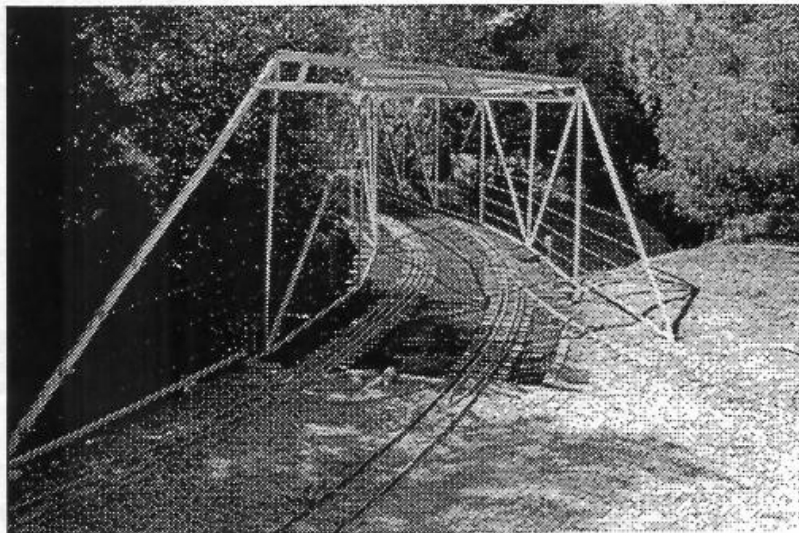
Arrange the weld sequence so the backside of joints can be welded. Welds that have to be made only from one side need a different preparation to ensure full penetration. If for some reason, you can't be certain of making a full penetration weld, consider giving the welding job to a professional.

First, fit and weld front flue sheet into barrel. Then machine for the smokebox connection. Next, layout and cut for dome, firebox and drill for drypipes. Install drypipes and dome. Weld throat sheet and firebox outer plates.

The firebox inner wrapper could be built up from pieces with a lot of welding, but it's preferable to have an iron shop bend it up to fit a template. Wide fireboxes can be done in one piece. Remember to bring extra pieces for practice bends. Narrow fireboxes can be bent from one piece twice as long as needed then cut and welded down center top.

Assemble firebox separately including girders. On wide firebox boilers the backhead can now be installed and the firebox slipped in the bottom. Remember to attach the mudrings first. Narrow fireboxes must be installed from rear followed by the backhead and door ring. Staybolt holes can be drilled through once the location of the firebox is set. Remove chips. After the staybolts are welded, the firetubes can be installed.

Thanks to John for preparing a very informative talk. His wide technical experience, particularly welding boilers, was evident in his explanations and illustrations regarding boiler design and construction.



The bridge with completed superstructure.