Tube Vibration Considerations for Maintenance Retubings

The retubing of a power plant steam surface condenser is often the result of old age – the tube material simply deteriorates over time. If the length of time is sufficiently long, the tube material selected as the replacement material will usually be the same as the original material. Unfortunately, not all retubings are the result of "old age" but rather are the result of a change in the tube environment that caused the original material to fail prematurely. For example, if the original circulating water pumps were replaced with larger pumps that increased the water velocity through the tubes, erosion-corrosion of the original tubes might result if the original tube material was not highly resistant to erosion-corrosion. Other examples of changes in the tube environment include a change in the quality of the cooling water that resulted in pitting of the condenser tubes, a change in the quality of the cooling water that resulted in excessive biofouling and attendant heat transfer degradation, or a change in the boiler feedwater treatment that resulted in excessive concentrations of ammonia that led to condensate grooving of the condenser tubes. In these situations, a different material is usually selected for the replacement material. Candidate replacement materials need to be evaluated for their waterside corrosion resistance, steam side corrosion resistance, galvanic compatibility with other system components, and heat transfer capability.

An additional factor to be considered when retubing a condenser is the effect that the condenser tube wall thickness and modulus of elasticity have relative to the propensity for mid-span collision. High velocity steam from the turbine causes the condenser tubes to vibrate, and if the support plate spacing is too long, the condenser tubes will repeatedly collide with one another. If not detected and corrected, the result can be a wearing away of the tube material until a through-wall perforation results, as shown in figure 1.

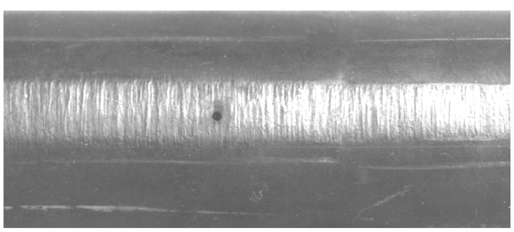

Figure 1 – Through-wall perforation resulting from mid-span collision.

Sebald & Nobles [(1)] research on the causes of tube vibration resulted in a model which related tube deflection to support plate spacing, and the tube material's modulus of elasticity and moment of inertia. Refinements to the Sebald & Nobles model by Impagliazzo and Bell [(2)] resulted in the following equation for calculating the maximum allowable tube span (L):

$$L = 2.25\ \{EI(P-D) / W_D\}^{1/4}$$

where:

- L = Maximum allowable tube span, inches
- E = Material Modulus of Elasticity, lbs/in^2
- I = Tube Cross Sectional Moment of Inertia, in^4
- P = Tube Pitch, inches
- D = Tube Diameter, inches
- W_D = Maximum load on any tube, lbs per lineal inch

In similar work, Coit, Peake, and Lohmeier [3] proposed the following equation for calculating the maximum allowable tube span (L_c):

$$L_c = 21.8 \{S_c E I \delta / \rho V^2 D\}^{1/4}$$

where: L_c = Maximum allowable tube span, inches
S_c = Severity Factor (conservative value = 1.7, 2.0 = acceptable)
ρ = Steam Density, lbs/ft^3
V = Average Steam Velocity @ Inlet, ft/sec
D = Tube Diameter, inches
δ = Logarithmic Decrement of Vibrating Tube
E = Material Modulus of Elasticity, lbs/in^2
I = Tube Cross Sectional Moment of Inertia, in^4

The tube material related factors in both equations are the tube material modulus of elasticity (E), the tube outside diameter (D), and the tube cross sectional moment of inertia (I).

In a retube situation, if the replacement material is going to be different from the original material, these equations can be used to evaluate if the replacement material will be susceptible to excessive tube vibration and possible mid-span collision. Regardless of which equation is selected for use, the variables that aren't related to the tubes are going to be the same for the original material and the replacement material. Thus, if vibration and mid-span collision have not been a problem with the original material, the minimum allowable wall thickness for a potential replacement material can be calculated by equating $(EI/D)^4$ of the original material with $(EI/D)^4$ for the potential replacement material.

This equation can be reduced to:

EI (original material) = EI (replacement material)

where: $I_{tube} = I_{OD} - I_{ID} = \pi(OD)^4/64 - \pi(ID)^4/64$

When calculating the moment for the tube ID, the theoretical minimum wall thickness of the material being replaced should be used. For example, if 18 BWG (0.049") average wall Admiralty Brass or Aluminum Brass tubing was being replaced, a wall thickness of 0.0445" would be used to calculate the minimum ID since ASTM B-111 and ASTM B-543 both specify a wall thickness tolerance of 0.0045".

The moduli of elasticity for several copper alloys are as shown below:

C443 (Admiralty Brass) = 16,000,000 psi.
C687 (Aluminum Brass) = 16,000,000 psi.
C194 (Iron Modified Copper) = 17,500,000 psi.
C706 (90/10 Copper-Nickel) = 18,000,000 psi.
C722 (85/15 Copper-Nickel) = 20,000,000 psi.
C715 (70/30 Copper-Nickel) = 22,000,000 psi.

Thus, if 1.000" OD x 18 BWG (0.049") average wall C443 Admiralty Brass or C687 Aluminum Brass was being replaced, these moduli of elasticity values could be used to calculate the following minimum wall thicknesses for each potential replacement material:

C194 = 0.0402"
C706 = 0.0389"
C722 = 0.0345"
C715 = 0.0311"

This information can also be derived graphically by plotting $(EI/D)^{1/4}$ versus wall thickness for a given diameter; the resultant curves are illustrated in figure 2.

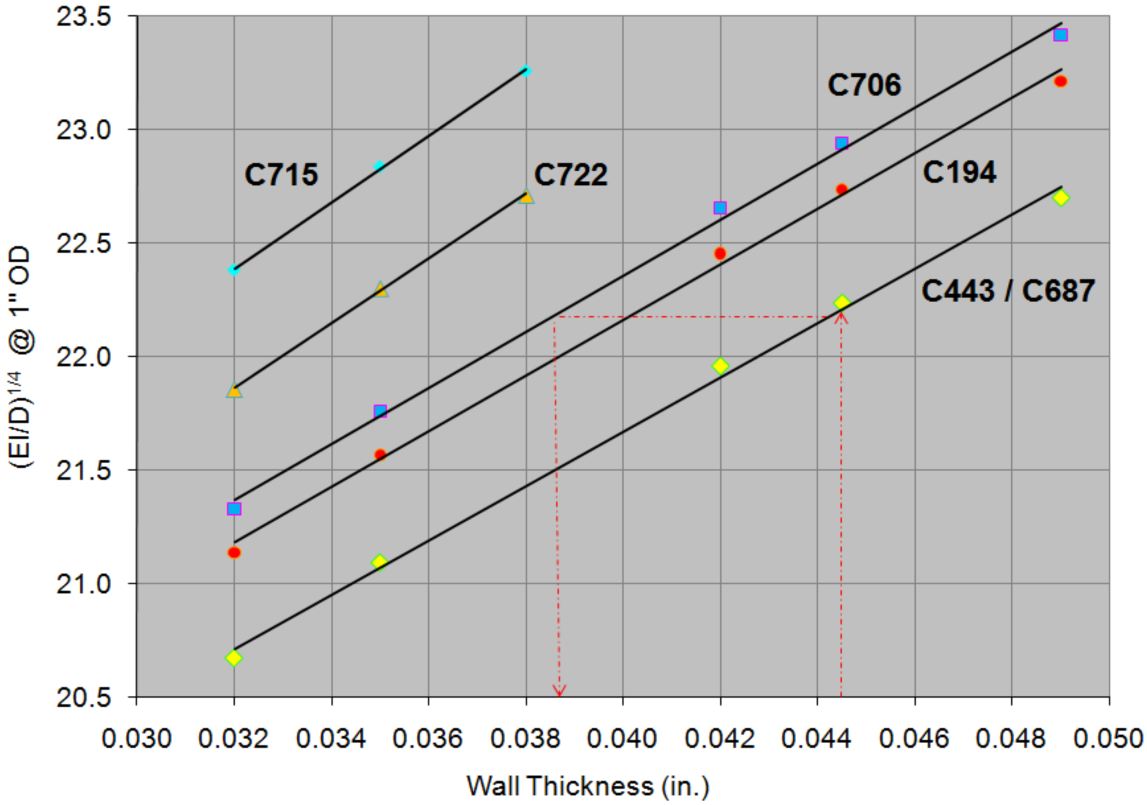

Figure 2 – $(EI/D)^{1/4}$ for 1.000" OD Tubes plotted vs. Wall Thickness.

The dashed red line in figure 2 illustrates how 18 BWG average wall C443 or C687 (0.0445 minimum wall) could be replaced with 20 BWG minimum wall (0.035" min) 90/10 Copper-Nickel without any concern for flow-induced vibration resulting in mid-span collision of the tubes.

Conclusion

Condenser tube materials rarely, if ever, fail from general corrosion; failures are almost always the result of localized selective attack. Further, localized corrosion such as pitting or erosion-corrosion generally occurs over a very short period of time relative to the life of the power plant and, in the wrong environment, failures will occur regardless of the tube wall thickness that is utilized. Thus, the use of wall thicknesses heavier than are necessary is a waste of money; the lightest wall thickness that satisfies the functional and corrosion resistance requirements for the specific application should be selected. This is especially true when a condenser is being retubed with a more corrosion resistant material than was originally installed. In a retubing situation, EI (the material modulus x the cross-sectional moment of inertia) for the replacement material should set equal to EI of the original material to determine the minimum wall thickness that should be specified for the replacement material.

Bibliography

1. *Control of Tube Vibration in Steam Surface Condensers;* Sebald & Nobles; Proceedings of the American Power Conference; Volume XXIV; 1962.
2. *Steam Surface Condenser Operating and Design Considerations*; Impagliazzo & Bell; Proceedings of the Joint ASME/IEEE/ASCE Power Generation Conference; 1978.
3. *Design and Manufacture of Large Surface Condensers – Problems and Solutions*; Coit, Peake, and Lohmeier; Proceedings of the American Power Conference; 1966.