

Lessons Learned With A Partial LPFWH Re-Sleeving - “5% Rule” Rate of Failure Criteria For Ameren Labadie Plant Unit 4, 5A Feedwater Heater

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Introduction

This paper references slide 12 of the slide presentation for explaining further the Ameren “5%-Rule” expected remaining service life criteria evaluation for the AmerenUE Labadie unit 4, 5A LP feedwater heater.

Abstract

A practical industry operating record criteria is proposed as a general guideline as to when to plan scheduling the re-sleeving of cuprous alloy tubed feedwater heaters, both high-pressure and low-pressure.

Benefits in Timing of a Re-Sleeving in Avoided \$-Losses

With longer time spans between major generating unit outages to plan a *re-bundling*, time-to-failure for a heat exchanger with advanced pluggage may not time well with those opportunities. So a predictive tube-failure rate model of remaining service life becomes invaluable; for instance, as to when to take a Spring mini-outage for interim measures such as a low-cost *re-sleeving* to avert larger losses. In the case of the Labadie 4-5A LPFWH, an avoided *additional* -16mw de-rate which otherwise may have occurred by Sept. 16, 2009. The 4-5A’s re-sleeving decision was enacted by March of 2009, and in-service by June of 2009. Sleeve delivery was about 8 weeks.

Ameren fully expects at least 2 years of extended life out of the 4-5A until the re-bundling outage by keeping the heater *valved-in and running* at 40% plugged vs. permanently valved-out of service by 9/16/09, which otherwise could have occurred hadn’t we re-sleeved (Fig.1).

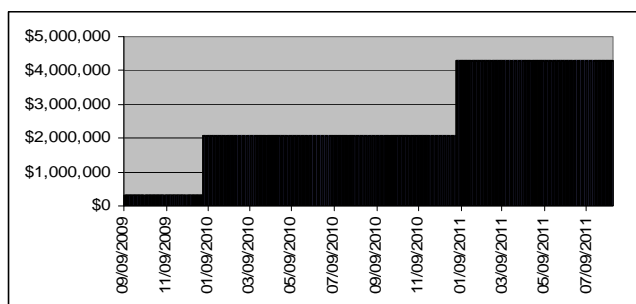


Fig. 1 - Cumulative Averted Dollar Losses, Sept. '09- Sept. '11, by Re-Sleeving the Ameren Labadie 4-5A LPFWH by June, 2009.

Background

Ameren fitted the % plugged vs. time, $y(t)$, tube failure characteristic of 38 year old 80-20 cu-ni tubed high pressure feedwater heaters in 1989 at their Meramec power plant to a higher-order form of the Gompertz eqn.¹, which closely approximates actual tube-pluggage severely spiking *near-vertical* with cuprous tubing toward the end of expected design life of the heater:

$$\% \text{ plugged}(t) = y(t) \sim a b^{c^{(e^{T[\ln(c)]})}} \quad (1)$$

... with $T = (t - t_{\text{int}})$ and t in years

The Meramec Plant unit 1&2 HP heaters were permanently valved-out of service in 1989 due to intolerably poor on-line reliability (exfoliation of 80-20 cu-ni tubing). Meramec Plant 1&2 ran with these HP heaters bypassed until their replacements in 1991. It is interesting to note (for the same 38 years of run-time) that the *Meramec* case did *not* quite reach the advanced (42%) plugged of the Labadie 4-5A, but the Meramec *rate* of failure nevertheless drove their valve-out’s in 1989.

It was observed, to a +90% coefficient of correlation, ‘R-Squared’ goodness of fit of (1)’s best-fit linear-regression line, that the Meramec out of service dates occurred *18 months after* the failure rate, $dy(t)/dt$, reached 5% / year, hence the ‘5% Rule’ predictive criteria of this paper. For this purpose, equation (1) can be linearized to:

$$\ln \left[\left\{ \frac{\ln(\ln(y - y_{\text{int}}) - \ln(a))}{\ln(B)} \right\} - 1 \right] = T[\ln(c)] + K \quad (2)$$

...with slope of best-fit regression line = $\ln(c)$
for the substitutions :

$$B = \ln(b), \quad C = [\ln(c) / \ln(B)], \quad \text{and} \quad K = \ln(C)$$

Procedure

The heater’s % tube pluggage v. time historical data for the heater is fit to (2), using Microsoft Excel ‘Tools/DataAnalysis/Regression’ ToolPack plug-in, or similar statistical analysis code.

Since tube pluggage data typically have one or more ‘stair-step’ disjuncts, typically early in a heater’s service life history (see Fig. 3), use only the *most recent, largest*

number of closest grouped datasets² for most accurate results. That is, avoid using *all* available datasets to fit a *discontinuous* trend with a single *continuous* function.

Results

Including the 6 most recent datasets (the most recent % plugged being 42.9% as-of **12/8/08**), a decision to re-sleeve 100% of the inlet pass tubes of the 4-5A heater was made based on the majority of tube failures suspected at or near the heater's (partial-length) drain cooler endplate. *Timing-wise*, to do so by June, 2009 was indicated, based on a **92.56%** linear regression line R-Squared, having the following a, b, c shape coefficients:

$$\% \text{ plugged} = 21.4 \left[1.27 \left\{ 1.4741 e^{(yr. - 2006.44)0.3880} \right\} \right] \quad (3)$$

... for $Y_{int} = -52$ and $T = (yr. - 2006.44)$

As would be expected for a heater running beyond expected design life, note that the 6 datasets of interest were over the fairly brief Δt : $2006.44 < yr. < 2008.939$.

Taking the $dy(t)/dt$ of (3) gives the rate of failure, and the heater reached 5%/year on **3/16/08**. The permanent out of service date corresponds to **9/16/09** (18 months later).

The re-sleeving option was the fastest-response we could exercise for the summer of '09 generating season (compared to the delivery time for a replacement 4-5A tube bundle – not to mention *much* less costly). For example, a replacement bundle was also ordered later in '09 as a contingency, but wasn't on-site until Dec. '09.

Discussion of Uncertainty (Stability Criterion)

As a sensitivity case, one would expect as more time goes by after the re-sleeving (without additional tube failures), that there would be a return of the higher R-Squared's, corresponding to a longer-term recurrence of the rate of failure reaching 5%/year again. Ameren (as-of this writing, 6/15/10) has indeed found this to be the case (Fig. 2).

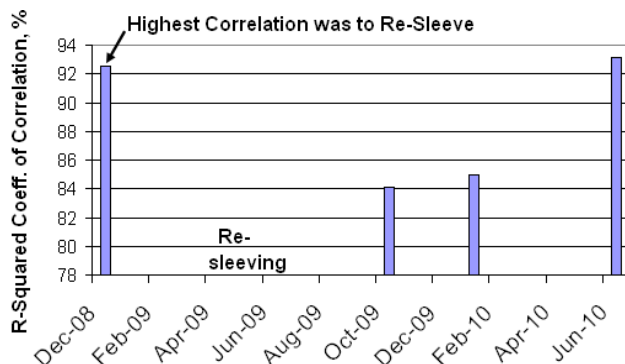


Fig. 2 - Current confidence interval is 93.13% since Re-sleeving. 5% / yr. rate returns on April 18, 2018 (new out of service 18 mos later, or **August 14, 2019**).

The corresponding 'remedial' $y(t)$ since the re-sleeving indicates the tube-failure pluggage trend has been effectively cropped (Fig. 3).

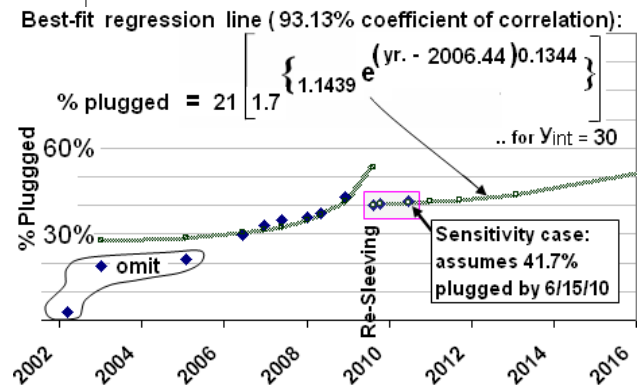


Fig. 3 - Corresponding piece-wise discontinuity in the pluggage trend, $y(t)$, since re-sleeving at year 2009.6, with Eqn. (3) valid for $yr. < 2009.6$. At the 9/16/11 start of re-bundling outage: projecting **42.17%** pluggage.

Conclusion

A practical statistical analysis criteria based on actual field experience from 1989 helped plan a well-timed feedwater heater re-sleeving at AmerenUE. Heater life can be extended beyond design life (perhaps *substantially* so), by addressing the most active root cause tube failure mechanism with a targeted, partial re-sleeving. The loss of \$4M was averted until the next major outage needed to re-bundle.

Delivery-time, field time and cost advantages of the re-sleeving option all are favorable within the context of these new demands of flexible response times, well-suited to changing conditions and deferred outage schedules.

References

- 1 Gompertz function – Wikipedia, the free encyclopedia
- 2 "Some Simpler Statistical Tests for Rejecting Outliers in Quantitative Data" mrsec.wisc.edu/.../research/topic_guides/outlier_handout.pdf

About the Author

Glenn Tiffin has 29 years project development experience in the electric utility business, with an emphasis in first-to-use strategic initiatives and technology transfer. His B.S. Mechanical Engineering is from Washington University, is P.E. licensed in Missouri and was a 1997 EPRI Innovators Award recipient.