Monte Carlo Simulation on Estimation of Contact Pressure at Tubular Exchanger

Abdulaziz S. Al-Aboodi

Abstract—The strength of tube-to-tubesheet joints is influenced by many factors such as method of attachment, details of construction, and material properties. The strength of tube-tubesheet joints is measured in terms of the force required to pull or push the tube out of the hole in which it was expanded or by the radial interfacial residual contact pressure. In this paper, Monte Carlo method was conducted to estimate the tube/tubesheet mean interfacial pressure and its standard deviation using experimental sample data Sampling repetition were conducting to estimate the mean and standard deviation. Finally, a linear relation between force and contact pressure were introduced with the coefficient of determination, R2 of 0.9895.

Index Terms—Monte Carlo, Simulation, Contact pressure, Tubular Exchanger.

I. INTRODUCTION

In the construction of heat exchangers, the holes in a tubesheet are drilled slightly larger than the outside diameter of the tubes in order to permit easy installation of the tubes. Methods of attaching the inserted tubes to the tubesheet consist of uniform expansion such as hydraulic and roller expansion, tube welding to the tubesheet, explosive expansion, or any combination of above procedures.

Most of the works were concentrating on theoretical, experimental, numerical analysis or mixing different approach. Grimison and Lee [1] gives in their paper a result of an experimental investigation to determine the fundamental involves in tube expanding, the various practical methods of measuring the degree of expansion, the optimum degree of expanding, and the ultimate strength of expanded joints under various conditions of service. Scot, et al. [2] did an experimental work to determine the stresses in hydraulically expansion tube. Jawad [3] studied the tube to tubesheet expansion experimentally with different methods of expansion and constrictions details. Sherburne, et al. [4] initiated a project to measure the residual stress distribution and cold work in a tube roll transition and in assorted rolled tube mockups, using X-ray diffraction techniques and finite element analysis. Shuaib, et al. [5] have been conducted an experimental study to evaluate the effect of roller expansion of heat exchanger tubes in enlarged tubesheet holes on joint strength, tube wall reduction, and strain hardening of the tubes and surrounding tubesheet ligaments. Stress-corrosion cracking SCC in tubular exchanger is one of the most problem that threads its regular operation. Thus, many researchers investigated of crack, pitting using probabilistic, and simulation techniques.

Lee et al [6] proposed a statistical assessment model for structural integrity of steam generator tubes with axial cracks at the top of the tubesheet using Monte Carlo method to estimate the number of real cracks from in-situ inspection data. Similarly, Gary [7] proposed a probabilistic -mechanistic approach focused on modeling Stress-corrosion cracking SCC propagation in tubes with uncertainty using an empirical model and a simulation process. Steam generators in nuclear power plants experienced varying degrees of under-deposit pitting corrosion. Mao [8] proposed the Markov chain Monte Carlo algorithm to model the pitting corrosion characterizing the inherent randomness of the pitting process and measurement uncertainties of the in-service. Inspection data was obtained from eddy current inspections and the Weibull probability distribution were used.

Plow-induced vibration is also a common phenomena in shell-and-tube heat exchangers. The resulting vibrations can lead to component failure by fretting wear or fatigue. Vincent [9] develop a methodology that can be used at the design stage to give an overall estimate of service life and during component operation to monitor known flaws and ensure that, they will not fail during operation. Leak-before-break is an analysis based on the assumption that there is negligible chance that a flaw will fail before a leak can be detected. As part of this project. Leak rate calculation are made on growing flaws. This information can then be used when assessing whether LBB criteria will apply.

In this paper, a parametric study of loading and interfacial residual contact pressure is achieved using Monte Carlo method.

II. MONTE CARLO METHOD

Monte Carlo simulation is a numerical experimentation technique to obtain the statistics of the output variables of a given function, the statistics of the input variables. In each experiment or trial, the values of the input random variables are sampled based on their distributions, and the output variables are calculated using the computational model. The generation of a set of random numbers is central to the technique, which can then be used to generate a random variable from a given distribution. Typically, the random values, x, from a particular distribution are generated by inverting the closed form CDF for the distribution F(x) representing the random variable, where:

$$x = F^{-1}(u) \qquad (1)$$

where u = random number generated from 0 to 1.

Many distributions can be represented in closed form except for the Normal and Lognormal types. The CDF for these distributions can only be determined numerically. For example, the 3-parameter Weibull distribution's CDF is in closed form, where:

$$F(x) = 1 - \exp\left(-\left(\frac{x - x_0}{\theta - x_0}\right)^{\beta}\right) \qquad (2)$$

Manuscript Received on May, 2014.

Abdulaziz S. Alaboodi, Mechanical Engineering Department, Qassim University, Buraydah, Saudi Arabia.

where xo = expected minimum value, θ = characteristic value, and β = shape parameter.
Therefore, for the 3-parameter Weibull distribution, the inverse CDF with respect to u is:

$$x = x_0 + (\theta - x\ )\left[-\ln(1-u)\right]^{1/\beta} \quad (3)$$

We can use Monte Carlo simulation to determine the mean and standard deviation of a function with knowledge of the mean and standard deviation of the input variables..

III. RESULTS

The equivalent pressure that developed between tube and tubesheet and which result in the net compressive stress can be calculated from the following equation.

$$P_o = \frac{F}{2\pi f r_o L} \quad (4)$$

where P_o is the contact pressure, F the required push out force, r_o, the outer radius L is the length of the tube and f is the friction coefficient taken as 0.74 ± .001 [7]

Table 1 Experimental samples

Tube no.	Force	Length	Radius r_o
1	1860	6.021	0.4980
2	2220	6.018	0.4995
3	1500	6.007	0.4980
4	2000	6.015	0.4950
5	2040	6.016	0.5005
6	1380	6.014	0.5000
7	1880	6.013	0.4990
Average	1840	6.015	0.4986
S.D	299.778	0.00438	0.00184

F~N(l840, 299.77) lb-f L~N(6.015, 0.00438) in
ro~N(0.4986, 0.0084) in f~N(0.74, 0.001)
Table (1) shows the experimental samples done by Jawad [7]. Normal distribution was simplified by a 3-parameter Weibull distribution using the mean, μ, and standard deviation, σ, for a normal distribution (assuming β = 3.44). The parameters x_o and θ can be determined from:
$x_o \approx \mu$-3.1394σ
$\theta \approx \mu$ + 0.3530184σ β = 3.44
However, with this approximation, it is still assumed that the output variable will be a Normal distribution for each variable F, a and b in the stress equation, therefore:
x_{0F} = 898.8879 lb-f θ_F = 1945.824 lb-f β_F= 3.44
$x0_L$ = 6.001249 in θ_L = 6.016546 in β_L= 3.44
$x0_{ro}$ = 0.472229 in θ_{bro}= 0.501565 in β_{ro}= 3.44
x_{0f}= 0.736861 θf = 0.740353 β_f= 3.44
The inverse CDF is then used to generate the random numbers using the 3- parameter Weibull distribution, as given earlier. A Monte Carlo subroutine simulation code was generated and feed with 10000 trials. It requires the declaration of two label objects to display the mean and standard deviation. By running the code we get the mean and standard deviation of the stress as: P~ N(131.84, 30.69) psi (for one particular set of trials). The line Randomize (time) give the first set of time depends randomly numbers, so the followers will depend on it. Thus, each time the code runs, it generates a different data. However, the last answer is not differing as much. The first twenty data from the 10000 random data appear in table 2. By running the code many times we get different sets of results. Table 3 has a ten result after ten running time. Then we can say: P~ N(131.96, 30.84) psi

Table 2 Random data

i	*F (lbf)*	*L (in)*	*R (in)*	*fr*	*P (ksi)*
1	1373.827	6.008323	0.48944	0.738487	100.6424
2	1846.801	6.015163	0.503636	0.741227	130.8428
3	2041.131	6.007286	0.503808	0.739627	145.0642
4	1380.476	6.007159	0.484969	0.740407	101.8172
5	1919.411	6.014775	0.507521	0.738924	135.3756
6	2013.739	6.015787	0.50021	0.739355	143.9959
7	2034.605	6.016311	0.495229	0.739857	146.8389
8	2262.15	6.010832	0.49961	0.739765	161.9971
9	1940.08	6.014856	0.500348	0.740571	138.4845
10	2099.258	6.006792	0.481049	0.739874	156.2145
11	1958.827	6.014823	0.509256	0.7396	137.5577
12	1930.425	6.01958	0.493726	0.741901	139.2835
13	1891.933	6.019004	0.490213	0.739276	137.9859
14	1636.09	6.014247	0.497316	0.739287	117.7133
15	1290.944	6.004349	0.494061	0.739149	93.66425
16	2071.341	6.010941	0.506207	0.740769	146.1987
17	1437.946	6.014137	0.503275	0.740042	102.13
18	2135.647	6.015792	0.498513	0.740621	152.9711
19	1996.63	6.018335	0.505701	0.739718	141.0933

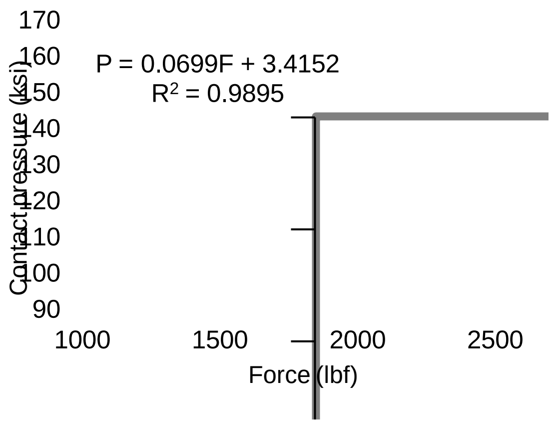

Figure 1 Force vs. Interfacial contact pressure

Figure (1) shows the pull out force verse the interfacial residual contact pressure which is fit linearly with 0.9895 R-squared. Relation is given by:
P= 0.0699 *F* +3.4152

IV. CONCLUSION

In conclusion the use of Monte Carlo simulation method for experiments with low number of samples is useful to predict the mean and standard deviation for a normal sampling distribution. The prediction of mean contact pressure between the tube and tubesheet is required using small number of experimental samples and data. A code program were conducted to simulate the available data samples with many generated data using Monte Carlo methods. With Monte Carlo method, new samples data were generated depending on the available ones.

Then the new mean and normal deviation were predicted. In addition the program code could be repeated which generates the sample randomly and to get a slightly different result. Ten times of sampling repetition were conducting to estimate the mean and standard deviation. Finally, a linear relation between force and contact pressure were introduced with the coefficient of determination, R^2 of 0.9895.

REFERENCES

1. Grimison, E. D., Lee, G. H., "Experimental Investigation of Tube Expansion", Transaction of The ASME, July 1943, pp. 497-505.
2. Scott, D. A., Wolgemuth, G. A., Aikin, J. A., "Hydraulically Expanded Tube-to-Tubesheet Joints", Journal of Pressure Vessel Technology, Vol. 106, Feb. 1984, pp. 104-109.
3. Jawad, M. H., Clarkin, E. J., Schuessler, R. E., "Evaluation of Tube-to-Tubesheet Junctions" Journal of Pressure Vessel Technology, Vol. 109, Feb. 1987, pp. 19-26.
4. Sherburne, P. A., Hornbach, D. J., Ackeman, R. A., Mcllree, A. R., "Residual Stresses in OTSG Tube Expansion Transitions" 8th Water Reactors, Proceeding, Aug 10, 1997, Amelia Island, Florida, NACE, TMS.
5. Shuaib, A. N., Merah, N., Khraisheh, M. K., Allam, I. M., Al-Anizi, S. S., "Experimental Investigation of Heat Exchanger Tubesheet Hole Enlargement" Journal of Pressure Vessel Technology, Vol. 125, Feb. 2003, pp. 19-25.
6. Lee, Jae Bong; Park, Jai HakView Profile; Kim, Hong-Deok; Chung, Han-Sub; Kim,Tae Ryong, "Statistical assessment of integrity in steam generator tubes considering uncertainty of nde", Key Engineering Materials 326-328 (2006): 545-548.
7. Wu, Gary,"A probabilistic-mechanistic approach to modeling stress corrosion cracking propagation in Alloy 600 components with applications", University of Maryland, College Park, ProQuest, UMI Dissertations Publishing, 2011. 1501253.
8. Mao, Dan, "Bayesian modeling of pitting corrosion in steam generators", University of Waterloo (Canada), ProQuest, UMI Dissertations Publishing, 2007. MR35285.
9. Vincent, Brady, "A probabilistic assessment technique for shell-and-tube heat exchanger inspection", University of New Brunswick (Canada), ProQuest, UMI Dissertations Publishing, 2007. MR56487.

AUTHORS PROFILE

Dr. Abdulaziz S. Alaboodi completed his PhD from King Fahd University for Petroleum and Minerals, Saudi Arabia. He is Assistance Prof. at Qassim University. He has over 20 Multi-national Journal and Conference papers to his credit.