RESEARCH ARTICLE OPEN ACCESS

Dynamic Analysis And Optimization Of Fatigue Crack Propagation Using Full Factorial Design

Om Prakash Samal *, Hemanta Kumar Rana*, Shiba Narayan Sahu**
*(Department of Mechanical Engineering, Centurion University of Technology and Management, Bhubaneswar India)
** (Department of Mechanical Engineering, Gandhi Institute for Education and Technology, Bhubaneswar, India)

ABSTRACT
A pipe installation experiences fluctuating loading condition and occasionally high amplitude Seismic Vibration. The modelling of fatigue crack growth becomes more substantial if the pipes carry harmful fluids. However there is an insufficiency of fatigue crack model for pipes. Generally a prior step before developing a simplified model is to analyze the process and to identify the effective process parameters of the process .The primary objective of this investigation is dealt with identification and analysis of fatigue crack growth process for part-through cracked pipes. In the present investigation an attempt has been made identify the effective process parameter of fatigue life and optimization of the process parameters by using full factorial design methodology, so that it will be help full to develop a simplified fatigue crack growth model in future research works.

***Keywords* -** fatigue crack propagation, part-through cracked pipes, full factorial design, Crack length, ANOVA

I. INTRODUCTION

Pipe installations find extensive uses in industry. They are generally used to transport fluids from one place to another. During these services the pipes experienced hoop stresses developed by the transferring fluid. Also they are exposed to fluctuating bending stresses along with the high amplitude seismic vibrations. These stresses and vibrations tend to initiate new fatigue cracks from a highly stressed region or support extension of existing cracks. In a number of industries the pipe connections carry hazardous fluids [1, 2]. Therefore, the monitoring of these connections in relationships of initiation of crack and their subsequent growth are important for firmness of structure and safely. The first step towards the development of an efficient, simplified fracture mechanics based fatigue crack propagation model is identification and analysis of concerned fatigue crack growth process. In present investigation an attempt has been made to identify and analyze the effective process parameters of fatigue crack growths for part-through cracked pipes under constant amplitude loading using a systemic approach. To identify and analyze a process there is a necessity of conducting the experiments in an organized and systematic approach which was found out to be short comings in earlier researches [3-8]. In these researches [3-8] as the effect of process parameters on responses of fatigue crack process have not been studied properly, the models were based upon the complicated numerical integration. So here a full factorial design approach has been followed up by ANOVA (Analysis of Variance) to conduct the experimental runs as well as to perform the analysis part, so that it will be help full to develop a simpler fatigue crack growth model in future research works.

II. EXPERIMENTAL DETAILS

The fatigue crack growth tests were performed on TP316L grade of stainless steel pipes. All the tests were performed in a servo-hydraulic dynamic testing machine (Instron-8800) using part-through cracked pipe specimen under load control mode. A four point bend fixture was made-up for conducting fatigue crack growth tests. Before performing the test, COD gauge was calibrated for part-through cracked pipe specimens at notch angle 45^o. It can be here noted that in the present study the monitoring of crack was done with the help of a COD gauge. All the tests were conducted in ambient and at room temperature.
The pipes were of 60 mm outer diameter having 9 mm wall thickness. The pipe samples had a notch at the outer wall in the circumferential direction. Straight surface notches of angle ($2\theta=45^o$) from the center of pipe were made on the outer circumference by wire EDM which is shown on Figure 1. The detailed dimensions of the specimen and notch are given in Table 1.

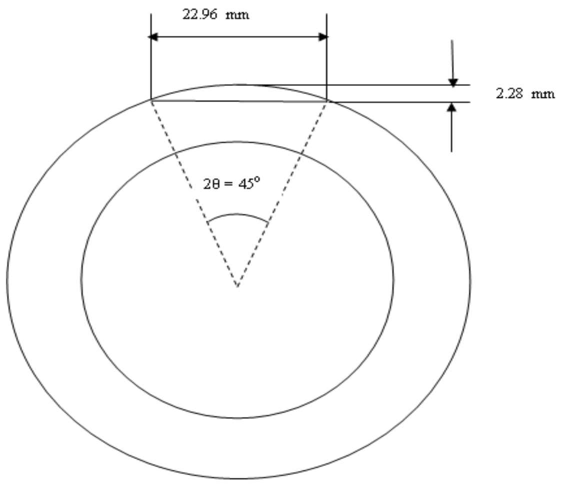

Figure.1 Cross section of specimen

Table 1 :Specimen and notch dimension of pipe

Specimen	Dimension (mm)
Outer radius (R_0)	30
Inner radius (R_i)	21
Thickness (t)	9
Crack depth	2.28
Crack length (L)	23
Length of the specimen	505
Angle (2θ)	45^o

The servo-hydraulic dynamic testing machine (Instron8800) having load cell of capacity 250KN were used for fatigue test which is interfaced to a computer for machine control and data acquisition.

III. FULL FACTORIAL DESIGN

Here the influence of input parameters i.e., crack depth calculated chord Ac(mm), crack depth calculated arc length Aa(mm) and load(N) on performance parameters no. of cycles, monitor Crack length(mm) have been investigated with the help of full factorial method. For each run one number of replicate was created to consider the effect of variation in performance parameters, so a total of 27 runs were conducted in the investigation. The experiment was designed using general full factorial design considering the input parameters at different level as tabulated below in table 2.

Table 2: Factors and their levels

Factor	Levels		
	1	2	3
Ac	2.396	3.562	6.742
Aa	2.396	3.467	8.575
Load	38264	38349	38360

The basic aim of present work is to conduct the 27 numbers of experiment runs, the influence of each input parameters on each response parameter was studied by using ANOVA (Analysis of Variance).The main effect plot has also been referred to analyze the influences of input parameters.

IV. EXPERIMENTAL RESULT:

The experimental result of 27 runs designed by full factorial design has been tabulated as below in table 3.

V. RESULTS AND DISCUSSIONS

Effect on Monitored Crack length (mm):

Figure 2 shows the main effect plot for mean monitored crack length. From the main effect plot the effect of individual parameters on mean monitored crack length has been defined subsequently. The three loads used here, seems to have less effect on mean monitored crack length. Crack depth calculated chord (Ac) has clearly outperformed the other two input/process parameters. With the increase in crack depth calculated arc length (Aa) values, mean monitored crack length is reducing and maximum monitored crack length was achieved at Aa is equal to 2.396mm.For Ac, the higher values is favoring the maximum monitored crack length.

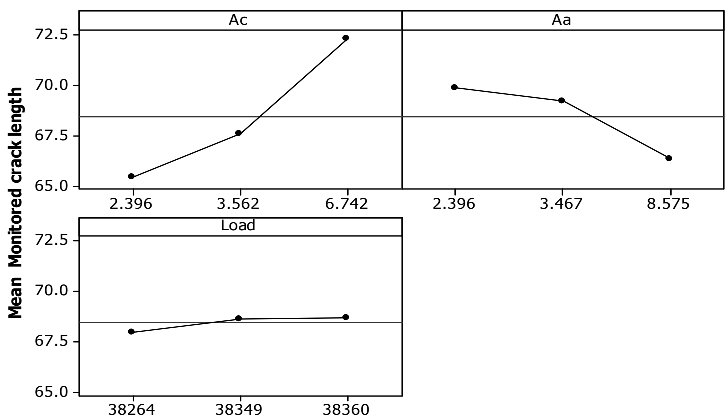

Fig. 2 Main effect plots for mean monitored crack length

Table 3: Observation table for full factorial method

Run Order	crack depth calculated chord (Ac(mm))	crack depth calculated arc length(Aa(mm))	Load(N)	No. of cycles	Monitored crack length
1	2.396	2.396	38264	533342	66.7366
2	2.396	2.396	38349	552220	67.0316
3	2.396	2.396	38360	554651	67.1086
4	2.396	3.467	38264	522636	65.753
5	2.396	3.467	38349	541516	66.248
6	2.396	3.467	38360	543956	66.525
7	2.396	8.575	38264	552081	62.8172
8	2.396	8.575	38349	570957	63.6122
9	2.396	8.575	38360	573393	63.4892
10	3.562	2.396	38264	558710	68.7483
11	3.562	2.396	38349	577580	69.4225
12	3.562	2.396	38360	580020	69.1995
13	3.562	3.467	38264	548001	67.9439
14	3.562	3.467	38349	566870	68.5389
15	3.562	3.467	38360	569310	68.6159
16	3.562	8.575	38264	577449	64.9081
17	3.562	8.575	38349	596323	65.7031
18	3.562	8.575	38360	598760	65.5801
19	6.742	2.396	38264	550440	73.1658
20	6.742	2.396	38349	569310	73.7608
21	6.742	2.396	38360	571747	73.8378
22	6.742	3.467	38264	539730	72.5823
23	6.742	3.467	38349	558610	73.2773
24	6.742	3.467	38360	561047	73.5543
25	6.742	8.575	38264	569177	69.5464
26	6.742	8.575	38349	588043	70.5414
27	6.742	8.575	38360	590490	70.7184

Table 4: Analysis of Variance for Monitored crack length

Source	DF	Seq SS	Adj MS	F	P	% of contribution
Ac	2	221.025	110.512	23301.62	0.000	76.44
Aa	2	64.747	32.374	6826.00	0.000	22.39
Load	2	2.843	1.422	299.75	0.000	0.98
Ac*Aa	4	0.169	0.042	8.93	0.005	0.06
Ac*Load	4	0.140	0.035	7.40	0.008	0.05
Aa*Load	4	0.171	0.043	9.00	0.005	0.06
Error	8	0.038	0.005			0.01
Total	26	289.134				100.00
S = 0.0688672 R-Sq = 99.98% R-Sq(adj) = 99.99%						

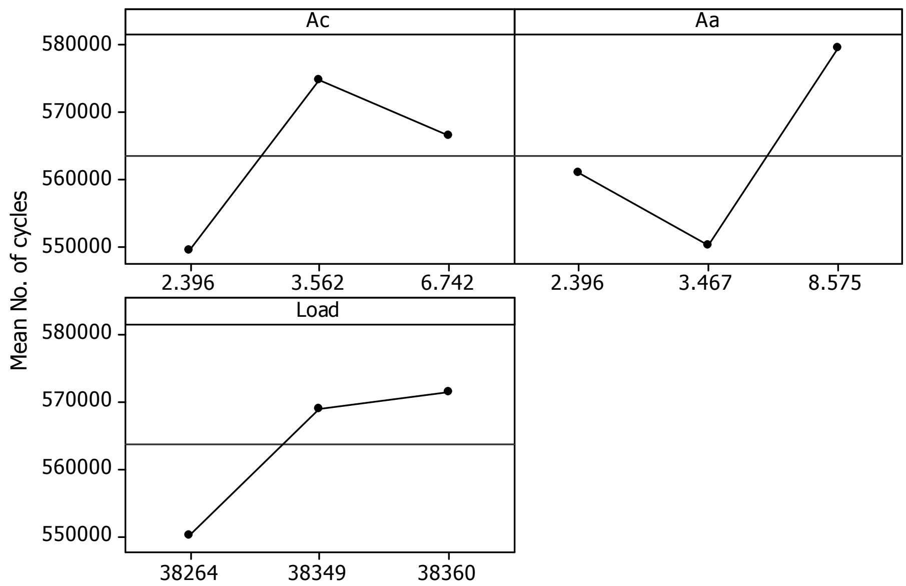

Fig. 3: Main effect plots for mean no. of cycles

Table 5: Analysis of Variance for No. of cycles

Source	DF	Seq SS	Adj MS	F	P	% of contribution
Ac	2	3011655054	1505827527	1.56224E+08	0.000	31.84
Aa	2	3998126324	1999063162	2.07396E+08	0.000	42.27
Load	2	2449086321	1224543160	1.27042E+08	0.000	25.89
Ac*Aa	4	98	25	2.55	0.121	0.00
Ac*Load	4	47	12	1.22	0.374	0.00
Aa*Load	4	42	10	1.08	0.426	0.00
Error	8	77	10			0.00
Total	26	9458867963				100.00
S = 0.0688672 R-Sq = 99.99% R-Sq(adj) = 99.96%						

Analysis of Variance (ANOVA) for mean monitored crack length is shown in Table 4 .From p-values of corresponding input parameters and its interactions, it can be conclude that all individual parameters and their interactions are found to be significant for the response. And as Ac is having highest contribution of 76.44 percentages towards mean monitored crack length, it is highly significant parameter.

Effect on No. of cycles:

Figure 3 shows the main effect plot for no. of cycles. From the figure assessments drawn are; all process/input parameters have significant effect on no. of cycles, the values of Ac, Aa and load respectively at 3.562mm,8.575mm and 38360Nare liable for the higher no. of cycles.

From the ANOVA for no. of cycles as shown in Table 5, it was found that all the individual parameters except all two-level interaction parameters have significant effects on no. of cycles. All the interaction effects among the individual parameters express zero significant effects towards the no. of cycles at a significance level of 0.05. A major 42.27 percentage of contribution effect was added to no. of cycles by Aa.

VI. CONCLUSION

The main effect plots plotted above on the basis of experimental data is providing a qualitative picture about the effect of process parameters on responses and ANOVA is giving a quantitative idea on the same .The ANOVA revealed that crack depth calculated chord has highest significance towards the performance of this fatigue crack model, and is followed by the crack depth calculated arc length on the average basis. This concept of relationship between the process parameters and responses of the fatigue crack process will certainly lead to the better conceptualization of the process and also will certainly help to build up a fatigue crack model using non-linear regression method, or ANN method or some empirical relationship, rather going for the complicated numerical integration. Experimentation may be done using large number of sample in wide range for better accuracy and refinement of process parameter and response parameter relationship.

REFERENCES

[1] Shibata K, Isozaki T, Ueda S, Kurihara R, Onizawa K, Kohsaka A., *Results of reliability test program on light water reactor piping. Nuclear Engg, Des-86,1994, pp. 71-86.*

[2] Yeon-Sik Y, Ando K. ,*Circumferential fatigue crack growth and crack opening behaviour in pipe subjected to bending moment, SMIRT-15, 1999,Seoul, Korea.*

[3] S. M. Beden, *Review of fatigue crack propagation models for metallic components, European Journal of Scientific Research , ISSN 1450-216X vol.28 No.3, 2009,pp.364-397.*

[4] Wang, GS. and AF. Blom, *strip model for fatigue crack growth predictions under general load conditions, Engineering Fracture Mechanics, vol. 40, 1991,pp. 507–533.*

[5] Paris, P.C. , *The growth of cracks due to variations in loads, PhD. Dissertation, Lehigh University. Bethlehem. PA, 1960.*

[6] PC, and F. Erdogan, *A Critical Analysis of Crack Propagation Laws. Journal of Basic Engineering; Transaction, American Society of Mechanical Engineers, Series D 85, 1963,pp. 528-534.*

[7] Paris PC, H. Tada and JK. Donald, *Service load fatigue damage – a historical Perspective, 1999,International Journal of Fatigue, vol. 21, pp. S35–S46.*

[8] Carpinteri Andrea, Brighenti Roberto, Spagnoli Andréa, *Part-through cracks in pipes under cyclic bending, Nuclear Engineering and Design vol. 185, 1998pp. 1–10.*