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ANALYSIS OF FAULT IN BOILER TUBE USING BY FUZZY LOGIC TECHNIQUE

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Abstract

In this paper, a novel approach to detecting fault location and its intensity in the boiler tube by Fuzzy logic techniques is established. The analysis has been done by using finite element method with the help of ANSYS. It has been noticed that when the crack depth increases natural frequency decreases and also there is a deviation in the mode shape. The fuzzy logic controller used here comprises of one input parameter and three output parameters. The triangular membership functions are used for the fuzzy controller. Here the input parameters to the fuzzy-triangular controller are relative deviation of first natural frequency, and the output parameters of the fuzzy inference system are relative thickness, sl. No of tube and relative fault location. The series of fuzzy rules is derived from vibration parameters which are finally used for prediction of fault location. This method provides the knowledge towards working conditions in the boiler tube.

Key words: natural frequency, relative thickness, sl. No of tube relative fault location, and fuzzy- triangular controller.

1. INTRODUCTION

During operation, fault diagnosis in vibrating Boilers has drawn a lot of attention from the engineering community in the last three decades. . The presence of faults in a boiler tube was undetected for a longer period of time will lead to the failure of the system and may cause loss of life and loss of resources. Boiler failure is a major concern in power plants and other industrial units [1–3] and the tube corrosion is known to be the main cause. The total cost of boiler tube failures in power plants is estimated to be about $5 billion a year [4]. Scale deposits in boiler system are a main concern since they considerably increase the fuel consumption. In order to control the scale formation, phosphates are used to form controllable participates (phosphate treatment). Phosphate reacts with calcium and magnesium to form a soft particle which can be suspended in the boiler water and removed through blowdown. Chelant and dispersant programs are other common methods to control the scale formation [5]. Vibration based methods can offer an effective and convenient way to detect fatigue cracks in structures.

2. SIMULATED GEOMETRY FIGURE OF BOILER TUBE

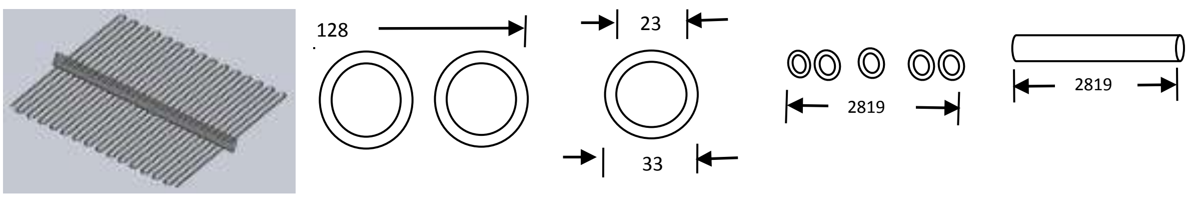


Fig.1 (a) Fig.1 (b) Fig.1 (c) Fig.1 (d) Fig.1 (e)

Figure.1 (a) Geometry boiler tube, (b) Distance between two conjugate tubes,(c) Dimension of each tube,(d) Total length of boiler , and (e) Total length of boiler each tube.

3. NUMERICAL ANALYSIS

The FEM analysis is carried out for the faulted boiler tube to find the relative thickness, sl. No of tube and relative fault location of transverse vibration at different fault location. The dimensions of the faulted boiler tube of the current research have been given in figure 1 (a)-(e). The relative location two damage from left and right side of the middle of each boiler tube have been taken here. Relative thickness varies from 0.6 to 1.0,there are total 30 numbers tube in each set of one boiler .

4. TABULATION OF FREQUENCIES FOR FIRST MODE SHAPES CONSIDERING FAULT AND WITHOUT FAULT

Table 1: Thickness boiler tube: 10 mm

a*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
b*	0.999674	0.999715	0.999776	0.999786	0.999825	0.999831	0.999839	0.999857	0.999817	0.999939	0.999919	0.999939	0.999939	0.999857	0.999022	0.999145	0.999267	0.999348	0.999470	0.999552	0.999613	0.999735	0.999756	0.999878	0.999837	0.999837	0.999878	0.999939	0.999845	0.999957
c*	0.999740	0.999837	0.999935	0.999902	0.999967	0.999837	0.999837	0.999805	0.999740	0.999805	0.999772	0.999805	0.999805	0.999772	0.999317	0.999642	0.999870	0.999935	0.999935	0.999837	0.999675	0.999610	0.999447	0.999447	0.999382	0.999382	0.999480	0.999280	0.999560	0.999870
d*	0.999837	0.999919	0.999988	0.999884	0.999907	0.999768	0.999826	0.999849	0.999849	0.999965	0.999930	0.999884	0.999803	0.999710	0.999570	0.999907	0.999977	0.999803	0.999605	0.999501	0.999524	0.999745	0.999861	0.999884	0.999837	0.999617	0.999742	0.999827	0.999942	0.999967
e*	0.999550	0.999958	0.999935	0.999902	0.999967	0.999837	0.999837	0.999805	0.999740	0.999805	0.999772	0.999805	0.999805	0.999772	0.999317	0.999642	0.999870	0.999935	0.999935	0.999837	0.999675	0.999610	0.999447	0.999447	0.999382	0.999382	0.999480	0.999610	0.999690	0.999810

a*= Serial number of boiler tube, b*=Relative location From support from 1st left, c*= Relative location From support from 2nd left, d*= Relative location From support from 1st right ,e*= Relative location From support from 2nd right,

Table 1: Thickness boiler tube: 09 mm

a	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
b	0.999022	0.999145	0.999267	0.999348	0.99947	0.999552	0.999613	0.999735	0.999756	0.999878	0.999837	0.999837	0.999878	0.999939	0.998505	0.999317	0.999577	0.999935	0.999902	0.99974	0.99948	0.99922	0.99896	0.998797	0.998537	0.99987	0.999057	0.999187	0.999375	0.999634
c	0.999317	0.999642	0.99987	0.999935	0.999935	0.999837	0.999675	0.99961	0.999447	0.999447	0.999382	0.999382	0.99948	0.99961	0.996334	0.996803	0.997291	0.997638	0.998106	0.998513	0.998819	0.999022	0.999267	0.99947	0.999613	0.999715	0.999617	0.999739	0.999845	0.999939
d	0.99957	0.999907	0.999977	0.999803	0.999605	0.999501	0.999524	0.999745	0.999861	0.999884	0.999837	0.999617	0.99942	0.999327	0.997497	0.998732	0.999545	0.999902	0.99987	0.999577	0.99909	0.998472	0.998082	0.997822	0.99779	0.997952	0.998342	0.998831	0.999587	0.999883
e	0.999013	0.999872	0.999791	0.99964	0.999234	0.999013	0.999129	0.999489	0.999814	0.999954	0.999547	0.999153	0.998897	0.998549	0.998363	0.999698	0.999907	0.999303	0.998584	0.998235	0.998433	0.99899	0.999675	0.999965	0.999605	0.998781	0.997992	0.99692	0.998992	0.999769

Table 1: Thickness boiler tube: 08 mm

a	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
b	0.997862	0.998228	0.998371	0.998737	0.998961	0.999145	0.999348	0.999511	0.999593	0.999695	0.999552	0.999654	0.997862	0.998228	0.995905	0.998082	0.999382	0.999902	0.999837	0.999317	0.998537	0.997692	0.99701	0.996522	0.996522	0.99688	0.99742	0.998115	0.998426	0.999783
c	0.998505	0.999317	0.999577	0.999935	0.999902	0.99974	0.99948	0.99922	0.99896	0.998797	0.998537	0.99987	0.999898	0.999817	0.997318	0.999594	0.999919	0.998932	0.997736	0.997156	0.997516	0.998456	0.999559	0.999965	0.999408	0.998189	0.996854	0.996227	0.998562	0.999562
d	0.999013	0.999872	0.999791	0.99964	0.999234	0.999013	0.999129	0.999489	0.999814	0.999954	0.999547	0.999153	0.999057	0.999187	0.991548	0.992648	0.99387	0.994746	0.995703	0.996436	0.997271	0.997719	0.998432	0.998798	0.998798	0.999328	0.999654	0.999737	0.999854	0.999946
e	0.993972	0.994949	0.995764	0.996273	0.996986	0.997617	0.998147	0.998513	0.9989	0.999185	0.99943	0.999654	0.999715	0.999898	0.994312	0.997205	0.99909	0.999837	0.999805	0.999025	0.997887	0.996457	0.995645	0.994929	0.994929	0.995189	0.997614	0.998278	0.999614	0.999727

Table 1: Thickness boiler tube: 07 mm

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.999674	0.996334	0.996803	0.997291	0.997638	0.998106	0.998513	0.998819	0.999022	0.999267	0.99947	0.999613	0.999715	0.999817	0.999939
0.999740	0.997497	0.998732	0.999545	0.999902	0.99987	0.999577	0.99909	0.998472	0.998082	0.997822	0.99779	0.997952	0.998342	0.99883
0.999837	0.987862	0.989898	0.991344	0.992566	0.994135	0.995092	0.996212	0.997047	0.99776	0.99831	0.99888	0.999287	0.999552	0.999756
0.999550	0.991874	0.996165	0.998765	0.99987	0.999772	0.998472	0.997075	0.99532	0.993922	0.992979	0.992882	0.993564	0.994734	0.996165

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
0.996343	0.999408	0.999849	0.998491	0.996773	0.99574	0.996343	0.997643	0.999385	0.99993	0.99993	0.997156	0.995298	0.996509	0.998247
0.987862	0.989898	0.991344	0.992566	0.994135	0.995092	0.996212	0.997047	0.99776	0.99831	0.99888	0.999287	0.999552	0.999756	0.999834
0.991874	0.996165	0.998765	0.99987	0.999772	0.998472	0.997075	0.99532	0.993922	0.992979	0.992882	0.993564	0.994734	0.996165	0.998745
0.994788	0.999141	0.999837	0.997887	0.9956	0.994172	0.994915	0.996935	0.999095	0.999907	0.998828	0.996262	0.993662	0.99235	0.997479

Table 1: Thickness boiler tube: 06 mm

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.999674	0.993972	0.994949	0.995764	0.996273	0.996986	0.997617	0.998147	0.998513	0.9989	0.999185	0.99943	0.999654	0.999715	0.999898
0.999740	0.995905	0.998082	0.999382	0.999902	0.999837	0.999317	0.998537	0.997692	0.99701	0.996522	0.996522	0.99688	0.99974	0.998115
0.999837	0.997318	0.999594	0.999919	0.998932	0.997736	0.997156	0.997516	0.998456	0.999559	0.999965	0.999408	0.998189	0.996854	0.996227
0.999550	0.988705	0.998375	0.999559	0.995159	0.989006	0.98737	0.987915	0.992791	0.998026	0.999965	0.997539	0.99091	0.985164	0.982413

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
0.983666	0.986334	0.988351	0.990163	0.991752	0.993422	0.994888	0.996029	0.996925	0.99778	0.998493	0.999002	0.999434	0.999633	0.995434
0.989176	0.994864	0.998277	0.999837	0.999642	0.998147	0.996035	0.993759	0.991647	0.990574	0.990477	0.991484	0.993044	0.994669	0.993069
0.99307	0.998932	0.999721	0.997214	0.993801	0.992176	0.993174	0.995914	0.998758	0.999942	0.998456	0.995031	0.991595	0.989389	0.994534
0.964991	0.971019	0.972465	0.977656	0.982607	0.985662	0.989471	0.991181	0.993483	0.995051	0.996477	0.9978	0.998615	0.999267	0.998815

5. ANALYSIS OF THE FUZZY CONTROLLER

The fuzzy controller developed has got three input parameters and two output parameters.

The linguistic term used for the inputs is as follows;

Relative first natural frequency = "RNF";

The linguistic term used for the outputs is as follows;

Relative Thickness = "RT" , Sl. No Of tube ="ST", and Relative Fault location = "RFT"

The Fuzzy controller used in the present text is shown in Figure 8a. The Triangular membership functions are shown pictorially in Figure 8b. The linguistic terms of the Triangular membership functions, used in the fuzzy controller, are described in the Table 5.

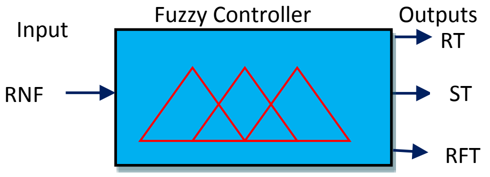


Fig. 2(a) Triangular fuzzy controller

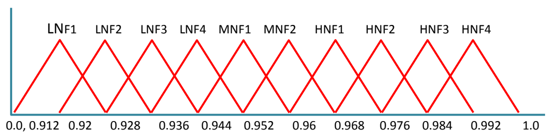


Fig. 2 (b) Triangular membership functions of relative natural frequency of the first mode of vibration

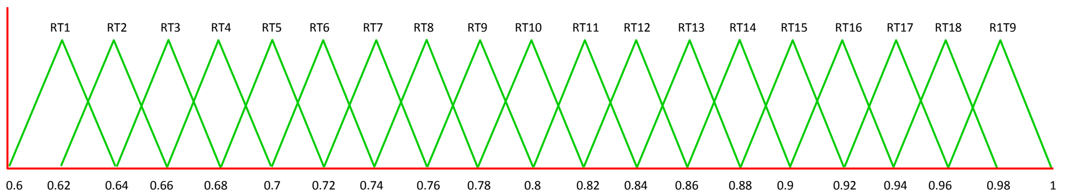


Fig. 2(c) Triangular membership functions for relative thickness

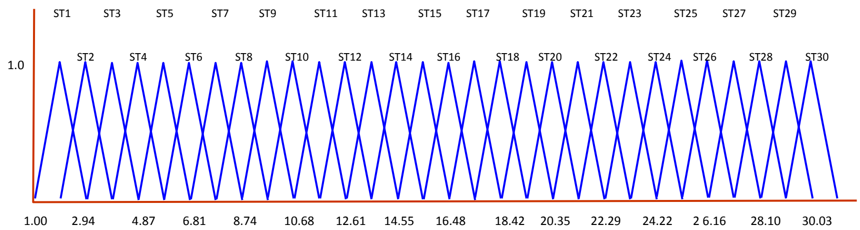


Fig. 2(d) Triangular membership functions for SL. number of tube

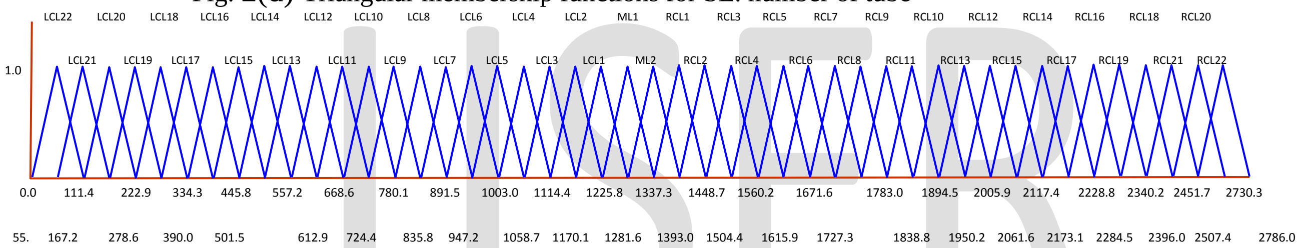


Fig. 2(e) Triangular membership functions for relative fault location

Table 6: Description of fuzzy Linguistic terms

Membership functions Name	Linguistic Terms	Description and range of the Linguistic terms
LNF1 LNF2 LNF3 LNF4	LNF $_{1\ to\ 4}$	Low ranges of relative natural frequency of the first mode of vibration in descending order respectively
MNF1 MNF2	MNF $_{5,6}$	Medium ranges of relative natural frequency of the first mode of vibration in ascending order respectively
HNF1 HNF2 HNF3 HNF4	HNF $_{7\ to\ 10}$	Higher ranges of relative natural frequency for the first mode of vibration in ascending order respectively.
RT1 – RT19	RT_{1-19}	Relative thickness in ascending order, respectively
ST1-ST30	ST_{1-30}	SL. Number of tubes in ascending order, respectively
LCL1- LCL22	LCL $_{1-22}$	Left hand side Relative fault location in ascending order respectively
ML1- ML2	ML_{1-2}	Middle side Relative fault location in ascending order respectively
RCL1- RCL22	RCL $_{1-22}$	Right hand side Relative fault location in ascending order respectively

6. Fuzzy Mechanism Used For Localization and Identification of Fault

The fuzzy controller has been developed (as shown in Fig.2 (a)-(e), where there are one input and three output parameter. The natural linguistic representations for the input are as follows

Relative first natural frequency = "RFNF"

The natural linguistic term used for the outputs is

Relative Thickness = "RT", Sl. No Of tube ="ST", and Relative Fault location = "RFT"

Based on the above fuzzy subset the fuzzy rules are defined in a general form as follows:

If RNF is RNFi then RT is RTi, ST is STi and RFT is RFTi

Where i= 1to n, where n is the number of membership functions.

7. Fuzzy Controller for Finding Out Relative thickness, sl. No of tube, and relative fault location.

The input to the fuzzy controller is relative first natural frequency. The outputs from the fuzzy controller are relative thickness, sl. No. of tube, and relative fault location. Ten numbers of the fuzzy rules out of several hundred fuzzy rules are being listed in table 7.

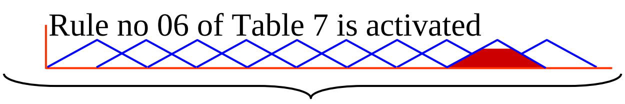
Table 7: Examples of tenth fuzzy rules are used in fuzzy controller.

Sl. No.	Examples of some rules used in the fuzzy controller
1	If RNF is LNF 1, then RT is RT12,ST is ST01 and RFT is LCL21
2	If RNF is LNF 2, then RT is RT09,ST is ST22 and RFT is LCL20
3	If RNF is LNF 4, then RT is RT04,ST is ST25 and RFT is RCL17
4	If RNF is LNF 1, then RT is RT03,ST is ST15 and RFT is ML 2
5	If RNF is LNF 3, then RT is RT11,ST is ST18 and RFT is LCL08
6	If RNF is LNF 1, then RT is RT14,ST is ST04 and RFT is LCL05
7	If RNF is LNF 3, then RT is RT16,ST is ST08 and RFT is RCL06
8	If RNF is LNF 2, then RT is RT07,ST is ST05 and RFT is LCL16
9	If RNF is LNF 4, then RT is RT04,ST is ST04 and RFT is LCL21
10	If RNF is LNF 3, then RT is RT05,ST is ST09 and RFT is ML 1

Figure 3 (a) -(d): Relative Thickness, Sl. No Of tube, and Relative Fault location when RNF = 0.997719, then RT is 0.68, ST is 16 and RFT is 1003.68.

8. Results of Fuzzy Controller

Fig.No 3 (a) Inputs



Outputs

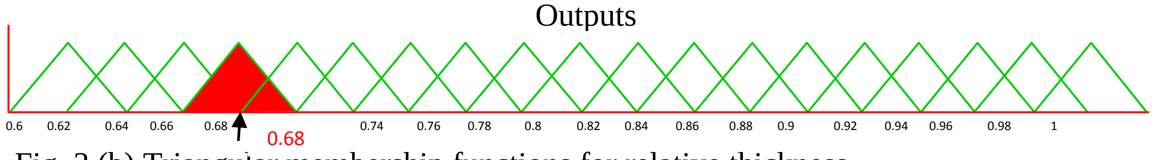


Fig. 3 (b) Triangular membership functions for relative thickness

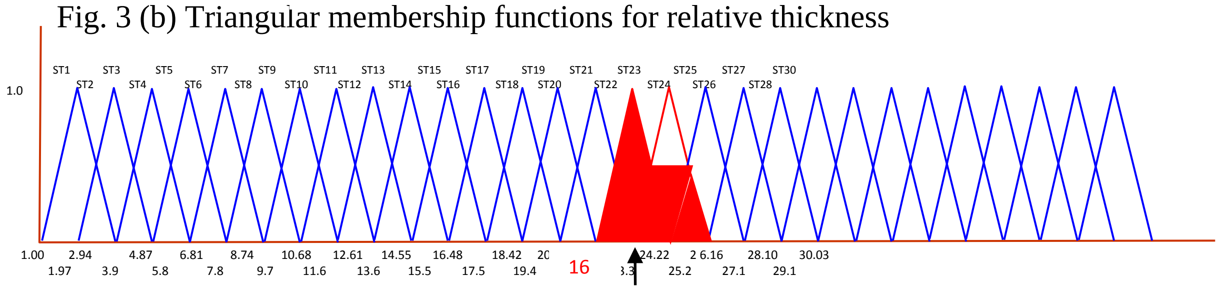


Fig. 3 (c). Triangular membership functions for SL. number of tube

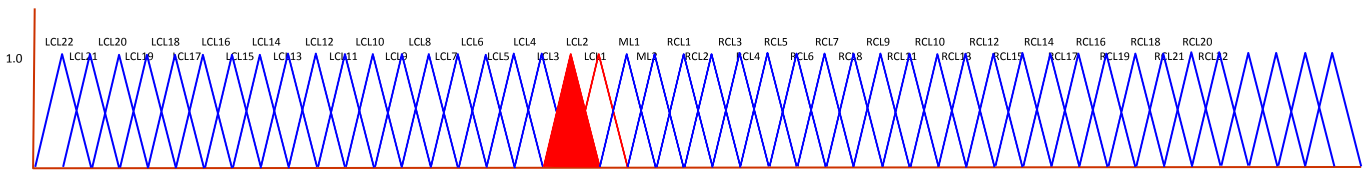


Fig. 3 (d). Triangular membership functions for relative fault location

9. RESULT AND DISCUSSION

The discussion is based upon the outputs of ANSYS. With the help of ANSYS, for boiler tube with different fault location, natural frequencies for first mode shapes have been obtained as shown in the Table number from 1to5. It can be noticed that with the increase in fault depth, frequency of vibration decreases for first mode, of vibration and also it is observed that there are significant variations in Relative frequency in the vicinity of fault location due to presence of faults. To find out Relative Thickness, Sl. No Of tube, and Relative Fault location, fuzzy controller with Triangular have been used. Table no. 6 shows Description of Fuzzy Linguistic terms and Table no. 7 represents fuzzy rules used in Fuzzy controller. For a given set of inputs when Triangular membership function uses uses the output we are getting is approximately equal to the theoretical one having 4.23% of error.

10. CONCLUSION

From the results and discussions the following conclusions have been drawn

- Small fault depth ratios have little effects on the natural frequencies of the faulted boiler tube. Analysis of change in natural frequencies is effective for prediction of fault in the boiler tube containing a small fault.
- A clear-cut deviation in natural frequencies in the vicinity of fault location has been observed from the comparison of the results of the un-faulted and faulted boiler tube during the vibration analysis.
- Unique changes have been observed in the natural frequencies with the change of relative thickness, serial number of tubes, and relative fault location.
- It has been observed that the developed fuzzy controllers can predict the relative thickness, serial number of tubes, and relative fault location of the boiler tube with a considerably less amount of computational time.

11. Applications

- The developed controllers can be used as effective tools for online condition monitoring of engineering systems.
- The present study can be utilized for inverse engineering application/problems, and can also be used in different engineering system for fault detection.
- The methodologies formulated using artificial intelligence techniques can be used for prediction of fatigue, fault of offshore structure, flow lines, turbo machinery, nuclear plants, ship structures etc.

12. Scope for future work:

In this research fault diagnosis and structural health monitoring systems have been derived using vibration signatures. These developed techniques can be extended to predict the health of complex structures with multiple faults.

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