Damage Detection Method for Wind Turbine Blades Based on Vibration Signals

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ABSTRACT: The aim of this paper is to use the vibration based analysis to detect the transverse crack location and depth in wind turbine blades. The actual data for training neural network is obtained using finite element method via ANSYS software for different crack locations and depth. This data is validated using experimental data from literature. The test results show that the proposed neural networks are able to predict the crack specifications accurately.

KEYWORDS: wind turbine blade, neural network, crack, natural frequency, beam.

I.INTRODUCTION

The presence of crack leads to reduction in stiffness with an inherent reduction in natural frequency and increase in modal damping. The study of vibration analysis of cantilever beam with crack finds application in wind turbine blade damage analysis.

In literature Yang et al. performed the analytical study on the vibration of beams containing open edge cracks. Analytical solutions were obtained for cantilever, with different conditions to evaluate the dynamic response of the beam with edge crack.

Salawu and Williams presented an excellent review on the use of modal frequency change for damage diagnostics. The observation that changes in structural properties cause changes in frequencies was the impetus for using modal methods for damage identification and health monitoring.

In this paper Euler-Bernoulli beam is analysed. First the natural frequency and deflection of Un-cracked and cracked cantilever beam is obtained using ANSYS with various conditions of beam with crack. The paper gives the effect of crack on natural frequency of beam with crack depth at different location. This study implies how natural frequency changes as the structure affected due to damage.

II.THEORY

The stability and local flexibility of the beam depends on the material properties, physical dimensions, boundary conditions of the structure. The characteristics of beam greatly depend on the position of crack, depth of crack orentiation of crack and number of cracks.The beam with rectangular crackclamped at one end and free at other endand tapered width cross section and uniform thickness. The crack is assumed to be open crackand no damping is considered.

$$\omega_n = C * \sqrt{\frac{EI}{\rho A L4}}$$

$$I = \frac{bd3}{12}$$

C1= 0.56 for first mode
C2= 3.52 for second mode
C3= 9.82 for third mode
 b0= width of beam at base end and b1= width of beam at small end.

Christides and Barr (1984) considered the effect of crack in continuous beam and calculated stiffness, EI, for a rectangular beam to involve an exponential function given by

$$EI(x) = EI0/(1 + C\exp(-2\alpha(x - xc)/d)$$

Where $C = (I0 - Ic)/Ic$

$I0 = wd^3/12$ and $Ic = w(d-dc)^3/12$ are the area moment of inertia at the crack and dc is the depth of the crack. X is the position along the beam and xc the position of the crack from the fixed end. α is estimated from experiments to be 0.667.
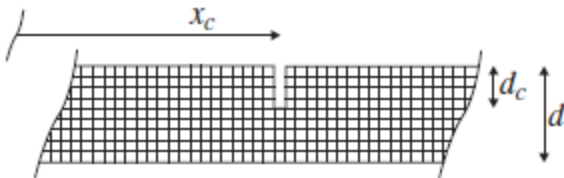

Fig:1 Crack location and depth

III.CRACK CONFIGURATIONS

In this study, static and modal analysis of an aluminium cantilever beam having rectangular crack are studied. The dimensions of the beam are 400mm long 30 mm width and 5 mm thickness. The material properties are modulus of elasticity is $70*10^9$ N/m^2, the density (ρ) 2700 kg/m^3 and poison's ratio (μ) 0.3.

Crack locations at 100 mm and 200 mm with crack depth as 1 mm and 2mm are used to find natural frequency.

IV.FINITE ELEMENT ANALYSIS

The ANSYS 15.0 was used for static and model analysis of an un cracked and cracked beams. In pre-processor, eight key points were created and area created. The area was extruded along normal plane to create a un cracked beam. And by deleting volume two cracks are created. Solid 185 Element selected to mesh the beam with tetrahedral element. Refinement level 3 is used. First three natural frequencies for each case were obtained. Cantilever boundary conditions were used by constraining all degrees of freedom on the left end.
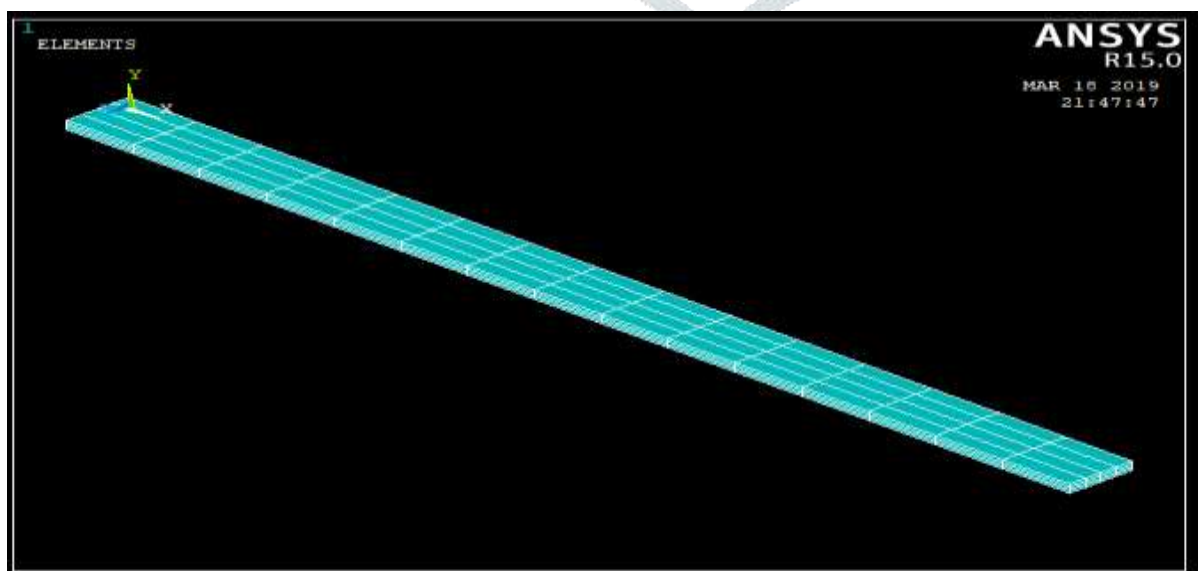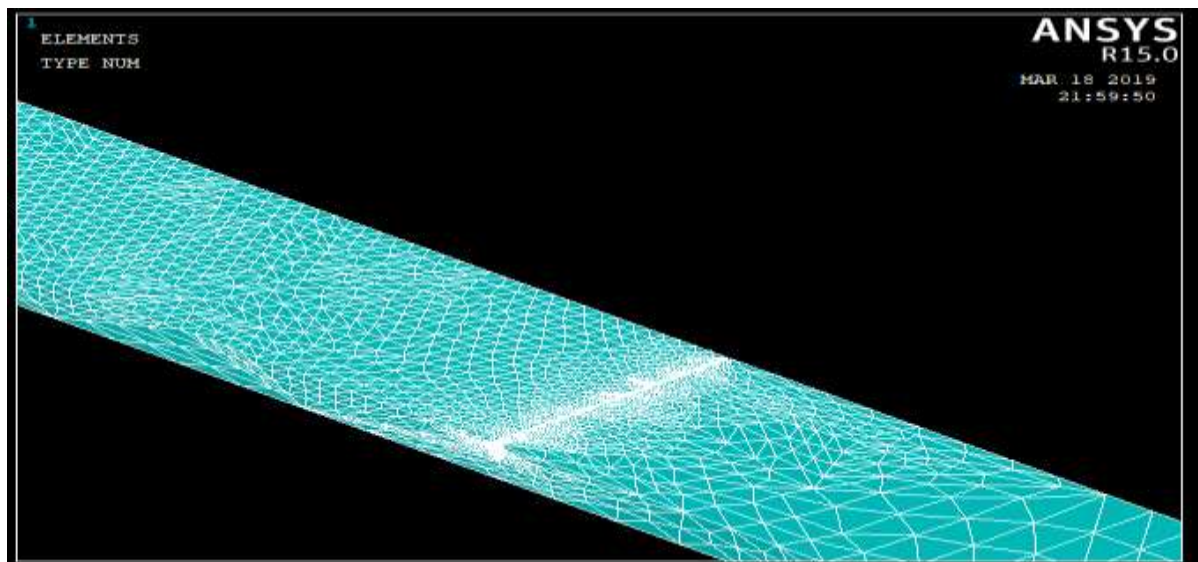

Fig:1 Un cracked beam ANSYS model

Fig: 3 Cracked beam ANSYS model

V. EXPERIMENTAL ANALYSIS

A composite beam of E Glass Epoxy with dimensions 550mm×50mm×10mm is used for analysis. The transverse cracks were created at different locations with varying depths by using Hack saw [32 teeth per inch]. The beam is excited for free vibrations to obtain the natural frequencies. The beam is clamped on a table with the help of clamping device arrangement (baby vice). The impact is applied by striking the hammer at different positions. During free vibrations, the dynamic responses of the beam are measured through the accelerometer as shown in figure. For this test, the position of accelerometer is also varied in order to extract the signals of vibration. The layout of the sensors on the test specimen is depicted in Figure A data acquisition system i.e. vibration analyzer is used to record and transfer measured data to the user interference (laptop) for post processing. Frequency response functions (FRFs) were obtained and analyzed.
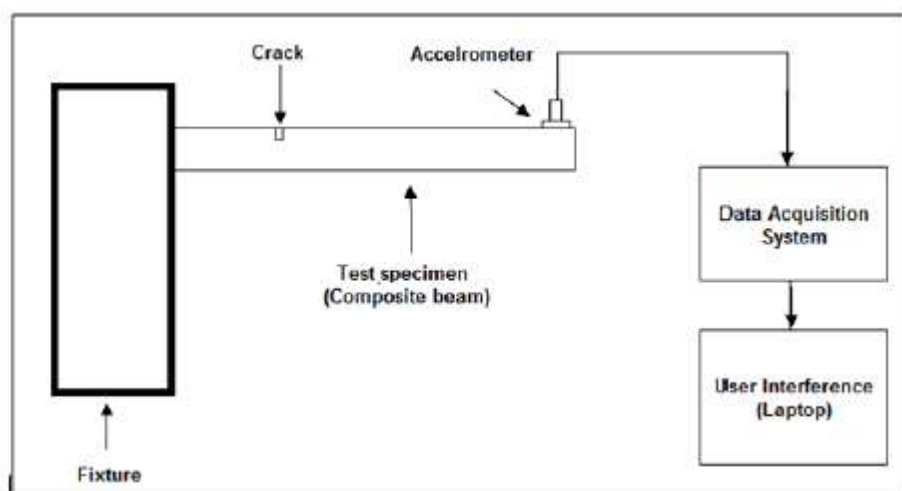

Fig:4 Experimental setup schematic diagram

Nueral network Program in MATLAB

```
%crack size
a1=0.0003:0.0003:0.003;
a2=0.0003:0.0003:0.003;
%crack location
L1=0.04:0.04:0.68;
L2=0.08:0.04:0.72;
%input
x=[a1 a2 L1 L2];
%target (transpose of f1)
```

```
f1=[138.04  138.06  138.06  138.05  138.02  138.05  138.03  138.06  138.05  138.06
138.05  138.04  138.04  138.02  138.03  138.03  138.04  138.01  138.04  138.02  138.01
137.97  137.95  137.99  138.03  138.05  138.04  138.01  137.96  137.92  137.91  137.95
137.98  138.02  137.92  137.01  137.99  137.93  137.86  137.83  137.89  137.97  137.03
138 137.97  137.84  137.78  137.77  137.82  137.89  137.97  137.85  138.01  137.99
];
%initiation
net=newff(minmax(a1),[13 1],{'logsig','purelin','trainln'});
%specifications
net.trainparam.epochs=100;
net.trainparam.goal=1e-25;
net.trainparam.lr=0.01;
%training
net=train(net,x,f1);
%testing
x=sim(net,a1(6))
%answer is 138.0400
```

VI. RESULTS AND DISCUSSION

The results obtained from the experimental and numerical analysis on cracked composite plate for crack depth 2 mm, 4 mm and 6 mm. The length of the crack location is also varied as 110mm, 220mm and 330mm from left hand support.The 1st, 2nd and 3rd mode natural frequencies in case of both cracked and uncracked composite beams for cantilever condition are shown in Table Test data in APPENDEX

VII. CONCLUSION

It can be seen that the natural frequencies for cantilever conditions decrease with the introduction of a crack. It can be concluded that the natural frequency of vibration of the composite plate decreases with increase in depth of the crack. The natural frequency of the beam decreases with increase in length of the crack from left hand fixed end till the mid span of beam and again starts increasing towards free end. The nueral network is able to predict the location and depth of crack.

REFERENCES

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APPENDEX

Test data

Sno	a1	a2	L1	L2	f1	f2	f3
1	0.0003	0.0003	0.04	0.08	7.8668	49.293	138.04
2	0.0003	0.0003	0.08	0.12	7.8678	49.302	138.06
3	0.0003	0.0003	0.12	0.16	7.8683	49.306	138.06
4	0.0003	0.0003	0.16	0.2	7.8682	49.305	138.05
5	0.0003	0.0003	0.2	0.24	7.8671	49.296	138.02
6	0.0003	0.0003	0.24	0.28	7.8694	49.306	138.05
7	0.0003	0.0003	0.28	0.32	7.8686	49.297	138.03

8	0.0003	0.0003	0.32	0.36	7.8697	49.3	138.06
9	0.0003	0.0003	0.36	0.4	7.8889	49.292	138.05
10	0.0003	0.0003	0.4	0.44	7.8702	49.298	138.06
11	0.0003	0.0003	0.44	0.48	7.8699	49.296	138.05
12	0.0003	0.0003	0.48	0.52	7.8702	49.298	138.04
13	0.0003	0.0003	0.52	0.56	7.8706	49.301	138.04
14	0.0003	0.0003	0.56	0.6	7.8699	49.299	138.02
15	0.0003	0.0003	0.6	0.64	7.8701	49.301	138.03
16	0.0003	0.0003	0.64	0.68	7.8697	49.3	138.03
17	0.0003	0.0003	0.68	0.72	7.8697	49.301	138.04
1	0.0006	0.0006	0.04	0.08	7.8591	49.269	138.01
2	0.0006	0.0006	0.08	0.12	7.8594	49.284	138.04
3	0.0006	0.0006	0.12	0.16	7.8602	49.292	138.02
4	0.0006	0.0006	0.16	0.2	7.8635	49.306	138.01
5	0.0006	0.0006	0.2	0.24	7.8644	49.303	137.97
6	0.0006	0.0006	0.24	0.28	7.8646	49.287	137.95
7	0.0006	0.0006	0.28	0.32	7.8665	49.282	137.99
8	0.0006	0.0006	0.32	0.36	7.8679	49.276	138.03
9	0.0006	0.0006	0.36	0.4	7.8683	49.266	138.05
10	0.0006	0.0006	0.4	0.44	7.8683	49.259	138.04
11	0.0006	0.0006	0.44	0.48	7.869	49.261	138.01
12	0.0006	0.0006	0.48	0.52	7.8689	49.265	137.96
13	0.0006	0.0006	0.52	0.56	7.869	49.272	137.92
14	0.0006	0.0006	0.56	0.6	7.8692	49.278	137.91
15	0.0006	0.0006	0.6	0.64	7.8706	49.295	137.95
16	0.0006	0.0006	0.64	0.68	7.8703	49.298	137.98
17	0.0006	0.0006	0.68	0.72	7.8702	49.301	138.02
1	0.0009	0.0009	0.04	0.08	7.8443	49.215	137.92
2	0.0009	0.0009	0.08	0.12	7.8458	49.256	137.01
3	0.0009	0.0009	0.12	0.16	7.8497	49.287	137.99
4	0.0009	0.0009	0.16	0.2	7.8545	49.302	137.93
5	0.0009	0.0009	0.2	0.24	7.8577	49.296	137.86
6	0.0009	0.0009	0.24	0.28	7.8595	49.274	137.83
7	0.0009	0.0009	0.28	0.32	7.8617	49.25	137.89
8	0.0009	0.0009	0.32	0.36	7.8636	49.228	137.97
9	0.0009	0.0009	0.36	0.4	7.8656	49.215	137.03
10	0.0009	0.0009	0.4	0.44	7.8651	49.196	138
11	0.0009	0.0009	0.44	0.48	7.8685	49.214	137.97
12	0.0009	0.0009	0.48	0.52	7.8678	49.218	137.84
13	0.0009	0.0009	0.52	0.56	7.8701	49.242	137.78
14	0.0009	0.0009	0.56	0.6	7.8704	49.262	137.77
15	0.0009	0.0009	0.6	0.64	7.8706	49.279	137.82
16	0.0009	0.0009	0.64	0.68	7.8697	49.286	137.89
17	0.0009	0.0009	0.68	0.72	7.8697	49.294	137.97
1	0.0012	0.0012	0.04	0.08	7.8268	49.159	137.85
2	0.0012	0.0012	0.08	0.12	7.8307	49.233	138.01
3	0.0012	0.0012	0.12	0.16	7.8383	49.291	137.99
4	0.0012	0.0012	0.16	0.2	7.8431	49.303	137.84
5	0.0012	0.0012	0.2	0.24	7.8499	49.293	137.74
6	0.0012	0.0012	0.24	0.28	7.852	49.251	137.67
7	0.0012	0.0012	0.28	0.32	7.8546	49.202	137.74
8	0.0012	0.0012	0.32	0.36	7.8593	49.176	137.91

9	0.0012	0.0012	0.36	0.4	7.8618	49.145	137.01
10	0.0012	0.0012	0.4	0.44	7.8655	49.139	137.03
11	0.0012	0.0012	0.44	0.48	7.8667	49.144	137.9
12	0.0012	0.0012	0.48	0.52	7.8681	49.165	137.72
13	0.0012	0.0012	0.52	0.56	7.8699	49.194	137.57
14	0.0012	0.0012	0.56	0.6	7.8702	49.229	137.55
15	0.0012	0.0012	0.6	0.64	7.8702	49.257	137.63
16	0.0012	0.0012	0.64	0.68	7.8693	49.273	137.76
17	0.0012	0.0012	0.68	0.72	7.87	49.291	137.92
1	0.0015	0.0015	0.04	0.08	7.7981	49.062	137.71
2	0.0015	0.0015	0.08	0.12	7.8079	49.201	138.01
3	0.0015	0.0015	0.12	0.16	7.8181	49.272	137.92
4	0.0015	0.0015	0.16	0.2	7.8276	49.296	137.7
5	0.0015	0.0015	0.2	0.24	7.8351	49.278	137.49
6	0.0015	0.0015	0.24	0.28	7.8425	49.223	137.46
7	0.0015	0.0015	0.28	0.32	7.8497	49.166	137.63
8	0.0015	0.0015	0.32	0.36	7.8536	49.094	137.84
9	0.0015	0.0015	0.36	0.4	7.8587	49.058	138.02
10	0.0015	0.0015	0.4	0.44	7.862	49.036	138
11	0.0015	0.0015	0.44	0.48	7.8652	49.054	137.81
12	0.0015	0.0015	0.48	0.52	7.8667	49.08	137.52
13	0.0015	0.0015	0.52	0.56	7.869	49.132	137.3
14	0.0015	0.0015	0.56	0.6	7.8701	49.183	137.24
15	0.0015	0.0015	0.6	0.64	7.8699	49.227	137.37
16	0.0015	0.0015	0.64	0.68	7.8718	49.275	137.66
17	0.0015	0.0015	0.68	0.72	7.8721	49.299	137.89
1	0.0018	0.0018	0.04	0.08	7.7674	48.959	137.56
2	0.0018	0.0018	0.08	0.12	7.7809	49.155	137.99
3	0.0018	0.0018	0.12	0.16	7.7944	49.268	137.9
4	0.0018	0.0018	0.16	0.2	7.8087	49.296	137.55
5	0.0018	0.0018	0.2	0.24	7.8205	49.264	137.25
6	0.0018	0.0018	0.24	0.28	7.8306	49.188	137.2
7	0.0018	0.0018	0.28	0.32	7.8388	49.093	137.4
8	0.0018	0.0018	0.32	0.36	7.8469	49.01	137.75
9	0.0018	0.0018	0.36	0.4	7.8528	48.943	137.99
10	0.0018	0.0018	0.4	0.44	7.8574	48.9	137.96
11	0.0018	0.0018	0.44	0.48	7.861	48.924	137.67
12	0.0018	0.0018	0.48	0.52	7.8653	48.969	137.25
13	0.0018	0.0018	0.52	0.56	7.88681	49.049	137.95
14	0.0018	0.0018	0.56	0.6	7.87	49.132	137.9
15	0.0018	0.0018	0.6	0.64	7.8704	49.2	137.1
16	0.0018	0.0018	0.64	0.68	7.8718	49.257	137.45
17	0.0018	0.0018	0.68	0.72	7.871	49.284	137.78
1	0.0021	0.0021	0.04	0.08	7.7269	48.826	137.37
2	0.0021	0.0021	0.08	0.12	7.75	49.103	137.96
3	0.0021	0.0021	0.12	0.16	7.7668	49.257	137.83
4	0.0021	0.0021	0.16	0.2	7.7844	49.293	137.9
5	0.0021	0.0021	0.2	0.24	7.7997	49.247	136.92
6	0.0021	0.0021	0.24	0.28	7.8138	49.138	136.84
7	0.0021	0.0021	0.28	0.32	7.8254	49	137.13
8	0.0021	0.0021	0.32	0.36	7.8375	48.886	137.63
9	0.0021	0.0021	0.36	0.4	7.8463	48.806	137.96

10	0.0021	0.0021	0.4	0.44	7.8524	48.752	137.93
11	0.0021	0.0021	0.44	0.48	7.8604	48.768	137.53
12	0.0021	0.0021	0.48	0.52	7.8613	48.82	136.89
13	0.0021	0.0021	0.52	0.56	7.8667	48.939	136.49
14	0.0021	0.0021	0.56	0.6	7.8691	49.059	136.43
15	0.0021	0.0021	0.6	0.64	7.8696	49.15	136.67
16	0.0021	0.0021	0.64	0.68	7.8717	49.235	137.2
17	0.0021	0.0021	0.68	0.72	7.8725	49.285	137.69
1	0.0024	0.0024	0.04	0.08	7.673	48.65	137.12
2	0.0024	0.0024	0.08	0.12	7.7055	49.03	137.92
3	0.0024	0.0024	0.12	0.16	7.7321	49.231	137.73
4	0.0024	0.0024	0.16	0.2	7.7564	49.293	137.11
5	0.0024	0.0024	0.2	0.24	7.7777	49.232	136.57
6	0.0024	0.0024	0.24	0.28	7.7932	49.076	136.4
7	0.0024	0.0024	0.28	0.32	7.8102	48.897	136.81
8	0.0024	0.0024	0.32	0.36	7.8251	48.736	137.46
9	0.0024	0.0024	0.36	0.4	7.8361	48.596	137.92
10	0.0024	0.0024	0.4	0.44	7.8468	48.554	137.9
11	0.0024	0.0024	0.44	0.48	7.8554	48.605	137.36
12	0.0024	0.0024	0.48	0.52	7.86	48.686	136.58
13	0.0024	0.0024	0.52	0.56	7.8644	48.802	135.92
14	0.0024	0.0024	0.56	0.6	7.8683	48.959	135.78
15	0.0024	0.0024	0.6	0.64	7.8702	49.104	136.21
16	0.0024	0.0024	0.64	0.68	7.8712	49.206	136.89
17	0.0024	0.0024	0.68	0.72	7.872	49.272	137.55
1	0.0027	0.0027	0.04	0.08	7.62	48.479	136.891
2	0.0027	0.0027	0.08	0.12	7.6534	48.943	137.86
3	0.0027	0.0027	0.12	0.16	7.6849	48.202	137.62
4	0.0027	0.0027	0.16	0.2	7.7176	48.283	136.76
5	0.0027	0.0027	0.2	0.24	7.7454	48.206	136.05
6	0.0027	0.0027	0.24	0.28	7.7688	49	135.89
7	0.0027	0.0027	0.28	0.32	7.7907	48.762	136.42
8	0.0027	0.0027	0.32	0.36	7.8112	48.562	137.28
9	0.0027	0.0027	0.36	0.4	7.8246	48.372	137.86
10	0.0027	0.0027	0.4	0.44	7.8365	48.294	137.79
11	0.0027	0.0027	0.44	0.48	7.8501	48.367	137.12
12	0.0027	0.0027	0.48	0.52	7.8564	48.477	136.11
13	0.0027	0.0027	0.52	0.56	7.8634	48.652	135.3
14	0.0027	0.0027	0.56	0.6	7.8666	48.827	134.9
15	0.0027	0.0027	0.6	0.64	7.8687	48.029	135.6
16	0.0027	0.0027	0.64	0.68	7.8723	48.182	136.54
17	0.0027	0.0027	0.68	0.72	7.8724	48.262	137.39
1	0.003	0.003	0.04	0.08	7.5523	48.27	136.59
2	0.003	0.003	0.08	0.12	7.5899	48.844	137.8
3	0.003	0.003	0.12	0.16	7.6353	49.189	137.51
4	0.003	0.003	0.16	0.2	7.6737	49.273	136.39
5	0.003	0.003	0.2	0.24	7.7025	49.156	135.35
6	0.003	0.003	0.24	0.28	7.7414	48.916	135.32
7	0.003	0.003	0.28	0.32	7.768	48.607	135.97
8	0.003	0.003	0.32	0.36	7.7928	49.323	137.06
9	0.003	0.003	0.36	0.4	7.8129	48.118	137.83
10	0.003	0.003	0.4	0.44	7.8288	48.031	137.75

11	0.003	0.003	0.44	0.48	7.8418	48.042	136.8
12	0.003	0.003	0.48	0.52	7.863	48.737	136.3
13	0.003	0.003	0.52	0.56	7.861	48.46	134.56
14	0.003	0.003	0.56	0.6	7.8658	48.717	134.29
15	0.003	0.003	0.6	0.64	7.8697	48.955	134.88
16	0.003	0.003	0.64	0.68	7.8724	49.14	136.03
17	0.003	0.003	0.68	0.72	7.8715	49.242	137.16