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Crack detection in structures using statistical parameters

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ABSTRACT

In this paper, a simple cantilever beam has been considered to detect the presence of crack from measured vibration data using signal processing techniques. A beam with crack at different locations and without crack was considered for the experiment. At different crack location, statistical parameters and sensitivity analysis such as Crest Factor, Kurtosis and RMS were used for crack detection in a cantilever beam. It was observed that all parameters were good in indicating the presence of crack.

Keywords: RMS, Crest Factor, Kurtosis, Crack Detection, Signal Processing Techniques.

1. INTRODUCTION

Continuous monitoring and inspection of fitness, strength and condition of structures as well as damage detection of structures and systems at the very early stage is greatly significant in: engineering and construction; health and safety; production facilities and general industrial systems. As a result, researchers all over the world are digging deep and coming up with solution methods and procedures to damage and detection of structures (Ezekiel C. K. 2009). In the last few years, there is great determination and contentious efforts witnessed by scientist and researchers in the development of non-destructive techniques (NDT) that can reliably detect faults, diagnose the type of faults, localize the fault, determine its severity and predict the remaining life of structures. In literature, it is evident that vibration based methods are extensively used for damage recognition in a beam like dynamic structure.

Traditional localized non-destructive techniques for damage detection in machine and structural components pose some drawbacks. It is required to have knowledge of the location of damage as well as the proportion of damage for easy inspection during assessment (Suraj et al., 2014). In order to detect a crack the whole component requires scanning which becomes uneconomical for long beams and pipelines which are widely used in bridges, power plants, railway etc. This makes the process tedious, time consuming and costly (Deokar and Wakchaure, 2011). However, global vibration based damage detection methods offer a low-cost, timely and non-destructive means of detecting and locating cracks in structures (Ozer and Ornek, 2016; Allurkar and Patil, 2016)

According to Ravi et al. (2015), about 80% of failures of rotating machinery lead to significant changes in vibration. By examining these changes, fault detection can be determined from the vibration data (Suraj et al., 2014). The change in vibration parameters e.g. acceleration responses, signals, stiffness and increase in damping therefore becomes a major source of information available from the machinery for fault detection and diagnosis (Deokar and Wakchaure, 2011; Prasad and Vinod, 2013). Ganesh et al. (2016) anticipated that damage or crack in overstressed zones could be as a result of continuous loading conditions of members of engineering structures and systems. Therefore, they concluded that it is it is important to monitor variations or changes in response parameters of a configuration or pattern for effective assessment of safety, structural integrity and performance of structures.

Cracks regarded as physical discontinuity in the geometry of structures changes the dynamic behavior of a component (Allurkar and Patil 2016; Rahul Sathe and Ajay Pathak (2016). They may be as a result of fatigue, mechanical defects, environmental effects or faults from manufacturing process; cracks however could be on the surface or inside the material (Parhi et al., 2012; Pushkar et al. 2014). A particular method of crack detection known as vibration based method is of great importance in quantifying and detecting cracks in structures. This method takes into consideration statistical parameters and sensitivity, mechanical independence, mode shapes, natural frequency and other range of characterizing parameters (Dubey and Kapila, 2012). The presence of cracks and it location can be characterized by changes observed when vibration signals are being processed. Hence, in this paper a parametric study has been done to validate the applicability and efficiency of the suggested methods for crack detection.

2. SIGNAL PROCESSING TECHNIQUES USED FOR CRACK DETECTION

According to Vimal et al. (2013), the supporting expertise or technique for quick understanding, transformation and generation of information is called signal processing. This technique is a very favorable method for researchers, scientist and engineers in NDT field. It involves mathematical manipulation, operation and application of signals. It is characterized by the representation of unconnected domain indicators by a classification of figures or symbols and the processing of these indicators. Time Domain Techniques (TDT), Frequency Domain Technique (FDT), Time Frequency Analysis (TFA) are some of the processing methods or techniques employed in crack detection.

2.1. Time Domain Statistical Parameters for Crack Detection

The investigation of diverse constraints and parameters with respect to time is referred to as time domain. These constraints are quite diverse and may include: time series for cost-effective or economic dataset; time series for environmental dataset; physical signals or mathematical functions (Vimal et al., 2013). Fault and failure analysis is possible with the help of time series signal. This is achievable by investigating and analyzing dataset obtained from vibration equipment (Yong-Ham, 2006). Statistical parameters associated with time domain technique includes Root Mean Square, Crest Factor and Kurtosis etc., they are obtained from measured vibration response of a structure and are useful for detecting incipient defect in structures Lee J. (2005). They were described by (Lakis, 2007) as indicators used for machine condition monitoring and fault detection. Songpon et al. (2014) simulated faults conditions using boundary decision generation from vibration signals of statistical parameters for crack detection. Biswal et al. (2016) reviewed that Statistical parameters such as skewness, kurtosis, root mean square (rms) value, crest factor, shape factor, clearance factor, impulse factor etc. have been used for fault detection and fault severity prediction.

Time domain technique is one of the easy methods of detecting, analyzing and diagnosing verified or documented vibration signals (Vimal et al., 2013; Yong-Ham et al. (2006). Yong-Ham et al. (2006) study presented uncovering of the existence of defects in low speed bearing. This was done by analysis of vibration signals with statistical parameters. In the research conducted, a correlation in the middle of the revolving speed of the bearing and the statistical constraints were determined. It was noted by Lee

(2005) and Lakis (2007) that statistical parameters are useful parameters for detecting damages in rolling element bearing, gearboxes etc. Dron et al. (2004) pointed out that statistical parameters are commonly used in antifriction bearing to detect the presence of the impulsive nature of vibration signal due to the defect in the bearing. It was identified that RMS, crest factor, probability density moments (skewness, kurtosis) are the most popular statistical time domain parameter for bearing defect detection (Hiremath, and Reddy, 2014).

2.1.1. RMS ANALYSIS: One of the most relevant statistical parameter is the RMS. This is a measure of the content of energy in the vibration indicator or signal (Vimal et al. 2013). It is suited for steady-state signals and it is considered by most ultrasound detector manufacturers as one of the best indicator for condition monitoring (Yong-Ham, 2006).

2.1.2. CREST FACTOR: This is also referred to as the "peak-to-rms" ratio, defined as the ratio of peak value or level of a waveform to its RMS level in a system (Vimal et al. 2013; Lakis, 2007; Yong-Ham, 2006).

2.1.3. KURTOSIS ANALYSIS: Kurtosis analysis is a classic analysis obtained from the fourth order fundamental moment (usually moment about the mean) of bounty likelihood distribution. It has to do with finding the middle ground during measurement between the unresponsive lower moments and the over-responsive higher moments (Yong-Ham, 2006). Hadjileoutiadis *et al.,* (2005) demonstrated the use of kurtosis to identify damages in structure by carrying out an experiment on a Plexiglas beams; the size of the damage was related to the measured kurtosis which increases with crack depth while the location of damage was identified by a sharp change in spatial variation of the analyzed response.

3. RESULTS AND DISCUSSION

3.1. RMS

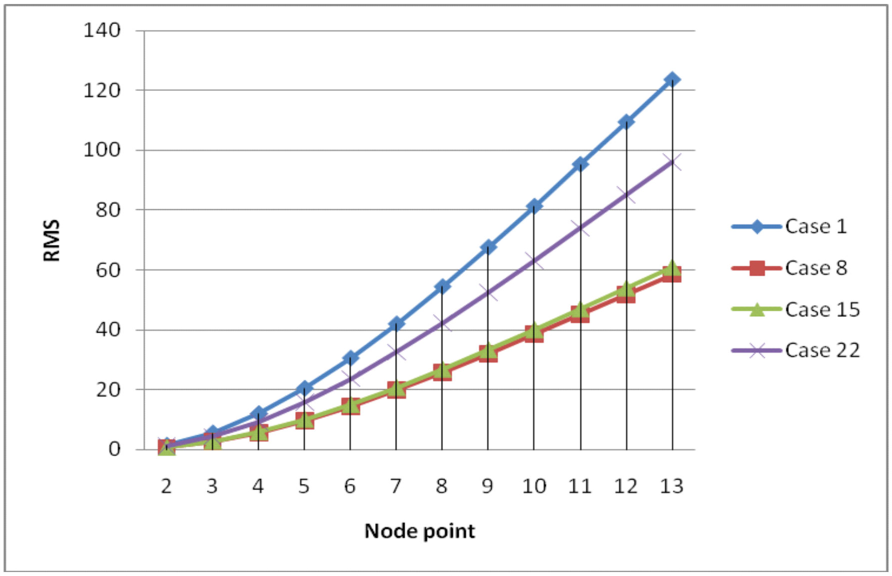

Figure 1 RMS vs Node point

Table 1 RMS Values

Root Mean Square				
Node Point	**Case 1** **(Healthy)**	**Case 8** $x_c = 250, c_r = 5\%$	**Case 15** $x_c = 450, c_r = 10\%$	**Case 22** $x_c = 650, c_r = 15\%$
2	**1.4572**	**0.68915**	**0.72051**	**1.1335**
3	**5.5825**	**2.6391**	**2.7569**	**4.3393**
4	**12.032**	**5.6969**	**5.9363**	**9.3465**
5	**20.464**	**9.7017**	**10.09**	**15.888**

6	30.545	14.484	15.069	23.706
7	41.955	19.893	20.716	32.55
8	54.39	25.785	26.868	42.209
9	67.573	32.027	33.386	52.469
10	81.258	38.506	40.152	63.121
11	95.24	45.125	47.064	74.005
12	109.36	51.81	54.046	85
13	123.53	58.514	61.049	96.029

Table 1 shows the values of RMS calculated for the acceleration responses selected node points for the four cases (1, 8, 15, 22). These values are also represented graphically in Figure 1.

From Figure 1 it has been observed that the RMS increases along the beam from Node 2 to Node 13 (free end) and the value of RMS at the nodes for the healthy case (Case 1) is generally higher compared to the faulty cases (Case 8, 15, 22). This implies that when there is crack in the beam the value of RMS reduces which seems to indicate the presences of crack. However the low level crack (Case 8) shows the maximum drop in RMS than other crack cases while high level crack (Case 22) show the least drop in RMS. Hence RMS seems to be a good indicator of the presence of crack.

3.2. CREST

The values of Crest Factor calculated from the RMS for the acceleration responses at all nodes of four cases (1, 8, 15, 22) and are listed in Table 2 which are also represented graphically in Figure 2.

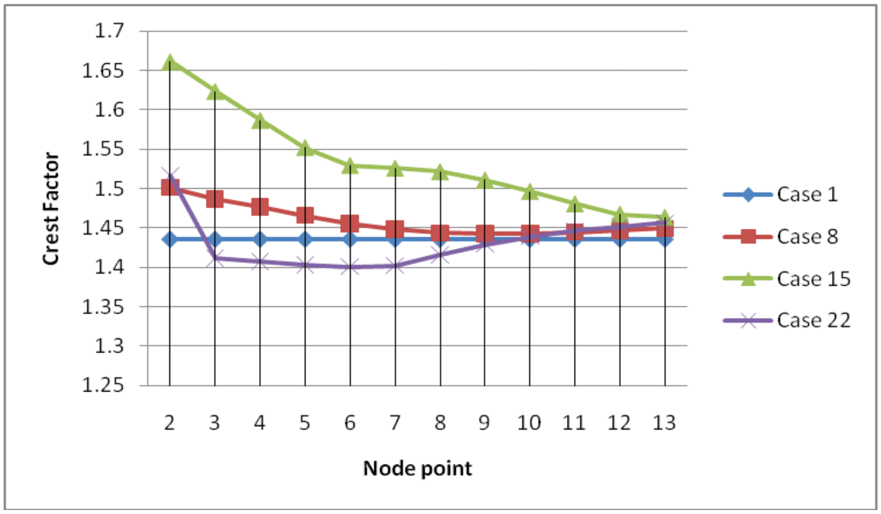

Figure 2 Crest Factor vs Node Points

Table 2 Crest Factor Values

CREST FACTOR

Node Point	Case 1 (Healthy)	Case 8 x_c = 250, c_r = 5%	Case 15 x_c = 450, c_r = 10%	Case 22 x_c = 650, c_r = 15%
2	1.4357	1.5014	1.6613	1.5162
3	1.4357	1.4870	1.6236	1.4120
4	1.4357	1.4765	1.5868	1.4074
5	1.4357	1.4660	1.5522	1.4034
6	1.4357	1.4558	1.5295	1.4008
7	1.4357	1.4481	1.5261	1.4024
8	1.4357	1.4437	1.5215	1.4161
9	1.4357	1.4425	1.5109	1.4291

10	**1.4357**	**1.4428**	**1.4965**	**1.4391**
11	**1.4357**	**1.4448**	**1.4806**	**1.4463**
12	**1.4357**	**1.4472**	**1.4675**	**1.4519**
13	**1.4357**	**1.4494**	**1.4635**	**1.4562**

Fig 2 shows that at healthy state of the beam, the values of crest factor are the same in all the node points but when there is crack in any of the locations in the beam the values of crest factor changes in a non-uniform manner in all the node points. This implies that Crest Factor can detect the presence of crack.

3.3. KURTOSIS

Table 3 Kurtosis Values

KURTOSIS

Node Point	**Case 1**	**Case 8**	**Case 15**	**Case 22**
	(Healthy)	**x_c = 250, c_r = 5%**	**x_c = 450, c_r = 10%**	**x_c = 650, c_r = 15%**
2	**1.5005**	**1.5061**	**1.5365**	**1.5189**
3	**1.5005**	**1.5038**	**1.5273**	**1.5145**
4	**1.5005**	**1.5025**	**1.5188**	**1.5106**
5	**1.5005**	**1.5016**	**1.5121**	**1.5074**
6	**1.5005**	**1.5012**	**1.5080**	**1.5049**
7	**1.5005**	**1.5011**	**1.5059**	**1.5031**
8	**1.5005**	**1.5011**	**1.5049**	**1.5020**
9	**1.5005**	**1.5011**	**1.5043**	**1.5014**
10	**1.5005**	**1.5011**	**1.5039**	**1.5011**
11	**1.5005**	**1.5011**	**1.5038**	**1.5011**
12	**1.5005**	**1.5011**	**1.5040**	**1.5013**
13	**1.5005**	**1.5011**	**1.5044**	**1.5015**

A computational program has been developed to compute the value of kurtosis at all node points. The values of Kurtosis of all nodes computed for four cases (1, 8, 15, 22) are listed in Table 3 and represented graphically in Figure 3.

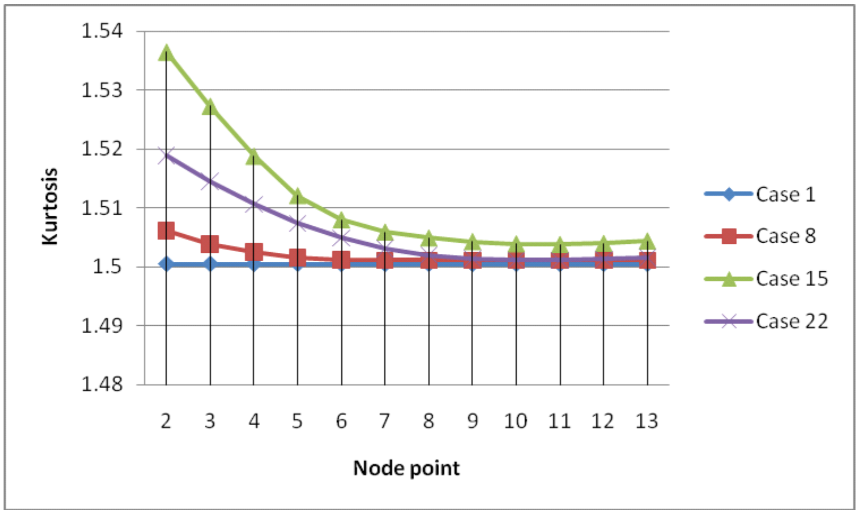

Figure 3 Kurtosis vs Node point

Figure 3 show that kurtosis remains constant when the beam is healthy but when there is crack in the beam, kurtosis increases in all the node point but higher towards the fixed end. The value of kurtosis is higher for crack case 15 (c_r = 10%) compared to other crack cases and the shape of Kurtosis for all crack cases is similar, which indicated the presence of crack. Also, further analysis using percentage of faulty kurtosis (**%K$_F$**), which is calculated using $\%K_F = (K_{FN} - K_{HN}) / K_{FN}$, where **K$_{FN}$** and **K$_{HN}$** are the values of kurtosis for faulty and healthy states of the beam respectively. This has been calculated for all the node points for the three crack cases (8,15,22) and the values are listed in the Table 4.

Table 4 Percentage of Faulty kurtosis Values

Node Point	Crack case 8	Crack case 15	Crack case 22
	%K$_{F8}$	%K$_{F15}$	%K$_{F22}$
2	0.0037	0.023	0.0121
3	0.0022	0.0175	0.009
4	0.0013	0.012	0.007
5	0.0007	0.0077	0.0046
6	0.0005	0.005	0.0029
7	0.0004	0.0036	0.0017
8	0.0004	0.0029	0.001
9	0.0004	0.0025	0.0006
10	0.0004	0.0022	0.0004
11	0.0004	0.0022	0.0004
12	0.0004	0.0023	0.0005
13	0.0004	0.0026	0.00067

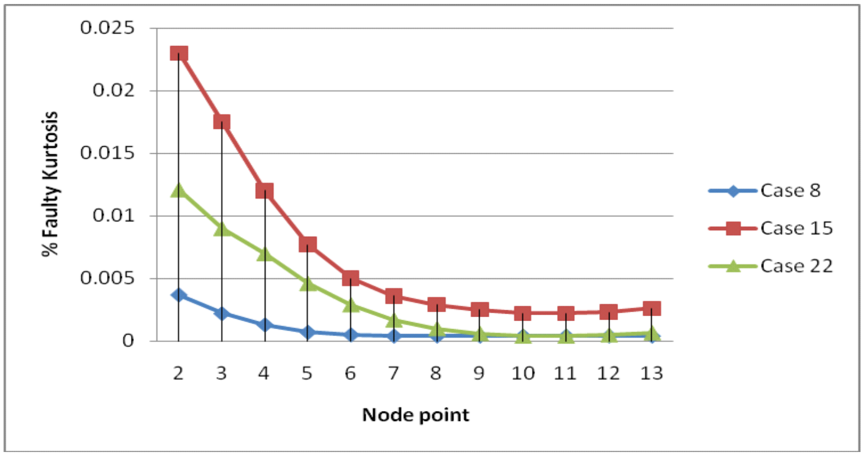

Figure 4 %K$_F$ vs Node point

From Figure 4 it has been observed that the shape of Kurtosis for all crack cases are similar and the value of kurtosis for crack case 15(c_r =10%) is higher when compared to other crack cases. Hence the crack size and location are not detected using percentage of faulty kurtosis.

4. CONCLUSION

Statistical parameters such as RMS, Crest Factor and Kurtosis were used for crack detection in a cantilever beam. It was observed that the value of RMS at the nodes for the healthy case is generally higher compared to the faulty cases, which implies that when there is crack in the beam the value of RMS reduces which indicated the presences of crack. For the crest factor, the value of healthy state of the beam are the same in all the node points but when there is crack in any of the locations in the beam, the values of crest factor changes in a non-uniform manner in all the node points, which implies that Crest Factor can detect the presence of crack. For kurtosis, it remains constant when the beam is healthy but when there is crack in the beam, kurtosis increases in all the node point but higher towards the fixed end. Also, further analysis using percentage of faulty kurtosis gave similar result. Hence RMS, Crest Factor and Kurtosis seem to be a good indicator of the presence of crack.

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Conflicts of Interest: The authors declare no conflict of interest.

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