Experimental and Numerical Study of The Crack Position and Depth Effects on Natural Frequencies of Turbine Blades.

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Abstract

Turbine blades are the most important and expensive part of turbines; the losses due to maintenance is very large so must be analyze the causes of failure that may occur due to manufacturing defects or vibrations resulting from operating and other service conditions.

In this work will, focus on vibrationthat occurs due to operating conditions. The blade represents as a cantilever beam manufactured fromaluminum, a square crack have constant breadth 5 mm formed on the blade for positions from (5 to 30) cm to fixed end with different crack depths (2,4,6) mm.The experimental work results were computed by using impulse test, and numerical result gain using finite element method. Good agreement was found between the results.The results showed that the increasing in crack's depth caused decreasing in the fundamental natural frequency of blade for all crack positions.

Key words: Cracked blade, Turbine blade, Cantilever beam, Natural frequency.

1. Introduction:

Recently, vibration investigation of a damaged structure has become an approach for failure diagnosis. A crack in a structure introduces change the natural frequency of the structure, and from this change, the crack position and crack size can be investigated. [1] presented the one dimensional .theory for the .flexural motion of an Euler beam containing one or more pairs of similar cracks. The theory depends on modeling the stress field disorder induced by the crack .in an approximate way which .includes an exponential decay coefficient, which has been estimated from the experimental data on natural frequency change as a function for crack depth. [2] used a non-destructive analysis procedure to spot position and size of a crack in a cantilever beam, measured the frequencies and mode shapes from modal tests, and utilized an identification method to spot the cracked element supported a simple reduction in stiffness to identify the crack location and also the crack size. They found that the procedure also can be extended to structures with multiple cracks. [3] investigated the influence of a transverse surface crack on the mechanical impedance of cracked beams under different boundary conditions; analytically and experimentally. They modeled the crack by the convenient equivalent spring connecting the two segments of the beam, and showed that the mechanical impedance changes substantially, the changes depend on the location and the size of the crack. [4] investigated the vibration analysis on a cantilever beam with two open transverse cracks, and used a suitable boundary condition to find out the natural frequency and mode shapes. It was verified that the presence of crack decreases the natural frequency of vibration, and the mode shape is changed.[5] simulated the crack by an equivalent spring, connecting the two segments of the beam, and got an equation relates the natural .frequencies of the beam .and crack .location. It was found the relationship .between the natural frequencies and the developed crack's location .and size. [6] investigated the change in natural frequencies with the presence of crack at different locations and with various depths. ABAQUS software used for the analysis, and the cracked beams with different boundary conditions were analyzed. It was found that for cantilever beam, the largest effect has been felt at the fixed end, and the change in frequencies is not only a function of crack depth and crack location, but also of the mode number. [7] studied the natural frequency of a cracked beam with completely different supports: simply support beam and clamped beam; analytically and numerically with various crack depths and locations influence, compared the analytical results with the numerical results, and concluded that the biggest error percentage was about (1.8 %). He found that the crack near the middle of the beam has more influence on the stiffness and the natural frequency of beam than other positions; the natural frequency of beam decreasing with increasing the crack depth as a sequence decreasing of beam stiffness at any location of the crack within the beam. [8] used the finite element method to study the effect of an open crack on the modal parameters of the cantilever beam subjected to free vibration. They found that the structure vibrates with more frequency in the status of crack presence away from the fixed end. [9] developed a viable relationship between natural frequency and mode shape at different crack depth by using finite element analysis software package ANSYS and the results was compared with the result obtained from the experiment. They were seen that natural frequencies increase and Mode shapes decrease as the crack depth increases. [10] studied the effect of crack on the natural frequency and mode shape of a cantilever beam type serial manipulator. They used Overall flexibility matrix to analysis of crack in used beam. They found that the frequency reduction is increasing as depth if crack increases, and frequency reduction decreases as the crack moves from fixed end to free end. [11] studied the presence of crack for a simple cantilever beam from vibration data. They took a beam with crack at different locations and another one without crack for the experiments and determined natural frequencies, mode shapes and acceleration responses at different crack locations. It was found that natural frequencies and mode shapes give no significant presence of crack, but time domain acceleration response method was able to detect the presence of crack.

The .main object of this work .is studies the effect of crack depths and crack positions on the natural frequency of turbine blade.

2. Experimental work

2.1 Material properties

An aluminum 6061 T6 plate was cutted as a beam to represent as turbine blade.The properties of material and the chemical composition of the samples is shown in tables (1) and (2) respectively [12].

Table (1): Properties of material of samples.

Properties	Values
Density(kg/m^3)	2700
Modulus of elasticity (GPa)	68.9
Yield Strength (MPs)	276
Poison's ratio	0.33

Table (2): Chemical composition of plate material.

Component	Wt.%
AL	
Cr	0.04 – 0.35
Cu	0.15 – 0.40
Fe	Max 0.70
Mg	0.80 – 1.20
Mn	0.15
Other ,each	0.05
Other , total	Max 0.15
Si	0.40 - 0.80
Ti	0.15
Zn	0.25

2.2 Samples

The blade represented as a cantilever beam, the plate cutted with uniform exterior dimensions (600 mm length x 22 mm width x 10 mm thickness), a square cracked is formed with constant breadth 5 mm at different positions (50, 100, 150, 200, 250, 300) mm from fixed end.

2.3 Test of Vibration

The impulse test was utilized to find the natural frequencies

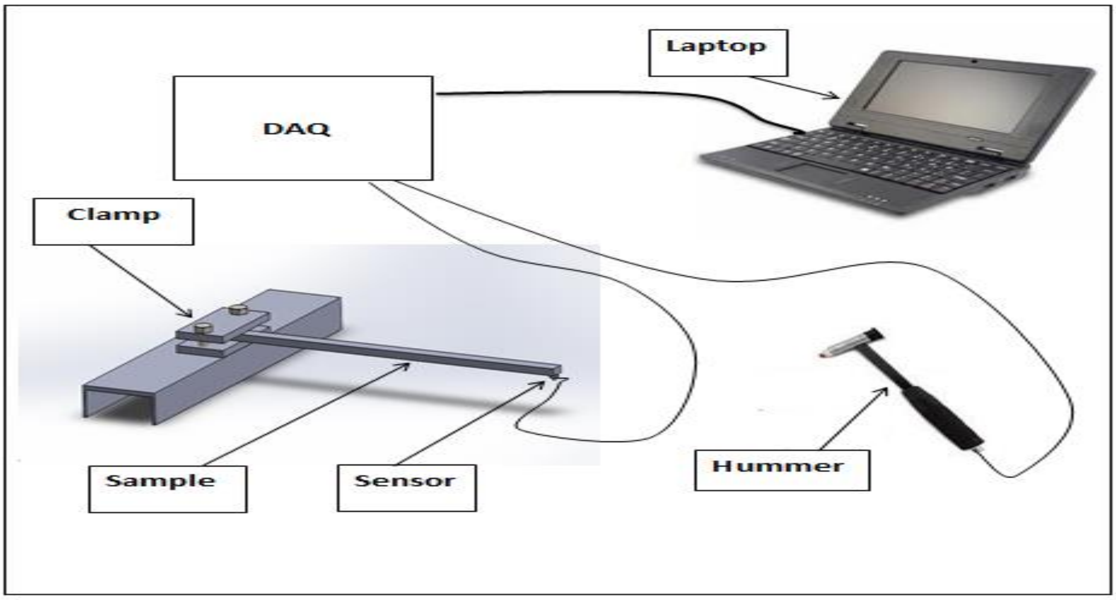

Figure (1): Schematic chart showing the connection methodtest rig.

The equipment that used in experimental work as shown in figure (1) are:

- Impact hummer type IH-01
- Accelerometer type YMC161A
- Data acquisition system type YMC 9004.

The experimental natural frequency amplitude curves was found from Frequency response function (FRF) by using YMC 9600 program in vibration system test, as shows in figure (2).

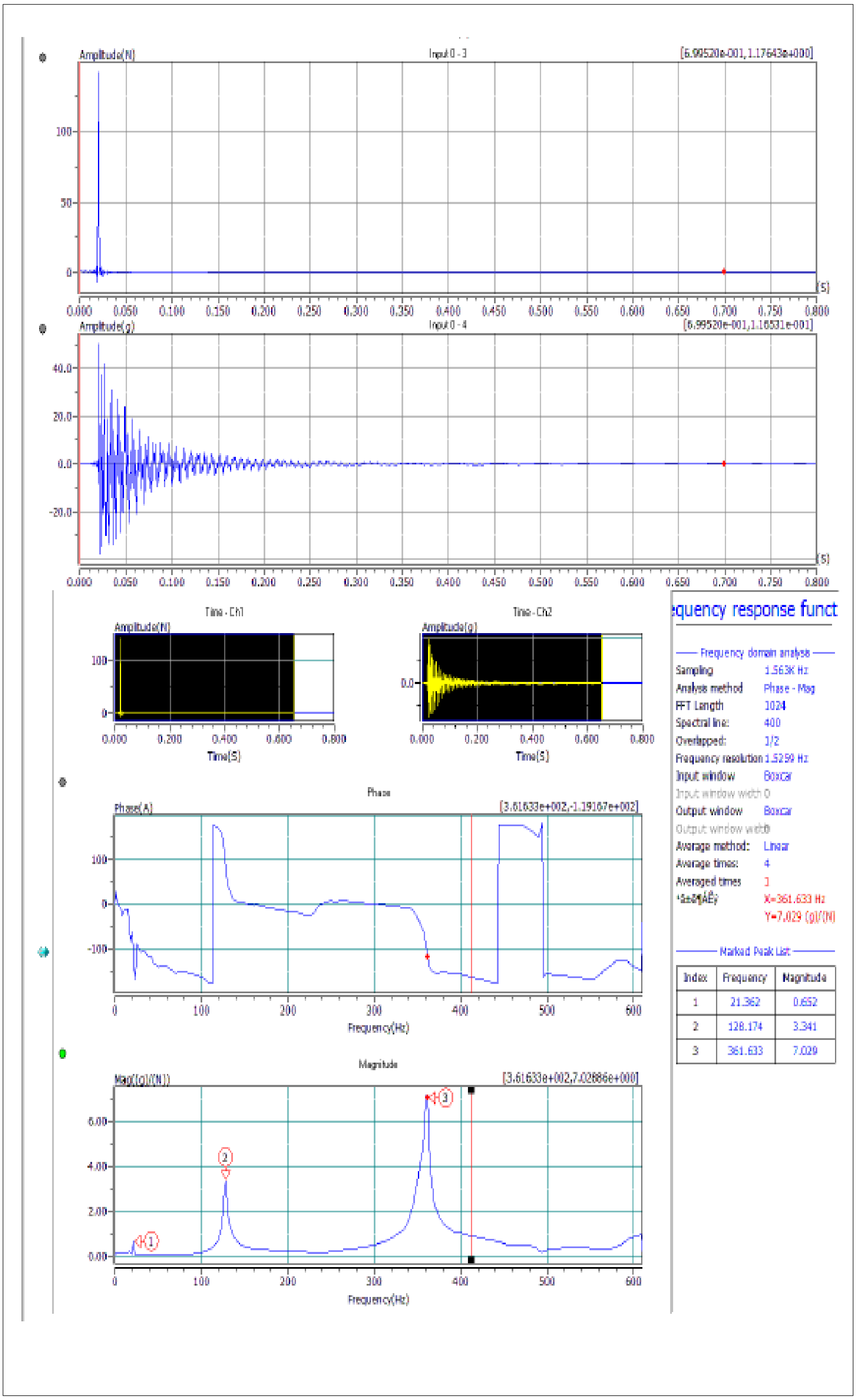

Figure (2): Impulse test for 20 cm position and 4 mm depth of crack.

3 Finite Element Method (FEM)

ANSYS Workbench software, version 19.1, is used to calculate the natural frequencies and its vibration mode shapes of blade, as shown in figure (3) and figure (4).

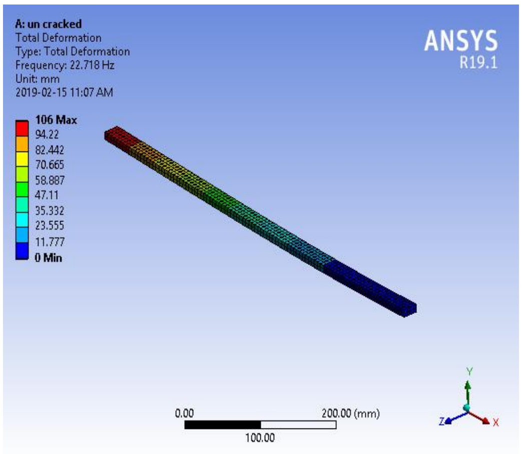

Figure (3): First mode of un cracked blade

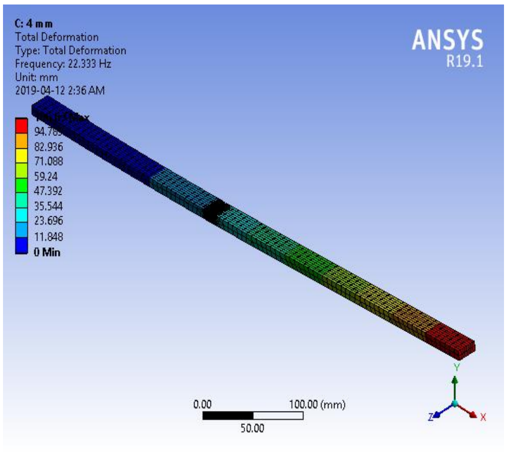

Figure (4): First mode of cracked blade.

4. Results and Discussions

Tables (3), (4), and (5) show the first, second, and third natural frequencies of cracked blade, For all crack positions, the natural frequencies is decreasing when the crack depths is increasing, and the effect of crack near the fixed end of blades on the natural frequencies is larger than the far position; therefore, the crack positions will take until the middle of blades. Good agreement between the results were found .The maximum error between the results was about 12 %.

Table (3): First natural frequency of cracked blade

Position of crack(cm)	Depth of crack (mm)	First natural frequency (Hz)		Error %
		numerical	experimental	
Without crack	/	22.718	20.311	10.60
5	2	22.352	19.836	11.26
	4	21.254	19.546	8.04
	6	18.469	19.436	5.24
10	2	22.397	20.436	8.76
	4	21.583	19.836	8.09
	6	19.285	20.162	4.55
15	2	22.504	21.762	3.30
	4	21.876	20.836	4.75
	6	20.062	21.362	6.48
20	2	22.57	21.862	3.14
	4	22.127	21.363	3.45
	6	20.778	/	/
25	2	22.623	21.962	2.92
	4	22.333	21.952	1.71
	6	21.404	19.836	7.33
30	2	22.663	22.836	0.76
	4	22.493	22.322	0.76
	6	21.915	18.311	16.45

Table (4): Second natural frequency of cracked blade

Position of crack(cm)	Depth of crack (mm)	Second natural frequency (Hz)		Error %
		numerical	experimental	
Without crack	/	142.19	131.26	7.69
5	2	141.18	135.80	3.81
	4	138.21	129.36	6.40
	6	132.12	137.39	3.99
10	2	141.88	137.32	3.21
	4	141.65	134.38	5.13
	6	140.61	133.65	4.95
15	2	142.17	132.75	6.63
	4	142.07	129.7	8.71
	6	141.7	125.78	11.24
20	2	141.73	135.80	4.18
	4	140.27	128.17	8.63
	6	135.98	123.59	9.11
25	2	141.15	132.75	5.95
	4	137.92	127.7	7.41
	6	128.95	119.01	7.71
30	2	140.78	126.64	10.04
	4	136.47	125.9	7.75
	6	124.73	117.49	5.80

Table (5): Third natural frequency of cracked blade

Position of crack(cm)	Depth of crack (mm)	Third natural frequency (Hz)		Error %
		numerical	experimental	
Without crack	/	397.32	378.41	4.76
5	2	396.52	378.41	4.57
	4	393.55	375.36	4.62
	6	388.14	374.62	3.48
10	2	396.63	376.89	4.98
	4	396.23	386.04	2.57
	6	393.6	378.58	3.82
15	2	394.89	375.89	4.81
	4	387.32	364.68	5.85
	6	367.26	358.90	2.28
20	2	394.25	369.26	6.34
	4	385.13	361.63	6.10
	6	362.85	332.64	8.33
25	2	396.06	381.47	3.68
	4	392.33	374.89	4.45
	6	382.75	368.58	3.70
30	2	397.28	372.31	6.29
	4	397.29	367.73	7.44
	6	397.22	379.94	4.35

Figures (5), (6), and (7) show the first three natural frequencies of 2 mm crack depth at different positions in blades. Figure (5) shows the first natural frequency is increase with increasing the displacement of crack from fixed end, the natural frequency increase about 1% numerically and about 15% experimentally. So, the crack caused decreasing in natural frequency of blade at same position and the natural frequency of cracked blade increase when the crack progressing from fixed end.

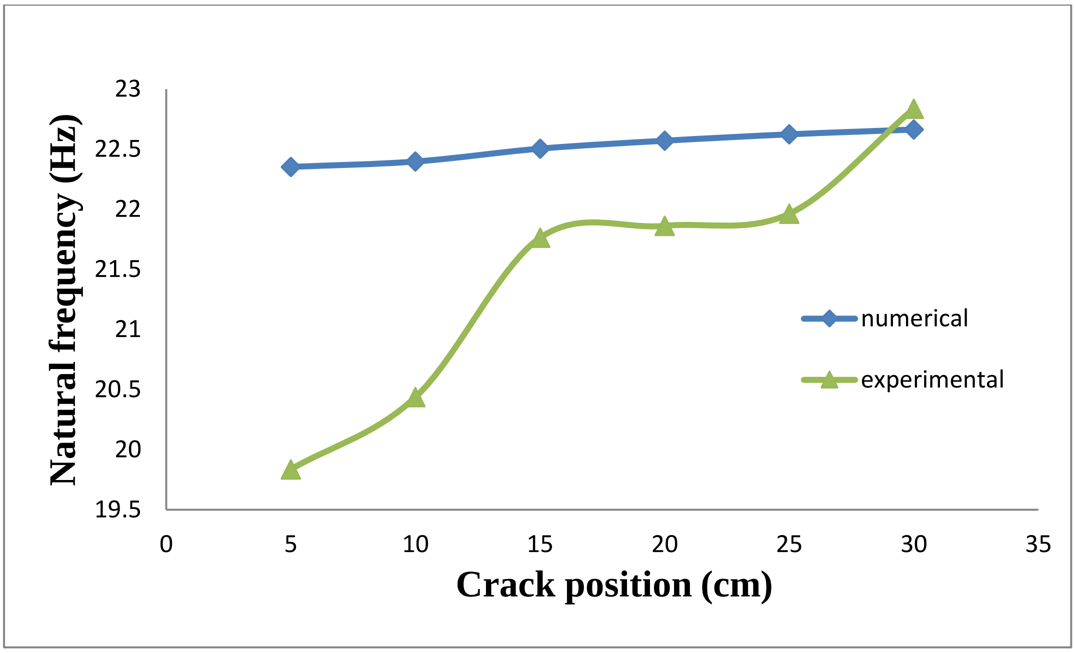

Figure (5): Variation of 1 st natural frequency with crack position for 2 mm crack depth.

Figure (6), (7) show the variation of the second and third natural frequency with crack positions, their show relations is irregular; there is a rise and fall in values of frequencies of blades. Therefore, the second and third natural frequencies have a random relation with crack location because the change in frequencies is not a function of crack depth and crack location only, but of the mode number too.

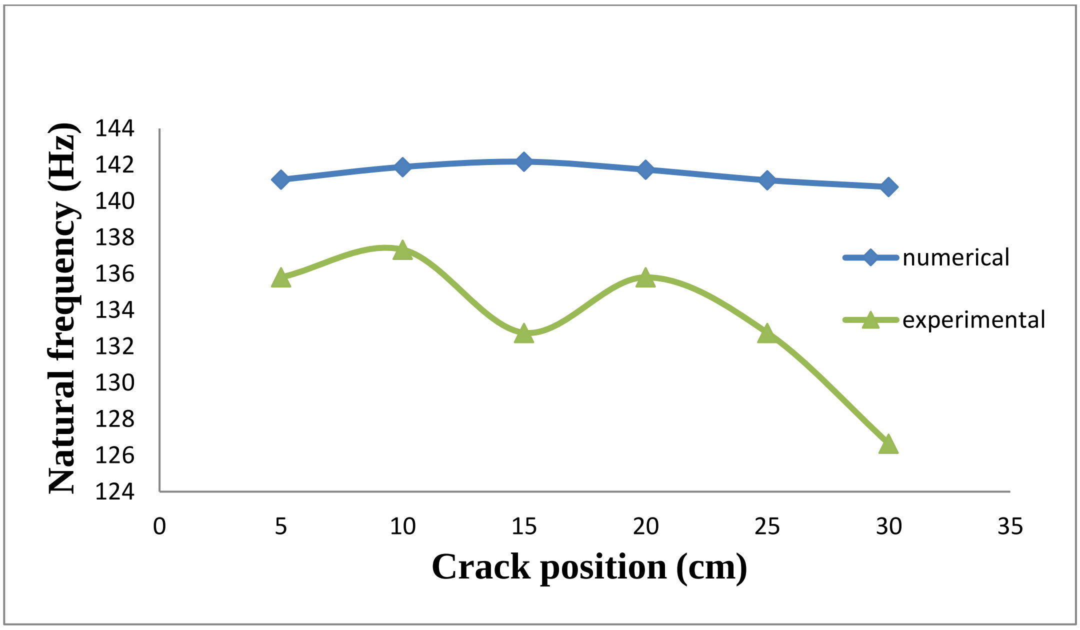

Figure (6): Variation of 2 nd natural frequency with crack position for 2 mm crack depth.

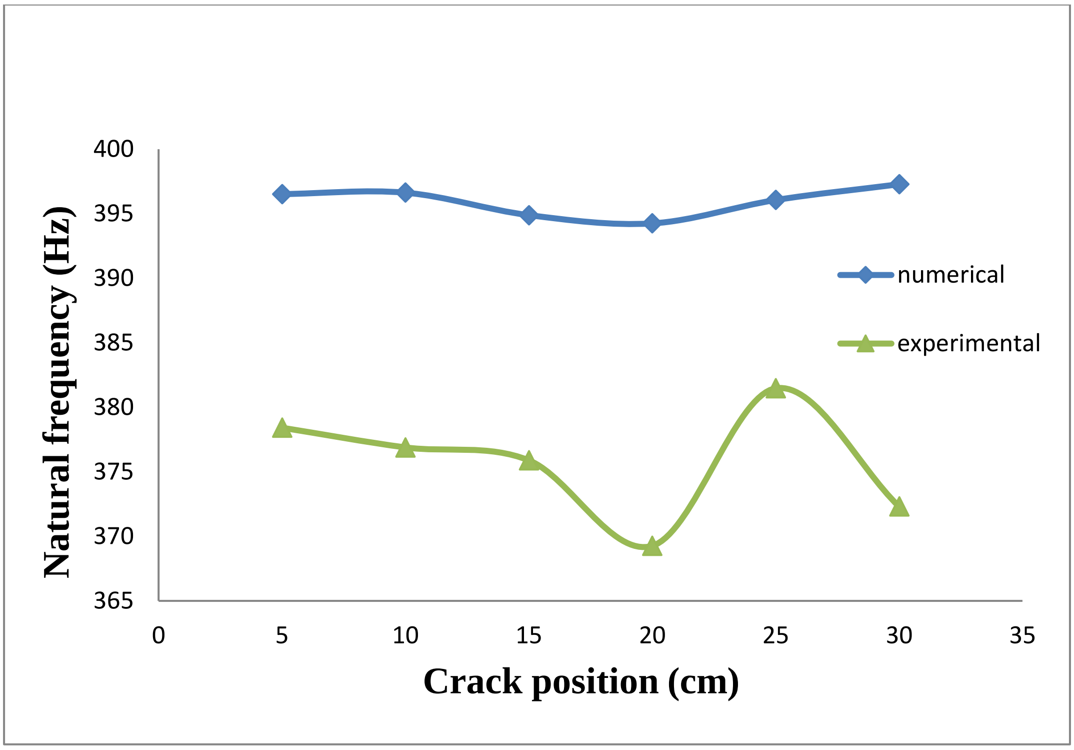

Figure (7): Variation of 3 rd natural frequency with crack position for 2 mm crack depth

Figures (8), (9), and (10) show the first three natural frequencies of 4 mm crack depth, figures (11), (12), and (13) show the first three natural frequencies of 6 mm crack depth at different positions in blades. Figure (8) shows the first natural frequency is increase with increasing the displacement of crack from fixed end, the natural frequency increase about 6% numerically and about 14% experimentally, for 6 mm crack depth from figure (11) the natural frequency increase about 18.5 % numerically and about 6 % experimentally So, the crack causes decreasing in natural frequency of un cracked blade and the natural frequency of cracked blade increase when the crack progressing from fixed end.

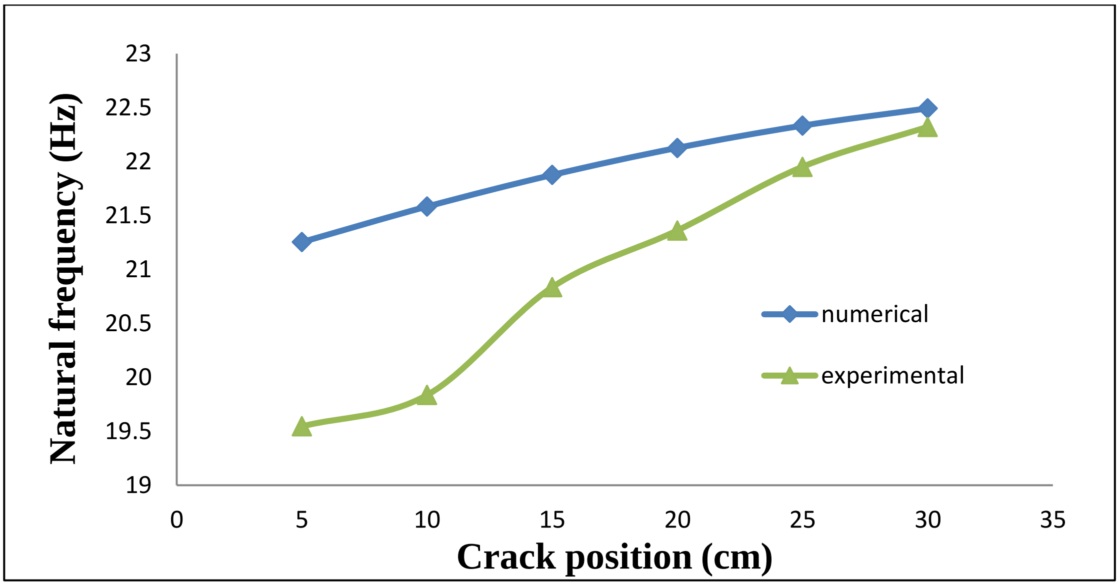

Figure (8): Variation of 1 st natural frequency with crack position for 4 mm crack depth.

Figures (9) and (12) show the relation between the crack position with second natural frequencies of (4 and 6) mm crack depths respectively, there are show the second natural frequencies are increase to specific location then it is decrease with progressing position, figures (10) and (13) show the relation between the crack position with the third natural frequencies of (4 and 6) mm crack depths respectively, there are show that their have a uniform waves increasing and decreasing with progressing position.

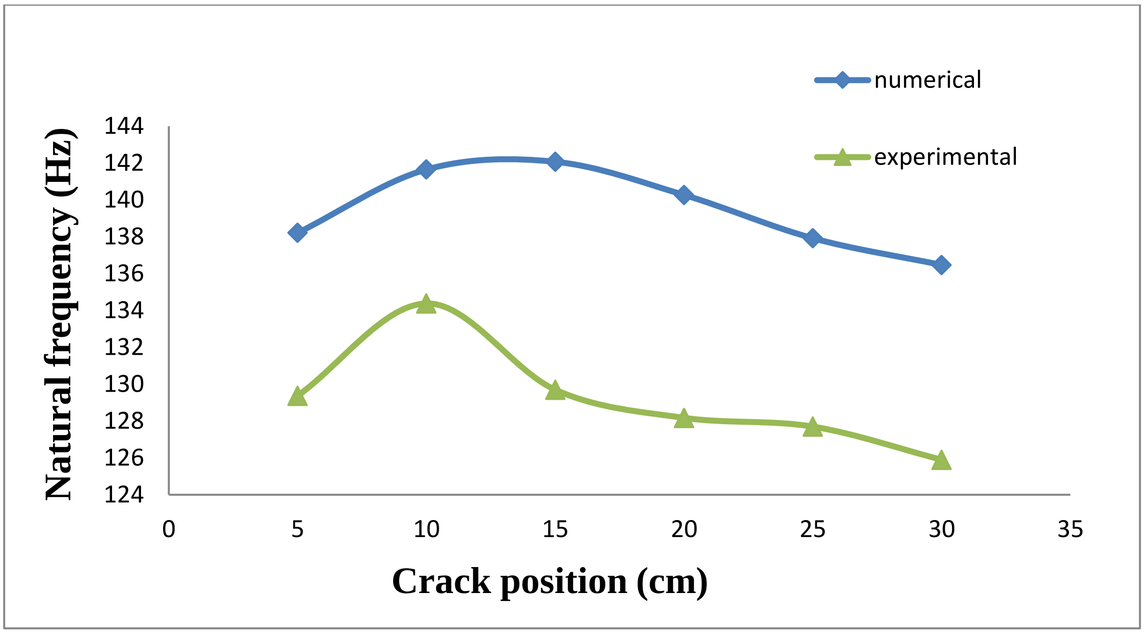

Figure (9): Variation of 2 nd natural frequency with crack position for 4 mm crack depth.

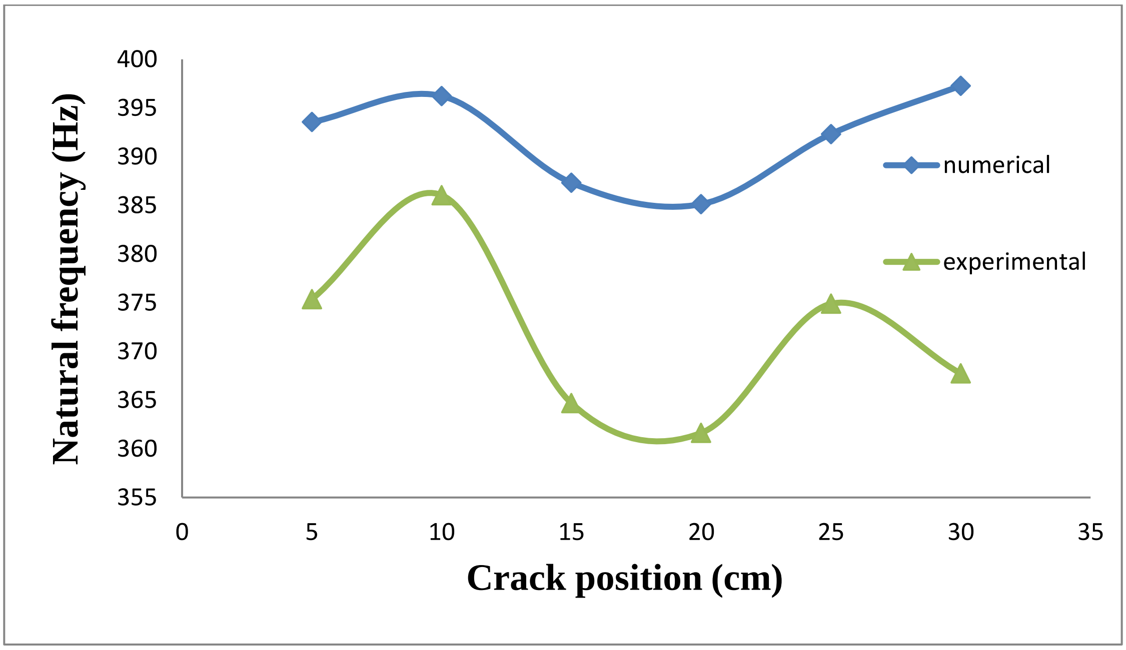

Figure (10): Variation of 3 rd natural frequency with crack position for 4 mm crack depth.

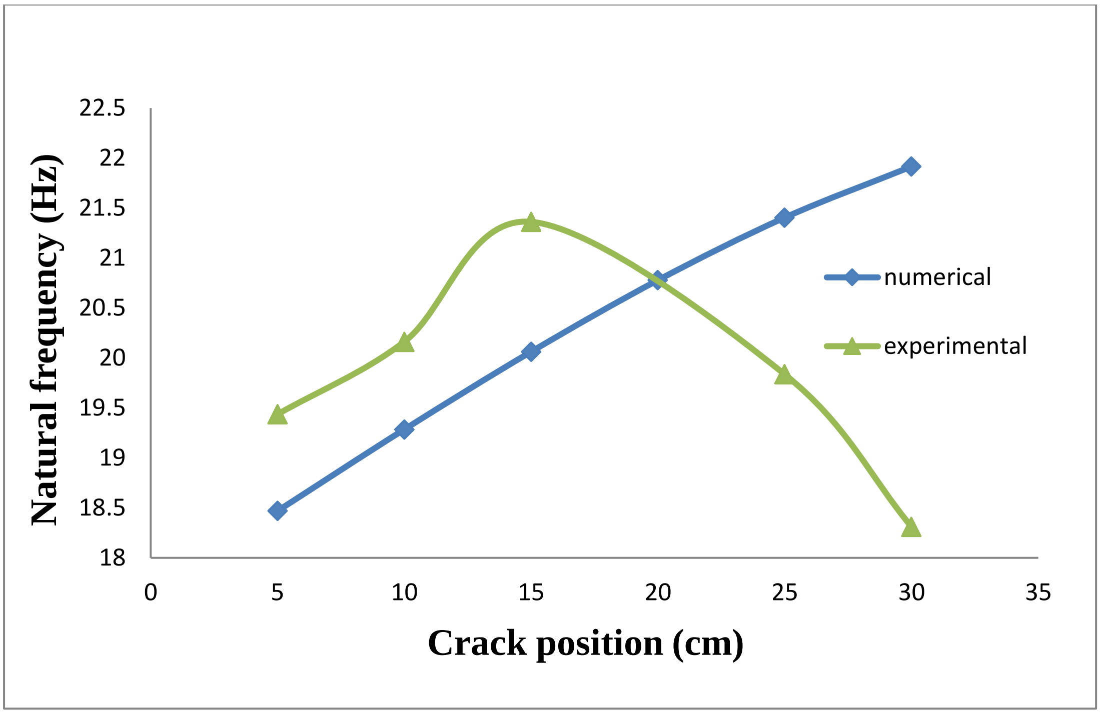

Figure (11): Variation of 1 st natural frequency with crack position for 6 mm crack depth.

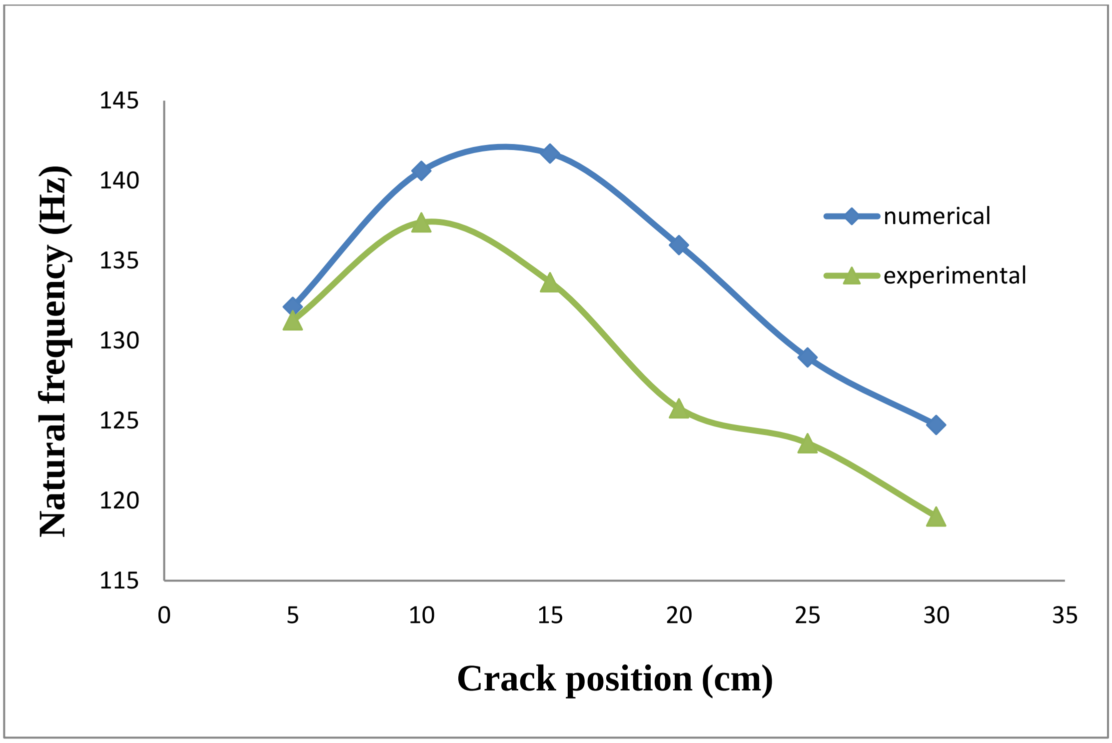

Figure (12): Variation of 2 nd natural frequency with crack position for 6 mm crack depth.

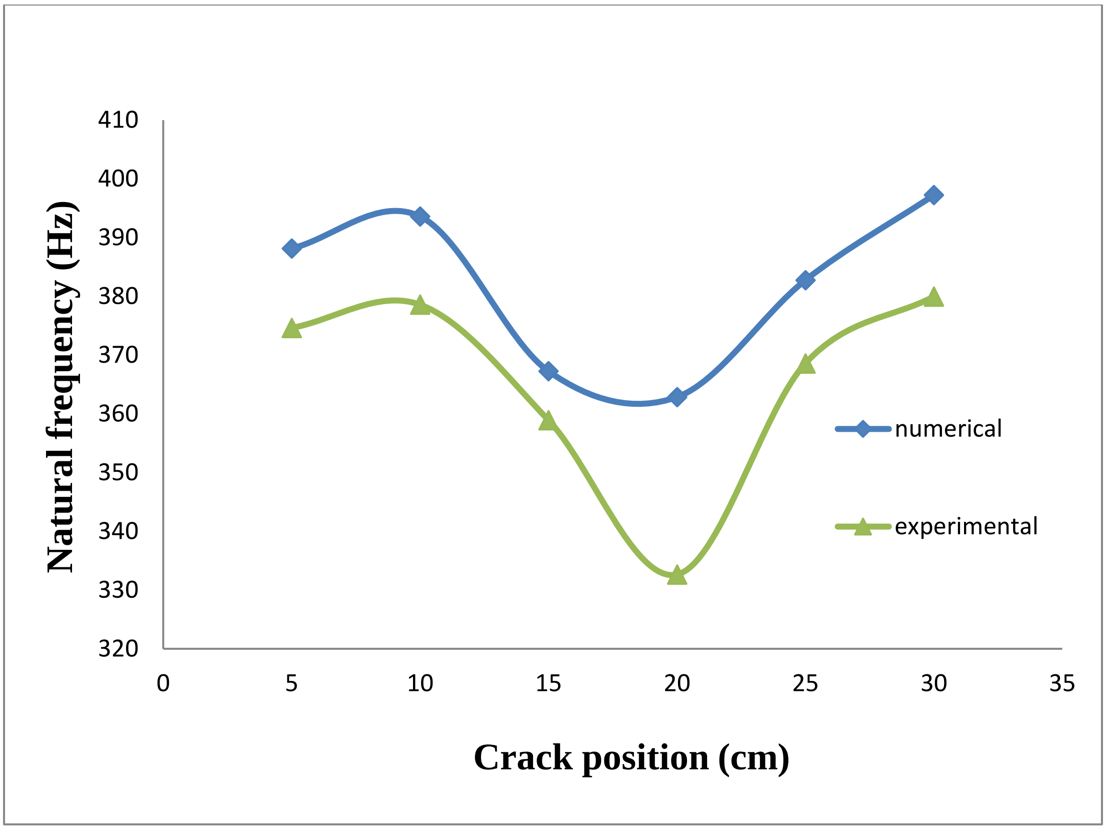

Figure (13): Variation of 3 rd natural frequency with crack position for 6 mm crack depth.

5. Conclusions

1. The natural frequency is decrease when increasing the crack depth for all crack's positions in cracked blades.
2. The first natural frequency increase when the cracks Progressing from fixed end for all crack's depths.
3. The second natural frequencies are increase to specific location then it is decrease with progressing positionfor all crack is depths.
4. The third natural frequency have a same behavior, increasing and decreasing with progressing positionfor all crack's depths.

CONFLICT OF INTERESTS.

There are no conflicts of interest

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دراسة عملية وعددية لتأثير موقع وعمق الحز على الترددات الطبيعية لريش التوربين

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الخلاصة:

ريش التوربين هي الجزء الأكثر أهمية وكلفة في التوربينات وان الخسائر الناتجة عن صيانتها كبيرة جدًا، لذا يجب تحليل أسباب الفشل التي قد تحدث بسبب عيوب التصنيع أو الاهتزازات الناتجة عن ظروف التشغيل وغيرها من ظروف الخدمة. يركز هذا العمل على الاهتزاز الذي يحدث بسبب ظروف التشغيل. تمثل الريشة كعتبة كابولية مصنّعة من الألومنيوم، يتم عمل صدع مربع بعرض ثابت (5 ملم) على الريشةفي ابعاد مختلفه من (5 إلى 30) سم من الطرف الثابت بأعماق تصدع مختلفة (6,4,2) ملم. تم حساب نتائج العمل التجريبي باستخدام اختبار الطرق، والنتائج العددية باستخدامطريقة العناصر المحددة،تم العثور على توافق جيد بين النتائج. وأظهرت النتائج أن الزيادة في عمق الكراك تسبب في تناقص في قيمة التردد الطبيعي للريشة لجميع مواقع التصدع.

الكلمات الدالة: ريشة متصدعة، ريشة التوربين، عتبة كابولية، التردد الطبيعي.