Military Technical College
Cairo, Egypt

12th International Conference
on Applied Mechanics and
Mechanical Engineering (AMME)

CRACK DETECTION IN BARS WITH LONGITUDINAL CRACK USING VIBRATION MEASURING TECHNIQUE

Bennaya* M. Mahgoub* H. M. and Sherif** H. A.

ABSTRACT

In this paper the dynamic behavior of a cylindrical bar with longitudinal crack as a new case of crack geometry is investigated. The bar is bounded and excited in way which permits only torsional vibration of the bar. This work is based on crack induced by the manufacturing processes not due to applied load. The dynamic analysis of the cracked bar is based on the investigation of the measured transient response in time and frequency domains beside its modal parameters. Experiments are carried out in two different specimens of the bar providing that their mechanical properties and dimension are kept identical. The first specimen of the bar is uncracked while the second one has a longitudinal crack along its whole length. The bar is excited with its first torsional mode and the measured signals are analyzed using (FFT) analysis. A finite element model has been made using ANSYS software to simulate the uncracked bar. Modal, transient and harmonic analysis are made to validate the experimental work. The finite element prediction of the dynamic response and the fundamental natural frequency were in good agreement with the experimental results. This work suggests a simple method for crack detection in beams.

KEY WORDS

Crack detection, torsional dynamic response, cracked bar.

NOMENCLATURE

A, B, C ,D	Arbitrary constants.
a	Constant.
D	Bar diameter [m].
E	Modulus of elasticity [GPa].
f(x,t)	External torque acts on the shaft per unite length.
G	Shear modulus [Pa].
J_o	Mass moment of inertia of the concentrated mass [Kg.m^2].
J^{beam}	Mass moment of inertia of the beam [Kg.m^2].
J(x)	Polar moment of inertia of the cross section at distance x [m^4].

* Egyptian Armed Forces.
** Higher Institute of Technology-10th of Ramadan.

L	Bar length [m].
$M_t(x,t)$	Twisting moment at bar location x and time t [N.m].
t	Thickness of the concentrated mass [m].
W_0	Static load [N].
ω_n	Natural frequency [Hz].
$\theta(x,t)$	Twisting angle [Deg].
θ_i	Initial twisting angle [Deg].
ρ	Density of the bar material [Kg/m^3].
υ	Poison's ratio.

1. INTRODUCTION

Cracks in any structure can initiate catastrophic failures. Therefore, there is a need to understand the dynamics of cracked structures. The crack identification in structures has been the subject of intensive investigations during the last three decades.

Cracks in the element of a structure have many causes. They may be fatigue cracks, mechanical defects and another group involves cracks that are inside the material, they are created during the manufacturing processes .These cracks open for a part of the cycle and close when the vibration reverses its direction. These cracks will grow over time, as the load reversals continue, and may reach a point where they pose a threat to the integrity of the structure. As a result, all such structures must be carefully maintained and monitored so that in the event of the development of any crack, it can be located and repaired before it can impair the safety of the structures.

There are several non-destructive test techniques available for crack detection, for example: visual examination, radiographic test, ultrasonic test, liquid penetrate test and magnetic test. All the above methods cannot be utilized under the operating conditions of the structures. Due to this limitation it is now believed that the monitoring of the global dynamics of structures offer promising alternative for damage detection. Vibration-based techniques have been proved a fast and inexpensive means for crack identification.

2. CRACK-VIBRATION RELATIONSHIP

When a structure suffers from damage, its dynamic properties can change. Specifically, crack damage can cause a stiffness reduction and increases the damping of the structure. As a consequence many researchers have used the decrease in natural frequencies and modification of the modes of vibration to detect and locate cracks accordingly; vibration-based methods for crack detection have been developed. Murigendrappa et al. [1] made a technique based on measurement of change of natural frequencies to detect multiple cracks in long pipes containing fluid at different pressures. Lele and Maiti [2] used frequency measurements for crack detection in short beams, taking into account the effects of shear deformation and rotational inertia through the Timoshenko beam theory and representing the crack by a rotational spring. Crack extension is estimated from the change in the first natural frequency .The accuracy of the results is quite encouraging. Chaudhari et al. [3] modeled transverse vibration of a beam of linearly variable depth and constant thickness in the presence of an open edge crack using the concept of a rotational spring to represent the crack. The main disadvantage of using natural frequency changes for crack detection is the fact that significant cracks may cause small changes in natural frequencies so, research has been focused on using changes in mode shapes. Mode shapes are more sensitive to local damage compared to changes in natural frequencies. Ratcliffe [4] used a modified Laplacian operator on mode shape data to locate the damage in a beam. But it requires cumbersome post processing of determining cubic polynomial to fit the Laplacian locally at each spatial coordinate. The theory of spring loaded fracture-hinge was used by Ju and Mimovich [5] to diagnose the fracture damage in structures by post processing the experimentally obtained frequency values with analytical frequency equations. Tasi and Wang [6] used the change in fundamental mode shapes between the cracked and uncracked shaft to identify the crack location. The crack was modeled as a joint of a local spring. The transfer-matrix method was employed to obtain the dynamic characteristics.

More sensitive methods capable of detecting local abnormalities with high resolution became important. In that vein, methods based on wavelet analysis and fast Fourier transform. The wavelet transform, as opposed to Fourier or modal analysis, breaks down a signal into a series of functions (wavelets). Chih-Chieh Chang et al [7] have detected the location and size of cracks in the multiple cracked beams by spatial wavelet based approach based on spatial wavelet analysis. Gomez-Mancilla et al [8] have used the local resonance for crack detection in rotor. They based on Vibration peaks occurring at rational fractions of the fundamental rotating critical speed, here named Local Resonances; facilitate cracked shaft detection during machine shut-down. Ertugerul et al. [9] were used the impact-echo method, The signals obtained in defect-free and cracked beams were compared in the frequency domain. The results of the study suggest determining the location and depth of cracks by analyzing the measured signals. Hadjileontiadis et al. [10] Introduce new technique for crack identification in beam structures based on fractal dimension analysis (FD). In this work, the fundamental vibration mode of a cracked cantilever beam is analyzed and both the location and size of the crack are estimated. The location of the crack is detected by a sudden change in the spatial variation of the analyzed response, while the size of the crack is related to the fractal dimension measure. The proposed technique forms an FD-based crack detector (FDCD), which accesses the complexity of the vibrational signal in order to efficiently detect both the location and the size of the crack.

For stress analysis purposes many researchers have used the finite element method (FEM) , Anifantis and Dimarogonas [11] introduced the full 6 x 6 flexibility matrix for the cracked region and computed for a rectangular beam with a transverse crack the 5 x 5 local crack flexibility matrix neglecting torsion. Further, they observed that this matrix was not purely diagonal but had off-diagonal terms which indicated the coupling between the longitudinal and lateral vibration. A full 6 x 6 matrix for a general loading of a Timoshenko beam was introduced by Papadopoulos and Dimarogonas [12]. They introduced the coupled longitudinal, torsional and bending vibration analysis of a cantilevered beam with a transverse crack. Using a local flexibility matrix for the crack, they determined the first three modes of free vibration. During the analysis and experiment, they gave the beam a longitudinal, harmonic displacement at its fixed end and plotted the response as a function of the excitation frequency. At small crack depths, peaks occurred at the natural frequencies of longitudinal vibration. As the crack depth increased, other peaks appeared due to the coupling with bending vibration.

For crack modeling process there is extensive confusion in distinguishing between a notch and a crack. Wendtland [13] reported that there is extensive confusion between a notch and a crack. Many authors treat cracks as notches experimentally, analytically and numerically. Saw cuts are used to model cracks. It must be understood that no matter how much thin a saw cut is, the obtained notch will not behave as a real crack.

The aim of the present paper is to investigate the free torsional vibration of bar with longitudinal crack and using FFT analysis technique on the measured dynamic response to detect the crack in bar. Both experimental as well as numerical (FEM) procedures are used. At first, measurements were performed on an uncracked bar in order to construct reference results, which can be compared with other results of cracked bar to diagnose the crack. Secondly, Modal analysis is performed through ANSYS software to estimate the fundamental natural frequency for uncracked bar before the comparison of the obtained experimental frequencies (in both cases cracked and uncracked bar) has been done. The dynamic response of the cracked bar is obtained with the same measurement procedure of the bar in good condition. The cracked bar has a longitudinal crack which is not a fatigue crack but it is created during the manufacturing processes. During the measurement we will permit the beam to vibrate under its fundamental mode due to an initial displacement $\theta_i(x)$ and then the dynamic transient response is measured at some points on the bar through strain gauge. Finally the transient and harmonic analysis has been performed through ANSYS to validate the experimental work in the case of uncracked bar.

3. THEORITICAL BACK GROUND

The equation of motion for forced torsional vibration of a bar From Newton's second law [14] can be written as

$$(M_t + dM_t) + f(x,t)\ dx - M_t = J_0\ dx \frac{\partial^2 \theta}{\partial\ t^2} \tag{1}$$

Eq.(1) for the free torsional vibration of a uniform bar oscillate about its own axis will be in the following form

$$a^2 \frac{\partial^2 \theta(x,t)}{\partial x^2} = \frac{\partial^2 \theta(x,t)}{\partial\ t^2} \tag{2}$$

Where

$$a = \sqrt{\frac{G}{\rho}}$$

The solution of Eq.(2) will be

$$\theta(x,t) = \left[A\cos(\frac{\varpi}{a}x) + B\sin(\frac{\varpi}{a}x) \right] \left[C\cos(\varpi t) + D\sin(\varpi t) \right] \tag{3}$$

Where A, B, C and D are arbitrary constants depend on the boundary and initial conditions.

4. CRACK EFFECT ON LOCAL MODAL PARAMETER

In general, crack adds flexibility to the structure. This flexibility will affect the bar stiffness in local area around the crack more than any other area of the structure. Since monitoring of modal parameters natural frequency and mode shapes will give a more direct and significant indication of the crack occurring in the structure [15].

Lakshimi et.al. [15] Have studied a beam with transverse crack and concluded that the effect of crack is observed obviously in mode shape in the location of the crack. Namely, in the vicinity of the crack tip only. Therefore, measurement of strain by a sensor in the crack location would be ideal but all other places the sensor will not have any sensible variation. Therefore, measurement of mode shapes values is not a practical one to locate the crack since prior knowledge of the location of the location of the crack is not valid to us. So, an attempt is made by Lakshimi to look into the global parameters (like frequencies and change in frequency). To identify the presence of crack instead of local parameters (like mode shape) which has insignificant contribution or high localized contribution which cannot be practically measured to identify the presence of the crack.

5. EVALUATION OF THE FREQUENCY CHANGE

In the present work both analytical and numerical FEM solutions were performed to estimate the value of the natural frequency of the uncracked bar, Then the experimental work is performed to the uncracked bar. The different procedures namely, experimental and numerical should be verify each other. Finally the experimental work is performed on the cracked shaft and the deviation of the natural frequency due to the presence of the crack is evaluated.

6. ANALYTICAL MODEL

Consider a cylindrical steel bar with length L=300[mm], diameter D=13[mm] and with material properties (ρ=7815 [kg/m3], E=215 [Gpa] and ν=0.3). A concentrated mass in the form of a solid disc with diameter 236 [mm] and thickness t=7.7 [mm] is welded to its free end as shown in Fig.(1) to reduce the fundamental frequency of the bar. The bar is mounted with fixed support from one end and with roller support from the end which has the concentrated mass.

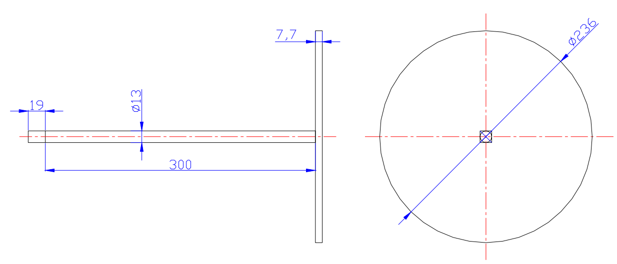


Fig.(1) A beam with concentrated mass

By solving Eq.(2) we can get the frequency equation.

$$\beta_n \tan(\beta_n) = \frac{J^{beam}}{J_0} = const. \quad (4)$$

Where

$$\beta_n = \frac{\varpi_n}{a} L$$

Eq.(4) is the frequency equation or characteristic equation of the bar with end disc. The values of ω_n are the eigen values (natural frequency) values of Eq.(2). The n^{th}

natural frequencies are given by solving Eq.(4). Eq.(4) is solved by using graphical solution to get the first fives natural frequencies, the result is shown in Table 1.

Table.1. Analytical solution of first fives natural frequencies

Mode no.	Mode-1	Mode-2	Mode-3	Mode-4	Mode-5
natural freq.[Hz]	32.7	5438.7	10970	16690	22691

7. FINITE ELEMENT MODEL (FEM)

Consider the model given in Fig(2). Using ANSYS software, the bar FEM model is selected to have 13 elements of element type pip16 to simulate the bar. Element type mass21 is used to simulate the concentrated mass and it is shown as element no.14 in Fig.(2).

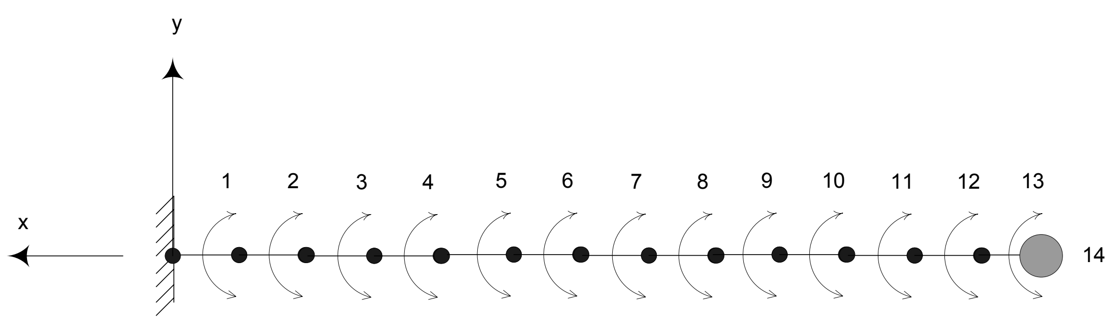


Fig.(2) Finite element model for uncracked bar (pipe16 & mass 21)

Modal, transient and harmonic analysis modules has been used for dynamic analysis of the uncracked bar.

7.1 Modal analysis of uncracked beam

The modal analysis has been performed. Only the first fives torsional natural frequencies and mode shapes are extracted. The calculated natural frequency for each mode is shown in Table.2. Fig.3) illustrates the obtained first fives mode shapes.

Table.2. Numerical result for first fives natural frequencies

Mode no.	Mode-1	Mode-2	Mode-3	Mode-4	Mode-5
natural freq.[Hz]	32.7	5438.7	10970	16690	22691

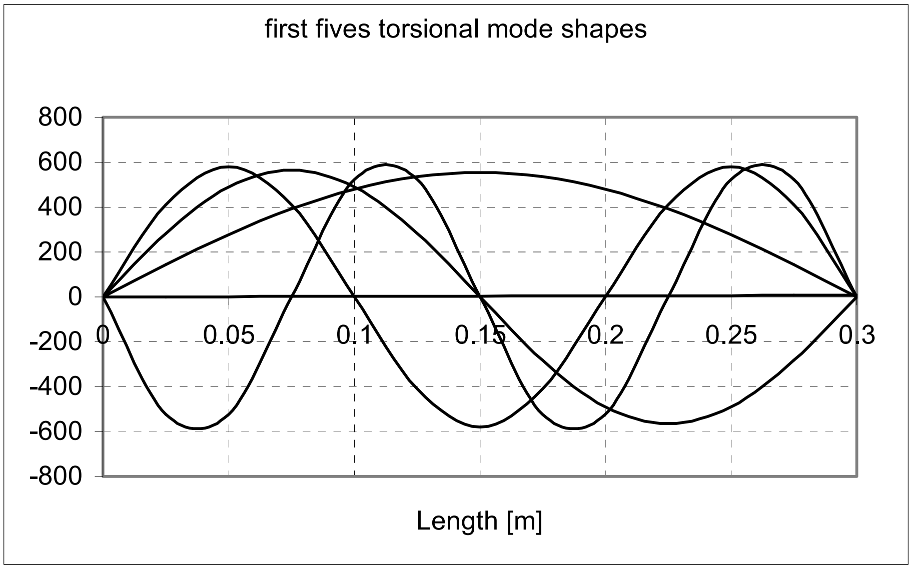
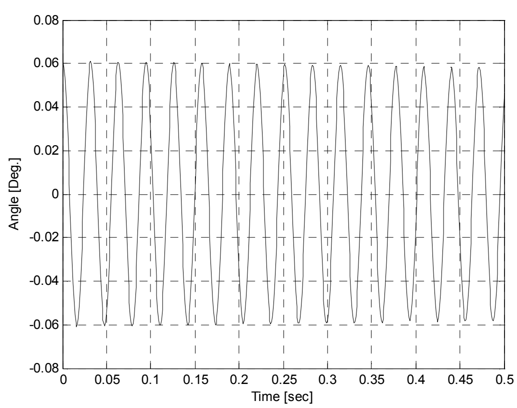


Fig.3. First fives mode shapes of uncracked bar

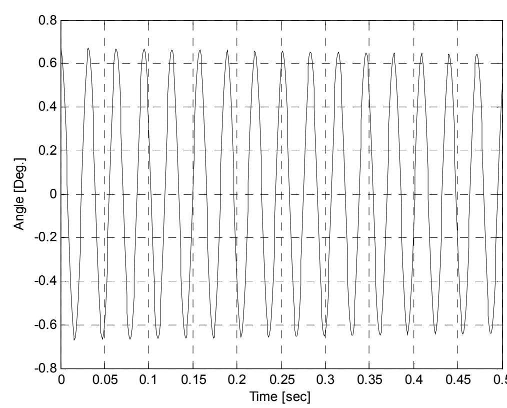
According to Tables 1 and 2, the modal analysis validates the analytical calculation of first fives natural frequencies.

7.2 Transient and harmonic analysis for uncracked beam

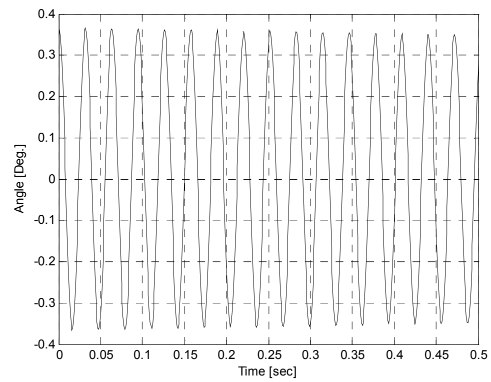
A transient and harmonic analysis has been performed. The transient signals are obtained at the same locations of measuring points in experimental work.
Fig.4-a), Fig.4-b) and Fig.4-c) illustrate the transient response of the twisting angle (θ) [Deg.] due to applied weight 10.26 [kg] at the three different points on the beam 2,12 and 22 [cm] respectively from the fixed support. Fig.4-d) represent the harmonic analysis of transient response of the model. The harmonic analysis illustrate that the fundamental frequency is 32 [Hz].



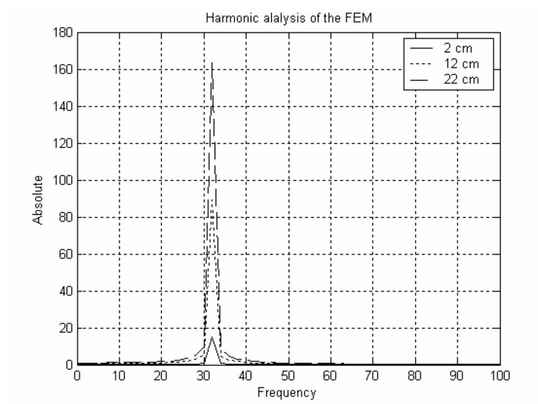
(a)



(c)



(b)



(d)

Fig.4. Transient response at (a) 2 [cm] , (b) 12 [cm], (c) 22 [cm] from the root due to applied weight10.26 [kg]. (d) The harmonic analysis of the transient response at the three points.

8. EXPERIMENTAL WORKS

According to Wendtland [13], there is crack model confusion happened between researchers during their experimental modeling of cracks in structure. Wendtland concluded that the real crack is different from the crack created experimentally in the form of a notch made with thin saw, what ever how thin the saw is. In the following procedure, a crack due to manufacturing process in steel bar was investigated in order to understand its real effect in the dynamics of structures. The cracked bar is obtained from an iron store which feeds the turning workshops with their needs of steel work pieces. This means that the crack is created during the manufacturing processes not due to fatigue. The cracked bar has longitudinal crack Fig.(5). The uncracked piece of bar is obtained from the same source.

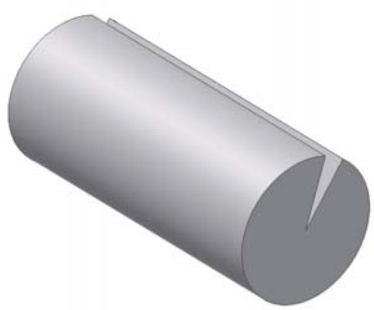
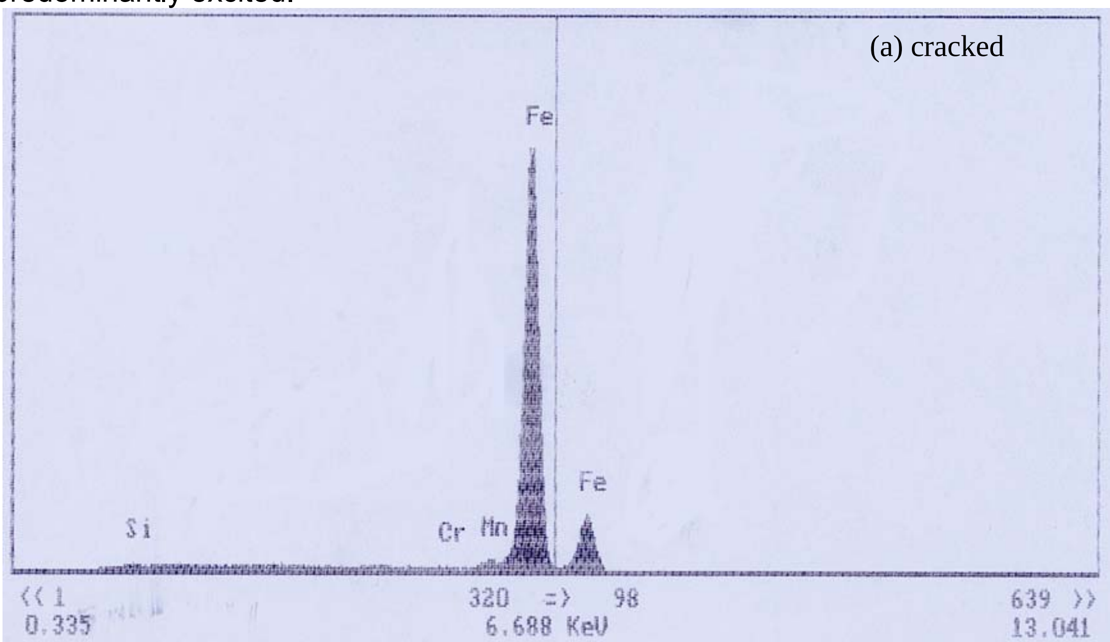


Fig.5. Bar with longitudinal crack

The material composition for the two bars has been analyzed by using the x-ray analysis technique with the help of the scanning electron microscope (machine SEMMA 202M) to assure that the two pieces of the used bars have the same material properties. The material composition analysis is shown in Fig.(6). From Fig.(6-a) and Fig.(6-b) we can conclude that the two specimens of bars (crack & uncracked) have the same material properties.

Then, the two bars, cracked and uncracked are turned to the same dimensions given in Fig.(1). A concentrated mass in the form of solid steel disc is welded to the bar to reduce the fundamental natural frequency and increase the signal amplitude. The two measured bars have been supported to become fixed-roller supported bar. The

fixed support has been represented as shown in Fig.(7-a). The roller support has been represented by a ball bearing which is mounted as shown in Fig.(7-b). A static load is applied on the disc represented by a standard weight connected to a point on the peripheral of the disc through a steel wire as shown in Fig.(8).
The tested bar is twisted with an initial twisting angle θ_i under the applied static load W_0. Once the applied load is released by cutting the steel wire the beam will perform a torsional vibration due to the initial displacement θ_i, and fundamental mode is predominantly excited.



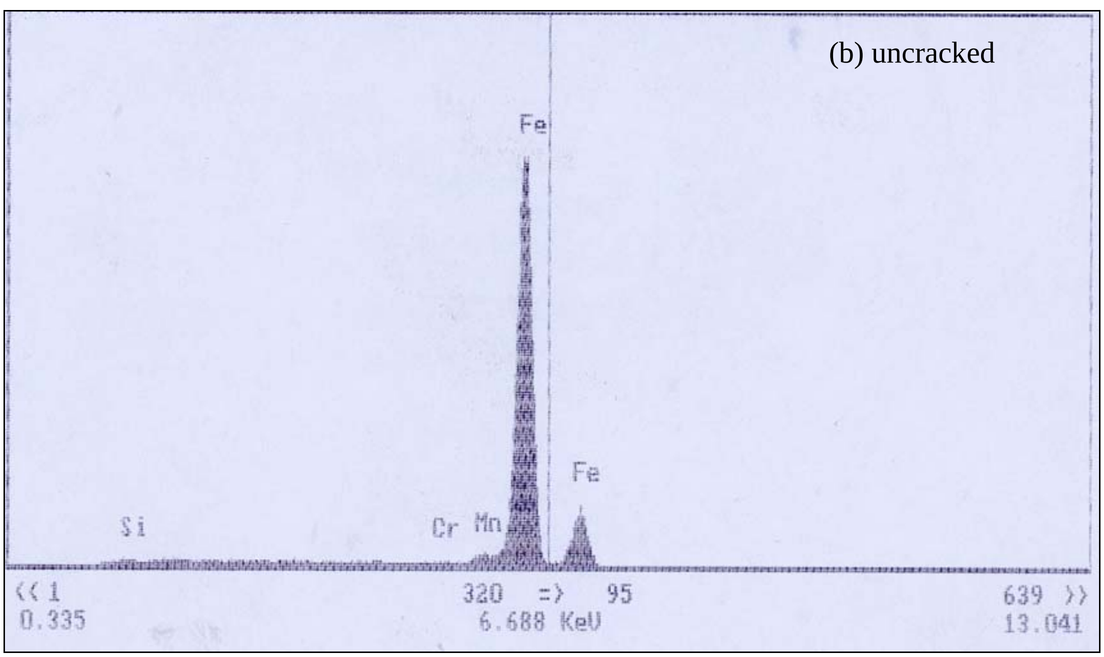
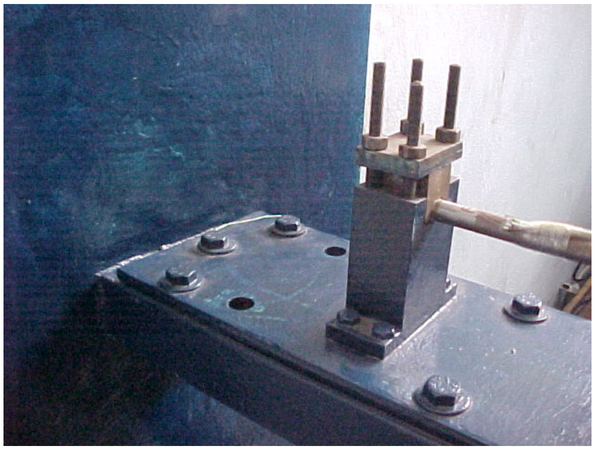


Fig.6. Material composition analysis: (a) uncracked bar (b) cracked bar



(a)

(b)

Fig.7. mounting and fixation of (a) fixed support (b) roller support

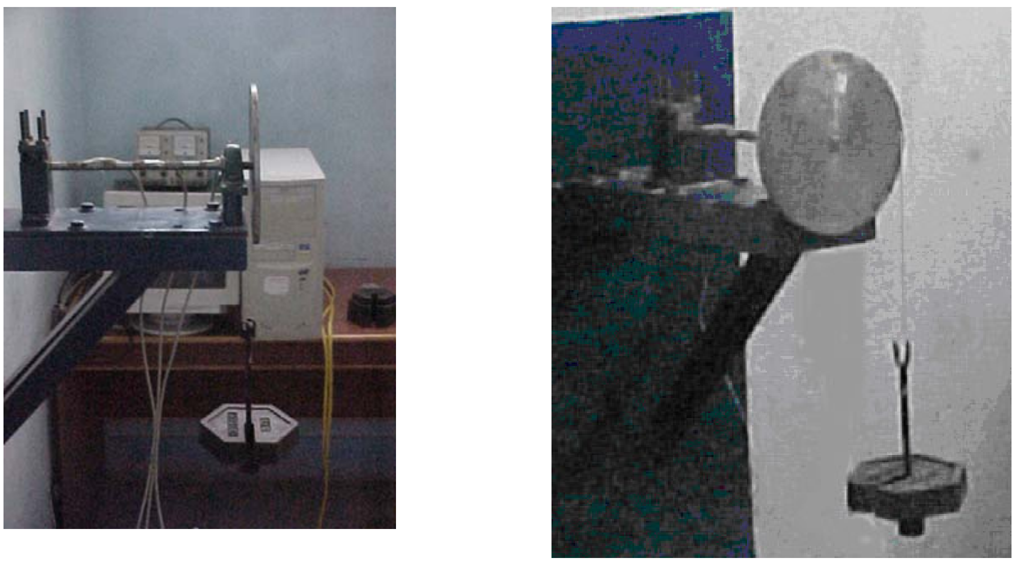


Fig.8. the static load which create the initial displacement

A data acquisition system is used to measure the signal as the shown in the block diagram Fig.(9).

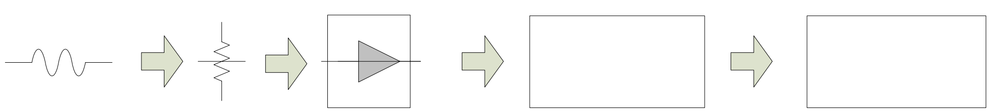


Fig.9. Data acquisition system block diagram

For each bar (cracked and uncracked), the transient response is measured by using metal foil strain gauge type KFG-2-120-D31-11 which is suitable for measuring torsion in steel, Fig.(10). The Half bridge strain gauge configuration illustrated in Fig.(11) was bonded on three different points on peripheral of the bar at distances 2, 12, 22 [cm] from fixed support as shown in Fig.(12).

Fig.10. Photography of metal foil strain gauge type KFG-2-120-D31-11 mounted on the measured bar

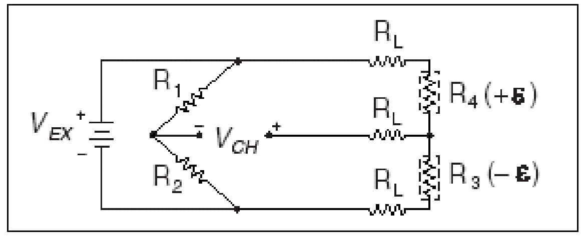


Fig.11. Half-Bridge configuration circuit

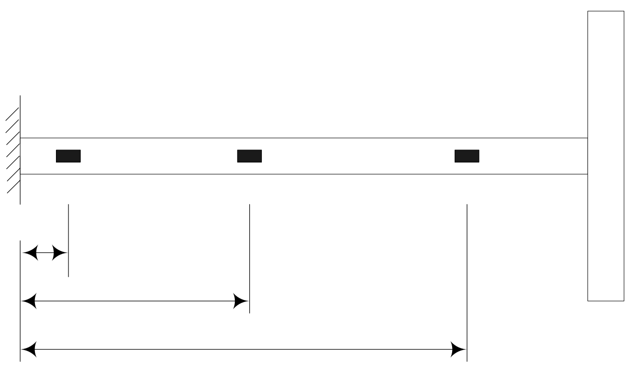


Fig.12. Strain gauges locations

The measured signals are transferred to the strain gauge signal conditioning amplifier type (RS stoke no. 826-171) to make the required balancing and amplification for the obtained signals. Finally the resulting signals are converted from analog to digital by using A/D converter device type CIO-DAS16/330 which is compatible with MATLAB software and the obtained signal is displayed in PC by using Simulink program. Fig.(13) shows photography of the test rig and instrumentation.

Fig.13. Photography of the test rig and instrumentations

9. EXPERIMENTAL RESULT

Fig.(14) and Fig.(15) show the measured strain for uncracked and cracked bar when the applied weight is 10.26 [kg] and with sampling rate 1 [KHz]. Fig.(16) shows the measured twisting angle of uncracked bar which has been calculated from the strain shown in Fig.(14). Fig.(17) shows the measured twisting angle of cracked bar which has been calculated from the strain shown Fig.(15). It can be observed from Fig.(16) and Fig.(17) that the damping in the cracked bar is more than the damping in the uncracked bar.

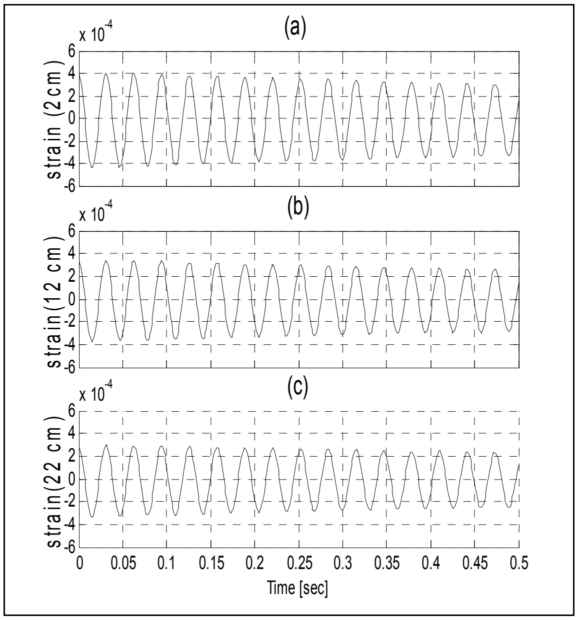


Fig.14. Measured strain for uncracked beam at three points (a) at 2[cm] from the root (b) at 12[cm] from the root (c) at 22[cm] from the root

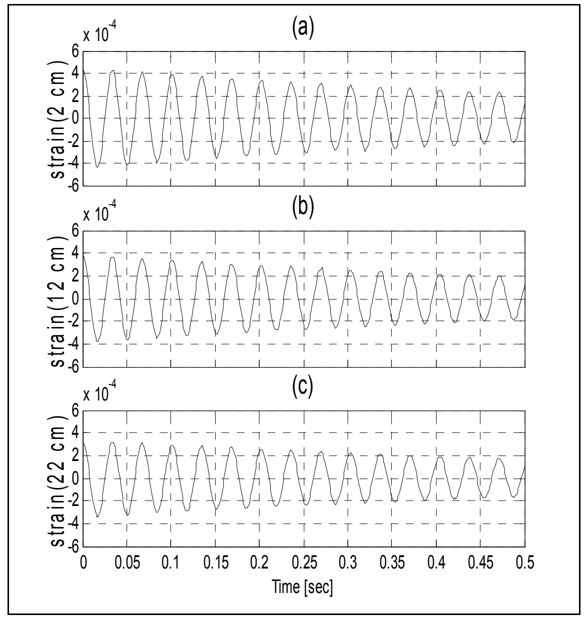


Fig.15. Measured strain for cracked beam at three points (a) at 2[cm] from the root (b) at 12[cm] from the root (c) at 22[cm] from the root

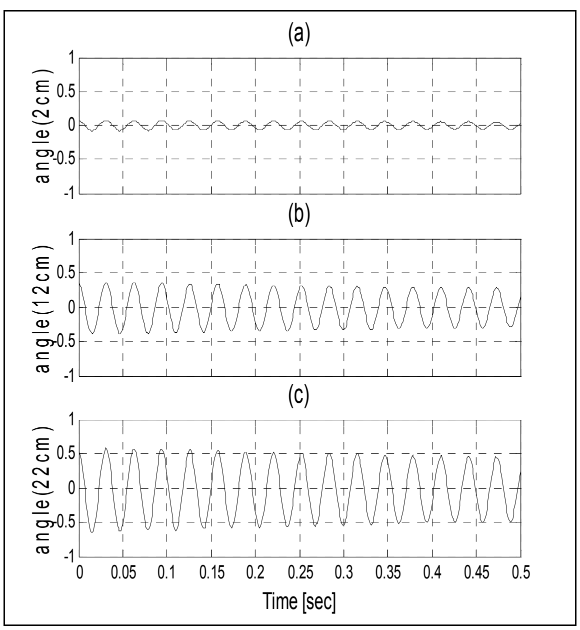


Fig.16. Measured angle [degree] for uncracked beam at three points (a) at 2[cm] from the root (b) at 12[cm] from the root (c) at 22[cm] from the root.

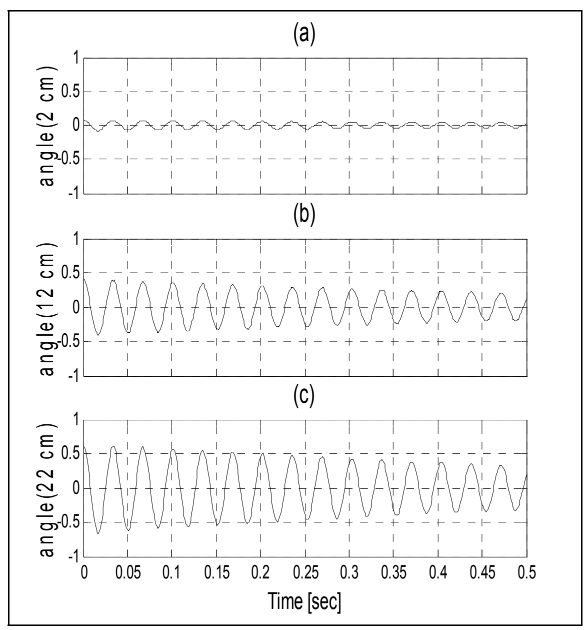


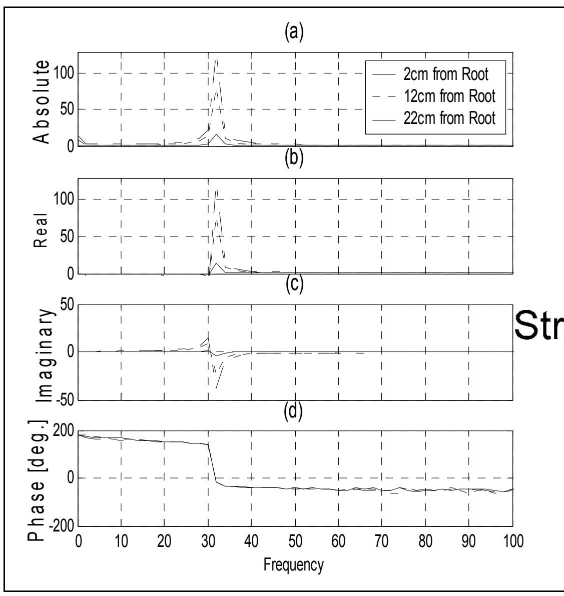
Fig.17. Measured angle [degree] for cracked beam at three points (a) at 2[cm] from the root (b) at 12[cm] from the root (c) at 22[cm] from the root.

10. TRANSIENT FREQUENCY RESPONSE

Dynamic signal analysis has been performed to the measured signals using the Fast Fourier transform (FFT). FFT algorithm has been performed on the PC by using MATLAB software. Fig.(18) shows the block diagram for FFT.

Fig.18. FFT block diagram

Fig.(19) displays the FFT of measured twisting angle shown in Fig.(16). While Fig.(20) displays the FFT of measured twisting angle shown in Fig.(17).



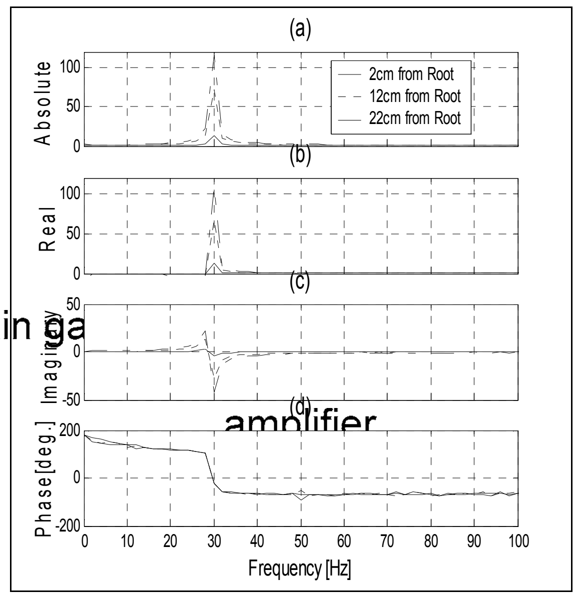
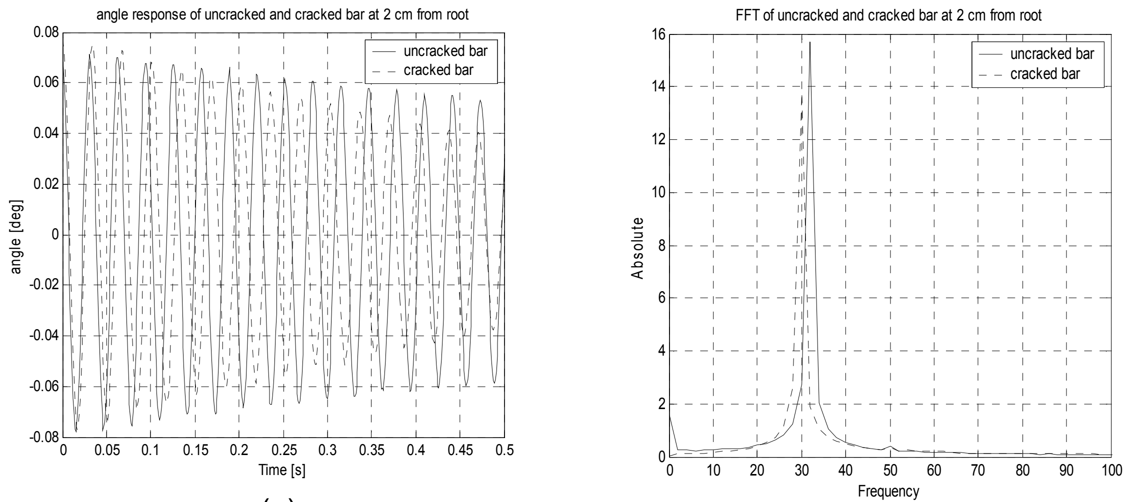


Fig.19. FFT of uncracked bar

Fig.20. FFT of cracked bar

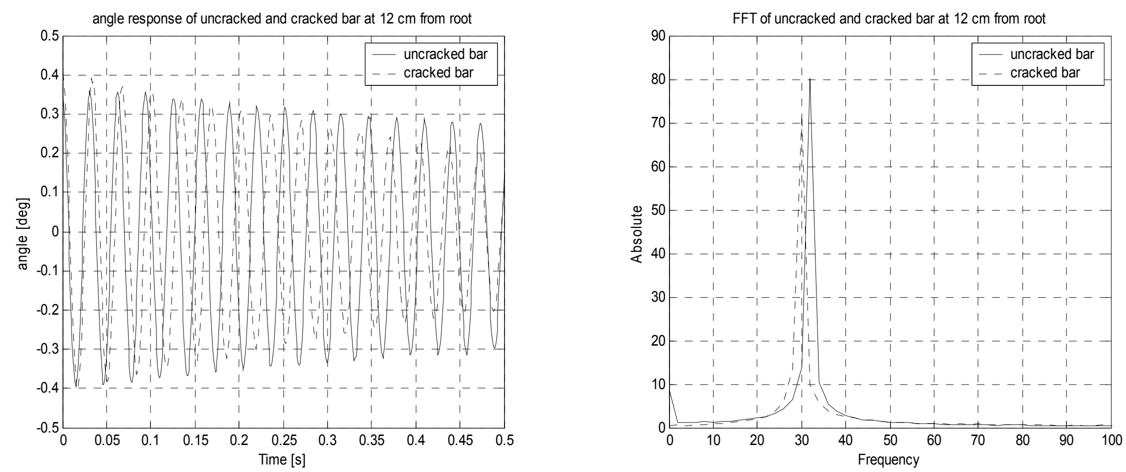
11. EFFECT OF CRACK ON BEAM RESPONSE

The measured signals for the cracked and uncracked bars are displayed in both time and frequency domains to illustrate the effect of the presence of the crack. Fig.(21), Fig.(22) and Fig.(23) illustrate (a) time history (b) spectrum for various measurement points on the bar 2,12 and 22 [cm]. From the shown figures, both uncracked and cracked bars vibrate predominantly at its fundamental frequency. We can observe that the signals obtained from the cracked bar is dissipated higher than the dissipation of the uncracked bar. Which mean that the damping of the cracked bar is higher than the damping in uncracked bar and it is cleared for each point of test in Fig.(21-a), Fig.(22-a) and Fig.(23-a). Also the fundamental frequency of the cracked bar and the uncracked bar have different values and it is cleared in Fig.(21-b), Fig.(22-b) and Fig.(23-b).



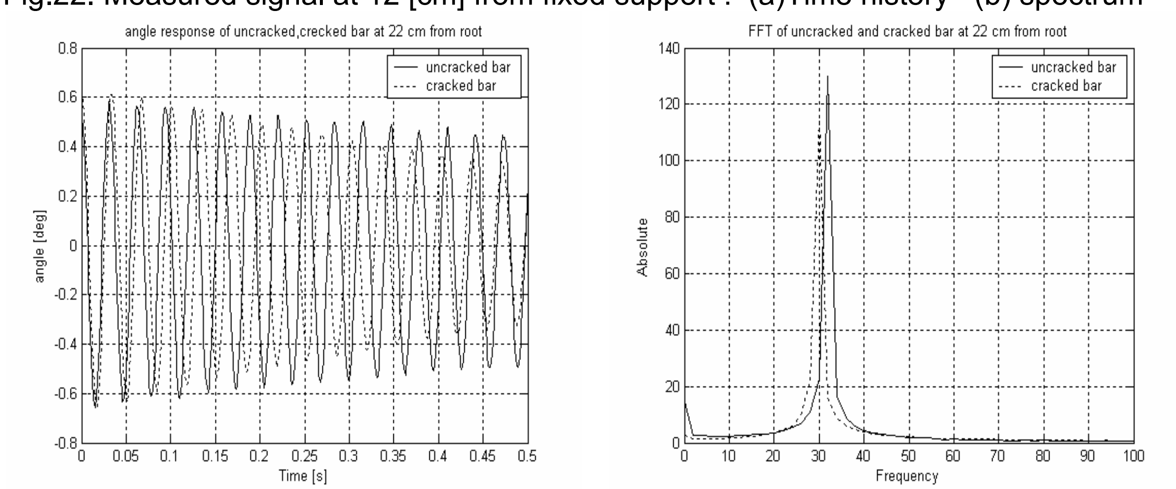
(a) (b)

Fig.21. Measured signal at 2 [cm] from fixed support : (a)Time history (b) spectrum



(a) (b)

Fig.22. Measured signal at 12 [cm] from fixed support : (a)Time history (b) spectrum

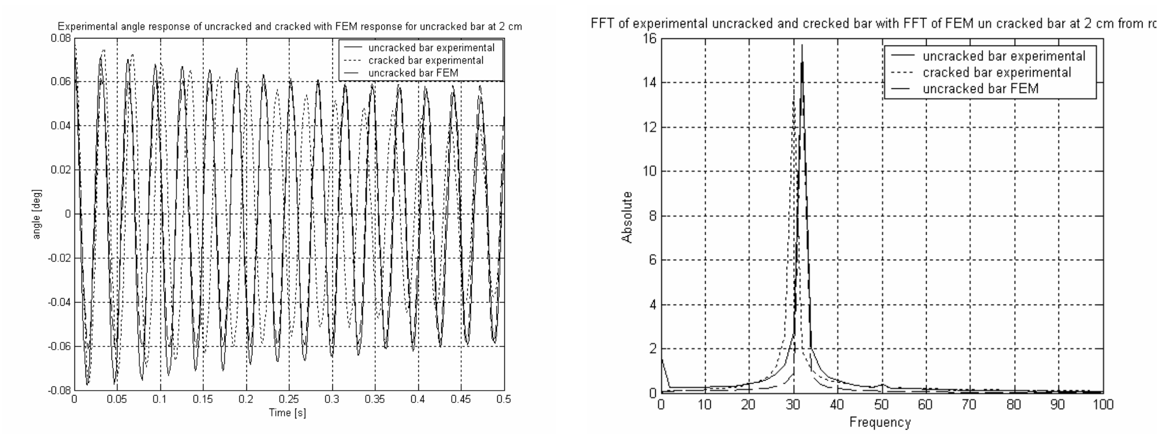


(a) (b)

Fig.23. Measured signal at 22 [cm] from fixed support : (a)Time history (b) spectrum

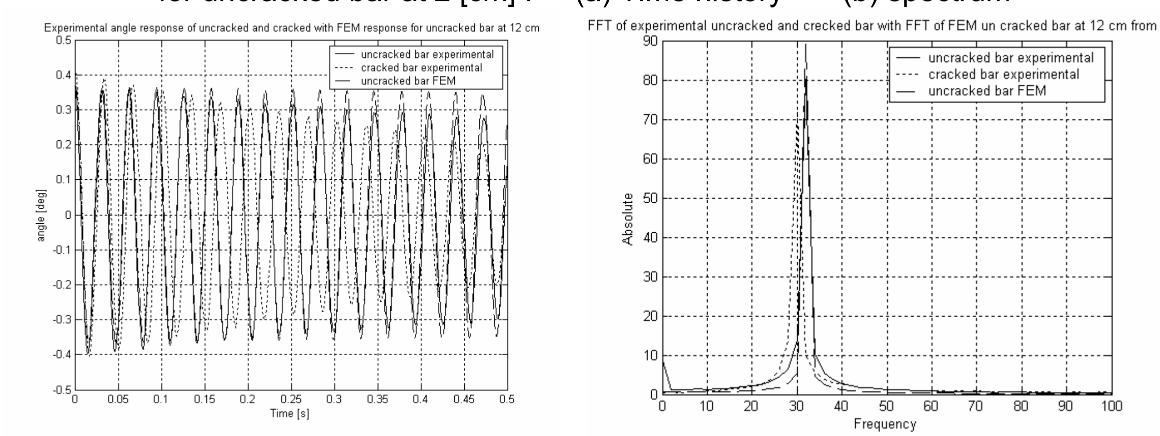
12. EXPERIMENTAL WORK VALIDATION

In the present work both the experimental as well as the numerical (FEM) procedures are used. The output results for the two procedures should validate each others. As was mentioned before that we deal in the present work with real crack occurred during the manufacturing processes. And by taking Wendtland [13] conclusion in our consideration, the modeling of real crack by FEM will not be a real simulation of the real crack. So, the dynamic simulation of the cracked bar has real crack is not available in the FEM package. As a result of this, The FEM discussed before has been established only for the uncracked bar. Fig.(24), Fig.(25) and Fig.(26) illustrate the experimental time history and spectrum for various measurement points on the bar at 2,12 and 22 [cm] from fixed support for uncracked and cracked bar as well as the result of FEM for uncracked bar at the same points. From these figures, we can observe that, the FEM results of the uncracked bar were in excellent agreement with the experimental result of uncracked bar in both time and frequency domains.



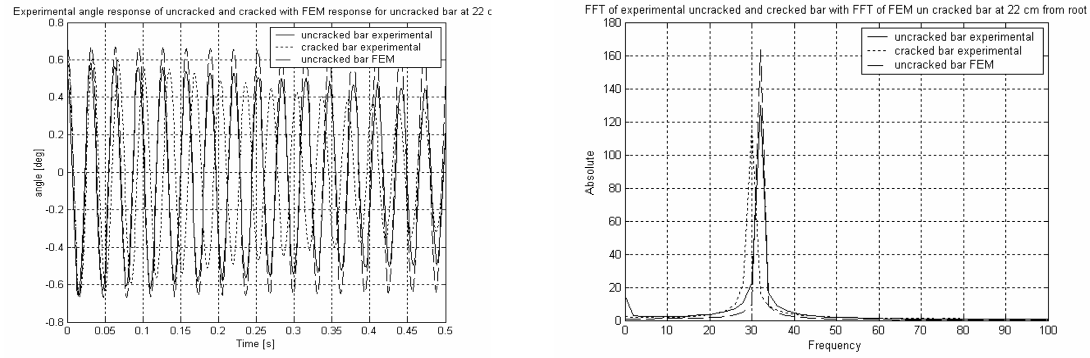
(a) (b)

Fig.24. Experimental angle response of uncracked and cracked bar with FEM response for uncracked bar at 2 [cm] : (a) Time history (b) spectrum



(a) (b)

Fig.25. Experimental angle response of uncracked and cracked bar with FEM response for uncracked bar at 12 [cm] : (a)Time history (b) spectrum

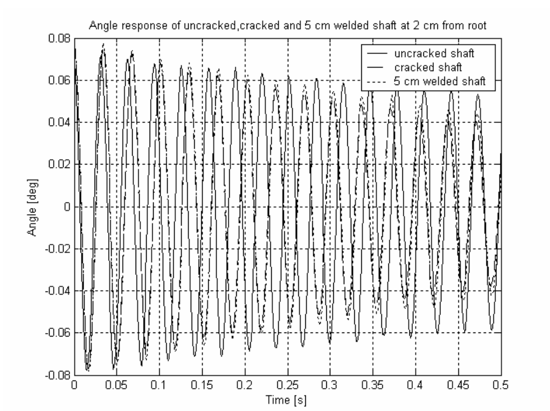


(a) (b)

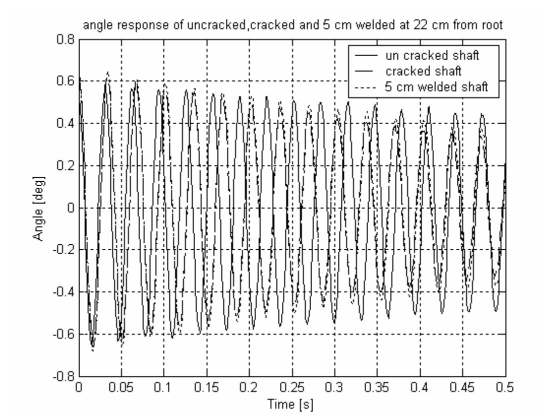
Fig.26. Experimental angle response of uncracked and cracked bar with FEM response for uncracked bar at 22 [cm] : (a)Time history (b) spectrum

13. CRACK WELDING EFFECT

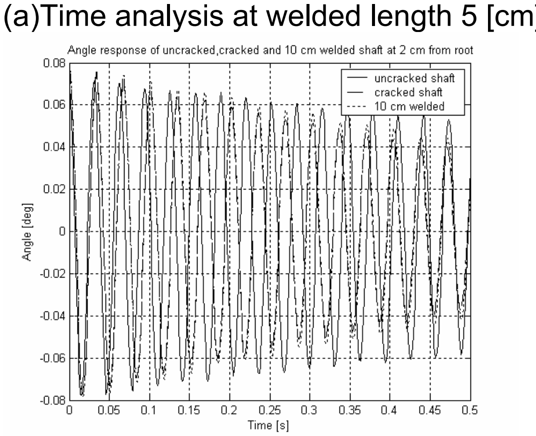
The effect of the crack welding on the dynamic of the cracked bar has been experimentally investigated. The experimental work is repeated and the cracked bar is welded with variable lengths (5, 10 and 15 [cm] long) from the fixed support to study the effect of welding on the dynamics of cracked bar.



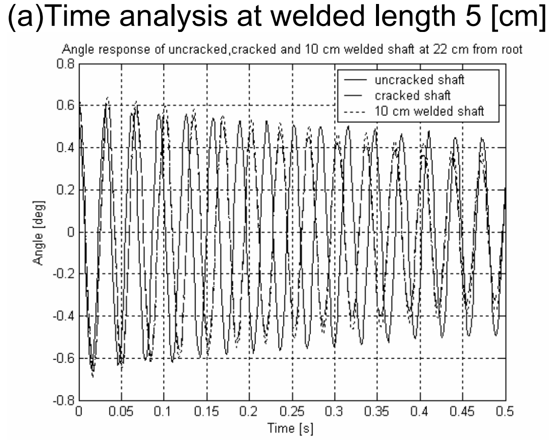
(a)Time analysis at welded length 5 [cm]



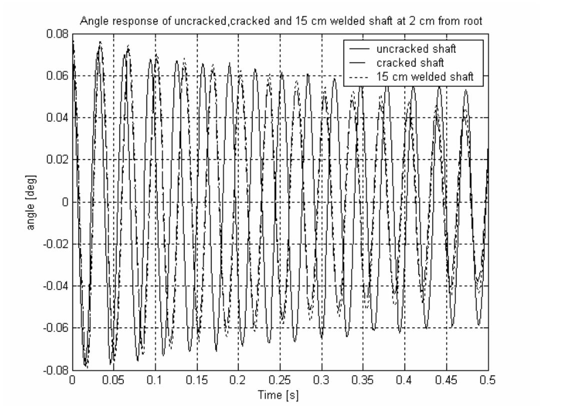
(a)Time analysis at welded length 5 [cm]



(b)Time analysis at welded length 10[cm]

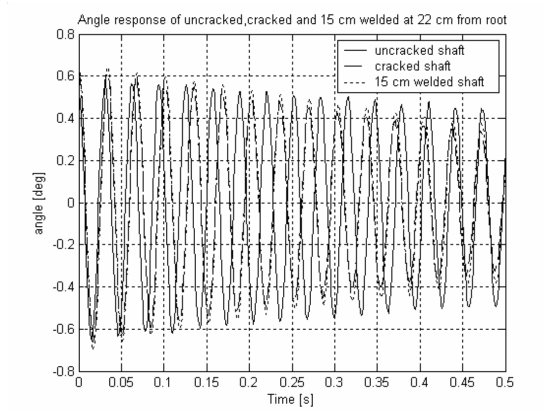


(b)Time analysis at welded length 10[cm]



(c)Time analysis at welded length 15 [cm]

Fig.27. Time analysis at 2 cm from root signal for various welded length (a) 5 cm welded length (b) 10 cm welded length (c) 15 cm welded length



(c)Time analysis at welded length 15 [cm]

Fig.28. Time analysis at 22 cm from root signal for various welded length (a) 5 cm welded length (b) 10 cm welded length (c) 15 cm welded length

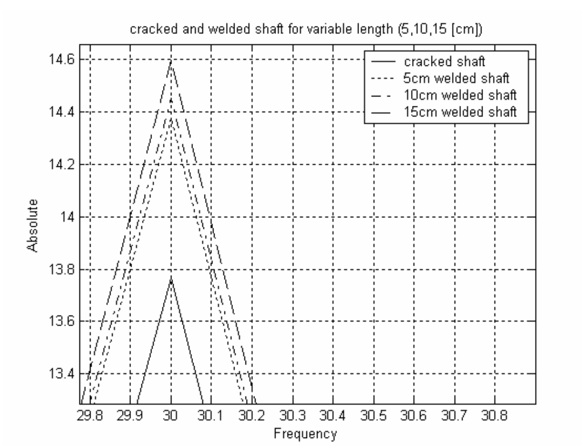


Fig.29. Frequency analysis of the cracked beam and the welded beam for various lengths At 2 cm from root

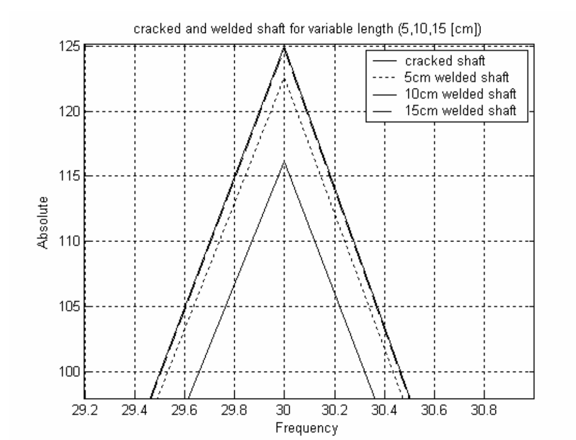


Fig.30. Frequency analysis of the cracked beam and the welded beam for various lengths At 22 cm from root

The signals are measured at the same point 2, 12, and 22 [cm] from the fixed support with the same conditions as the previous experimental work. Fig.(27) and Fig.(28) show the time history of the twisting angle measurement at extreme points 2 and 22 [cm] from the root at various welded lengths for cracked bar (5,10 and 15 [cm] long). For the time domain the responses show that, the amplitude of the signal increased in the welded cracked bar more than the cracked bar without welding. Also, there is insignificant increase in amplitude with the increase in welded length. Fig.(29) and Fig.(30) show the spectrum of the twisting angle response measurement at extreme points 2 and 22 [cm] from the root at various welded lengths for cracked bar (5,10 and 15 [cm] long). It is clear from the above figures that, the frequency of the cracked bar doesn't change and the amplitude increases with increasing in welding length.

14. DISCUSSION

In general, the values of the fundamental frequency and damping change due to the presence of crack. Both experimental and analytical study were carried out for the uncracked bar in time and frequency domains. For time domain, at each point of measurement 2, 12 and 22 [cm] from the fixed support as shown in figures Fig.(24-a), Fig.(25-a) and Fig.(26-a), respectively. The calculated transient response (FEM) was in good agreement with the experimental measurement of transient response. For frequency domain, the harmonic analysis of the calculated signal (FEM) illustrate that the fundamental frequency is 32.7 [Hz]. This value has a good agreement with fundamental frequency which calculated from the experimental work as shown in Fig.(24-b), Fig.(25-b) and Fig.(26-b). Also, the analytical and numerical solution of the fundamental frequency for the uncracked beam was also 32.7 [Hz] as shown in Table.1 and Table.2. Thus the experimental study validates the FE model.

In the present work, two important parameters are affected with the presence of the crack. The first one is the natural frequency. From the experimental work Fig.(21-b), Fig.(22-b) and Fig.(23-b) we can observe that the fundamental frequency for the cracked bar is 30 [Hz] and for uncracked bar is 32.7 [Hz] . So, we can conclude that the value of fundamental frequency decreased due to the presence of crack. The second parameter is the damping effect. Friction happens between the crack faces during the vibration of the cracked bar at each cycle. This friction cause increase in the dissipation of energy from the structure since the damping in the cracked bar is higher than the uncracked bar as shown in Fig.(21-a), Fig.(22-a) and Fig.(23-a).

15. CONCLUSIONS

The result of the present work indicated that the presence of the crack affects the modal parameters of the structure. The change in frequencies such as the fundamental frequency is a valid parameter to detect the crack. In the real application the change in frequency value can be obtained by mounting sensors in a structure. For that purpose, both simulated and experimental works were analyzed by using FFT. It was found that there is frequency deviation in the fundamental frequency of structure due to the presence of crack. The dynamic response of the measured signals indicated that the damping of the measured signals increase in the case of the cracked structure. The damping increase due to the increase in the energy dissipation because of the friction between the crack faces. The parameter of damping can also be an important indicator for the presence of crack in structure. For cracked bar with high crack geometry (high length and depth) vibrates in such mode which permit the friction between the crack faces such as torsion mode (mode III) as our case. The friction between the crack faces has significant effect on the damping of the structure. But this effect has insignificant change in the damping of the structure for the small crack geometry or during the vibration in such a mode which not permits the friction between crack faces for example the transverse or longitudinal vibration of a bar has transverse crack (mode I). The presented results provide a foundation of using FFT technique and the modal parameter as an efficient tool for crack detection.

REFERENCES

[1] S.M. Murigendrappa et al., “Frequency-based experimental and theoretical identification of multiple cracks in straight pipes filled with fluid”, NDT&E International 37, 431–438, (2004).

[2] S.P.Lele and S.K.Maiti “modeling of transverse vibration of shortbeams for crack detection and measurement of crack extension”, Journal of Sound and vibration 257(3), 559-583, (2002)

[3] T.D. Chaudhari& S.K. Maiti, “Modelling of transverse vibration of beam of linearly variable depth with edge crack”, Engineering Fracture Mechanics 63, 425-445, (1999).

[4] Ractliffe, “Damage detection using a modified lablacian operator on modal shape data”, Journal of Sound and vibration 204, 505-517, (1997)

[5] Ju & Mimovich, ”Experimental diagnosis of fracture damage in structures by the modal frequency method”, Transaction of ASME 110,456-463, (1988).

[6] Tisa & Wang,”Vibration analysis and diagnosis of cracked shaft” , Journal of Sound and vibration 192, 607-620, (1996).

[7] Chih-Chieh Chang, Lien-Wen Chen,” Detection of the location and size of cracks in the multiplecracked beam by spatial wavelet based approach”, Mechanical Systems and Signal Processing 19, 139–155, (2005)

[8] J. Gómez-Mancilla et al., “The influence of crack-imbalance orientation and orbital evolution for an extended cracked Jeffcott rotor”, C. R. Mecanique 332, 955–962, (2004).

[9] Ertugerul C, Sadettin Orhan, Murat , “ An analysis of cracked beam structure using impact echo method “, NDT&E International 38 ,368–373, (2005).

[10] L.J. Hadjileontiadisa, E. Doukab, A. Trochidisc, “ Fractal dimension analysis for crack identification in beam structures “, Mechanical Systems and Signal Processing 19, 659–674, (2005).

[11] Anifantis, N. and Dimarogonas, A. D.,”Identification of peripheral cracks in cylindrical shells “ A. S.M.E. Wint. Ann. Meeting, Boston, U.S.A., (1983).

[12]Papadopoulos, C. A. and Dimarogonas, A. D., “ Coupled longitudinal and bending vibrations of a rotating shaft with an open crack “J. Sound Vibration, 117, 81-93, (1987).

[13] Wendtland, D.,” Anderung der biegeeigen frequenzen einer idealisierten schaufel durch risse.” Thesis, University of Karlsruhe, (1972).

[14] RAO " Mechanical vibration" book.

[15] K.Lakshimi and C. Jebaraj, “Sensitivity analysis of local/global modal parameters for identification of a crack in a beam”, Journal of Sound and vibration 228, 977-994, (1999).