

In-situ Monitoring for Fatigue Crack Detection using Control System and Image Processing

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Abstract - A method for automatic in-situ monitoring of specimen for detection of fatigue crack is proposed in this paper. The system is designed to alarm the user as soon as it detects the crack. The purpose is achieved by building a control system using a camera and Raspberry Pi controller. The crack is identified by an image processing algorithm. The dimensions of crack are also measured automatically by the algorithm. The aim of project is to alarm the user about the presence of fatigue crack and display the dimensions of the crack. Use of controller for image processing instead of computer makes the system compact.

Key Words: Stroboscope, Control System, Image Processing, Digital Image Correlation, Crack Detection.

1. INTRODUCTION

Fatigue failure is an important mode of failure in engineering components. Fatigue failure results mainly due to variable loading or more precisely due to cyclic variations in the applied loading or induced stresses [3]. That's why structure monitoring has been popular research topic. A large number of power plant systems present a general steady torsion combined with cyclic bending stress due to the self-weight bending during the rotation or possible misalignment between journal bearings. The dynamical behaviour of plate structures with minor irregularities in the form of crack inspected in laboratory under uniaxial loading conditions.

The inspection is done by expert engineers based on their experience to identify any visual signs, thus the results are based on their personal perspective and may vary from person to person. Experimental fatigue tests typically require large testing times. This testing time drastically increases when one periodically increases when one periodically has to interrupt fatigue test to manually measure the crack lengths. [5]

The control system will be achieved with help of sensor to a measure speed, camera and a controller. The failures of large parts in industrial facilities are the fatigue failures therefore, the fatigue data is very important to study material characteristics. However, it takes much time and efforts to get the fatigue data. Thus the digital image processing techniques used to measure growing behavior of fatigue cracks with reduced time and efforts. Continuous monitoring

of system will be achieved using image processing of the recorded camera images.

2. LITERATURE REVIEW

Z. Kanovic et al. [1] This paper deals with detection of broken rotor bar using vibration signal analysis. Vibration signal analysis is fault detection technique which is generally used for mechanical fault diagnosis, such as bearing problems, gear mesh defects, rotor misalignment and mass unbalance. Rotor bars can be partially or completely cracked during the operation of induction motor, due to stresses, improper rotor geometry design or some imperfection in material or rotor production process. The faulty operation of the particular motor was manifested through high level of vibration and acoustic noise and decreased momentum when operating under load, which implied the presence of broken bar. Vibration signals were collected through accelerometer. Based on the results obtained, it was suggested to remove the rotor and inspect it, which confirmed the fault diagnosis and proved that vibration analysis can be successfully applied to detection of rotor faults.

B. Lian, et al. [2] developed an in situ fatigue crack observing system for rotating bending testing machine. It is proved that this system can detect a small fatigue crack and its propagation behavior. For verifying performance of this observing system, fatigue tests were carried out by using fatigue specimen having a small artificial defect. In the case of the rotating bending fatigue tests, since the fatigue specimen at the minimum cross section is curve inward. By adopting a configuration where several light sources are circularly placed around the fatigue specimen, it is possible to enlighten favorably a larger zone. In order to get observation in adequate synchronization with the rotation speed of the fatigue test, stroboscope device is usually set in order to make the observation of the highest position of the fatigue specimen, where the maximum tension stress level is reached. A long working distance microscope and digital camera, and using combination of a LED stroboscope an observation system to study fatigue crack initiation and propagation phenomenon.

Wei Shang et al. [3] perform tests on polymethyl methacrylate (PMMA) which is installed on the top of aircraft cockpit canopies. They used stroboscopic principal

for the experiment and charge coupled device (CCD) camera to observe the objects moving at high speed under stroboscopic illumination. They programmed the image acquisition software based on the principle of the intensity superposition. They entirely used fatigue testing machine, an image acquisition system, and a synchronous control system. A three-point bending fatigue test was performed on a biaxially directional PMMA specimen with a semicircular notch formed by the stress concentration in the fatigue testing machine. The length of the specimen was 100mm, the width was 22 mm, the thickness was 22 mm, and the radius of the notch was 1 mm. The sinusoidal load with the maximum of 3 kN and the minimum of 1 kN was applied at a frequency of 1 Hz. They study the fatigue crack propagation for directional PMMA. The fatigue testing was also performed on laminated directional PMMA. This research tracked the growth of fatigue crack in directional PMMA by a stroboscopic method.

Thomas Thurner [4] proposed method which targets on detection and measurement of cracks on metallic surfaces where initial artificial cracks have been applied to the specimen's surface prior to dynamic loading in a test rig. The method was based on the optical observation of the specimen's surface under special illumination conditions, where prior to the test an initial notch as a well-defined starter point for cracks has been positioned on the polished metallic surface of the specimen. The developed technique provides the accurate measurement of crack length with a resolution in the order of 0.01 mm and better over crack lengths of 10 mm and more.

The proposed measurement method provides a robust and accurate detection of crack initiation and the highly resolving measurement of crack lengths on metallic specimen with a pre-treated surface in dynamic loading scenarios. In Contrast to existing methods the developed methodology provides high measurement resolution by a non-contacting optical setup and real time on-site measurement capabilities.

Steve Vanlanduit, et al. [5] This paper introduce a DIC based approach to monitor the crack propagation during cyclic fatigue test experiments. Therefore, low-speed (and therefore reasonably low-cost) cameras can be used. The sub-sampling principle makes use of stroboscopic illumination of the specimen. a novel DIC evaluation algorithm is introduced. In literature many DIC evaluation algorithms are used in the proposed procedure to evaluate the sub-pixel displacement values.

S. V. Panin et al [6] have described the algorithm of fatigue crack detection and deterministic tip position. As most system like VIC 3D, Strain Master uses macroscopic observation mode. They have done the procedure for detection of an Object with the Maximum Area of an image from the optical flow of images. The data of images is converted in binary format and then the binary image is

subjected to morphological closure to fill small gaps between continuous objects. The process is finalized by searching for contours of objects remaining in the image and estimating their shape. Blurring of images has a more pronounced effect on the error value, which increases to a much greater extent. The object with the greatest area is taken as a crack. The selected image is used to find the crack and then to calculate its tip location. The proposed algorithm is characterized by the maximum error of crack detection in extremely noisy images.

3. ALGORITHM FOR CRACK DETECTION

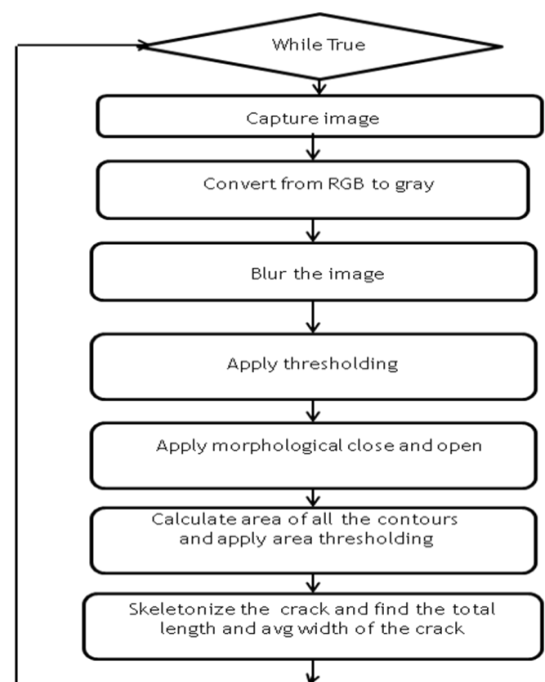


Chart -1: Flow chart for crack detection algorithm

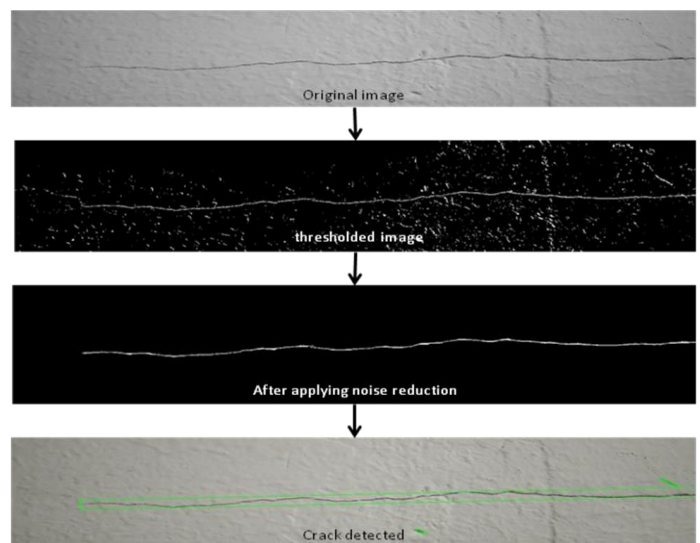


Fig -1: Steps in crack detection algorithm

The images captured are stored and processed by the controller. The algorithm used for the crack detection is as follows.

- The image which is in the RGB form is converted into the gray image. Then image is blurred by using Gaussian blur filter to eliminate possible small noise in thresholding.
- Then the adaptive thresholding method is used which will enable the crack isolation irrespective of the provided illumination. This method improves the versatility of the algorithm and can be used in different work environments.
- Morphological open() and close() functions are used to reduce the noise and to close the parts of crack which are disconnected from each other.
- Areas of each contour are calculated. The crack is separated from the background noise by using area thresholding. All the contours smaller than the minimum area requirement are deleted from the image.
- Till this step the crack is nearly isolated. Now the crack is skeletonized using the skeletonize function. The skeletonized image will have only one pixel value which gives the exact shape of the crack.
- The exact crack length is found out by taking the area of the skeletonized image. The average width is calculated by making the assumption that after the crack is fully elongated to make it straight its shape will be as rectangle. The remaining noise is deleted by giving the minimum length requirement to the contours.

Area of rectangle is given by-
 $A = l \cdot b$

Here,
 A=area of crack
 l=Crack length
 b=Crack width

Thus,
 $b = A/l$

Thus the crack width and length of the crack is found out for the given image of the crack-The crack satisfies the requirement of the minimum area, minimum length and minimum perimeter to area ratio. Thus when the above conditions are satisfied the crack is detected and thus the user is alarmed about the presence of the crack by the controller.

4. DESIGN OF SPECIMEN

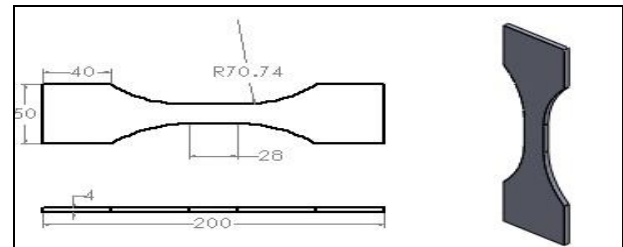


Fig -2: Dimensions of specimen

- i. Material Specification
 - International steel grades
BS: C45, 50CS, 080M46
AFNOR: C45, AF65C45, 1C45
SAE: 1045
 - Chemical composition

C	: 0.42 to 0.5
Si	: <0.4
Mn	: 0.5 to 0.8
P	: <0.04
S	: <0.045
Cr	: <0.4
Mo	: <0.1
Ni	: 0.4
Cr+Mo+Ni	: <0.63
 - Mechanical Properties

Density	: 7872 Kg/m ³
Modulus of Elasticity	: 201 GPA
Coefficient of Thermal Expansion	: 11.7 x 10 ⁻⁶ C ⁻¹
Specific Heat Capacity	: 486 J/Kg K
Thermal Conductivity	: 50.9 W/mK
Electric Resistivity	: 1.62x10 ⁻⁷ Ωm
Ultimate Tensile Strength	: 625 MPA
Yield Strength	: 530 MPA

4. ANALYSIS

The static and fatigue analysis was carried out using Ansys software. The geometry of the specimen was modelled using catia, based on the specimen used in the experiment study. The 3-D geometric design of the tested specimen is shown in fig illustrates the 3-D solid FE-mesh of the specimen with mesh characteristics.

- Results and Discussion

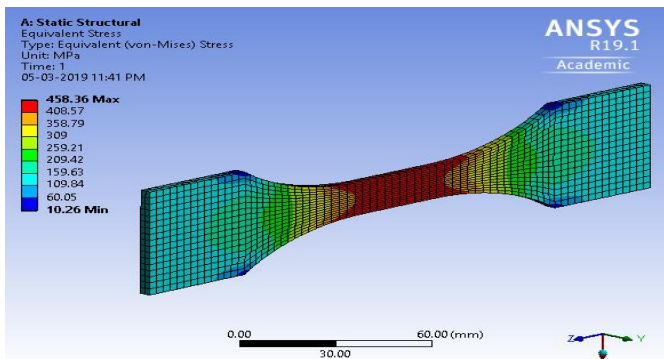


Fig -3: Equivalent stress in the specimen under fatigue load

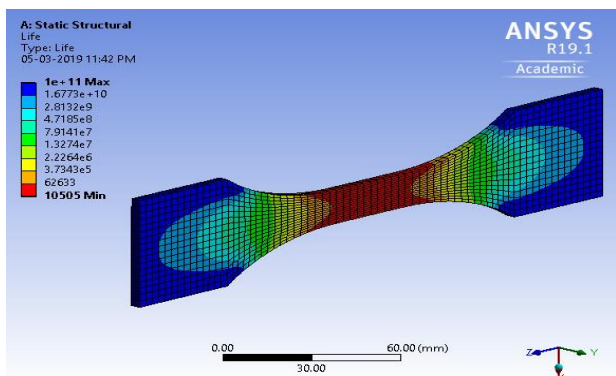


Fig -4: Life of the specimen under fatigue load

5. EXPERIMENTAL SETUP

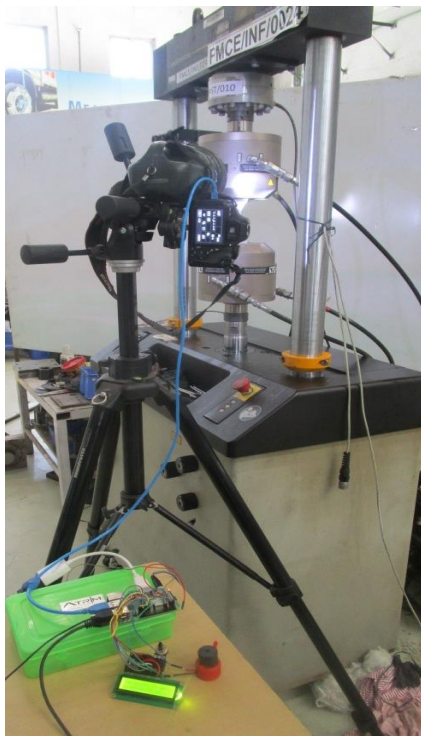


Fig -5: Life of the specimen under fatigue load

As shown in the fig-5 the specimen was mounted between the two chucks of the uniaxial fatigue testing machine. The fatigue testing machine used was instron 8801 having capacity of 100KN. A

27.5 KN fully reversed force was applied on the plate with a frequency of 5 Hz. A camera was mounted on a tripod stand and positioned at a safe distance in front of the plate.

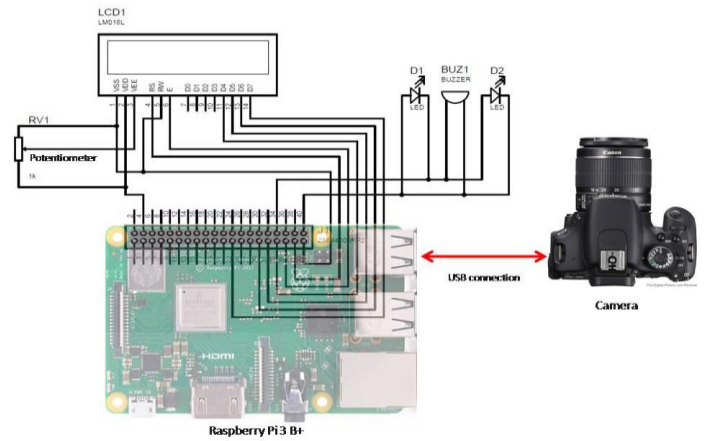


Fig -6: Circuit diagram of the setup

Raspberry PI 3 B+ controller was used in the experiment. The camera used is Canon 600D. The camera was connected to the controller through a USB cable to continuously feed the captured images to controller. A 16x2 LCD was connected to the controller in a 4-bit mode as shown in the fig-6. A potentiometer was connected to adjust the contrast of the LCD. A buzzer and two LEDs are all connected in parallel to each other between pin no. 40 of the Raspberry Pi and pin no. 36 which is ground.

After the distance between the camera and the plate is fixed the ratio of actual length to corresponding no. of pixels in camera representing the length was found out. The exact shape of the plate which can be observed in the photo is replicated. The pixels which lie outside the plate specimen are deleted or simply not taken in account in the image processing algorithm.

5. EXPERIMENTAL PROCEDURE

The plate was mounted on the setup and a alternating force of 27.6 KN was applied on the plate by the machine. The camera is set to take a photo for every 24 seconds delay. The controller processes the image and decides whether the crack exists on the specimen or not. The images taken by the camera and the images produced after different filters are applied on them during and the final image for each cycle are automatically saved in the memory which can be studied later.

The algorithm keeps running displaying 'no crack' on the LCD until the crack is detected. The controller will automatically turn on the buzzer and display the dimensions of the crack on the LCD when the crack is detected.

6. RESULTS

- Initially the small cracks were initiated and could be observed over the sides of the plate at around 5400 cycles.
- The camera successfully identified the crack and turned on the alarm before the break down of the component when the crack grew sufficient enough on the front side of the specimen.
- The component broke after around 6100 cycles.

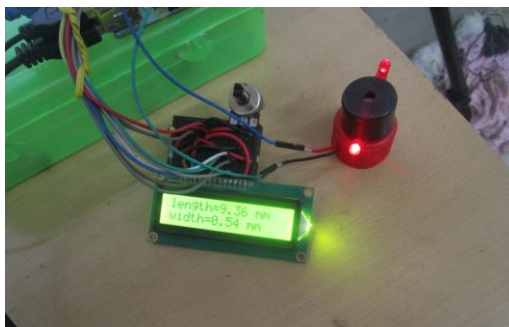


Fig -7: LCD displaying the results and beeping alarm

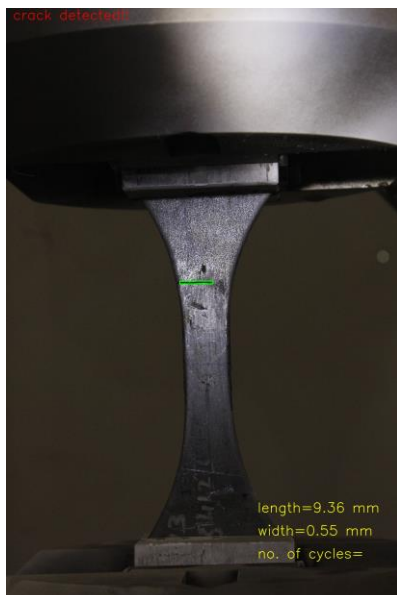


Fig -8: Crack detection result

```
photo
time= 0.0
original length= 9.36
width= 0.54
area= 1156
var= 1
time2 26.00242328643799
time= 21.185105085372925
photo
time= 0.0
original length= 9.29
width= 0.55
area= 1162
var= 2
time2 26.00261092185974
time= 20.97151470184326
photo
time= 0.0
original length= 9.22
width= 0.54
area= 1133
var= 3
time2 26.00270105633399
```

Fig -9: Results in python IDE

- The average crack length prior to failure calculated by algorithm was 9.29 mm and average crack width was 0.54 mm.
- The actual crack length measured by vernier caliper was nearly 9.4 mm. Thus the results were verified to have 98.08 % accuracy.

7. CONCLUSION

A compact control system for monitoring the crack on the plate specimen was successfully designed and constructed. An experiment was conducted to verify the performance of the control system. The control system successfully detects the crack and alarms the user about the presence of the crack. The length and width of the crack were calculated by the system. The results verified to have around 98.08% accuracy.

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