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CRACK LENGTH DETECTION BY DIGITAL IMAGE PROCESSING.

by

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SUMMARY

It is described how digital image processing is used for measuring the length of fatigue cracks. The system is installed in a Personal Computer equipped with image processing hardware and performs automated measuring on plane metal specimens used in fatigue testing. Normally one can not achieve a resolution better than that of the image processing equipment. To overcome this problem an extrapolation technique is used resulting in a better resolution. The system was tested on a specimen loaded with different loads. The error σ_a was less than 0.031 mm, which is of the same size as human measuring with a microscope.

1. INTRODUCTION

Digital Image Processing (DIP) is a quite new technique, which has gained widespread use in laboratories and industry in recent years. The reason is the general decrease in prices and increase in speed for computers and equipment. Previously, digital image processing required data power from a mainframe computer (typically a VAX 780). Now PC ATs have grown so powerful that it is possible to perform digital image processing at an acceptable speed. This tendency is supposed to continue, and that means that digital image processing will become more common in the future.

The technique gives access to new methods and facilities in analyzing, recognizing and surveying. In /5/ it is described how DIP is used in robotic vision, and in /3/ examples of the use of DIP in astronomy are given. Other examples of use are quality classification of floor boards /6/, and recognition of zoo-plankton in water for control of pollution.

In the Structural Research laboratory at The Institute of Building Technology and Structural Engineering, The University of Aalborg, a program based on digital image processing has been developed for measuring crack lengths in metal sheets. In /2/ another way of measuring crack lengths by DIP is described

2. TECHNIQUE OF THE EQUIPMENT

The computational equipment used for image analyzing is a 16 Mhz 80286 PC AT with monitor and printer. The hardware of the image processing consists of a DT2851 high resolution frame grabber card. To utilize fast averaging of images and other procedures a DT2858 Arithmetic Coprocesor card is also installed in the PC. Both cards come from the company Data Translation.

As camera for the system a CCD camera with CCIR standard output is used. For visualizing the images a monitor is connected to the frame grabber card. The equipment is shown in fig. 1.

The software used in image processing is a library called IRIS from Data Translation. The library consists of a number of routines, which are available from the programming languages Microsoft Fortran, Pascal and C. The program for crack length detection is written in C.
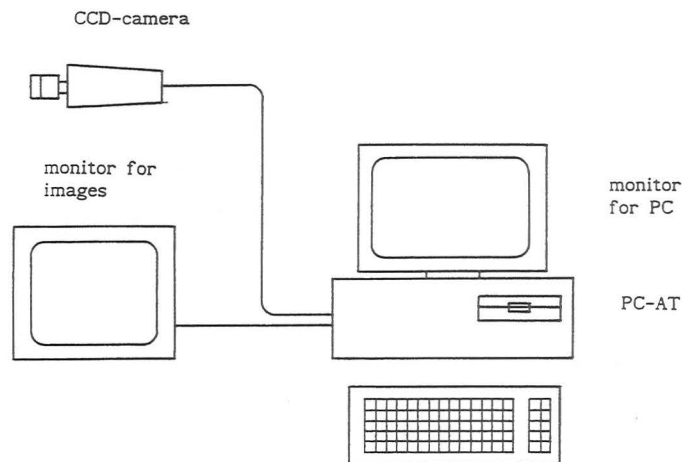

Fig. 1.   *Schematic drawing of equipment.*

When an image is "read" into the computer, the light sensitive chip in the camera is scanned and an analog signal is transmitted to the frame grabber. The frame grabber card performs an analog to digital conversion, and the image is stored in a 512x512 matrix. Each element in the matrix (a pixel) can have 2^8=256 different values ranging from 0 to 255 and representing grey levels between dark and light. The matrix is stored in an array on the frame grabber's memory (a frame buffer). This buffer can be read and manipulated from the programs performing the digital image processing. The process captures 40 msec for a single image. For reducing the random noise in the picture a number of averages are often performed. In this situation 16 averages are performed reducing the random noise by a factor 4.

It is possible to store images on hard disc. An image requires 262656 bytes. When performing crack length measuring no images are stored to disc.

3. MANUAL CRACK LENGTH DETECTION

Fatigue in metals is caused by cracks growing through the material. When evaluating crack growth models and material properties, various standard experiments are performed. It is common for most of these that the crack length has to be measured as a function of the number of load cycles

applied. Various methods exist for crack length detection; visual, potential drop, compliance, clip gauge etc. Each method has both advantages and disadvantages.

The visual method is the most general method for 2-D measuring, as it requires no apriori knowledge of the test specimen or the loading. One of its disadvantages is that it is not objective. In practice the crack length measuring is often performed with a microscope and a length scale drawn or etched on the surface of the specimen. Everyone, who has tried it, knows that visual crack length measuring is everything but attractive. This is because it is time consuming and boring, and one often has to work in an uncomfortable position. To eliminate these disadvantages, the program based on digital image processing has been developed for crack length measuring.

4. CRACK LENGTH MEASURING WITH IMAGE PROCESSING

When measuring crack lengths with digital image processing it is necessary to modify the surface of the test specimen. The area in which the crack is expected to grow, was polished to a surface roughness of about $R_a= 0.1\mu m$. The polishing direction is normal to the expected crack growth path to avoid confusion between the fatigue crack and tracks from polishing, see fig.2.
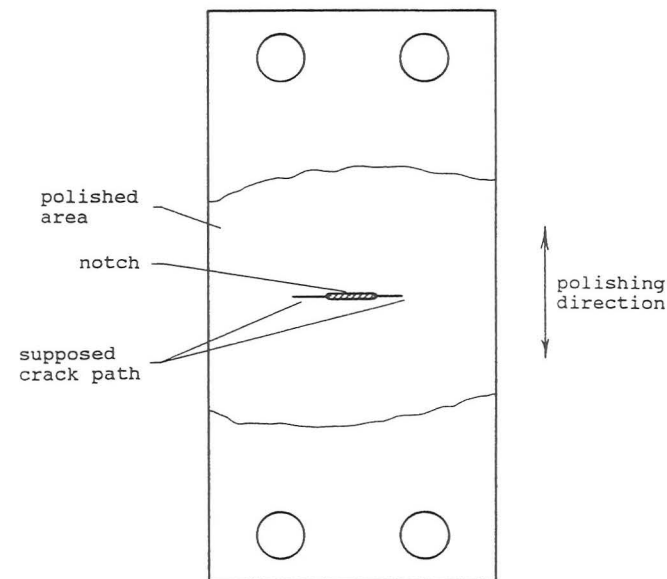

Fig.2.   *Test specimen with polishing area and direction.*

During the test, the test specimen is illuminated by an optic fiber light source at an angle of about 30°, see fig. 3. The polished area will reflect the light as a mirror and appears dark, whereas the lips of the crack will scatter the light and the crack will appear light. Since the crack lips and not the crack opening represent the crack, the image analysis is not supposed to be influenced by the load applied.
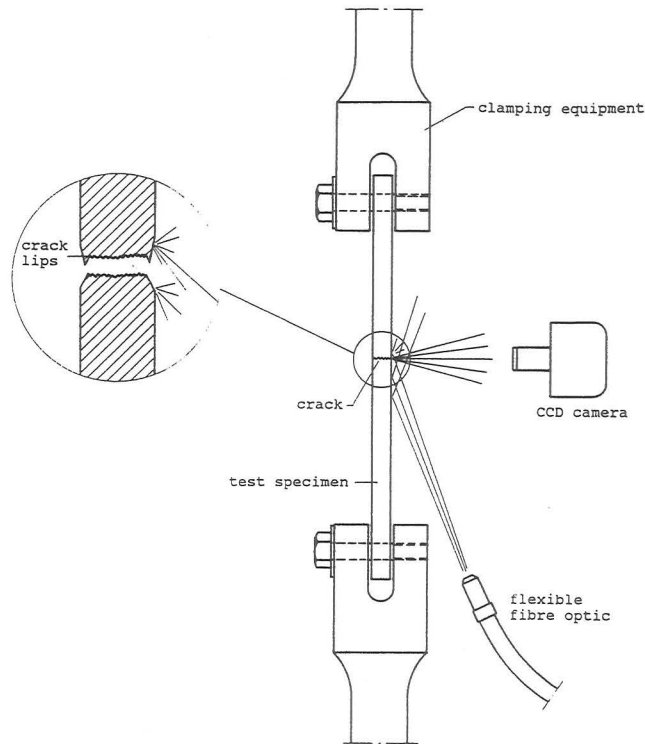

Fig. 3.   Illumination of test specimen.

To eliminate small surface scratches, pits etc., which might interrupt the crack detection, the crack growth is determined by subtracting the previous image from the current image. The difference is an image of the crack growth without any other disturbing elements. The crack tip is found from the previous crack tip position by following the crack until the new tip is found.

In this specific situation the system is surveying an area on the test specimen of about 50×50 mm. With 512×512 pixels this gives a resolution of approximately 1/10 [mm/pixel]. This resolution is too rough for most fatigue analysis. To increase the resolution a method has been developed

for obtaining crack lengths with sub pixel accuracy.

In fig. 3.5 a 3-D plot of a 20x20 subset including the crack tip is shown. It has been found, that the crack has a width of about 3 pixels.
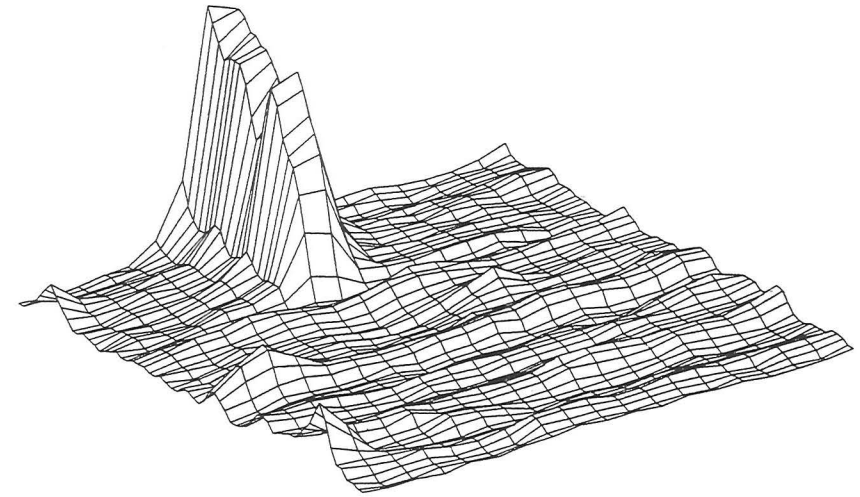

Fig. 4   20x20 pixel subset showing the crack tip.

If the pixels across the crack are summed, see fig. 5, one has an expression for the total amount of light, scattered by the crack lips and detected by the camera,

$$\text{pixelsum}_i = \sum_{j=-1}^{1} \text{window}_{ij}, \text{ where}$$

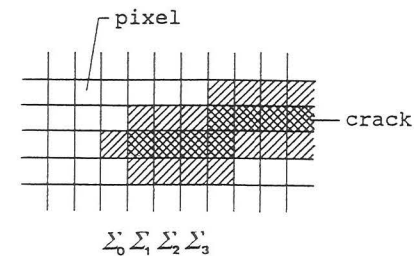window_{ij} is pixels in the subset containing the crack

Fig. 5.   Summing of pixels across the crack.

In fig. 6 the pixelsums in the crack tip are shown for 5 different crack lengths. On the vertical axis the sum of pixel intensities across the crack are shown. It is seen, that far from the crack tip the total amount of light scattered by the crack is more or less constant, whereas a distinct transition zone is identified just prior to the crack tip. The size of the transition zone is seen to be about 3-4 pixels in this case.
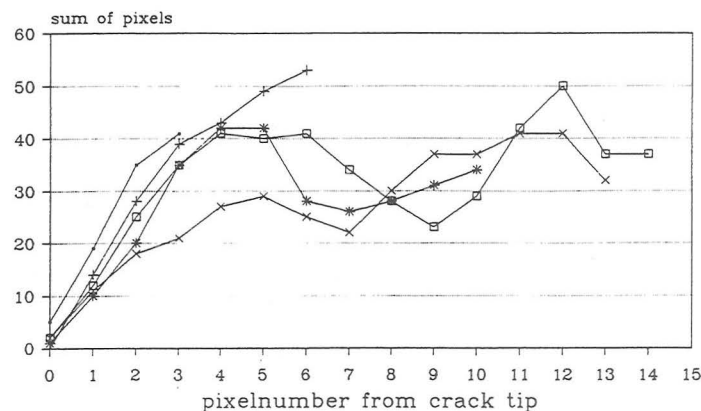

Fig. 6. Pixelsums across crack shown as a function of pixels from crack tip.

It is assumed, that the crack tip is situated where the light intensity decreases to zero. To detect this point a curve-fitting is performed on the 3 last pixel sums in the crack tip. The 3 sums are fitted to a linear function, which is forced to cross the outer pixel sum of the crack tip, see fig. 7.
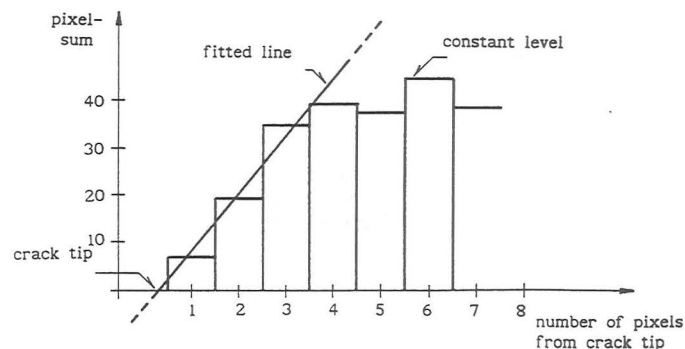

Fig. 7. Curve-fitting function to the 3 outer pixel sums of the crack.

With this technique the crack length is measured in pixels. A routine has been developed for transforming from pixels to usual length units. The cm scale shown in fig. 8 is glued to the test specimen. When a crack length measuring is performed, the routine detects the resolution in pixels per mm and the physical position of the left edge of the image. In the routine a sub pixel technique is used too. The routine searches the wide beam, and when it is found, the pixel intensity of the vertical streaks is scanned. The middle of the left and right streak is found as the points of gravity. The resolution is found as the number of pixels between these two points of gravity divided by the number of mm between them. The number of mm is detected from the number of horizontal streaks below these two vertical streaks. The position of the left edge of the image is also detected from the number of horizontal streaks below the wide beam and the resolution of the image.
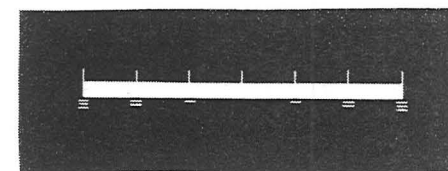

Fig. 8. Cm scale used for transformation from pixels to physical world.

In fig. 9 an image from a fatigue test is shown. The image shows a crack growing from a notch (the hole). Below the crack the cm scale is mounted. The system can detect crack lengths from such a scene.

When performing a fatigue test the starting position of the crack is observed by the operator and read into the program, and the test is then started. After a number of load cycles the test is interrupted, and the crack length is measured. The crack has to grow at least 5 pixels (about 0.3 mm) between each measuring for curve fitting to be possible. The time captured for one crack length detection is about 10 seconds.

5. TEST RESULTS

The program was slightly modified, making it possible to perform several measures of the same crack (fixed crack length). 20 measuring were performed at each of the loads 0 kN, 10 kN, 20 kN, 30 kN and 40 kN.

The crack lengths were also measured with a microscope mounted on a sliding stage. An electronic position measuring system with a resolution of 0.005 mm is connected to the stage. Crack length measuring were performed at loads of 0 kN and 10 kN by two persons (A and B). The results of the tests are shown in table 1.
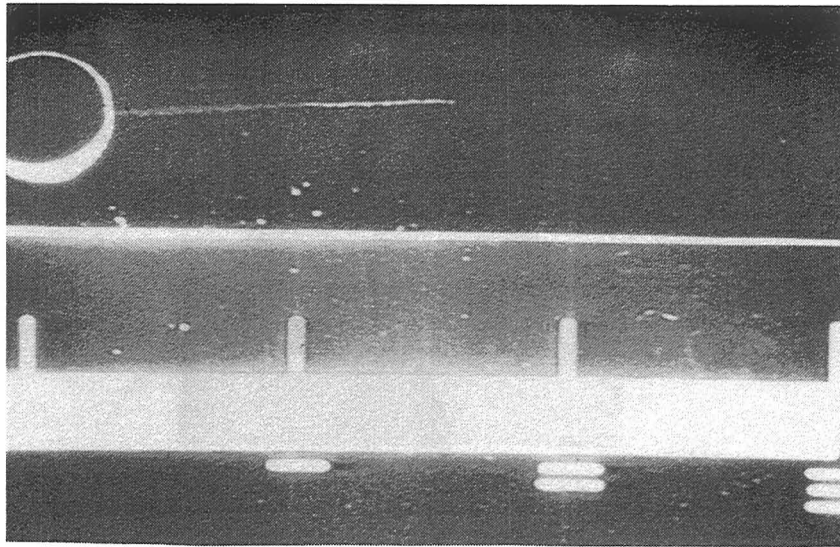
Fig. 9.   An image showing the test specimen with crack and cm scale.

loading	$\bar{a}$ [mm]	σ_a [mm]	σ_{plx}
0 kN	15.998	0.015	0.215
10 kN	16.015	0.031	0.219
20 kN	16.017	0.013	0.195
30 kN	15.998	0.006	0.083
40 kN	15.996	0.010	0.143
mic. 0 kN A	16.007	0.039	——
mic. 10kN A	16.039	0.009	——
mic. 0 kN B	16.135	0.039	——

Table 1   Test of crack length measuring. A and B indicates the person performing the test. σ_a and σ_{plx} is the deviation in crack length measured in mm and pixels, respectively.

The procedure detecting the resolution of the image (e.g. how many pixels pr. mm of the test specimen) and the physical left edge position of the image were tested too. The deviations of the resolution were less than 0.003 pixels/mm for all loads, and the deviations of the left edge positions were less than 0.001 mm for all loads.

6. CONCLUSIONS

Based on the test of the proposed technique it is concluded that there is no dependence between measured crack length and loading of the test specimen. The uncertainty of the system is of the same magnitude or less than measurement uncertainty when using a traditional manual technique. This equipment represents the best available today.

The crack length measuring has been automated, and it is possible to automate the process further, if the load frame is controlled from the same Personal Computer as the crack measuring system.

The system is flexible and easy to use, however it requires that the area of the crack growth is polished and correctly illuminated. Fulfillment of the latter condition can sometimes be difficult because of shadowing from clamping equipment.

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