REAL TIME X-RAY MICROFOCUS INSPECTION OF HONEYCOMB

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INTRODUCTION

Honeycomb structures are often used because they are light in weight, yet able to bear large pressure loads. Because weight is such a major consideration in the aerospace industry, honeycomb is used in many non-load bearing structures such as control surfaces, access doors, floors, and speed brakes. As may be expected in a complicated structure, there are many possibilities for defects or damage to be induced into these parts, both during the fabrication process and while the part is in service. The presence of these defects necessitate that honeycomb structures be inspected. Film radiography is often used as the primary inspection technique for honeycomb. Alternatively, real time imaging is a filmless radiographic inspection technique which has speed and arbitrary orientation of the sample as its primary advantage. This technique has not been widely used, primarily because of poor image quality. The first point is poor spatial resolution, and the second is poor contrast sensitivity, as compared to film. When a microfocus x-ray source is used in conjunction with a real time system, the result is a marked improvement of the image resolution. The use of image processing can significantly improve the contrast sensitivity. The result is a real time system with resolution equivalent to the present film inspection techniques thus allowing for quicker and less costly inspections, so long a the sensitivity requirements are not too stringent.

Benefits Of Microfocus

The microfocus technique, developed for the rapid inspection of turbine blades, has been described in the literature(1,2,3) and, as such, we will give only a brief review of the technique. Typical x-ray sources have a focal spot on the target with a diameter of a few millimeters, however, microfocus sources with a focal spot of about 5-10 microns and as such better simulate a point source. An effect directly related to the size of the source is the geometric unsharpness (Ug), or penumbra of the shadow and is given by Uk = a/d, where a is the focal spot size, d is the object to sample distance, and D is the source to object distance. It should be noted that the Ug factor decreases as the source to object distance decreases. Previous studies (4) have shown that for standard spot sizes, and experimental configuration yielding, a magnification of 2X causes a drop in the contrast of small flaw signals by half. Magnification with a microfocus source with present spot sizes is essentially limited only by the source to detector distance available and the limits of sufficient flux.
The usefulness of inspections using both radiographic film and real
time imaging was studied with particular attention on the effects of the
magnification and image processing capabilities of the microfocus real
time system. Several samples were tested, which were different
combinations of aluminum or Nomex honeycomb with either aluminum or
graphite/epoxy composite face sheets. There were a variety of flaws in
these samples, ranging from fabricated inclusions to impact and fatigue
damage. The samples also ranged in thickness from 1 to 4 inches.

Of the many possible types of damage, the following conditions were
observed in this study: crushed core, condensed core, cut core, foreign
material damage, blown core, adhesive porosity. Crushed core is
localized buckling of the cell walls, and may result from impact damage.
Condensed core pertains to rows of core which are pushed together and are
not their full size. Cut core and foreign object damage may occur during
the manufacturing process as a result of handling. Blown core usually
results from heating trapped volatiles, which expand the cell walls.
Bondline porosity is sometimes created during fabrication, and can cause
delamination of the face sheet if too much exists. Incomplete core
splices may also exist, which is characterized by lack of bonding filler
between the core sections. Many other conditions not observed in this
study may exist, such as distorted core, missing core, cracks, and
crazings.

Magnification

To quantify the benefits of the microfocus source of the system,
the samples were inspected at different levels of magnification, using
both film and real time imaging for detection. Intensity of the source
was varied using the different voltage and current settings to present
the best contrast for each image. Samples were set on an automated
rotation stage and x-y positioner. As expected, without magnification,
it was much easier to see flaws in the film because of the high spatial
resolution. Magnifications for X-1, 2, 3 were recorded, and higher
magnifications observed.

For the film, 1X generally gives a good enough picture to
distinguish major flaws in a sample, but it takes a trained eye to see
damage such as core crush. Core crush is difficult to determine because
of its subtle doubling effect of the cell walls. It would be easier to
distinguish this type of flaw if the contrast between cell and cell wall
were clearer, something easily done with magnification. At 3X and higher
magnification, core crush becomes even more distinguished making
inspection easier, more reliable, and faster (figures 1a and 1b).

The use of magnification for the real time inspection of honeycomb
is critical. It is very difficult to distinguish damage without
magnification. As magnification increases, the detectability of damage
in the sections also increases. Our observations show that most damage
can be distinguished with the present imaging system at approximately 3X.

Thickness And Orientation Effects in Real Time Inspections

Intuitively, one would think that magnification of a radiographic
image would help show the flaws in all cases; however, this is not true
in the case of very thick samples. Because there is a difference in the
distances of the front and rear of the sample with respect to the source,
one side of the part is magnified more than the other. This, in
conjunction with the effect of the radial divergence of the beam,
produces a very distorted picture, with only a small portion of the
radiograph acceptable for interpretation. Although this distortion is
apparent in this particular case, a system with a larger source to
detector distance would not have as great of an effect. Indeed, in
industrial inspections large source to film distances are used to
minimize the effects of the radial divergence of the beam. However, the
positioning of parts with respect to film is very tedious with thick

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Fig. 1. Real time x-ray image of aluminum core, aluminum skin honeycomb with impact damage indicated by narrow dark lead marker. Note the cell layover due to the close source to sample distance and the lack of any indication of cell wall crushing in 1a. The damage is easily seen in 1b. This image is a 3x magnification with the crushed walls showing up as a split line. Bubbles in the skin - honeycomb adhesive are easily seen in 1b.
honeycomb parts. Lining up the part so that the beam is going through the cell is difficult, because the slightest angle on a thick part will cause a lay over effect, resulting in a hopelessly complicated image. This use of large distances to minimize the effect of cell layover has a consequence of making the cells very small, thus making the inspection more difficult. This overlap difficulty is avoided with a real time system, in that parts can easily be positioned in a mode that maintains the large size of the cells before capturing an image. The part can be scanned in its entirety with far greater ease and speed than the corresponding film inspection.

A further example of a difficulty due to orientation problems is that of detecting crack-like flaws. The angular orientation requirements of any inspections needed to locate node separation or cracks make them easily missed. Samples can not be moved at all during a film exposure, and would need to be reoriented several times before the proper angle was found to locate a crack or orient for thickness, an expensive procedure to say the least. With real time imaging and its continuous rotation capability, the likelihood of finding this type of flaw greatly enhanced. The orientation dependence of flaws, and cracks in particular, is not the only factor in their detection. As mentioned earlier, the second major influence is the contrast sensitivity. The greater the contrast sensitivity of the inspection system, the more reliable the flaw detection. It is in this area that image enhancement of the real time images yields an increase in the contrast.

**Figure of Merit for Image Processing**

Real time image enhancement can be a very beneficial tool, when used correctly. Unfortunately, image processing is not always the cure for a difficult to interpret image. As in the case of the honeycomb inspection, some of the filters and routines actually produced deceiving results. Sections of the image which were darkened due to effects of the set-up, were emphasized instead of the desired damaged portion. This is an example of an artifact introduced by the enhancement routine and is one element that makes the effectiveness of an image enhancement procedure is difficult to assess. The second area that is difficult to measure visually is the amount of improvement for equal quantities of computer processing time. This is a critical issue in that the real time image processing must be done in real time.

We developed a method to evaluate the effectiveness of image processing routines both for the introduction of artifacts and the value of the enhancement. To do this we make use of a simulation of the image formation process(4,5,6). There are several important features of this approach including the fact that the process noise is modeled and as such it can be turned on or off at will. Secondly, the exact knowledge of the flaw shape and size is known. The procedure is to turn off the noise and run the simulation. This gives an ideal image which would be obtained if one had ideal detectors and no process noise. An image with identical setup parameters is generated with the process noise on. A comparison to the ideal image gives a quantitative measure of the loss in contrast and the reduction of the geometric extent of the size of the flaw. This represents the maximum amount that good image processing could recover. We now have a standard to compare the effectiveness of image processing routines.

Figures 2a, 2b, 2c, and 2d illustrates the result on a simple part, namely a flat plate with a conical shaped void. It should be pointed out that the simulation is not limited to simple shapes, but is able to handle most any part and flaw shape. The normal process noise can cause a factor of two under sizing of the flaw, especially if the thickness of the flaw is close to the sensitivity limit of the system. Some of the most effective real time processing routines proved to be the simplest.
Figure 2a is the simulated image of a conical axial in a flat plate with no process noise and figure 2b represents the same flaw with the normal noise processes. Figures 2c and 2d represent the result of simple image processing, specifically background subtraction and grey level stretching. Note that the sizing of the processed image (2d) compared to the perfect image (2a) are very close.
Table I.

<table>
<thead>
<tr>
<th>Figure</th>
<th>Image</th>
<th>Spatial Extent</th>
<th>Contrast</th>
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</thead>
<tbody>
<tr>
<td>2a</td>
<td>Image with no noise</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>2b</td>
<td>Image with noise</td>
<td>67%</td>
<td>84%</td>
</tr>
<tr>
<td>2c</td>
<td>Processed image with background substracted</td>
<td>77%</td>
<td>131%*</td>
</tr>
<tr>
<td>2d</td>
<td>Processed image with additional constant substracted</td>
<td>99%</td>
<td>220%*</td>
</tr>
</tbody>
</table>

*Artifact for quantitative sizing

Fig. 3. The detectability of the same flaw based on experimental measurements using film and an image intensifier with and without image processing. The thickness sensitivity of the image intensifier without processing falls off rapidly at about 4% as compared to unprocessed fiber and processed real time images which fall off at 2%.

A simple background subtraction and subsequent grey scale stretch yields an impressive improvement of flaw sizing. The artifact that is easily apparent is the huge increase over the actual contrast. This would, if used, result in an over sizing of the thickness of the flaw. For quantitative measure, see Table I.

Figure 3 shows the summary of the results of image enhancement comparing an image intensifier with and without real time image enhancement to film. As can be seen the thickness sensitivity of the real time system with image enhancement compares with those obtained from unprocessed film. Of course, when a film radiograph is digitized and processed, the results will be better than those of an image intensifier.

CONCLUSIONS

As noted, there are some drawbacks of real time inspection systems, the first being spatial resolution, the second being poor thickness.
sensitivity. The solution of the problem of poor resolution is to use geometric magnification. Magnification with the microfocus system is relatively easy to do, and increases resolution by approximately the magnification factor. This increases the ability to interpret the image, and locate flaws, thus compensating for the initial poor spatial resolution. The solution to the lack of thickness sensitivity is the proper application of real time image enhancement. Unlike the improvements in resolution, improvements that are readily seen with a resolution gage, the improvements of a particular image enhancement routine remain unclear. The development of a quantitative figure of merit to measure the improvement in the spatial sizing, the detectability of the indication, and the artifacts introduced give a way to evaluate the best image enhancement procedure. The evaluation of the optimum procedures is particularly important in real time inspection where the enhancement must be effective to recover lost sensitivity without loosing the flexibility of the real time inspection.

The use of the magnification capabilities of a microfocus x-ray source in conjunction with a real time imaging system provides an effective way to inspect honeycomb structures. The most obvious asset is the speed at which an image can be produced, which is quite a bit faster than the time necessary to process film. Another advantage is that the orientation of the object can be adjusted using positioners in real time while viewing the image. Also, the digital image created allows for immediate image processing, which may or may not help the image.

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