SIEMENS

VJ INSPECTION SYSTEMS
A VJ Technologies Company

Using High Energy Computed Tomography (CT) to Aid Design Engineering in Optimizing Combustion Turbine Airfoil, Cooling Performance

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Siemens Energy experienced a localized temperature increase in a component shortly after there first (24K) repair cycle. A root cause analysis concluded that the temperature increase was due to a lack of impingement cooling. Engineering wanted to determine the spatial relationship (1.0mm – 4.0mm, min – max), of the newly assembled insert to the inner wall of the airfoil, after the repair had been completed. To accomplish this task, the Non-Destructive Engineering Department recommended Computer Tomography.

Figure 1

Based on their high energy (6MEV) facility (Figure 1 and 2), VJ Technology was selected by Siemens to develop a CT process for scanning these parts. Preliminary CT scans demonstrated a reliable means of accurately measuring this gap in the area of interest, identified several manufacturing issues that were critical in the repair process, and was used to qualify a simplistic technique to insure the proper spacing during subsequent manufacturing (eliminating the cost of CT).


Figure 2

VG Studio Max software was used by both Siemens and VJ, not only identified insert positioning but, determined other quality issues were controlled. Consequently a purchase order was issued to VJ Technology for multiple sets to be inspected by Computer Tomography. The cost of the program was administered at approximately 10% of the replacement cost of new components. This resulted in a significant savings to Siemens.

The initial request for CT scanning services of the component assemblies was to accurately measure the spacing between the inner wall of the leading edge cavity and the insert within the cavity at eleven specific points, from inner to outer shroud in approximately 150 micron (0.006in) slices or steps (Figure 3).

The primary objective was to produce accurate and reliable High Energy CT reconstructions. Due to the geometry of the part, several considerations were factored into the application. First and foremost the material thickness of the part was an issue. When rotated through 360 degrees, the thickness ranged from a quarter inch at the trailing edge to approximately six inches through the airfoil. Other thicknesses that come into view and require penetration are up to nine inches of the inner shroud that is partially reconstructed as well.

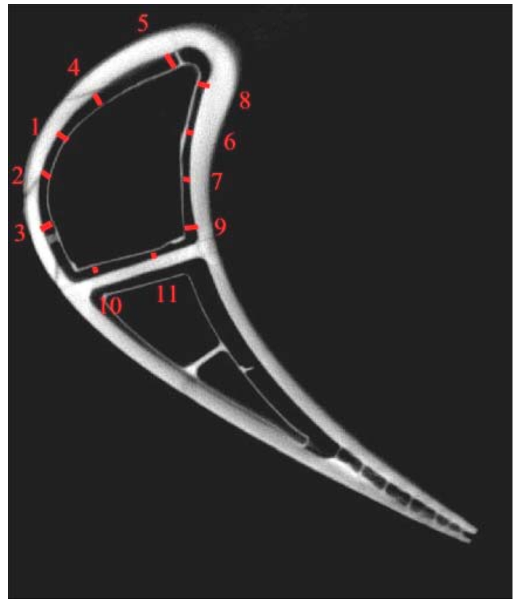
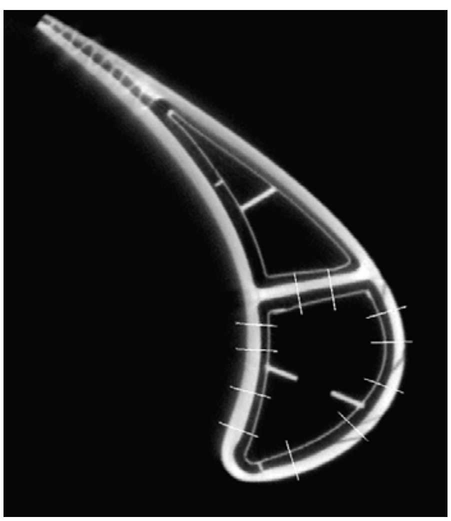


Figure 3

With such a wide range of factors including material thickness, energy, radiation dose, and beam hardening filtration required; such that there would be no saturation in areas of low density, while adequate intensity was achieved through the areas of highest density. In order to produce the results Siemens required, a 6MV photon energy beam, with 200 Rads and 1.5 inches of steel beam hardening was utilized. Other factors taken into consideration for repeatability were the size, shape, and the 18kg component weight. A fixture designed by Siemens was adapted to the position system and used to manipulate the component, so that each part would be placed into a repeatable orientation for each successive scan.

The next challenge was to define an acquisition technique that would produce the results required. To achieve this we took eight hundred projections with no pixel binning, and geometry which yielded a voxel size of <150 microns (0.006in). Pixel binning refers to the collection of photons to record them in a single image pixel. Thus, thearea per pixel decreases by a specified factor giving improved resolution. Eight hundred 2D images were taken through 360 degrees of rotation of the sample, approximately 0.45 degrees per projection, at six seconds each. Without pixel binning the effective pixel/voxel size of 150 microns (0.006in) was established based on the geometries of the scan. Due to the extremely large size of the resultant data set, the vane was scanned in two sections. One from the inner shroud to the center of the airfoil, and the other from the center of the airfoil to the outer shroud. This translated into about three hours of scanning for each part.


AVI 1

Our software department was then commissioned with creating an algorithm that would automatically output measurement data specified at the eleven points, across the entire length of the airfoil from inner to outer shroud. An example of this is shown here with an AVI file (AVI 1) to illustrate the measurement algorithm in process and the following spreadsheet shows (Table 1) the data from one of the components. In order to accomplish the task automatically the samples needed to be scanned and acquired for reconstruction as explained previously. Then the resultant data set needed to be converted into an

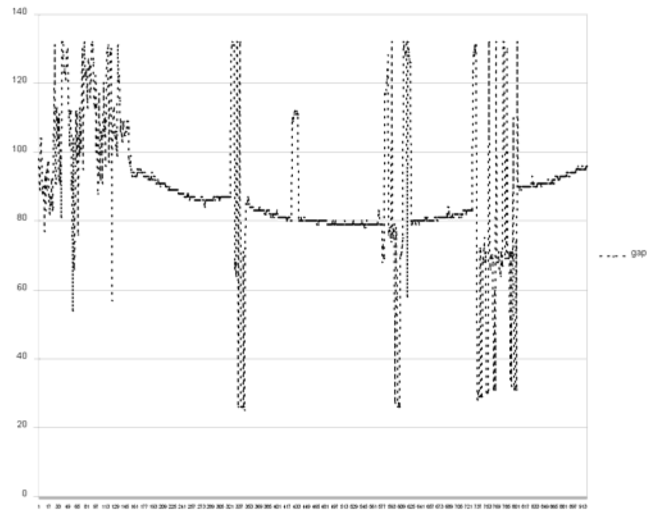


Table 1

image stack of TIF files. The TIF Files would be used to create a spreadsheet containing a graph and data points of the points of interest. Following this the TIF files would be converted into an AVI movie.

At first this requirement seemed like it might be a fairly straight forward analysis. The initial approach was to use "cutting" line profile at the pre-defined points, with the airfoil set nearly vertical for the acquisition and reconstruction. However, once we began to analyze the slices, it was clear that although the airfoil was vertical, the pre-defined points for measurement, moved within the volume with the tapered contour of the airfoil. With this in mind, the line profile had to be adjustable to cover the area of interest from inner to outer shroud at each of the eleven pre-defined points of interest (regardless of airfoil taper), it would track the trajectory of the implied position of the pre-defined points through the airfoil.

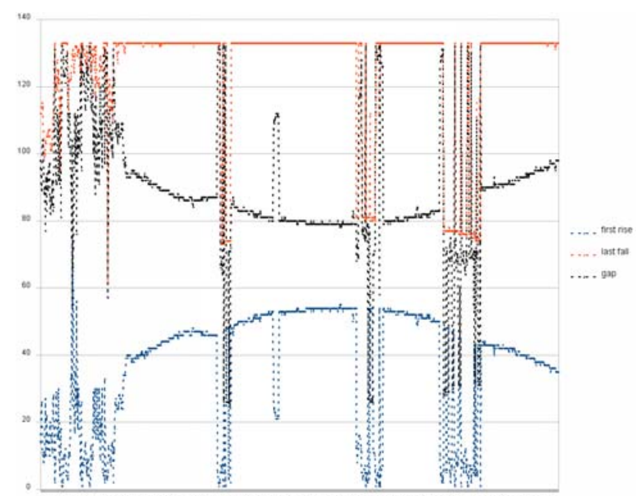


Table 2

Once this was established, it was determined that each volume needed to be consistent with the next so that the pre-defined position was within the same location of the volume repeatedly, in order for the line profiles to be in the proper location each time. The line profiles provided an indication that represented the two edges of the airfoil wall, from the inner wall surface to the outer edge of the insert surface. This information provided the distance in voxels from inner surface of the airfoil to the insert, which was then monitored throughout the length of the airfoil in the image stack.

In order to ensure the accuracy of the measurement data, the scans had to be refined to a level that minimized noise in the slice images to a level that would not generate "false" locations that might be detected by the line profiles. This required optimization of our beam hardening filtration, detector calibrations, frame averaging, and rotational axis calibrations. In addition, we optimized our algorithm for enhanced edge detection. This data was then output numerically to a spread sheet that provided the exact location of each cutting line within the volume that could be correlated to a precise point on the airfoil and it illustrated the gap space as desired for every slice of the volume

After the first round of scans it was determined that the accuracy and repeatability required was more than necessary, to effectively evaluate the distance between the insert and the inner wall cavity. As such, it was

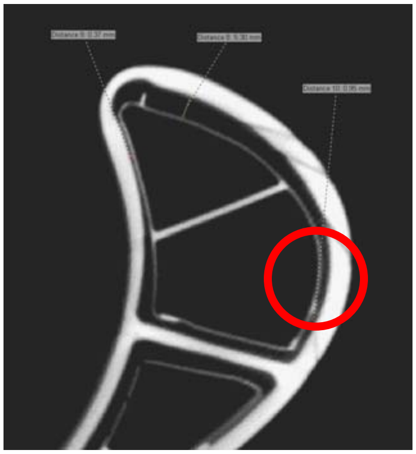


Figure 4

determined that a 400 projection acquisition using the same geometry and a 2x2 pixel binning feature, which yielded a <300 micron (0.012in) voxel size, was adequate to manually evaluate the critical points of interest along the length of the airfoil. Of the eight hundred projections, four hundred were adequate to provide the resolution needed to manually evaluate the slices. By using the same geometries for the scans and 2x2 pixel binning means that each pixel becomes part of a group of four pixels so that the effective pixel/voxel size is now doubled to approximately 300 microns, which is still small enough to provide adequate resolution as stated above.

Using the combination of advanced computer technology and human interaction allowed us to find additional indications that were outside the scope of this analysis. Such indications included weld repairs, airfoil surface indications and trailing edge cavity insert damage. This combination resulted in shorter acquisition times and eliminated the need for the algorithm to be applied to each image stack. This helped conserve resources such as time and money that would have been needed.

Review of the initial CT demonstrated that the supplier performing the repair was grinding down critical standoffs on the inserts to allow for easier assembly (Figure 4). The removal of standoffs was determined to be the highest probability as the source of the temperature increase. Even after the vendor was given specific instruction not to grind down these standoffs, it was very evident by CT on the next set that grinding of the insert was still occurring. In order to prevent this issue in the future, the vendor was informed that all components would be CT scanned and the cost of repair would be covered by the vendor.

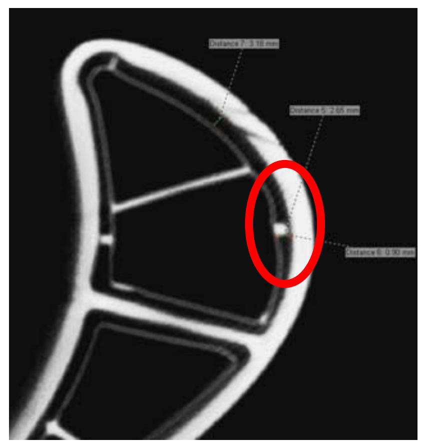


Figure 5

Once grinding was eliminated, CT revealed something else that appeared to cause the same effect. The insert now contained a very large depression in the same area where the standoffs had been previously ground (Figure 5). This would suggest that there was an excess of force being applied to assemble the components. When consulting with the vendor they confirmed that not all inserts fit into the components easily and sometimes a minor force was applied. This resulted in another new procedure, preventing the use of any insert that did not fit easily into the part. Our insert manufacturer was also provided a more strict tolerance to acquire more uniform inserts.

In addition to validating an acceptable repair a new wire gage technique was established to eliminate the need for the high cost of the CT. a final set was scanned to demonstrate the acceptability of this cost effective technique after using the new wire gage. During this final set, CT revealed evidence of potential improper welding (Figure 6), something that was never detected in the root cause analysis. The CT found evidence of poor welding practices in the airfoil when they were being repaired. These weld defects were also located in a similar place where the localized temperature issue had occurred. Further analysis of these weld defects are presently under investigation. A formalized failure investigation is being conducted to find out the exact reason for these welding anomalies and their effect.

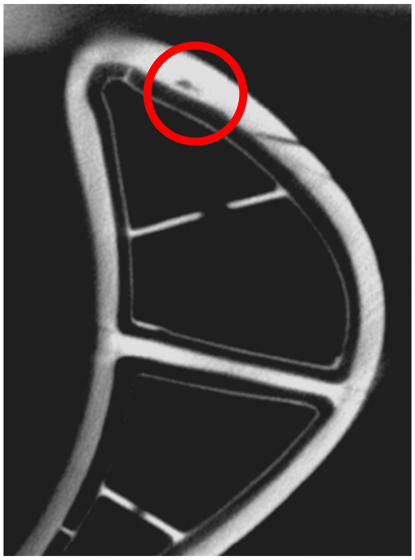


Figure 6

In conclusion, CT identified approximately 18% of the components inspected contained unacceptable conditions. In addition, CT provided additional information that will provide additional insight into the source of past failures. Finally, one of the most important things that the CT accomplished was validation of the development of a cost effective alternative to itself. The new wire gauge technique was developed and eliminated the need for CT. By utilizing CT and knowledge of these two companies; Siemens and VJ Inspections were able to develop a methodology for inspecting components critical to Siemens Energy and saved Siemens millions of dollars in component replacement costs.