

A NOVEL AUTOMATED METHOD FOR ANALYZING CYLINDRICAL COMPUTED TOMOGRAPHY DATA

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ABSTRACT

A novel software method is presented that is applicable for analyzing cylindrical and partially cylindrical objects inspected using computed tomography. This method involves unwrapping and re-slicing data so that the CT data from the cylindrical object can be viewed as a series of 2-D sheets in the vertical direction in addition to volume rendering and normal plane views provided by traditional CT software. The method is based on interior and exterior surface edge detection and under proper conditions, is FULLY AUTOMATED and requires no input from the user except the correct voxel dimension from the CT scan. The software is available from NASA in 32- and 64-bit versions that can be applied to gigabyte-sized data sets, processing data either in random access memory or primarily on the computer hard drive. Please inquire with the presenting author if further interested. This software differentiates itself in total from other possible re-slicing software solutions due to complete automation and advanced processing and analysis capabilities.

KEY WORDS: Nondestructive Evaluation, Computed Tomography, Image Processing, Software, Data Visualization and Analysis, X-ray

INTRODUCTION

Computed tomography results are usually presented as a set of slice images in different planes and / or as a volume as shown in figure 1 for x-ray computed tomography results of a metal cylinder with a manufactured flaw pattern. Although these views are very helpful in analyzing the condition of the component, it has been found that the ability to “unwrap” the volume view and create 2-d planar images incrementally viewed from the exterior to the interior can facilitate both qualitative and quantitative analysis depending on the objectives of the inspection. For example, if one needs to measure the lateral dimensions of the flaws in the flaw pattern, the views shown in traditional CT software only allow this measurement on the volume itself (if that). Many times, based on the software employed, this measurement is neither easy nor accurate because of component curvature. NASA has developed software using LabVIEW and associated toolkits for unwrapping / re-slicing CT data in order to create the 2-d planar views of the volume. The software is available in 32-bit and 64-bit versions. The procedure is explained below.

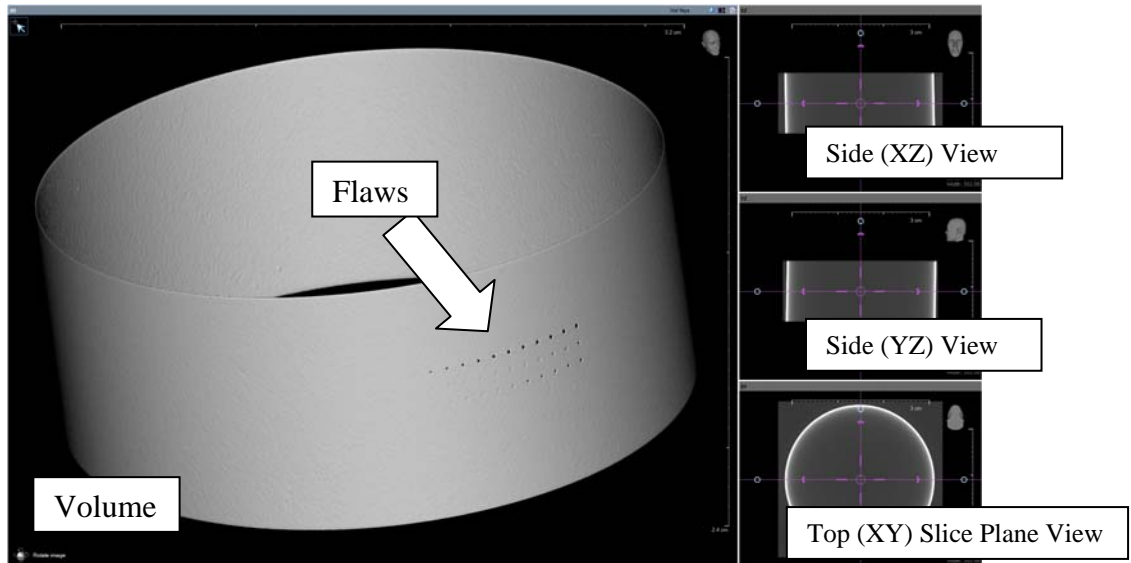


Figure 1. Top (XY), side views (XZ and YZ) and an opaque volume rendering for a CT slice set for a metal cylinder with flaw pattern.

PROCEDURE

The top (XY) slice plane CT images that show the circular view are the working set of images used in the process. These images are first “registered” to create an aligned set of images in case the CT setup resulted in some misalignment. This can be done in external software using the rigid body transformation or other methods [1]. It is planned to add registration methods directly to the NASA software also. Figure 2 outlines the CT volume unwrapping / re-slicing software procedure. An annulus (shown in red) automatically positions itself surrounding the cylinder walls based on the interior and exterior edges that it finds on one of the XY images. This procedure relies on an edge strength (difference in gray levels between background and component) of 50 which has shown to work well for a variety of components at NASA. The user specifies the voxel dimension in mm from the CT scan and adjusts annulus width for display of the annulus. The voxel dimension is the only parameter that is absolutely required from the user since an annulus will automatically initially position itself based on the edge detection process. Each of the XY slice plane CT images within the annulus region is unwrapped to linearize the 360° circular view. Each of these linearized regions is now a thin 2-d section with the width composed of a number of pixels (again determined from the voxel dimension of the CT scan and the width of the annulus). Consider that 400 XY slices were obtained from the CT scan. These linearized sections are now stacked vertically to form a thin data cube. The cube is then sliced vertically at each pixel position from exterior to interior to create the new 2-d sheets.

Edge Detection to Create Annulus Around CT Images of Cylinder

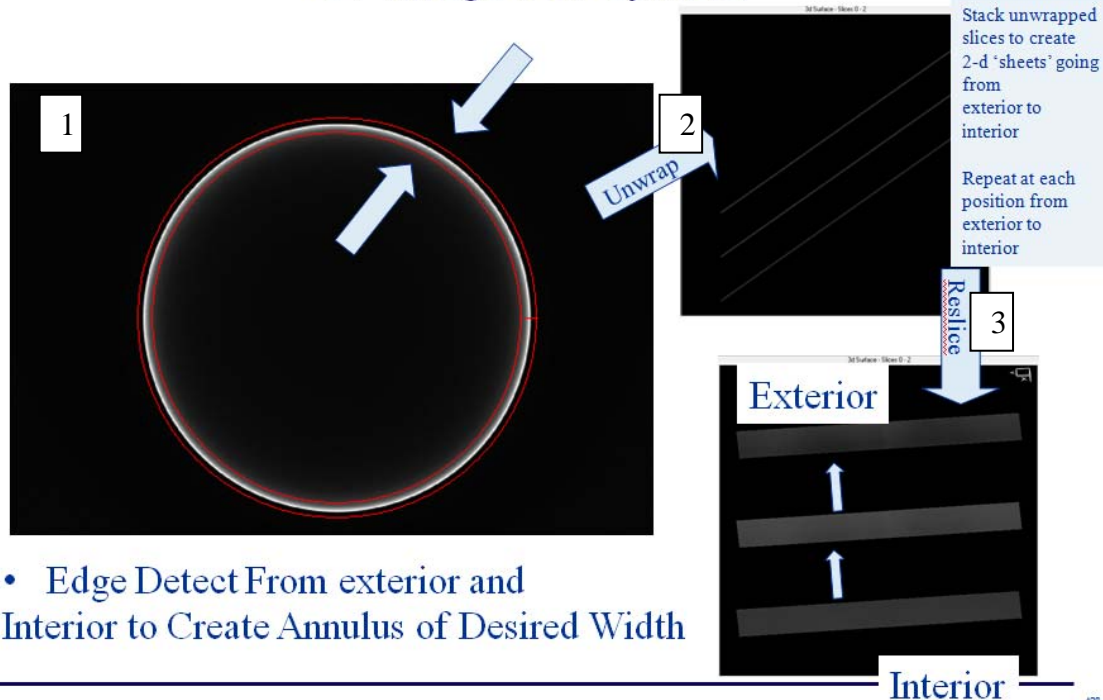
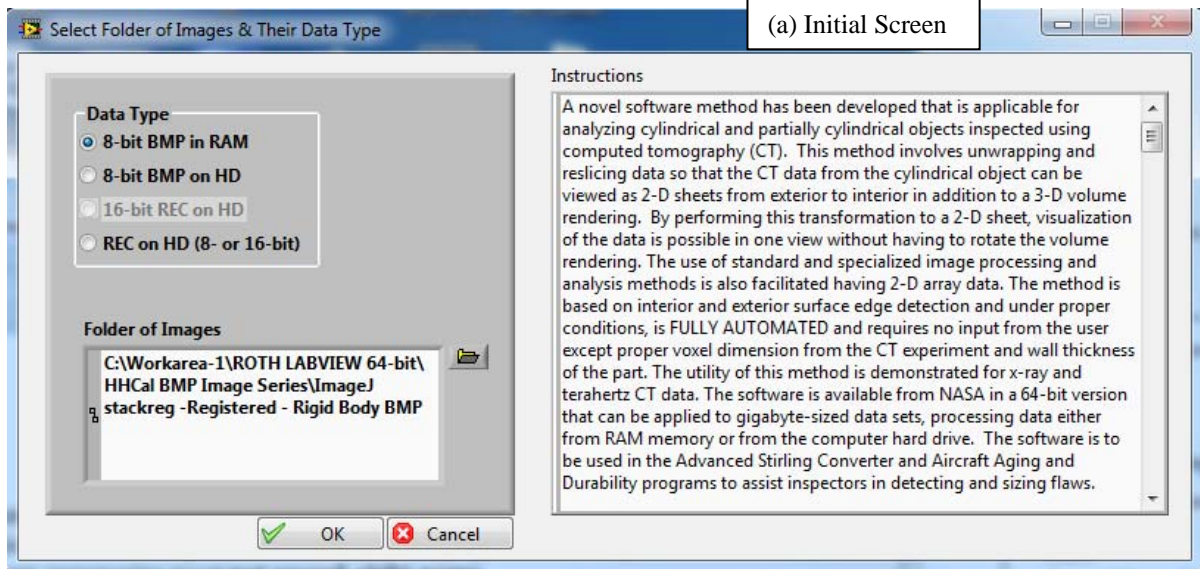
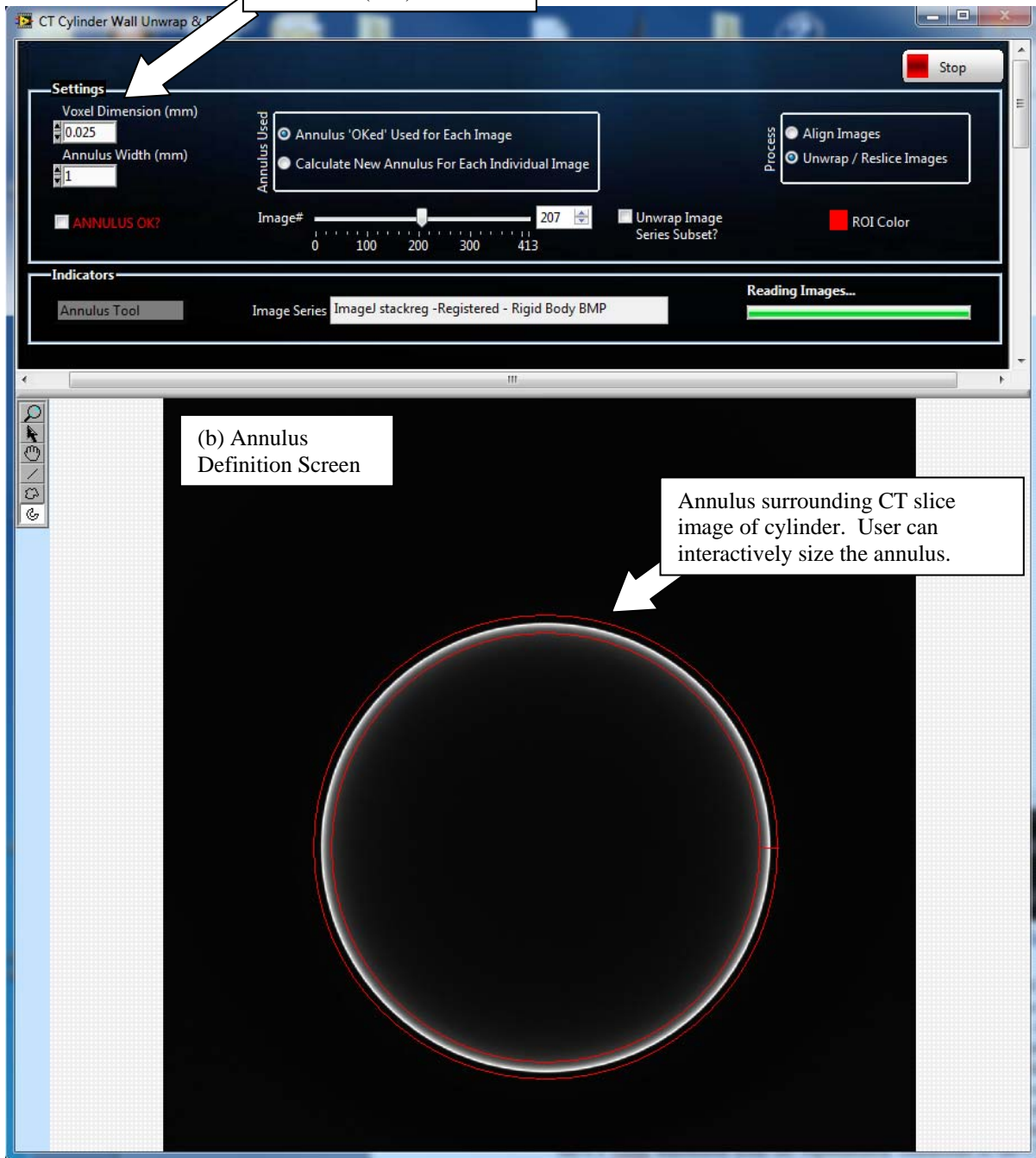


Figure 2. Schematic of software procedure for unwrapping / re-slicing the CT volume.

Figure 3 shows the main windows of the software. The starting screen allows the user to select either BMP or REC (binary file type used by Hytec, Inc. [2] and exportable from Northstar, Inc. format) type files. For BMP files, the user has the option to process completely in random access memory (RAM) of the computer if the data set is small enough as compared to the amount of RAM available. For this option, the 64-bit version is really necessary and it is recommended to have about three times the size of RAM available as compared to the data set size. For processing primarily on the hard drive (HD), the user can proceed with CT data sizes of practically unlimited size (egs. 10s of gigabytes). The advantage of working in RAM is the speed increase and a 10 gigabyte-sized CT image set was processed on a computer with 32 gigabytes of RAM. Once the user has selected data and data type, the software window screen for annulus precision control is opened. It is important that the user accurately inputs the voxel dimension in this screen so that the proper number of re-sliced images is created. The user can adjust the annulus interactively directly on the image by grabbing with the mouse or input an annulus width in mm. For the latter, a good starting width for the annulus is the wall thickness of the cylindrical component. The width of the annulus along with the voxel dimension defines the number of 2-d sheets that will be created from exterior to interior. After the annulus is OKed, the re-sliced image screen opens. This window also has a thumbnail image of the XY slice view that shows the position within the cylinder wall thickness of the unwrapped / re-sliced image. This is a critical visual cue for the user. Within this window, the user can apply specialized image processing, sizing, and analysis methods to the unwrapped / re-sliced image. The image processing methods include all of the common image processing methods as well as segmentation, wavelet-based filtering, and image series interpolation [3]. Image analysis methods include automated particle analysis, image series averaging, image series principal component analysis, and a unique magnification module to aid inspectors in flaw detection [3]. Additionally, the unwrapped / re-sliced data images can be saved as a new image series or even panel series with the thumbnail image indicating the slice location within the cylinder wall thickness as the images sequentially are saved. The images in a saved image series can be further processed in 3rd party software if needed.



Input correct voxel dimension (mm)



(b) Annulus Definition Screen

Annulus surrounding CT slice image of cylinder. User can interactively size the annulus.

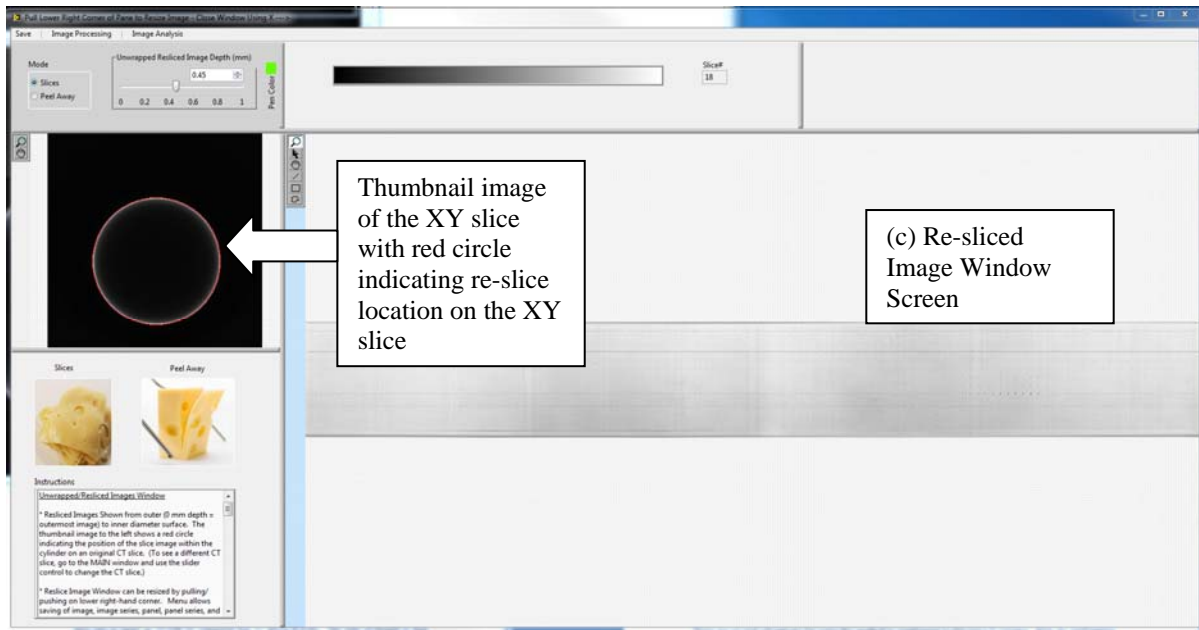


Figure 3. The three main software screens of operation.

There are several advantages for using this software method to supplement traditional CT data viewing. First, by performing this transformation to a 2-D sheet, visualization of the data is possible in one view (per pixel position moving from exterior to interior) without having to rotate the volume rendering. Additionally, there are generally many fewer resulting images to view when compared to the number of top view slices. For example, for the metal cylinder shown which has a wall thickness of 315 μm , and with the voxel dimension of 25 μm , one might have 13 slices to view versus the 400 XY slices. Finally, the more accurate sizing of flaws in the lateral directions is facilitated.

CT “Re-slices” close to the exterior and interior, respectively, of the metal cylinder are shown in figure 4. Note how some of the flaws, which were drilled to different depths, disappear as we move from the exterior to the interior of the cylinder. In these views, the flaws can now be accurately sized within the limits of the resolution as shown in figure 5.

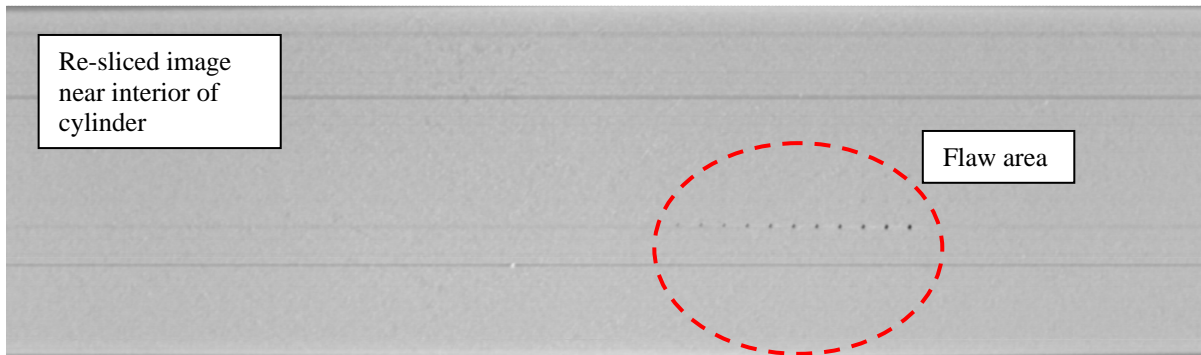
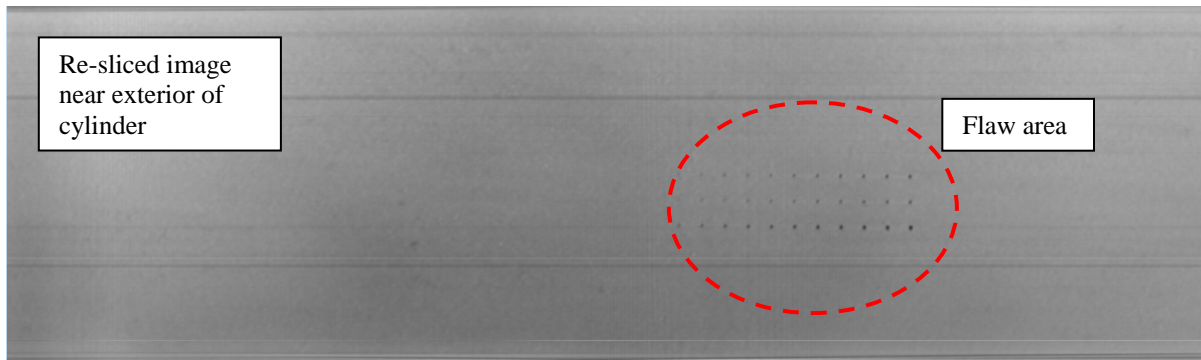


Figure 4. Magnified views of flaw area in Unwrapped / Re-sliced Images.

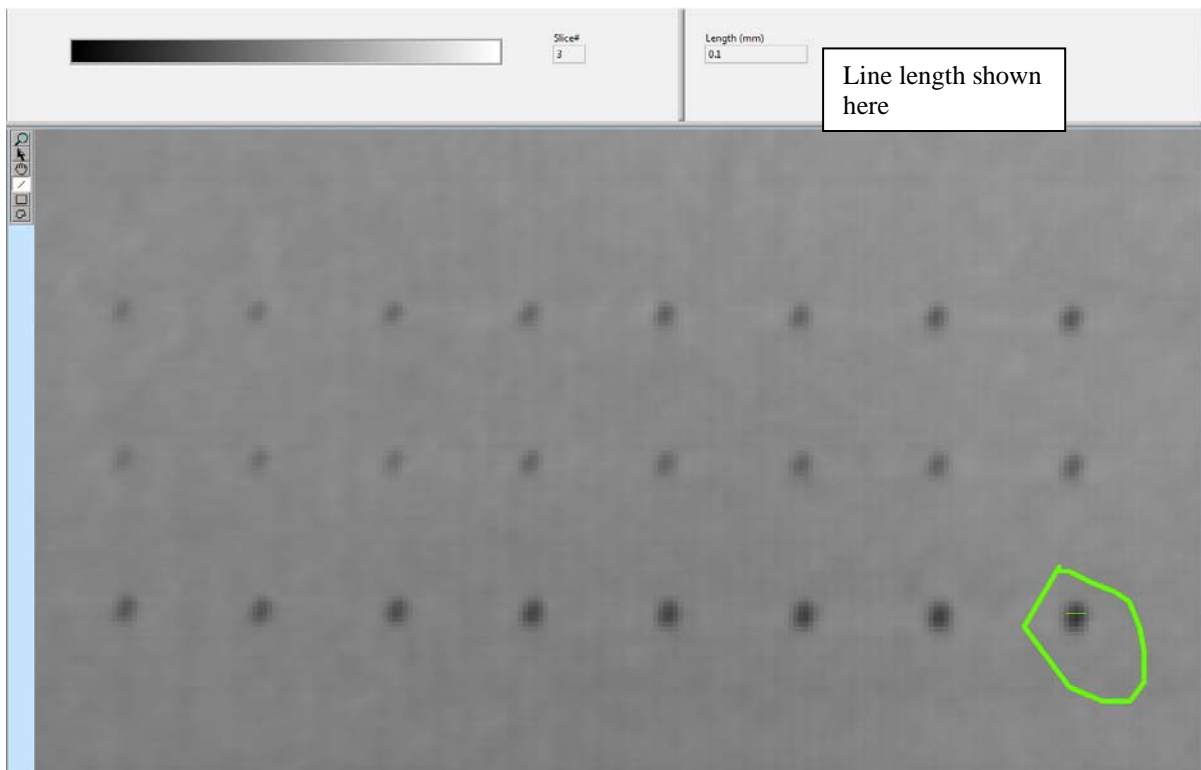


Figure 5. Circled flaw is sized within the limits of the resolution (pixel dimension) after drawing line across the flaw. This flaw was about 100 μm in diameter.

Figure 6 shows the automated particle analysis of the image of figure 5 after crop, wavelet bandpass, color inversion, and binary thresholding image processing steps. The automated particle analysis labels and calculates flaw statistics such as maximum dimension on detected flaws.

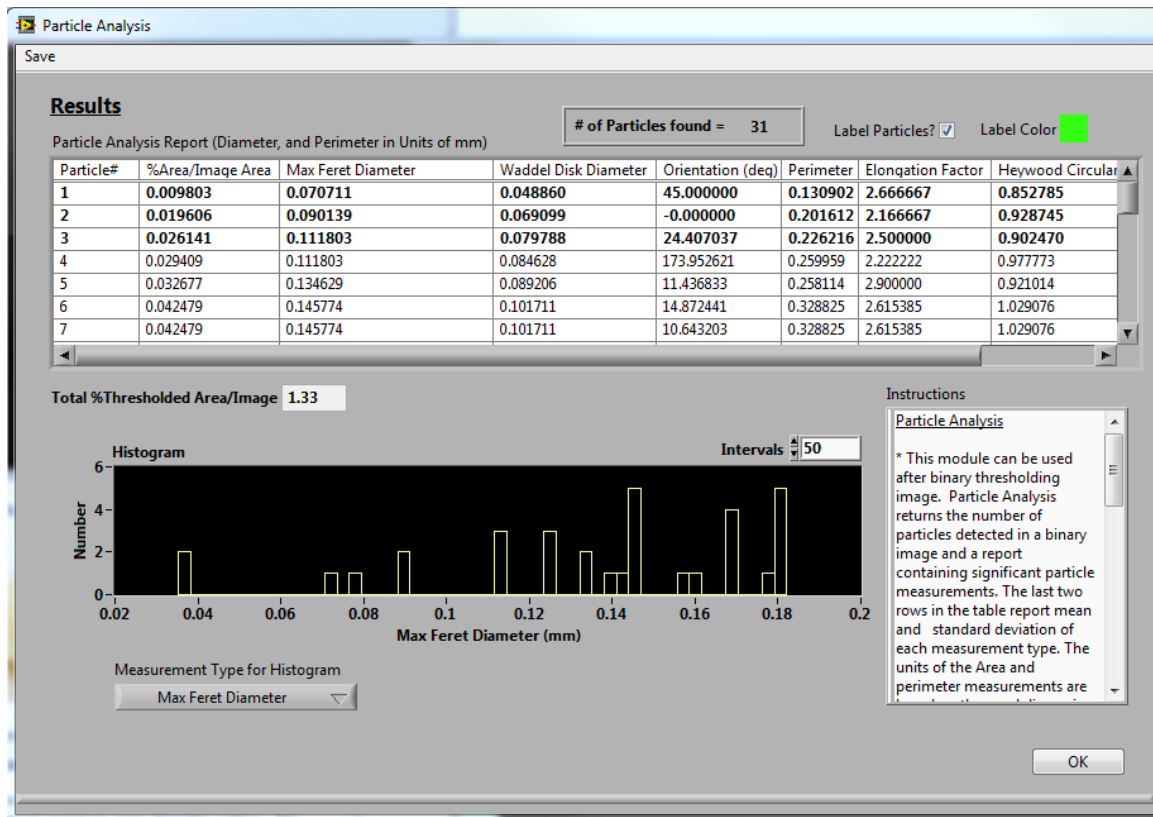


Figure 6. Automated particle analysis after image processing steps.

CONCLUSION

The software is currently used in the NASA Advanced Stirling Converter (ASC) and Aircraft Aging and Durability (AAD) programs to assist inspectors in detecting and sizing flaws in cylindrical components that have been CT scanned. The software can be updated and modified fairly easily based on user needs. It is also planned to add registration facilities and a 3-d volume rendering window so that the user simultaneously can view the XY slices, re-sliced images, and volumes. Other organizations are welcome to either acquire a copy of the program or send me BMP or REC data from the CT of a cylindrical component for unwrapping and re-slicing. This software differentiates itself in total from other possible re-slicing software solutions due to complete automation, visual cues, large data set handling, and advanced processing and analysis capabilities.

REFERENCES

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