Geodetic Systems

# V-STARS S8 Demonstration
# Measurement Report for

## Korea Plant Service and Engineering (KPS)
### Gas Turbine Technology Service Center
### Incheon, Korea

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## Object Measured

One items was measured as part of the V-STARS demonstration. The object was a large section of a turbine.

The primary objective of this measurement was to demonstrate how objects can be measured using V-STARS. To do this, the objects were targeted and measured. The turbine measured is shown on the cover of this report.

## Equipment Used

1. V-STARS S8 INCA3 Camera (INCA3 camera shown in image below)
2. AutoBar
3. Coded targets
4. Single dot targets and strip tape
5. Scale Bars

## Measurement Objectives

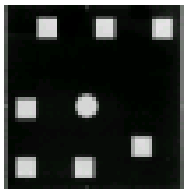
1. Demonstrate INCA3 camera use
2. Determine location of key points on turbine
3. Complete geometric analysis to determine key diameters and center points

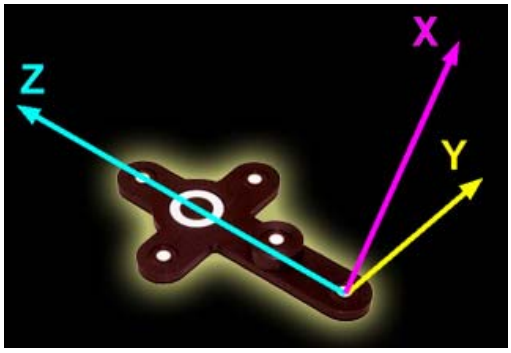
## Targeting

1. AutoBar for initial coordinate system
2. Reference coded targets to tie photography together
3. Single dot targets on key planes, circles and cylinders.
4. Scale bar points to scale measurement.

In order to meet the measurement objectives outlined earlier it was necessary to target the turbine and surrounding area. In general, targets are placed on points or surfaces that are of interest. For surfaces, strips of retro-reflective tape of variable pitch and dot size are commonly used. They are relatively cheap, disposable and easy to apply. To coordinate tooling datums such as bushed holes or button datums, tooling targets are used. These come in a variety of shank and dot sizes. They are also available in variable orientations.

To automate the measurement process it was necessary to add "coded" targets to the object or surrounding area. These targets are automatically detected and help the software determine the location and orientation of the camera at the time the photo was taken. They also help tie the entire object into a uniform coordinate system. The codes were placed on and around the turbine.

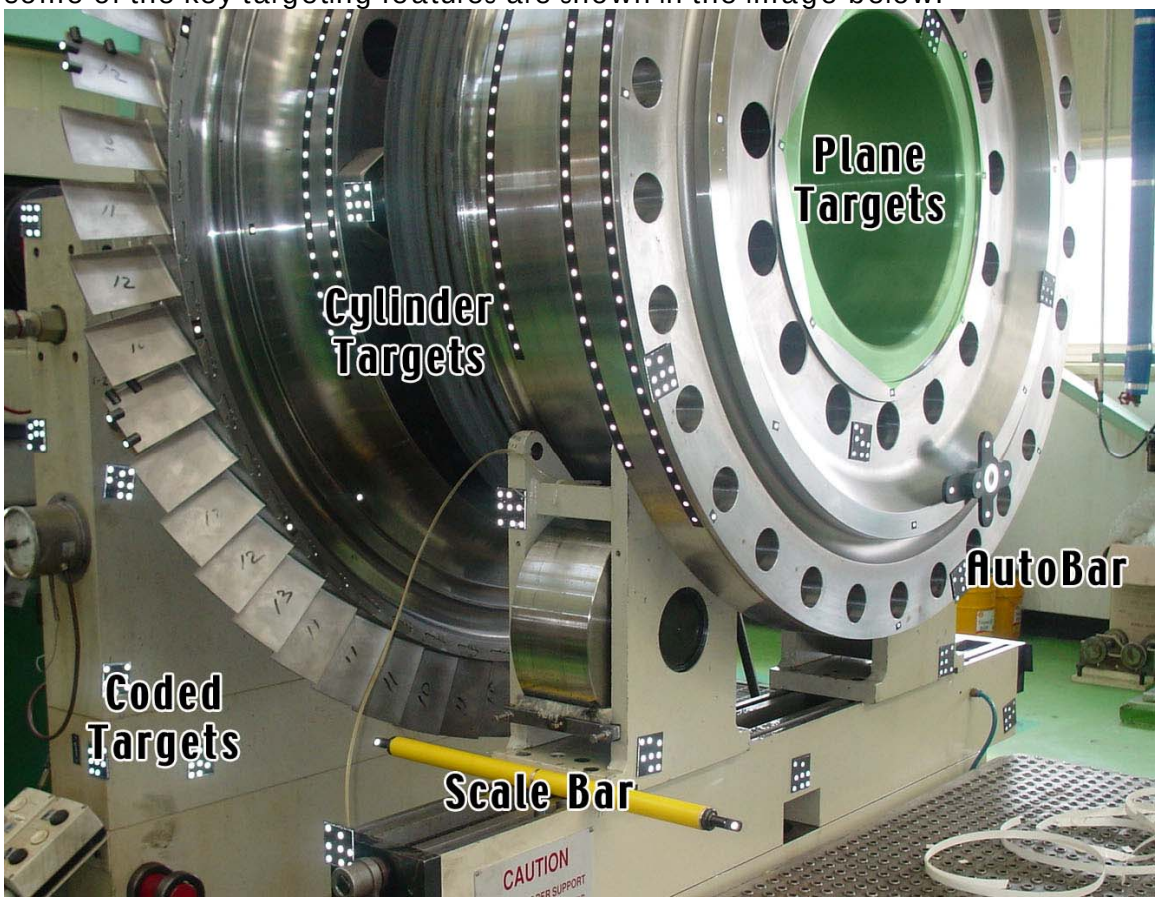





The initial coordinates system and scale is determined via the AutoBar. The AutoBar used by the V-STARS system is a fixture with five targets arranged in the form of a cross. The target's known coordinates are used by the AutoMatch procedure to determine the camera's orientation relative to the AutoBar. The AutoBar is securely attached on or near the measured object, preferably in a highly visible location. The AutoBar's default coordinate system has its origin at Target 1 at the bottom of the AutoBar. The positive Z-axis goes through Target 3 at the top of the bar. The positive X-axis is up out of the AutoBar. The diagram on the left shows both the AutoBar and its coordinate system

To scale a photogrammetric measurement, there must be at least one known distance. Normally this distance comes from a calibrated coded graphite scale bar or invar scale bar (Refer to adjacent image). Typically multiple scales are used for redundancy. Two scales were used in this measurement.

Some of the key targeting features are shown in the image below.

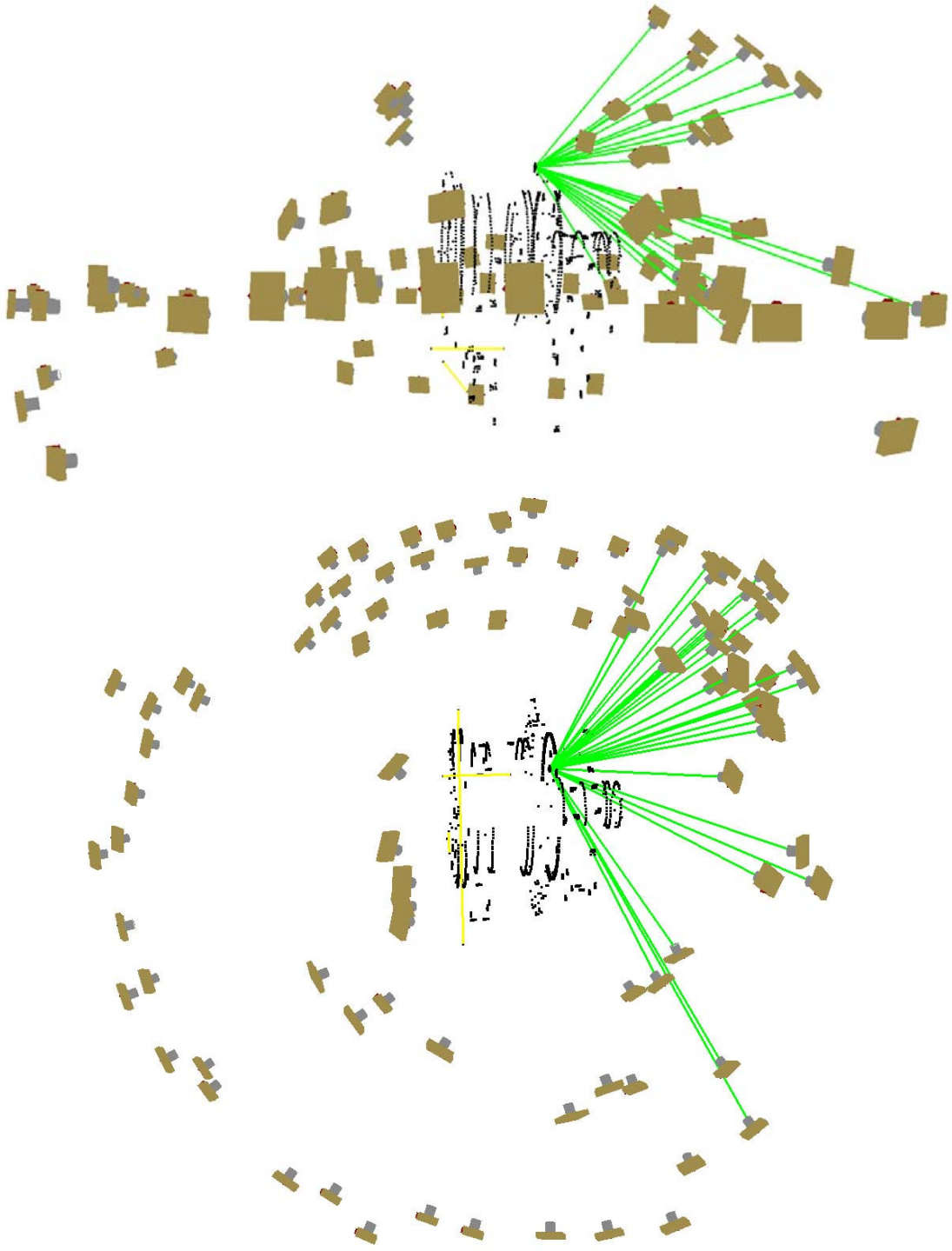



*Targeting used for the measurement*

## Photography

The photography is carried out once the object targeting is completed. Put simply, the aim of the photography is to record each of the targeted points in as many images as possible from as wide a range of angles as possible. To improve the accuracy of the measurement, generally photos are taken both close to the ground and from an elevated position. The number of photos taken depends on the complexity of the measurement and accuracy requirements.

The diagram below illustrates the geometry used to create the point cloud for the measurement.

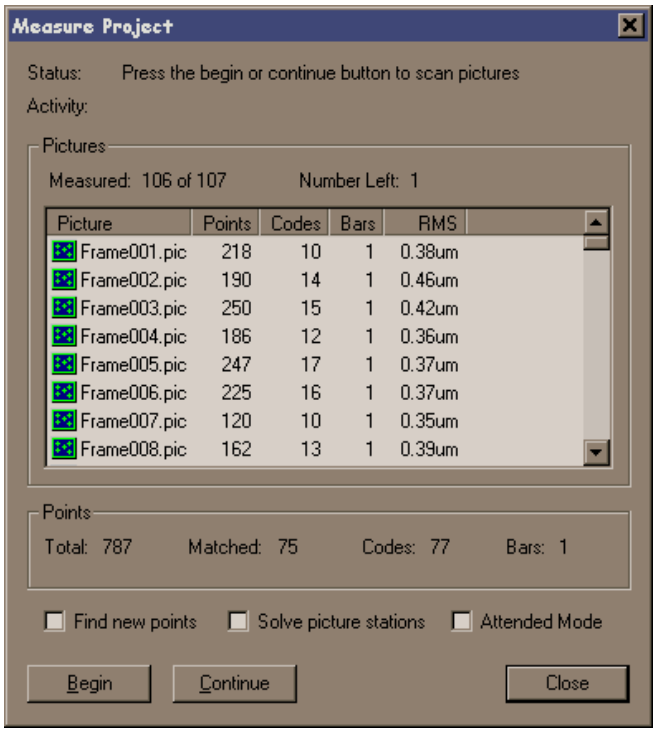


*Network Geometry*

## Processing

Once the photography has been completed the images are transferred to the system laptop. The images are stored on a PCMCIA hard drive and V-STARS accesses these images directly from the drive.

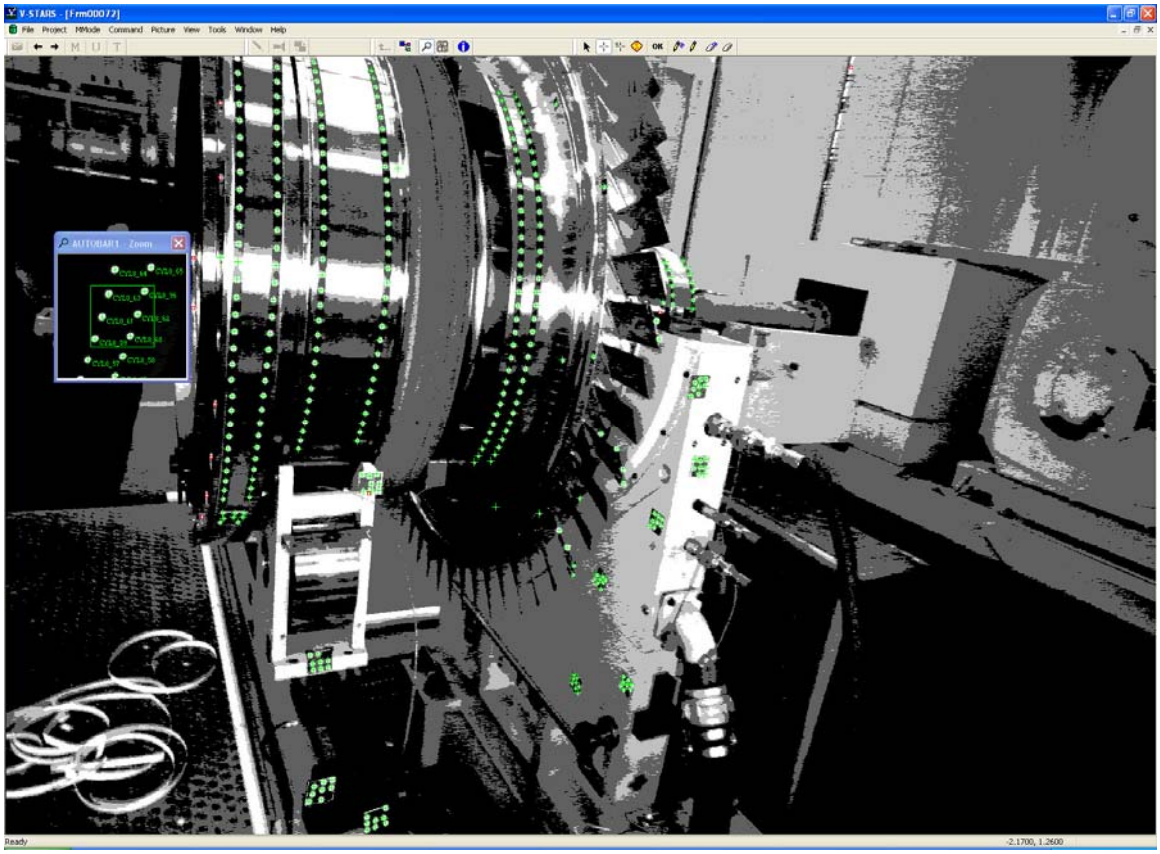
Almost all of the measurement process is automated. The images are processed and the coordinates extracted by the "AutoMeasure" command. A typical AutoMeasure dialog box is shown on the right. The AutoMeasure command will open each of the images, determine the camera location, find new target points and finally adjust all the measurements in the "Bundle Adjustment".




At the conclusion the user is left with the XYZ coordinates for all the target points in the network. The AutoMeasure procedure is very powerful as it allows the user to continue working while it processes the data. It also means that relatively unskilled workers can be used to process the data.

The AutoMeasure routine will assign random labels to the points it finds. These labels start with the key word "Target" followed by a number. If specific labeling is required the random labels can be easily changed to labels defined by the user. This is possible in both the picture view and the graphical 3D view. For this particular project it was necessary to re-label the points so that analysis could be simplified.

Seen below is an image taken as part of the measurement.

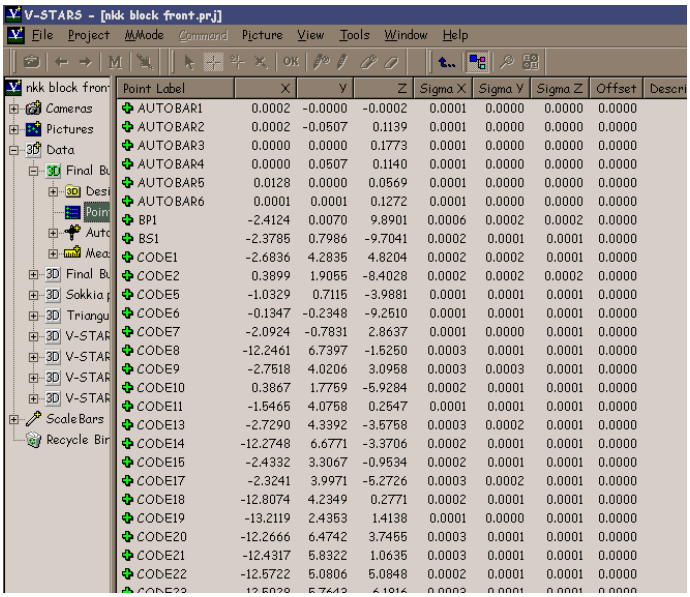


The green crosses represent points that have been located in this particular image. Note that the image appears a little dark and difficult to see. This is intentional as the best photogrammetric measurements are made on images that have dark backgrounds and bright targets. Some of these targets are shown in the zoom window in the corner. If the scale bar is visible then a yellow line will be drawn between the two end points.

## Measurement Statistics

| | |
|---|---|
| No. of photos | 94 |
| No. of points | 1146 |
| Accuracy RMS X | 0.016mm |
| Accuracy RMS Y | 0.011mm |
| Accuracy RMS Z | 0.020mm |
| Scale Agreement | 0.005mm |

A typical point listing is shown below.

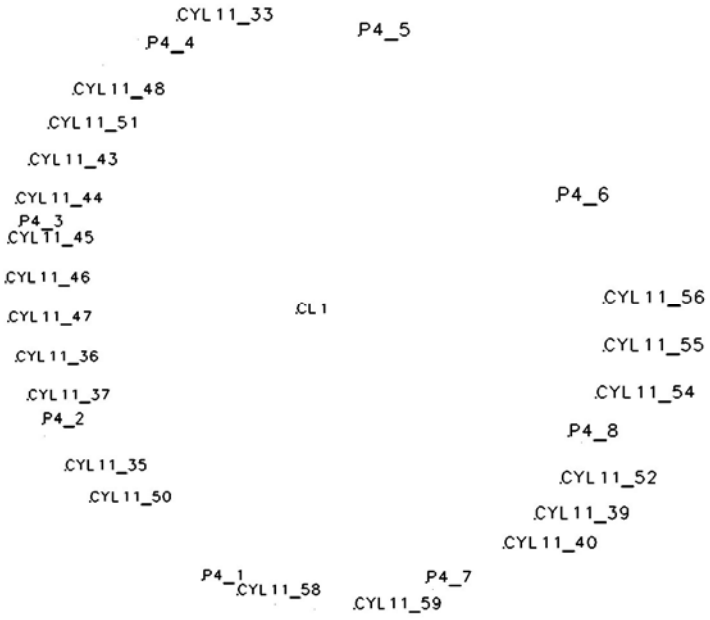



| Point Label | X | Y | Z | Sigma X | Sigma Y | Sigma Z | Offset | Descri |
|---|---|---|---|---|---|---|---|---|
| AUTOBAR1 | 0.0002 | -0.0000 | -0.0002 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | |
| AUTOBAR2 | 0.0002 | -0.0507 | 0.1139 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | |
| AUTOBAR3 | 0.0000 | 0.0000 | 0.1773 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | |
| AUTOBAR4 | 0.0000 | 0.0507 | 0.1140 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | |
| AUTOBAR5 | 0.0128 | 0.0000 | 0.0569 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | |
| AUTOBAR6 | 0.0001 | 0.0001 | 0.1272 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | |
| BP1 | -2.4124 | 0.0070 | 9.8901 | 0.0006 | 0.0002 | 0.0002 | 0.0000 | |
| BS1 | -2.3785 | 0.7986 | -9.7041 | 0.0002 | 0.0001 | 0.0001 | 0.0000 | |
| CODE1 | -2.6836 | 4.2835 | 4.8204 | 0.0002 | 0.0002 | 0.0001 | 0.0000 | |
| CODE2 | 0.3899 | 1.9055 | -8.4028 | 0.0002 | 0.0002 | 0.0002 | 0.0000 | |
| CODE5 | -1.0329 | 0.7115 | -3.9881 | 0.0001 | 0.0001 | 0.0001 | 0.0000 | |
| CODE6 | -0.1347 | -0.2348 | -9.2510 | 0.0001 | 0.0001 | 0.0001 | 0.0000 | |
| CODE7 | -2.0924 | -0.7831 | 2.8637 | 0.0001 | 0.0000 | 0.0001 | 0.0000 | |
| CODE8 | -12.2461 | 6.7397 | -1.5250 | 0.0003 | 0.0001 | 0.0001 | 0.0000 | |
| CODE9 | -2.7518 | 4.0206 | 3.0958 | 0.0003 | 0.0003 | 0.0001 | 0.0000 | |
| CODE10 | 0.3867 | 1.7759 | -5.9284 | 0.0002 | 0.0001 | 0.0001 | 0.0000 | |
| CODE11 | -1.5465 | 4.0758 | 0.2547 | 0.0001 | 0.0001 | 0.0001 | 0.0000 | |
| CODE13 | -2.7290 | 4.3392 | -3.5758 | 0.0003 | 0.0002 | 0.0001 | 0.0000 | |
| CODE14 | -12.2748 | 6.6771 | -3.3706 | 0.0002 | 0.0001 | 0.0001 | 0.0000 | |
| CODE15 | -2.4332 | 3.3067 | -0.9534 | 0.0002 | 0.0001 | 0.0001 | 0.0000 | |
| CODE17 | -2.3241 | 3.9971 | -5.2726 | 0.0003 | 0.0002 | 0.0001 | 0.0000 | |
| CODE18 | -12.8074 | 4.2349 | 0.2771 | 0.0002 | 0.0001 | 0.0001 | 0.0000 | |
| CODE19 | -13.2119 | 2.4353 | 1.4138 | 0.0001 | 0.0000 | 0.0001 | 0.0000 | |
| CODE20 | -12.2666 | 6.4742 | 3.7455 | 0.0003 | 0.0001 | 0.0001 | 0.0000 | |
| CODE21 | -12.4317 | 5.8322 | 1.0635 | 0.0003 | 0.0001 | 0.0001 | 0.0000 | |
| CODE22 | -12.5722 | 5.0806 | 5.0848 | 0.0002 | 0.0001 | 0.0001 | 0.0000 | |

## Point Numbering

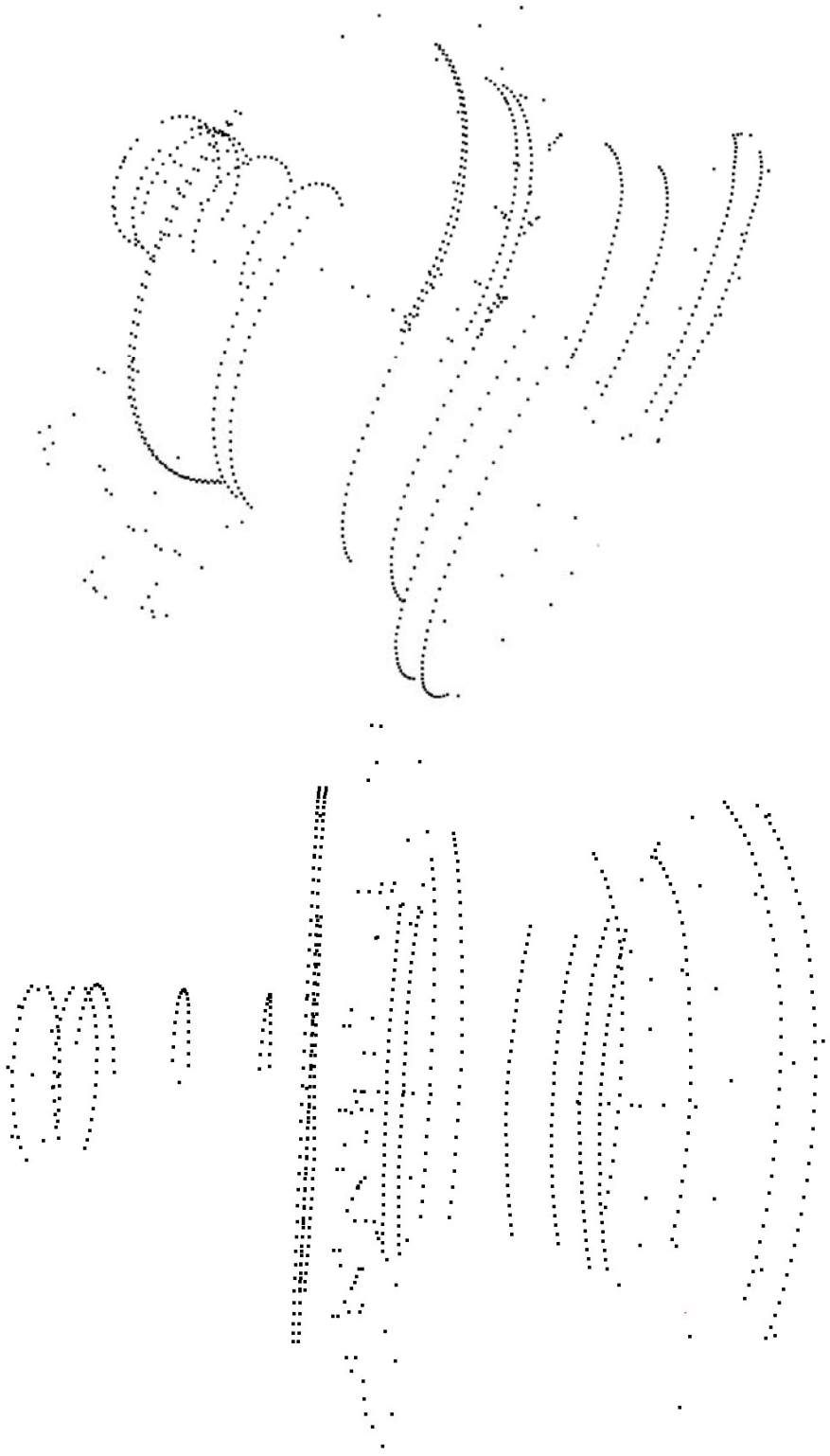
The points were renamed according to the following naming convention. An example of this point naming is shown in the image below.

| | |
|---|---|
| Points on cylinder | CYL |
| Points on plane | P |
| Points on circle | C |
| Points along Centerline | CL |



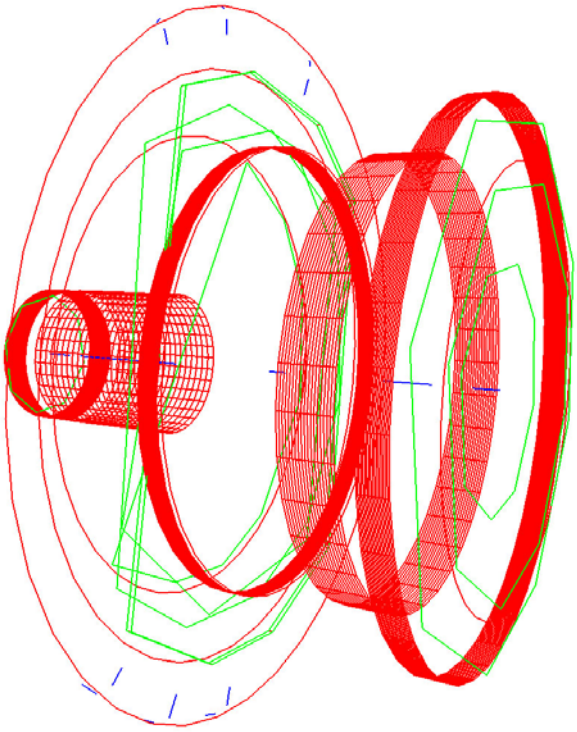
## Point Cloud

The point cloud produced is shown below:

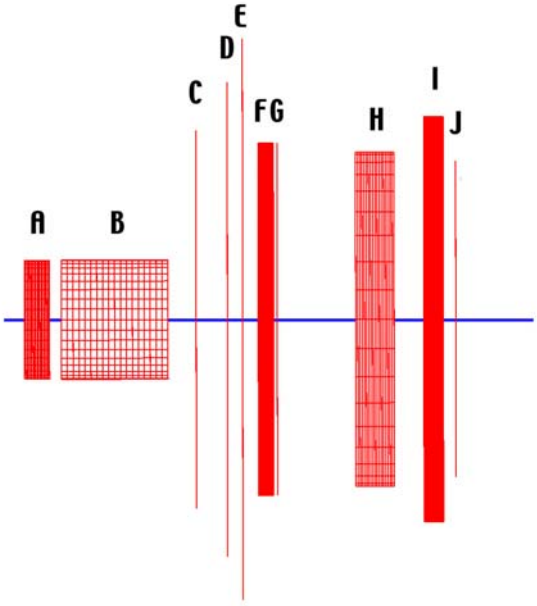


## Alignment
No alignment was carried out for this measurement.

## Analysis
The data collected in the measurement was used to compute the best fit planes, circle and cylinders. The results are shown graphically below.



The circles and cylinders calculated are shown in the images below.




The diameters and their calculated RMS values are summarized in the table below.

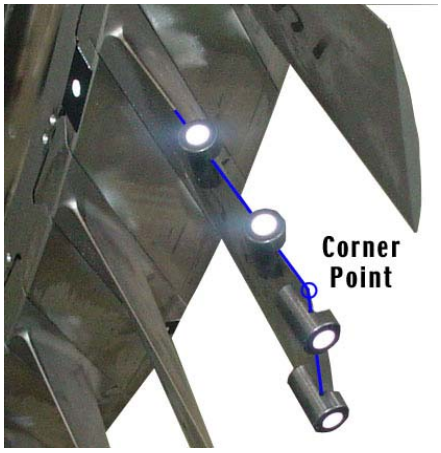
| Dimension | V-STARS(") | Drawing(") | Difference(") | RMS(") |
|---|---|---|---|---|
| A | 13.8948 | | | 0.0010 |
| B | 13.9720 | | | 0.0012 |
| C | 44.4294 | | | 0.0012 |
| D | 55.7464 | | | 0.0014 |
| E | 65.4884 | | | 0.0013 |
| F | 41.4688 | 41.4700 | 0.0012 | 0.0010 |
| G | 41.4298 | 41.4300 | 0.0002 | 0.0007 |
| H | 39.2490 | 39.2506 | 0.0016 | 0.0008 |
| I | 47.6614 | 47.6670 | 0.0056 | 0.0007 |
| J | 37.1732 | 37.1730 | -0.0002 | 0.0006 |

The center points of each circle/cylinder were also computed. The center points of "B" and "H" were used to calculate the centerline. The other points were then compared to this centerline to determine the eccentricity of each point.

The results are summarized in the table below.

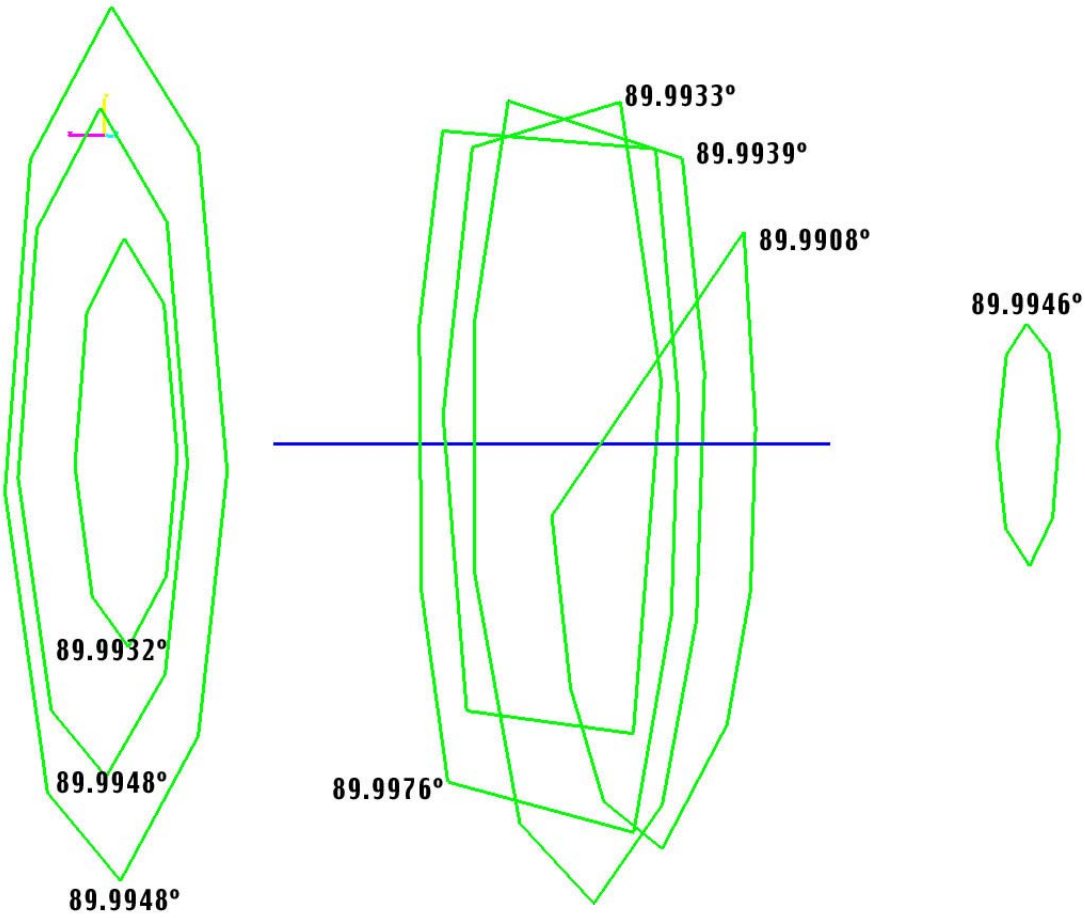
| Section | ΔX | ΔY | ΔZ | Total |
|---|---|---|---|---|
| A | 0.000 | -0.002 | -0.001 | 0.002 |
| B | 0.000 | 0.000 | 0.000 | 0.000 |
| C | 0.000 | -0.001 | -0.001 | 0.002 |
| D | 0.000 | 0.001 | -0.001 | 0.001 |
| E | 0.000 | 0.014 | 0.003 | 0.014 |
| F | 0.000 | 0.000 | 0.000 | 0.000 |
| G | 0.000 | 0.000 | 0.000 | 0.000 |
| H | 0.000 | 0.000 | 0.000 | 0.000 |
| I | 0.000 | 0.001 | 0.000 | 0.001 |
| J | 0.000 | 0.001 | 0.001 | 0.001 |

The results for Section “E” show a much higher deviation than would be reasonably expected. This is due to the method used to determine this particular circle. This section center is based on the corner points of the blades. The method used to determine the corner is shown in the adjacent image. Two edge targets were used on each side to fit a line. These lines were intersected to determine the corner. It is felt that this method is less than ideal.




The data collected was also used to calculate the nominal length. The length was determined to be 51.1299"

The image below shows the angular relationship between the planes measured and the computed centerline.



## Time Summary

| | |
|---|---|
| Initial Investigation | 10 minute |
| Targeting | 30 minute |
| Photography | 10 minute |
| Processing | 5 minutes |
| Analysis | 20 minutes |
| **Total** | **75 minutes** |

## Concluding Remarks

The measurement undertaken has shown that V-STARS can be a very powerful measurement tool. The results of the measurement undertaken were very accurate and produced quickly.

GSI would like to thank KPS for welcoming us into their facility. We will be happy to discuss the results of this report or any other aspect of the technology presented.