# Prepared for:
Caterpillar

4-20-2006

**Part Name:** Fuel Injector Pin
**Part Number:** 285-6439

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**Features Studied:** 0.5mm Radius

**Purpose:** To determine the angle position to utilize when measuring the 0.5mm radius using the anchoring method.

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**Introduction:**
A critical 0.5mm radius on the shoulder of a fuel injector pin, manufactured by Caterpillar, was repeating within .025mm when measured by the OGP Vision system. The tolerance of the radius is +/- 0.05mm. The uncertainty of the inspection system was too high to determine whether the parts were in or out of specification.

An evaluation of the radius geometry and a repeatable inspection method were needed to accurately measure the 0.5mm radius.

**Inspection Method:**
The 0.5 radius will not repeat using conventional vision system targets. A different measurement approach was needed to determine if repeatability and accuracy could be improved. After discussion of the radius with a renounced GD&T expert, it was determined that this radius could only be measured using one of two techniques: 1. Profile the feature or 2: Use an anchoring technique (described on the attached document).

The profile method did not offer Caterpillar enough information on the size of the radius. Therefore, the anchoring technique was determined the preferred method.

**Part Geometry:**
It is critical to under stand the part geometry before analyzing the data that was measured in this report. Below is a close up of the fuel injector pin with the 0.5mm radius highlighted:

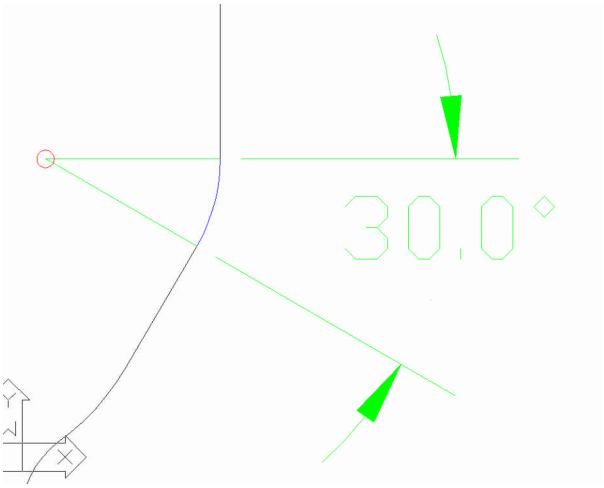


**Figure 1.** Close up of the fuel injector pin.

Note that the 0.5mm radius only has a 30degree arc segment available to measure. This can create problems when using the anchoring technique, especially if the anchored feature is not repeatable.

The tip radius of the fuel injector was utilized as the anchoring feature. Studies were performed to determine the repeatability of this feature. It was determined that the worst case repeatability of the tip radius, the anchoring feature, is 0.005mm. An error zone of 0.025mm was utilized in this study to add a factor of safety to our analysis. With this in mind, figure 2 illustrates the error zones associated with anchoring off of the tip radius.

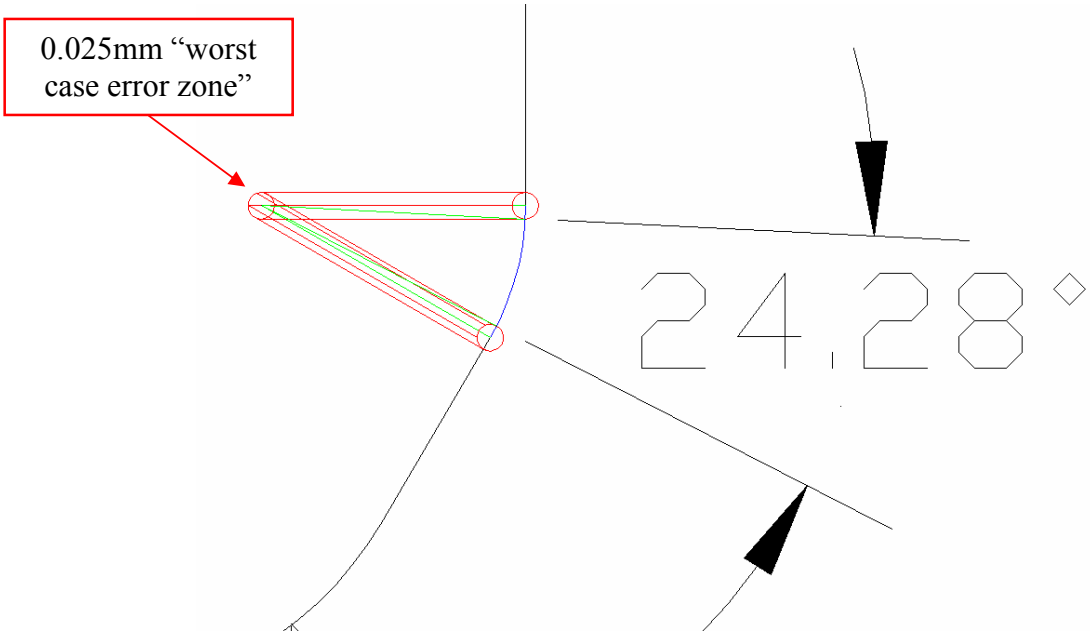


**Figure 2.** Representation of the worst case error zones as a result of measuring the tip radius with .025mm repeatability.

Figure 2 also points out that there is a 24.28 degree arc segment, or zone, that the measurement shall lie inside to avoid the worst case error associated with the repeatability of the tip radius. In other words, the 0.5mm radius measurement should take place somewhere inside the 24.28 degree arc segment when utilizing the anchoring technique.

**Data:**

Data was gathered to determine radius results along the entire 30 degree arc segment (reference Figure 1 above). Measurements were taken from 2 to 28 degrees along the arc in 2 degree increments. Table 1 represents the data gathered when measured using the AVANT OGP system.

| | Average Radius | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Part # | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 |
| 1 | 0.499 | 0.499 | 0.499 | 0.501 | 0.501 | 0.501 | 0.506 | 0.506 | 0.506 | 0.511 | 0.511 | 0.511 | 0.518 | 0.518 | 0.518 |
| 2 | 0.499 | 0.499 | 0.499 | 0.501 | 0.501 | 0.501 | 0.507 | 0.507 | 0.507 | 0.512 | 0.512 | 0.512 | 0.518 | 0.519 | 0.518 |
| 3 | 0.499 | 0.499 | 0.499 | 0.500 | 0.500 | 0.500 | 0.504 | 0.504 | 0.504 | 0.507 | 0.507 | 0.507 | 0.513 | 0.513 | 0.512 |
| 4 | 0.499 | 0.499 | 0.499 | 0.501 | 0.501 | 0.501 | 0.506 | 0.506 | 0.506 | 0.511 | 0.511 | 0.511 | 0.519 | 0.518 | 0.518 |
| 5 | 0.498 | 0.498 | 0.498 | 0.500 | 0.500 | 0.500 | 0.504 | 0.504 | 0.504 | 0.508 | 0.508 | 0.508 | 0.512 | 0.512 | 0.512 |
| 6 | 0.498 | 0.498 | 0.498 | 0.500 | 0.500 | 0.500 | 0.505 | 0.505 | 0.505 | 0.510 | 0.510 | 0.510 | 0.516 | 0.516 | 0.516 |
| 7 | 0.498 | 0.498 | 0.498 | 0.500 | 0.500 | 0.500 | 0.504 | 0.504 | 0.504 | 0.507 | 0.507 | 0.507 | 0.512 | 0.512 | 0.512 |
| 8 | 0.499 | 0.499 | 0.499 | 0.501 | 0.501 | 0.501 | 0.508 | 0.508 | 0.508 | 0.516 | 0.516 | 0.516 | 0.523 | 0.523 | 0.525 |
| 9 | 0.499 | 0.499 | 0.499 | 0.501 | 0.502 | 0.502 | 0.508 | 0.508 | 0.508 | 0.516 | 0.516 | 0.516 | 0.524 | 0.524 | 0.527 |
| 10 | 0.499 | 0.499 | 0.499 | 0.499 | 0.499 | 0.499 | 0.501 | 0.501 | 0.501 | 0.503 | 0.503 | 0.503 | 0.506 | 0.506 | 0.506 |
| **Max Avg:** | **0.499** | **0.499** | **0.499** | **0.501** | **0.502** | **0.502** | **0.508** | **0.508** | **0.508** | **0.516** | **0.516** | **0.516** | **0.524** | **0.524** | **0.527** |
| | | | | | | | | | | | | | | | |
| | Range | | | | | | | | | | | | | | |
| Part # | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 |
| 1 | 0.002 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.003 | 0.003 | 0.003 | 0.006 | 0.006 | 0.005 | 0.012 | 0.012 | 0.007 |
| 2 | 0.002 | 0.002 | 0.002 | 0.002 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.004 | 0.005 | 0.005 | 0.007 | 0.007 | 0.008 |
| 3 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.003 | 0.003 | 0.003 | 0.006 | 0.006 | 0.006 | 0.008 | 0.008 | 0.008 |
| 4 | 0.002 | 0.002 | 0.002 | 0.003 | 0.003 | 0.002 | 0.003 | 0.003 | 0.003 | 0.005 | 0.006 | 0.005 | 0.002 | 0.001 | 0.002 |
| 5 | 0.001 | 0.002 | 0.002 | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.002 | 0.003 | 0.003 | 0.003 | 0.002 | 0.002 | 0.002 |
| 6 | 0.002 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 | 0.002 | 0.002 | 0.006 | 0.006 | 0.006 | 0.008 | 0.008 | 0.008 |
| 7 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.008 | 0.007 | 0.007 | 0.007 | 0.007 | 0.008 | 0.008 | 0.008 |
| 8 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.003 | 0.003 | 0.003 | 0.003 | 0.002 | 0.009 |
| 9 | 0.009 | 0.009 | 0.009 | 0.008 | 0.008 | 0.008 | 0.007 | 0.007 | 0.007 | 0.006 | 0.006 | 0.006 | 0.007 | 0.007 | 0.011 |
| 10 | 0.001 | 0.002 | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.001 | 0.002 | 0.003 | 0.003 | 0.002 | 0.003 | 0.004 | 0.004 |
| **Max Range:** | **0.009** | **0.009** | **0.009** | **0.008** | **0.008** | **0.008** | **0.007** | **0.008** | **0.007** | **0.007** | **0.007** | **0.007** | **0.012** | **0.012** | **0.011** |

**Table 1.** 0.5mm average radius data gathered using the **AVANT OGP** system. 10 parts were measured, 5 times in different orientations on the fixture.

Note that the radius measurement increases as you move further away from the 0 degree position along the arc. More data was collected using the QUEST OGP system, as shown in Table 2.

| | Average Radius | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Part # | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 |
| 1 | 0.499 | 0.499 | 0.500 | 0.501 | 0.503 | 0.505 | 0.506 | 0.508 | 0.510 | 0.511 | 0.514 | 0.516 | 0.517 | 0.519 | 0.521 |
| 2 | 0.499 | 0.499 | 0.500 | 0.502 | 0.503 | 0.505 | 0.508 | 0.510 | 0.512 | 0.514 | 0.516 | 0.519 | 0.521 | 0.523 | 0.525 |
| 3 | 0.499 | 0.499 | 0.499 | 0.501 | 0.502 | 0.503 | 0.504 | 0.506 | 0.506 | 0.508 | 0.509 | 0.511 | 0.512 | 0.514 | 0.516 |
| 4 | 0.498 | 0.499 | 0.499 | 0.501 | 0.503 | 0.504 | 0.507 | 0.508 | 0.510 | 0.512 | 0.514 | 0.517 | 0.518 | 0.521 | 0.523 |
| 5 | 0.498 | 0.498 | 0.498 | 0.500 | 0.501 | 0.502 | 0.503 | 0.505 | 0.506 | 0.507 | 0.509 | 0.510 | 0.512 | 0.513 | 0.515 |
| 6 | 0.498 | 0.498 | 0.499 | 0.500 | 0.502 | 0.504 | 0.507 | 0.508 | 0.510 | 0.512 | 0.514 | 0.517 | 0.519 | 0.521 | 0.523 |
| 7 | 0.499 | 0.499 | 0.500 | 0.501 | 0.502 | 0.504 | 0.505 | 0.506 | 0.507 | 0.509 | 0.511 | 0.512 | 0.513 | 0.515 | 0.517 |
| 8 | 0.498 | 0.498 | 0.500 | 0.501 | 0.503 | 0.505 | 0.508 | 0.511 | 0.513 | 0.515 | 0.518 | 0.521 | 0.524 | 0.526 | 0.529 |
| 9 | 0.498 | 0.498 | 0.499 | 0.501 | 0.502 | 0.505 | 0.507 | 0.510 | 0.513 | 0.515 | 0.517 | 0.520 | 0.523 | 0.525 | 0.528 |
| 10 | 0.498 | 0.498 | 0.499 | 0.500 | 0.500 | 0.501 | 0.501 | 0.502 | 0.503 | 0.504 | 0.505 | 0.506 | 0.507 | 0.508 | 0.509 |
| **Max Avg:** | **0.499** | **0.499** | **0.500** | **0.502** | **0.503** | **0.505** | **0.508** | **0.511** | **0.513** | **0.515** | **0.518** | **0.521** | **0.524** | **0.526** | **0.529** |
| | | | | | | | | | | | | | | | |
| | Range | | | | | | | | | | | | | | |
| Part # | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 |
| 1 | 0.001 | 0.002 | 0.002 | 0.002 | 0.001 | 0.002 | 0.003 | 0.003 | 0.004 | 0.004 | 0.005 | 0.006 | 0.007 | 0.008 | 0.008 |
| 2 | 0.002 | 0.002 | 0.002 | 0.003 | 0.003 | 0.003 | 0.004 | 0.005 | 0.006 | 0.006 | 0.007 | 0.008 | 0.008 | 0.009 | 0.009 |
| 3 | 0.001 | 0.001 | 0.002 | 0.001 | 0.002 | 0.002 | 0.004 | 0.005 | 0.005 | 0.006 | 0.006 | 0.007 | 0.008 | 0.009 | 0.008 |
| 4 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| 5 | 0.001 | 0.001 | 0.002 | 0.003 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| 6 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.002 | 0.003 | 0.002 | 0.003 | 0.004 | 0.003 |
| 7 | 0.005 | 0.005 | 0.005 | 0.005 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.005 | 0.004 | 0.004 | 0.005 | 0.004 |
| 8 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.001 | 0.001 |
| 9 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 |
| 10 | 0.002 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.001 | 0.001 | 0.002 | 0.002 |
| **Max Range:** | **0.008** | **0.008** | **0.008** | **0.008** | **0.008** | **0.008** | **0.008** | **0.008** | **0.008** | **0.008** | **0.008** | **0.008** | **0.008** | **0.009** | **0.009** |

**Table 2.** 0.5mm average radius data gathered using the **QUEST OGP** system. 10 parts were measured, 5 times in different orientations on the fixture.

The results were graphed to help visualize the measurement differences along the 30 degree arc segment. Figure 3 and 4 below represent the data in Tables 1 and 2 respectfully.

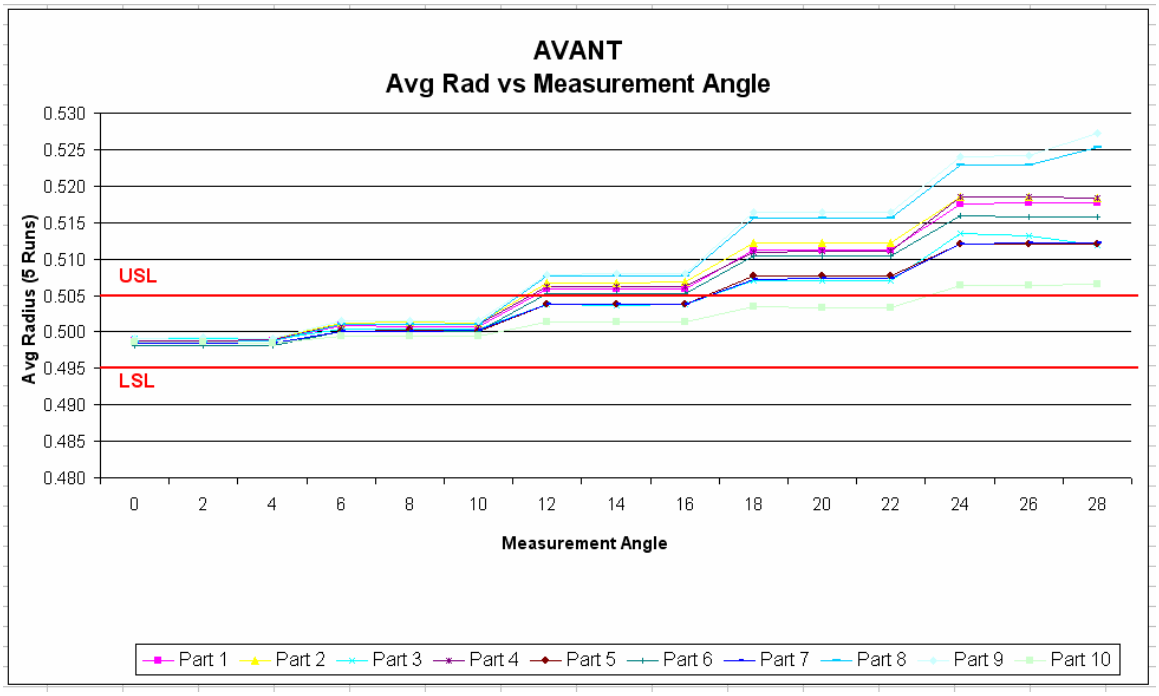


**Figure 3.** AVANT OGP radius measurements along the 30 degree arc segment.

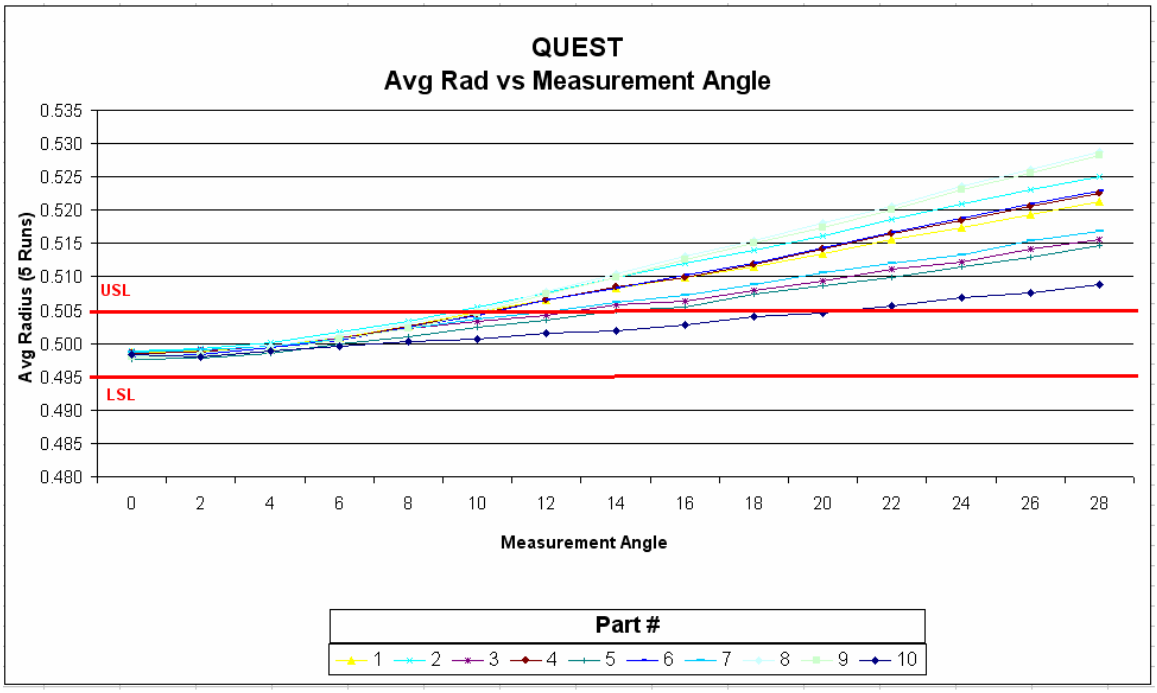


**Figure 4.** QUEST OGP radius measurements along the 30 degree arc segment.

Both graphs show an increase in variation of measurement result from part to part after the 10 degree measurement angle. This is important since it will help us determine the accurate measurement angle when compared to the part geometry and error zones.

**Results:**
The geometry of the part and the repeatability of the anchoring feature proves that the ideal measurement zone along the 30 degree arc segment should lie within the 24.28 arc segment shown in Figure 2. This translates into taking a measurement within a 3 to 27 degree measurement angle.

The graphs in figures 3 and 4 suggest taking our measurement within the 0 to 10 degree measurement angle to keep part to part variation within a minimum. Therefore, combined with the 3 to 27 degree measurement angle determined from before. It is recommended that the 0.5mm measurement be taken at the 6 degree measurement angle.

**Conclusion:**
Studies have proven that the anchoring technique is a repeatable measurement method that can be utilized to measure Caterpillar's 0.5mm radius. This study has shown that the radius shall be taken at a 6 degree measurement angle when using the OGP AVANT or QUEST system to minimize the amount of uncertainty in the measurement.