# Developing a Digital Thread Between Product Technical Specification and Metrology Inspection.

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## Abstract

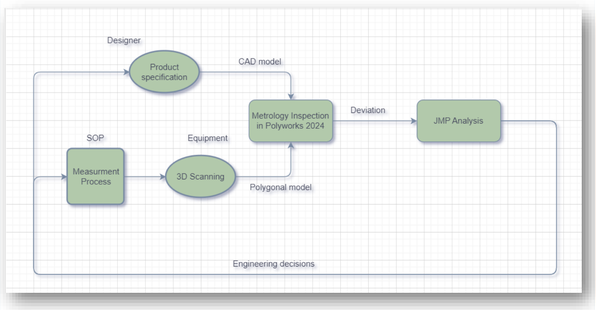
The digital thread serves as an interconnected flow of data that defines a product throughout its lifecycle, facilitating automated product inspection and optimizing the connectivity between manufacturing and engineering processes. This study focuses on the integration of product technical specifications, such as Geometric Dimensioning & Tolerancing (GD&T), with metrology inspection methods like Polyworks Inspection and statistical analysis using JMP and Minitab. Gauge Repeatability & Reproducibility (Gauge R&R) is employed to assess measurement variation, providing insights into %Tolerance and %Variation based on product specifications and process control limits.

The methodology includes 3D scanning with standardized operating procedures to ensure consistency, metrology inspection by aligning CAD models with polygonal data, and JMP analysis for organizing measurement data and performing Gauge R&R. Excel is used to identify correlations between measurement data. Results show that both scanners exceeded the 20% threshold for %Tolerance in Gauge R&R, with MetraScan outperforming Creality. Appraiser A's correlation analysis indicated good correlation for parallelism ($R^2 > 0.9$) but poor correlation for certain features, such as cylinder hole positioning. These findings highlight opportunities for improving measurement accuracy and process reliability.

## Introduction

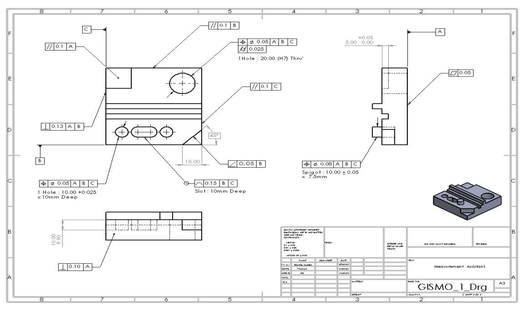
### Digital thread

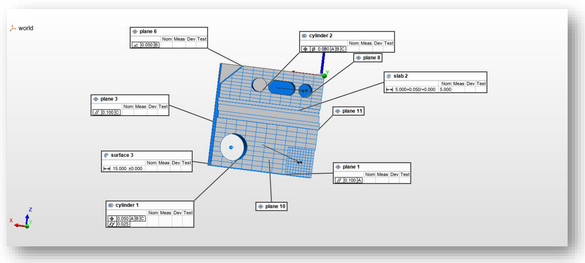
- An interconnected flow of relevant data that defines a product throughout its lifecycle.
- Helps to achieve automated product inspection.
- Optimize connectivity between manufacturing and engineering processes.




### Product Technical Specification and Metrology Inspection

- Geometric Dimensioning & Tolerancing (GD&T) often communicated through a technical drawing.
- Polyworks Inspection.
- JMP analysis/ Minitab.




### Gauge Repeatability & Reproducibility

- Guage R&R is a method used to define the amount of variation in the measurement data due to the measurement system.
- %Tolerance – Calculation of %GRR based on product Specifications.
- %Variation – Calculation of %GRR based on process control limits.

## Materials

### 3D Scanners for measurement and Data collection

- Creality .
- Creaform MetraScan.

### CAD & Metrology Software

- Polyworks 2024.
- SOLIDWORKS 2019.

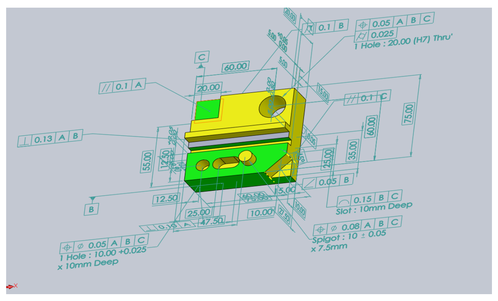
### Analysis software

- JMP Pro 18 /Minitab 19.
- Excel.

## Methodology

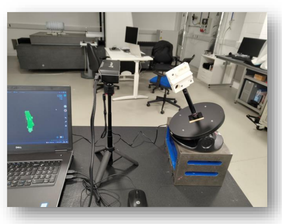
### Dimensioning and Tolerancing in CAD package

- Geometric Dimensioning & Tolerancing (GD&T) in SolidWorks.



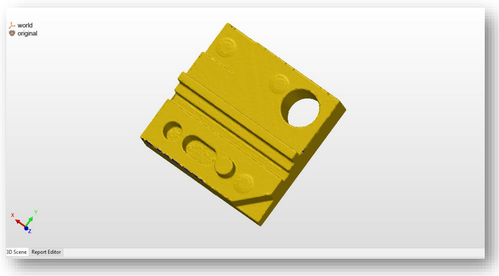
### 3D Scanning

- Create a standard operating procedure.
- Use the same settings for all scans.
- Label parts to avoid scanning the same part more than once.
- Collect Measurement data.



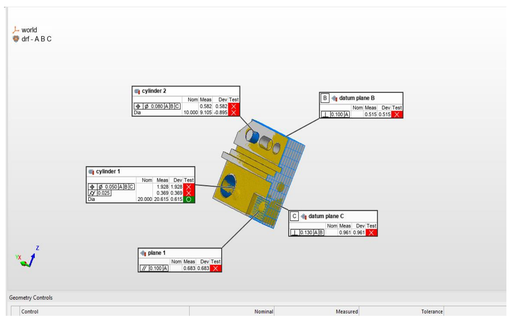
### 3D Scans

- Creality Scans.
- MetraScan.




### Metrology inspection

- Insert CAD Part with it's GD&T.
- Insert polygonal model generated from 3D Scans.
- Align the CAD with polygonal model and extract measurements.
- Generate a report of the desired features.




### JMP Analysis

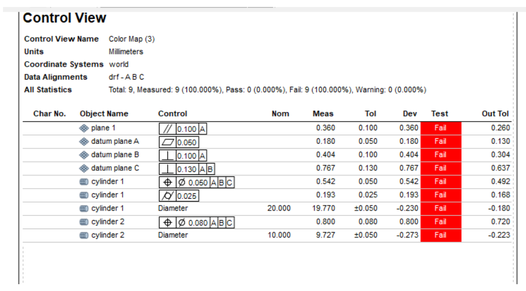
- Organise the measurement data from Polyworks.
- Import the Excel file and conduct a Guage R&R.

### Excel

- Organise the results and find the correlation between measurements.

## Results

### Polyworks Report



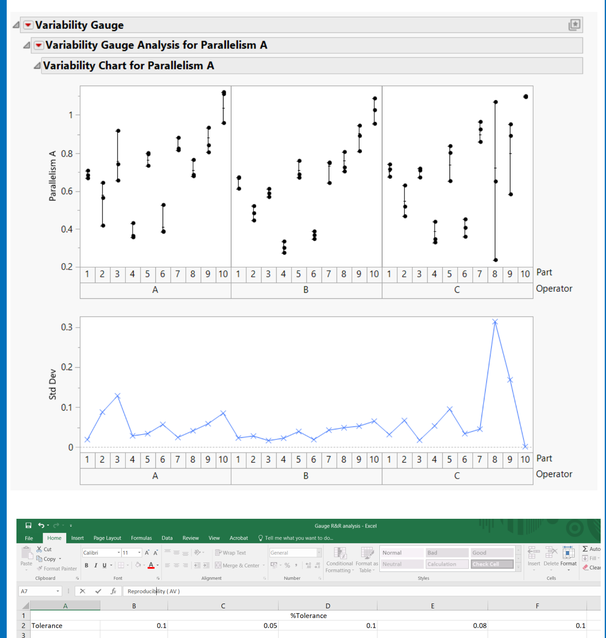
**Control View**

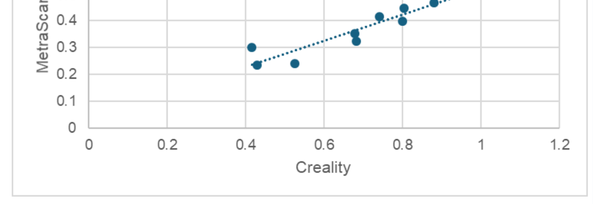
| | |
|---|---|
| Control View Name | Color Map (3) |
| Units | Millimeters |
| Coordinate Systems | world |
| Data Alignments | drf - A B C |
| All Statistics | Total: 9, Measured: 9 (100.000%), Pass: 0 (0.000%), Fail: 9 (100.000%), Warning: 0 (0.000%) |

| Char No. | Object Name | Control | Nom | Meas | Tol | Dev | Test | Out Tol |
|---|---|---|---|---|---|---|---|---|
| | plane 1 | // 0.100 A | | 0.360 | 0.100 | 0.360 | Fail | 0.260 |
| | datum plane A | ▱ 0.050 | | 0.180 | 0.050 | 0.180 | Fail | 0.130 |
| | datum plane B | ⊥ 0.100 A | | 0.404 | 0.100 | 0.404 | Fail | 0.304 |
| | datum plane C | ⊥ 0.130 A B | | 0.767 | 0.130 | 0.767 | Fail | 0.637 |
| | cylinder 1 | ⌖ Ø 0.050 A B C | | 0.542 | 0.050 | 0.542 | Fail | 0.492 |
| | cylinder 1 | ⌭ 0.025 | | 0.193 | 0.025 | 0.193 | Fail | 0.168 |
| | cylinder 1 | Diameter | 20.000 | 19.770 | ±0.050 | -0.230 | Fail | -0.180 |
| | cylinder 2 | ⌖ Ø 0.080 A B C | | 0.800 | 0.080 | 0.800 | Fail | 0.720 |
| | cylinder 2 | Diameter | 10.000 | 9.727 | ±0.050 | -0.273 | Fail | -0.223 |

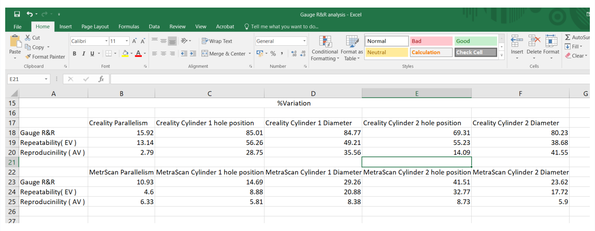
### Gauge R&R

- Both scanners are above 20% acceptance for %Tolerance.
- MetraScan performs better than creality for %Tolerance.
- Both scanners have good and bad results for %Variation.
- MetraScan also has better results for %Variation.



| %Tolerance | | | | | |
|---|---|---|---|---|---|
| Tolerance | 0.1 | 0.05 | 0.1 | 0.08 | 0.1 |
| | Creality Parallelism | Creality Cylinder 1 hole position | Creality Cylinder 1 Diameter | Creality Cylinder 2 hole position | Creality Cylinder 2 Diameter |
| Gauge R&R | 549.97 | 9397.3 | 2099.3 | 3958.7 | 2432.1 |
| Repeatability( EV ) | 499.55 | 7644.9 | 1599.5 | 3533.7 | 1688.7 |
| Reproducibility ( AV ) | 230.03 | 5464.8 | 1359.6 | 1784.6 | 1750.3 |
| | MetrScan Parallelism | MetraScan Cylinder 1 hole position | MetraScan Cylinder 1 Diameter | MetraScan Cylinder 2 hole position | MetraScan Cylinder 2 Diameter |
| Gauge R&R | 250.82 | 1535.3 | 307.73 | 1518.9 | 444.22 |
| Repeatability( EV ) | 162.74 | 1193.7 | 259.95 | 1349.7 | 384.78 |
| Reproducibility ( AV ) | 190.86 | 965.56 | 164.7 | 696.77 | 221.98 |

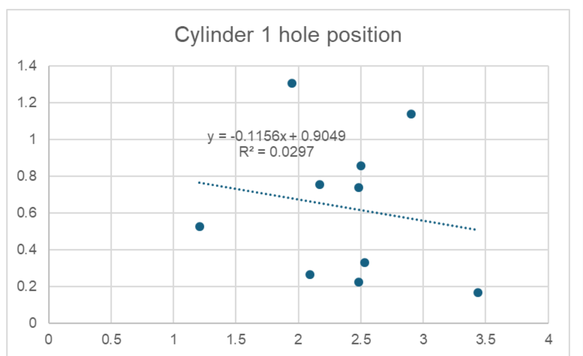


| %Variation | | | | | |
|---|---|---|---|---|---|
| | Creality Parallelism | Creality Cylinder 1 hole position | Creality Cylinder 1 Diameter | Creality Cylinder 2 hole position | Creality Cylinder 2 Diameter |
| Gauge R&R | 15.92 | 85.01 | 84.77 | 69.31 | 80.23 |
| Repeatability( EV ) | 13.14 | 56.26 | 49.21 | 55.23 | 38.68 |
| Reproducinility ( AV ) | 2.79 | 28.75 | 35.56 | 14.09 | 41.55 |
| | MetrScan Parallelism | MetraScan Cylinder 1 hole position | MetraScan Cylinder 1 Diameter | MetraScan Cylinder 2 hole position | MetraScan Cylinder 2 Diameter |
| Gauge R&R | 10.93 | 14.69 | 29.26 | 41.51 | 23.62 |
| Repeatability( EV ) | 4.6 | 8.88 | 20.88 | 32.77 | 17.72 |
| Reproducinility ( AV ) | 6.33 | 5.81 | 8.38 | 8.73 | 5.9 |

### Measurement correlation for Appraiser A

- Potential for good correlation and Bad Correlation.
- For correlation acceptance Parallelism R2 > 0.9 but for cylinder 1 hole position R2 < 0.




## Conclusion

### Process

- The process directly relates 3D technical specification with 3D metrology software for Product inspection. This study demonstrates that the use of 3D scanning technology, combined with metrology inspection and statistical analysis, can provide valuable insights into product quality and measurement system variability.

### Tolerance & Variation

- The %tolerance from the results show that both 3D scanners cannot operate with the current acceptance criteria.
- To achieve the desired acceptance for %tolerance with 3D printing and scanning, the analysis needs tolerance of more than 1 mm.
- The Guage R&R for %Variation is good showing it can measure process variation but the Guage R&R for %tolerance specification limits are tighter than the process control limits.

### Measurement Correlation

- The correlation analysis for Appraiser A demonstrated mixed outcomes. While there was a strong correlation for parallelism ($R^2 > 0.9$), indicating consistency in those measurements, there was poor correlation for cylinder hole positioning ($R^2 < 0$), highlighting areas of concern for certain geometries. This suggests potential challenges in achieving measurement accuracy for more complex features.

### Process Improvement

- The findings emphasize the importance of refining both the measurement tools and methods. The variability in %Tolerance and measurement correlation suggests that further calibration and standardization efforts may be necessary to improve accuracy and consistency in the inspection process.

## Recommendations

### 3D Scanners

- Prioritize the use if higher performing scanners, particularly for critical dimensions and complex geometries. Additionally, regular calibration and maintenance of the scanners should be implemented to minimise variability.
- Refine the scanner settings to further reduce the measurement variability, ensure consistent use of optimal scanner settings.
- Creating a standard operating procedure for scanning with the MetraScan that can help to maintain consistency in measurement quality.

### Process

- Revisit the measurement process and make improvements where possible.
- Use another method to take measurements and repeat the Gauge R&R to compare.
- Fully integrate the digital thread across all stages of the product lifecycle

### Tolerancing

- Re-evaluate the GD&T specifications for critical features to ensure they are achievable with the current measurement systems.

## Acknowledgements

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