InnovMETRIC Software

Geometric Inspection of Small Components with CT-scanners

- Mark Bliek, Bolton Works

A completely new way of thinking is needed for the inspection and functional analysis of small injection-molded components and assemblies. Today, non-conventional hardware and software tools are used in a unique combination, yielding better and easier-to-understand results when dimensional inspection is done on small and complex geometric forms. This article describes how Bolton Works has used the PolyWorks suite to perform a virtual assembly using scanned components and CAD models, allowing specialists to tackle design and manufacturing problems at an early stage. Through a case study examining miniature valve and pump manufacturer Parker Hannifin's Pneutronics Division, this article also explains how CT-scanners can be used to measure small features efficiently and perform diverse quality control tasks such as Geometric Dimensioning and Tolerancing.

About Bolton Works

Bolton Works, from Vernon, CT, USA, specializes in the use of CT-scanners for metrology and inspection. Mark Bliek, its founder, can be reached at mark.bliek@bolton-works.com

About Pneutronics

Pneutronics, a division of Parker Hannifin Corporation, located in Hollis, NH, USA engineers and manufactures miniature solenoid valves, miniature diaphragm pumps, and system solutions for critical fluidic applications. The Pneutronics valve product line includes miniature digital, proportional, and multi-media solenoid valves with orifice sizes from .003" to .250", which are used in a range of medical technologies and analytical instrumentation.

Limits of the current technology

With the advent of better design tools and materials, engineers seek to integrate multiple functions in injection-molded parts. By doing so, the overall cost, assembly time, and reliability of the assembly are improved.

Unfortunately, "contact" measurement tools like calipers, gages, or CMMs (Coordinate Measurement Machines) have proved to be ineffective for measuring small components (< 25mm) with feature sizes smaller than 1mm. Here are some of the reasons why:

- Mechanical touch probes, due to their inertia, set limits to the speed at which they can operate and therefore limit the number of data points that are sampled.
- Geometry created by using slides and inserts in the injection mold often creates undercuts, which cannot be reached by conventional tools in a single setup.
- The size of a probe limits the size of features that can be measured.
- A CMM needs to be programmed like a CNC machine tool to get the probe to the area of interest while avoiding the fixture which holds the part.
- Gages, optical comparators, microscopes, etc. all work in 2 dimensions. These instruments work in planar sections and do not offer information about how the measured features relate to other features in 3D space, a major drawback whenever datums need to be used.

Turning to CT-scanners

Pneutronics, a division of Parker Hannifin Corporation (Hollis, NH), engineers and manufactures miniature solenoid valves, miniature diaphragm pumps, and system solutions for critical fluidic applications. The Pneutronics valve product line includes miniature digital, proportional, and multi-media solenoid valves with orifice sizes from .003" to .250", which are used in a range of medical technologies and analytical instrumentation.

In 2003, Pneutronics was searching for technology that would allow it to analyze a valve in a non-destructive manner. This product, X-Valve® is a two-position, three-way miniature pneumatic valve (24mm x 8mm x 9mm) that consists of a glass-filled polymer valve housing, a stainless steel core, a stainless steel actuator, a plunger with an elastomeric seal, and a solenoid (Fig 1).

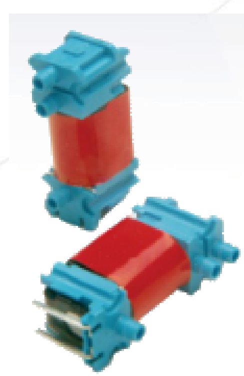

Fig.1: X-Valve Assembly

[418] 688-2061
2014 Jean-Talon Nord,
Suite 310, Sainte-Foy,
Québec Canada G1N 4N6
www.innovmetric.com

Finding a solution that could measure both the plastic and silicon rubber components accurately was an important requirement for deciding on the technology. Pneutronics development engineer, Drew Brenner, investigated many options before turning to Bolton Works and its CT-scanning service to generate a complete "digital" paper trail of the metrology process.

CT-scanners (Computer Tomography) are used in the industrial and medical worlds to capture information from both the inside and the outside of an object under investigation. A CT-scanner consists of an X-ray source, a platform that holds the object, and a detector. A CT-scanner measures the attenuation of the X-ray beams passing through an object and creates a complete 3-dimensional volumetric dataset. The digitized model consists of very dense point clouds that can reach several million points. (For more information on CT-Scanners see Appendix A)

To handle this great amount of information, Bolton Works turned to PolyWorks, InnovMetric's point cloud processing software solution. After several years of point cloud processing in the automotive and aeronautic industries, PolyWorks has proven to be the most robust software package capable of efficiently handling the large point clouds generated by CT-scanners.

"Through the use of CT-scan technology and the PolyWorks software, Pneutronics decreased its product development time, gained significant input about its valve, and streamlined its testing process with the ability to analyze more accurate data when compared to traditional inspection methods."

Drew Brenner,
Pneutronics
Development Engineer

The Inspection Process

1) Part digitizing

In order to work with the mix of materials present in the X-Valve assembly, Bolton Works began by scanning the (blue) plastic housing separately, which resulted in a dataset consisting of 1500 images with a distance between the images of 20µm. The total size of the image dataset produced was 1.8 gigabytes. From this stack of images, a 3D point cloud model consisting of roughly 6 million data points was created (fig. 2-3).

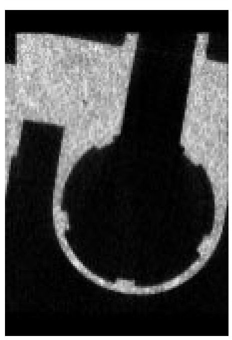

Fig.2: Image data

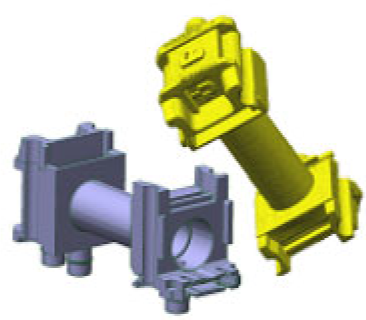

Fig.3: CAD and scanned data

Advantages

- ✓ The benefits of sampling so many data points are significant, especially when compared to traditional measuring techniques.
- ✓ With one CT-scan, Pneutronics obtained all the data needed to study the valve, eliminating time involved with additional scanning for new measurements.
- ✓ Most importantly, the high number of data points greatly improved the precision and detail of the model, resulting in more accurate design data and a more complete product analysis.

2) Comparison to CAD

After scanning and generating the 3D model, the point cloud data-set was aligned with the 3D CAD model using a "best fit" method (fi.4). The software compares every point on the point cloud to the CAD surface information, records deviations, and displays these in a color map (fig.5).

[418] 688-2061
2014 Jean-Talon Nord,
Suite 310, Sainte-Foy,
Québec Canada G1N 4N6
www.innovmetric.com

InnovMETRIC Software

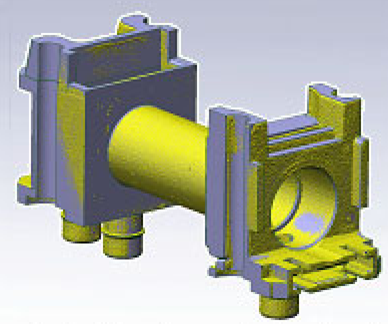

Fig.4: CAD and scanned data aligned

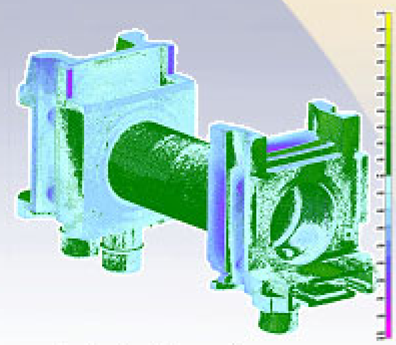

Fig.5: Deviation color map

The color map immediately provided Pneutronics with information about the discrepancies between the actual part and the 3D CAD-designed part.

3) Geometric Dimensioning and Tolerancing

The PolyWorks software allowed Pneutronics to perform geometric dimensioning and tolerancing (GD&T) and efficiently develop a mechanical drawing standard by defining a datum-based reference coordinate system for the assembly (fig.6). It uses the 3D CAD model and automatically extracts primitives, such as planes, cylinders, and cones, from the point cloud. To define the datum planes for the pneumatic valve, the plane in the 3D CAD model was identified. PolyWorks then extracted the corresponding plane from the point cloud by using points surrounding this CAD feature within an 0.25 mm distance. It further excluded points of which the normals were not within a 20 degree tolerance of band of the surface normal. Through this filtering process, out of the millions of scanned data points, a correct datum was constructed The initial best fit therefore is only used to align the points close enough for the software to find the points forming the datums and other features (fig.7).

The drawing shows how the extracted datums, cylinders, planes, etc. relate to each other. The drawing specifies the tolerances with maximum/minimum material conditions. These relationships are fed into the PolyWorks inspection software. This is essential, because if the drawing specifies that a cylinder should be positioned to datum A, B, and C, the software should virtually align the point cloud accordingly. After extraction of the desired features and comparison to what had been defined on the drawing, the information is output in Excel format for documentation purposes.

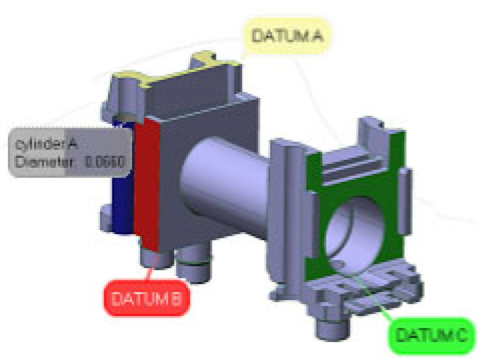

Fig.6: Definition of datums and a cylinder on 3D CAD file

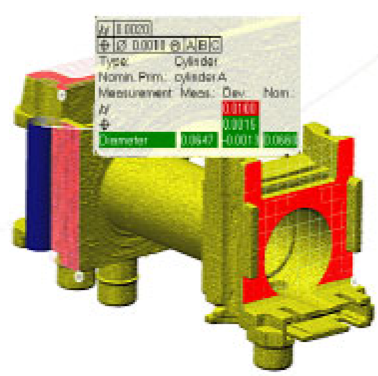

Fig.7: Datum, feature, and dimension extraction

[418] 688-2061
2014 Jean-Talon Nord,
Suite 310, Sainte-Foy,
Québec Canada G1N 4N6
www.innovmetric.com

InnovMETRIC Software

4) Virtual assembly

Pneutronics wanted to enhance specific performance characteristics of the X-valve and needed an accurate GD&T report highlighting the current state of critical dimensions. Brenner decided to evaluate the interaction of the stainless steel and rubber components with the plastic housing.

The valve assembly consists of components with different materials, including plastic, rubber, stainless steel, and copper wiring. All these materials have a different density, which means that different energy levels had to be used by the CT scan for each component. It was not feasible to segment out the materials for individual scanning and then try to reconstruct them into an accurate model. It was decided to employ another approach to visualize the assembly.

The cylindrical stainless steel parts were measured with conventional tools such as comparators and calipers. After confirmation that they were within tolerance, the part was virtually assembled in PolyWorks using the CAD models of the stainless cylinders and the rubber valve and then overlaying them in 3D with the scanned data of the housing. Fig. 8 shows how the 3D cylinder (from CAD model) fits the scanned plastic housing. Fig. 9 shows how the rubber valve interacts with the valve seat of the plastic housing (the green area means that it fits within tolerances). The virtual assembly validated the design geometrically and confirmed that the valve should close as intended. As the design was now validated, the focus of the investigation went to the assembly process.

A CT scanner with a higher voltage was used to visualize only the metal components. The scans revealed (Fig. 10) that when the actuator was pressed in the housing, it could move out of alignment. A revision of the assembly process was therefore called for.

The geometric inspection and virtual assembly were instrumental in understanding the component interaction and allowing Pneutronics to concentrate on the assembly process rather than the design process to enhance the valve.

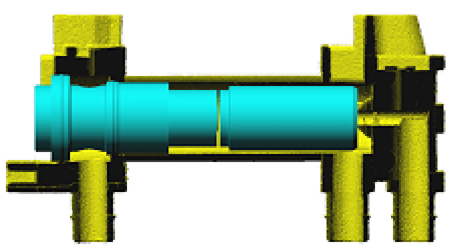

Fig.8: The 3D cylinder from CAD fits the scanned plastic housing

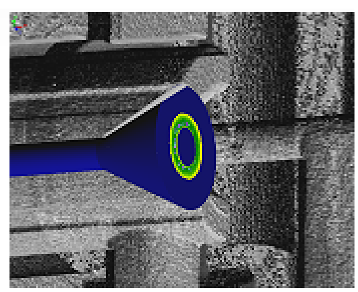

Fig.9: Virtual assembly of CAD and scanned data. The cylinder fits perfectly in the plastic housing.

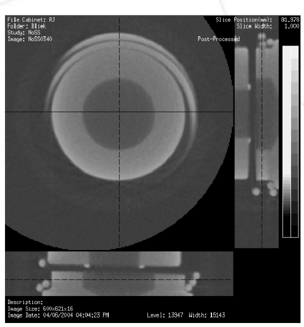

Fig.10: CT scan of the assembly, with only metal components visible shows that the cylinder is not properly aligned.

[418] 688-2061
2014 Jean-Talon Nord,
Suite 310, Sainte-Foy,
Québec Canada G1N 4N6
www.innovmetric.com

Automation and reports

PolyWorks offers a powerful scripting language that enable specialists to automate entire inspection tasks. All tasks previously discussed in this article can be automated and executed in one click of a mouse. It is just a matter of loading the next point cloud and having the results output to an Excel spreadsheet or uploaded to a Web server in HTML format. This level of automation is especially helpful when inspecting multi-cavity tools. Bolton Works has been using PolyWorks since 2003 to create inspection reports automatically from CT-scan data.

"I looked at various solutions and found that Bolton Works' capabilities were unique. "I also liked the PolyWorks software capabilities for report generation, which were quite powerful."

Drew Brenner,
Pneutronics
Development Engineer

Conclusion

As seen by the results at Pneutronics, CT scanning proved to be a cost-effective way of implementing a viable inspection process of miniature valves. The use of traditional "contact" measurement tools had proven to be difficult. The use of a CT-scanner combined with the right software tools has enabled to establish a complete digital inspection process at Pneutronics, applicable at different phases of the manufacturing process (design, prototype, production, and assembly). This inspection method proved to be very effective in validating parts through global analyses, GD&T measurements, and virtual assembly.

PolyWorks has proved to be the most appropriate tool for handling CT-scanner data for various reasons:

- PolyWorks very efficiently handles the large datasets (2GB) produced by CT-scanners.
- PolyWorks offers instant global analysis through data-to-CAD comparisons.
- PolyWorks has a unique embedded GD&T engine to verify that the parts comply to the *ASME Y14.5M-1994* standards.
- PolyWorks enables users to "virtually assemble" scanned data with CAD models.
- PolyWorks offers a powerful scripting language to automate inspection processes.

CT scanners require a substantial capital investment. By providing CT scanning as a service, Bolton Works made the technology affordable and still allows its customers to do their analysis in house, based on the point cloud and the help of the PolyWorks software solution.

For more information on this article

Mark Bliek, President,
Bolton Works, USA
Tel: 860-646-3948
mark.bliek@bolton-works.com

Sacha Villeneuve, Marketing Coordinator,
InnovMetric Software, Canada
Tel: 418-688-2061
svilleneuve@innovmetric.com

Appendix A

CT-scanners (***C**omputer **T**omography*) are used in the industrial and medical fields to capture information about both the inside and the outside of an object under investigation. The CT-scanner consists of an X-ray source, a platform that holds the object, and a detector.

Using a **medical CT-scanner** (fig.11 - fig.13), a stack of images is acquired when the patient is guided through the gantry of the scanner, resulting in a 3-dimensional, volumetric dataset.

Fig.11: CT-scanner

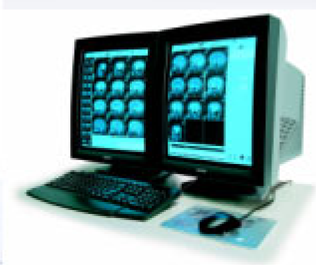

Fig.12: 2D image data

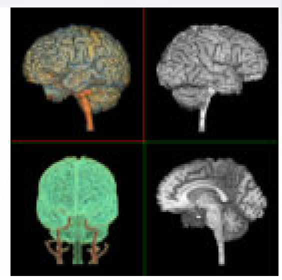

Fig.13: 3D reconstruction

In the case of an **industrial CT-scanner**, the object rotates in discreet steps and the X-ray source and detector are stationary (fig. 14). The detector measures the attenuation of the X-ray beams after passing through the object. Thus, during each rotation, multiple measurements are taken. This results in hundreds of measurements. After one full rotation, the measurements are then reconstructed into a cross-sectional digital image, with each pixel representing different densities of the object and its surroundings. After one rotation, the part is then translated along the axis of rotation to allow for the next cross-sectional data to be acquired. The end-result is a complete 3-dimensional volumetric dataset.

Advantages

- Both the inside and outside of parts are captured. This means that porosity and other unintended voids will show up in the data.
- Unattended process, no operator needs to be present during scanning
- As the scanned data set is going to be aligned using software, there are no accuracy requirements for the fixture that holds the part during scanning.
  The fixture should be X-ray translucent and stable; other than that it can be as simple as a tube or piece of tape.
- There is no need to program the CT scanner. This in contrast with a CMM, where a path has to be programmed for the touch probe to get to the region of interest while avoiding collision with the part and fixture.

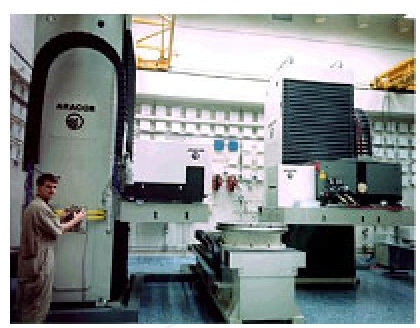

Fig.14: Industrial CT-scanner

Drawbacks

- CT scanners range in cost from several hundred thousand to several million dollars.

[418] 688-2061
2014 Jean-Talon Nord,
Suite 310, Sainte-Foy,
Québec Canada G1N 4N6
www.innovmetric.com

- The resolution decreases with material density and object size; consequently, there is no "one size fits all" solution.
- The reconstruction time to go from X-ray attenuation measurements to the 3D volumetric data, is computer intensive, and can take hours.

The Physics of CT-Scanners

X-rays are produced by bombarding an anode with electrons. The kinetic energy of the electrons is transformed into X-rays and heat. The anode has to have sufficient size to dissipate the heat. The spot size of the X-ray beam therefore increases with the energy level of the X-ray source.

Depending on the size and material of the object to be scanned, there can be significant differences in the voltage needed to generate X-rays powerful enough to pass through the object in sufficient quantity to be measured. Large metal objects, like an engine block, require a voltage above 450 kV. For smaller bone samples, it can be as low as 30kV. The voltage used determines the amount of shielding a CT-scanner needs to protect the operator. In order to limit the exposure to radiation to a patient, the scan times of medical scanners are in the range of seconds. Minutes or even hours of scan time are required when using industrial scanners.

With the lower energy levels, the beam can be focused to several µm, at which point one refers to these scanners as µCT-scanners. The focused beam size has a direct relation to the resolution of the image created. The feature sizes which can be distinguished with a µCT-scanner are therefore smaller (fig. 15). Due to the high resolution of the µCT-scanner, image datasets can easily surpass 1 GB and can be about the same size as one would see with a large, industrial CT-scanner.

Typical use of µCT-scanners is seen in the biomedical field to image intricate structures like bone samples and different kinds of fibers. Larger industrial CT-scanners are primarily used for fault detection (e.g. cracks), reverse engineering, and metrology (fig. 14).

There is a particular size range, highlighted in fig. 16, where CT-scanners are very effective and sometimes are uniquely qualified for metrology of plastic injection-molded components. From experiments with very small parts, like fiber-optic connectors, it has become apparent that there is no lower size limit of features that can be measured with a CT-scanner, using current injection-molding techniques.

Fig.15: µCT scanner

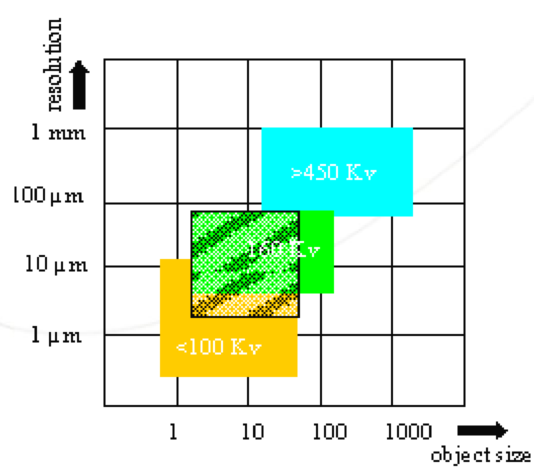

Fig.16: Optimum size for scanning injection-molded components.

[418] 688-2061
2014 Jean-Talon Nord,
Suite 310, Sainte-Foy,
Québec Canada G1N 4N6
www.innovmetric.com