Automated Inspection Systems: The Whole Picture

Why The Sum of the Features Doesn't Always Add Up to the Whole Part.

Richard Jennings

No one (not even you and I) consistently makes parts with perfect form and dimensions, so we must be able to efficiently check size and shape at many stages in the manufacturing and assembly process to eliminate scrap and rework and improve processes and profits. Automated inspection systems, which are widely used in all kinds of manufacturing operations, provide great efficiencies in checking individual features, but may not be as effective when asked to evaluate an entire part. You need to know why this is true and what you can do to improve your part yields.

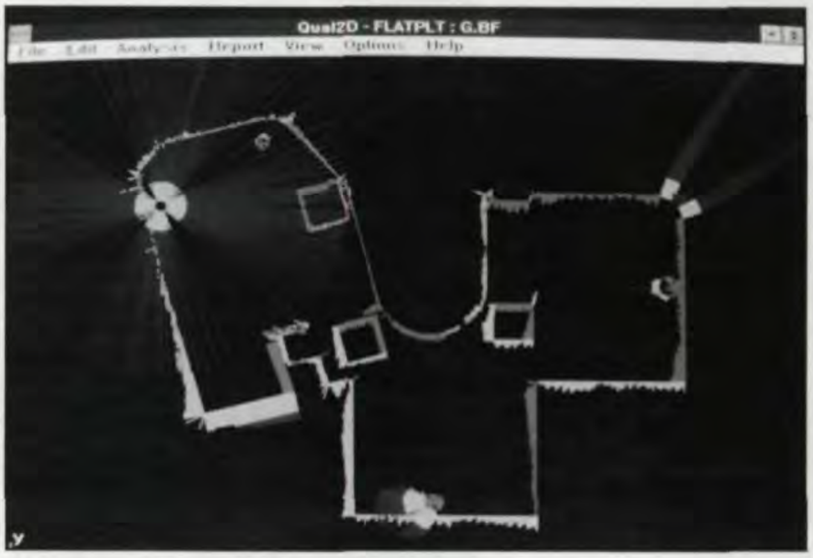
But, you ask, if all of the features are "good," doesn't that mean that the part passes? Not if you are measuring the size and shape of *individual part features,* expecting to learn whether or not the *entire part* passes or fails. Automated inspection systems measure individual features. But you don't make or buy features; you are interested, instead, in complete parts and assemblies.

When you need to know if the part conforms to specified design criteria or whether it will fit in assembly, individual feature measurements are not sufficient.

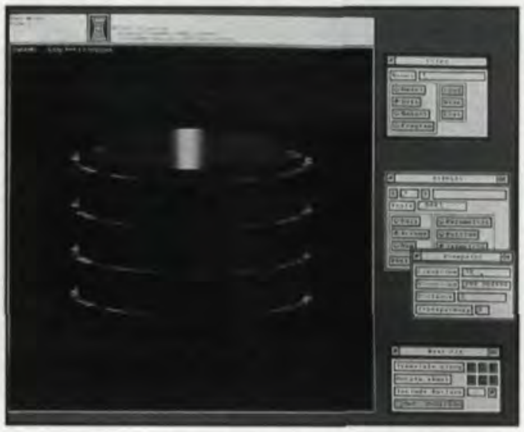
You need a way to easily evaluate the entire part, all at one time. If you do 2-D inspection, your old reliable optical comparator will serve very nicely. You must put the proper profile chart on the comparator screen; then you put your part on the inspection stage, and you move and rotate ("wiggle and jiggle") the part until it fits between the "railroad" tracks on the comparator screen. You can see the results, and everyone lives happily ever after.

But the optical comparator has drawbacks too. It is relatively slow and labor intensive; results are subjective (two users may arrive at different conclusions for the same part); there is no way to quantify the dimensions of a single feature (diameter of a hole, width of a slot); and there is no permanent record (printed reports, computer files, etc.) for the inspection.

The automated inspection system (AIS) overcomes each of these shortcomings, but fails to duplicate the one capability which makes the comparator so powerful and easy to use—its ability to show at a glance if the complete part is within tolerance limits (contact probe systems fail this test as well). These systems can measure and report on individual part features (holes, slots, edges, etc.), but tell nothing about the acceptability of the complete part.



(Above) Fig. 1 — A part profile shown with an ICAMP template. 4500+ points were collected on this part, and each point is shown as a colored "whisker"; green (low) and yellow (high) whiskers show deviations from nominal. When whiskers turn to red, a user-set scale has been exceeded; the total length of each whisker is a multiple of the green/yellow segment. The scale can be set to the design tolerance for the part, so if red appears, the part fails. In this picture, the hole at the upper left was punched with an oversized tool. The hole at the bottom is oval-shaped (not circular) and shifted down and to the left. In both cases, the rays are in the red zone. The upper right section of the part does not match the model. Is it the wrong model or the wrong part?



(Left) Fig. 2 — A solid model of a shaft with data taken at four depths.

Measuring Perfect Features . . . Every Time

The problem is this: When measuring prismatic features (lines, arcs, circles, cylinders, cones, planes, etc.), automated inspection systems gather data on *real* features (geometry), but report on approximate or *substitute* geometry. If you remember your high school geometry and trigonometry, you know that the measurements (diameter, etc.) and computations (angle between

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two lines, etc.) you learned in those courses implicitly depend on *perfect* geometry—but no one ever made a perfect part to be measured.

And therein lies another problem.

When measuring prismatic features, the user first tells the inspection software what type of feature is being measured. Then he or she gathers data, and the software "constructs" the perfect (substitute) feature which most closely approximates the real feature in terms of dimensions and orientation. The software then compares the substitute feature to the ideal (nominal) feature and reports any differences between the two perfect features.

The inspection machine software measures perfect substitute features (or substitute geometry), **not** the real part, or even the real feature. If the actual feature is very close to the intended design, this approximation may provide acceptable measurements, but if the actual feature differs widely, then misleading results can be reported.

Once a substitute feature measurement (circle diameter, etc.) has been computed, the discrete point values that were collected on the real part are thrown away because there is no further use for them in the inspection system.

Measuring, Sort Of, Against ASME Y14.5M-1994, The GD&T Standard

Most automated inspection systems generate at least some measurements that do **not** conform to ASME Y14.5M-1994, "Geometrical Dimensioning and Tolerancing Standard," and its predecessors. For years, users, if they thought about it at all, assumed that their inspection equipment complied with the measurement definitions in Y14.5M.

In August, 1988, a GIDEP (Government-Industry Data Exchange Program) Alert Message disclosed that large numbers of automated inspection systems were failing good parts and passing bad parts when the dimensioning and tolerancing standard was used as the measurement criterion. Hard gage advocates could say, "We told you so!"

Should You Worry?

So long as you are comfortable with the knowledge that:

1) Automated inspection systems measure *features, not parts*;

2) The features that are measured are *not* even the real features;

3) The reported feature measurements are not based on the Y14.5M; then you may not need to worry about how inspection data is being used in your company or in your customer's in-coming inspection areas. Bear in mind that virtually all inspection systems, with one or two very high-end exceptions, share these three characteristics.

If you are not comfortable with this situation, you will want to rethink your inspection functions, processes and architecture.

AIS Architecture

Let's look at the architecture of an automated inspection system. For our purposes, we can think of these systems as having three components:

a) A motion control subsystem that moves the sensor around the part,

b) A data acquisition subsystem that registers point readings from the part surfaces,

c) A software subsystem which computes the measurements, performs the analysis and creates the reports that users see.

The three problems that we have highlighted all fall under (c).

Motion control (a) and data acquisition (b) are so closely intertwined that they must share the same software operating platform, but discrete point values are passed from (b) to (c) for processing, and the measurement and reporting software can actually reside on a separate computer and even be at a distance from the inspection system. If the discrete data points can be transferred to another computer

ALGORITHM TESTING & EVALUATION PROGRAM FOR COORDINATE MEASURING SYSTEMS (ATEP-CMS)

The National Institute of Standards and Technology (NIST) has established the ATEP-CMS Special Test Service to evaluate the performance of data analysis software embedded in coordinate measuring systems.

To do this, ATEP-CMS compares the output of the customer's software under test to predetermined corresponding reference values; the comparisons currently use orthogonal-distance, least-squares algorithms and support features such as circle, line, plane, sphere, cylinder, cone and taurus.

ATEP-CMS personnel work with customers to define the general guidelines for testing. NIST then provides to them a set of test data based on the guidelines. Then customers produce fit results for the data sets from their analysis software and sends them to NIST. ATEP-CMS processes the same data through reference alogorithms and compares the two sets of results and provides a comparison report to the customer.

The performance measures developed by ATEP-CMS quantify how well the software under test computes "substitute geometry" (see main article) over a range of inspection problems.

ATEP-CMS asserts that "there are no standards for testing and assessing the performance of dimensional metrology software" (NISTIR 5651), and this program is the first in the U.S. which provides traceability of data analysis results to an internationally recognized calibration body.

ATEP-CMS is addressing a portion of the problem described in the main body of this article; that is, it recognizes that CMMs measure perfect (single feature) substitute geometry, and their tests will determine how well the CMM software performs that role and helps the CMM user to understands what analysis algorithms are being used in the CMM. It is a first step in providing insight into analysis software behaviors and accuracy when compared to applicable standards.

Technical contacts at ATEP-CMS are Cathleen Diaz Pluguez at 301-975-2889 and Craig Shakarji at 301-975-3545.

MIMETEK is developing a complimentary rapid response system, 2nd Opinion™, for online periodic performance verification after the user, working with ATEP-CMS, understands algorithm behavior and output. For more information on MIMETEK's 2nd Opinion™, call 860-643-1711 or visit their Web site at *www.mimetek.com*.

as they are taken, then third-party software can be used for measurement, analysis and reporting. This means that the AIS becomes an automated data acquisition system, and users can evaluate and analyze data *independently* of the vendor's software.

Moving Data Analysis Off the AIS

Of course, this is never as easy as it sounds. Not every vendor wants to lose control of the analysis, measurement and reporting of the status of the measured part, nor will he make it easy to extract point measurements from his systems. It may require sustained customer pressure to persuade vendors to add or reveal the procedures to support data transfer.

All inspection systems (touch trigger probe, electrostatic probe, laser, video), somewhere deep down inside, are acquiring point readings and using them in computations, and the software on the AIS can be modified to output those values.

Individual data points can be written to a file on the AIS hard disk or on a floppy disk, or individual points can be sent as they are taken through a serial port to another computer. While data files are most easily transferred and translated when in ASCII format, a variety of formats are supported.

Once We Have The Data, What Do We Do With It?

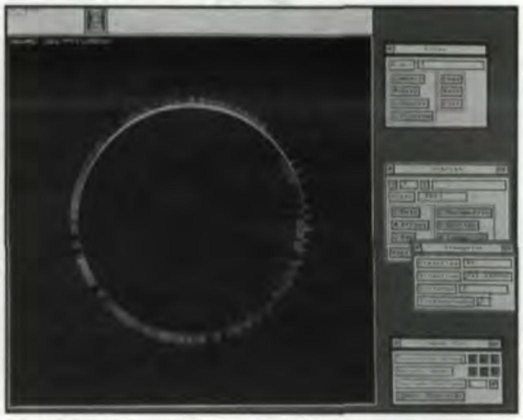
We started this article with the question, "Wouldn't it be nice if an automated inspection system could behave like an optical comparator?" Thanks to several inspection vendors who are adding more measurement and evaluation tools to their product lines, we are arriving at that point.

While their part programming software is more widely used, the following companies offer some analysis: Automation Software (PC-DMIS); Origin; and Technomatix (ROBCAD and Valisys). At least two inspection companies, Carl Zeiss and Leitz (Brown & Sharpe) have developed their own analytical capabilities for prismatic parts.

Ely Software for 2-D (through Metronics and OGP) offers dedicated contour software; Mitutoyo is reported ready to introduce a dedicated contour package; and ICAMP (2-D and 3-D) provides 3-D profile analysis such as Sheffield's DirectAnalysis and supports video systems such as Micro-Vu RAM Optical and View Engineering with its 2-D TEMPLATE analysis. ICAMP also supports "independent distributed analysis" with articulated arm digitizers from Faro and Romer, contract probe systems from Mitutoyo and Sheffield, laser and video systems and any device which can output point readings in ASCII format.

Benefits

There are some very real benefits which flow from the use of independent analysis software.



(Left) Fig. 3 — Looking down the long axis of the shaft, the data at the four levels is shown in one plane, and the deviations show that the shaft is tilted relative to its Z axis. Yellow whiskers turning to red (lower left) indicate that the shaft is larger than nominal on one side; on the opposite side of the shaft, (right in photo) blue whiskers indicate that the shaft is smaller than nominal at one depth, and yellow whiskers indicate that the shaft is larger than nominal at another height. This configuration is sometimes called the "banana" shape.

1) It can be performed anywhere—on the shop floor, at your desk or at your customer's facilities.

2) Moving analysis off-machine frees the inspection system to measure more parts faster.

3) Part programming can be reduced as more emphasis is placed on the part rather than on the feature measurement and analysis.

4) Single features, multiple features and/or the entire part can be simultaneously evaluated.

5) The actual features, not substitute features, can be measured and evaluated.

6) Measurements based on Y14.5M-1994, the GD&T standard, can be processed correctly.

7) Independent software can be easily verified by NIST and other certification agencies.

8) Independent, stand-alone analysis can work with machine tool probes as well as CMMs.

9) Finally, the inspection vendors, all relatively small operations compared to their customers, will be able to concentrate their software development efforts on better positioning accuracy, resolution and data acquisition rather than on measurement and analysis.

For several years, inspection departments have successfully pushed for the development of off-line inspection programming tools. Now, as the customers (the rest of the corporation) better understand what inspection equipment can and cannot do, we expect to see increasing demand for independent measurement and analysis performed remotely from the inspection station.

This will lead to AISs being used as data acquisition devices which are linked through networks to design and manufacturing engineering workstations and manufacturing planning systems where sophisticated, but simpler profile analysis can be used to evaluate both part and process condition. This, in turn, will lead to simpler, cheaper, modular general purpose inspection devices and standardized analysis software and reporting formats. We will see more accurate, better understood measurements and, in turn, this will lead to better controlled processes and products.

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