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Real-World Application of Scanning and Discreet Probing of Large Components Using an Integrated System of a Structured Light Scanner and a Portable CMM.

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Abstract

Wyman Gordon is a major supplier of forgings to both military and commercial aerospace manufacturers. The need to generate critical high-accuracy measurement data in a hostile forging environment presents unique challenges. These challenges include the need to measure large components (up to 23 ft long), hot dies, a need for both discreet point probing as well as high-density point cloud acquisition, all in a setting where thermal extremes and particulate contamination are virtually guaranteed. In addition, there is a frequent need to reverse-engineer patterns and tooling that may be up to 50 years old.

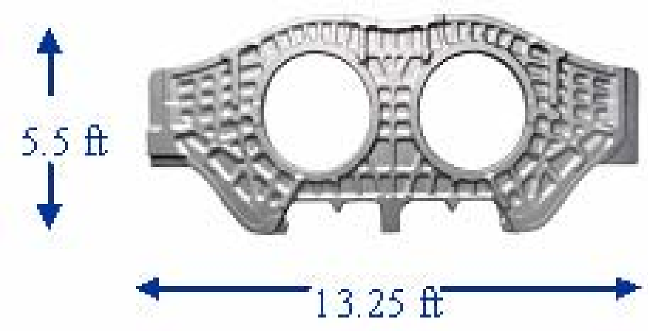
Wyman Gordon is using a unique measuring solution consisting of a Breuckmann structured light scanner navigated by a Metronor DUO electro-optical large volume coordinate measurement system. The combined system is portable, and allows for both discreet point measurement deep into hidden areas, as well as fast, high-accuracy scans of large surfaces. Various measurement tasks at WG's North Grafton plant will be presented. These include scanning of hot dies after weld-up to determine adequate material for repair, combined single-point and scanned component applications, as well as discrepant part inspection, first-article inspection, and reverse-engineering of very old tooling.

Background

This real world application of scanning and discreet probing is centered on the needs and products of the Wyman Gordon Co's, North Grafton MA facility.

Wyman-Gordon is a 118 year old forged products manufacturer and a major player in a multitude of markets. W-G is among the leading manufacturers of forged components for the aerospace and power generation markets. They manufacture forged components from sophisticated titanium and nickel-based alloys for jet engines, including fan discs, compressor discs, turbine discs, seals, spacers, shafts, hubs and cases. Wyman-Gordon airframe structural components are used on both commercial and military aircraft and include landing gear, beams, bulkheads, wing structures, engine mounts, struts, tail flaps and housings. These parts are made of titanium, steel and other alloys. W-G also provides forged products for use in power plants worldwide, as well as in oil and gas industry applications. These products include discs, spacers and valve components for land-based steam and gas turbine engines, as well as shafts, cases, and compressor and turbine discs for marine gas engines. For naval defense applications, Wyman-Gordon supplies forged components for propulsion systems on nuclear submarines and aircraft carriers, as well as forgings for pumps, valves and structural applications.

An example of one of Wyman-Gordon's forged products made in the Grafton facility and the end use finished product that the forging goes into:



Mid-Section F-22 Fuselage Bulkhead Forging (6,560 lbs. Titanium)

F-22 Raptor -Stealth Air Superiority Fighter
Wyman-Gordon makes 48 different structural parts for F-22. The raw stock input weight of these parts totals 625,000 lbs of Titanium and 17,000 lbs of Steel for each fighter.

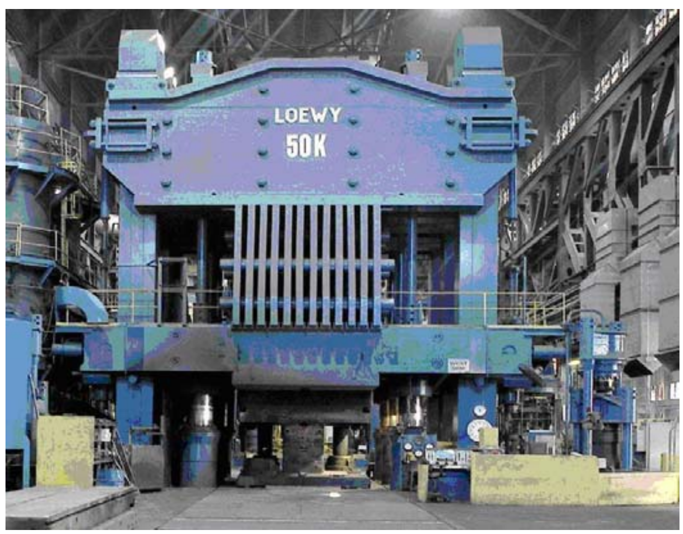
Process Description, Unique Needs

The forging processes that are performed at the Grafton facility to produce this broad range of components include:

Open-Die Forging - In this process, the metal is pressed between dies that never completely surround the metal, thus allowing it to be observed during the process. This manufacturing method is used to create relatively simple, preliminary shapes to be processed further by closed-die forging.

Closed-Die Forging - Closed-die forging involves pressing heated metal into shapes and sizes determined by machined impressions in specially prepared dies that completely surround the metal. This process allows the metal to flow more easily within the die cavity and thus produces forgings with superior surface finish and tighter tolerances, with enhanced repeatability of the part shape.

Conventional Closed-Die / Multi-Ram -The closed-die, multi-ram process, which is employed on the 35,000 ton press, enables WG to produce complex forgings with multiple cavities such as valve bodies, in a single heating and pressing cycle.



Wyman-Gordon 50,000 Ton Forge Press

Wyman-Gordon is an extremely active job shop due to the wide range of customer requirements and processes in operation. Adding to the difficulties of this mix is an extremely hostile forge shop environment where forging, grinding, blasting, welding and machining operations virtually guarantee that high levels of dust, soot, fluids and thermal extremes are prevalent.

Being a 118 year old company, many processes are still done with old "tried and true" methods, including layout and inspection of forged product. In many cases established procedures call for a manual layout and verification of forged product. For example, customer requirements call for a "first article" inspection of one part of the first run of new or modified product. This entails a complete dimensional verification of every shape characteristic of the entire forging. Done with a manual inspection method, this single inspection can take weeks on a large part, plus require a very qualified and skilled inspector.

Further, as CAD design and manufacturing has made great strides in the key markets in which WG is competing, customers are specifying CAD model forge shapes, not drawings, as the contractual definition of the desired forged part. This makes manual inspection an almost impossible task.

Recognizing this trend a number of years ago, WG investigated turning to computer aided inspection devices. Their fixed base traditional CMM was not a good fit for this type of forged product as every part is an individual entity due to the typical variations in the overall forge process. Therefore a portable CMM with operator involvement was seen as a good fit for the desired results. At this time Wyman-Gordon chose the capabilities of the Metronor Portable CMM.

Recently, Wyman-Gordon was faced with mounting customer demand for increasingly detailed and accurate shape verification of forged parts. While the Metronor Portable CMM could provide this data, it was again becoming a longer process than desired because of the limitations of discrete single point data collection. Plus WG had identified a number of internal needs where better shape definition, properly timed within the production process, would yield significant cost savings.

Based on these needs and desired results, Wyman-Gordon again looked for a computer aided inspection method that would produce more dense, detailed and accurate shape measurement. Scanned point cloud data was the obvious solution.

Less obvious were the obstacles for the use of most of the currently available scanning devices in the Wyman-Gordon shop. First was the general shop environment. With the typical dirt and oil atmosphere combined with large shop floor temperature variations most scanners would not have a long service life on the shop floor.

Next was the issue of needing extreme portability of the scanning system within the shop. The Grafton plant is a very large facility and it was envisioned that the scanner would be utilized in numerous areas of the shop, such as the die shop, machine shop, and several inspection areas. Therefore the system must be easily transportable and quick to set up for use.

The size of the objects to be scanned was the next requirement to be met. One of the larger forgings that Wyman-Gordon produces is the 747 Gear Beam Forging, which is over 22 feet in length and about four feet wide at its widest point. Accuracy must be maintained over this entire part for inspection on both sides of the forging. Typical scanning devices would need a number of setups to reach this scope of size. Each scanned area must properly relate to every other scanned area to produce an overall "picture" of the forging, accurate to within +/- 0.010" across the entire part.

Die scanning was another of the requirements of the system, which poses a special constraint on any scanning system. Many forge dies have narrow, deep impressions with steep side walls that need to be measured or characterized accurately. While almost any scanning system would be able to capture the shapes at the tops of these areas, few would be able to see the bottom of the narrow rail impressions. The side walls of these areas become almost impossible to capture.

Highly varied surface conditions were another constraint. Scanned forging surfaces range from dull, matte, slightly rusty steel to shiny ground and chemically milled titanium. Die surfaces can range from shiny machined or ground steel, to dark black almost mirrored surfaces. These surfaces all must be scanned with an absolute minium of surface preparation.

Lastly, as part of Wyman-Gordon's internally recognized needs, the system needed to be able to scan hot die welded surfaces. Major cost saving would result from the ability to scan a forge die in its hot, just welded state, in order to determine two critical factors. First, to determine if sufficient weld is in place to be able to machine the final die shape out of the welded die. This prevents the possibility of having a die welded, heat treated, and machined only to determine that there are areas that did not receive enough weld material. Second, the scan data provides the die machining programmer with a "stock model" of exactly how much excess weld material there is to be removed. This enables much more efficient machine programs that eliminate large areas of "air machining" just to avoid tool crashes.

NaviSCAN3D

With these considerations in mind, Wyman Gordon purchased a NaviSCAN3D system consisting of a Breuckmann StereoSCAN3D scanner which has the ability to be 'navigated' by the Metronor DUO systems already in operation at the plant. The NaviSCAN3D measurement system satisfies all the criteria for portability, functionality, accuracy and durability.

NaviSCAN3D System showing Metronor DUO cameras and Breuckmann StereoSCAN3D fitted with NaviTarget

Description

The NaviSCAN3D scanning system is comprised of a standard Breuckmann StereoSCAN3D scanner fitted with a dimensionally stable structure holding LEDs (NaviTarget) that are measured by the Metronor DUO cameras. With LED measurements, the DUO system is able to calculate the scanner's 6DOF position and orientation in a machine coordinate system or in a local alignment. The NaviTarget is a 3D framework of aluminum spheres connected with carbon fiber rods. Geometrical stability is guaranteed with the triangular geometry of the structure and the precision of the assembly. The LEDs are embedded in the spheres, and are distributed such that the NaviTarget can be observed in all orientations and positions within the Field Of View of the DUO cameras.

NaviTarget and close-up of LEDs inserted in spheres

The NaviTarget is attached to the Breuckmann StereoSCAN3D scanner's main structure through a clip-on mechanism. The clip-on is a 3-2-1 defined (non-constrained) arrangement, ensuring maximum attachment repeatability. The scanner can be used in stand-alone mode without the target (no navigation). If navigation is needed, as in the case of measuring large objects, the NaviTarget is easily mounted using the clip-on mechanism. Due to the mechanical strength of the NaviTarget, the structure itself may be used as a handle for moving or carrying the scanner.

In order to produce high accuracy data, the coordinate system of the NaviTarget must be mathematically aligned to the coordinate system of the scanner. The basic alignment principle is to measure 3D positions of several common geometrical features using the Metronor Light pen and the scanner, and based on the readings from both systems, calculate the transformation matrices between the two. The 6DOF position and orientation of the NaviTarget is calculated using photogrammetry bundle adjustment. All observed LEDs, both those common for the two DUO cameras and also those that are visible from only one camera, are used in the calculation. Bundle adjustment is ideally suited to deal with this measurement task, as it will give the theoretically optimal result. Bundle adjustment is also able to handle the necessary mathematical constraints defining this adjustment task in a straightforward manner. This alignment can be accomplished in a few minutes.

Given the extreme stability of the NaviTarget and the rigidity of its attachement to the Breuckmann StereoSCAN3D scanner, this alignment of the NaviTarget to the scanner only needs to be performed when something in the relationship between the two has changed. For example when the lenses are changed in the scanner for a different FOV or the NaviTarget / scanner pair has been improperly handled. This allows the system to be aligned on a periodic basis in the climate controlled environment of the WG CMM room for maximum accuracy, and then moved about the shop to various measurement tasks.

Measurement Operations

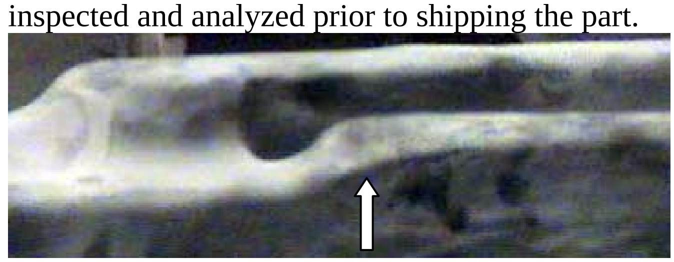
Using the NaviSCAN3D in the shop is a simple matter of rolling the system out to the area of the shop where the object is to be scanned, then setting up the Metronor DUO system as it would normally be used for single point measurement. At this point the light pen can be used to establish the object coordinate axis system, or scanning can commence without an axis system in place. Wyman Gordon will use the system in both scenarios depending on the task at hand. Most jobs will have an axis system, so we will go through two distinct types of measurement jobs as an example.

Part Scanning Example:

The first example is that of scanning a discrepant part to determine the depth of a "non-filled" area.

Part to be scanned

This area of non-fill may jeopardize the ability of the customer to produce a usable machined part from the forging, so it is imperative that this be inspected and analyzed prior to shipping the part.

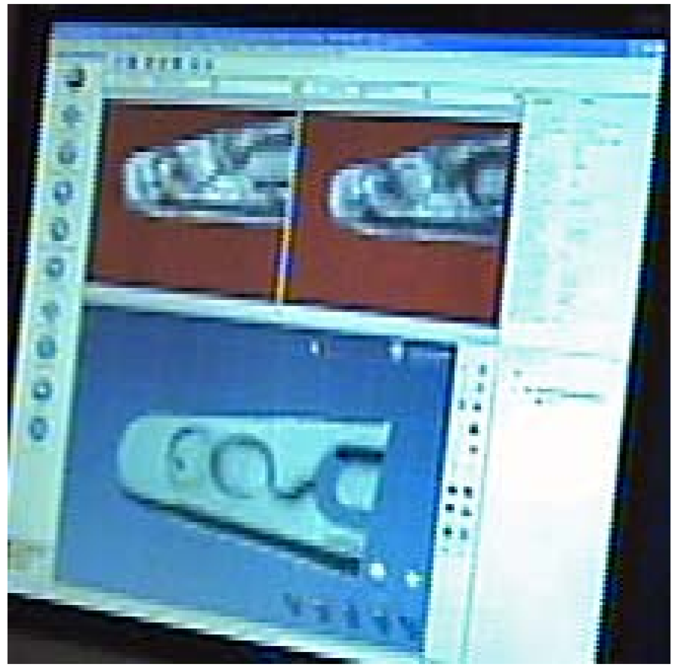


Close up of Non-fill Area

In the past this evaluation would be done with the Metronor system using single point probing by a skilled operator. Numerous points on the forging are needed to be characterized to determine if the non-fill jeopardizes the machined part, and the operator would need to decide if there were any adjustments needed to the axis system to minimize any impact on the machined part. This can be a lengthy trial and error process.

With the NaviSCAN3D system the part is set on a stable base and the normal Metronor single point probing procedure is used to establish the axis system of the part. This is a tooling point set-up job, so a discrete measurement point is taken at each tooling point location to establish the part axis system. Scanning can then begin. The scanner is brought into range on the part and the first of a series of scans are taken.

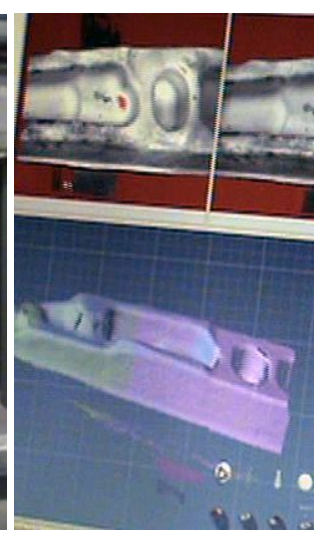
First scan



The resultant dense point cloud is displayed on screen

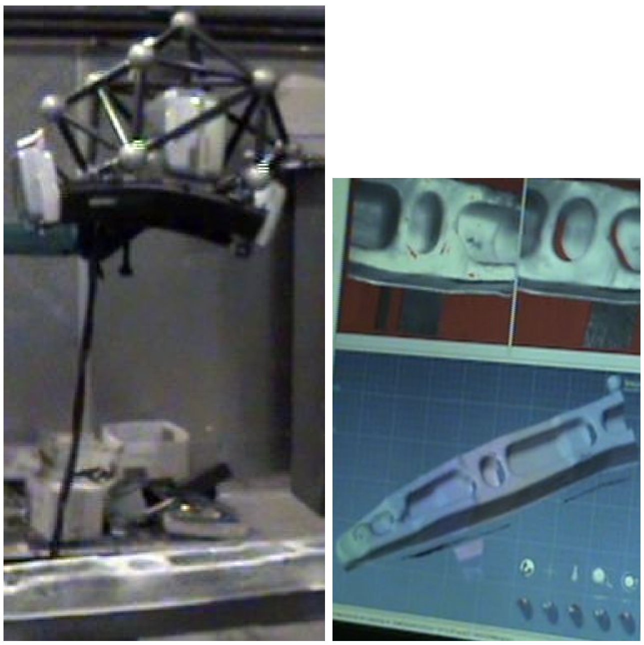
The scanner is then moved to the next location for a slightly overlapping scan. Positional movement is aided by a pair of laser triangulation pointers built into the system that gives standoff focus distance. A "light box" is projected from the scanner that shows both on the part, and on screen, where the next scan will take place.

The next scan is taken and the system tracks in 6 DOF where this has taken place and ties it into the coordinate system automatically.



2nd scan and screen shot

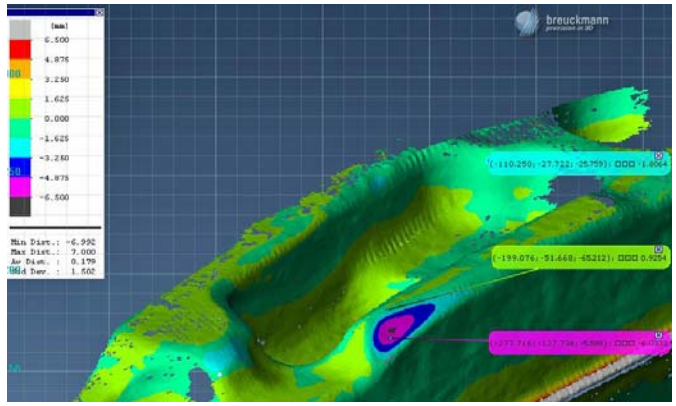
This sequence continues down the part until enough area has been covered to characterize the discrepant area and this side of the part. The scanner is then moved to the other side of the part to capture the features that were blocked by the physical part geometry itself.



Scanning on back side of part and screen capture

Another series of scans is completed down this far side of the part to complete the part shape scan.

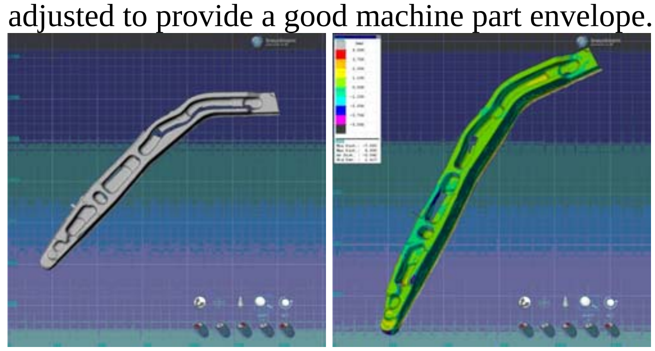
Evaluation of the non-fill is now possible by a simple comparison to the CAD Model "perfect shape" and can be output as a color coded deviation map or sampled for individual non filled depth, thereby easily determining if the part is qualified as a shippable part.



Scan data comparison to CAD showing extent of non-fill depth – with specific point location deviations highlighted

This entire process took less than 6 minutes to complete.

If it is determined at this point that the machine part is in jeopardy, the scanning can be extended seamlessly from where it was stopped, due to the 6 DOF capabilities of the system. The rest of the part could then be scanned top and bottom within a few more minutes and third party software used to "Best-Fit" the machine part within the forged part envelope. The forged part axis system would be adjusted to provide a good machine part envelope.



Full part scan data with CAD comparison shown

A similar process is followed for a complete first article inspection. In addition the same process flow is used to reverse engineer an old part that had no CAD model.

Hot Die Scanning Example:

As mentioned, significant savings could be captured at Wyman-Gordon if newly welded dies could be scanned prior to cool down – heat treatment - and machining to verify that the welded envelope was large enough to yield the final machined die shape. Also minimized machine time would be realized if the exact "stock shape" of the welded die could be used by the die machine programmer in order to eliminate "cutting air" to insure no tool crashes during the die sinking machine process.

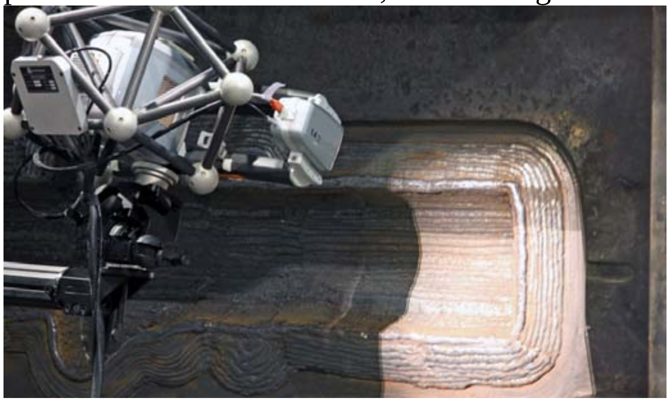
This next example is of the scanning of a large forge die, just after weld, while the die is still at a welding temperature of approximately 450ºF.

450ºF Welded Die ready for scanning – Note red dot laser focusing pointers in front of scanner at edge of the weld.

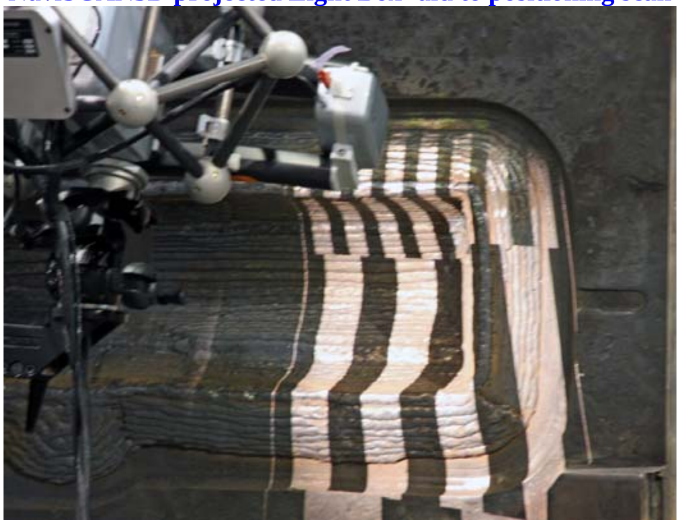
Again the process is started by determining the die axis system. Here the major datum is the flat surface of the die, and the other two axes are located with scribed lines and punch marks located on the face of the die. The Metronor system Light pen is used to take a number of discrete points on the flat die face to locate that axis in space. Then a pointed tip is placed in the Light pen to pick up the punch marks that locate the other axis locations. With the axis system established, scan data can now be taken.

View of the NaviSCAN3D system, with curious onlookers Metronor DUO cameras are in upper left and right of photo & the scanner is behind the cart in front of the die.

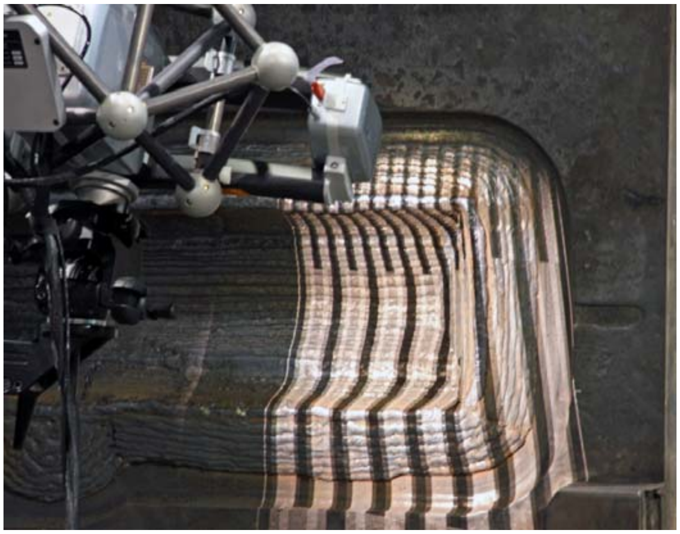
The scanner is simply moved in position in front of the die, focused and positioned using the laser pointers and projected "light box". A scan is taken of the area, then the scanner is moved and angled as needed into the next position for the another scan shot. Again the Metronor NaviTarget tracks the scanner with full 6DOF and enables the NaviSCAN3D system to build a complete scan profile of the welded die face, without targets.



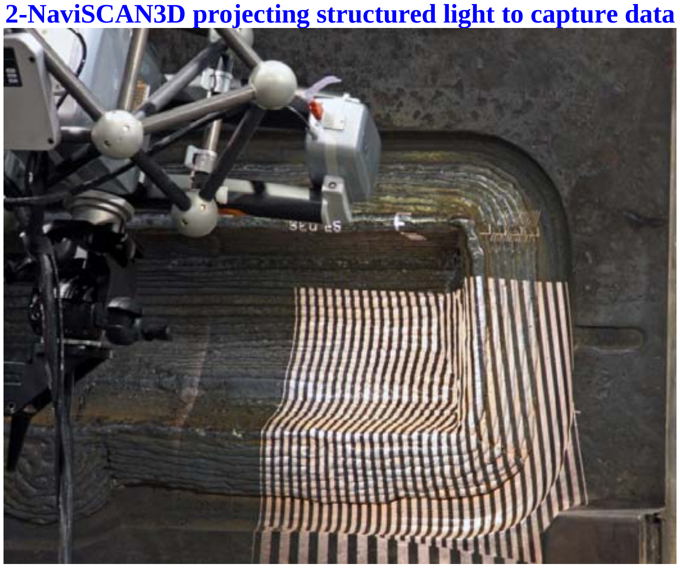
NaviSCAN3D projected Light Box- aid to positioning scan



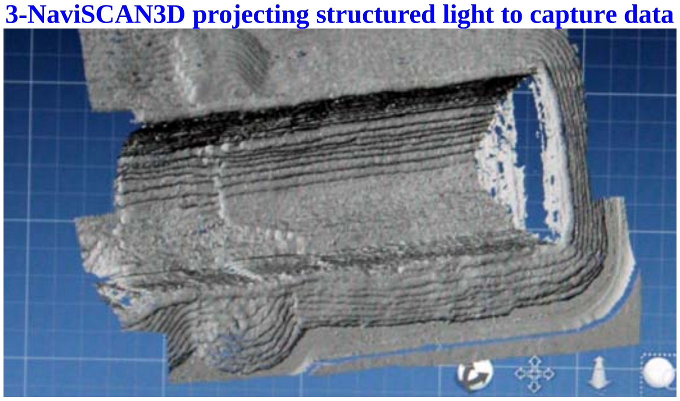
1-NaviSCAN3D projecting structured light to capture data



2-NaviSCAN3D projecting structured light to capture data



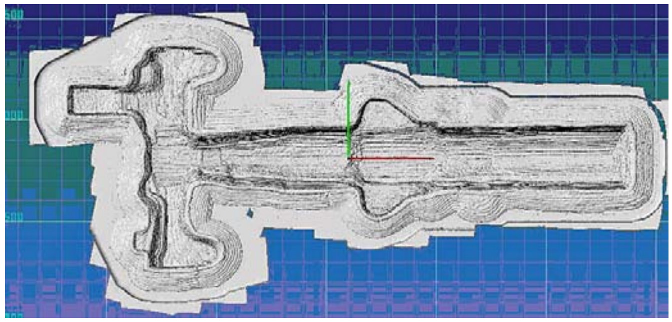
3-NaviSCAN3D projecting structured light to capture data



Scan data point cloud from above capture (+ next location)

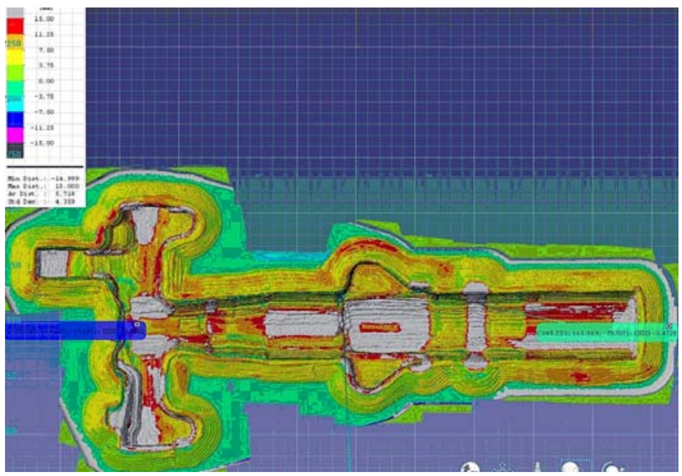
Deep or narrow die features can be captured using the ability of the StereoSCAN3D scanner to use a single camera at a 20 or 10 degree incident angle.

Or, if the feature is too deep or narrow for that approach, the Metronor Light pen can be used to seamlessly add discrete single points to the scan data file.

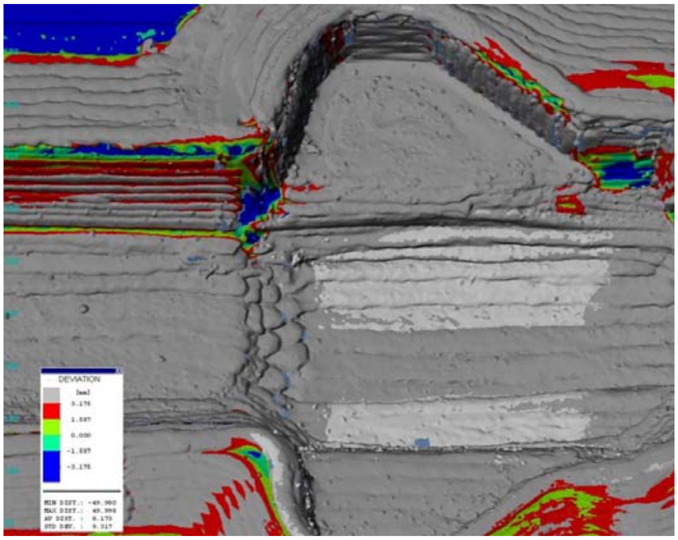


Point cloud of completed die scan

The completed scan profile is now compared to the CAD shape of the desired die machined shape. The system compensates for the difference in measured data due to the elevated die temperature. Any areas lacking in weld stock are shown in blue or magenta. Any areas of substantially 'plus' weld material are shown in red or grey as an indication of an area that may need a special machine pass to remove excess weld material before starting normal die shape machining.



Point Cloud comparison to CAD showing excess and missing material conditions



Close up of areas that have missing weld material conditions – Blue - thereby jeopardizing the final die machine shape. Light green, red and grey areas have ample weld material for the final die shape.

Because it was determined that there were areas of missing weld stock and the die is still at weld temperature, the die can be immediately returned to the welder to fill in these areas. Once welding is completed a quick setup and scan of the known problem areas allows the die re-machining process to continue with full confidence that the machined die shape is available. Plus, the die machine programmer can avoid time-wasting air cuts, as the scan data gives him exact weld stock shape.

This same process flow is utilized to reverse engineer an old die shape or to establish a database of die wear on critical shapes after each forge run.

Summary

The need to generate high-accuracy measurement data in a hostile forging environment presents unique challenges. These challenges include the need to measure large components, hot dies, a need for both discreet point probing as well as high-density point cloud acquisition. Process limitations require measurements in different locations throughout the plant where thermal extremes and particulate contamination are prevalent.

Wyman Gordon's choice of the NaviSCAN3D scanning system satisfies these requirements. The combined system is portable, and allows for both discreet point measurement as well as fast, high-accuracy scans of large surfaces. The measurement of a discrepant part as well as hot welded dies was performed on the plant floor, with no adverse effects due to environment or part size.