PRACTICAL INTEGRATION OF VISION METROLOGY AND CAD IN SHIPBUILDING

George W. Johnson, Quality Engineer, Bath Iron Works Corporation
700 Washington Street, Bath, Maine-USA
email: gwjohns@biw.com phone (207) 442-2083

Invited Paper, Commission V, Working Group V/3

KEY WORDS: CCD Sensor, Digital, Close-Range, Measurement, CAD, Visualization

ABSTRACT:

Photogrammetry, the science of obtaining precise coordinate measurements from images, has until recently been dominated by the use of photographs taken with specially designed, film based cameras. With the development of high resolution solid state video imaging sensors, the era of digital photogrammetry has arrived. Digital based systems provide far faster results and greater flexibility than their film based counterparts, which has led to more widespread use of photogrammetry in the shipbuilding industry. This paper will provide a brief introduction on Bath Iron Works Corporation (BIW) emergence into the Digital Close-Range Photogrammetry (DCRP) field, then present measurement techniques for applications representing different stages of construction within the ship yard; located in Bath, Maine. Implementation of vision metrology stresses the linking of shop floor measurements with Engineering's Computer Aided Design (CAD) design and graphic visualization functionality to compliment the use of 'traditional' Surveyors optical tooling equipment (theodolites, transits, optical micrometers, right angle prisms/optical squares, etc..). All savings and benefits provided are from real services being performed in production. Long term expectations are summarized by noting plans to apply Total Quality Management (TQM) principles and/or Statistical Process Control (SPC) techniques to achieve strategic improvement goals.

1. INTRODUCTION

1.1 Background

The Shipbuilding Industry has many diverse measurement applications all performed under a wide range of operating conditions. Traditionally theodolites and optical micrometers have been the standard tools. This equipment is accurate and reliable, but one dimensional. Over the last ten years the emergence of three dimensional measurement systems is having a significant impact on the way ships are manufactured. One of the most promising technologies is Photogrammetry (Fraser and Brown 1986) which offers stereo and convergent techniques. Both enable the user to economically measure large numbers of points in an off line manner.

1.2 Digital Emergence in Shipbuilding

In 1992 BIW assembled a highly skilled and diverse group of employees, representing the various divisions of the company, and initiated a Continuous Process Improvement (CPI) project to determine the "Cost effectiveness and feasibility of utilizing photogrammetry for shipyard processes requiring precision measurement" (Johnson 1993). The following year brought about extensive testing of many different types of existing measurement systems (photogrammetry, laser based theodolites, and light pen technology). At the same time research and development of using charged coupling device (CCD) cameras instead of the existing film based types was being pursued in a cooperation with Prof. Armin Gruen and researchers at the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland. The results (Maas and Kersten 1994) proved beyond a doubt that measurement accuracies from the KODAK DCS200mi camera and off the shelf components were well within tolerances required in the shipbuilding industry for a wide range of applications. In 1994 an ongoing dialogue with Geodetic Services Inc. resulted in the acceptance and subsequent implementation of the first Digital Photogrammetry Measurement System (DPMS) in shipbuilding. This event changed the way BIW approaches Dimensional Control for many reasons but two stand above the rest. First and foremost is the technological ability to measure rigid bodies quicker, more accurately, and with less impact to surrounding workers than ever before. Secondly is the versatility of the software in handling data.

1.3 Direct Benefits

The significant benefits derived from these features has proven to be both economical and social in nature. Simply stated one can typically obtain three dimensional data (versus one dimensional) in about one half the time for selected jobs requiring thirty or more points to be measured. Savings are maximized when the number of points to be measured is increased. At BIW this is readily being achieved by refocusing and combining many of the Quality Inspection and production service checks. Socially (yet still very positively linked to the economy) is the improvements in shop floor productivity through enhanced visualization of measurement results utilizing CAD. The old adage "one picture is worth a thousand words" is quite applicable here. Another reason is the pride associated with using the first Digital Measurement System and experiencing a true 'change of pace' from years of traditional optical tooling practice. Safety, which is of high social and economic importance, has also been improved. In one and a half years of implementation there has yet to be an on the job injury. And finally the integration of Data Management software (SAS) with the final coordinate outputs of measurements from the shop floor will enabled the shipyard to utilize data for SPC analysis that in the past has been neglected due to the high costs of manual input. This is a very economical effort because the data output is a standard ascii delimited text file it is easily imported and shared between softwares. It is very satisfying to see measurement data be used for multiple purposes. Not only is data used for production service; but for process control and capability determination then monitoring as indicators of quality levels in the quest for continuous improvement.

2. VISION METROLOGY AND CAD

2.1 Structural Design

Traditional uses of CAD in shipbuilding is typically focused on extracting data in .dxf format from design plate and/or shape files to create drawings for visualization and dimensioning purposes.. Once these drawings are created and distributed to the various shipyard manufacturing areas they are used for many purposes from planning through ship's completion and delivery. During a ship's life cycle many construction measurements are taken and constantly being compared to paper copies of these design drawings manually ... one at a time. However; for BIW personnel, much more is being done. Due to the versatility of the digital measurement software in its handling of data outputs as delimited ascii text, CAD software (AUTOCAD, etc..) being used extensively as a graphical interface to import actual measurements directly into a drawing. Customized programming routines easily orient, layer, and even color code points in seconds that are routinely shared across networking platforms. There is an unprecedented link evolving between the many shipyard disciplines. Increased three dimensional mea-surement capabilities has resulted in Structural Design, Accuracy Control, and Manufacturing, areas requesting more Surveyor measurements be performed and analyzed.

2.2 Measurement Enhancement

In addition to improving the interpretation and visualization of actual ships data CAD is used more and more to enhance the measurement process itself. The benefits are realized in planning stages where these very same design drawings are used by the Surveyors for initial target placement. Customized programs enable the operator to affix alpha-numeric tags appropriately sequenced and located for the extraction of XYZ coordinates. serving three basic purposes. The first is to instill a systematic approach to labeling and targeting each application. The ensuing consistency minimizes wasted time and effort. Secondly the extracted design data can be imported into the measurement software to increase automation of image measurement. By knowing the approximate coordinates of each target the software can automatically drive to each point prior to bundle adjustment calculations. This reduces time setting up the initial image measurement and assists in target recognition in places where obstructions are of concern. Thirdly the extracted design XYZ coordinates form the basis for comparisons to the as-built conditions. For similar products or repetitive in-process checks this forms the basis for SPC techniques to be developed and applied for process control and capability monitoring .

2.3 Shop Floor Results

The bottom line to the shop floor mechanic is that they are receiving three dimensional data in less than half the time of past measurements. They now have the ability to view pictures, graphs, and drawings of products as well as processes. The effectiveness of enhanced visualization techniques and communication of results cannot be over emphasized. For many three dimensional measurement systems the job begins with a request for data and ends with the delivery of a measurement file from the Surveyor to the shop floor mechanic. Today this is only a small portion of the process. Measurement results now are left on-line for access by almost any one. Depending on ones point of view some would say this cooperation and growth is a small scale example of Concurrent Engineering at its finestThe support received for improved measurement capabilities (upper managements commitment to implementation of Digital Photogrammetry) is one of many initiatives at BIW aimed at supporting and sustaining a truly empowered, high per-formance work organization.

2.4 Summary

The future promises to be exciting for BIW as this overall effort becomes refined and focused. More applications will be found while new equipment and technologies are developed then brought on-line. For this paper; though, we will stay with the present and go on to discuss individual applications depicting the benefits of DCRP in shipbuilding. Examples of data visualization and analysis techniques (CAD & SAS) employed within the measurement process will be provided. The first application, Unit Erection, will be covered in depth to build a basic understanding of equipment usage and benefits. The remaining applications will offered more for diversity; being representative samples of jobs throughout the construction process.

3. CURRENT SHIPBUILDING APPLICATIONS

3.1 Unit Erection

With the acceptance of modularized construction in shipbuilding a common practice is to build interfacing steel edges with excess material on one end to be trimmed during the erection process. Initial manufacturing practices positioned the module in the ship's plane, at an approximate location on the ship, and traced the existing ship's shape on the erected unit so that when the excess steel was burned off the unit should fit into its proper place. Significant gains in productivity were realized by

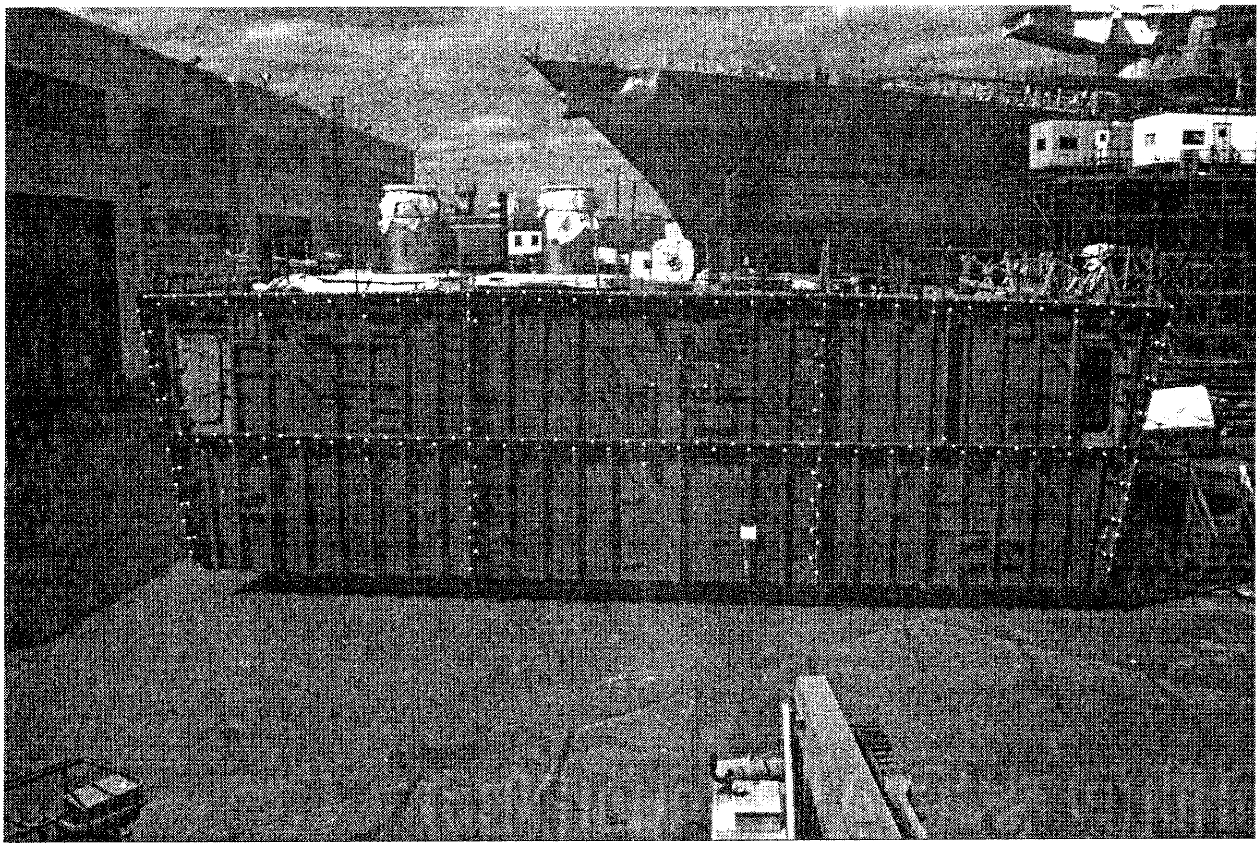


Figure 1

the trimming of this steel prior to erection so that the unit could be mated together neat in one short lift of the cranes. However; the traditional 'neat cutting' process was atheodolite based labor intensive process for the Surveyors. DCRP techniques into manufacturing is very cost effective benefits. A description of this transition follows:The traditional approach of neat cutting unit erections utilizes two Surveyors with a theodolite to measure the stock edge of a unit after it is assembled. The theodolite is set up in the production area, referenced into the local coordinate system, and each point is measured for length, width, or height manually from visual readings to a rule or rod placed at the required spots one point at a time until a complete girth or seam condition has been measured. This is an expensive, time consuming, and stressful process due to obstructions (staging, welding leads, sucker tubes, etc..), people working around the instrument, job site noise levels, and pressure to get the job done right , quickly (it is not uncommon for assembly units to be shipped to the next construction stage immediately after Surveyor readings are completed). The matching data to derive the neat cuts is obtained by repeating this process for the interfacing edge by taking readings of the actual condition of the ship on the erection ways. The output (neat cut data) from these two measurements is manually computed for each point and noted on a table provided to the structural team. Accompanying this list is a hand sketch depicting the location of each point. The results for this process as a whole are fully dependent on a stable working platforms. preferably the units are positioned gravity level in assembly or on ships declevity out on the ways. This process is very subjective to surrounding working conditions, schedule, and operator skills but is cost effective, none the less.

DCRP techniques employ a much different approach because the measurements are not dependent on special positioning or stable platforms, only that the object being measured remains structurally rigid regardless of its position. The first step minimizes the impact to production schedules by replacing the measurement of the complete edge conditions in the assembly areas by establishing predetermined dimensional references or control points for scale at the extremes of selected girths, seams, and/or decks to be measured. After the units are shipped out, they are tracked so that when they are the most accessible and the surrounding work is at a minimum the complete edge conditions can then be obtained in a very safe, fast and accurate manner. For the DDG 51 class of ships, this is very often done in storage areas (Figure 1) because most of the units are structurally rigid. Units that twist or rack are typically measured in Pre-outfit areas where they are leveled as part of their normal work cycle.

The measurement process starts off by targeting the unit; placing magnetic retro-reflective targets at all key structural locations as requested by the structural fitting team. This task if usually performed with the use of a

	Meas. Hrs per Girth	Accuracy	Data pts. per Girth	Data Gathering	Units per Month	Avg. Injury per Qtr.
Traditional Theodolite	25	(+/-) 3mm	50 ... 75	Assembly	9	2:01
Digital Photogrammetry	6 ... 16	(+/-) 1mm	150 ... 300	Storage	13+	0:6

Table 1

scissors lift or condo lift and really has few hindrances provided the targets are clean and in good shape. Target placement is depicted on an AUTOCAD sketch (Figure 2) which is directly tied into the Engineering AUTOKON database for accuracy. Customized LISP routines enable the Surveyor to extract design XYZ dimensions for each targeted point automatically. Next, images (typically 15 to 40) are taken of the targeted unit at many converging angles from the same lift used in the targeting. Camera settings are usually quite constant at ISO 100, aperture setting of F16, and a shutter speed of 250. Image measuring is initiated by downloading the images into the PC or laptop, entering the control point data, and importing the design data for the target locations. Each image is then brought up on the computer screen, measured, and saved. This can be automated to a significant degree using the design data previously obtained or remain manual by measuring each point, one at a time, if needed. After many or all of the images are measured the data is merged together and XYZ coordinates are calculated through a least squares, self-calibrating bundle adjustment. Measurement is completed when all targets are within imaging and dimensional requirements and the resulting XYZ dimensions in object space have been transformed to the units local coordinate system. Quality control features enable the operator to view estimated accuracies for each target point measured and to edit images to obtain extremely consistent accuracy levels. The data for this edge is stored until the measurement process is completed for the interfacing edge of the mating unit. Once the stock edge and neat edge conditions are obtained, a comparision program is then run to calculate the amount of excess steel. The output to the structural trades is in the form of the original AUTOCAD sketch being modified to provide the target identification number and the amount of excess steel to be cut at each targeted point measured. Currently digital photogrammetry has neat cut over 150 structural units and the results clearly show it superior for this application (Table1). The data from the digital photogrammetry neat cut process is three dimensional, and is readily imported for use into BIW's Data Management System (SAS) for Statistical Analysis so that process control and process capability information is available for each stage of the construction contributing to the neat cut process. This provides our High Performance Work Teams (HPWT) feedback on the quality of their work. Figures 3 and 4 are representative of the versatility and functionality of software involved as they depict a menuing system and example of SPC outputs respectively. Also Structural Design and Accuracy Control personnel will have current information available pertaining to the amount of excess steel (stock) being cut, misalignment of structural members for height and halfbreadth, and structural alignment data at key shapes intersections (bulkheads, decks, shell plating). By analyzing this data in conjunction with the process control/capability information and by applying sound shipbuilding methodology, BIW plans to achieve a level of robustness that will shorten the transition time to neat construction and make it easier for the structural trades to maintain higher levels of fitup quality.

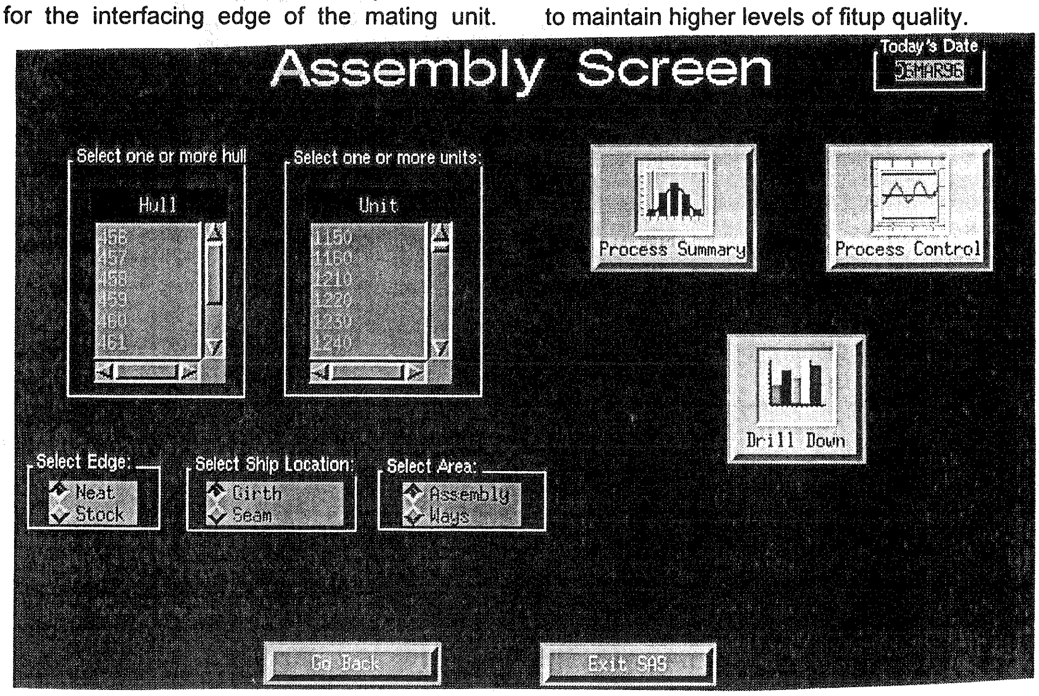


Figure 3.

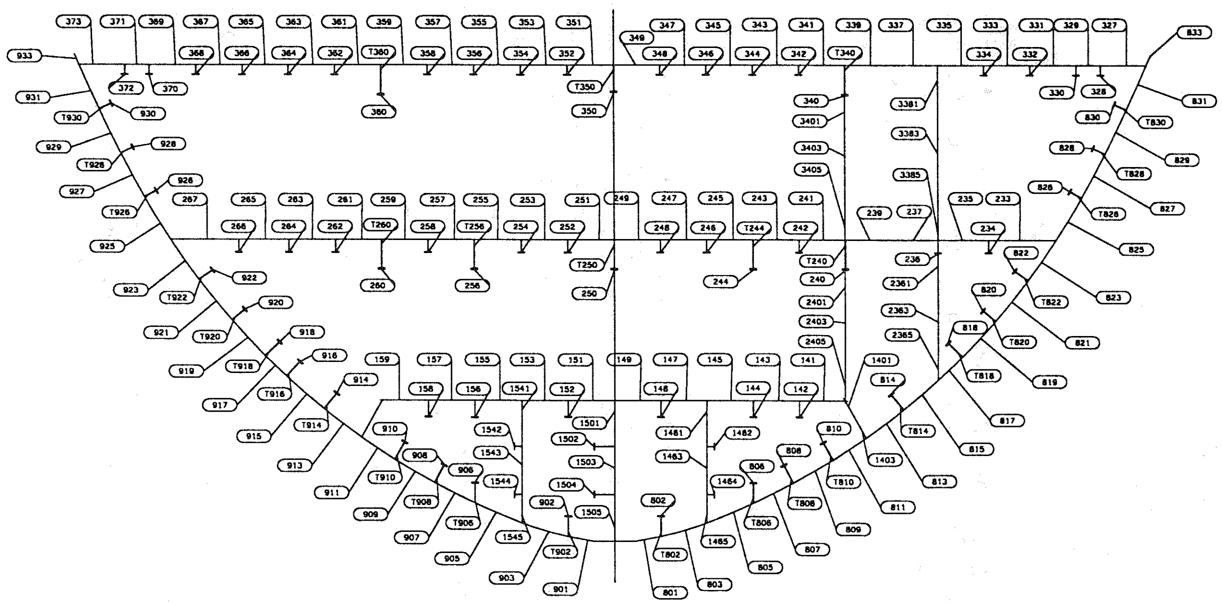
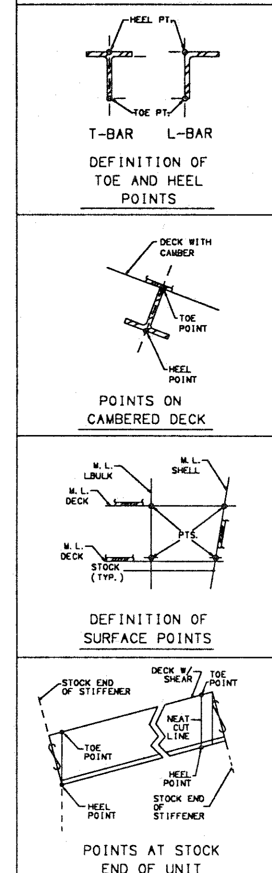


Figure 6.

TOP
PORT

HULL: 461 UNIT: 2120fwd	
WORK CENTER: - CUSTOMER: - SURVEYOR: - DATE/TIME: - WEATHER: - TEMP: -	
MFR: - MCL: - MWL: -	



Target #	Target #	Target #	Target #	Target #	Target #	Target #
Act. X	Act. X	Act. X	Act. X	Act. X	Act. X	Act. X
Act. Y	Act. Y	Act. Y	Act. Y	Act. Y	Act. Y	Act. Y
Act. Z	Act. Z	Act. Z	Act. Z	Act. Z	Act. Z	Act. Z

STIFFENER PTS FRAME 125

SIZE	BIW SURVEYOR SKETCH	REV
C	461-2120fwd-PHO	A
SCALE: 1/4=12	DATE THIS DWG. GENERATED: 08/21/95	

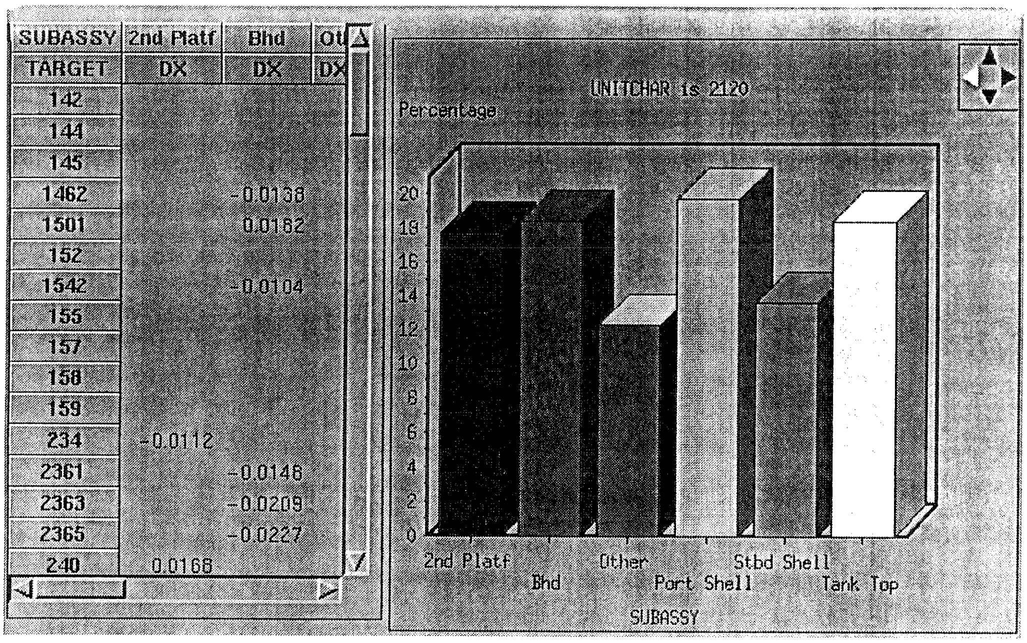


Figure 4.

3.2 Anchor Castings

Castings offer a unique problem not only because of their size, shape, and weight but also because of the dimensional instability of the forging process. The Port Anchor Bolsters in the Arleigh Burke Class of destroyers is a prime example of this. The accuracies required of the outside face of the casting to perform the function of receiving and storing the anchor is readily achieved by the shape of the mold at the time of pouring. The problem lies in the fact that as the casting cools the dimensional stability is somewhat unpredictable. This results in structural location and perimeter edge contour inconsistencies. This deviation (from design dimensions as well as from casting to casting) makes installation difficult because the use of templates or patterns to establish the deck and sideshell cutouts is not practical.

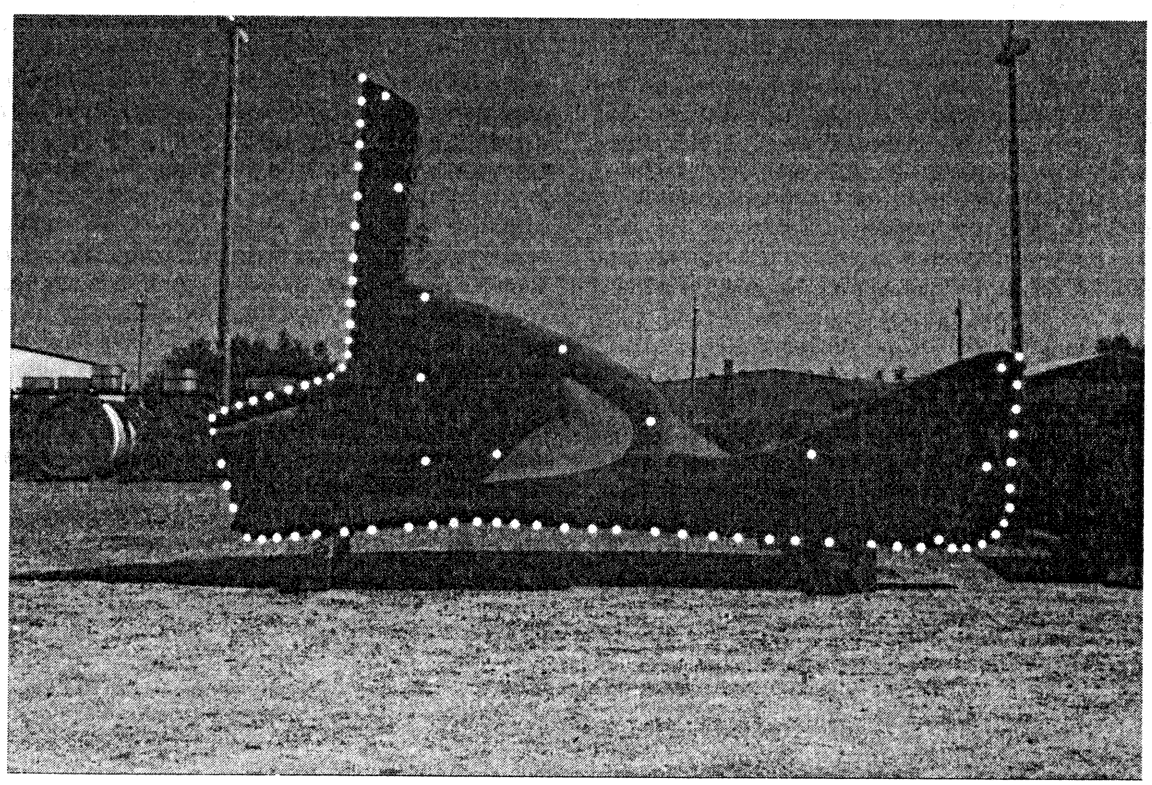


Figure 5

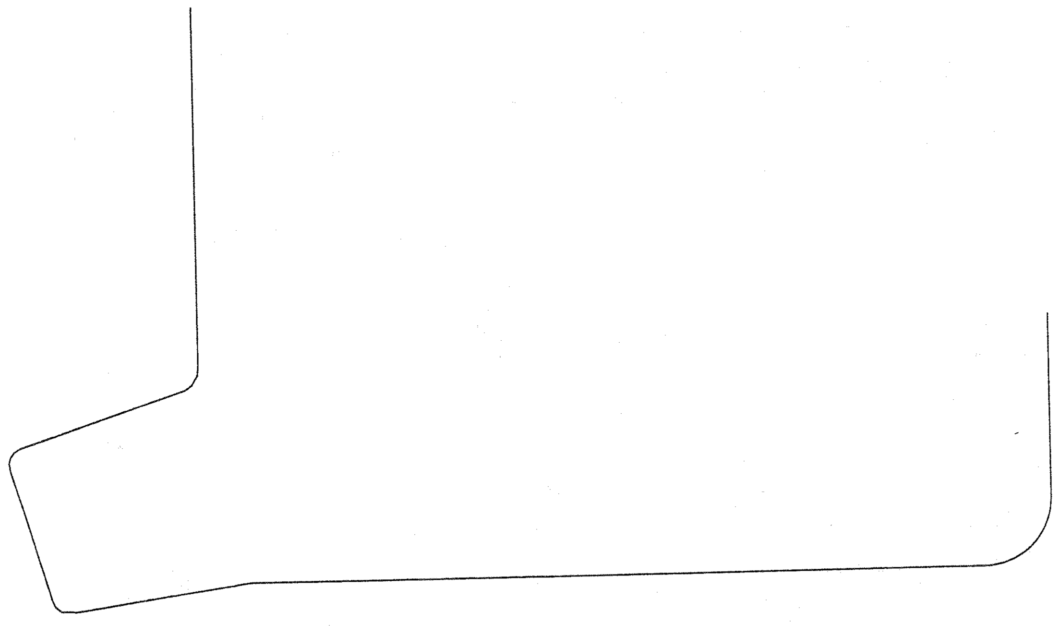


Figure 6.

Traditional approaches utilize an overhead crane to position the casting near the deck while a structural team maintains its proper plane and location. A rough scribe is made then the deck is burned. This placement, scribing, and burning process is repeated a number of times until final placement is achieved. The typical deck installation consumes a complete eight hour shift for 1 crane and up to 6 people. (The process for side shell installation is similar except that in this case the casting is now welded into the deck and the shell plating is 'stepped' into place). Significant gains are achieved by precutting the deck and shell to the shape and proper structural alignment of the casting so that the crane merely lifts the object into the cutout to be secured and then welded. The difficulties associated with establishing accurate measurement references and the time consumed measuring and then calculating the three dimensional coordinates for this object have made traditional theodolite use for this job too costly. DPMS techniques rely on the ability to obtain measured coordinates quickly and easily. Actual data points for the perimeter of the of the casting is then imported into CAD software for analysis to design. Then it is run through an optical nesting software that creates a true sized template to orient and mark out the proper burn line (Figure 6)

The improved burn quality results in no patches, the best possible structural alignment, and consistent weld gaps. This lessens the structural fit up time which in turn positively impacts other jobs for the structural team. Also, current vendor quality checks can be modified to take advantage of photogrammetric readings and CAD casting models to determine acceptance or rejection of the product at the foundry. Performing this check at the foundry would be much more reflective of the customer requirements and allow time for mold modifications if needed.

3.3 Structural Misalignment

During the fitup and welding of units in the erection process one of the most costly areas of unplanned labor occurs at the turn of the bilge, in the mid body area, where there can be a significant amount of structural misalignment from time to time. Here the transition from a horizontal bottom to a vertical side shell occurs over a three to seven meter distance. Since this happens to be an area of high stress there is a lot of support structure welded to the interior of the hull. Even though this welding is performed while the unit is restrained by mock diaphrams to maintain its shape; when it is released, the internal forces from welding can still cause distortion. Sometimes these forces are so strong that they can even distort the hull while it is restrained. Many attempts to monitor this movement have been tried over the years but none have shown the potential that DPMS techniques have thus far. Here the ability to quickly measure three dimensional XYZ data and then import the results directly into AUTOCAD models of the design hull profile are used to analyze the deviations as the subassemblies are built. Figure 7 depicts such a comparision between the mock diaphrams of the side shells and the hull profile for Unit 2120.

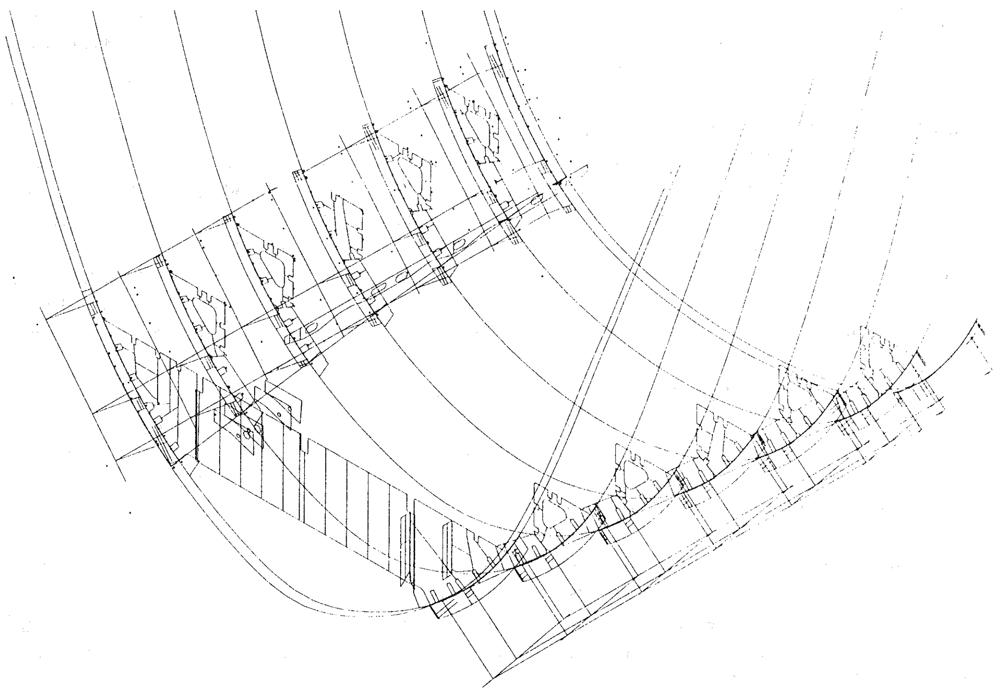


Figure 7

To date BIW Surveyors have monitored three fabrication and products from start to finish. Data from measurements has been provided to Structural Design for analysis. Short term results range from quick fixes in dimensioning to formal fitting and welding procedures for particularly tough areas. Over the long run the increased knowledge of how welding and fitting practices effect structural movement result in improvements in the quality of unitconfiguration.

3.4 Burning Machine Accuracy

One of the most critical structural operations of any ship-yard starts with the dimensional control of structural shapes and plates as they are burned from raw steel plating. Large shape deviations (+/- 1cm) can usually be noticed and corrected before the material is shipped into production. Smaller deviations (+/- 2mm) may go undetected and surface only when combined with other small deviations to compound and make a big one. Regardless of the deviation magnitude they threaten to increase unplanned labor, rework, or in extreme cases scrap. Current dimensional quality of shapes and plating is suitable for existing construction practices of stock utilization. To ensure Neat Construction strategic objectives are achieved, dimensional checks need to be performed on the accuracy of material as it is burned and monitor deviation trends. Conventional methods involve a Quality Engineer (with the assistance of a shop floor mechanic) measuring the perimeter and diagonal dimensions of plates (from a random sample) that have at least one square edge. The data collected is quite weak (four points for perimeter size and one for edge squareness) when viewed to the Digital Photgrammetry approch.. This process is very similar to the structural misalignment application, on a much reduced scale, by scrutinizing individual pieces and parts.Targets are places along the perimeter of the plate, at specified cutouts, and at key features (corners, structural layout lines, etc..). Actual object coordinates are imported into an AUTOCAD model for comparision to design coordinates (Figure 8)

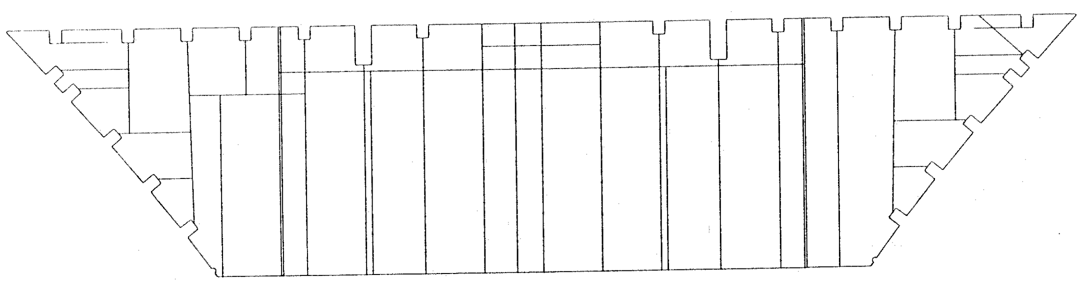


Figure 8.

So far the results have led to an increased awareness of the burning machines role in product quality. Structural Design areas have refined data inputs to the machine prior to burn as well as corrected the few problems that have surfaced. In process checks are now regularly maintained for this area of fabrication. With process control and capability levels determined it is now time to turn to adjustments within the machines themselves to secure the high\est possible quality levels.

3.5 Burning Machine Alignment

To ensure the plate and shape cutting process is operating properly checks need to be performed on the burning matching periodically, ideally as part of a regularly scheduled preventive maintenance program. The traditional approach utilizes two surveyors with a theodolite to check the flatness, straightness, parallelism of each crane rail in relation to each other. Also the machined surface that the burning torch travelson is checked in for squareness , straightness, and verticality to the crane rails. This operation is lengthy (approximately 15 running time hours for measurement, data reduction, and reporting) and is performed only when the machine is shut down. Since these machines often have work scheduled to run twenty four hours a day seven days a week, any work stoppage impedes production. Digital Photgrammetric techniques aim at capturing the data quickly during production breaks and performing the measurements off line. This process requires 4 - 6 control points at the extremes of the machine. In this case we can easily make use of existing theodolite benchmarks. Next targets are placed at the same places checked traditionally (crane rails and burning torch traveling surface). From here 25 - 35 images are needed to ensure proper coverage and accuracy. Measurement is initiated with the entry of the known control point scale dimensions/coordinates and is completed when all target points are accounted for and the overall accuracies are within acceptable limits. The output to The Maintenance Dept. is in the form of a computerized table listing the target ID, actual measurements, and corresponding deviations.

This application is surprisingly fast. Target placement, imaging, and target removal was accomplished by 2 photogrammetrists while the burning machine operator was on his 30 minute lunch break. The significance is that the impact to production (in a worst case scenario due to measurement time) from work stoppages is reduced from 15 running hours to 7 if the burning machine is left stationary until results are determined. . In

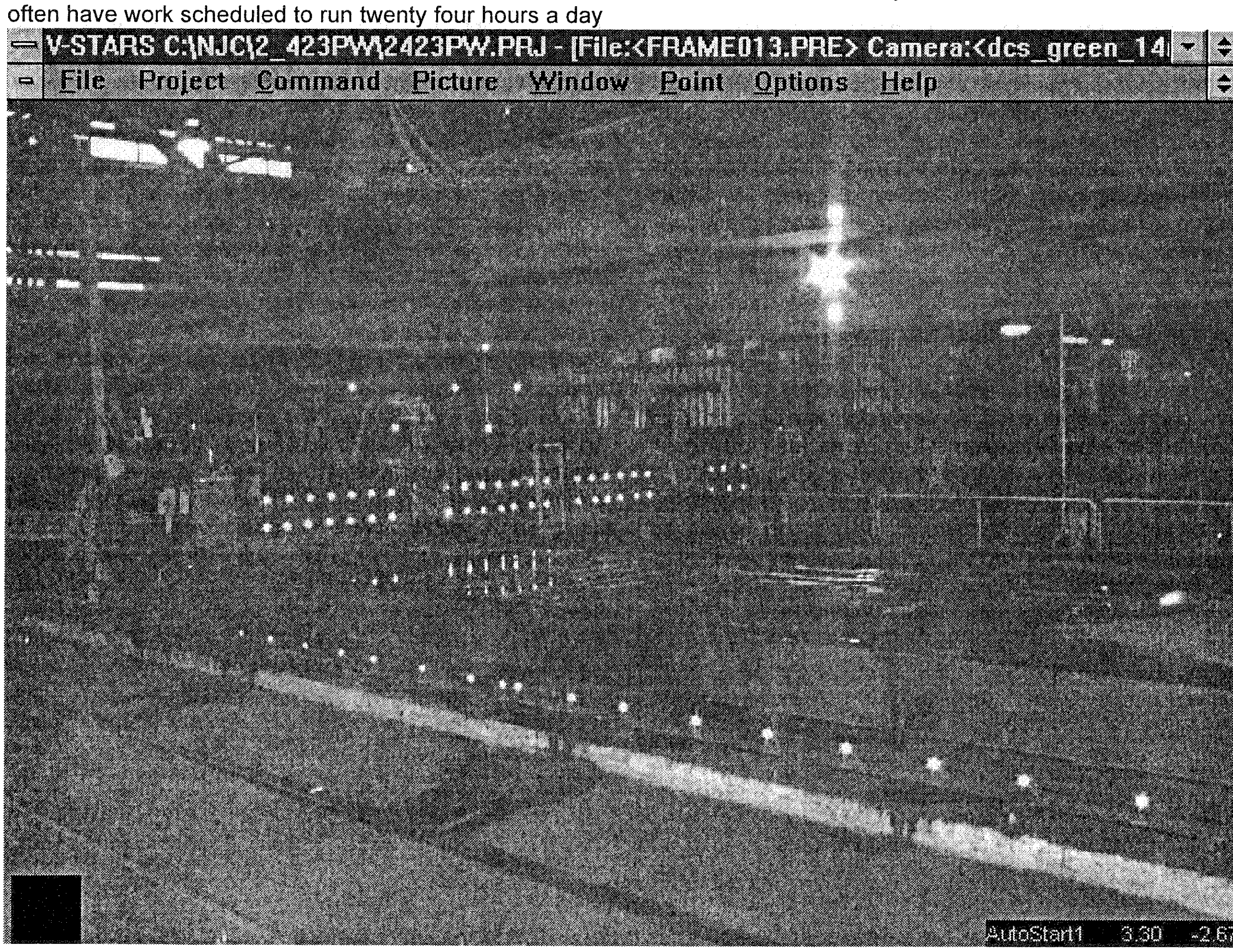


Figure 9

cases where process control has been established within a routine maintenance program it may be acceptable to continue the burning process until the machine stability is verified. Many times when production is in full gear the notion is leave equipment alone for as long as it works because work stoppages are too costly. This has discourage any thoughts that routine (preventative) maintenance equates to work stoppages and is costly.

4.0 CONCLUSIONS

Digital Close-Range Photogrammetry is a powerful and emerging technology functioning quite well in the demanding shipyard environment on daily basis. Seasonal variations in temperature have been of little consequence for measurements to date provided the camera has been acclimated to environmental surroundings. Neat cut measurements have been obtained in temperatures ranging from -10 to +100 degrees Farenheit. The speed of obtaining images and measuring off line is well appreciated at these extremes. Also important is the portability and ability to work on unstable platforms ensuring the least possible impact to surrounding production work is a decided advantage over existing measurement systems. The use of DCRP methodology to compliment traditional equipment and techniques has led to faster data turn around, improved accuracy, higher productivity, and increased safety as provided in the application discussions. There are many other areas of applications for Digital Technology. (One that can be mentioned briefly is the use of images for Ship Checking. Here the user has the ability to use the image as a documentation tool or import it into CAD software for dimensioning purposes...). This paper has covered the use of vendor purchased DPMS utilizing KODAK DCS 4xx mi series of cameras. The use of other digital components and software combinations (Gruen 1994) like video cameras, frame grabbers, surface reconstruction, etc are very attractive for measurement pur-poses. To date not much of this aspet of Digital technology has been tested in the Shipbuilding Industry. The potential is out there provided the researcher/developer keeps the functionality of a measurement system at a level that encompasses a wide range of users.

5.0 REFERENCES

References from Journals

Maas, Hans-Gerd & Kersten, Thomas, 1994. "Digital Close Range Photogrammetry for Dimensional Control in a Shipyard" Video Metrics III

Fraser, C.S., & Brown, D.C. 1986. "Industrial Photogrammetry: New Developments and Recent Applications" The Photogrammetric Record, 12(68):197:217

Gruen, Armin, 1994. "Digital Close-Range Photogrammetry - Progress Through Automation" ISPRS Commission V Symposium.

References from Other Literature

Johnson, George W., 1993. "Digital Photogrammetry a New Measurement Tool" Corporate Summary of Three Dimensional Measurement Technology Comparisions for Unit Erection.