National Shipbuilding Research Program (NSRP)
Surface Prep and Coatings (SP&C) Panel Project

Final Report

Reducing Inspection Costs Using the Latest Digital Inspection Tools

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Contents

1 Introduction

The National Shipbuilding Research Program (NSRP) is an industry-led, Navy-sponsored collaboration of U.S. shipyards working together to reduce the cost of building, operating and repairing Navy ships by improving productivity and quality through advanced technology and processes. In 2014 the NSRP Surface Preparation & Coatings Panel obtained approval from the Executive Control Board for funding of a project that would evaluate the latest in digital coating inspection instruments and their potential for cost savings in the inspection of Navy vessels. An important part of the NSRP mission is sharing non-classified projects with industry. This paper will share the findings of this twelve month Navy and industry project.

The four most labor and documentation intensive areas of Navy asset paint inspection are the verification of surface preparation, ambient conditions, substrate condition, and dry film thickness (DFT). Previous NSRP projects have concentrated their efforts on the first three of the aforementioned areas and their results have not only yielded significant cost savings but also supported revisions to the Navy Standard Item (NSI) 009-32. Current NSI 009-32 specifications for DFT inspections, however, rely heavily on outdated technology, with results manually input on paper-based documentation. For several years, other industries with similar applications have modernized their inspection and documentation protocol for DFT measurement to incorporate newer digital technologies. These industries have seen their corresponding inspection costs significantly reduced. In this project, a side-by-side comparison of three test methods were used to evaluate DFT in ballast tanks and other painted surfaces. These methods were evaluated for:

1. Completion Time
2. Data Accuracy
3. Data Processing

Paint and coating QA/QC Managers from BAE Systems Southeast Shipyards, HII-Newport News, HII-Ingalls, NASSCO - Earl Industries, and Elcometer all provided trained inspectors who completed DFT inspections both in the field and on laboratory prepared control panels. These inspectors performed:

- DFT inspections of painted areas according to current practice
- The same inspection using scanning probe technology, programmed to automatically calculate DFT data to the current NAVSEA standard, store results in the gauge, and export data to a paperless QA system.
- The same inspection using instruments with traditional place-and-lift probe technology, programmed to automatically calculate DFT data to the current NAVSEA standard, and exported results to a paperless QA system.
- The same inspection using a device that is factory calibrated for measuring on blast cleaned, roughened surfaces and suitable for use by untrained personnel, recording data manually according to NSI 009-32 Appendix 7.
- Current practice, scanning, pre-programmed, and factory calibrated inspections on a set of laboratory prepared control panels.

2 Background of Dry Film (Coating) Thickness Technology

Prior to 1947 - Destructive Coating Thickness Testing

- The measurement of paint thickness over steel substrates required the use of a destructive test. It required the user to cut into the coating system with an angled cutter and measure the thickness from the top of the coating to the substrate using a microscope with calibrated reticules. This process was time consuming, subjective, and only yielded a measurement for the area that was damaged as a result of that measurement.

1947 - Non-Destructive Coating Thickness Testing

- A non-destructive test using a calibrated “horseshoe-shaped” magnet attached to a simple magnetic needle meter was invented. There were many variations of the calibrated magnet method, however, the core measuring principle remained the same until the development of the electronic gauges.

1957- Analogue Electronic Instruments

- Transistors created an analogue signal that was sent to a needle movement display.

1972 - The Introduction of the Microprocessor

- DFT instruments were developed utilizing the electromagnetic induction principle; achieving a digital coating thickness measurement with enhanced accuracy was now possible. Digital measurement greatly increased the speed at which measurements could be taken while also reducing the time needed to perform a comprehensive inspection. However, while the measurement was now digital, the corresponding data retention was not; these digital measurements were recorded manually.

1984 – Statistical Analysis & Statistical Process Control (SPC): Data Collection and Analysis in Real Time

- Memory chips became affordable enough to fit into portable instruments and were soon incorporated into digital DFT gauges. Early adopters of this technology tended to be large scale manufacturing operations that could keep the instruments close to their mainframe and desktop computers. Having an instrument close to a data processing device allowed these manufacturers to track their measurements on the production line and make changes to their process in real time. As a result, digital statistical process control (SPC) was born.

3 Project Objectives

3.1 Streamlining the Production Process

Unlike industrial manufacturing, industrial marine protective coating applicators cannot always control their production environments. Production areas tend to be difficult to access and can easily become congested, with numerous trades having to perform their duties almost simultaneously. Over the last 15 years, incorporating digital Statistical Analysis and SPC for DFT measurement in industrial marine protective coating environments has been established primarily in Asian and European commercial shipyards. US Military shipyards and contractor facilities have been slow to adopt these techniques for reasons which include data security, specification conformance, and the need for more portable, robust, digital data collection and analysis instruments.

3.2 Streamlining the Reporting Process

To meet the requirements of the industrial marine protective coating industry, some of the latest digital coating inspection tools now have the power to process, retain (save), and export measurements. The use of handheld instrumentation that contain processing power previously relegated to desktop computers without any of the security concerns. Statistical Analysis and SPC in the military shipyard is now possible.[1]

3.3 Streamlining the Inspection Process

It is the goal of this project to provide the data necessary to justify the incorporation of the latest digital inspection tools into the Navy's paint production processes; thereby streamlining inspections and allowing the Navy standards to move away from obsolete inspection methods requiring colossal amounts of manually entered data and reams of paper documentation. Incorporating Statistical Analysis and SPC into Navy DFT specifications will bring with it the efficiencies of modern manufacturing and allow shipyards to benefit from the subsequent cost reductions and quality improvements.

[1] *Applying Statistical Process Control to Coatings Activities in Lean Production Implementation, Final report presented to NSRP/ASE Surface Preparation & Coatings Panel (SP-3) under subcontract number: 2005-360*

4 Overview

The following table outlines the inspection methods evaluated in this project. To verify accuracy in a controlled environment, inspections were undertaken in a laboratory using coated panels with varied surface profiles. To verify accuracy in a field environment, inspections were undertaken at participating shipyards according to NSI 009-32 specified procedures.

Data were compared and contrasted for:

- Accuracy, equivalency
  - Compare and contrast data generated by legacy tools vs. the latest digital inspection instruments
- Data Retention
  - Compare and contrast time to complete documentation. Legacy (paper-based) method vs. the latest digital inspection methods
- Speed
  - Compare and contrast the speed of legacy inspection tools vs. the latest digital inspection instruments

Three distinct instrument types and corresponding data collection methods were utilized for this project. They are as follows:

Method 1: Current Shipyard Practice - Analogue or digital measurements taken with Type 2 Coating Thickness gauge. Reporting was completed via legacy (current shipyard) method

Method 2: Scanning - New DFT scanning technology used to take measurements. Reporting completed using digital data management system

Method 3: Factory Calibration - New factory calibrated and pre-programmed DFT device designed to take a single measurement in lieu of the three spot-measurement requirement of SSPC PA2. Reporting was completed via legacy (current shipyard) method

Instrument Type	Corresponding Data Collection Method (meeting the requirements of SSPC-PA2[2])
Digital DFT Gauge	NSI 009-32, Appendix 7
Conventional Digital DFT Gauge with data collection points pre-programmed in batch and sub batch files with time- and date-stamped readings	Data download into a software program with cloud capabilities and generate inspection report
Scanning Probe Gauge with data collection points pre-programmed in batch and sub batch files with time- and date-stamped readings	Data download into a software program with cloud capabilities and generate inspection report
Fixed Calibration Digital DFT Gauge	NSI 009-32, Appendix 7

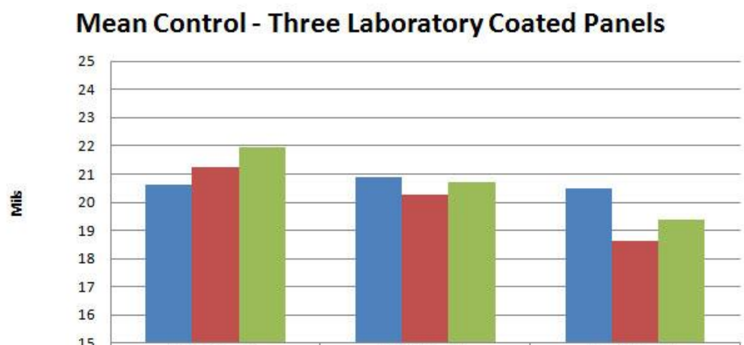
Figure 1 - Instrument Types and Corresponding Data Collection Methods

[2] *SSPC-PA 2, "Procedure for Determining Conformance to Dry Coating Thickness Requirements." (Pittsburgh, PA: SSPC, 2012).*

5 Project Results for Lab Testing - Data Integrity

5.1 Laboratory Panels - 20mil Target Control

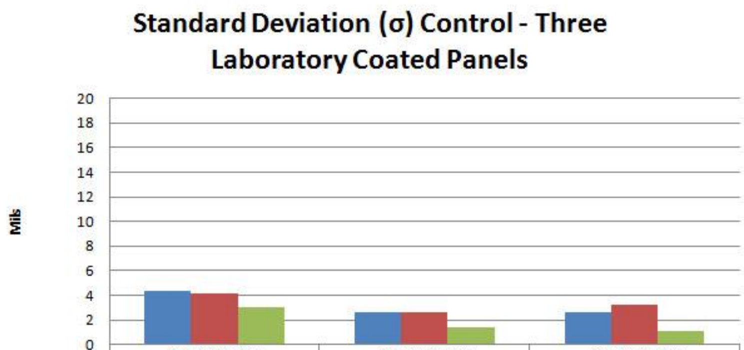
Three laboratory panels having NAVSEA approved single coat epoxy paint manually applied at a target thickness of between 20 and 30 mils (the lower and upper end of the specified range for single coat) over substrate profiles of 1 -2 mils, 2 - 3 mils, and 3 -4 mils were prepared. Each panel had variances in film thickness that can be attributed to manual application and variance of substrate profile.



	1-2 Mil Profile	2-3 Mil Profile	3-4 Mil Profile
Factory Cal	20.6	20.867	20.467
PA-2	21.26	20.28	18.62
Scanning	21.963	20.69	19.362

Figure 2 - 20mil Target DFT

Each instrument demonstrated a low standard deviation - with the scanning technology showing the lowest deviation overall . All three measurement systems have a standard deviation as a result of variation in substrate profile and DFT. A lower standard deviation demonstrates greater confidence in the statistical conclusions resultant from the data for the measuring device.

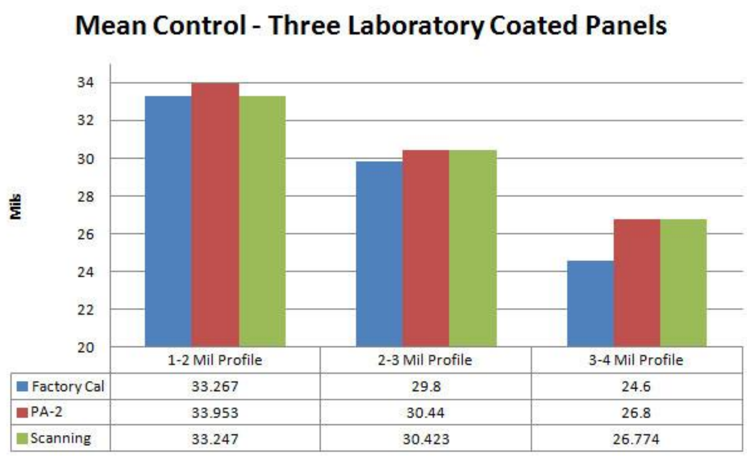


	1-2 Mil Profile	2-3 Mil Profile	3-4 Mil Profile
Factory Cal	4.356	2.615	2.588
PA-2	4.201	2.632	3.226
Scanning	3.087	1.387	1.111

Figure 3 - 20 mil Standard Deviation

5.2 Laboratory Panels - 30mil Target Control

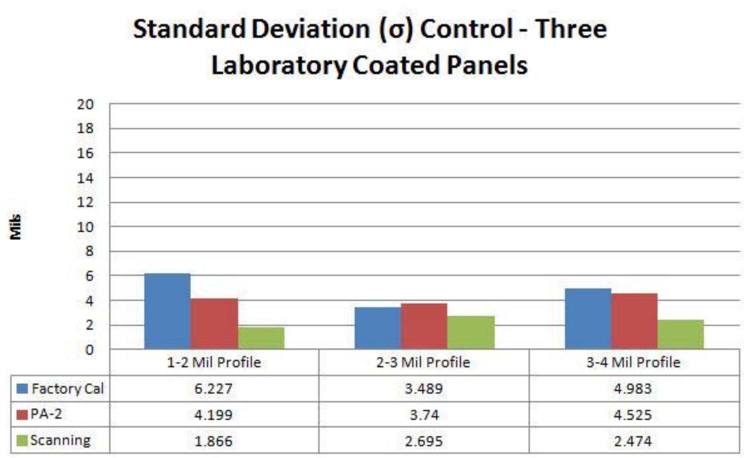
Three laboratory panels having NAVSEA approved single coat epoxy paint manually applied at a target thickness of between 20 and 30 mils (the lower and upper end of the specified range for single coat) over substrate profiles of 1 -2 mils, 2 - 3 mils, and 3 -4 mils were prepared. Each panel had variances in film thickness that can be attributed to manual application and variance of substrate profile.



	1-2 Mil Profile	2-3 Mil Profile	3-4 Mil Profile
Factory Cal	33.267	29.8	24.6
PA-2	33.953	30.44	26.8
Scanning	33.247	30.423	26.774

Figure 4 - 30mil Target DFT

Each instrument demonstrated a low standard deviation - with the scanning technology showing the lowest deviation overall . All of the measurements systems have a standard deviation as a result of variation in substrate profile and DFT. A lower standard deviation demonstrates greater confidence in the statistical conclusions resultant from the data for the measuring device.



	1-2 Mil Profile	2-3 Mil Profile	3-4 Mil Profile
Factory Cal	6.227	3.489	4.983
PA-2	4.199	3.74	4.525
Scanning	1.866	2.695	2.474

Figure 5 - 30mil Standard Deviation

6 Project Results for Field Testing

6.1 Data Integrity

There were over 30 field inspections performed over a wide variety of substrates and DFT specifications. Inspections were subject to the production schedule of each shipyard and the availability of each asset. The following data; two single coat tanks, one thick film application, and one thin film application, typify the results.

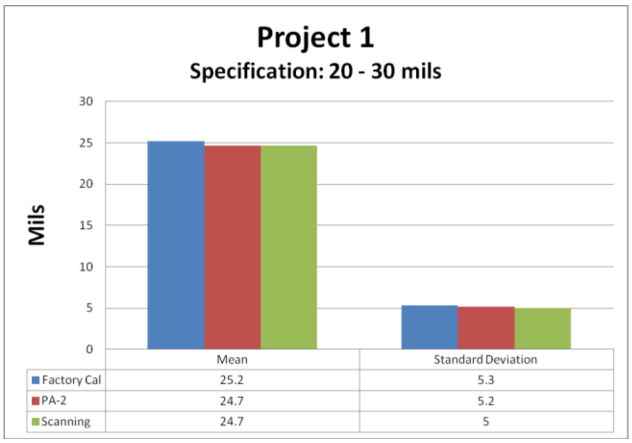


Figure 6 - Single Coat Tank

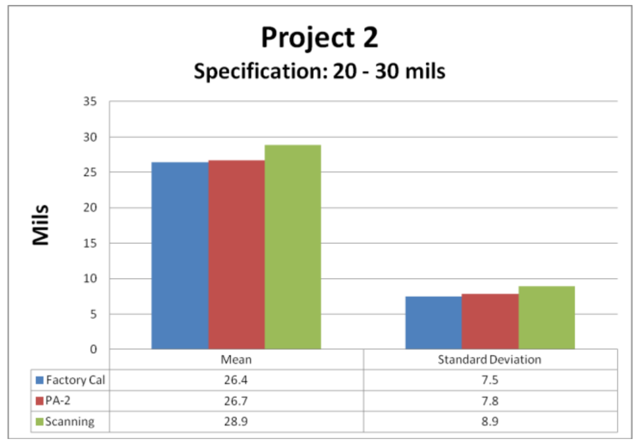


Figure 7 - Single Coat Tank

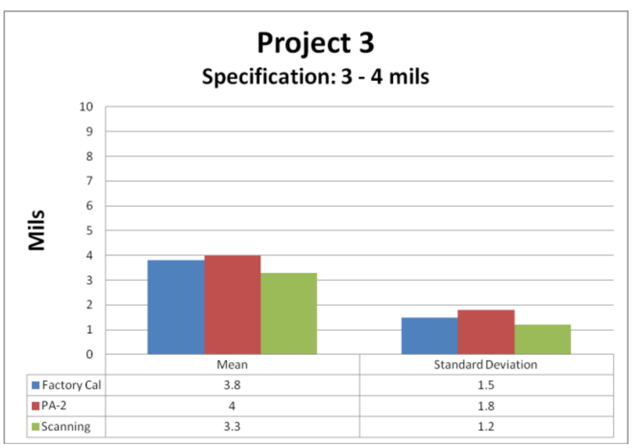


Figure 8 - Thin Film Application

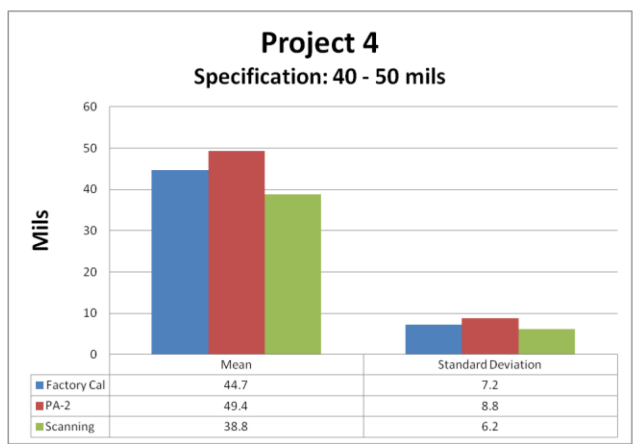
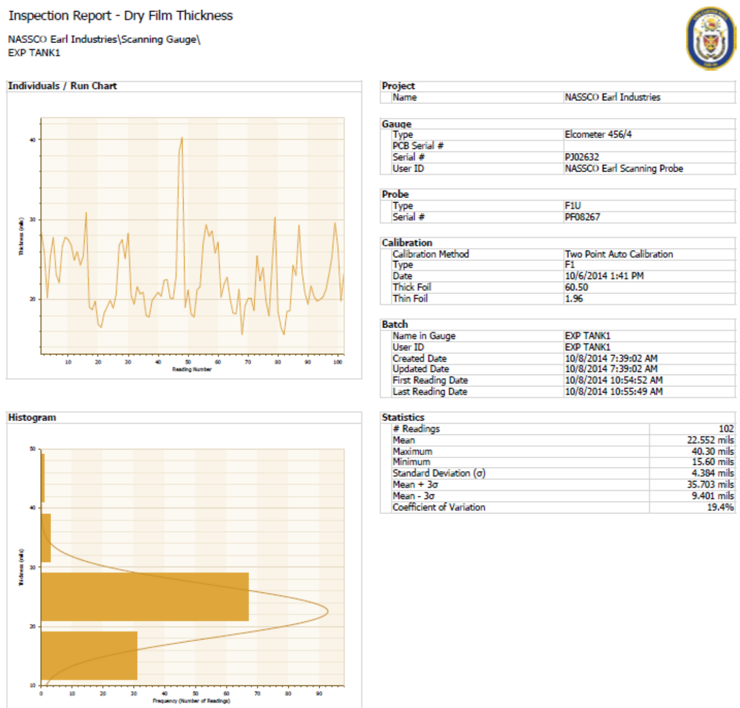


Figure 9 - Thick Film Application

6.2 Reporting

At the conclusion of each inspection data was entered either manually or digitally in accordance the the method being evaluated. The following are examples of digital and manual reports:



Inspection Report - Dry Film Thickness

NASSCO Earl Industries\Scanning Gauge\
EXP TANK1

Individuals / Run Chart

Project	
Name	NASSCO Earl Industries
Gauge	
Type	Elcometer 456/4
PCB Serial #	
Serial #	PJ02632
User ID	NASSCO Earl Scanning Probe
Probe	
Type	F1U
Serial #	PF08267
Calibration	
Calibration Method	Two Point Auto Calibration
Type	F1
Date	10/6/2014 1:41 PM
Thick Foil	60.50
Thin Foil	1.96
Batch	
Name in Gauge	EXP TANK1
User ID	EXP TANK1
Created Date	10/8/2014 7:39:02 AM
Updated Date	10/8/2014 7:39:02 AM
First Reading Date	10/8/2014 10:54:52 AM
Last Reading Date	10/8/2014 10:55:49 AM

Histogram

Statistics	
# Readings	102
Mean	22.552 mils
Maximum	40.30 mils
Minimum	15.60 mils
Standard Deviation (σ)	4.384 mils
Mean + 3σ	35.703 mils
Mean - 3σ	9.401 mils
Coefficient of Variation	19.4%

Figure 10 - Digital Inspection Report

Appendix 7 - Quality Assurance Inspection Form – Dry/Wet Film Thickness Measurements SHEET: ____of____

NAME & HULL #: USS CARTER HALL CONTRACT/TASK ORDER/CLIN/TWD: 679-009
LOCATION OR TANK: EXP TANK 2 WORK ITEM: 4667
REQ'T DOCUMENT: 009-32 FY: 2015 TABLE: NA LINE: NA COLUMN: NA (I) ☐ (V) ☐ (G) ☐ (N/A) ☒
CONTRACTOR: PRIME: ELCOMETER SUB: NASSCO EARL INDUSTIRES NAVAL FACILITY: VA

(All readings are in mils)

QA Equipt No. from App. 2	Area/Location/Edge	Reading (1)	Reading (2)	Reading (3)	Average (1) [2]	
	(A) TANK WALL 1	14.90	19.40	15.80	16.700	WFT / DFT DFT
	(B) TANK WALL 2	16.20	20.50	15.80	17.500	COAT: Top Coat
	(C) TANK WALL 3	18.10	25.20	15.70	19.667	
	(D) TANK WALL 4	14.90	20.50	15.30	16.900	
	(E) BASE WALL	18.70	18.00	16.40	17.700	Average (2): 17.693
	Area/Location/Edge	Reading (1)	Reading (2)	Reading (3)	Average (1) [2]	
	(A) STIFFENER 1	24.50	15.10	18.60	19.400	WFT / DFT DFT
	(B) STIFFENER 2	20.60	26.50	15.00	20.700	COAT: Top Coat
	(C) STIFFENER 3	18.40	17.10	14.70	16.733	
	(D) STIFFENER 4	20.70	21.20	24.40	22.100	
	(E) STIFFENER 5	20.40	21.70	23.20	21.767	Average (2): 20.140
	Area/Location/Edge	Reading (1)	Reading (2)	Reading (3)	Average (1) [2]	
	(A) STIFFENER 6	20.30	18.20	19.10	19.200	WFT / DFT DFT
	(B) STIFFENER 7	23.30	19.30	20.70	21.100	COAT: Top Coat
	(C) STIFFENER 8	15.00	22.30	17.80	18.367	
	(D) STIFFENER 9	18.40	22.00	20.50	20.300	
	(E) STIFFENER 10	26.20	27.30	32.20	28.567	Average (2): 21.507

Sat ☒ Unsat ☐	Average (3) WFT/DFT Total: 19.780	Visual Holiday Check Sat ☒ Unsat ☐	Shop/Contractor Signature & Date [1]: 12/6/2015
Remarks (continue on back if needed) ☐ See back for Continuation: ALL ACCEPTABLE. SAGS ON STIFFENER 4 WERE REMEDIATED.			(G) Quality Assurance Inspector Signature & Date [1]: 2/27/2015

DO NOT WRITE IN MARGINS

[1] Signature certifies, based on personal observation, that the data entered above is complete and accurate. Signature includes at least first initial, last name, badge/employee number, or inspector certification number, and date.
[2] For electronic equipment that accumulates information in batches and self averages, it is acceptable to enter only the average of the readings for each spot.

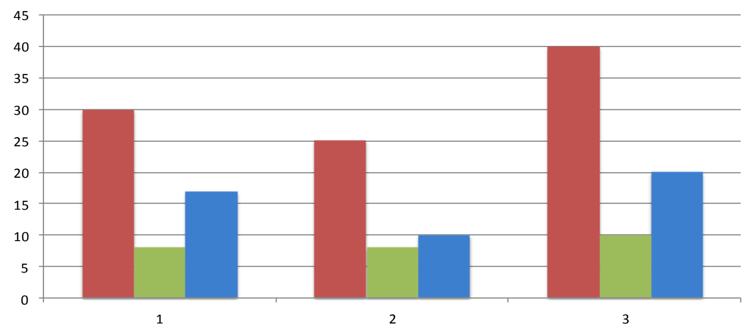
QA APPENDIX FORMS 1-8 NAVAL FACILITY FORMS FY 15 Page 1

Figure 11 - NAVSEA Legacy/Manual Inspection Form (Manual Data Input)

7 Cost Savings

7.1 Time of Inspection - Laboratory Control Panels

Time of inspection completion was recorded for both the laboratory and field inspections. Below is a graph displaying average time requirements for each inspection instrument and corresponding laboratory inspection method:



Method	Inspectors (Minutes) 1	2	3	Average (Minutes)
PA-2	30	25	40	31.67
Scanning	8	8	10	8.67
Factory Cal	17	10	20	15.67

Figure 12 - Average Inspection Time - Laboratory Inspections

7.2 Time of Inspection - Field

Below is a graph displaying average time requirements for each inspection instrument and method for the field inspections:

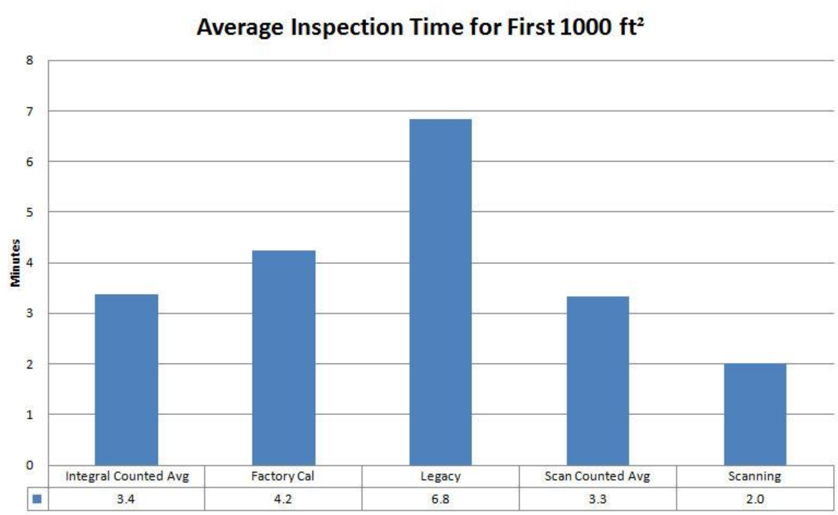


Figure 13 - Average Inspection Time - Field Inspections (First 1000 ft^2)

7.3 Cost Savings - Comprehensive

The potential cost savings are calculated for the most efficient inspection method vs. the legacy method and manual data entry into the NSI 009-32 Appendix 7. The number of readings shown below are an estimate of the total readings required to evaluate ballast tanks in a hypothetical Navy Carrier:

Current Practice:

- 30 seconds x 120,000 readings = 1,000 hours
- 1,000 hours = 125, 8-hour shifts
- 3 inspectors = 8.3 weeks / 2 months

  Assumptions:
  - No breaks for food, etc
  - No waiting time or delays
  - No review of manual input data

Scanning Technology Method:

- 5 seconds x 120,000 readings = 167 hours
- 167 hours = 21, 8 hour shifts
- 3 inspectors = 1.2 weeks
- An 86% reduction in data collection time

  Reduction in time and labor for digital report generation, data review, and audits leads to an exponential increase in productivity and cost savings.

7.4 Cost Savings - Report Generation

Time savings for report generation between manual report generation and digital methods were so significant that the benefits of digital reporting are incalculable. In one instance, a shipyard showed manually completed DFT reports for a single ship that represented 2,000 man hours to complete. The reports were stored in a 12" ring binder. Those same reports could have been generated digitally in under one minute**.**

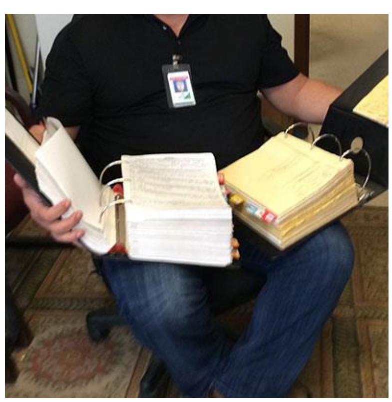


Figure 14 - NSI 009-32 Appendix 7 Documents

8 Project Results by Method

8.1 Scanning Probe Technology

Determining DFT using the scanning instrument was more than three times faster than the current NAVSEA method. It can therefore be inferred that scanning technology would reduce the labor cost of an inspection by almost 70%. When the benefits of digital data output and automatic report generation are added, the labor cost savings increase exponentially.

Figure 15 - Scanning Technology

8.2 SSPC-PA2 Programmed DFT Gauges - Standard Probe and Scanning Technology

Digital instruments that calculate the average of three gauge readings to obtain a spot measurement and combine five spot measurements to create an area measurement, were twice as fast as the current NAVSEA method. The time savings for these instruments are almost identical and have the potential to reduce the labor cost by 50%. When the benefits of digital data output and automatic report generation are added, the labor cost savings increase exponentially.

Figure 16 – SSPC-PA2 Programmed, Standard Probe Technology

8.3 Factory Calibration Technology

Calculating DFT using the factory calibrated instrument to complete the current paper-based data retention method performed the same inspection 33% faster than the current test method.

Figure 17 - Factory Calibrated Instrument with NSI 009-32, Appendix 7

9 Conclusions

9.1 Data Integrity

- Inspection data taken from three laboratory-prepared panels having NAVSEA approved single-coat epoxy paint applied over substrate profiles of 1-2mils, 2-3mils, and 3-4mils conclusively demonstrate that there is no loss of accuracy or repeatability using the latest digital inspection tools. The data further demonstrate that scanning technology has the lowest standard deviation of all the tested measurement methods.
- Inspection data taken from multiple inspections, working to a wide variety of coating specifications, at one new build shipyard and two maintenance/refit shipyards, conclusively demonstrate that there is no significant difference in data obtained by the currently specified inspection method and the latest digital inspection tools. The data further demonstrate that each measuring device and method has a comparable standard deviation.
- Inspection data taken from multiple field inspections, when compared to the laboratory prepared panels, conclusively demonstrate that there is no degradation of instrument performance when taken from a laboratory environment into the field.
- Data clearly demonstrate that the DFT instrument which was factory pre-calibrated to 009-32 profile specifications, saw no material difference in the accuracy of the data collected using the current SSPC-PA2 data collection method – despite taking one third of the number of readings.

9.2 Inspection Time

- When inspection completion time was analyzed, digital instruments were observed to be between two to three times faster than the current NAVSEA specified data collection method.
- Scanning technology demonstrated the most significant time savings despite recording ten to twenty times the number of individual measurements.
- The factory calibrated DFT instrument completed identical inspections in nearly half the time of the current paper based data retention method.

9.3 Data Output and Report Generation

- Time savings for report generation between manual reporting and digital methods are so significant that to publish them in dollar terms would defy credulity. In one instance, a shipyard showed NSI 009-32 Appendix 7 reports for a single ship that took almost 2,000 man hours to complete, review, and audit. The reports were stored in 12" ring binders(Figure 8). Those same reports could have been generated digitally in under one minute.

9.4 Action Items

- Subsequent to the presentation of this project to the NSRP Surface Preparation & Coatings Panel and the NAVSEA 05P Technical Warrant Holder, a request has been made to SSPC to update SSPC PA 2 to include the use of scanning technology.

10 Appendix 1 - Inspector Feedback

At the conclusion of each shipyard visit, inspectors were asked a series of questions regarding the use of the latest digital inspection tools and the current practice. Here are some of their responses:

Q: What are your Impressions of the factory calibrated gauge?

A: Very basic, easy to use. The gauge doesn't record data which would be an issue and a hassle. It would be good for foreman or painter to check job before calling for an inspection.
A: Great, I would love to use
A: Time consuming
A: It wasn't as fast as the others

Q: What are your Impressions of scanning gauge?

A: Easy to use and read DFT's at a fast, real time pace.
A: It gave a better scope of the total DFT of an area and made mapping out areas that are out of spec easier and more accurate.
A: Saves time
A: Saves 15 - 20 minutes per checkpoint
A: I really liked the scan. Much faster and can put readings right to appendix

Q: Did you prefer the counted average in the integral gauge or on the scan probe?

A: Scan probe
A: Scan
A: I preferred the scan probe. It gave me a way better overall feel for the tank.
A: It would depend on the size and arrangement of the area being inspected. For open areas with simple geometry, I would prefer the scan probe. In tighter areas with complex geometry, would prefer the counted average gauge.

Q: What is your biggest challenge when inspecting DFT's according to 009-32?

A: Mapping out large tanks and the time it takes
A: Inspecting, writing, and only having two hands
A: The amount of time it takes to do all the paperwork

Q: If you could make three changes in the way you take and record DFT's, what would those changes be?

A: Cut back on readings per sq. ft.
A: Taking out appendices on deck plate
A: I would have calibration memory spots
A: Less paper work
A: Utilizing the scan method
A: Uploading reading