Weld Sequence Planning for Major Assemblies

Presented by
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On behalf of the Project Team

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Manufacturing Issue

- The prevention and mitigation of weld-induced deformation creates a significant manufacturing challenge to the shop floor during fabrication of major ship assemblies
  - Impacts cost and schedule
- Preventing and correcting this weld deformation is done through trial and error and involves significant labor hours (rework)
  - Weld sequence plans for major structures often do not exist
  - Trades weld structures according to tribal knowledge
- Detailed weld analyses can be carried out by experienced FEA analysts to identify critical areas or to prescribe distortion-reduction measures
  - Often requires significant time (weeks or months) to set up and run the simulation and obtain useful results.
Project Objective

- Improve current weld sequence planning through the development and use of a quick and user-friendly weld sequence planning tool (enhancement of commercially available software)
- Apply, validate, and implement the tool for common major tank assemblies at GDEB
- Mitigate shipbuilding costs associated with trial and error, welding and joint rework, and assembly flattening.

NMC Weldment Contour Plot – Distortion (inches)

4ft x 4ft Sample Weldment Fabricated by NMC (17 parts, 42 weld joints, 220 individual weld passes)

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Project Team

- **PMS 450 and PMS 397** – Stakeholder, oversight
- **Naval Surface Warfare Center, Carderock Division (NSWCCD) Code 611** – Technical assistant, technical contribution
- **General Dynamics Electric Boat (GDEB)** – Technical contribution, testing and validation, implementation
- **Navy Metalworking Center (NMC)** – Project management, technical contribution
- **Office of Naval Research (ONR)** – Project funding and support
- **ESI North America** – Down-selected commercial partner for WSP Tool Development
WSP Tool Development
Project Approach

Requirements Document and Sample Problem
- Documented tool capability and usability requirements
- Fabricated a physical weldment as a sample problem
  - The structure was representative of a typical Navy structure
  - This was done as a means to benchmark current software capabilities and functionality

Sources Sought
- Used to gauge industry interest and capability
- Seven vendors responded. Many solutions:
  - Focused on highly accurate joint level analysis solutions with full physics transient heat sources.
  - Were limited in “higher level” distortion analysis of very large, complex structures

Sample Problem Analysis and RFP
- Vendors asked to solve sample problem, provide results, and provide proposal to advance software to desired state
- Three vendors responded with proposed solutions with simplified approaches to balance accuracy vs. solution time for large, complex models

Vendor Evaluation and Down Select
- ESI provided a full set of simulated measurements for all steps of fabrication
- ESI’s results most closely matched the trends and magnitudes of distortion exhibited by the physical weldment

Software Development, Validation, and Implementation
- Advance software to meet shipyard needs
- Evaluate alpha and beta versions of the software, provide feedback
- Demonstrate software improvements at GDEB

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Initial Vendor Evaluation of Sample Problem

- ESI offered a simplified approach with accurate distortion trends and was down-selected to advance the ease of use of their tool.

Comparison of maximum out-of-plane distortion for each surface of the structure, after each phase of construction.

CAD geometry with measurement points and surface designations.

ESI -to-physical (NMC) distortion contour plot comparison.
Purpose of the WSP Tool

• WSP Tool Intent
  • To develop sequencing plans for tank structure build plans at GDEB
    – Output recommended weld sequence for minimum / allowable distortion – given realistic manufacturing constraints
  • Quickly provide distortion trend data for a given geometry and weld joint configuration
  • Properly streamlined and intuitive so that it allows the user to quickly investigate the effects of changes to sequencing, clamping, preheat, etc.

• Intended User
  • User with limited to no FEA experience (but familiarity with CAD).
**Improvements Summary**

**Baseline vs. Improved Weld Sequence Planning Analysis Comparison**

Structure: 17 parts, 42 weld joints, and 220 individual weld passes, 200,000 nodes

- CAD Set-up /Import
- Weld Process Plan Development
- Weld Bead Geometry Creation
- Structure Meshing
- Assembly Advisor (Materials, Weld Parameters, Joint)
- Define Constraints / Clamping
- Solve Time (1 Run) with 12 CPU

*Results available 5x faster*

- Baseline: 6 weeks
- Improved: 1 week

*Estimated times based on ESI use of beta tool. Validation ongoing at NMC/GDEB.*
High Level Tool Overview

**User Inputs**
- CAD Geometry (Siemens NX)
  - Derived from Design Model
  - Joint Trajectory Lines
  - No Edge Prep
- Weld Process Plan (WPP) (Excel)
  - Part/Joint Information
  - Weld/Assembly Sequence
  - Tack Welds / Spacing
- Material Database (ESI Visual Assembly)
  - Prepopulated
  - HSS, HSLA, HY
  - Filler Materials
- Meshing (ESI Visual Mesh)
  - Automatic Bead Creation/Placement
  - Semiautomatic Meshing
  - Clamp Locations
- Distortion Analysis (ESI Visual Assembly)
  - Minimal User Input Req, Mainly Auto Populated
  - Clamping Definitions
  - External Forces
  - Submit Analysis

**Solution Approach**
- Shrinkage method
- No moving heat source, no thermal calculations
- Solid elements, no shells

**WSP Tool Outputs**
- Result Visualization (ESI Visual Viewer)
  - Contours of distortion
  - Animations showing weld sequence and movement
  - History Plots
- Weld Sequence Plan (CSV / Text File)
  - Best weld sequence obtained from Optimization
  - Manually Incorporated into Work Package Instructions

**Weld Process Database**
- Prepopulated with Common MIL-STD-22D Joints
- General weld process information
- Shrinkage database

**Optimization (ESI Visual Assembly)**
- Blocking and initial sequence from WPP
- Define objective / critical tolerances
- Max Number of iterations
- Submit optimization
WSP Tool Inputs
Geometry

• Native CAD model can be used for geometry
  • Joint lines need to be added to the CAD model
    – A reference and trajectory line need added for each joint line
  • Creating edge prep geometry on joints is not necessary
  • Adding root gaps is not necessary
    – Plates should be to be edge to edge
• Nx CAD was used as a direct interface for this project
• Direct interfaces with other CAD packages (Catia, Creo, Solidworks, etc.) are available
• Alternatively, STEP/IGES files can be used from any CAD package, but weld trajectories would need to be added in the ESI tool vs. the CAD package.
WSP Tool Inputs
Weld Process Plan (WPP)

- The WPP is an Excel spreadsheet with detailed information for components and weld joints
  - It contains information such as joint name (J001), component names, material designations, joint type, edge prep, fillet size, etc.
- Initial weld sequence and blocking constraints for accessibility and part flips can be defined in the WPP
- The WPP is manually populated from existing GDEB data sources
  - Scripts are being developed at GDEB to automatically populate the WPP.
The following MIL-STD-22D Joints are incorporated into the tool:
PT2S.1, PT2V.2, PT2V.5, T2V.1, T2V.2, B2V.1, B2(S)V.2, PT2V.1, C1V.2, C2V.2
Meshing and Weld Setup
With v/s Without WSP Tool

**Without WSP Tool**
- Cut geometry to add joint preparations
- Manually calculate number of weld passes per joint
- Draw 2D cross sections of individual weld beads for each joint
- Extrude/sweep weld beads along trajectories
- Split plate geometry to match weld joints for structured mesh
- Create structured mesh manually
- Inspect mesh for errors or poor elements
- Create groups and sets for weld material and trajectories
- Create and assign tack welds
- Assign weld material to all welds and structure
- Assign weld process data manually for each bead of every joint

**With WSP Tool**
- Populate weld process plan (WPP) spreadsheet from existing data
- Import CAD geometry and WPP
- Automated joint/bead creation, mesh generation, set/group assignment, tack welds, material assignment, and weld process assignment

**Without WSP automation, meshing & model preparation can take weeks to months**

**With WSP automation, meshing & model preparation takes minutes to hours**
Automated Meshing
Large Assembly
Sequence Manager

Initial Weld Sequence –
Table of Runs

Distortion amplitude (inches) magnified 10x for visualization
Optimization

- Optimization analysis is now possible with the WSP tool
  - Optimization builds on previous runs

- Blocking capability is critical to practical optimization results
  - Otherwise, optimization may require part flips every other weld
  - Blocking also reduces the total number of variables and runtime

- Optimization uses a two layer optimization approach
  - Block Optimization: Get the best order of the blocks which minimizes deformation
  - Weld Sequence: Based on the best block order, optimize the sequence of the welds within the blocks to minimize deformation

- The output is a table of runs and a text file (csv file) with the best weld sequence.
Optimization Results

Initial Sequence

Optimized Sequence

~15% reduction in distortion amplitude

Distortion amplitude (inches) magnified for visualization

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Benefits

• The Weld Sequence Planning tool is a commercially available tool to help develop weld sequence/build plans
  • Uses a CAD-neutral approach for geometry and associated joint data
  • Reduces time to set-up, run, and obtain results by over 5x baseline analysis
  • Allows for optimization of weld sequencing, clamping considerations
  • The WSP tool and training is available now for purchase from ESI
• Reduces the trial and error of distortion reduction predictions
• Reduces distortion mitigation operations, improving throughput
• Supports vision of driving toward a continuous flow of digital information from the CAD model to shop floor production
• Supports development of input necessary to implement robotic welding initiatives.
Near Term Activities

• GDEB is performing validation of a tank structure using the Weld Sequence Planning Tool
  • Documenting validation findings
  • Determining cost benefit and Return on Investment
• NMC is performing analyses and optimization on the sample problem
  – To confirm that the initial results match the results with the new tool enhancements
  – To determine optimization recommendations.
• ESI is providing support through GDEB/NMC validation
  – Users Guide is being finalized by ESI
• The project team will document project results in a Project Final Report (June 2017).
Future Enhancements

• Enhancements Beyond This Project
  • Additional Structure and Joint Types
    – Assemblies with structural shapes (I beams, C channels, angles, etc.) are not currently compatible with automatic meshing
      – Other structures can still be analyzed and optimized with the tool, but not with the full level of automation available for plate structures
      – Recommend incorporation of deck-like structures next
    – Pre-Cambering is not easily modeled with the current tool
    – Expand database of MIL-STD-22D Joints
  • WSP output could directly feed into the inputs required for robotic welding
    – Enable advancement of robotic welding
Additional Information

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- Charles Fisher, NSWCCD, (301) 227-4969
- Yogendra Gooroochurn (San), ESI, (248) 381-8706
- Jonathan Finley, GDEB, (401) 268-3578
Areas of Software Development

**CAD Import and Meshing**
- Automatic bead creation from user-defined weld trajectories (including multi-bead and multi-pass joints)
- Quick meshing of weld beads for typical weld joints
- Simpler meshing tools for semi-automated assembly meshing

**Setup and Solution**
- Automated creation of tack welds using weld joints
- Weld process database and automated joint/bead setup

**Optimization**
- Create Optimization Workflow (Local Minima Distortion)
- Blocking of variables and joints for optimization to represent stages of construction and address flipping/accessibility

**Post Processing**
- Improvement and simplification of Visual-Viewer
- Templates for easier post processing of distortion and shrinkage
- Determination of desirable weld sequence
Practical Usage of the WSP Tool

• Intended for:
  • Plate structures
  • Approximate distortion magnitudes
  • Production planning/support
  • Distortion trend data
  • Weld sequencing
  • Part flips with gravity
  • Clamping evaluations
  • Preheating

• NOT intended for:
  • Structures with shapes (I beams, channels, etc)
  • Exact distortion prediction
  • Transient analyses
  • Residual stress / fatigue
  • Detailed joint designs
  • Microstructure
  • Flame straightening
  • Precamber

• Very experienced FEA users can perform many of the “NOT intended” analyses with the existing software but will not benefit from all of the ease of use enhancements

• Future projects could expand the intended “simple mode” capabilities.