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END-EFFECTOR FOR ROBOTIC ASSEMBLY OF WELDED TRUSS STRUCTURES IN SPACE

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INTRODUCTION

In June 1987 work was initiated at LaRC on end-effectors and preloaded joints for robotic truss assembly. This is part of an on-going research effort centered on a test facility that assembles 1"x 2m identical struts into an 8m diameter x 1.5m deep platform truss. A detailed description of the test facility was published (2).

The end-effector being used for the LaRC assembly demonstration is quite suitable for the Precision Segmented Reflector or other precision applications. These require high stiffness provided by mechanical joint preloads. Stiffness thus obtained is only required and provided over a load range far less than the ultimate strength of the strut tubes. Beyond this useful range, truss behavior is somewhat unpredictable.

THE PROBLEM

Mechanically preloaded joints of this type are less suitable for applications such as the Aero Brake where predictable strength and stiffness are required over a greater fraction of the load bearing capacity of component parts.

Preliminary studies of the Aerobrake support truss indicate that struts of at least 3 different diameters and various lengths would improve performance (3, p.3.1.1.2-3). The double-ended end-effector in service currently is designed for only one diameter and length. Anticipated single-ended versions can accomodate varing lengths but not multiple diameters.

THE WELDED ALTERNATIVE

Tradeoff considerations for welded joints relative to their mechanically preloaded counterparts:

Advantages -

1. High Strength & Stiffness / Mass
2. Preload Not Required
3. Predictable Behavior, linear in both tension and compression to the material proportional limit.
4. Simplified Low Mass Strut-End

Disadvantages -

1. Bulky Complex End-Effector
2. High In-Orbit Power Demand
3. Modest Environmental Contamination
    a. Gas (inert and metalic)
    b. Particle (metalic / repair mode only)
4. Inspection Difficult

WELDED JOINT TYPES

Joints proposed by the MSFC Structures Group for automated assembly of welded truss structures have been placed into four representative catagories. Each catagory was evaluated based on the items listed below. The fractional representation of "Alignment" shows the division of alignment effort between strut-end and end-effector corresponding to the usual six degrees of freedom. Progressing from catagory 1 to 4 , joint structural performance is degraded as the joints become more complex. Complexity in the joint reduces tasks that must be performed by the end-effector thus simplifing it. The tradeoff is an inverse relation between strut-end and end-effector complexity. Also note that only catagories 1. and 4. do not require special struts for the repair mode. This advantage supposes that the weld seam can be cut and rewelded on the original weld site.

1. Simple Butt Weld Joint -

Strength / Mass: best
Stiffness/ Mass: best
Alignment
    end effector: 6 / 6
    strut end: 0 / 6
Grasp Sites / End: 2

Weld Seam: continuous, circular
Welds / Strut: 2
End-Effector:
    double-ended
    variable length
Special Struts for Repair: NO

2. Butt or Lap Weld with Threaded Sleeve -

Strength / Mass: good
Stiffness/ Mass: good
Alignment
    end effector: 1.5 / 6
    strut end: 4.5 / 6
Grasp Sites / End: (n + 2)
    where n = repair sites

Weld Seam: continuous, circular
Welds / Strut: 4
End-Effector:
    double-ended
    variable length
Special Struts for Repair: YES

3. Butt or Lap Weld with Turnbuckle -

Strength / Mass: average
Stiffness/ Mass: average
Alignment
    end effector: 1 / 6
    strut end: 5 / 6
Grasp Sites / End: (n + 2)

Weld Seam: continuous, circular
Welds / Strut: 4 or 5
End-Effector:
    single ended
Special Struts for Repair: YES

4. Butt Weld with Slip Joint -

Strength / Mass: fair
Stiffness/ Mass: fair
Alignment
    end effector: 0 / 6
    strut end: 6 / 6
Grasp Sites / End: 1

Weld Seam: 2 eliptical segments
Welds / Strut: 2
End-Effector:
    single ended
Special Struts for Repair: NO

SLIP JOINT

Joint type 4 was chosen for initial development because it allows the simplest and lowest mass end-effector. The " slip joint " required for welded assembly is a modification of the one under development at MSFC (3, p.3.1.1.3-8). Two modifications are required:

1. the flat circular cross-sectional interface separating strut from node must be tilted 5.7 degrees wrt the strut axis to make the strut-end virtually double-action. A description of the nature and benefits of double action strut-ends has been published (3). Briefly, they allow assembly to continue when the node spacing is more or less than anticipated.
2. the interface to be welded should present to the welding torch a material thickness of not more than 1/4" for a high quality weld seam.

END-EFFECTOR

A design to assemble and weld the joint described above would incorporated the following:

Features -

1. Simplified low mass strut-end.
2. Modified " slip " joints are virtually "double action".
3. Range of strut dimensions can be manipulated:
   Diameters from 2.25" to 6.0"
   Lengths variable (single-ended end-effector)
4. Struts retrievable from a hexagonal-close-packed tray.

Specifications -

5. End-Effector Envelope (including repair subassembly)
   Axial Length: 3'
   Transverse Depth: 2'
   Transverse Width: 1'
6. Strut-End Dimensions
   Diameters: 2.25" to 5.0"
   Length: 2.0' to 2.5' (plus scar length)
7. Torch Travel
   Axial: 2.5"
   Radial: 1.5"
   Orbital: +/- 190 degrees

Components and Subassemblies -

(* indicates subassemblies that can be eliminated if only one strut diameter must be accomodated)

I. Weld Functions -
   1. Torch - Plasma arc welding adaptation planned.
      (contract with Electric Propulsion Laboratory)
   2. Shielding (line of sight containment)
      a. Hood (semi-cylinder)
      * b. End Curtains (semi-iris)
   3. Torch and Shield Motions
      * a. Radial
      b. Orbital
      c. Axial
   * 4. Torch Assembly Retractor
   5. Torch Supply Line Dispenser

II. Strut Manipulation Functions -
1. Retrieval and Location (stud inserted into Zip-Nut)
** 2. Release Plunger (push off from Zip-Nut)
3. Nodal Scar Aquisition (slip joint lock bolt driver)
* a. Slip Joint Lock Bolt Insertion
b. Slip Joint Lock Bolt Torque

III. Repair Functions -
1. Stearable Saw (like inboard-outboard boat drive)
2. Inertial Chip Collector
(impeller integral with saw drive shaft)
3. Saw and Collector Motions
(components are mirror images of items
I.3 and I.4 above)

SUMMARY

Compared to robotically assembled & preloaded mechanical joints, welded joints:
1. have higher strength and stiffness for any given mass,
2. exhibit linear behavior to the failure load of components,
3. are relatively permanent and not as easily repaired.

End-Effectors devised to assemble welded joints:
1. will be less complex and massive if a simple mechanical joint is employed to facilitate alignments,
2. can accomodate struts of varing diameter and length,
3. will be able to repair and replace failed members,
4. allow very compact launch packaging of strut components.

CONCLUSIONS

Repair by cut and re-weld on the original weld site should be researched. Repair complexity would be significantly reduced.

Welded joints, though repairable, should not be used where high repair frequencies are anticipated.

Welded joints should be considered for an Aero Brake truss.

REFERENCES

(1) Brewer, W. V.,"Simplified Double Action Mechanism to Preload Joints for Robotic Assembly of Structures in Space", NASA/LaRC/HBCU Grant No. NAG-1-1125, proceedings of 14th IASTED International Symposium on Manufacturing & Robotics, Lugano, Switzerland, 6/25/91.

(2) Rhodes, M. D., Will, R. W., Wise, M.,"A Telerobotic System for Automated Assembly of Large Space Structures", NASA Technical Memorandum 101518, LaRC, Hampton VA 23665, 3/89.

(3) Thomson, M., ORBITAL CONSTRUCTION DESIGN DATA HANDBOOK, AAC-TN-1160, for NASA/LaRC, NAS1-18567, Task 7, Astro Aerospace, Carpinteria CA 93013-2993, 4/30/90.