WORK PLAN DISCUSSION

Topics

- BSC Stack Schedule
  - Overview Of Major Tasks Completed
- Technical Baseline For BSC
  - Stack Geometry
  - Downtube/Optics Plate
  - Scheduled Activities
- Damped Metal Spring Concepts
- SEI Task Elements
  - Base Support Concept
  - Design Issues
- Proposed Work Plan Modifications
  - New Work Plan Structured To Provide An Integrated SEI Design
  - Schedule Discussion Interwoven With Baseline Presentation

LIGO-G960173-00-D

COMMENTS ON GENERAL STATUS

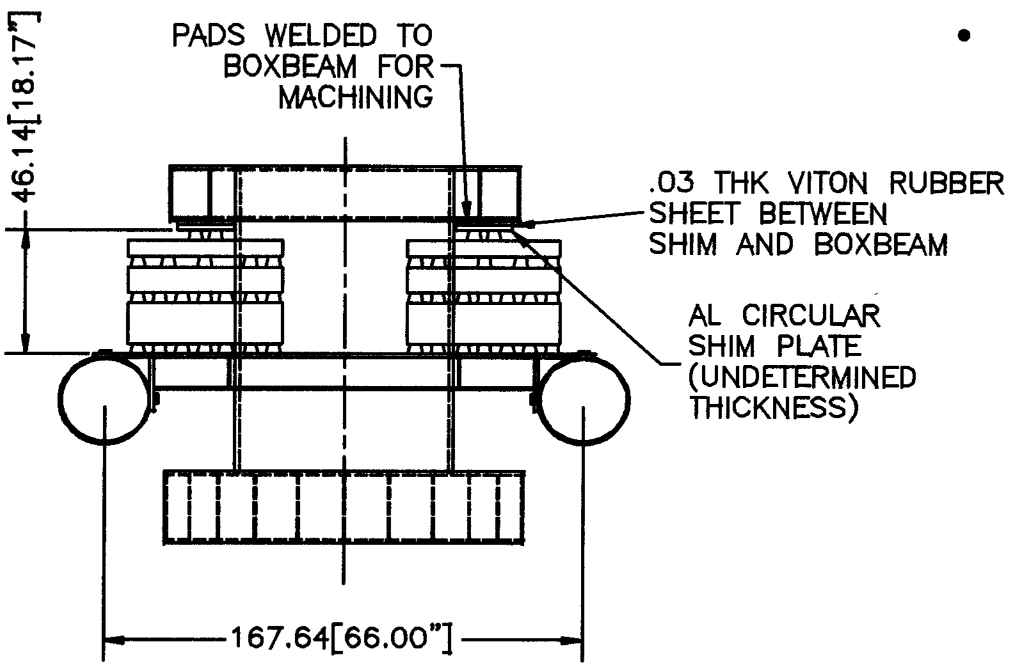
- Major Tasks Completed
  - BSC Stack Performance Predictions
    - VITON And Two Damped Metal Spring Concepts
    - Reflects Latest Downtube Structural Design
  - BSC Structural Modeling(FEA)
    - Simplifications Made To Basic Structure
  - Conceptual Design Layout Of BSC
    - Downtube/Optics Plate
    - Leg Elements
    - Base Support Structure
  - BSC SEI Design Initiated
    - Initial FEA Of Base Support Structure
    - Vacuum Interfaces(Hopefully Solved)
    - Key Assembly Steps Defined For BSC Stack
  - Preliminary Predictions Of BSC SEI Performance
    - Provides Insight To Dynamic Stiffness
      - Base Support, Piers, and Actuators
  - FEA Of HAM Optics Plate

HIGHLIGHTS OF PROPOSED ACTIVITIES

- **Expand Engineering Design To Include SEI For Both The BSC And HAM**
  - Activities Would Encompass Structural And Mechanical Design Of All Related Components
    - Construction Drawings
    - Participate In Prototype Testing
  - Isolation Performance Predictions
    - Stack Performance
    - Effects Of Base Support, Actuators, And Piers
  - Manufacturing Liaison
- **Design And Development For SEI Coarse And Fine Actuators**
  - Provide Final Construction Drawings, Selection Of Commercial Components
  - Participate In Prototype Testing (Where Applicable)
  - Manufacturing Liaison

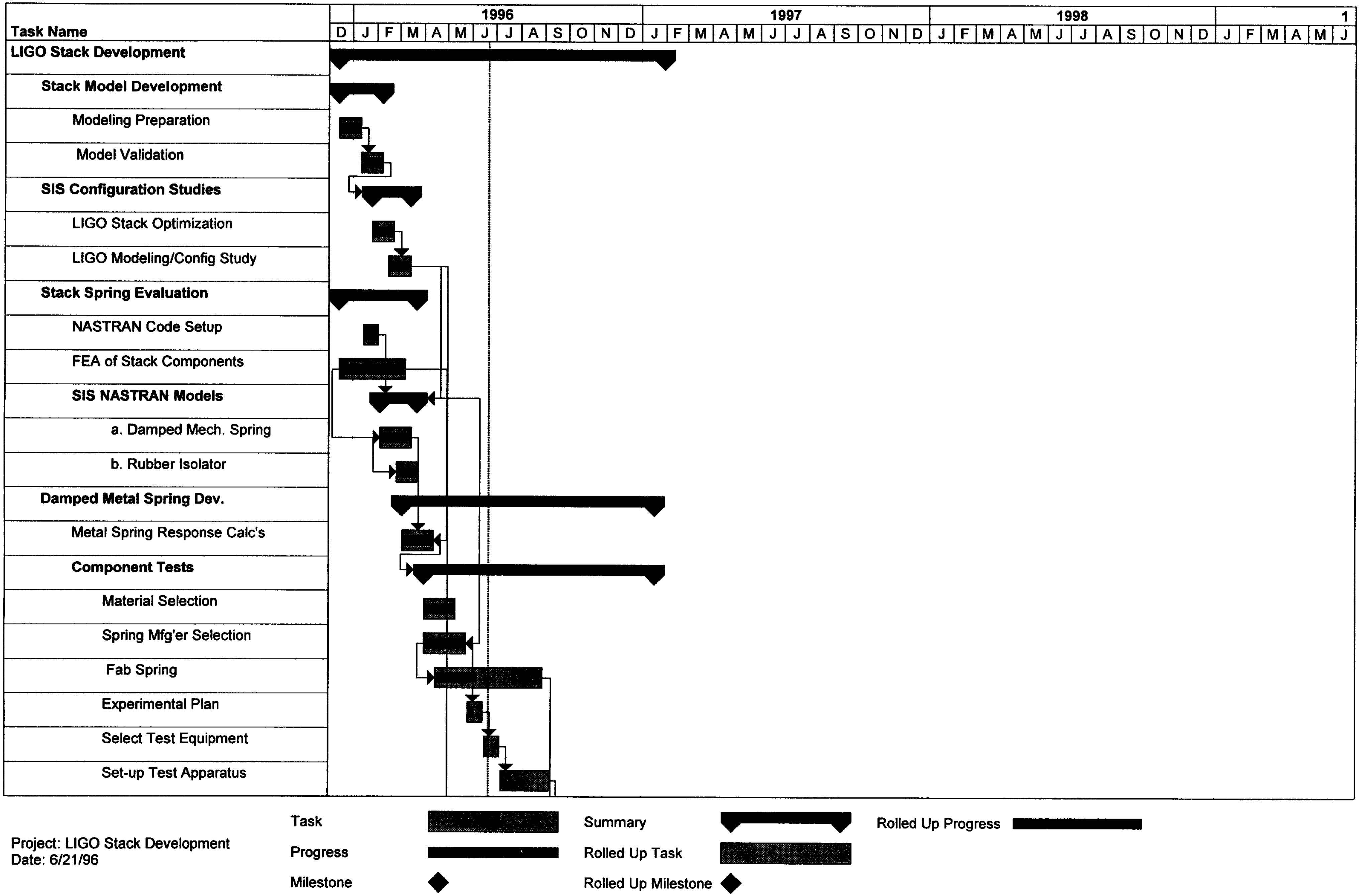
BSC STACK BASELINE DESCRIPTION - VITON SPRINGS

- **BSC Stack**
  - **Four Leg Elements, SS Material**
  - **Standard VITON Spring Concept**
  - **116 Springs**
  - **One Piece AL Downtube Structure**



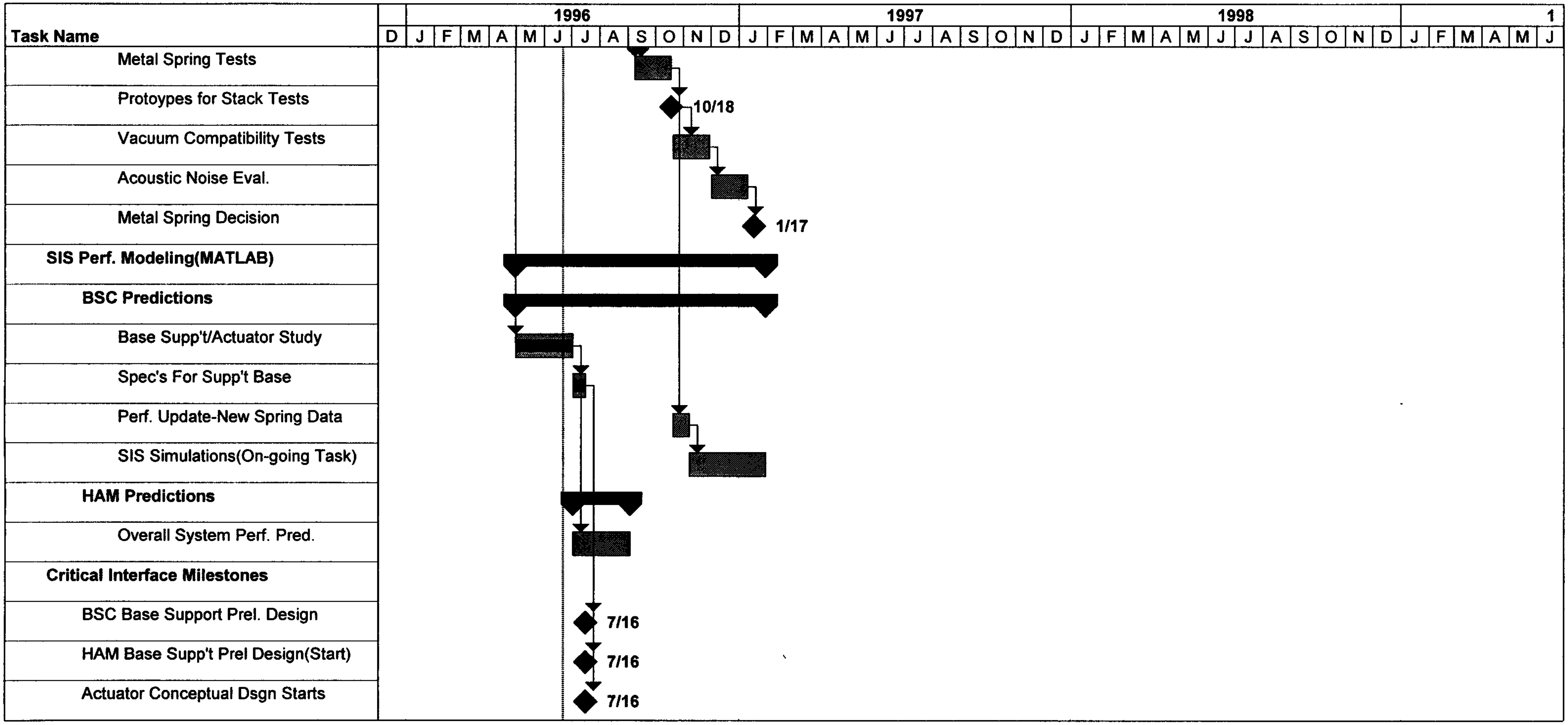
- **Total System Mass - 2813 kg**
  - **Downtube 376.1 kg**
  - **Leg Elements 2210 kg**
  - **Payload 226.9 kg**
  - **(6200 lbs vs Original 13499 lbs, And 270 Springs)**
- **Why 4 vs 3 Leg Stack?**
  - **Performance Differences Are Small**
  - **Downtube Shorter By ~33 %, Stiffer Structure**
  - **Less Mass, When Allowance Made For Downtube Length Differences**
  - **Loads On Base Support Structure More Symmetrical**
  - **Cost Not Significantly Different**

Attachment A



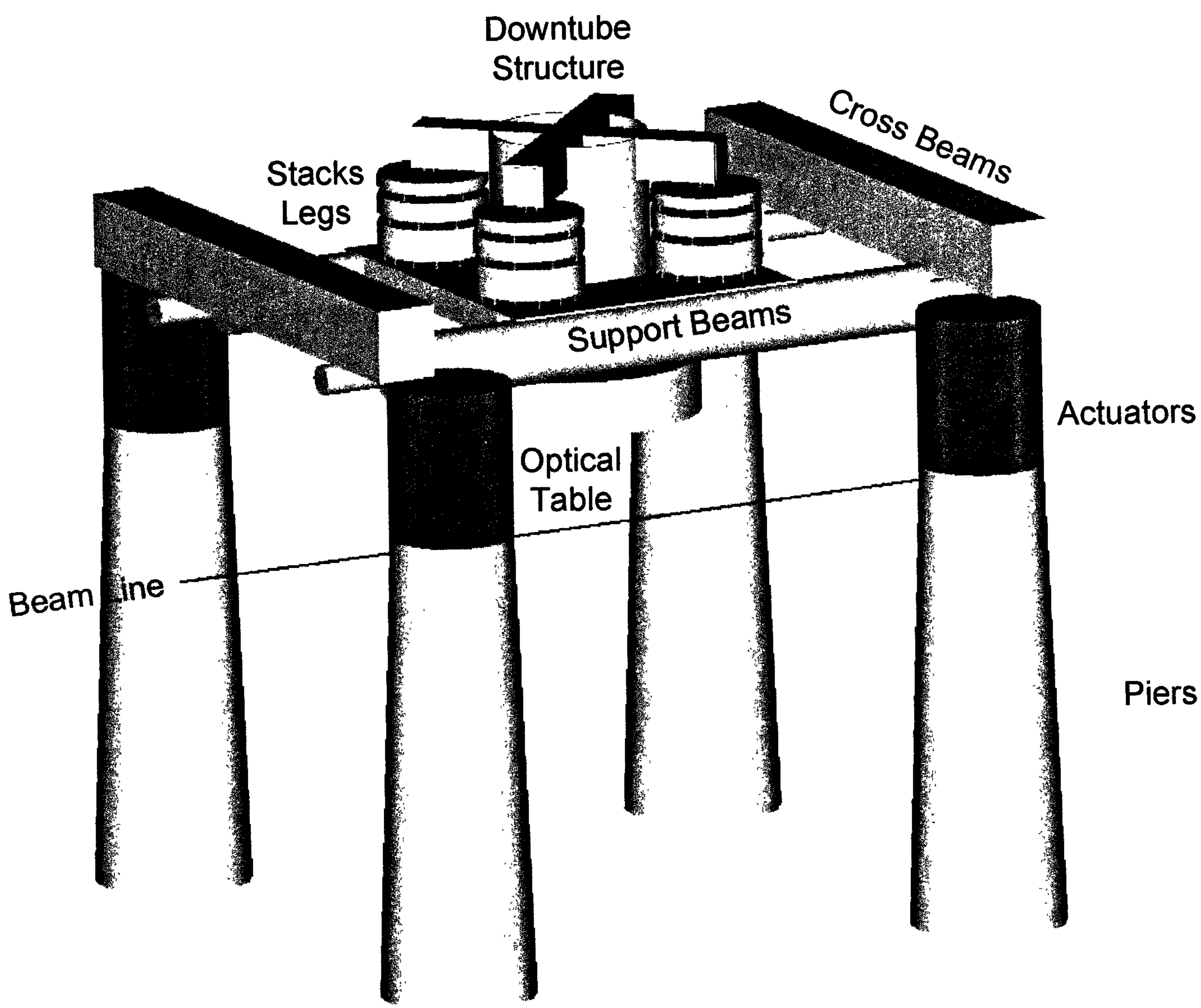
Project: LIGO Stack Development
Date: 6/21/96

Attachment A

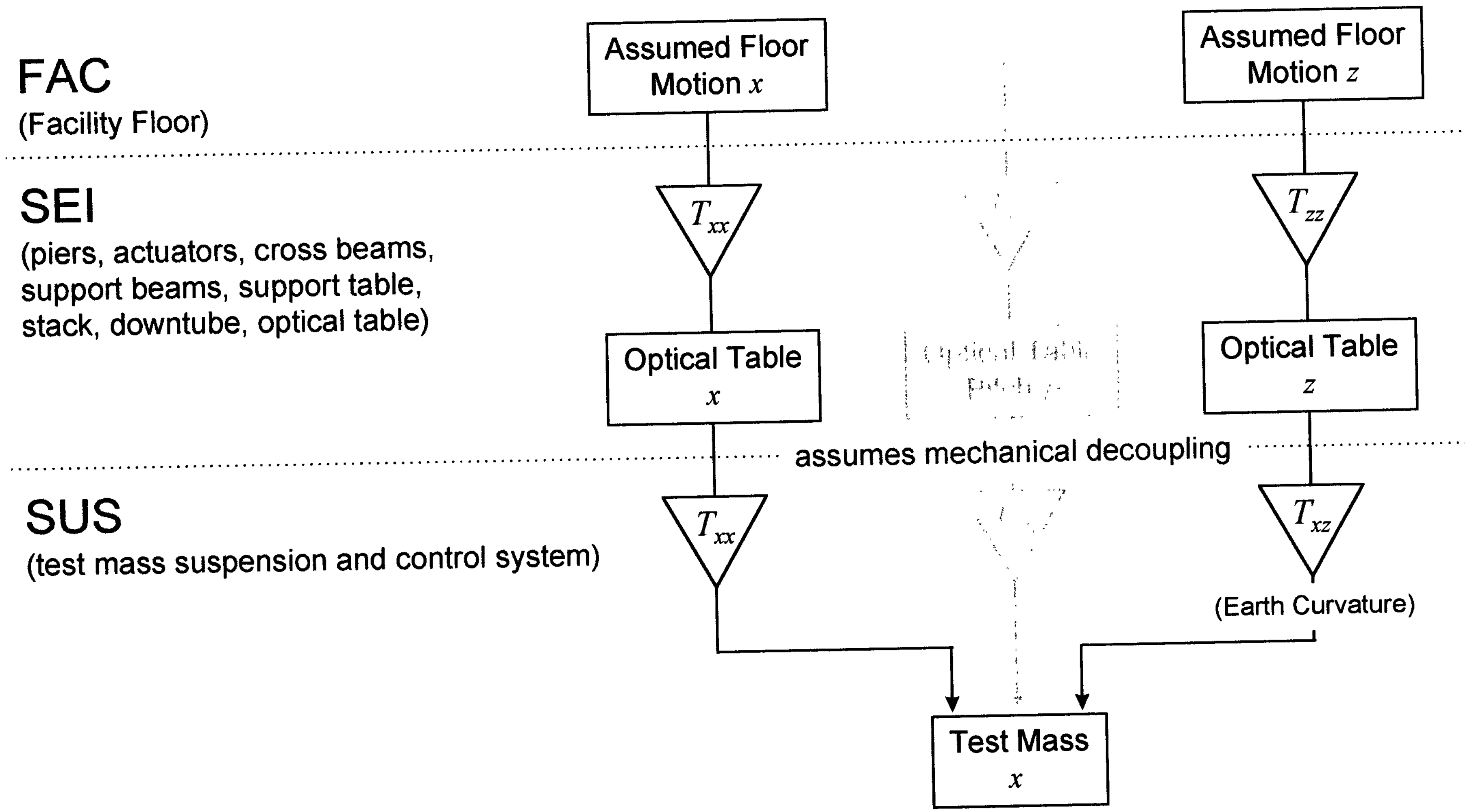


Project: LIGO Stack Development
Date: 6/21/96

BSC Stack Layout



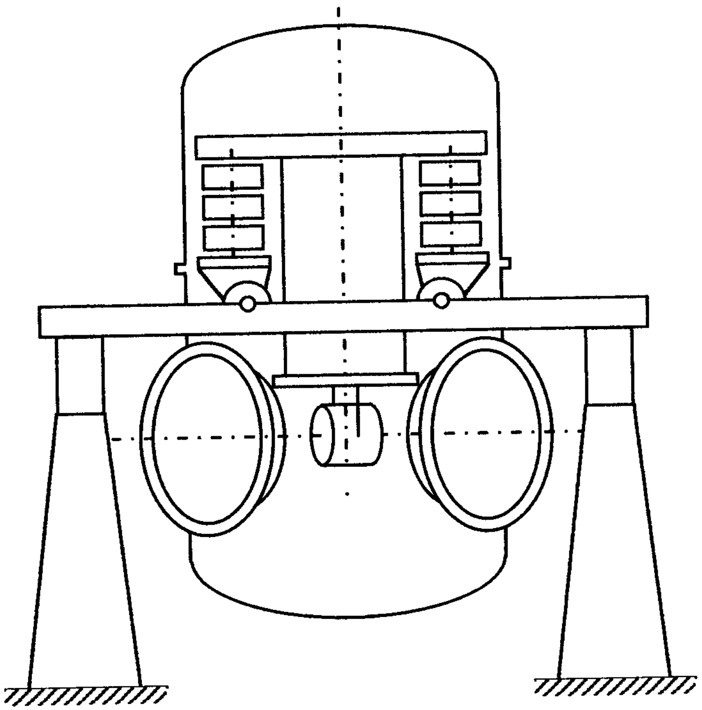
“Complete” System Modeling



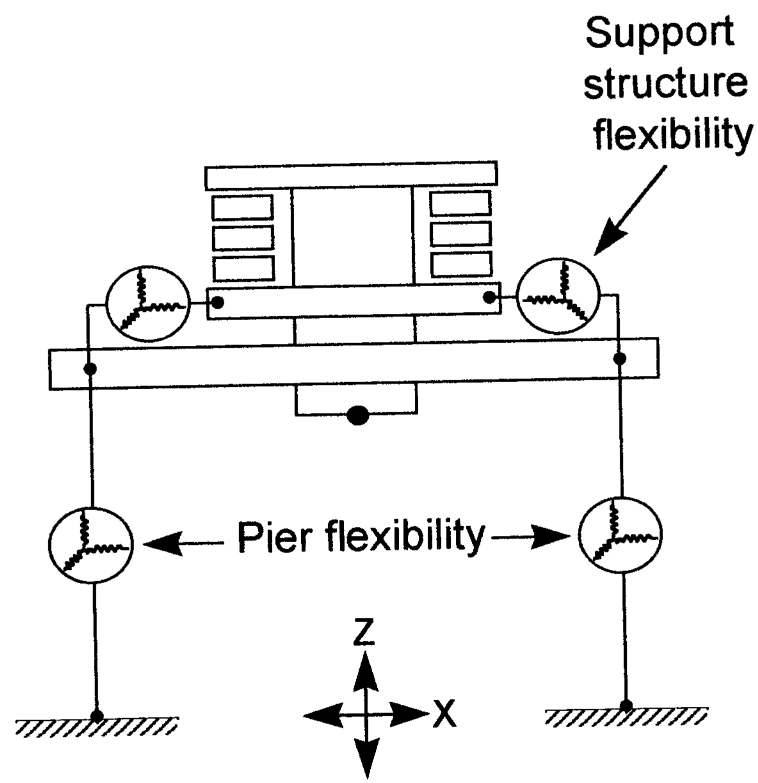
Support Flexibility

Piers
(Tall Columns)

Support Structure
(Cross beams, support beams, support table)

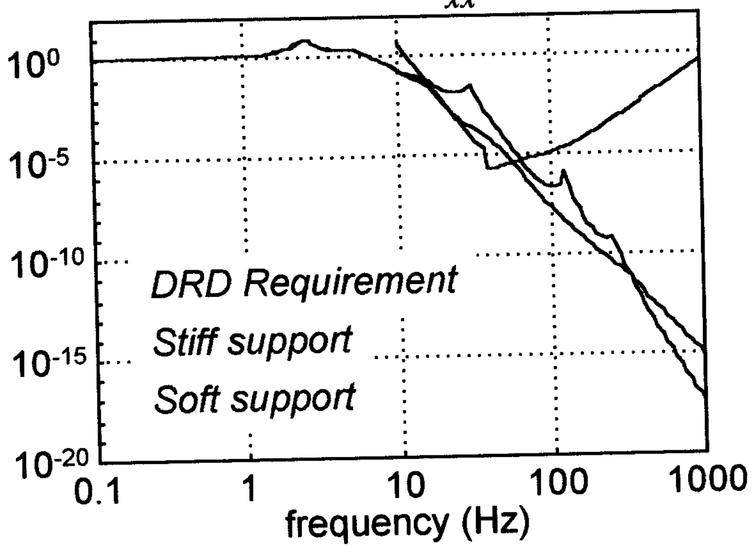


Two rigid bodies
Two sets of four 3D springs
12 d.o.f.

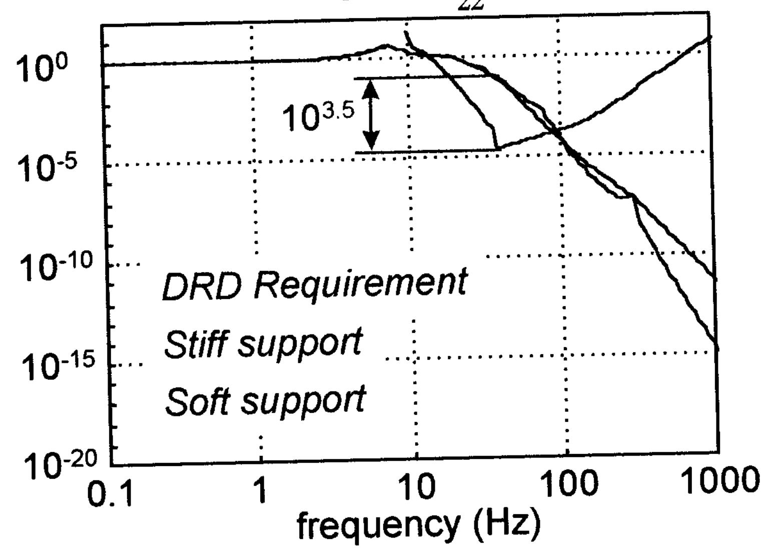


BSC Performance with VITON springs

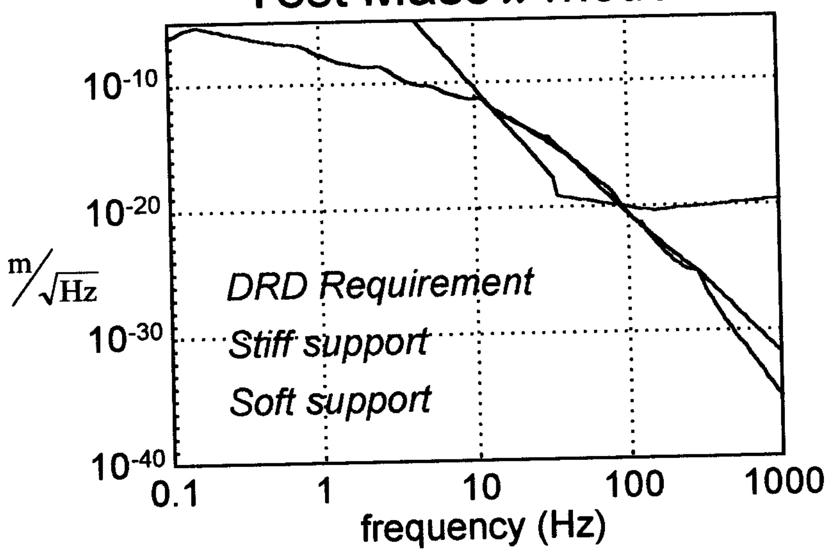
SEI T_{xx}



SEI T_{zz}



Test Mass x motion



Lock Acquisition

(test mass kinetic energy)

$v_{RMS} = 1.195\ \mu\text{m/sec} \sim 1\ \mu\text{m/sec}$

Lock Maintenance

(SUS actuator force rating)

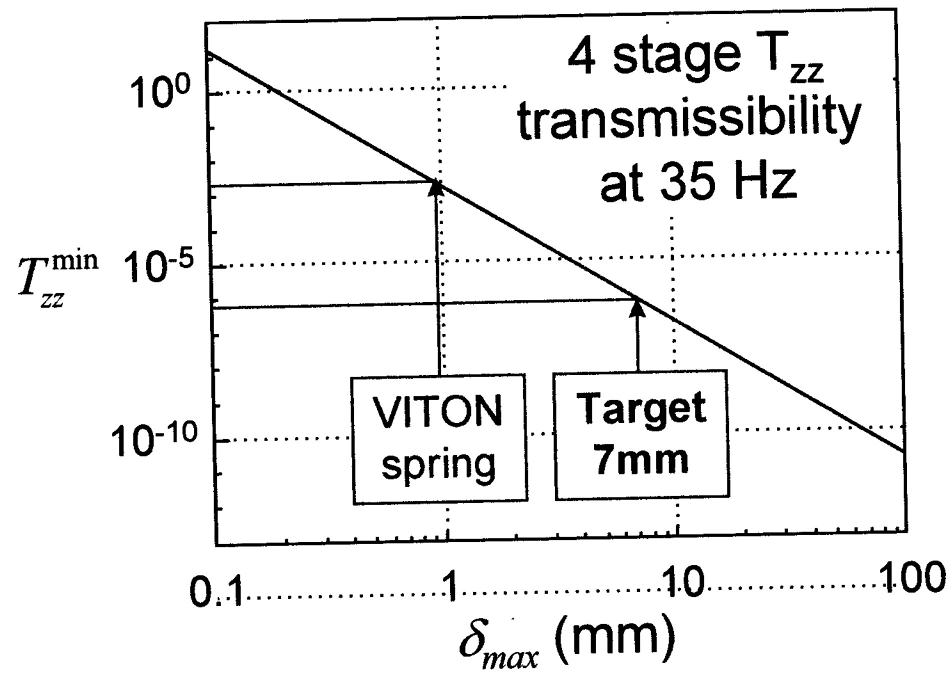
$\chi_{RMS} = 2.085\ \mu\text{m} < 2.7\ \mu\text{m}$

HYTEC

Performance VS Spring Design

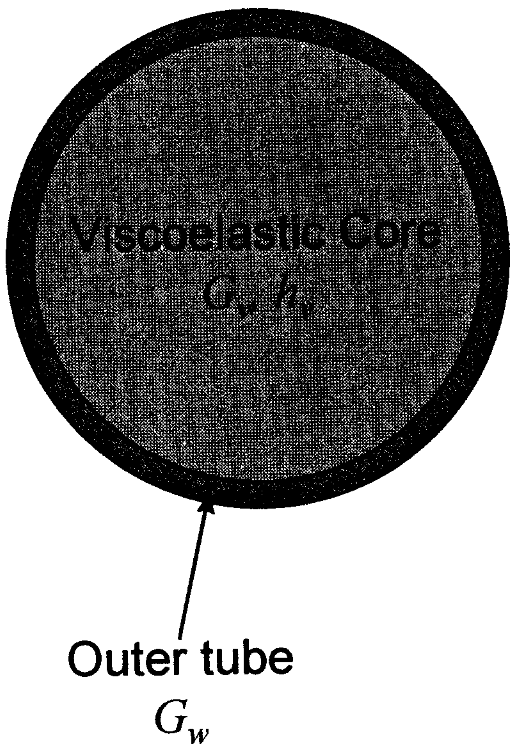
- T_{zz} performance determined by spring design

$$T_{zz}^{\min}(f) = \left(\frac{g}{4\pi^2 f^2 \delta_{\max}} \right)^n$$



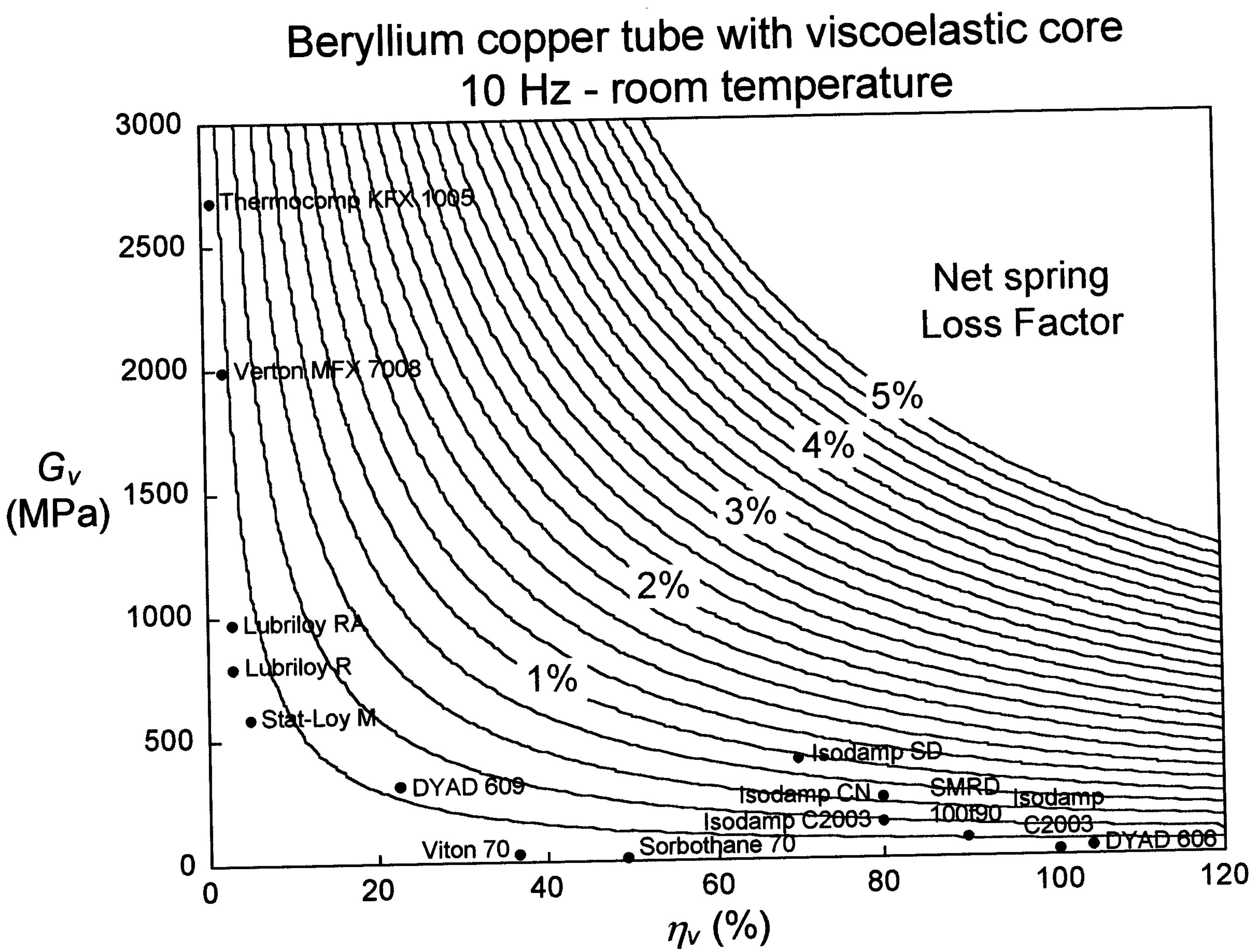
where $\delta_{\max}(f) \equiv \dfrac{P_{\max}}{k_{ax}(f)}$ = *"characteristic deflection"*

Concept



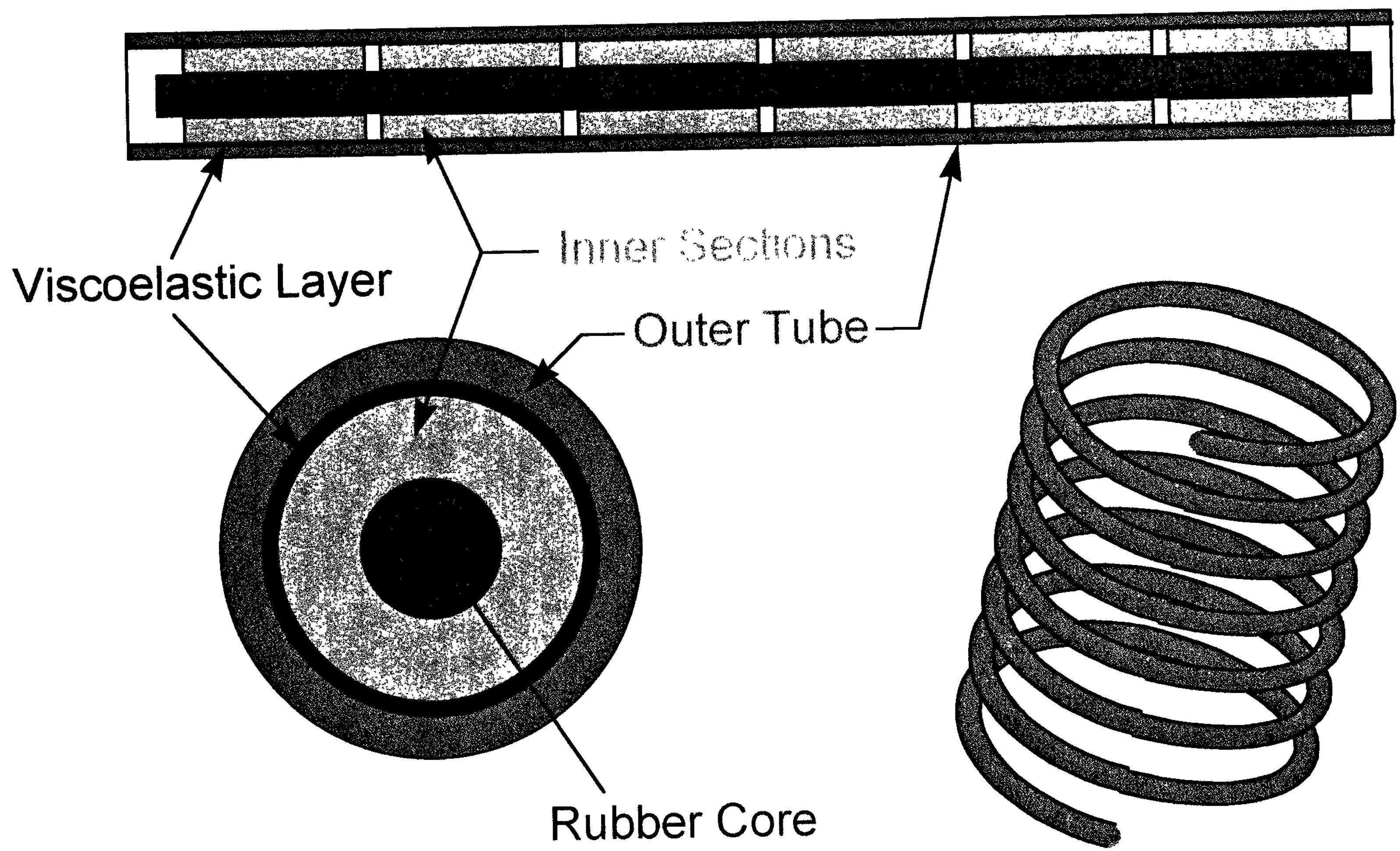
- Outer tube designed to take the static load
  (core: creep, low modulus)
- Design of hollow tubular spring:
  - BeCu tube (age hardened after coiling)
  - 9mm OD x 0.5mm Wall, mean coil diameter ~50mm.

Net Spring Damping VS Core Properties

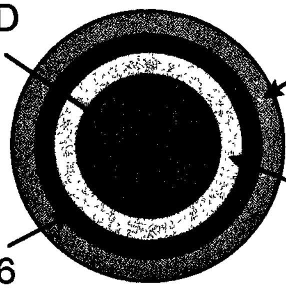


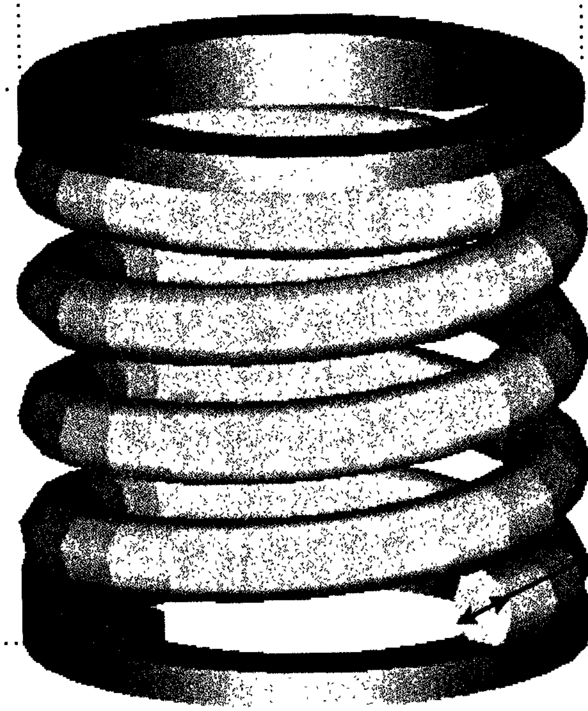
HYTEC

Concept



Design

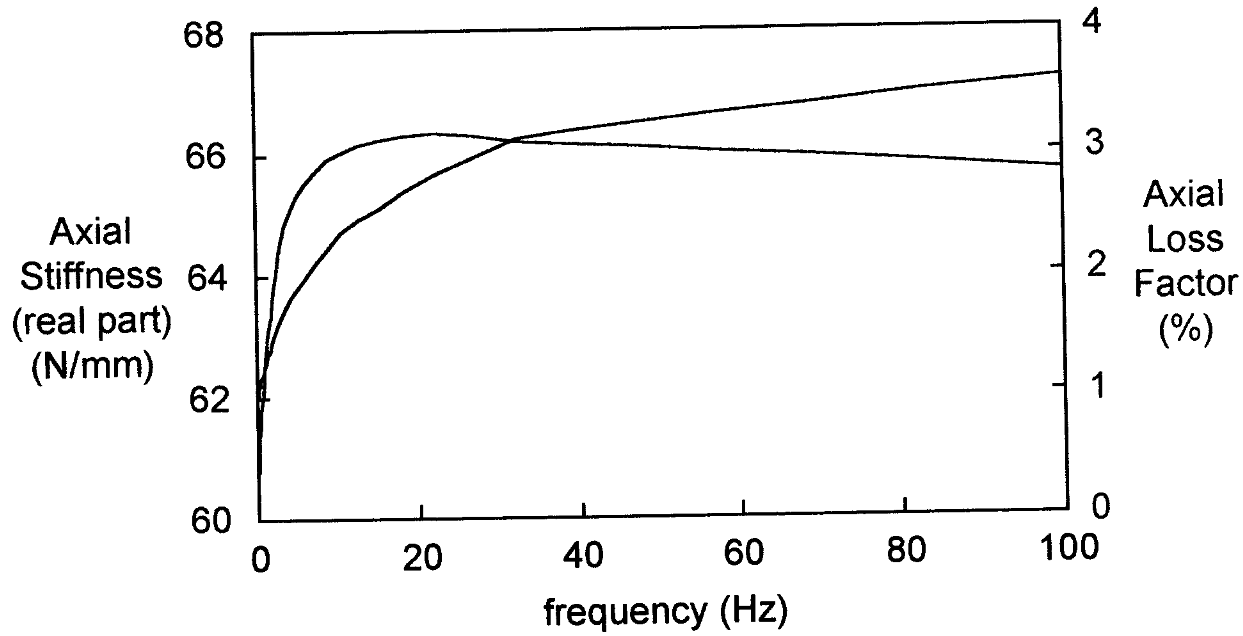




- Outer tube: Ph Bronze
  (high yield, low relief t°)
- Inner tubes: Aluminum
  (pliable)
- Viscoelastic Layer: Soundcoat DYAD 606
  (thick but stiff, high loss 105%)
- Design Optimization:
  - adjust cross section & coil geometry
  - maximize loss factor

Expected Performance

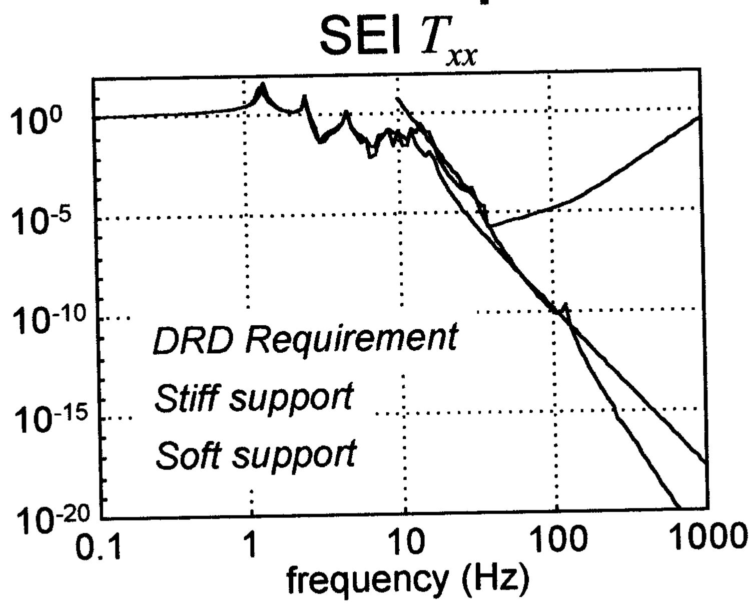
- Static Load Capacity: P_{max} = 445 N = 100 lbs
- Dynamic Stiffness and Damping

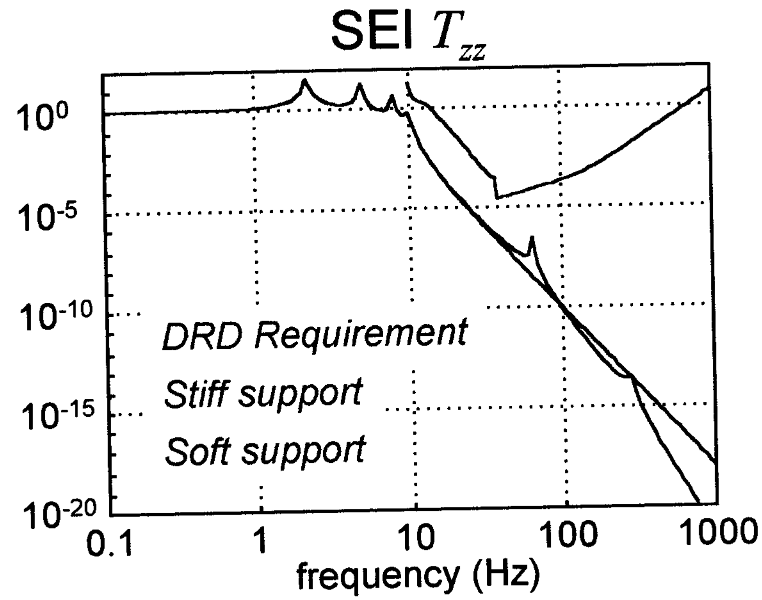


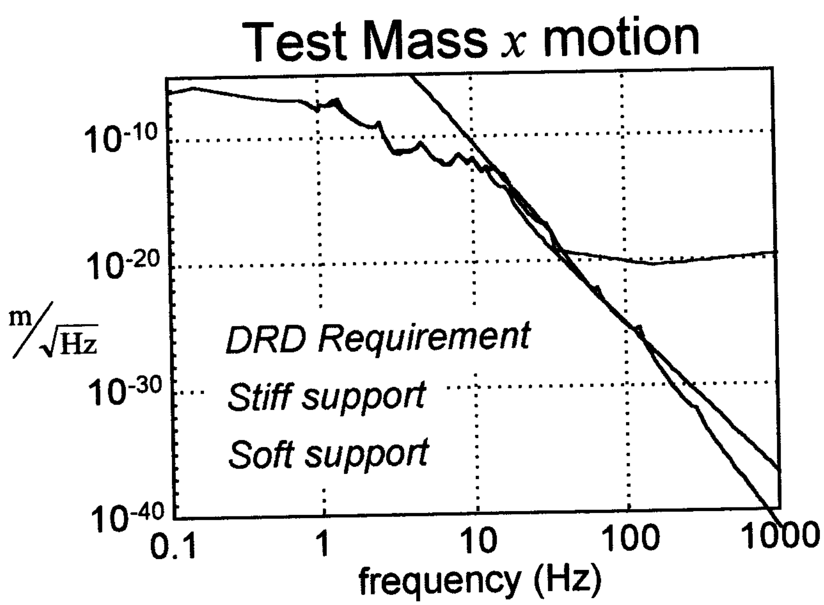
- Characteristic deflection @ 35Hz: δ_{max} = 15 mm
- Resonance: f_1 = 400 Hz

HYTEC

Expected Performance







Lock Acquisition

(test mass kinetic energy)

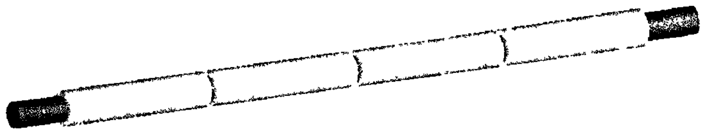
$v_{RMS} = 1.257\ \mu m/sec \sim 1\ \mu m/sec$

Lock Maintenance

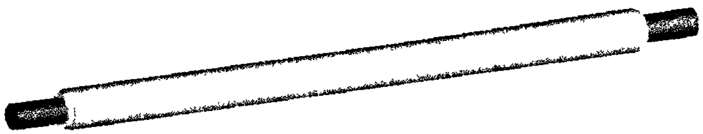
(SUS actuator force rating)

$\chi_{RMS} = 2.287\ \mu m < 2.7\ \mu m$

Manufacturing

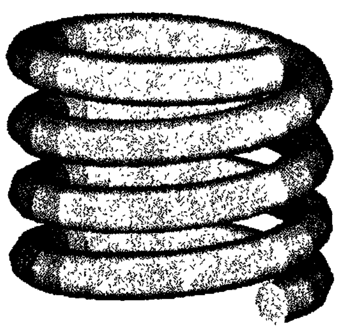


- swage Al tube sections on rubber core



- wrap with viscoelastic sheet (adhesive?)

- insert in Ph.Br. tube and swage (adhesive?), stress relief



- coil, weld caps, stress relief

Prototyping & Testing

- Rubber Filled PhBr Coils

  Coiling specimens made from 4 different tempers of PhBr (annealed, 1/4 hard, 1/2 hard, 3/4 hard), with solid rubber fill (no CLD layers)

  - manufacturing
    - PhBr tube cracking VS temper
    - Spring-back
    - Partial stress relief (temperature, duration)
  - Static axial load capacity
    - Permanent set
    - End coils & seat design
- Multi-Layer CLD Tube
  - manufacturing
    - Alignment & spacing of inner tube sections
    - Swaging tolerances
    - Visco layer wrap / adhesives

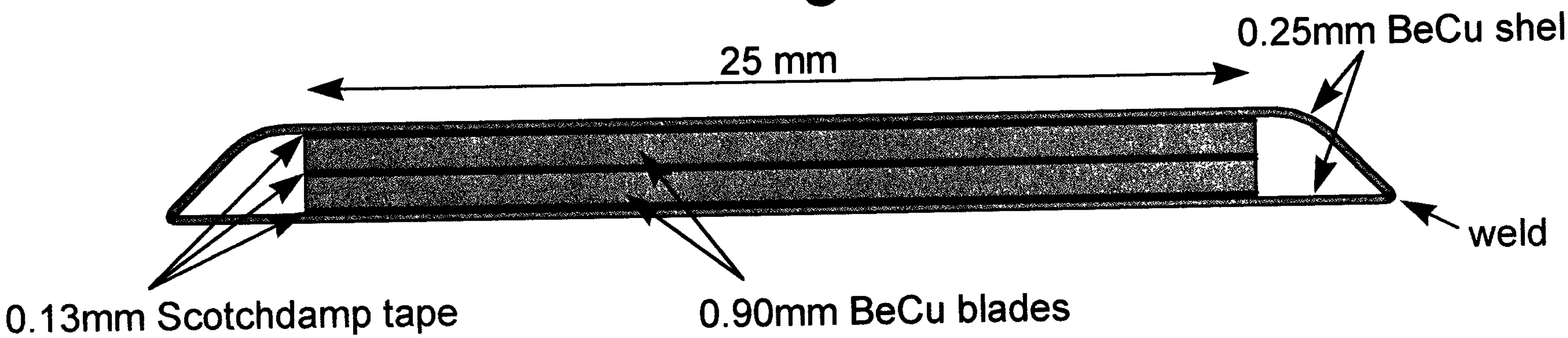
Prototyping & Testing (continued)

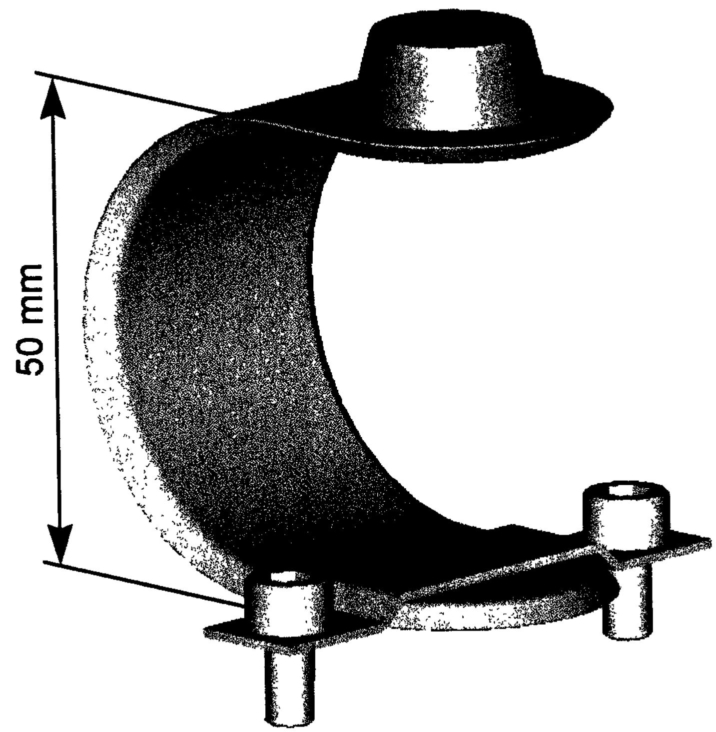
- Coiled CLD Spring
  - Manufacturing
    - Inner tube wrinkling
    - Breakage of adhesive bond, gaps
    - Vacuum caps
    - partial stress relief
  - Static load capacity & creep
    - breakage of adhesive bond
  - Stiffness, Damping, Resonance
    - single stage, 3 springs, modal tests (in air)
    - stack performance update
  - Creak under load
    - loaded spring hung in vacuum chamber, monitor microphone signals

Prototyping & Testing (continued)

- Acoustic transmission
  - spring in vacuum chamber piezo exciter on one face plate, microphone measurement on other
- Small amplitude damping & stiffness testing (?)

Design

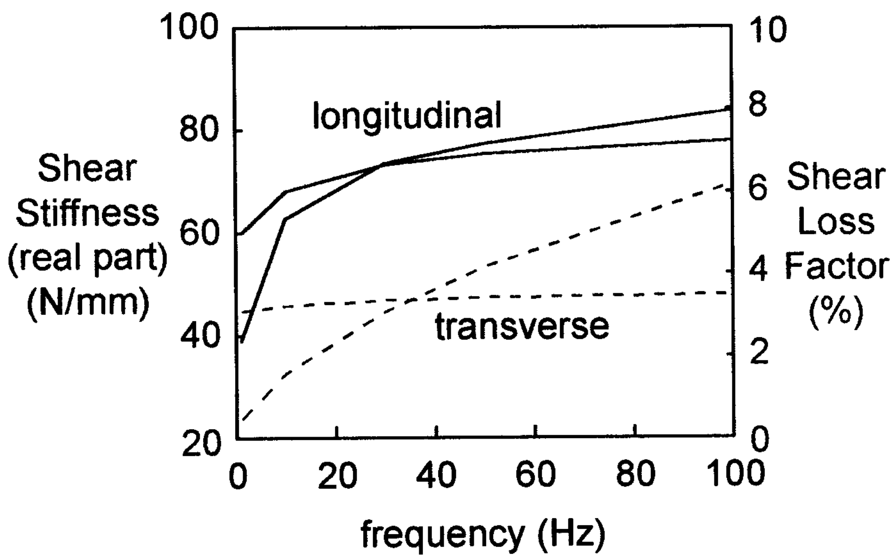


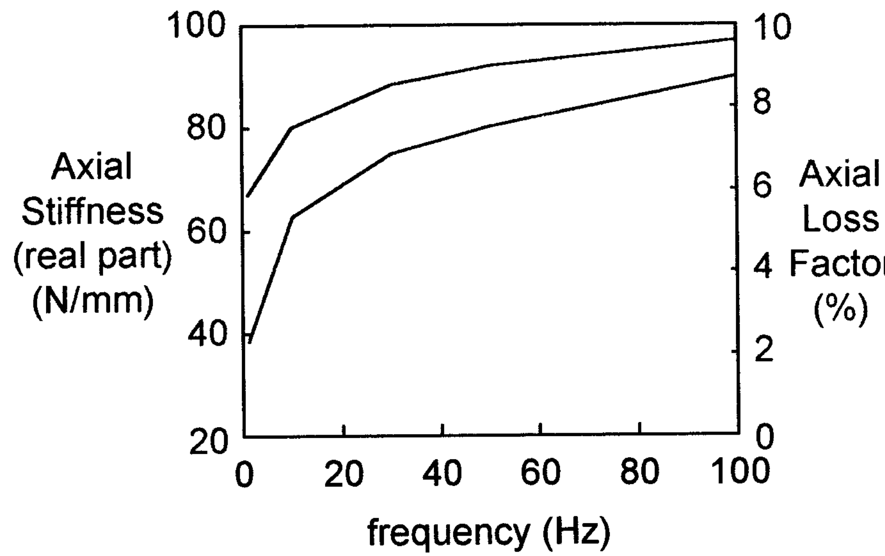


- Material: Beryllium Copper
  (high yield, pliable, age hardening)
- Viscoelastic: 3M Scotchdamp
  (thin, soft, self adhesive, high loss)
- Clamped at base
  (stability)
- Viton pad at tip
  (angular freedom, acoustic transmission)

Expected Performance

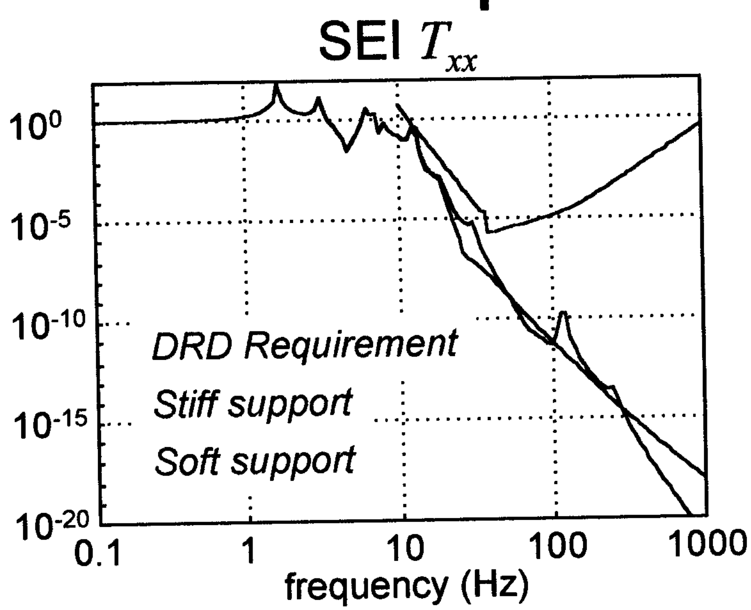
- Static Load Capacity: P_{max} = 556 N = 125 lbs
- Dynamic Stiffness and Damping (NASTRAN)

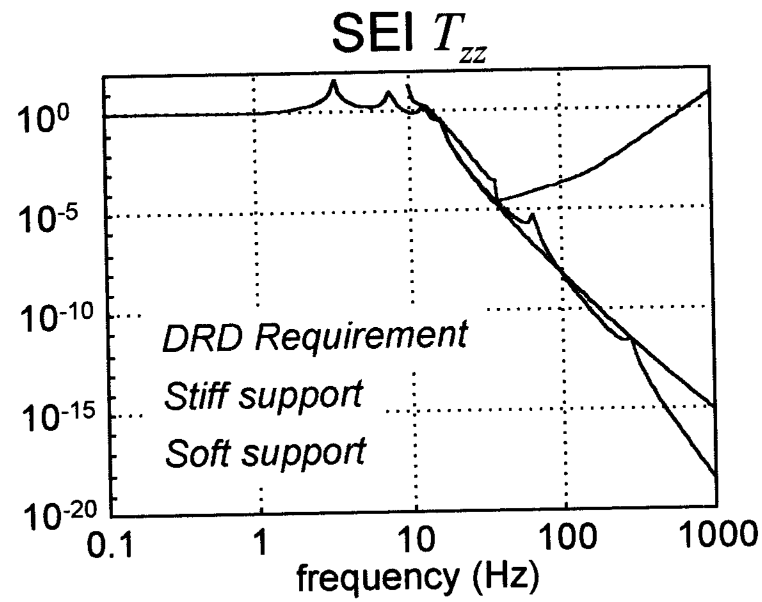


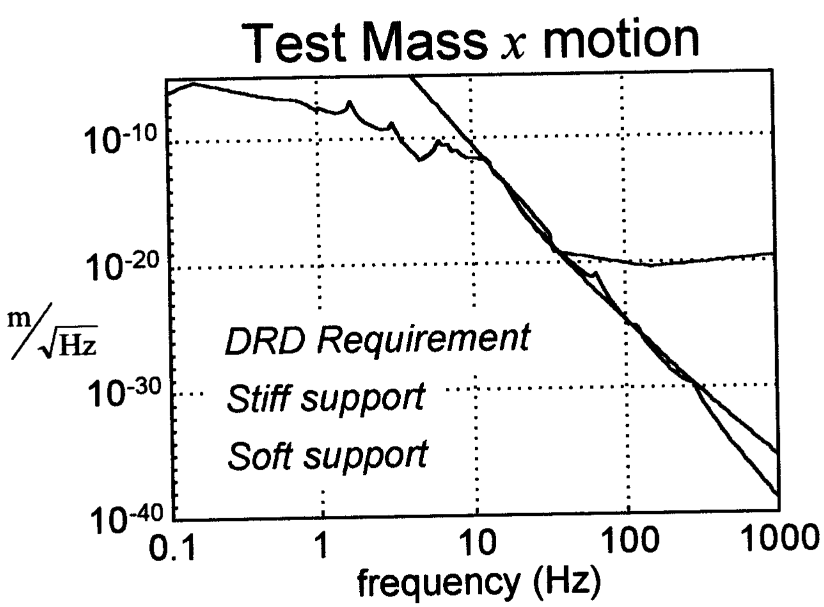


- Characteristic deflection @ 35Hz: δ_{max} = 6.2 mm
- Resonance: f_1 = 366 Hz

Expected Performance







Lock Acquisition

(test mass kinetic energy)

$v_{RMS} = 1.245\ \mu m/sec \sim 1\ \mu m/sec$

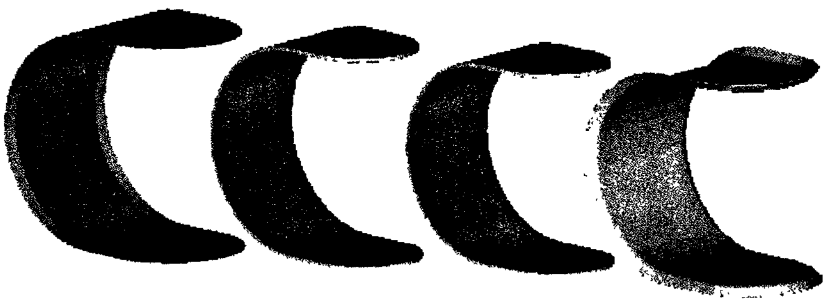
Lock Maintenance

(SUS actuator force rating)

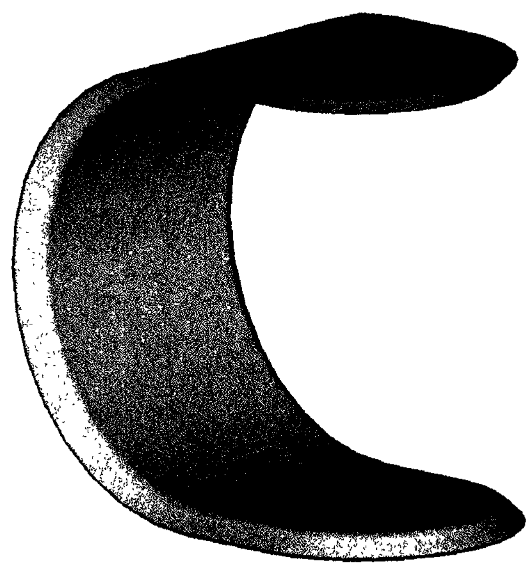
$\chi_{RMS} = 2.566\ \mu m < 2.7\ \mu m$

HYTEC

Manufacturing



- Stamp inner shell
- Cut & Bend outer shell & blades
- Age harden all BeCu
- Cut visco sheets
- Assemble



- weld outer edges of shell (laser), with heat sinks

Prototyping & Testing

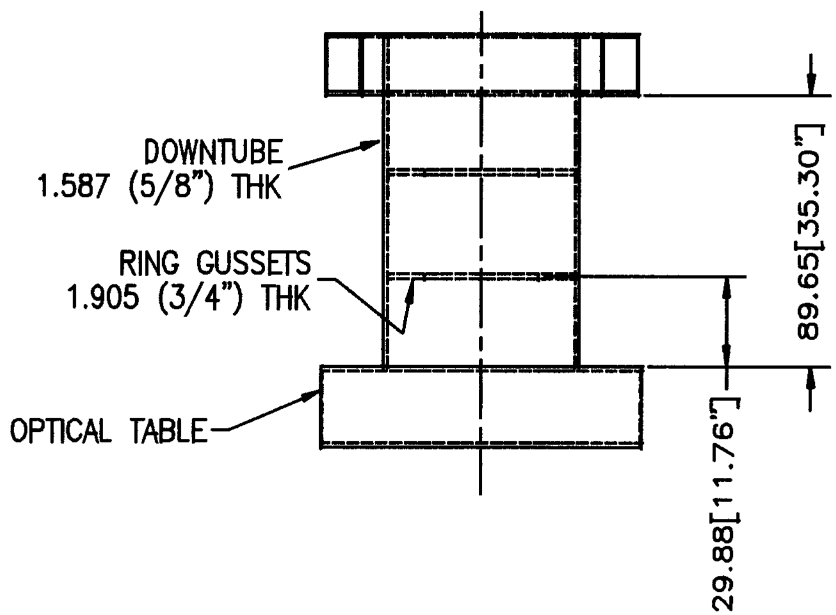
- Design Refinement
  - Static load capacity, permanent set (in weld area)
  - Adjust unloaded shape s.t. tip is horizontal under load
  - Design of base clamp and Viton pad & attachment
- Prototype CLD springs
  - Static load capacity & creep
    - Stress concentrations, weld resistance, local buckling
  - Stiffness, Damping, Resonance
    - Single stage, 3 springs, modal tests (in air)
    - Stack performance update
  - Creak under static load
    - Loaded spring hung in vacuum chamber, monitor microphone signals

Prototyping & Testing (continued)

- Acoustic transmission
  - Spring in vacuum chamber, piezo exciter on one face plate, microphone measurement on other
- Small amplitude damping tests (?)

BSC STACK DESIGN (VITON SPRINGS)

- **Side View Of Downtube**

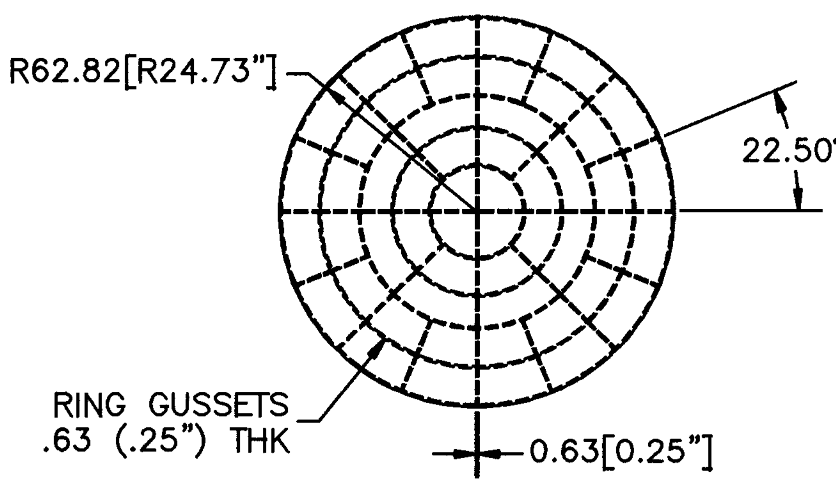


- **Structure Weight - 376 kgs (829Lbs)**
- **1.25 m Dia Optical Table**
  - 26.67 cm (10.5")Thick Sandwich Table Structure
  - 1.27 cm (0.5") Thick Facings
  - 227 kg Payload
- **Upper Support Welded Box Beams**
  - 20.32 cm (8") Box Beams
- **Downtube**
  - Length 89.65 cm (35.30")
    - Dim Subject To Change
  - 76.59 cm (30.15") OD
  - 1.587 cm (0.625") Wall

Dim cm's(in)

BSC STACK DESIGN (VITON SPRINGS)

- **Optics Plate Construction**

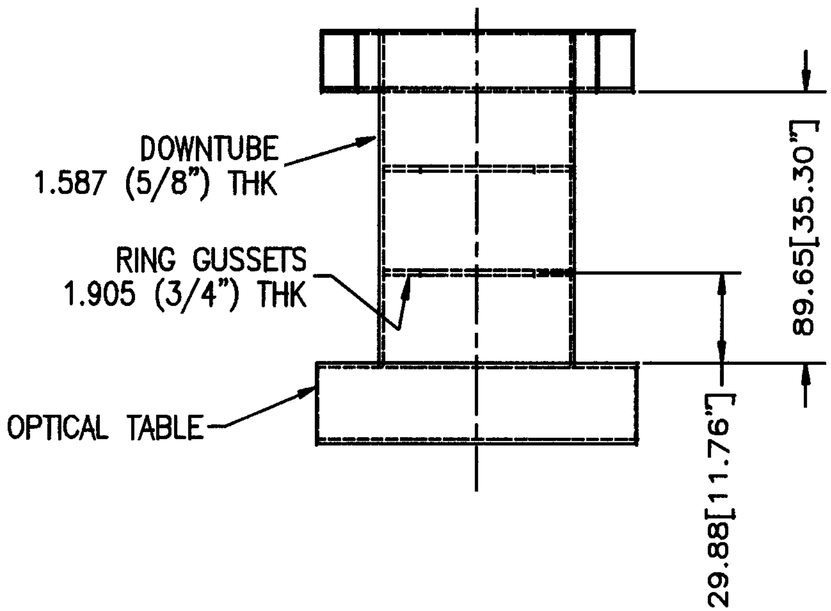


Dim cm's(in)

- **Initial Vendor Survey**
  - Brazed Structure Too Large
  - Uncertainties With Brazing Thick Plates
  - Al Honeycomb Sandwich Required Adhesive Bonding
- **Sandwich Plate Revisions**
  - Significantly Reduced Number Of Reinforcing Gussets
  - Improved Access For Welding Gussets
- **Optics Plate Welded To Downtube**
  - Dynamic Stiffness Of Overall Assy Within Design Goals

BSC STACK DESIGN (VITON SPRINGS)

- **Side View Of Downtube Assy**

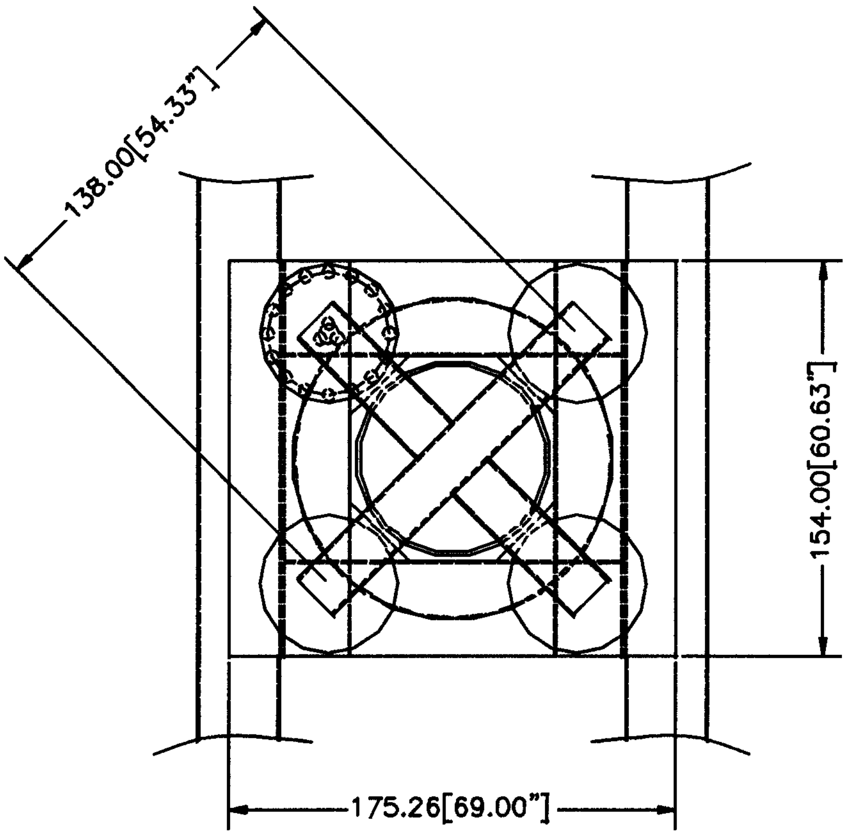


- **FEA Results With "Free-Free" BC**
  - **First Four Modes**
    - **355, 356,380, And 382 Hz,**
  - **Modes Involve Localized Bending And Twisting Of Cross Beams At Top**
    - **Box Beams Recessed In Tube, Tube End Distorts**
  - **No Evidence Of Distortion In The Optics Plate In This Frequency Band**

Dim cm's(in)

BSC BASE SUPPORT DESIGN (VITON SPRINGS)

- BSC Base Support Structure

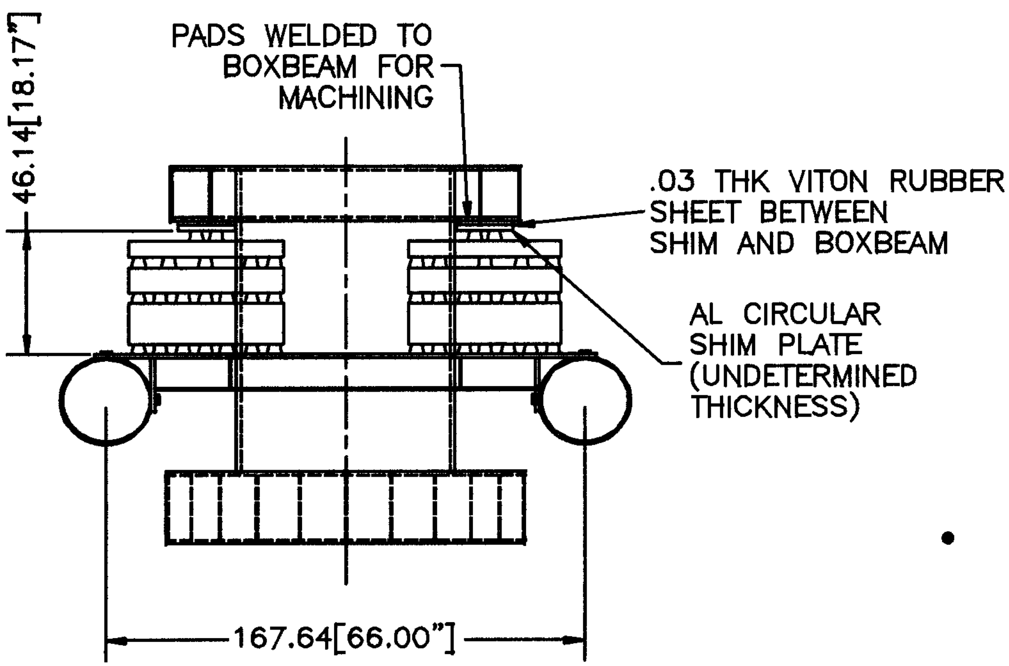


Dim cm's(in)

- AL Sandwich Platform
  - Supports Stack Leg Elements
  - Mounts To Stainless Steel Cross Beams
  - Provides Increased Stiffness (Dynamic) To The Cross Beams
  - Structure - 94.4 kgs(208 Lbs)
  - Material Thickness
    - Top Plate 1.27 cm(0.5")
    - Bottom Plate .9525 cm(0.375")
    - Sandwich Ribs 0.635 cm(0.25")
- Cross Beams - SS Tubes
  - 32.38 cm (12.75") OD
  - 0.953 cm (0.375") Thick Wall
  - Tubes - 549.5 kg (1211 Lbs)

BSC STACK CONSTRUCTION

- **BSC Stack With Cross Tubes**



Dim cm's(in)

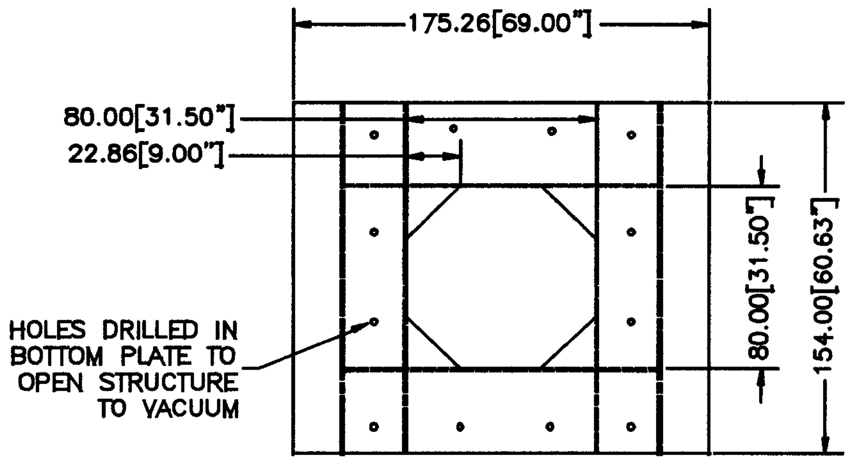
Downtube Assembly Construction

- **Steps At Fabricators**
  - **1st -Weldment And Machining Of Downtube/Optics Plate And Base Support Structure**
  - **2nd -Place Finished Base Support Structure Over Downtube/Plate Assy**
  - **3rd -Upper Downtube Cross Beams Inserted Into Downtube Shell Recess, And Then Welded**
  - **Final -VITON Spring Pads On Upper Box Beams Are Machined Parallel To Optics Plate Surface**
- **Experimental Hall**
  - **Assembly Installed Into Tank And Bolted To Cross Beams**
  - **Leg Elements Placed On Base Support Structure**
  - **Upper DT Box Beams Rotated Into Place Over Viton Springs**

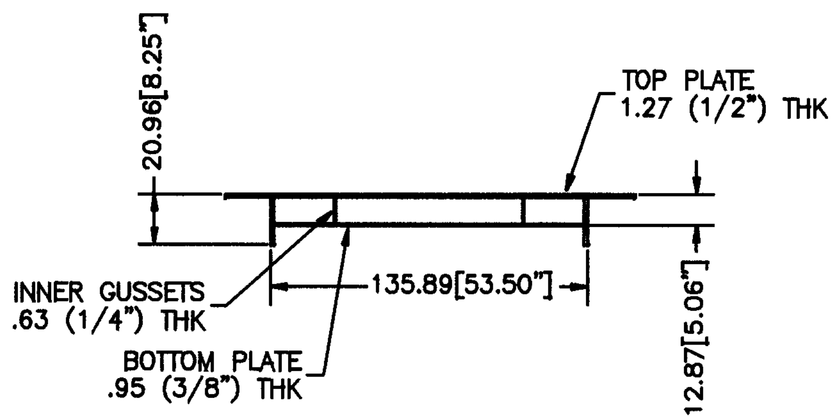
SEI WORK PLAN REVIEW

BSC BASE SUPPORT DESIGN

- **BSC Base Support Top View**
  - **Vented Sandwich Structure**

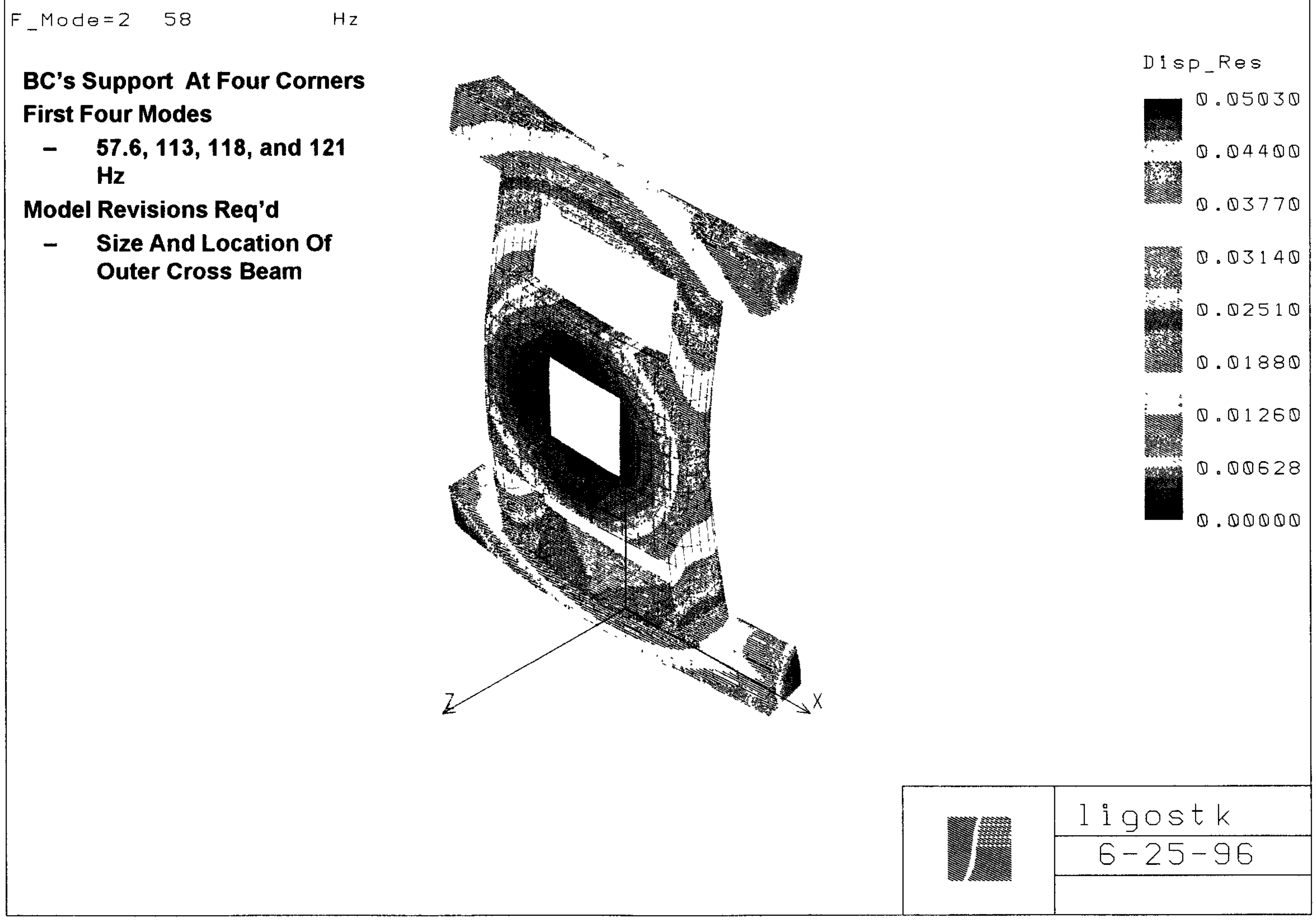


- **BSC Base Support Side View**
  - **Machined Mounting Surfaces To Interface With Cross Beam Tubes**



Dim cm's(in)

BASE SUPPORT DYNAMIC STIFFNESS STUDY



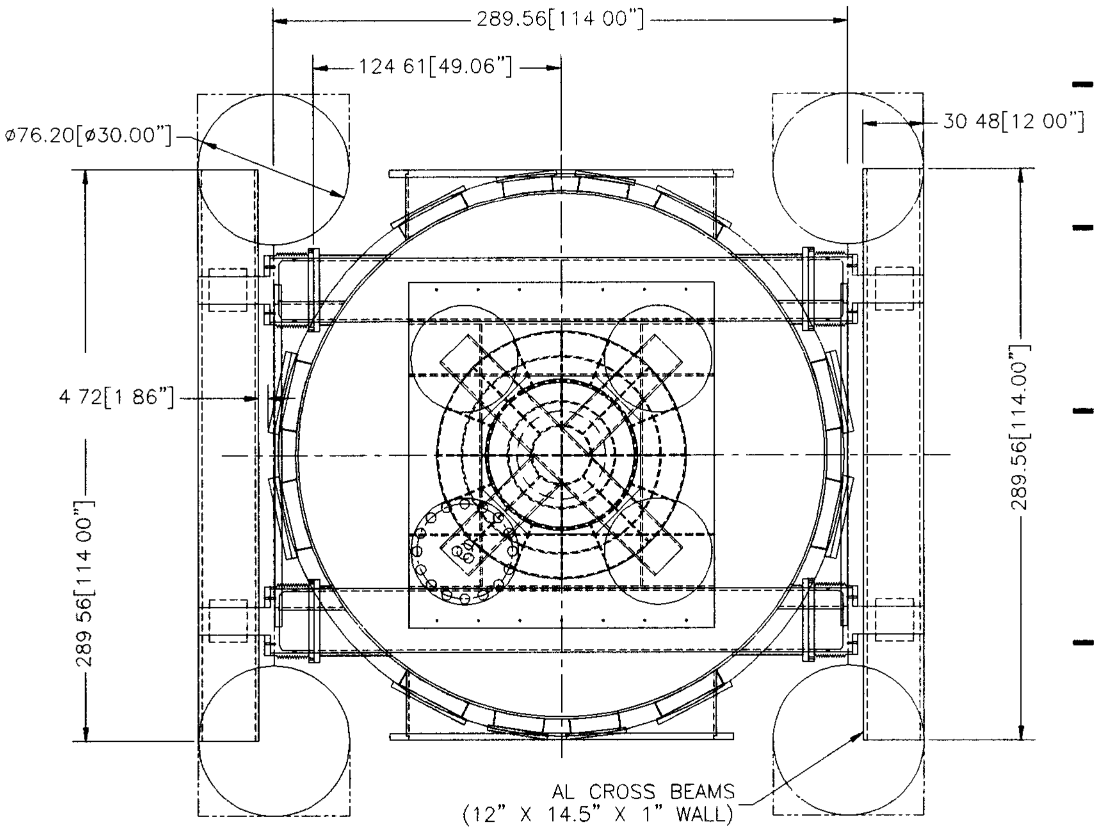
- BC's Support At Four Corners
- First Four Modes
  - 57.6, 113, 118, and 121 Hz
- Model Revisions Req'd
  - Size And Location Of Outer Cross Beam

BASE SUPPORT DYNAMIC STIFFNESS STUDY

- Base Support FEA Results
  - Natural Frequencies Quite Dependent On Outer Support Beam End Conditions
  - Present End Conditions Intended To Simulate Actuator Connections
    - Uncertain To What Extent The Present BC's Are Realistic
    - Further MATLAB Modeling May Be Useful In Defining Req'd Stiffness
  - 1st Mode Too Close To Machinery Vibration Modes
    - Desire Much Higher Frequency, Or A Slight Shift Lower
    - Modeling Of New Cross Beam/Outer Support Beam Connection May Lower Frequency Sufficiently (Or Too Much?)
- FEA Modifications
  - Update For New Connection
    - Offset Centerlines
  - Revised Beam Cross-Section
    - Rectangular To Provide Access To Ports
  - Distributed Reaction at Box Beam Face
    - Simulate Actuator Connection Differently
  - Look Into Alternative Reinforcements Of Base Support/Cross Beams

BSC STACK/BASE SUPPORT DESIGN

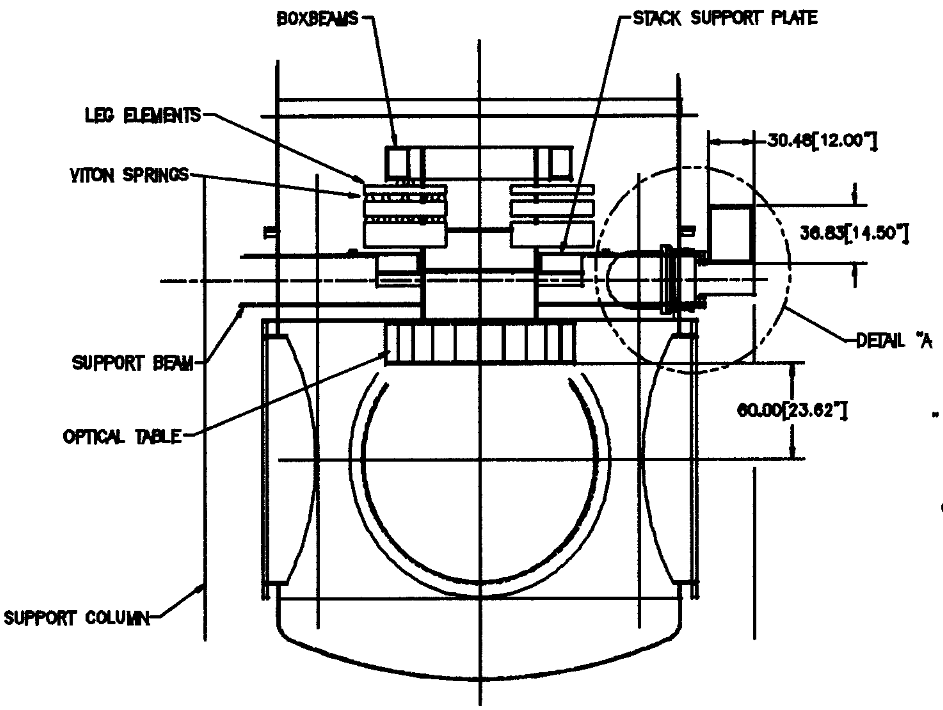
- **BSC Stack Top View**



- **Support Design Activities/Issues**
  - **Location Of Piers Relative To Outer Support Beams**
  - **Clearance Of Chamber Ports Adjacent To And In-Plane With Outer Support Beams**
  - **Vacuum Penetration Of Cross Beams**
    - **Coarse Actuator Movements Of Cross Beams**
  - **Outer Support Beams - Al Mat.**
    - **36.83 cm (14.5") Sq. Box Beams[1]**
    - **1.91 cm (0.75") Wall**
    - **Beams - 441.5 kg (includes end caps)**
  - **Mass Summary - kg**
    - **Stack 2813**
    - **Base 757.5**
    - **Outer Beams 441.5**
    - **Total 4012 (8842 lbs)**

1) Under Revision

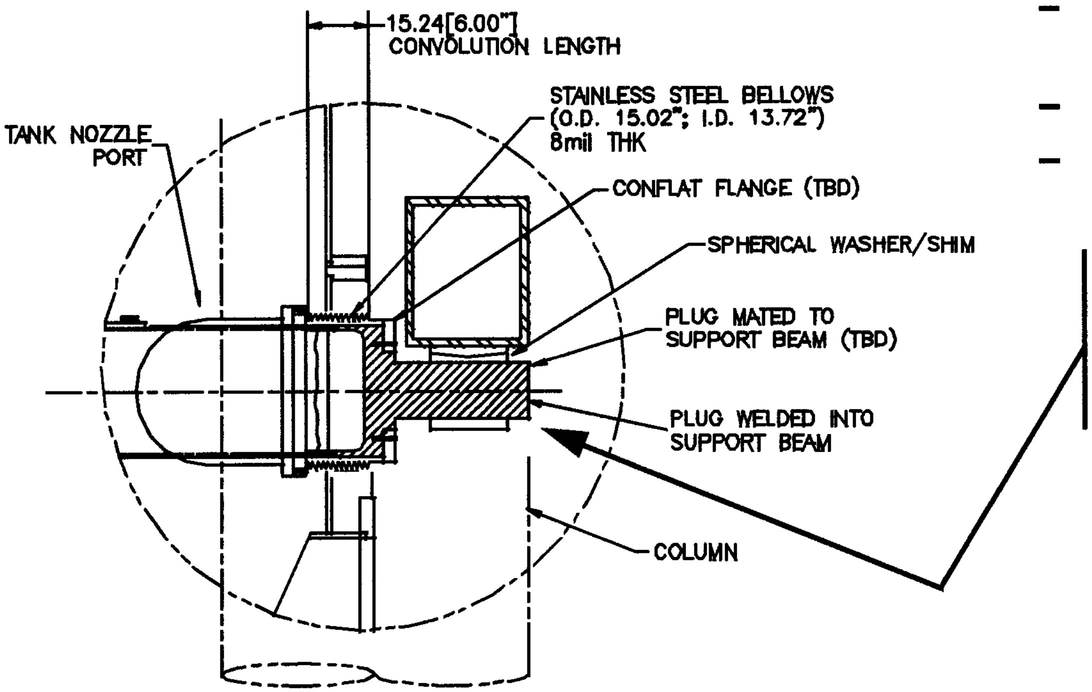
BSC STACK SUPPORT DESIGN



- **Current Design Studies**
  - Update FEA For New Tube/Cross Beam Structural Interface
  - Vacuum Interface
    - Bellows Design
  - Cross Beam Structural Support
    - Misalignments Causing Gaps At Mounting Interfaces
    - Concept To Eliminate Bolted Up Strains
  - Clearance For Tank Ports
- **Next**
  - Actuator Layouts
  - Pier Support

BSC STACK DESIGN

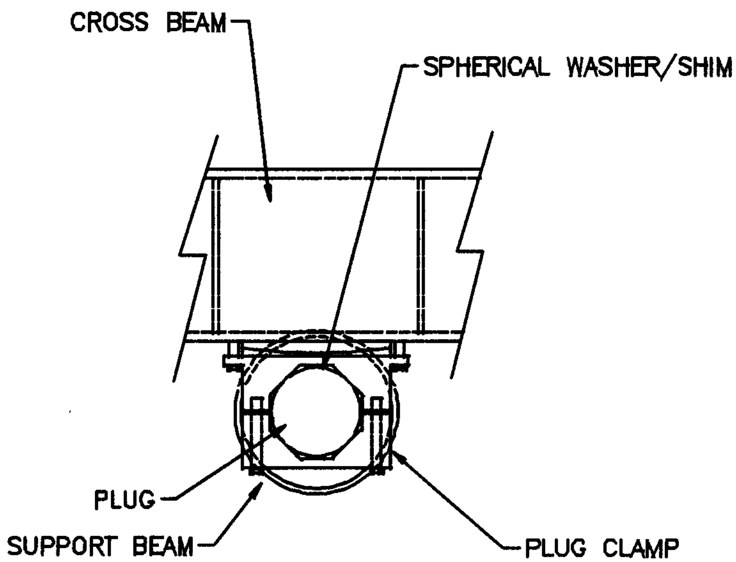
- Cross Beam Vacuum Interface



- Design Issues
  - Sizing Welded Diaphragm Bellows To Achieve Low Stiffness
  - Minimize Transverse Forces Into Actuator Components
  - Vacuum Seal For Cross Beam
  - Structural Connection To Outer Support Beams
    - Tolerance Build-up In Mating Faces
    - Minimize(Hopefully Eliminate) Built In Assembly Stresses
    - Maintain Structural Rigidity

BSC STACK DESIGN

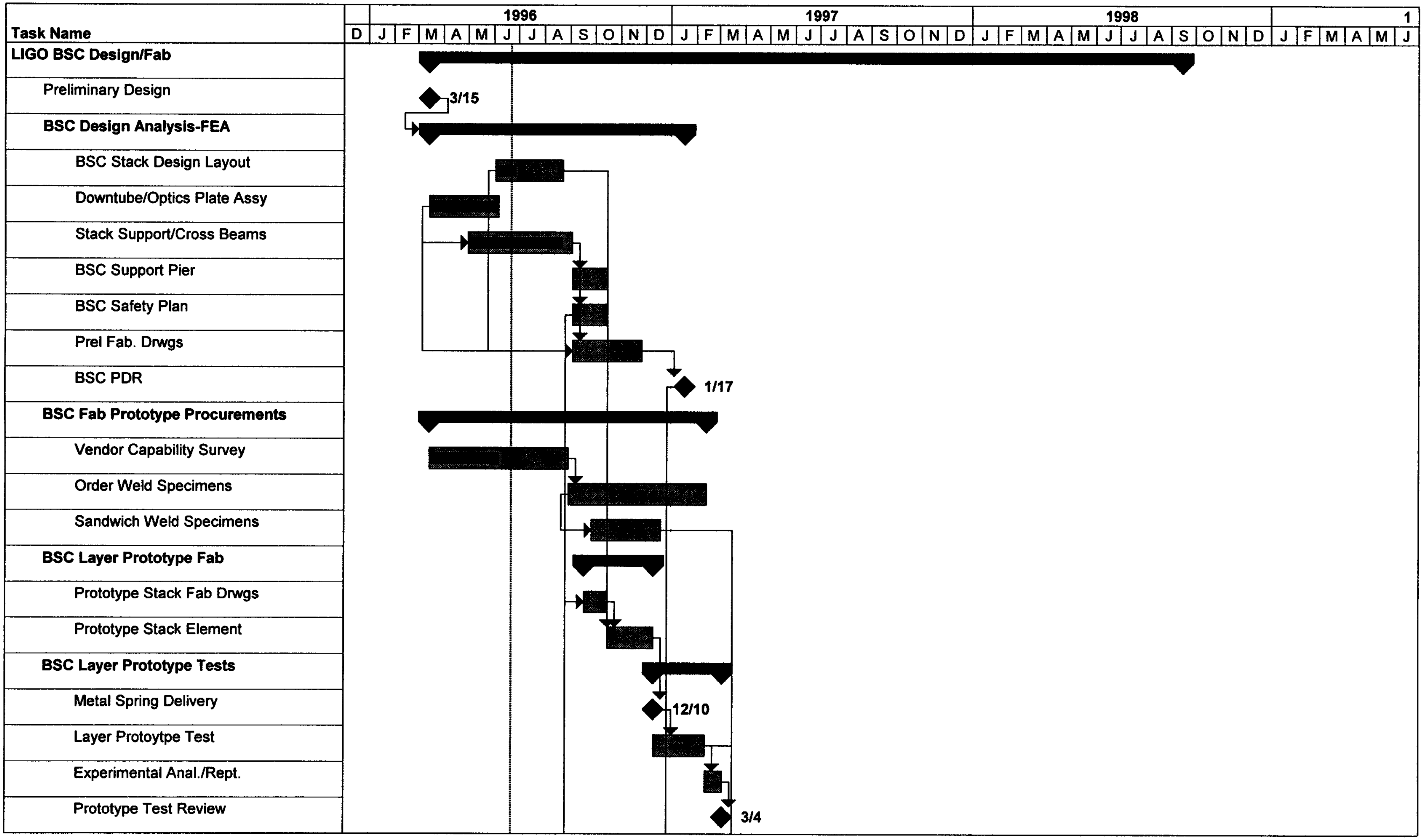
- **Cross Beam Connection Concept**



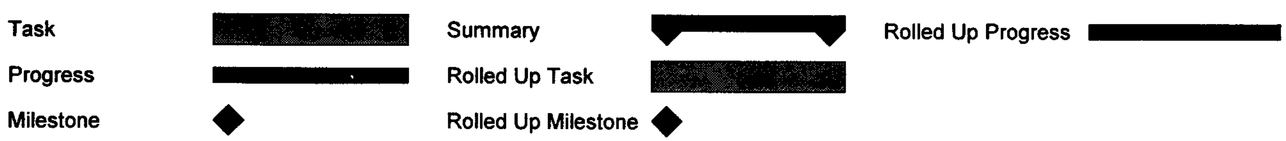
CROSS BEAM – SUPPORT BEAM JOINT
END VIEW

- **Objectives**
  - **Provide Moment Connection**
  - **Allow For Reasonable Fabrication Tolerances**
    - **Correct For Compound Angles Formed By Slightly Skewed Cross Beams**
  - **Secondly, Reduce Mechanically Induced Strains**
    - **Result Of Contact Planes Being Slightly Skewed**
    - **Spherical Washer Intended To Compensate For Skewed Contact Planes**

Attachment A



Project: LIGO Stack Development
Date: 6/21/96



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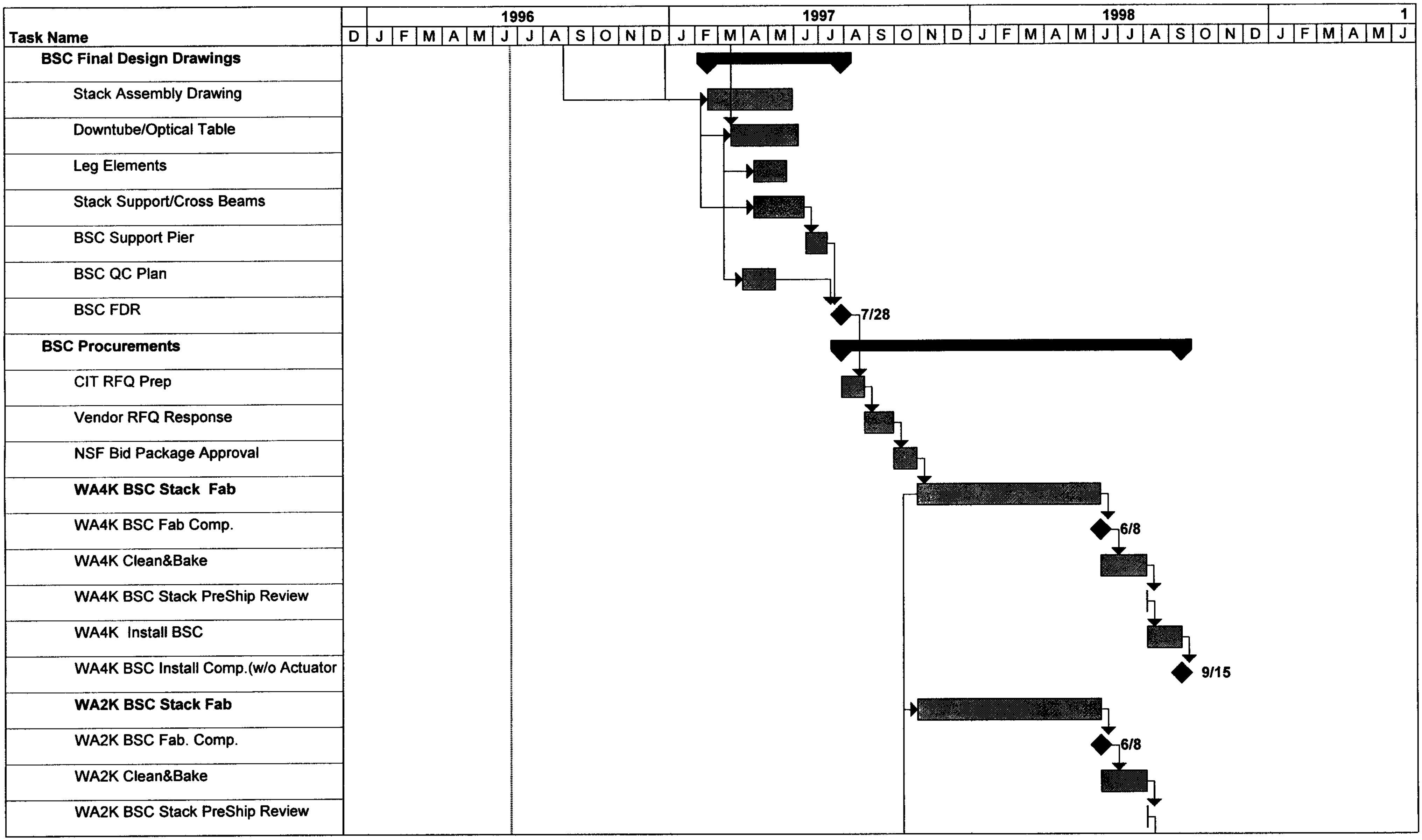


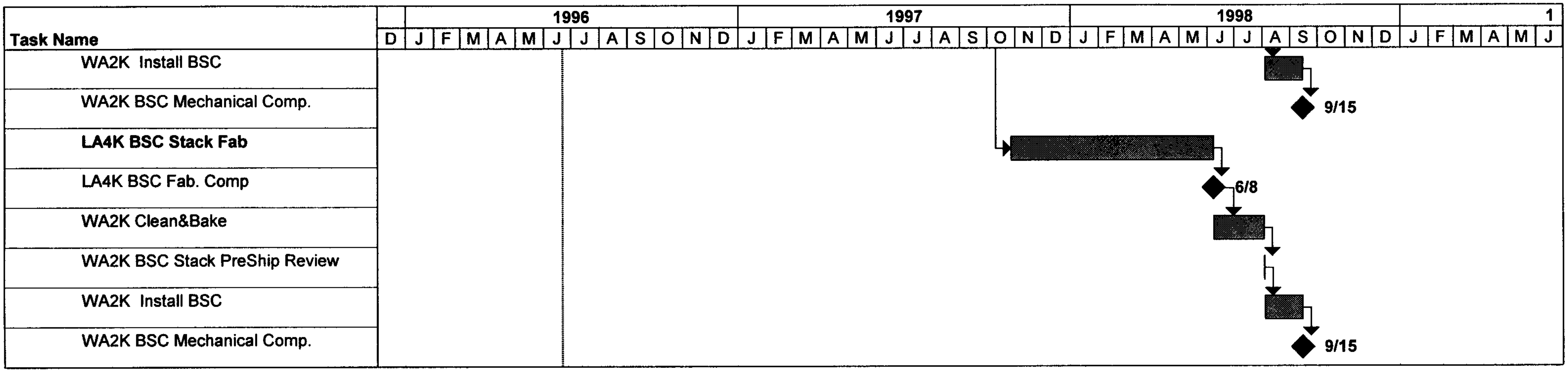
Task — Summary — Rolled Up Progress

Progress — Rolled Up Task

Milestone — Rolled Up Milestone

Project: LIGO Stack Development
Date: 6/21/96

Attachment A



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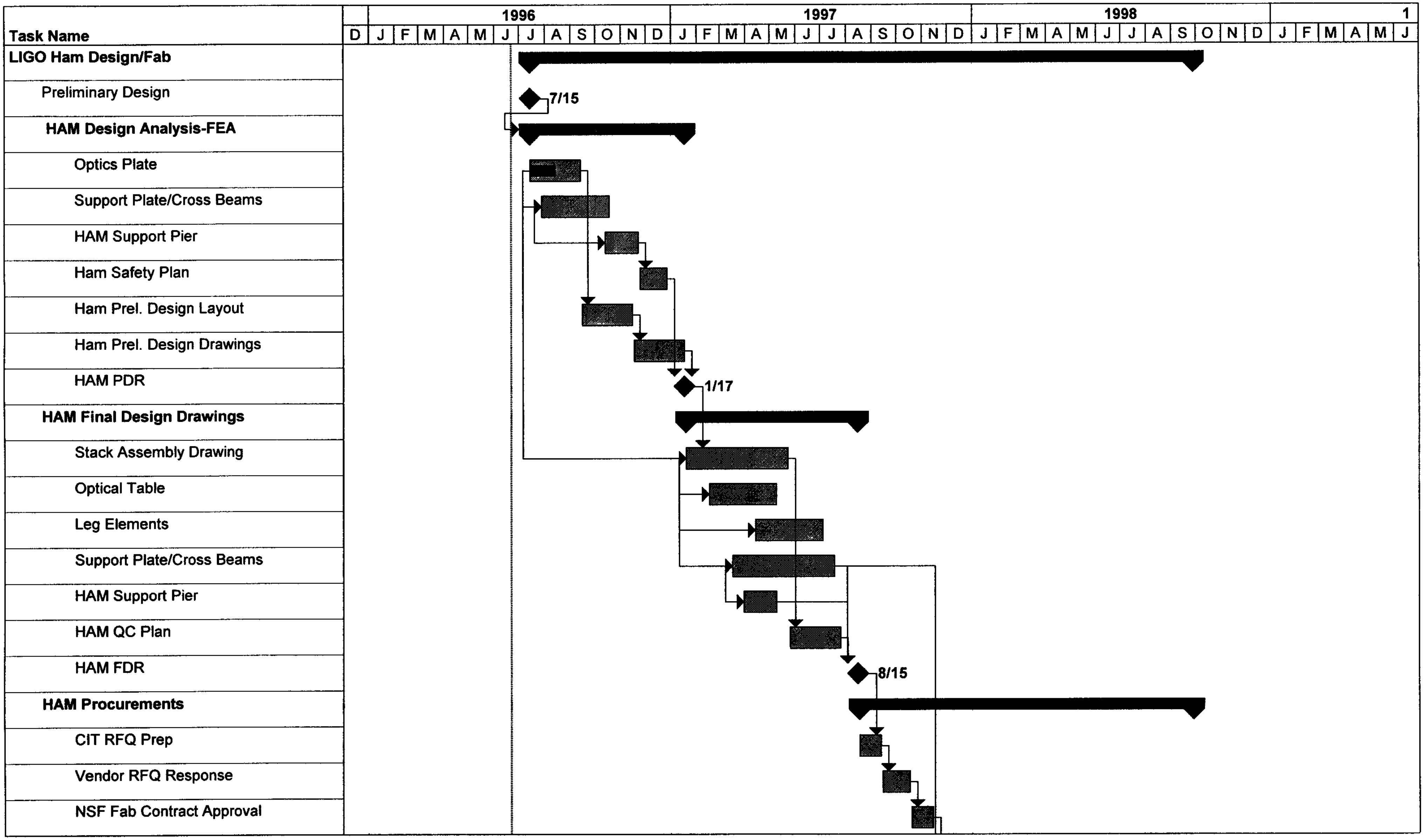

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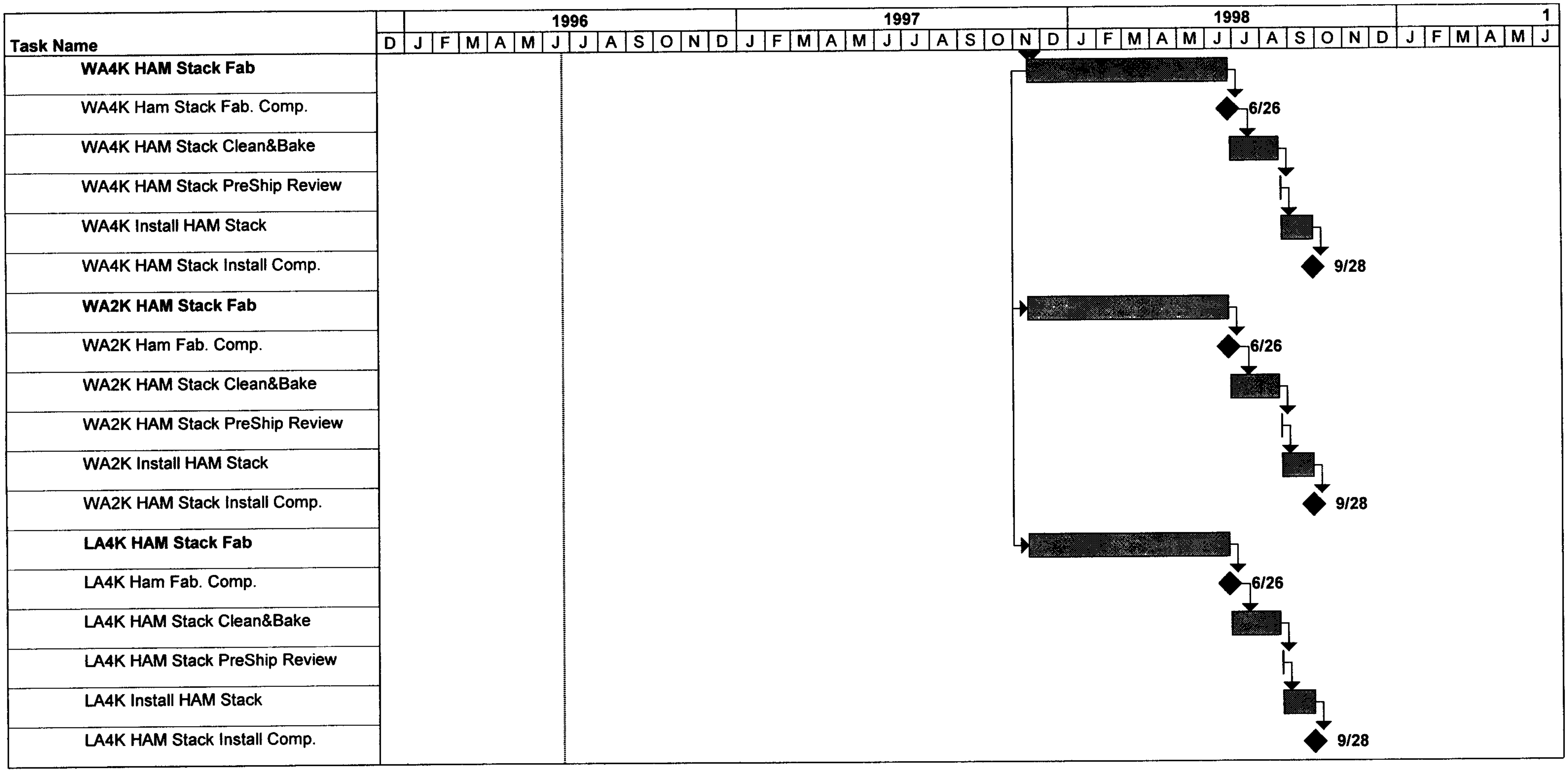

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SEI Fine Actuator Design Objectives

- SEI Fine Actuator Spec's(SEI/DRD)
  - X - Translation
    - +/- 100 micron Travel
    - Resolution ~ 1 micron
    - Response ~0.3 micron/minute
    - Rotation <0.5 mrad
  - Y,Z Translation And Rotation, Not Required

- Objectives
  - Single Stage Translation, 1 micron step Resolution, With Negligible Coupling In Y,Z(TBD)
    - No Vibrations In Support Beams In Excess Of Facilities Vibration Requirement
    - Tolerable Stick-Slip Or Impulsive Response On Stack Support Beams(TBD)
    - Total Driven Mass(TBD),

SEI Fine Actuator Design Issues

- Pure Translation Of A 4 Ton Mass, Without Coupled Motion
  - Position Corrections Made In Laser Locked Mode
  - Precise Motion In Direction Normal To Suspension System
    - Flexible "Link", Capable Of Carrying Entire Structural Mass
  - High Rigidity In All Directions
    - Even During Actuation
  - Stick/Slip In Actuator Parts
  - Coupled Strain In Coarse Actuator Elements
    - May Cause Sudden Bursts Of Motion
- Initial Steps
  - SEI Overall Performance Predictions
    - Back-out Effects Of Actuator Stiffness On Stack Performance
  - Configure Flexure Support
    - Work Out Potential Coupled Motions
    - Size Actuator To Overcome Extraneous Forces, e.g.., Bellows Transverse Forces
  - Assess Dynamic Stiffness
    - Include Actuator Stiffness Components
    - Update SEI Performance Predictions

SEI Coarse Actuator Design Objectives

- SEI Coarse Actuator Spec's (SEI/DRD)
  - X,Y, And Z Translation
    - +/- 0.5 cm Travel
    - Resolution 100 microns
  - Z Rotation
    - +/- 4 mrad (Perpendicular To Beam Axis)
    - Resolution +/- 0.1 mrad
    - X Rotation < 0.5 mrad

- Objectives
  - Correct For Long Term Drift
  - Single Mechanical Design Compatible With Both BSC And HAM
  - Stiffness Sufficient To Resist Squirm Loads Imposed By Bellows
  - Stable And Stiff Elements, Both Laterally And Vertically

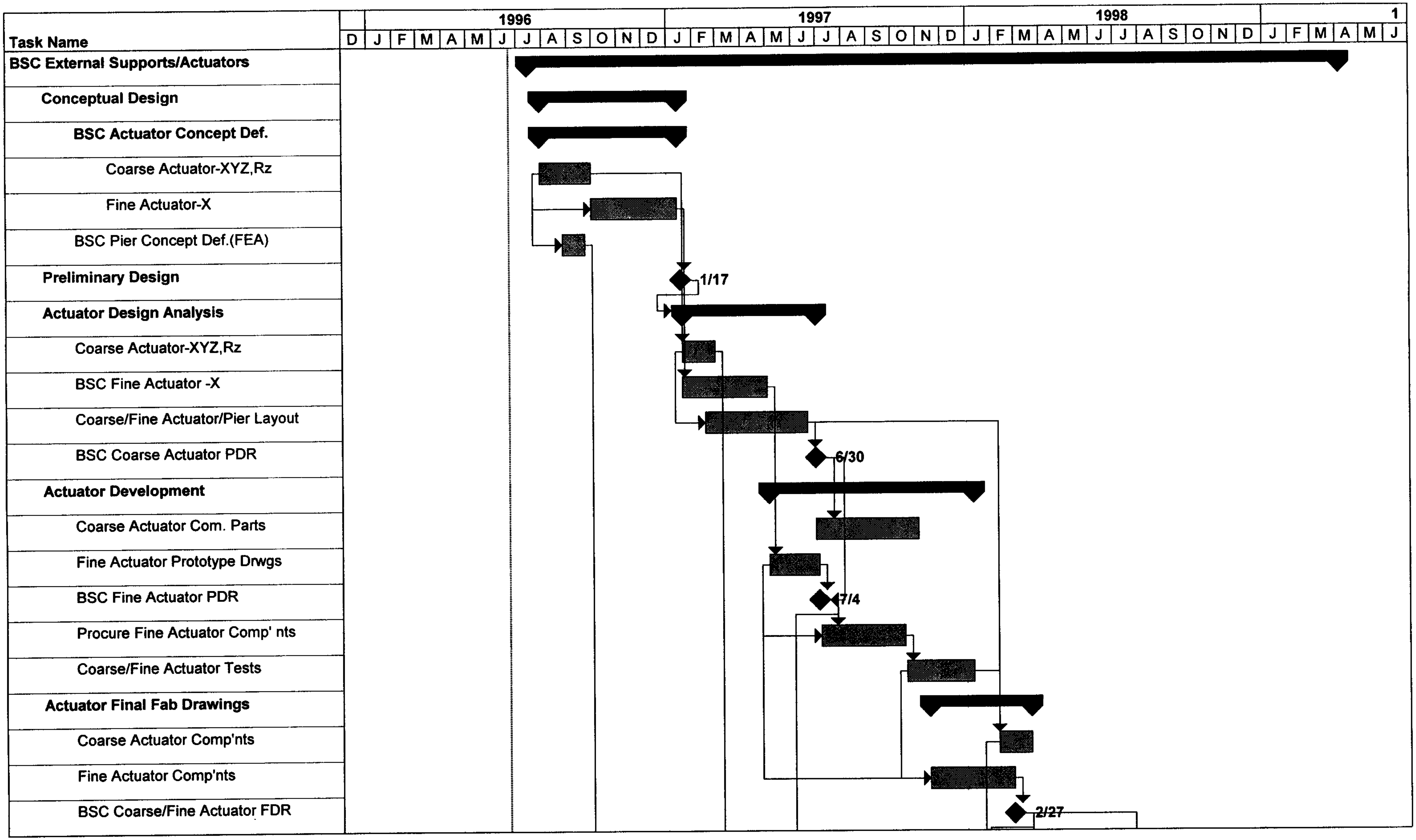
SEI Coarse Actuator Design Issues

- Stability Of Linear Translation Stages
  - Preload Ball Bearing Stages To Eliminate Unexpected Motions
  - Coordination Of Motion At Four Points
    - Alignment Of Stages
    - Uniform Rotation Of Large Body About Vertical Axis
- Vertical Lift At Four Points
  - Lead Accuracy Of (Ball) Lead Screws
- Initial Steps
  - Configure Mechanical Arrangement Using Commercial Precision Components
    - Work On Alignment And Tracking Of Multiple Stages Making Up Single Degree Of Movement
  - Assess Stiffness Of Combined Actuator Stages
    - Update SEI Performance Predictions
  - Develop Alternative Concepts Where Commercial Components Are Not Adequate

Component Testing

- Actuators
  - Prototyping Of Fine Actuator Concept Strongly Recommended
    - Demonstrate Final Concept
      - Flexures (?)
      - PZT Drive (?)
      - Smoothness/Resolution
      - Stiffness
  - Prototyping Of Coarse Actuator Concept Recommended Also
    - Evaluate Stacking Of Components
    - Demonstrate Precision
    - Evaluate Steps Taken To Eliminate Alignment Issues

Attachment A



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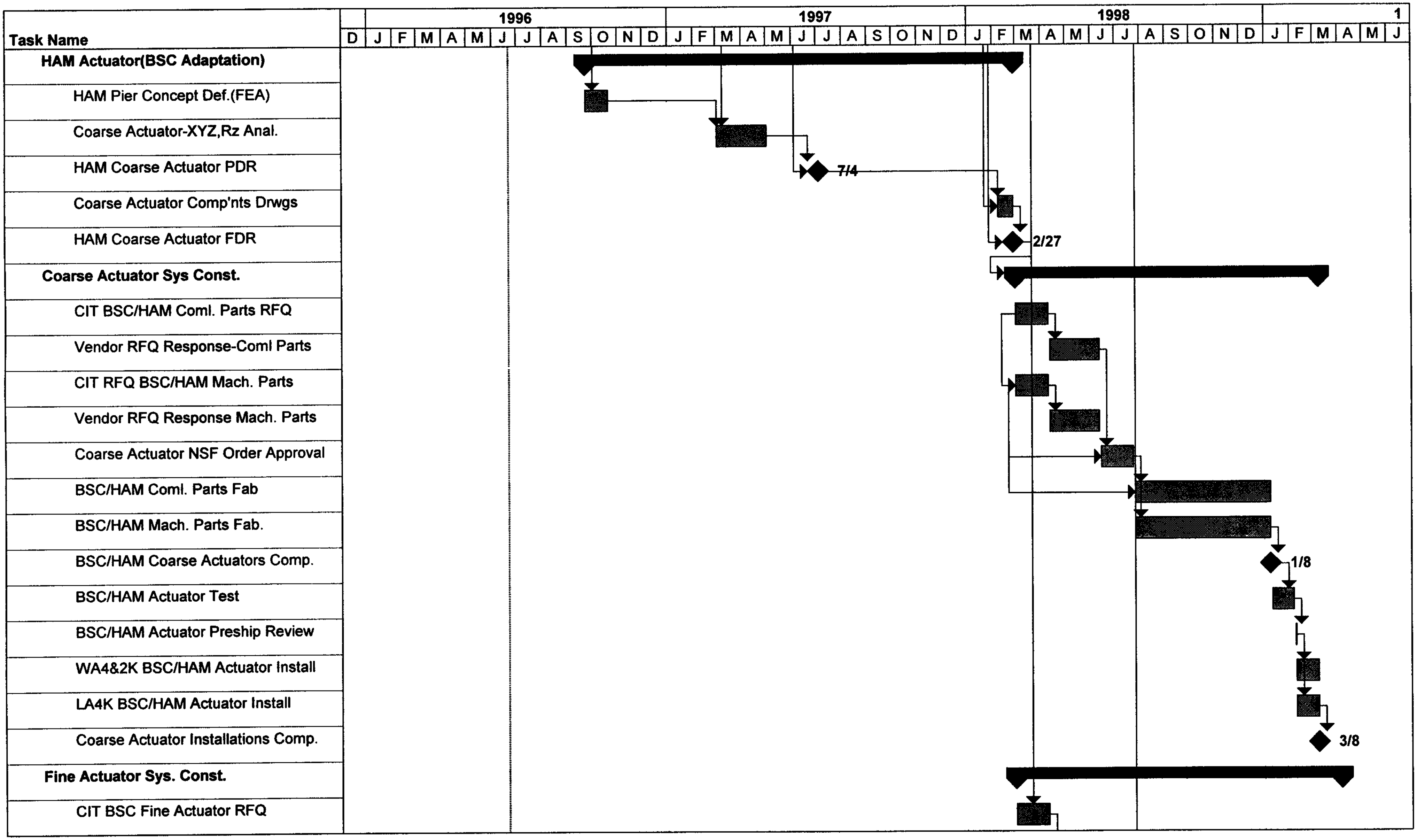

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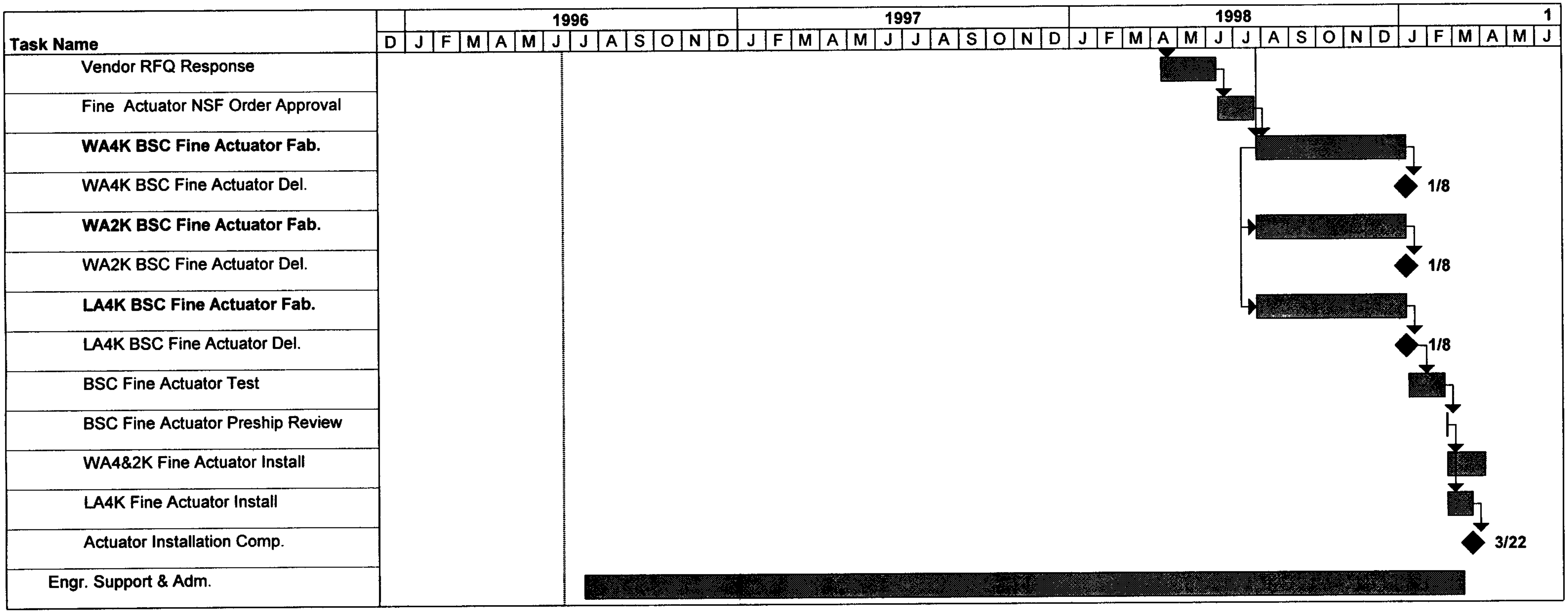

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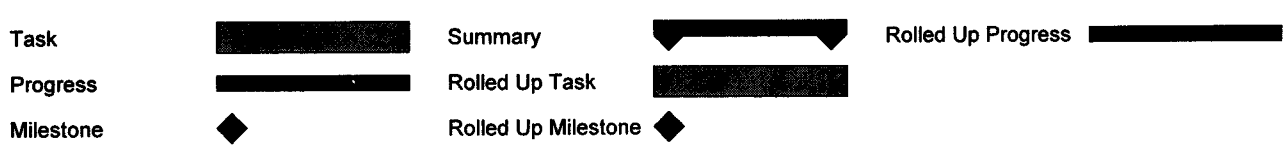

WORK PLAN REVIEW SUMMARY

- Schedule
  - Overall Schedule To Produce An Integrated Design Is Very Tight
    - PDR For BSC And HAM By 1/17/97 Includes Concept Definition Of Actuator System
    - PDR Milestone Also Includes Decision On Damped Metal Spring
      - Results For Coiled Spring Should Be Available
      - Development Tests Of Leaf Spring Most Likely Still In Process
    - *Numerous Issues To Investigate Before Ready For PDR*
- Damped Metal Spring Stack Design
  - Backward Compatible To VITON Spring Geometry
  - VITON Stack Design Is Not Forward Compatible With Alternative Spring Designs Requiring Increased Separation Between Layers
- Design Drawings
  - Suggest Electronic Files For Each Design (VITON/Coil/Leaf)
    - Downtube And Leg Element Geometry File For Each Design
    - Would Accommodate Different Spring Lengths, Shimming, Etc..
    - Facilitate Conversion To Alternative Design At PDR