Precision Alignment Capabilities at LLNL

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Abstract:

A presentation of the alignment capabilities at Lawrence Livermore National Laboratory.
Precision Alignment Capabilities at LLNL

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Lawrence Livermore National Laboratory
March 30, 1992
Agenda

- Overview - Sawicki
  - LLNL resources
  - design considerations

- Alignment control of large optical systems - Bliss
  - NOVA
  - LIS

- Alignment techniques at LLNL - Griffith
  - Poisson
  - Xray
  - SWAT
LLNL has a broad base of engineering resources, skills and experience

- LLNL possesses a large staff of engineering, design, technician and support personnel that has successfully demonstrated precision alignment on several large construction projects
  - NOVA
  - LIS
  - ATA
  - ETA
  - Nuclear test canisters
  - LODTM

- LLNL engineering organization possesses the diverse resources and skills required to address all aspects of precision alignment
  - analysis
  - environmental characterization
  - design
  - implementation
  - verification
## Alignment resources by Division

<table>
<thead>
<tr>
<th>Division</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weapons Engineering, Nuclear Explosives Engineering</td>
<td>FE code development, Analysis specialists</td>
</tr>
<tr>
<td>Nuclear Test</td>
<td>FE code development, Analysis specialists, SoI/structure Interaction, Earthquake engineering, Precision alignment engineering</td>
</tr>
<tr>
<td>Lasers</td>
<td>Analysis specialists, Precision alignment engineering, Active alignment control</td>
</tr>
<tr>
<td>Engineering Sciences, Engineering Research</td>
<td>Measurement and monitoring systems, Dynamic characterization, Analysis specialists</td>
</tr>
</tbody>
</table>
Present LLNL involvement in SSC alignment issues

- Participated in the workshop on Vibrational Control and Dynamic Alignment Issues at the SSC - February 11-14, 1992
  - Lessons Learned from the NOVA Laser Spaceframe Design - C. Hurley
  - Finite Element Analysis of Large Structures - D. McCallen, R. Murray
  - Dynamic Analysis of Six Strut System - B. Burdick
  - Natural Phenomenon Hazard Mitigation Program for the US Department of Energy - R. Murray

Existing contract for the characterization of the dynamic response of the accelerator module support structure - six strut system
- transmissability measurements
- supporting finite element models for detailed design evaluations
Precision alignment demands comprehensive consideration of all phases of the project

- Before design commencement, requirements must be established and environmental conditions defined
  - position, angle, reference points, stability (local and global)
- Environmental characterization performed before and after construction
  -- vibration (ambient and self-induced)
  -- thermal

- Systems must be analyzed to confirm compliance with requirements
  - detailed finite element modeling
  - interaction with all influences
  - design optimization
- Alignment techniques developed as required
  - precision capability applied cost effectively
- Appropriate design features incorporated consistently throughout
  - awareness of critical issues
- Meticulous implementation performed by assembly and installation team
  - strict control and monitoring
- System performance measured and verified
LLNL computational capabilities are state-of-the-art

- Octopus computer network provides high capacity computational capability throughout LLNL
  - Supercomputers - Crays
  - extensive disk and tape storage

- Extensive library of structural response codes
  - LLNL developed
  - Commercial products
    -- Nastran, ANSYS, CLASSI ...

- Experienced personnel
  - harmonic analysis
  - forced response
  - thermal analysis
  - static and dynamic
  - non-linear
Hardware Available to LLNL Structural Analysts

Sun Workstation

Structural Analysts Office

Workstation File Server

IO intensive tasks (require user interactivity)
- Mesh Generation
- Small and Intermediate Analyses

Supercomputers (Cray YMP)

CPU intensive tasks (i.e. number crunching)
- Finite Element Analysis of Large Systems
- Post Processing of Large Analysis Results
LLNL has a suite of computer codes which are utilized for structural and solid mechanics problems

- SLIC/INGRID - Mesh generating routines for interactive definition of model geometry (Cray/Sun/Vax versions)

- GEMINI - General purpose linear elastic program for structural analysis, essentially an updated and modernized version of SAPIV (Cray version only)

Category 1 Problems

- DYNA3D/DYNA2D - General purpose nonlinear program for analysis of solids and structures (Cray/Sun/Vax versions)

Category 2 Problems

- NIKE3D/NIKE2D - General purpose nonlinear program for analysis of solids and structures (Cray/Sun/Vax versions)

- TAURUS/ORION - Post processing routines for above analysis codes (Cray/Sun/Vax versions)
Example of large scale analysis of an alignment sensitive structure; *Nova Space Frame*

*Finite Element Analysis of Large Structures*  
*SSC Workshop Presentation  Feb. 11 1992*
Example of large scale analysis of an alignment sensitive structure; *Nuclear Test Canisters*

Finite element analysis provided guidance on cost and weight effective and weight minimizing stiffening schemes

*Finite Element Analysis of Large Structures*  
*SSC Workshop Presentation Feb. 11 1992*
Our Measurements Technologies Support R&D Efforts

Field Applications
- Experimental Modal Analysis
- Structural Analysis
- Machine Monitoring
- Field Instrumentation
  - Strain Gage Application
  - Data Acquisition and Analysis
  - Acoustic Analysis
  - Vibration Meas. and Isolation

Advanced Development
- Sensor Design
- On-line Monitoring Systems
- Acoustic Intensity
- Forced Response
  - Structural Modification
  - Data Transmission
  - Smart / Embedded Sensors

Sensor Calibrations
- Pressure
- Vacuum
- Acceleration
- Velocity
- Displacement
- Force / Mass
- Torque
- Flow
- Temperature
- Humidity
- Thermophysical Properties

Engineering Measurements and Analysis
Dynamic Characterization Studies

- Experimental modal analysis provides valuable insight into the dynamic behavior of structural systems
- Essential technique for finite element analysis model verification and for evaluating "as-built" structures
- Used for damping determination, resonance searches and signature analysis
- Both contact and non-contact methods can be employed
## Nova stability

| Mode | Laser bay frames | | Switchyard frames | | Target frame |
|------|------------------|------------------|------------------|------------------|
|      | Calculated frequency (Hz) | Measured frequency (Hz) | Calculated frequency (Hz) | Measured frequency (Hz) | Calculated frequency (Hz) | Measured frequency (Hz) |
| 1    | 9.95             | 8.27             | 6.66             | 5.5             | 4.15             | 5.6             |
| 2    | 10.08            | 8.45             | 7.06             | 6.3             | 5.45             | 5.9             |
| 3    | 11.32            | 8.72             | 8.25             | 8.6             | 5.72             | 6.3             |
| 4    | 12.11            | 9.57             | 15.56            | 19.1            | 5.91             | 6.5             |
| 5    | 13.61            | 11.25            | 16.13            | 21.4            | 6.56             | 7.5             |

Translation ± 5 µm  
Rotation ± 0.7 µ rad
Large Measurement Systems

- We have successfully designed, developed and fielded large measurement systems

- 1500 channel data acquisition system for superconducting magnet program
  - Strain gages, cryogenic temperature sensors, pressure transducers and platinum resistance thermometers

- We can implement remote instrumentation control, data collection and analysis
Engineering design of the LIS facility considered alignment requirements from the earliest design stages

- LIS program consists of 12 copper laser chains and 4 dye laser chains integrated together and to an experiment facility with thousands of optical elements
  - high power beams
  - precision alignment required for efficiency and stability
  - operational continuously 24 hours per day

- Alignment requirement generally required stability on the order of
  - 10 microradians
  - 10 microns

- Passive stability of the optical systems were developed to minimize reliance on active control
Laser system conceptual design

Copper amplifiers

Copper oscillator

Dye laser master oscillator

Dye pre-amplifier

Dye power amplifier

Enrichment chamber

Optical multi-pass
- Laser support systems
- Dye laser system
- Copper laser system
- Optical systems
- Instrumentation and control systems
- Refurbishment facilities
LIS passive alignment design features

- Basic properties
  - high stiffness to maximize resonances
  - high mass to minimize motion from on-structure devices and maximize thermal time constant
  - high damping to minimize amplifications

- Isolation
  - separate noise sources from critical elements
    - vacuum pumps, dye/ethanol pumps
  - isolate experiment from facility
    - air handling units, ducting
    - utility runs - water
    - building structure
    - work platforms

- Structurally couple elements with high relative motion sensitivity
  - separator multi-pass optics

- Control thermal environment
  - facility air
  - optical coatings
  - stray radiation shielding
Major laser facilities at LLNL
Separator Demonstration Facility (SDF)

- Module optics
- Vessel
- Separator units and Pods (3)
- Gas scattering cell
- Uranium handling room
- Pod transporter
- Product and tails withdrawal system
- Launch wall vessel and optics
- Consolidated control room
- Laser diagnostic location

MARTIN MARIEETTA
Strategy for multi-pass alignment stability
Launch Wall / Module Optics Screen 1

T1L1 1234.58  T1R1 1234.56
T1L2 1234.56  T1R2 1234.56
T1L3 1234.56  T1R3 1234.56

1SL1 0.00  1SR1 0.00
1SL2 0.00  1SR2 0.00
1SL3 0.00  1SR3 0.00

Overlap P & C

From LOS

Module Optics

Output 1 P & C

LW Tel 1 P & C
LIS Laser System Overview

large bore copper vapor lasers

small bore copper vapor lasers

copper beam combination

copper beam combination

dye beam combination

dye amplifier chains

dye master oscillators

fiber optic injection

line of sight pipe
LOS sensor locations and control points

Symbol Key
p = pointing sensor
C = centering sensor

Loop Key
- closed alignment loop
- loop offset adjustment
- safety shutter loop

B 335 vault
B 332

B 490

LEO vault

intermediate vault

“doghouse”

south vault
# UDS alignment specifications

<table>
<thead>
<tr>
<th>function</th>
<th>resolution</th>
<th>speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>General centering</td>
<td>±1.0 mm</td>
<td>iteration time = 1 sec</td>
</tr>
<tr>
<td>Overlap centering</td>
<td>±0.6 mm</td>
<td></td>
</tr>
<tr>
<td>Separator input cent.</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>Separator output cent.</td>
<td>&quot;</td>
<td>bandwidth = 120 Hz*</td>
</tr>
<tr>
<td>General pointing</td>
<td>±15 µr</td>
<td>iteration time = 1 sec</td>
</tr>
<tr>
<td>Overlap pointing</td>
<td>±1 µr</td>
<td>bandwidth = 120 Hz</td>
</tr>
<tr>
<td>Separator input point.</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>Separator output point.</td>
<td>±15 µr</td>
<td>iteration time = 1 sec</td>
</tr>
</tbody>
</table>
Low bandwidth alignment data is standard video

Dye beam centering image
UDS alignment sensor packages

Dye chain alignment package

Full size beam alignment package
LDF—corridor dye chain in operation
Atomic Vapor Laser Isotope Separation (AVLIS) process
Alignment Techniques
at
Lawrence Livermore National Laboratory

Muon Chamber Discussions
March 30, 1992

Lee V. Griffith
Mechanical Engineering
Alignment takes on many meanings at LLNL

- The physical scale of projects ranges from accelerators such as ATA and ETA to integrated circuits

- The objects to be aligned are also widely varied
  - images
  - magnetic fields
  - electrostatic fields
  - bearings
  - sliding parts
  - diagnostics
A diverse pool of scientists, engineers and technicians are essential to addressing new alignment issues

Optical design and engineering
- Erlan Bliss
- Lynn Seppala
- Gary Sommargren

Structural design
- Dale Schauer
- Brad Burdick

Precision manufacturing processes
- Irving Stowers
- Dan Thompson

Composite materials / stable structures
- Gordon Spellman
- John Horvoth

Electronics / controls and diagnostics
- Fred Deadrick
- Dick Schenz

Alignment systems

Physicists, engineers, designers, technicians, and coordinators in a concurrent effort
The remainder of this talk will note four of the less common alignment techniques, which are very useful at LLNL.

- The Poisson alignment reference
- X-ray alignment - Robert (Bob) Addis
- Stretched Wire Alignment Technique (SWAT)
- Interferometric and other techniques in inspection and machining tools
The Poisson line has the following characteristics:

1. The Poisson line is formed when an opaque sphere is illuminated by a plane wave. This line is perpendicular to the incident plane wave and if extended backwards, passes through the center of the sphere.

2. The intensity of the line increases monotonically for increasing distances from the sphere.

3. The diameter of the line decreases with increasing diameter of the sphere.

4. The diameter of the line can always be kept smaller than a Gaussian beam propagating over the same distance.
Two and three dimensional simulation of the diffraction pattern surrounding the Poisson spot aid in designing the alignment system.
One advantage of the PAR system is that it can align many components simultaneously.
X-ray Alignment Principles

General

"X-ray Alignment Systems are analogous to the visible light alignment methods"

Advantages

1) X-ray's have the ability to penetrate materials otherwise opaque to visible light.

2) X-ray technique essentially eliminates all optical aberrations, resulting in true geometric optics.

3) Near real-time images of entire alignment axis can be made.

Disadvantages

1) Requires strict health & safety procedures.

2) Image accumulation and processing can be time consuming.

3) Only a very small Field-of-View is available with near real-time camera images.
# Pre-Design of the LOS Model

## Feature/Fid Description

<table>
<thead>
<tr>
<th>Source</th>
<th>Vacuum Barrier</th>
<th>Fid</th>
<th>Fid</th>
<th>Fid</th>
<th>Slit</th>
<th>Window</th>
<th>USB Fid</th>
<th>U T/B SB Fid</th>
<th>L T/B SB Fid</th>
<th>LSB Fid</th>
<th>Camera</th>
</tr>
</thead>
</table>

### Distance

| 0 | 3" | 178.82" | 249.82" | 275.82" | 351.82" | 544.82" | 881.07" | 888.97" | 917.82" | 952.82" | 1007.08" | 1014.99" |

### Magnification

| N/A | N/A | 5.67 | 4.06 | 3.68 | 2.88 | 1.86 | 1.15 | 1.14 | 1.09 | 1.05 | 1.01 | N/A |

### Minimum Object Size Using O/S Ratio protocol where \( S = 75 \mu m \)

| N/A | N/A | 0.011" | 0.011" | 0.010" | 0.009" | 0.006" | 0.002" |

### Selected Object Sizes (projected image must be \( > 0.005" \) at image plane for camera system)

| N/A | N/A | 0.010" | 0.010" | 0.009" | 0.008" | 0.020" | 0.020" | 0.010" | 0.006" | 0.006" | 0.010" |

Addis 3/92 X-ray Alignment
Binary pattern for the Station 560 Fiducial is based on a FOV 6 units wide.

TUNGSTEN PATTERN DETAIL
for MIDDLE ALIGNMENT FIDUCIAL
Station 560 (Scale 20X)
Typical Distortion Fiducial Suspended w/in LOS

- Nuclear Field
- Pipe Wall
- Collimator or Fid Shelf
- Fid Plate & Fid adjustable in R & T
- Elevation 462
  Not to Scale
Design Summary

- Predicted Tolerances using x-ray camera system
  - Straightness on the order of 0.7 urad.
  - Position error 0.001".

- X-ray Source
  - Standard Kevex with tungsten target
    - 20 - 120 keV
    - Air cooled, 120 °F max.
    - Output: 25 watts with 100 µm spot, 10 watts with 50 µm spot size.
  - Nominal operating voltage, 50 - 69 keV.

- Target Fiducials
  - Material, tungsten.
  - Minimum feature diameter determined using O/S Ratio protocol with source diameter equal to 75 µm.

- Primary camera, Cohu vidicon. Secondary camera, Fairchild CCD.

- Predict approximate image acquisition time to be 12 minutes nominal +/- 3 min.
The Stretched Wire Alignment Technique* (SWAT) provides a way to measure transverse field errors.

- SWAT is well suited to alignment of discrete lens elements -- solenoids and multipoles.

* SWAT was adapted to our alignment application from earlier work on wiggler alignment and testing by Dodge Warren et al., of LANL.
SWAT is used to measure the ETA-II alignment by stretching a 4-mil wire from the injector to the beam dump.

- The stretched wire is positioned precisely on the straight line reference axis.
- Tilts and offsets are measured by energizing one magnet at a time.
- We compensate for the vertical droop or catenary of the wire by raising the wire end points a calculated amount, depending which magnet is energized.
- Offsets and tilts have separate and unique waveform signatures which we seek to null out by moving the wire to the magnetic axis, and by applying currents to the sine/cosine trim coils to null out magnet tilts.
The Stretched Wire Alignment Technique

The hardware is simple.

The photodetectors used to measure wire deflections are very sensitive—the output for a 4-mil wire is greater than 20 millivolts per micron of motion!
CONFIGURATION EXAMPLES

General Purpose Multiaxial Configuration
Used in Coordinate Measuring Machines
Summary

- General alignment capabilities at LLNL have been discussed
  - organization
  - analysis
  - measurement
  - design

- Following talks will discuss
  - active alignment systems in large optical systems
  - alignment techniques at LLNL
Alignment Control
in Large Optical Systems

Erlan S. Bliss
Lawrence Livermore National Laboratory
March 30, 1992
LLNL Laser Systems

**Nova**
- 10 beam glass laser for inertial confinement fusion research.
- 120 KJ in single 3 nsec pulse.
- Multiple wavelengths through frequency conversion.

**LDF**
- Laser Demonstration Facility for isotope separation.
- Approximately 2KW average power (multiple KHz rep. rate).
- Tunable dye lasers pumped by copper vapor lasers
Nova alignment systems

- Harmonic & target alignment
- Amplifier chain alignment
- Output alignment
- Front end alignment

40-00-0565-1831
Nova alignment system

- Tasks
  - Beam alignment from the oscillator to the target chamber
  - Output alignment at three wavelengths
  - Positioning of all ten focus spots within ±50 µm in the target plane

- Components
  - Four alignment subsystems integrated by a digital control system
  - Forty-five sensor packages, each with video imaging capability
  - More than 1300 controlled devices in more than 200 alignment loops

- Special features
  - Video format provides operators with complete monitoring capability
Nova output alignment & diagnostic sensor

- f/2 telescope
- 3w lens
- Attenuator
- 3w lens
- Calorimeter
- Photodiode
- Shutter
- Filters
- Fiber optic to streak camera
- Near-field camera
- 1w module
- CID camera
- Calorimetry & streak camera interface
- Near-field & far-field viewing optics
- Far-field camera

- Incident from laser
- Reflected from target