

Path to Ignition at National Ignition Facility (NIF) – The Role of the Automated Alignment System (AA)

ICALEPCS Oct 09, 2023

- Bela Praful Patel

Co-authors - Abdul A. S. Awwal, Mikhail Fedorov, Richard R. Leach, Jr.,
Roger Lowe-Webb, Vicki Miller Kamm, Payal Kamlesh Singh





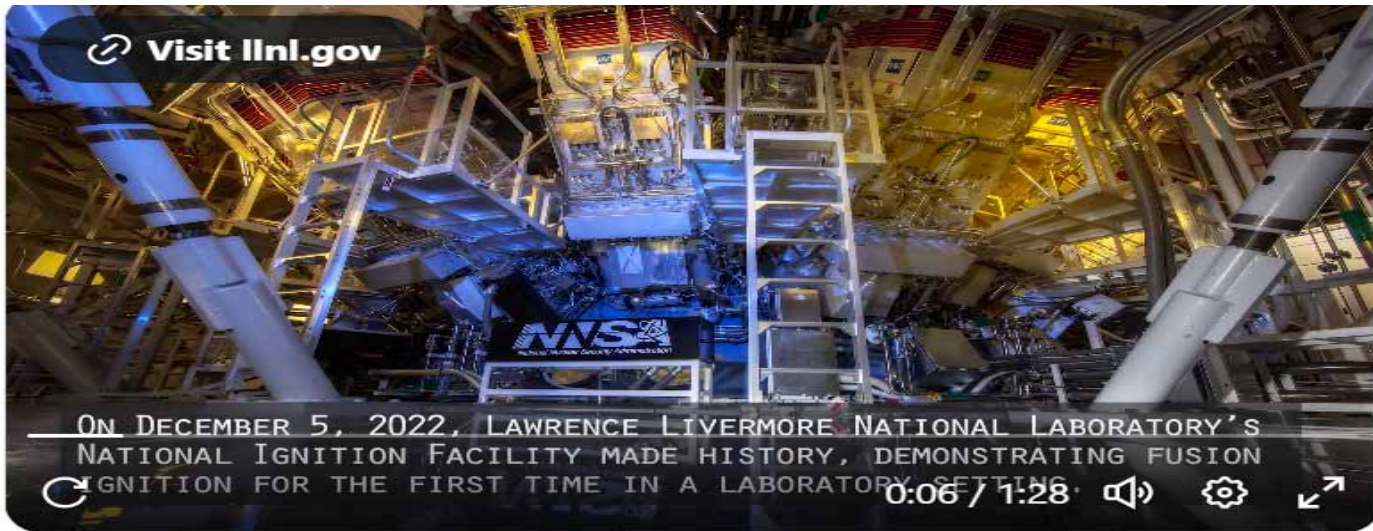
U.S. Department of Energy @ENERGY · Dec 13, 2022



BREAKING NEWS: This is an announcement that has been decades in the making.

On December 5, 2022 a team from DOE's @Livermore_Lab made history by achieving fusion ignition.

This breakthrough will change the future of clean power and America's national defense



Lawrence Livermore National Laboratory

Bela Patel – ICALEPCS – OCT 09, 2023

LLNL-PRES-854453



US scientists achieve net energy gain for second time in nuclear fusion reaction

The Lawrence Livermore National Laboratory's National Ignition Facility achieved the feat using lasers to fuse two atoms

US scientists have achieved net energy gain in a nuclear fusion reaction for the second time since a historic breakthrough in December last year in the quest to find a near-limitless, safe and clean source of energy

Scientists at the California-based Lawrence Livermore National Laboratory repeated the breakthrough in an experiment in the National Ignition Facility (NIF) on 30 July that produced a higher energy yield than in December, a Lawrence Livermore spokesperson said.

A second spark: US scientists repeat fusion ignition milestone

SUSTAINABILITY - U.S. scientists at the Lawrence Livermore National Laboratory in California have once again made history by achieving a net energy gain in a fusion reaction.

NEWS 9 AUGUST 2023



The Lawrence Livermore National Laboratory has announced a groundbreaking accomplishment in nuclear fusion research. For the second time since December, they reported a net energy gain from a fusion reaction, marking a significant milestone in nuclear fusion energy a viable power source. While commercial fusion is expected to require reactions generating between 30 and 100 times the energy in the lasers, this achievement provides a promising insight into the future of clean power. Fusion energy, unlike fission, produces minimal nuclear waste and does not emit harmful greenhouse gases, making it a potentially revolutionary source of low-carbon electricity.

l being analysed, the spokesperson added.

lives smashing together light elements such as hydrogen nuclei, releasing a huge burst of energy in the process. This gives rise to the heat and light of the sun and other stars.

Highlights

- US scientists reported a second energy gain from a fusion reaction.
- It's the second time the American researchers achieved this milestone.
- With minimal nuclear waste generation and without emitting greenhouse gases, nuclear fusion has the potential to be a revolutionary source of low-carbon electricity.

A major leap forward

U.S. scientists at the Lawrence Livermore National Laboratory in California have once again made history by achieving a net energy gain in a fusion reaction. This was not the first instance of such a breakthrough; a similar milestone was reached in December 2022. During that experiment, the scientists, working at the National Ignition Facility (NIF), used 192 laser beams to provide 2.05 megajoules of energy to a deuterium-tritium fuel pellet. The fusion reaction output was a substantial 3.15 megajoules of energy, demonstrating the scientific viability of inertial confinement fusion energy.

Fusion achieved again on July 30, 2023





BREAKING NEWS: This is an announcement that has been decades in the making.

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Fusion ignition a big breakthrough



The Hans India

Hans News Service | 19 Dec 2022 5:38 AM IST



The New York Times

Scientists Achieve Nuclear Fusion Breakthrough With Blast of 192 Lasers

The advancement by Lawrence Livermore National Laboratory researchers will be built on to further develop fusion energy.

Scientists have announced what they have called a major breakthrough in a long quest from nuclear fusion. The US Department of Energy said on Tuesday that after several decades of trying - scientists finally had to put in.

THE TIMES National Ignition Facility

You have searched for National Ignition Facility

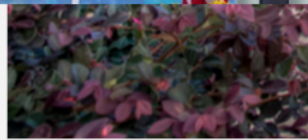
All(4) Articles(4)

NATIONAL IGNITION FACILITY NEWS

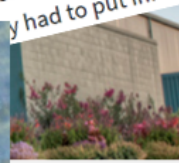


US research breakthrough

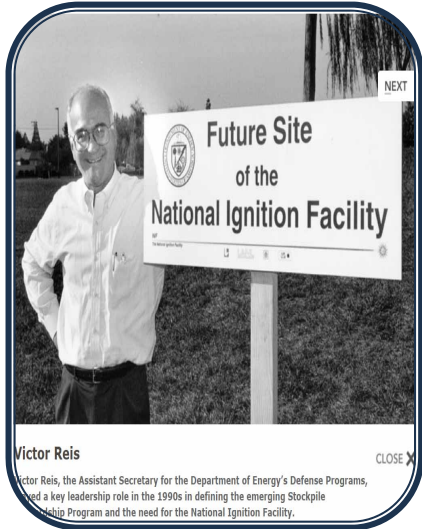
AP / Dec 13, 2022



nuclear fus



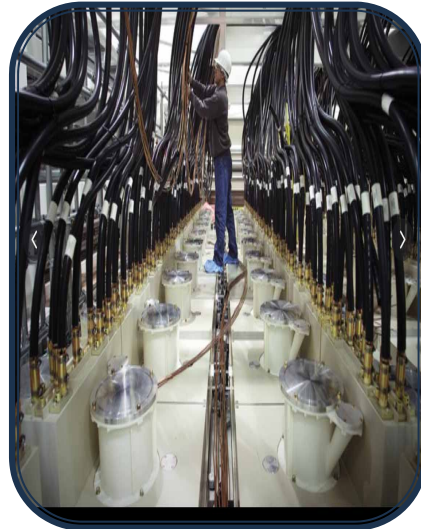
This was a result of...



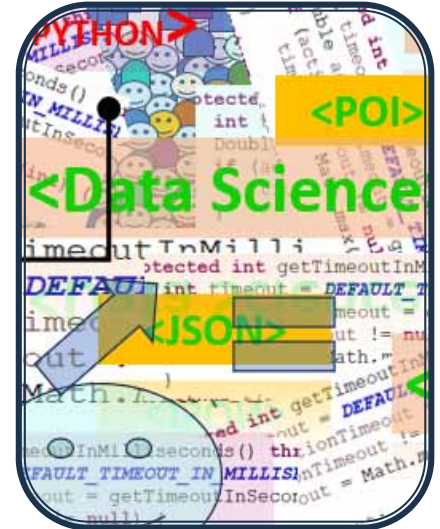
Decades of Research



Thousands of people



Hardware



Software

Automatic Alignment is a vital part of NIF and provided major contribution towards this achievement.





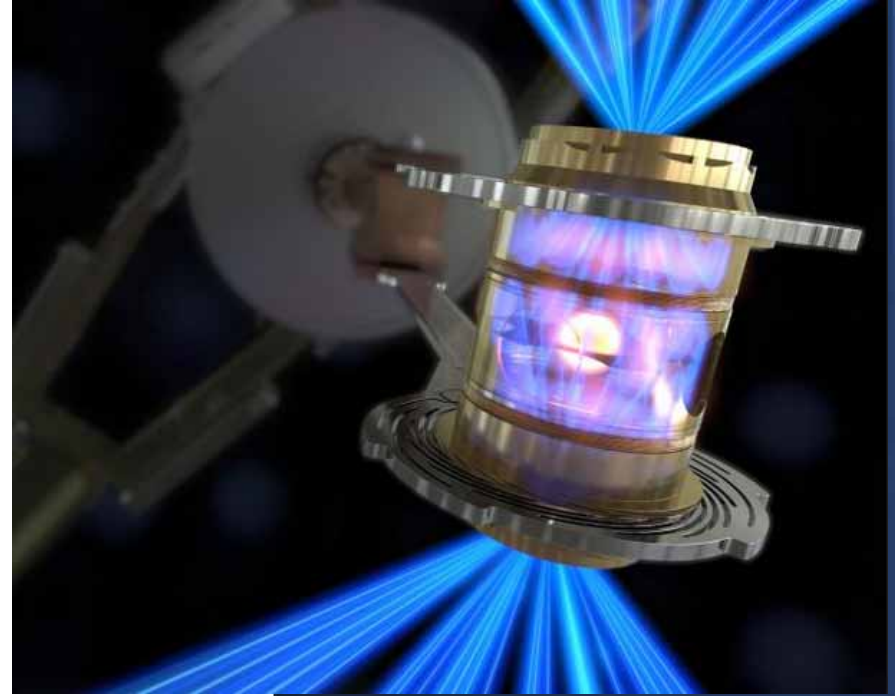
To Produce Fusion

- NIF 192 high powered Laser Beams are concentrated in 1 cm sized hohlraum containing a tiny BB sized target encapsulating heavy forms of hydrogen.

Alignment Requirements

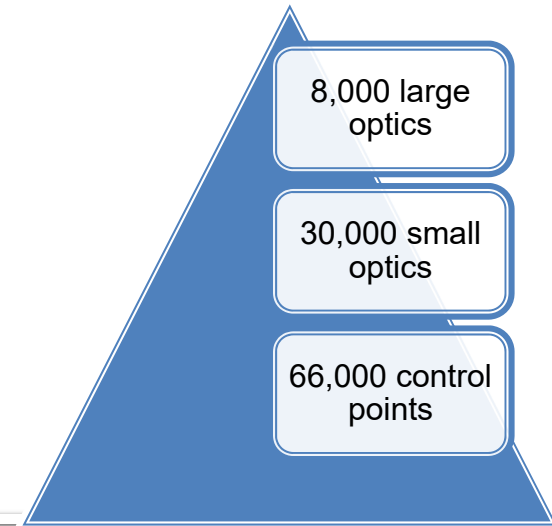
Each High Yield shot requires NIF 192 laser beams

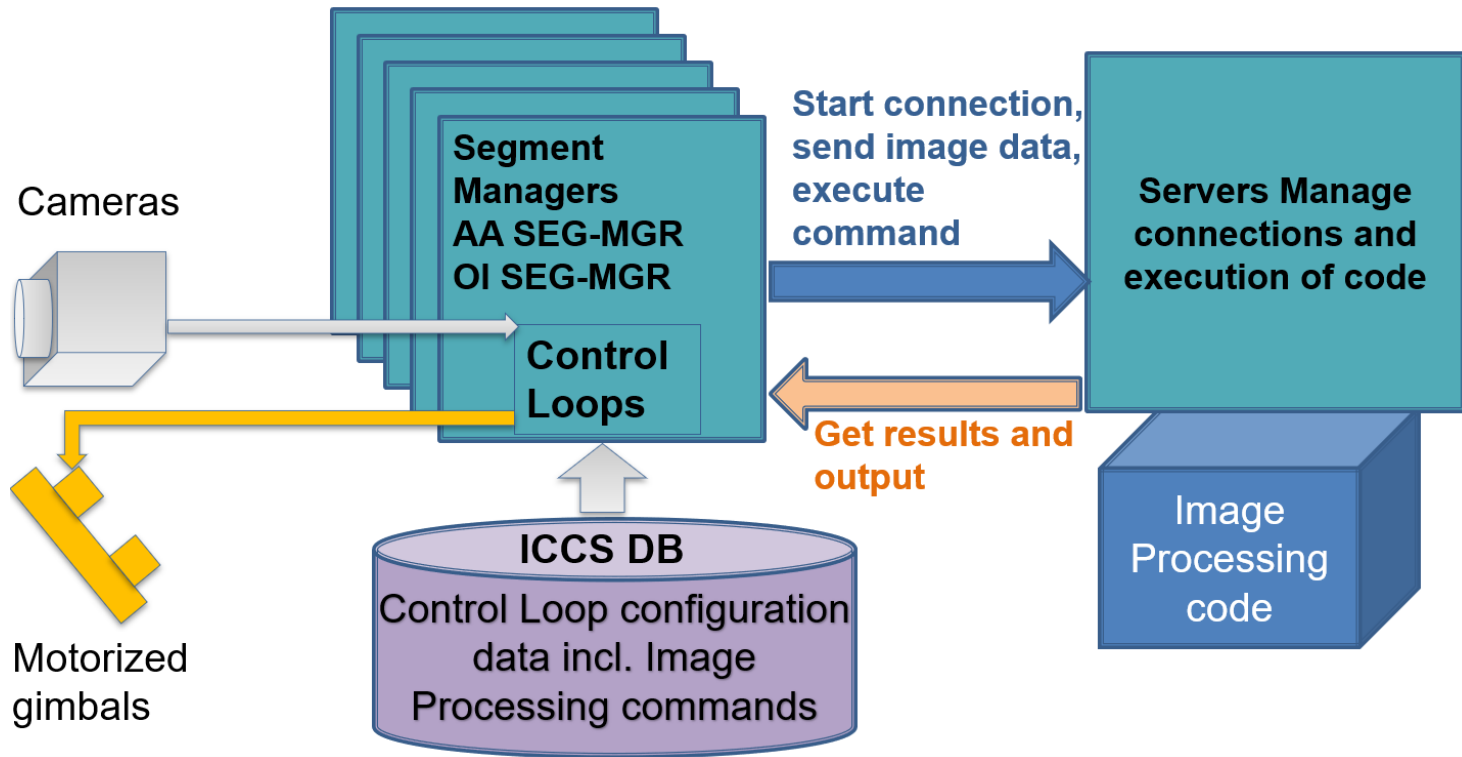
- Arrive at the target within 30 pico-secs
- Align within 50 microns
- Correct wavelength and energy



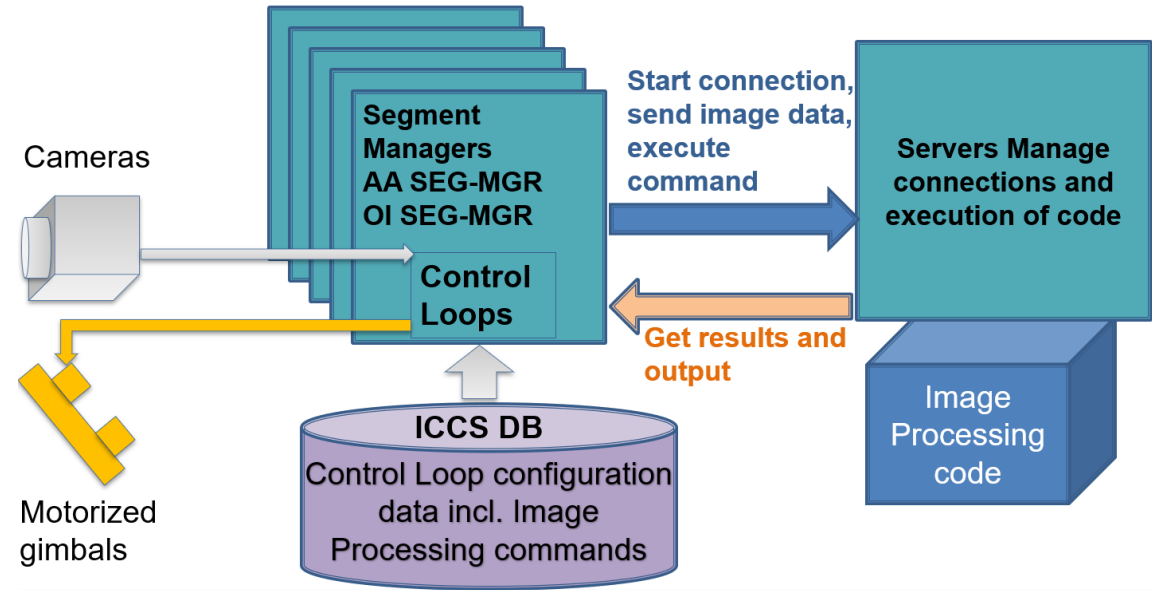
Automatic Alignment makes it possible to align and fire 192 NIF laser beams efficiently and reliably several times a day.

The success of a fusion shot is contingent on precision alignment of thousands of mechanical and optical components as the lasers are guided towards the target all of which is controlled by the AA system.





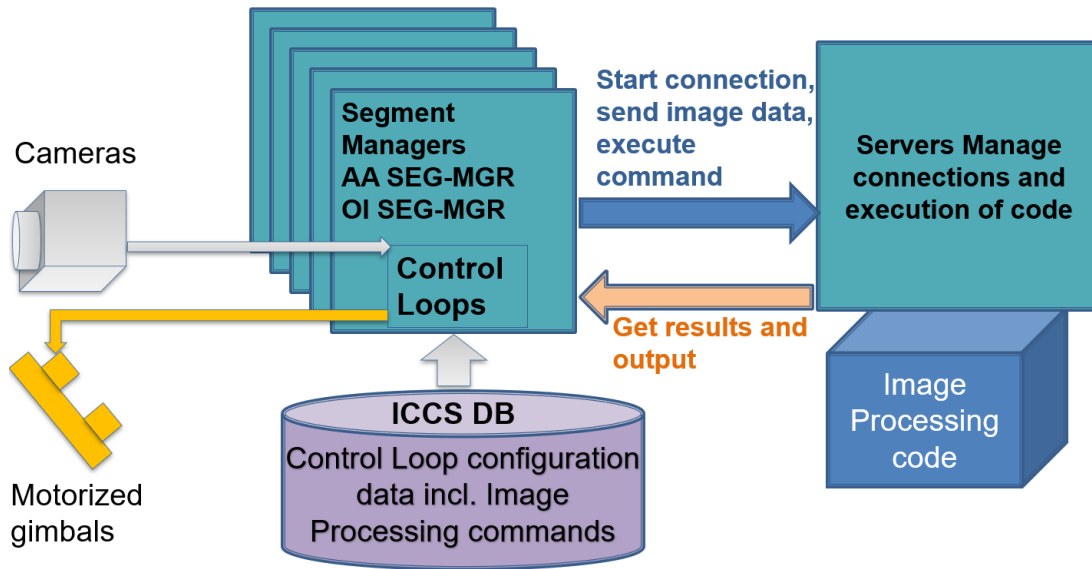
Automatic Alignment Software Architecture



NIF AA system

- Data driven software framework
- Ability to position optical and mechanical devices and
- Ability to align 192 high power laser beams accurately and consistently
- Minimal or no human interaction
- Complete shot cycle in timely manner
- Capable of operating at high repetition rates without influencing experiment results

Automatic Alignment Software Architecture



NIF AA has 6 main components:

- Segment managers
- Database retrieval
- Component mediation system (CMS)
- Loops
- Image processing
- Data analysis

Automatic Alignment Software Architecture

Each component has its own software platform and can run independently if needed.

NIF AA has a sophisticated user interface(UI) built on multiple layers, complex algorithms, testing framework and, Maintenance and Commissioning toolset.

The image displays two overlapping software interfaces for the NIF LCU. The top interface is the 'Segment Manager' and the bottom is the 'Component Mediation System'.

Segment Manager Interface:

- Segment Manager:** A table with columns 'Status' (green dots) and 'Type' (e.g., AAIBEAMIFOAISEG-MGR, AAIBEAMIMLISEG-MGR, etc.).
- Location:** A grid showing beam positions for locations C1, C2, C3, and C4. C3 has a blue square at position 34.
- Segment Commands:** A dropdown menu showing '3W_LS_BEAM_TO_TAS_CPP' and 'Shot ID'.

Component Mediation System Interface:

- CMS:** A table with columns 'Status' (radio buttons) and 'Type' (e.g., CMSIBEAMIBC-OPISCONFIG-MGR, CMSIHEMISPHEREIBC-OPISCONFIG-MGR, etc.).
- Location:** A grid showing beam positions for locations C1, C2, C3, and C4. C3 has a blue square at position 34.
- Configurator:** A list of configuration parameters (e.g., 375nm_WFL, AA_BEAM_T, AA_BKG_ON, AA_FF_REF, AA_FOA_BE, AA_FOA_RE, AA_ISP_CL_A).

Overlaid Assistant Window:

- Title:** NF AA|B341|FOA|SEG-MGR Assistant
- Menu:** File, Edit, View, Image, Services, Override, Mode, Status, Help
- Header:** B341 FOA
- Loop Section:**
 - Current: AA 3W LS BEAM TO TAS CPP
 - State: LOOP IDLE
 - Activity: IDLE
- Control Section:**
 - Buttons: Auto Perform, Resume, Clear Data, Release CMS, Setup Ref, Acquire Ref, Verify, Adjust Actual, Setup Actual, Acquire Actual, Stop.
- Details Section:**
 - Loop Details: Completed Adjustments 0 of 20, Units Millimeters
 - Reference: X Coord 0, Y Coord 0, Uncertainty 0

Segment Manager

Segment Managers occupies the topmost layer in the Automatic Alignment architecture and orchestrates all processes and devices in the AA process.

Automatic Alignment is comprised of multiple segment areas that contain commands containing many control loops

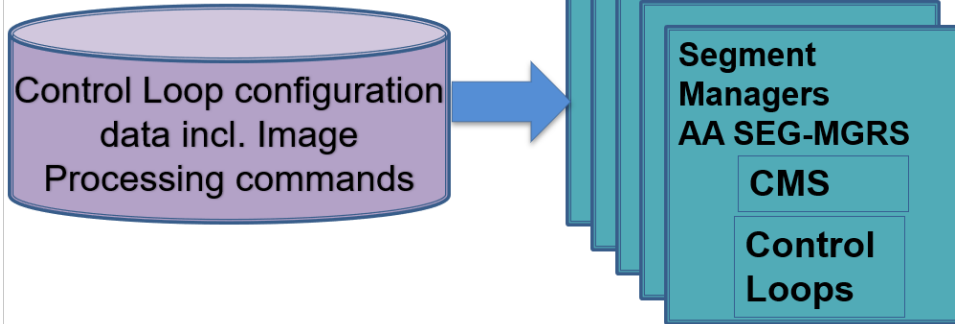
Each Segment Manager listed on the left has multiple segment commands and loops

The screenshot shows the 'Segment Manager' window with the following components:

- Segment Manager List:** A table with columns 'Status' and 'Type'. It lists various segment managers such as AA|BEAM|FOA|SEG-MGR, AA|BEAM|MJM|SEG-MGR, etc.
- Location Grid:** A grid showing alignment data for locations TC018-123, TC090-147, and TC161-326. The grid is divided into sections C1, C2, C3, and C4.
- Segment Commands:** A list of commands including COLLECT_M7M5_CLEAR_APERTUR, CORDON_LOIS_CHECK, CSF_P1_P4_PL, CSF_PINHOLE_CHECK, DARKSTOP, DECLARE_SHOT_SETPOINTS, FULL_ALIGNMENT (highlighted), FULL_ALIGNMENT_WF_CL_FLAT, INSERT_ISP_LOIS_MASK, LOIS_ALIGNMENT, MARK_RMDE_1_REGEN_TEST, MARK_RMDE_2_REGEN_TEST, MOVE_LM1_to_PASS_2, MOVE_LM1_to_PASS_4, PREP_ML_REGEN_TEST, PRE_SHOT_SETUP, TSF_P4_FINE, TSF_P4_ROUGH, TSF_PINHOLE_CHECK, VERIFY_ISP_LM3_CL, and VERIFY_ISP_LM3_CL_FULL_RES.
- Details Table:** A table at the bottom showing the status of a specific command: AA|B315|MJM|SEG-MGR, TSF_PINHOLE_CHECK, IDLE, Progress, 2023/05/02 08:36:52, 2023/05/02 08:37:22, 7 hr 7 min 38 sec, BCS|Q31B|SHOT|Local_Supervisor, Waiting on.

Each control loop employs image processing to determine reference and beam locations

AA Segment Manager interface



Data Retrieval

Data taken from the database includes

- Execution plan to complete the entire alignment
- Initial positions of the devices that is required for the process to run
- Loop configuration data
- Image processing commands

Component Mediation System (CMS)

CMS contains configurations for mediation systems

CMS

Status Type

- CMSIBEAMIBC-OPSCONFIG-MGR
- CMSIHEMISPHEREIBC-OPSCONFIG-MGR
- CMSIOUADIBC-OPSCONFIG-MGR
- CMSISWITCHYARDIBC-OPSCONFIG-MGR
- CMSIOUADIILS-OPSCONFIG-MGR
- CMSIBEAMILO-OPSCONFIG-MGR
- CMSIBEAMIPDS-IOMICONFIG-MGR
- CMSIBEAMIACQUIREICONFIG-MGR
- CMSIBEAMIFOAICONFIG-MGR
- CMSIBEAMIFODIICONFIG-MGR
- CMSIBEAMILOISICONFIG-MGR
- CMSIBEAMIMLICONFIG-MGR
- CMSIBEAMISIDEICONFIG-MGR
- CMSIBEAMIPDSICONFIG-MGR
- CMSIBEAMIARC-FODIICONFIG-MGR
- CMSIBEAMIARC-SIDEICONFIG-MGR
- CMSIBEAMIARC-TAICONFIG-MGR
- CMSIBEAMIDLICONFIG-MGR
- CMSINIFICCRS_060_MAINICONFIG-MGR
- CMSINIFICCRS_220_MAINICONFIG-MGR

Location

C018-12
NIE C090-14
C161-32

Legend: IDIF BUSY RESERVFD BLOCKFD ERROR

Configurations

- 375nm_WFL_to_BEST_FOCUS
- AA_BEAM_TO_ACTIVE_TARGET_CPP
- AA_BEAM_TO_ACTIVE_TARGET_NO_CPP
- AA_BEAM_TO_TAS_CPP**
- AA_BEAM_TO_TAS_NO_CPP
- AA_BKG_ONLY_BEAM_TO_TAS_CPP
- AA_FF_BEAM
- AA_FOA_BEAM
- AA_FOA_REF
- AA_ISP_CL_ALIGNMENT
- AA_ISP_CL_LOIS
- AA_ISP_PL
- AA_ISP_PL_CHECK

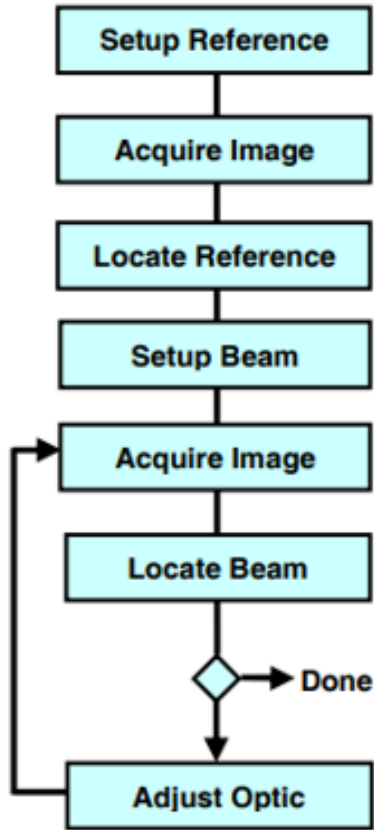
Job ID:

Reservation Type:

Details

Configuration steps for AA_BEAM_TO_TAS_CPP

R	CMS	Taxon	Gro...	Interface_T...	Interface_Name	Operation	Position	Final_Reser...	error_Beha...	parameter	timeout	Queue	Waiting on
91	CMS[B341]FOA[CON]FIG-MGR	ACIB341[SY IOMIAD...	2	SETPOINT	SETPOINT INTER...	AT SETPOI...	ACTIVE	NONE	IGNORE				
		ACIB341[SY IOMICC...	1	SETPOINT		GOTO SET...	REMOVE	NONE	RETRY		100.0 s		
		ACIB341[ITSFDI3W-LS...	1	SETPOINT		GOTO SET...	INSERT	NONE	RETRY				
		ACIB2[ITSFDI3W-LS...	1	SETPOINT		GOTO SET...	ON	NONE	RETRY				
		ACITC007-045[CIVS]I...	1	SETPOINT		GOTO SET...	AA_BEAM TO TAS CPP	NONE	RETRY				
		ACITC007-315[CIVS]I...	1	SETPOINT		GOTO SET...	OFF	NONE	RETRY				
		ACITC077-024[CIVS]I...	1	SETPOINT		GOTO SET...	OFF	NONE	RETRY				
		ACITC077-174[CIVS]I...	1	SETPOINT		GOTO SET...	OFF	NONE	RETRY				
		ACITC090-183[CIVS]I...	1	SETPOINT		GOTO SET...	OFF	NONE	RETRY				
		ACITC090-278[CIVS]I...	1	SETPOINT		GOTO SET...	OFF	NONE	RETRY				
		ACITC143-094[CIVS]I...	1	SETPOINT		GOTO SET...	OFF	NONE	RETRY				
		CMSINIFITAILOCK-M...	1	RESERVAT...		RESERVE	RESERVED	NONE	RETRY				



Generic loop execution

Loops

- Loops manage all actions required to adjust an optic
- There are more than 600 loops that provide these functions for specialized requirements of the different laser area
- All loops have a loop type for their individual function and are assigned a camera, a gimbal and CMS configuration based on its type
- All loops go through a finite number of iterations

Loop Types

As per the operations the Loops manage, they are categorized into different types.

Example of loop types are

- Centering Loops
- Pointing Loops

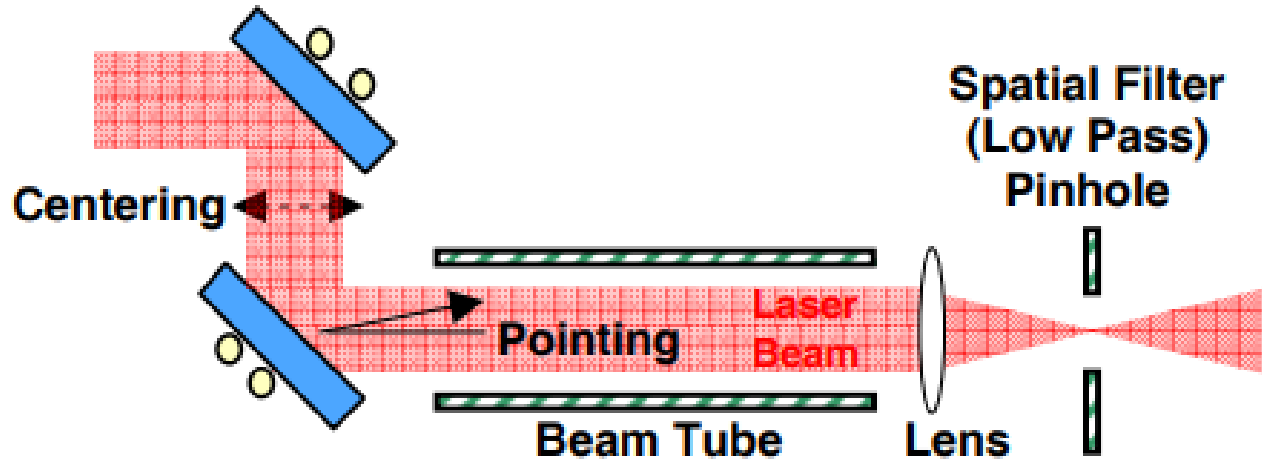
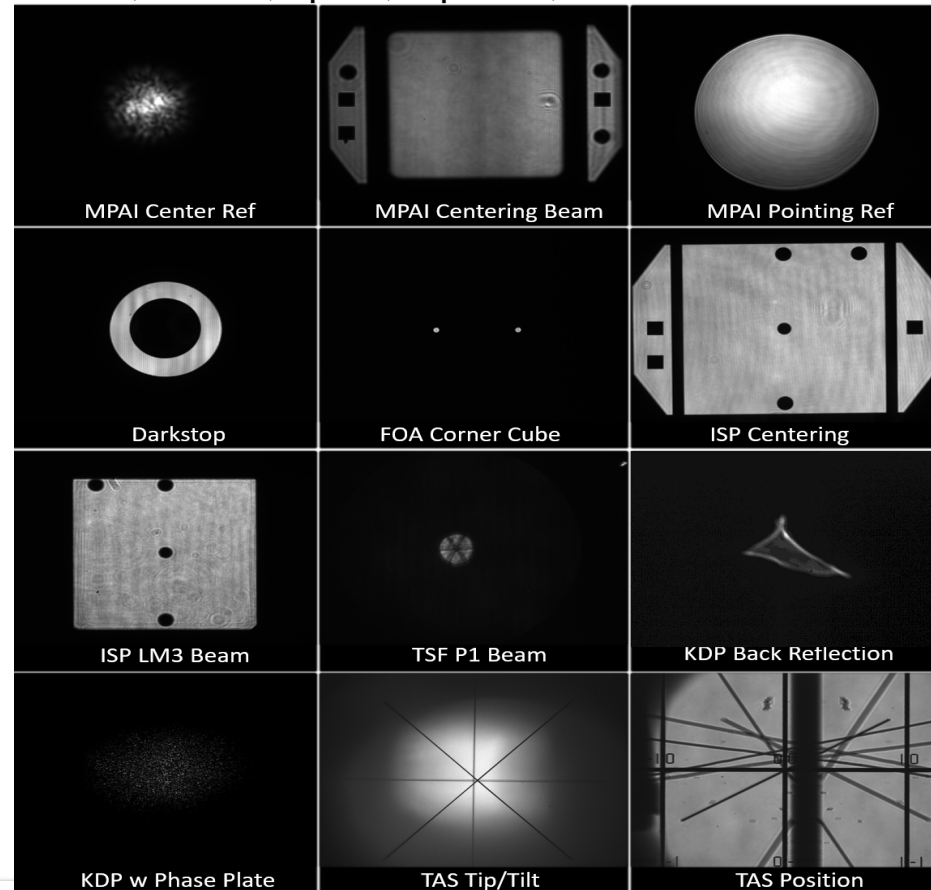


Image Processing - challenges of real-time image analysis

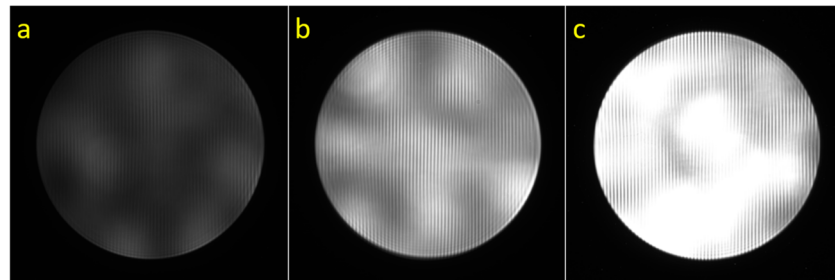
- Processing images with various types of noise
- Distortion
- Obscuration
- Imaging artifacts

Sample of various images and fiducials including lines, circles, spots, squares, etc.



Data Analysis

- 8-bit images of the back-lit Cavity Spatial Filter (CSF) pinholes illustrating marginal, nominal, and saturated signal levels.
- The images were archived for the same loop but different beamlines and are representative of the variation in signal levels across the system during alignment on a given shot.

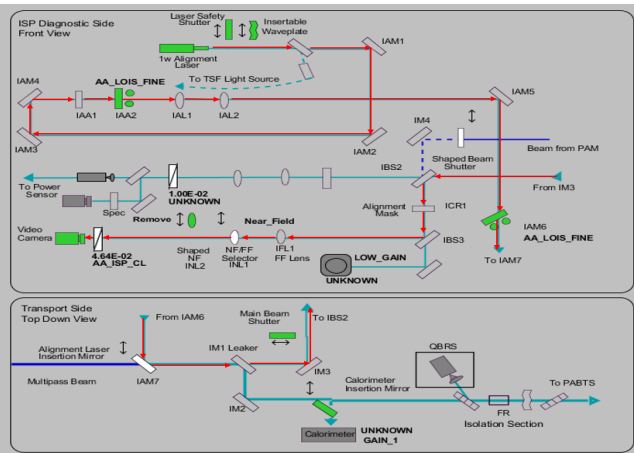


Analyzing critical data archived during AA operations helps to identify anomalies, improve planning, and evaluate overall performance critical to the NIF alignment system.

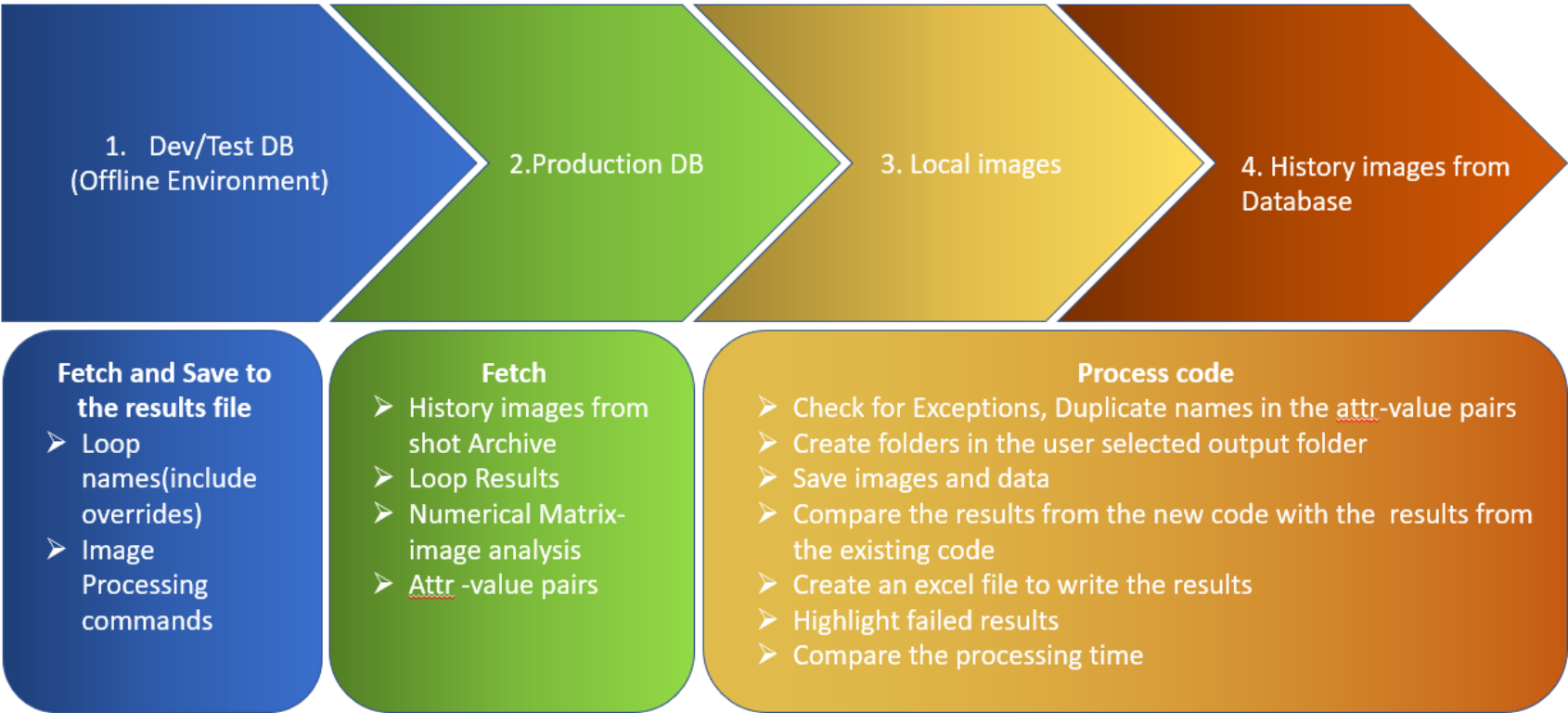


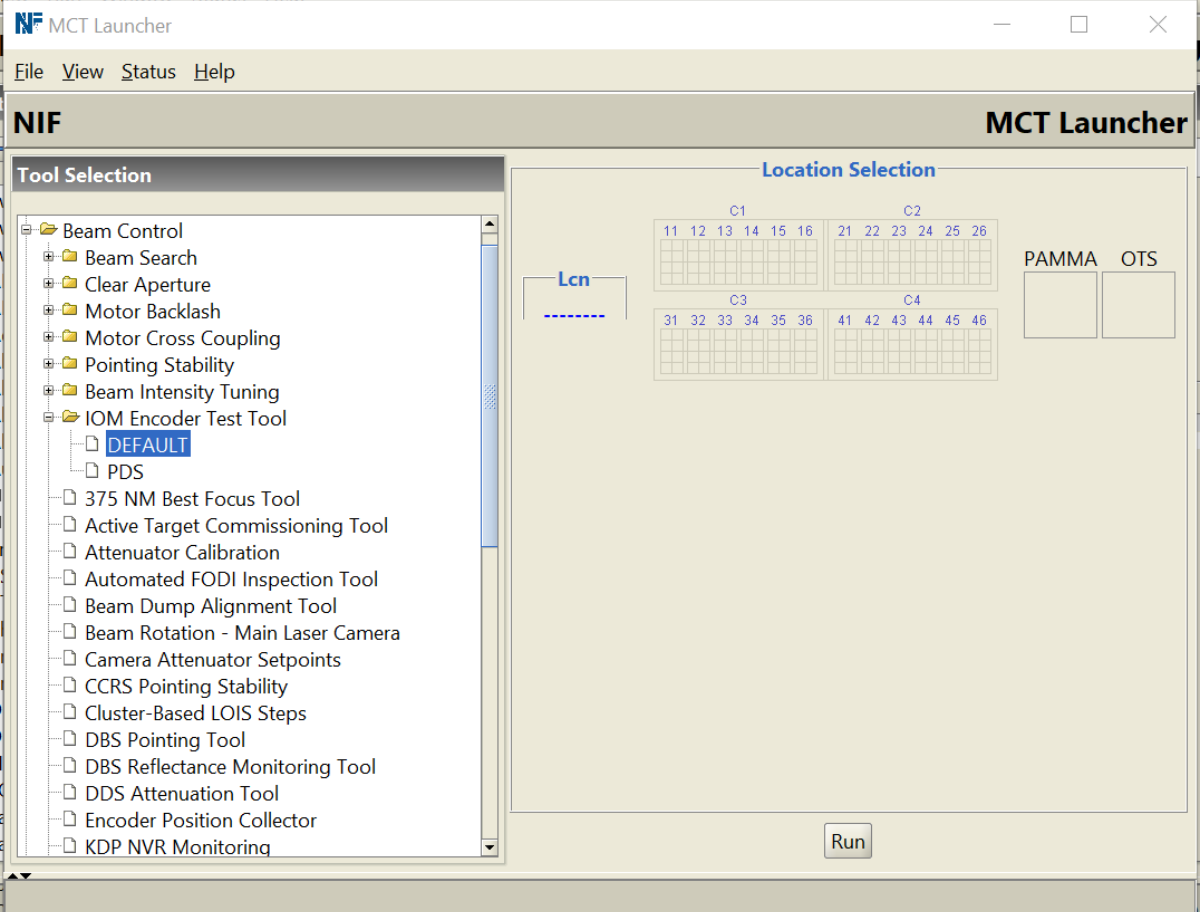
NIF Shot Setup

The entire setup of automatic alignment can be viewed and controlled from a single computer using an interactive UI



Given the fact that NIF AA is complex and interdependent, it is critical to check the effects of any code change on the overall alignment process.

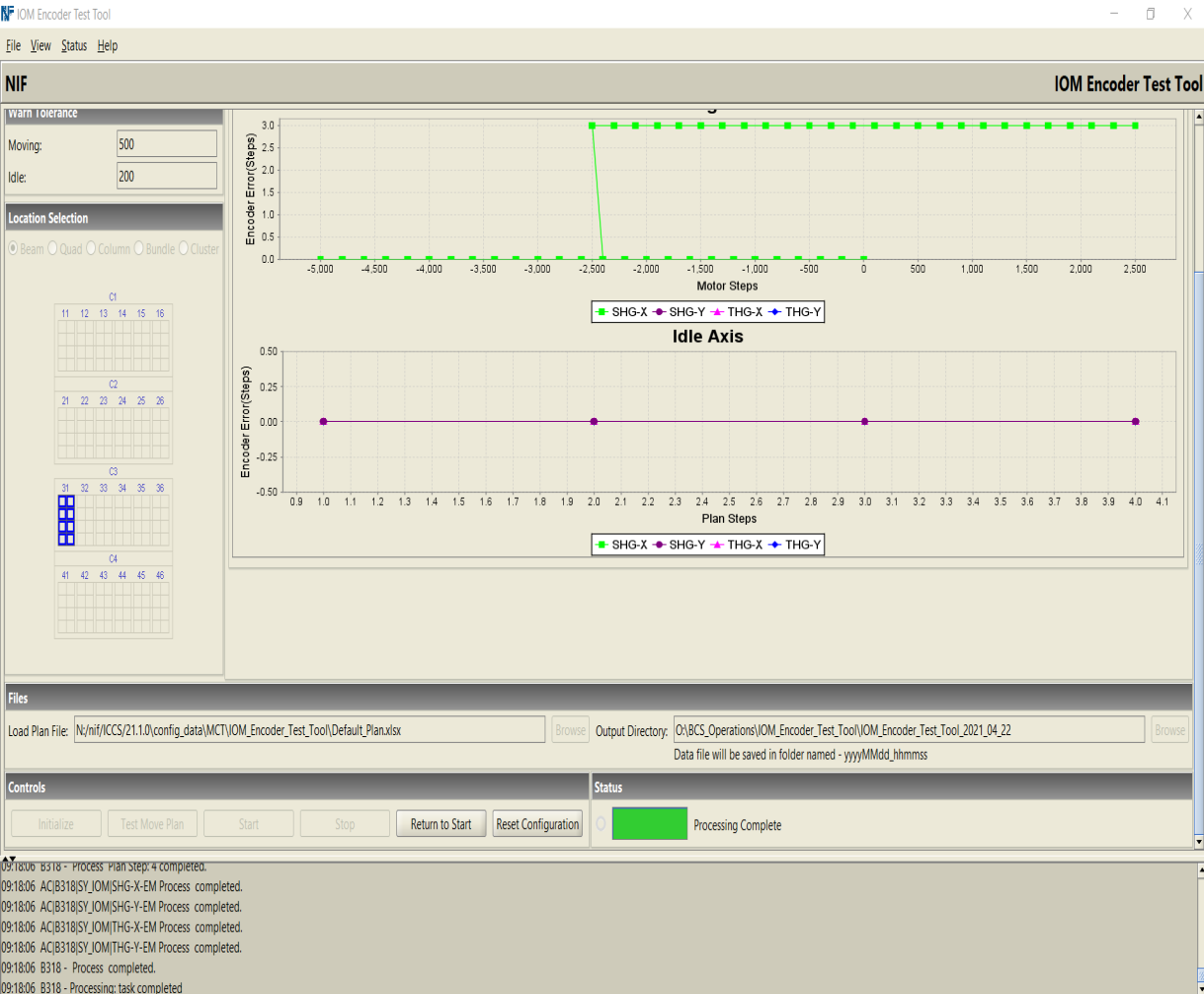




Online Maintenance & Commissioning toolset (MCT) developed to support AA

- Retrieves and analyzes data
- Determines motor and device problems, as well as optimizing operational parameters due to system variation
- Alleviates performing manual maintenance which can be time-consuming and inaccurate

MCT is comprised of 98 tools which can be run frequently and efficiently



Example MCT – IOM Encoder Test Tool

Problem: The motorized gimbal in the Integrated Optics Module (IOM) had occasional mechanical issues which were hard to detect. This caused significant operations time spent in malfunction identification.

Solution: IOM encoder test tool ran 192 beams in parallel and identified the problems in minutes.

NIF Camera and Attenuator Setpoints Tool - MAIN_LASER

File View Status Help

NIF Camera and Attenuator Setpoints Tool - MAIN_LASER

Alignment Kind Selection
MAIN_LASER Select

Location Selection
Beam Quad Column Bundle Cluster

Current and Recommended Setpoint Values

C1 C2 C3 C4

11 12 13 14 15 16 21 22 23 24 25 26 31 32 33 34 35 36 41 42 43 44 45 46

B311

Sel	AA Loop	Image Type	Camera / Attenuator Setpoint	Transmission				Exposure				Gain				Adjusted Signal Level	Desired Signal Level	Tolerance	Action	
				Initial	Current	Proposed	Locked	Initial	Current	Proposed	Locked	Initial	Current	Proposed	Locked				Process	Save
<input checked="" type="checkbox"/>	AA_LM13_CL	Reference	AA_NF_REF_TOP	0.0003	0.00008008		<input type="checkbox"/>	0.0299999	0.0299999		<input type="checkbox"/>	1	1		170	170.0	0.05	Process	Save	
<input checked="" type="checkbox"/>	AA_LM13_CL	Beam	AA_LM13_LS_TOP	0.004	0.004		<input type="checkbox"/>	0.6	0.6		<input type="checkbox"/>	1	1		170.0	170.0	0.05	Process	Save	
<input checked="" type="checkbox"/>	AA_JSP_LM3_CL	Beam	AA_JSP_NF_TOP	0.0001	0.0001457		<input type="checkbox"/>	0.5695	0.5695		<input type="checkbox"/>	1	1		170.0	170.0	0.05	Process	Save	
<input type="checkbox"/>	AA_CSF_P4_PL	Reference	AA_FF_REF_TOP	0.0001	0.0001728		<input type="checkbox"/>	0.26045	0.26045		<input type="checkbox"/>	1	1		230.0	230.0	0.043	Process	Save	
<input type="checkbox"/>	AA_CSF_P4_PL	Beam	AA_CSF_P4_TOP	1	1		<input type="checkbox"/>	0.2249999	0.2249999		<input type="checkbox"/>	1	1		190.0	190.0	0.05	Process	Save	
<input type="checkbox"/>	AA_CSF_P3_PL	Beam	AA_CSF_P3_TOP	1	1		<input type="checkbox"/>	0.506779	0.506779		<input type="checkbox"/>	1	1		170.0	170.0	0.05	Process	Save	
<input type="checkbox"/>	AA_CSF_PH_BEAM_CHECK	Beam	AA_JSP_FF_TOP	0.0000	0.0000189		<input type="checkbox"/>	0.001	0.001		<input type="checkbox"/>	1	1		200.0	200.0	0.075	Process	Save	
<input type="checkbox"/>	AA_TSF_P1_PL	Beam	AA_TSF_P1_TOP	1	1		<input type="checkbox"/>	0.27	0.27		<input type="checkbox"/>	1	1		170.0	170.0	0.05	Process	Save	
<input type="checkbox"/>	AA_TSF_PH_BEAM_CHECK	Reference	AA_TSF_P4_TOP	0.0335	0.0335377		<input type="checkbox"/>	0.15	0.15		<input type="checkbox"/>	1	1		210.0	210.0	0.05	Process	Save	
<input type="checkbox"/>	AA_DARKSTOP	Beam	AA_DS_SMALL_TOP	1	1		<input type="checkbox"/>	0.0299999	0.0299999		<input type="checkbox"/>	1	1		180.0	180.0	0.05	Process	Save	

Controls

Initialize

Process Selected Save Selected

Export Selected to Excel Export All to Excel

Stop Clear Error

Revert Selected Revert All

Revert Locations... Reset Configuration

Light Source Group 1W LSL Select Group Deselect Group

Save Images / Results

Save Images Save Results

Output Directory: E:\A

Data file will be saved in folder path - CameraAttenuatorSetpoint_<MMddyyyy>\/<Loop Name>\/<Image Type>\/<MMddyyyy>_hhmmss

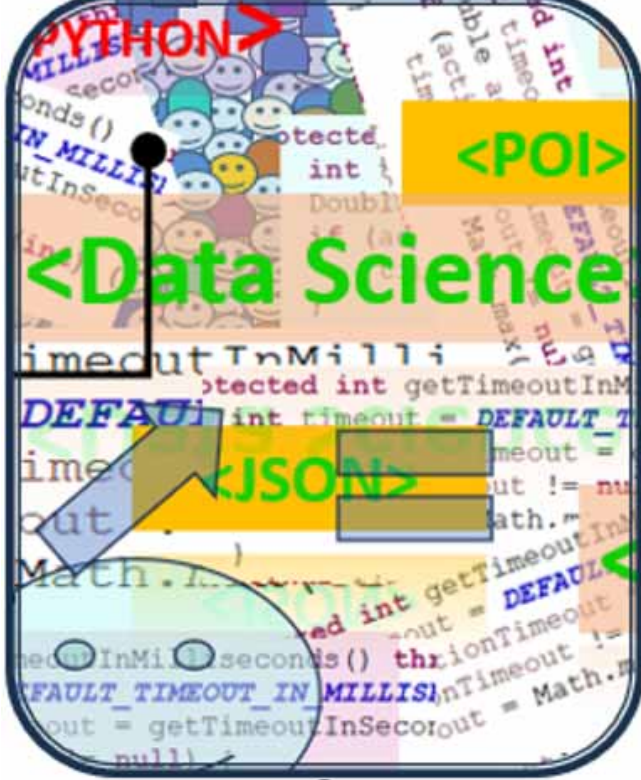
Status

Saving Selected Loops is Complete

Example MCT – Camera & Attenuator Setpoint tool

This tool automates the settings for the camera parameters, so that images with optimal signal to noise ratio can be passed to AA for processing and process camera and attenuator parameters for multiple beamlines in parallel and completes in a minute or two.

Future Sustainability and Modernization Plan



The Focus and Goals

- Identifying and optimizing technology and tools
- Determining resources and flexibility
- Balancing future development and modernization
- Maintaining accuracy and execution
- Verification test plan

The Future Sustainability and Modernization Plan is aimed at a long-term plan to keep up with constantly evolving technology and maintain current NIF Automatic Alignment requirements.

Thank You





**Lawrence Livermore
National Laboratory**