LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Advanced LIGO ERGO Arm Hazard Analysis

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LIGO Science Collaboration

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Summary

This document is to identify potential safety hazards associated with using the ERGO arm during installation of Advanced LIGO core optics. It attempts to put these hazards in a context of severity and likelihood to allow for managing of risk.

The most severe level of hazard found is level 2 (Critical) – D (Remote) from the danger of dropping a core optic during ERGO arm use. This level of hazard requires review by the Directorate.

Scope

This document is solely concerned with hazards during the use of the ERGO during installation of Advanced LIGO core optics. The ERGO arm is a device to pick up, move, hold, and install Advanced LIGO core optics. It consists of a plate with an O-ring that is placed against the optic, a vacuum system that can pull a vacuum in the space between the O-ring and the optic, a movable arm that can maneuver the held optic into place, and a wheeled cart that allows the whole structure to be moved.

Steps for use of the arm are:

Clean the O-ring

Use the adjustments to carefully lower the vacuum chuck on to the optic

Loosen all of the adjustment screws so that the plate rests gently on the optic

Start the portable vacuum tank to pull a vacuum between the chuck and the optic

Watch the valve for a couple of minutes to be sure the vacuum is holding

Close the valve between the vacuum tank and the optic

Tighten the adjustment screws on the vacuum chuck

Lift the optic and maneuver into place

Loosen the adjustment screws

Open the vacuum valve to vent the vacuum between the chuck and the optic

Tighten the adjustment screws

Carefully move the arm away from the optic.

Interfaces

Related Documents

Hazard Severity Table

This section identifies potential hazards to users of the ERGO arm, and evaluates them based on the severity (1-4) and likelihood (A-E) scales described more fully in M070360-04. This is not meant to be an exhaustive list of hazards, but a documentation of known risks.

Hazard	Cause	Effect	Severity Level	Probability Level	Risk	Comments
Dropped Optic	Failure of arm to hold optic	Damage to optic, injury to personnel	Critical - 2	Remote - D	2D	AdvLIGO core optics are 40 kg
Vacuum Failure	Decompression of vacuum chamber	Possible damage to optic, injury to personnel	Marginal -3	Remote – D	3D	
Scratch Optic	Arm contacting the optic anywhere but O-ring	Damage to optic, likely on edge	Marginal - 3	Occasional - C	3C	O-ring does not stick out much beyond plate

The ERGO arm has been tested to insure that it can hold a 40 kg optic during installation. If it drops the optic would likely be ruined and there is the possibility of crushing damage to feet, arms, legs, etc of those nearby. This may happen due to improper use of the arm, such as not connecting the vacuum chuck to the optic correctly, not ensuring the vacuum is holding before attempting to move optic, not adjusting the tightening screws at the correct time, etc. These problems can be avoided by having only qualified personnel operate the arm and following proper procedure. There is a very small chance of equipment failure, such as damage to the O-ring so a good vacuum is not held, weakened or damaged screws or other metal structures, failure of the portable vacuum system, etc. Most of these can be avoided by proper inspection of the arm before and during use.

Plans are in place to test the failure point of the arm using a metal plate for the optic. The plate will then be weighted down while in the vertical, clock position until the arm fails to hold it. It is anticipated that failure will occur much beyond the 40 kg weight of an Advanced LIGO core optic.

Findings from Tests by Steve Vass

We tested the arm's holding ability with a steel disc of 80 lbs similar to a large 40 kg TM (STM)
The Ergo arm is well designed, safe tool.
It is very strong to lift and hold in horizontal position up to ~1400 lbs (estimated)
As you tip the load to a vertical position the chance of slipping on the teflon covered o-ring
is increased by the size of the load (changing accidentally driving through a pot hole)

This was tested.
The CES crane was attached to the STM with a safety sling.
Uncalibrated Dillon force gauge was hooked to the bottom of the STM
and the other end of the force gauge was connected to the foot of the ergo device.
As the height of the load was increased by cranking it up, the force gauge was reading
the increased load.
The load was increased in 50lbs steps, it started slipping at ~200lb
It was stopped so it did not break vacuum.
Mike Gerfen estimates that it would support well over ~500 lbs in a slippage stopped
vertical position.

Recommending: 2 small, easy removable stop-hooks (3 if rotation is excessive),
SUS experts should be consulted for clearance; authorization

Test 2

Vacuum pressure holding was tested overnight.
The STM in vertical position for 12 hrs at 23" Hg did not move.
It lost 1.5" Hg during this period.

Test 3

Vacuum pressure holding with increased leak rate.
Single hair placed across the o-ring seal had no effect.
Nylon fiber of 0.5mm diameter across the o-ring vented the system in 5sec

recommending: self contained (with battery- no cables), small pressure transducer with audio alarm
(Steve will come up with device)
and manual vacuum plug to protect against accidental venting

Test 4

Minimum pressure to hold STM in horizontal position is 5" Hg ,
and it is 8" Hg in the vertical position.
The Ashcroft vacuum gauge was not calibrated and the test periods were 5 minutes only

Other recommendation: lock ability of horizontal arm,

This is a great loading- removing- positioning tool.
The vertical position of load requires stop hooks.
Rotation range is limited.

Thanks to Mike Gerfen, who was instrumental in the test.

Comments from Mark Barton – December 2009

* It would be nice to have finer control and a lock on the front/back DOF. Something like a handwheel (as for pitch) driving a pinion gear on the upright that engaged with a track gear on the arm, plus a lock screw to immobilize the arm. (If the handwheel was too stiff to turn when the arm was pushed directly as it is currently, it would also be good to make the engagement of the pinion gear with the rack optional.)

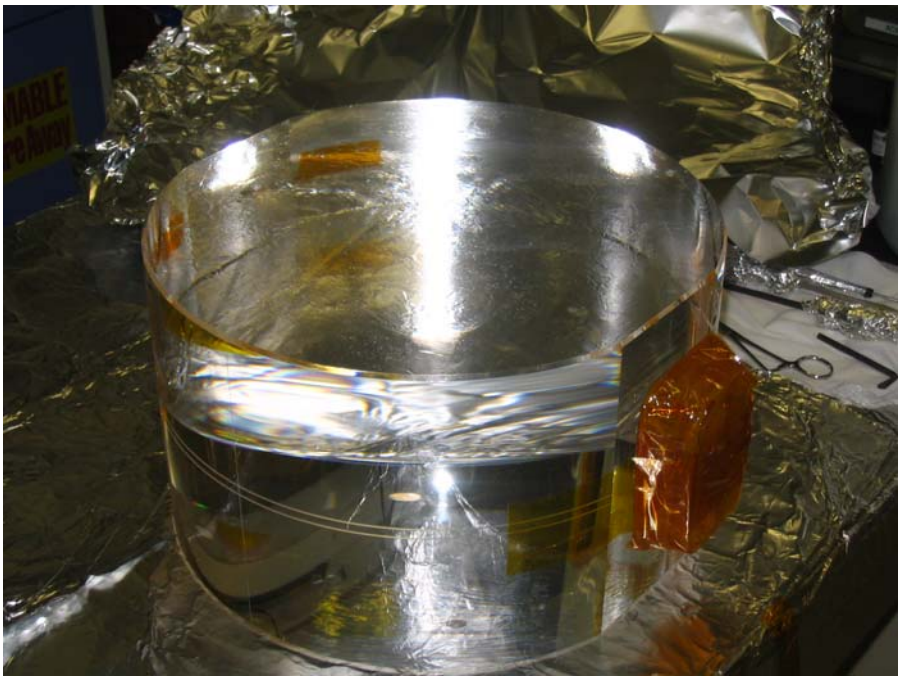
* The existing vacuum system is not very satisfactory. The tubing is inconveniently short and slightly too large for the pipe on the ergo arm head, so that it needs considerable force on the band clamp to prevent leaks. A better arrangement would be as follows:
- Vacuum reservoir, with gauge and valve, similar to existing but mounted on the ergo arm if possible.
- Directly after the valve, a T-piece.
- Connected to one arm of the T-piece, a valve and a quick release connector for connecting the vacuum pump.
- Connected to the other arm of the T-piece, a length of hose leading to the existing valve, gauge and suction head.
- A hose of sufficient length and appropriate fittings to connect the vacuum pump on the floor to the quick-release connector on the T-piece.

The idea here is to allow the reservoir to be a better safety backup for the main suction plate by ensuring that there are no band clamps or other unreliable connections between the two. All connections would be permanent except for the one quick-release one between the valve on the T-piece and the hose to the pump, and it would not need to be especially leak proof.

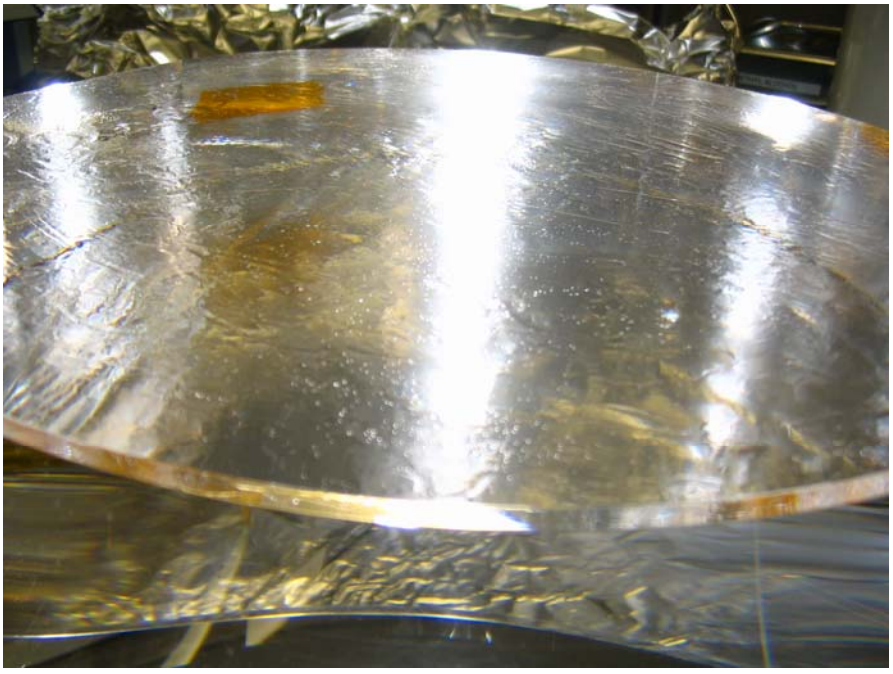
Tests at LASTI – January 2009

From the LASTI AdvLIGO Optics ILOG January 9, 2009

Following up on the tests Brett and Gregg did with the aluminum plate covered in First Contact, Gregg did tests with the chipped LASTI penultimate mass. Before the holiday, Gregg covered the non-chipped side with First Contact.

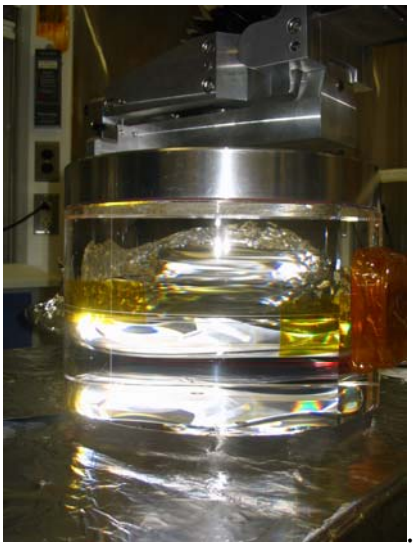


This figure shows the full option on the bench with First Contact on the surface before any tests with the ERGO Arm.

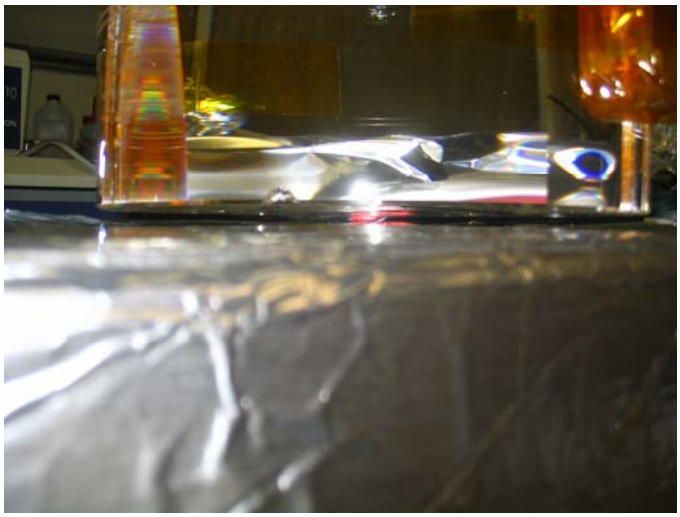


This figure shows a closeup of the surface of the First Contact before any ERGO arm tests.

The First Contact-covered surface of the optic was then connected to the ERGO Arm face. The optics was lifted about 1 inch off the table, remaining in the horizontal position. It remained that way for about 10 minutes, while the pressure was monitored. The pressure was slowly drifting down but was around 23 in Hg

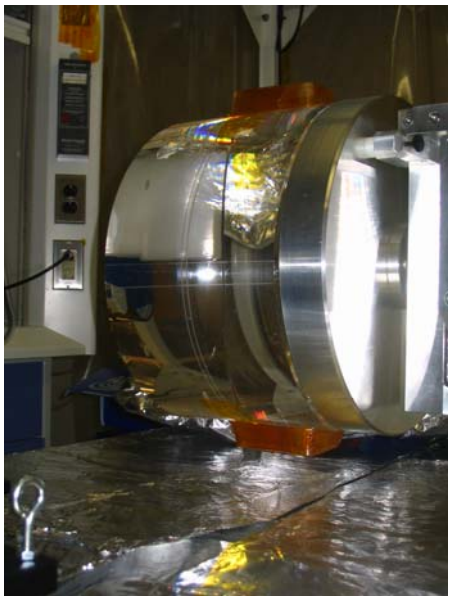


The picture shows the optic as it is held in the horizontal position.

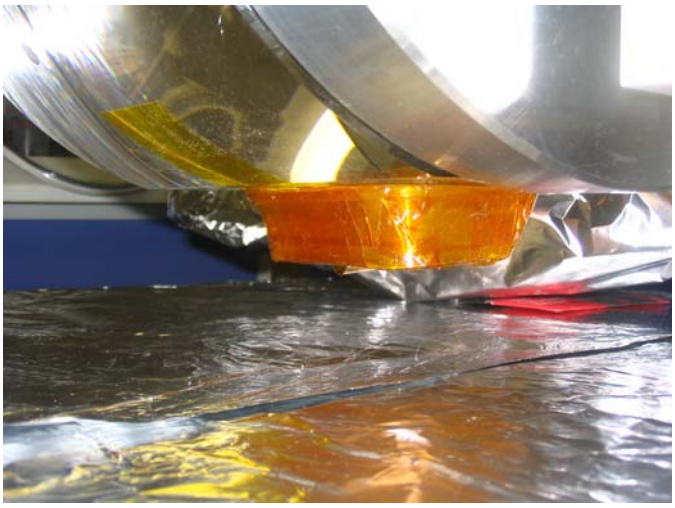


This figure shows a closeup of the bottom of the optic while being held horizontally, just to try to show the optic was off the table and fully supported by the ERGO Arm.

After the horizontal test, the optic was rotated so it was held vertically. It was held this way for another ~10 minutes, watching the pressure continue to slowly drop to about 22 in Hg.



The figure shows the optic in the vertical position.



This figure shows a closeup of the bottom of the optic in the vertical position, after being lowered but before the ear was rotated away. After taking this picture, the optic was rolled so the covering over the ear was not at the bottom, and lowered it so it was only about 1 inch off the bench.

After ~10 minutes in the vertical, everything was fine but the pressure was still slowly dropping, now about 21 in Hg. It remained in the vertical for another ~30 minutes, until the pressure got below 20 in Hg. Knowing that the aluminum piece fell off after between 1 and 2 hours, the optic was put back on the bench. The optic was rotated back to horizontal and lowered down to the bench.

The figure shows the surface that was in contact with the face of the ERGO Arm and has the First Contact on it after the tests. The picture is not the best way to prove this, but there was no evidence that the O-ring permanently changed the First Contact.