LCLS-II

Cavity Production Impact

F. Marhauser

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SLAC NATIONAL ACCELERATOR LABORATORY

BERKELEY LAB Lawrence Berkeley National Laboratory

Argonne NATIONAL LABORATORY

Cornell University Founded A.D. 1865

Fermilab

Jefferson Lab

E. ZANON

research instruments

U.S. DEPARTMENT OF ENERGY Office of Science

Cavity Production

- 266 LCLS-II 1.3 GHz cavities are being built by 2 European Vendors, i.e.
  - RI Research Instruments, GmbH (**RI**)
  - Ettore Zanon, S.p.A. (**EZ**)
  - Each vendor will provide 50% of the cavities per contract
- This covers 33 cryomodules (33 x 8 = 264 cavities)
  - 2 cavities are replacement cavities for FNAL and not spares for LCLS-II
- LCLS-II has presently no spare cavities ordered
  - However, contract leaves the option to procure additional 32 cavities (16 cavities each vendor) in a production Phase IV pending decision in Phase III

Production Schedule

- Production of cavities proceed well at both vendor sites
- 8 fully dressed cavities are expected to be shipped within the next 2 weeks
  - 4 cavities from RI currently prepared for customs clearance

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Cavities	Shipping Dates*	Status**
1-8	7/1/2016	~1-2 weeks delay
9-16	8/1/2016	On schedule
17-28	11/2/2016	On schedule
29-40	11/30/2016	On schedule
41-52	12/28/2016	On schedule
53-64	1/25/2017	On schedule
65-76	2/22/2017	On schedule
77-88	3/22/2017	On schedule
89-100	4/19/2017	On schedule
101-112	5/17/2017	On schedule
113-124	6/14/2017	On schedule
125-133	7/12/2017	On schedule

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~ 6 weeks behind RI
(have received production material later)

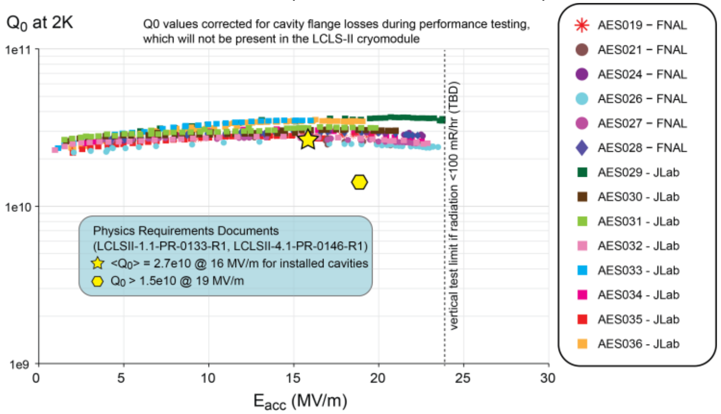
- Note: Cell material chosen by vendors at start of production was rather arbitrary (but no mix of TD and OTIC in individual cavities allowed)
- RI: **First 40 cavities are made from TD**
- ZANON: **First 8 cavities (at least) are made from OTIC material**

* ideal, ** status June 2016

Present LCLS-II Post-Processing Recipe

- Present recipe is based on past R&D and applied to 9-cell prototype cavities
  - Main Steps
    - Bulk EP
    - Vacuum Furnace Bake-Out
      - Heat treatment at 800 deg. C for 3 hours
      - N-doping at 800 deg. C for 2 minutes
      - 6 minutes dwell time at 800 deg. C
      - Unforced cool-down
    - Fine EP

vertical tests (status Oct. 2015)

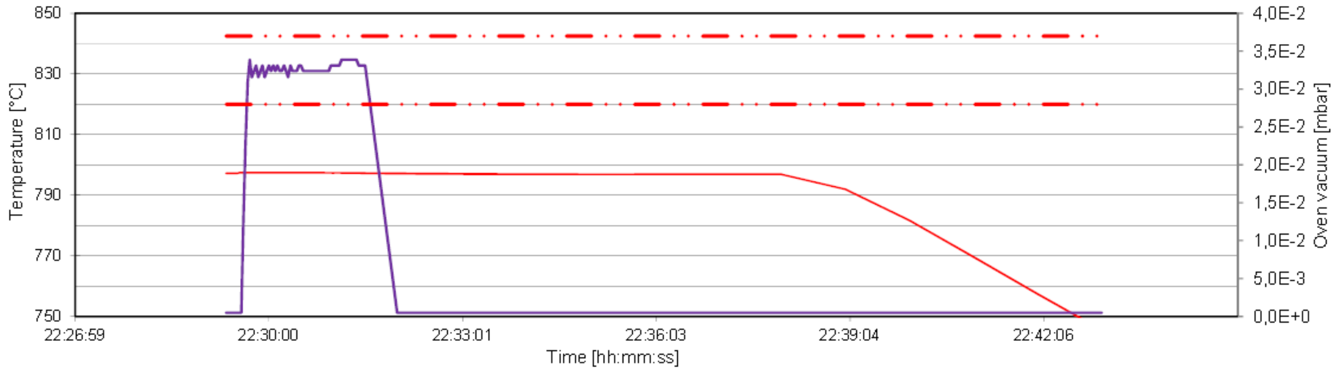


- Prototype cavities treated with this recipe routinely exceeded the high-Q_0 LCLS-II specification in vertical tests (Q_0 = 2.7e10 at 16 MV/m)

N-Doping Procedure

- The N-doping technology was successfully transferred to industry in 2015 during vendor qualification
- Same recipe currently being applied for first articles production and beyond at vendor sites
- RI's recent data show that N-pressure can be well controlled within specified limits with even for multiple cavities in the furnace (required for mass fabrication schedule)

Typical N-doping pressure control, here for CAV0007 & CAV0008



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Issue and Possible Remedy

- Prototype cavities were made from ATI WAH Chang Nb material
- Cavities exhibit long history of treatments, e.g.
  - Multiple furnace cycles at 800 deg. C (1 FNAL prototype cavity baked at 1000 deg. C)
  - Cavities have been partially barrel polished due to various blemishes (thinning wall)
- Production cavities are made either from Tokyo Denkai (TD) or OTIC Ningxia (OTIC)
- CD2 review recommendation was to investigate flux expulsion with production material
- Is ongoing with 4 single-cell cavities (2 x OTIC, 2 x TD)
  - Findings indicate very poor flux expulsion for both materials (Ari)
- Independent R&D at FNAL with single-cell cavities (Sam, Anna) implies that baking at 900 deg. C (instead of 800 deg. C) will significantly improve/regain flux expulsion
  - Further material annealing (grain size growth) matters, not regarded during initial R&D phase

What is Cost and Schedule Impact of a 900 deg. C Cycle (3 Hours)

- We asked for quotes from vendors mid May '16:

  Option 1: 900 deg. C for 3 hrs. annealing before the bulk EP & before N-doping (present recipe)
  Option 2: 900 deg. C for 3 hrs. as part of N-doping (after bulk EP) in lieu of 800 deg. C for 3 hrs., then N-dope with standard recipe at 800 deg. C (N2A6) and cool down

- Relative Cost Comparison Among Vendors

Option	E. ZANON	research instruments
1	highest	96% of EZ

- Option 2 has a relatively minor cost impact (~factor 10 less than option 1)

Schedule Impact

- The furnace treatment can only be carried out in one furnace (for both vendors)
- Schedule impact was more difficult to evaluate by vendors

Option	E. ZANON	research instruments
1	- Vacuum oven is bottleneck in the production cycle - Oven fully loaded during the work week for the treatment of the cavities - No free time or minimum spare time available for maintenance / production issues / recovering actions / other unscheduled needs **- Impossible to predict the impact and the delay**	- Additional treatment would mean a shift of the production schedule by ~2 weeks [for each cavity] - This includes possible idle times, when oven is occupied with other cavities - The general capacity of the oven should not be a major issue

- Option 2 has a relatively minor impact on schedule

Mechanical Risks due to 900 deg. C Annealing

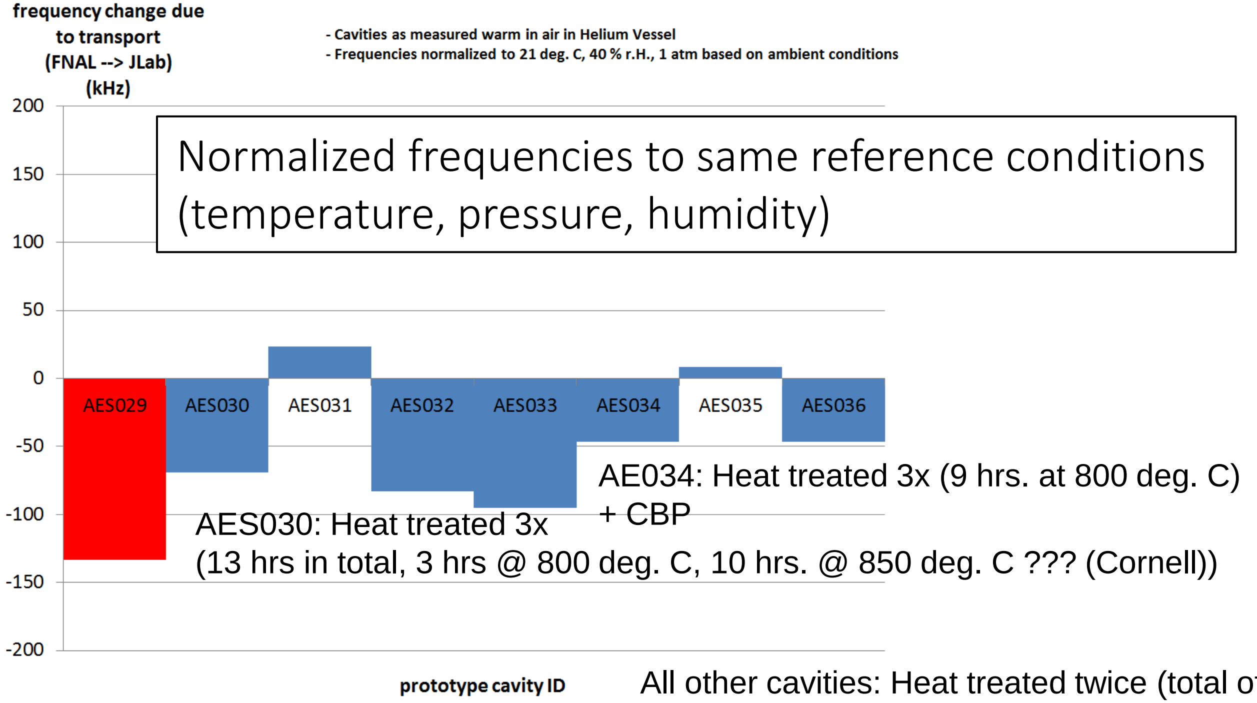
- **Softening of cavity Nb material**
  1. Higher risks for cell deformation due to handling and shipping
     → frequency change
     → field flatness change
     → HOMs, external Qs

  Note:
  - Cavity frequency requirement: On tune ± 100 kHz prior shipping
  - Field Flatness requirement: > 90% prior shipping

2. **Softening of cavity flange material**
   - Impact on vacuum seal integrity ?

Frequency Change observed after Shipping of LCLS-II Prototype Cavities (after HV welding) on Truck from FNAL to JLab

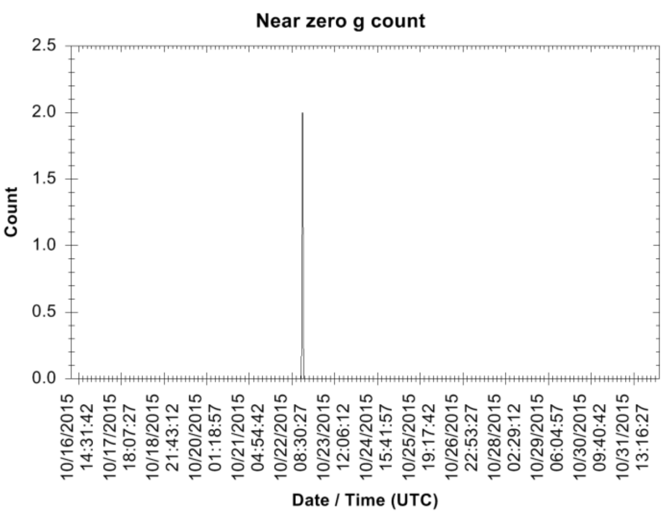
- Several cavities exhibit a change of close to 100 kHz (1 beyond 100 kHz)
- For delivered fully dressed LCLS-II cavities, such a frequency shift would be very problematic and/or unacceptable → would require retuning in Helium tank

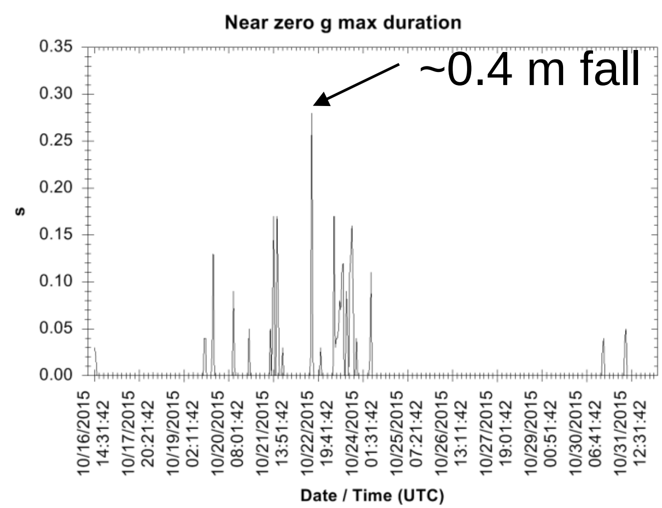


All other cavities: Heat treated twice (total of 6 hrs. at 800 deg. C)

Plan Forward

- By July '16 we will receive 8 fully dressed cavities from RI (4 to JLab, 4 to FNAL) and will determine whether or not cavities are being deformed during transit
  - We measure passband modes (in vacuum) after receipt and determine frequency changes compared to reference spectrum measured by vendors prior shipping → allows to evaluate impact on field flatness
  - If cell deformations are <u>not</u> negligible during standard transit the implementation of a higher temperature annealing becomes more risky for mechanical reasons
  - We hope to not see major incidences, e.g. free fall events





vendor qualification cavity AES014

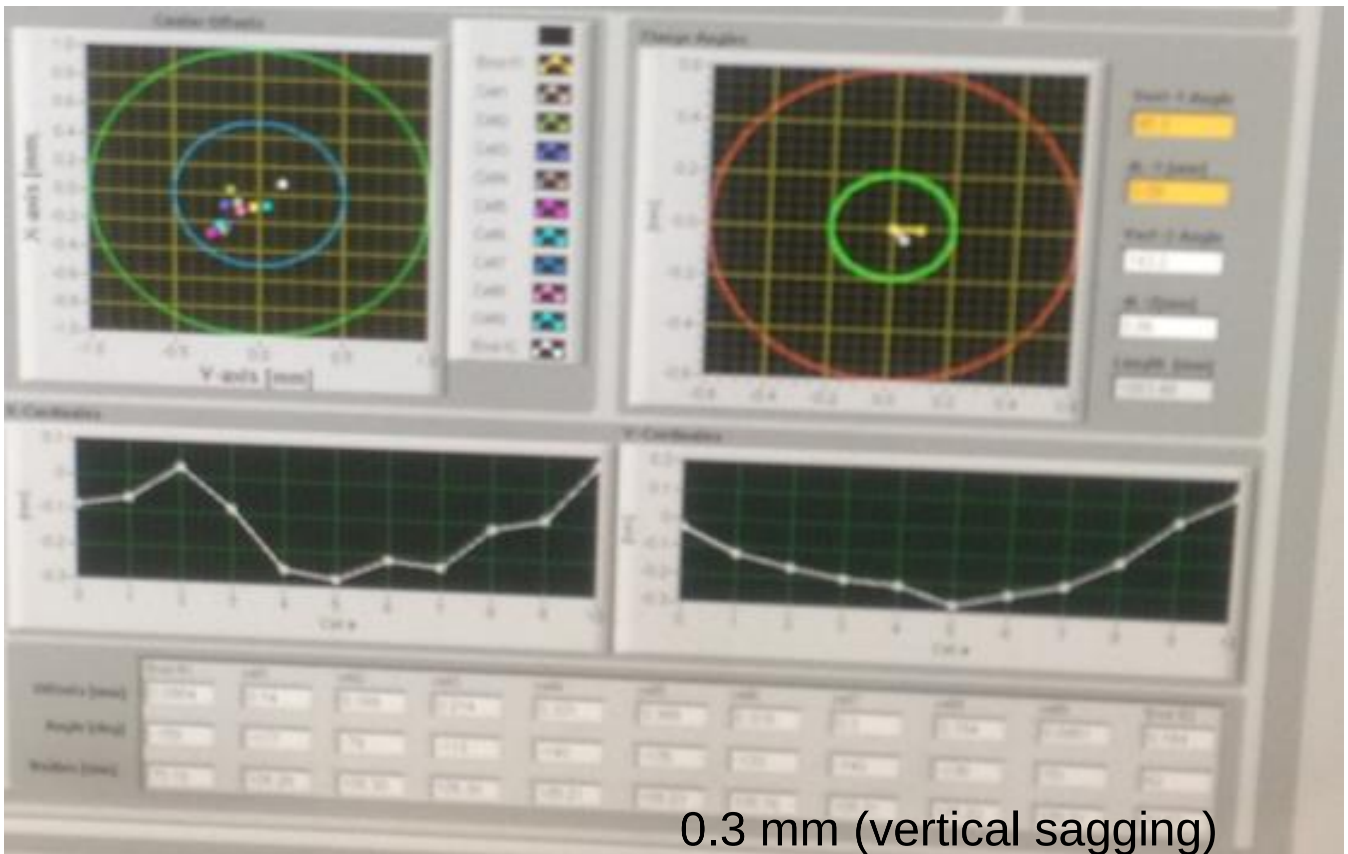
Plan Forward

- Finalize new recipe before implementation in production cycle including mechanical risk analysis (e.g. tensile strength analysis proposed by Ari)
    - Is lower than 900 deg. C annealing feasible to achieve the 50-60% flux expulsion needed in tradeoff with material softening
- <u>Option if further R&D on 9-cell bare cavities is conceived:</u>
- Bare cavities could be delivered to FNAL (or JLAB) and used to investigate the impact of a 900 deg. C annealing with minor impact to production schedule
- 2 out of 266 cavities are replacements for cavities that can be used for analyses
- These 2 cavities could be delivered on rather short term notice for R&D studies alone
    - Proceed with vertical tests on actual 9-cell cavities
    - E.g. bare cavities CAV0017 and CAV0018 from RI (made from TD material) are likely ready in August 2016
- Impact on production schedule is rather small since cavities are being shipped after Hold Point 1 is completed (i.e. mechanical fabrication, no post-processing which would take few weeks more), and the next production cavities are waiting in line (~1 week delay)
- ZANON could deliver 2 further cavities (made from OTIC material) later in time (~6 weeks), so that project could study 2 cavities made from OTIC material. These would need to be replaced by cavities for LCLS-II or welded to tank and used

- Alternative: If vendor(s) shall do bulk EP, 900 deg. C annealing, N-doping, fine EP on bare cavities, then we can expect ~1 to 1.5 months further delay to perform test on these bare cavities

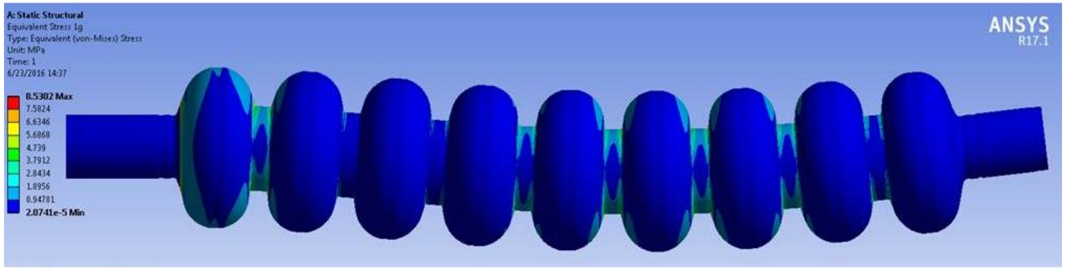
Cavity Sagging

- LCLS-II cavity at vendor site only supported on cell #1 and cell #9 (before CTM upgrade)
- Other cells unsupported (before CTM upgrade for LCLS-II cavities)
- → Vertical sagging of 0.3mm of middle cell

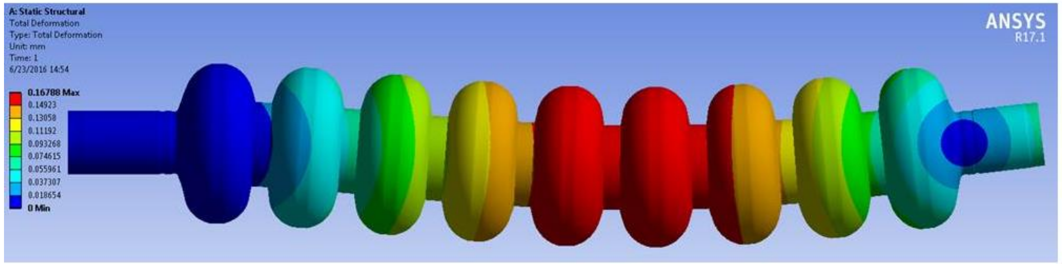


Mechanical Analysis

- Very preliminary study
- 0.17 mm vertical sagging in cavity center by gravity alone
- At 4g the max. stress is ~34 MPa at irises, for annealed Nb (800 deg. C @ 3 hours) the yield strength is 39.6/44.8 MPa (JLAB-TN-09-002 referring to JLAB-TN-02-01)
- At 2.5 g → 21.3 MPa, sagging would be 0.42 mm
- What is the permanent sagging (plastic deformation) especially after softening the material with higher temperature treatment?



Equivalent stress at 1g



Total deformation at 1g

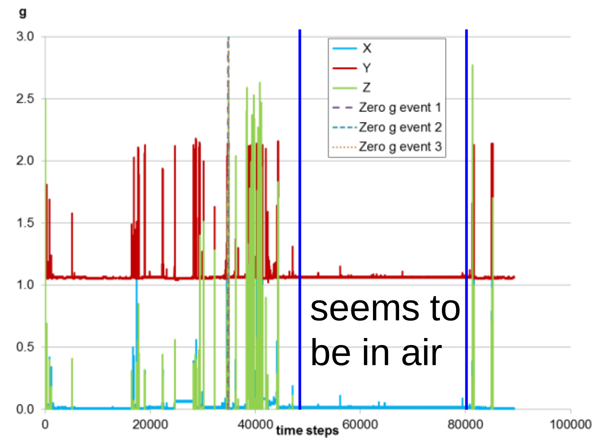
Shipping and Shipping Boxes

- Per contract, vendors are fully responsible for shipping cavities of the laboratories
  - Includes all delivery arrangements, custom duties and location transportation costs **and shipping boxes,** this means design of boxes

Backup Slides

Risks of Annealing Material?

- Yield strength of fine-grain Nb is reduced by high-temperature annealing
- Effect is well known from sample studies and it is related to grain growth during annealing
- In the case of high-purity (RRR>300) Nb, a reduction in yield strength is observed already after annealing at 800 °C/2 h
- Forces on shipping box during transit (overseas) can be several g at various times → requires adequate transport box for dampening, but cells are not supported in Helium vessel
- Cavity might sag in Helium Vessel

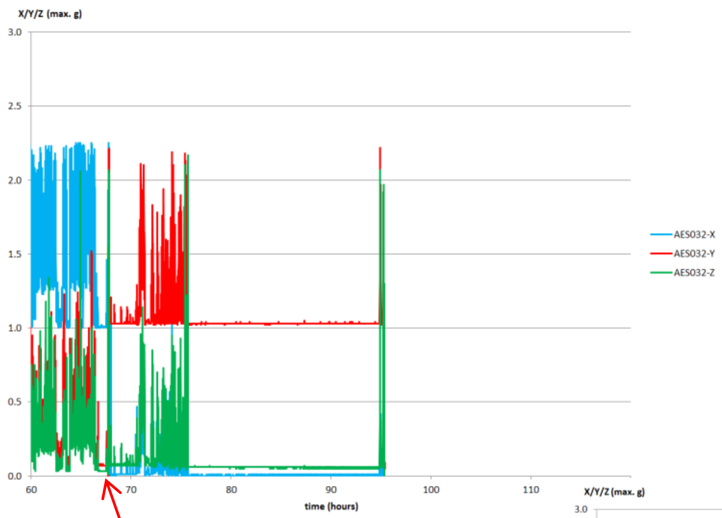


Accelerometer data for Vendor Qualification cavity (AES014) – Oversea shipping (JLab to Italy)

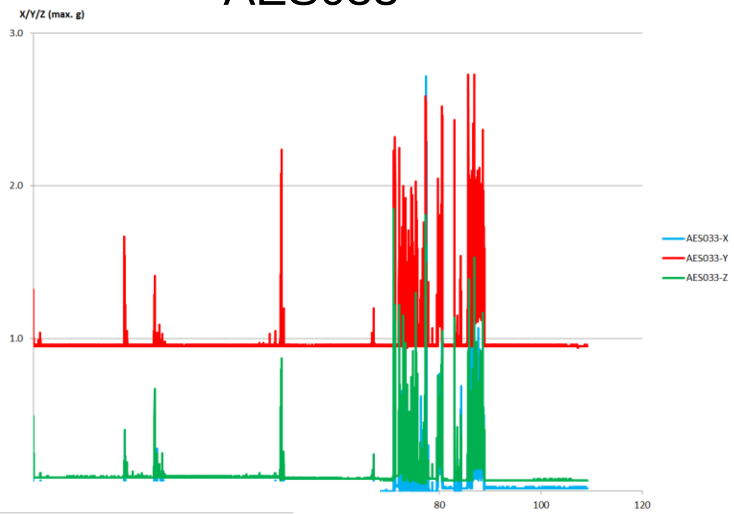
Accelerometer Data

- Dressed prototype cavities delivered on truck from FNAL to JLab

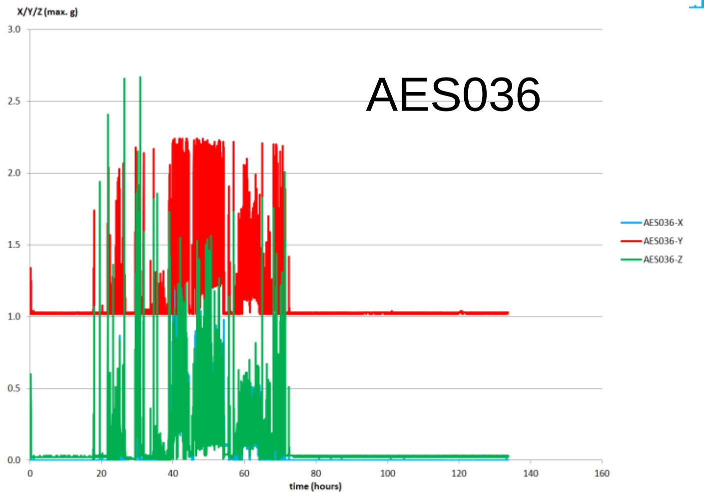
AES032



AES033



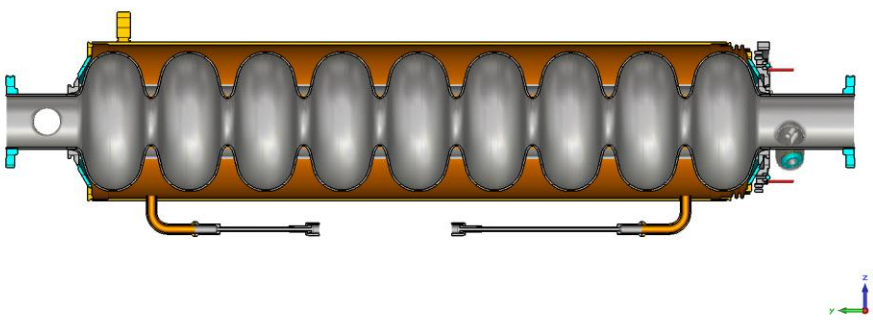
AES036

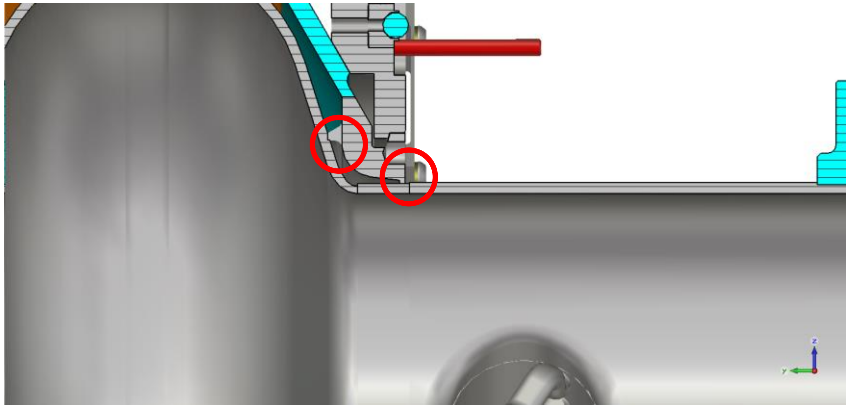


Indicates issue (transport box flipped)

Mechanical Analysis

- Cavity resting on Helium vessel in transport box
- No support of cavity cells
- Trying to resemble condition in He vessel with 1st simple model
    - Constraints: Connection flanges attached to both the end cell and the beam tube





Frequency Change observed after Shipping of LCLS-II Prototype Cavities (after HV welding) on Truck from FNAL to JLab