Dawn-V Workshop

"Technical Updates III: Beam Tubes, Vacuum, Excavation & Construction"

LIGO-hosted vacuum technology workshop

Albert Lazzarini

LIGO Laboratory, Caltech

26-27 May 2019

EGO, Cascina, Italy

NGC 4993 + GW170817
Credit: ESO/A.J. Levan, N.R. Tanvir

Vacuum technology workshop LLO, 29-31 January 2019

- Sponsored by NSF, hosted by LIGO
- Workshop dedicated to revisiting LIGO vacuum tube design, technologies from 1990s
- Take cognizance of ensuing 25+ years of technology evolution to reconsider how to build ~80 km (2 arms) of vacuum tubing needed for 3G interferometers
- Brought together some of the original builders of initial LIGO, experts from US, EU, Japan with high vacuum experience
- Publicly available report in LIGO document control center (DCC):
  - URL: https://dcc.ligo.org/LIGO-P1900072/public

Workshop format

- 38 participants (listed in Appendix A of report)
- Overview of initial LIGO design & requirements
- Goals:
  - Examine range of concepts that could significantly reduce cost of 3G ~ 80km (2 arms) of beam tubes
  - Identify, prioritize technologies that need to be investigated with detailed engineering & cost studies that will follow after the workshop
- Part I: Plenary "blue-sky" conceptual presentations followed by in depth discussions
- Part II: Four breakout working groups assigned to look at four particular technology challenges (cf. following slides)

WG1: Conventional signal-wall vacuum tube design

- Consider cost-reduction methods for a conventional design
- Materials, fabrication and processing (e.g., bakeout)
- Stainless vs. mild (low carbon) steel vs. aluminum
  - Minumum thickness: resistance to buckling
    - Current LIGO BTs: 3.2 mm (1/8”)
    - Virgo, KAGRA use larger wall thicknesses
    - BT enclosures as now designed may be prohibitively expensive to protect BTs -- need to protect from environment, human-caused threats
  - Mild steel, Al are less expensive per unit length
  - Steel-making technology for mild steel has improved since LIGO was built
    - Possible to obtain steel with intrinsic H_2 outgassing rates much lower (1/100 x) than stainless
    - May obviate need for a bakeout

WG1: Conventional signal-wall vacuum tube design (cont.)

- Fabrication techniques
  - Spiral welding – initial LIGO approach, longest weld lengths
  - Longitudinal welds – Virgo, KAGRA approach
  - Seamless piping – fewest welds, available today in large-bore from some vendors
  - Extrusion (for Al) – successfully used in accelerators. Large-aperture tooling not known to exist today – would need to develop
  - Joining of dissimilar metals will be needed for non stainless approaches (expansion joint flexures).
- Surface treatment
  - Reduce surface roughness to mitigate adsorption
  - Need to handle stray light control, e.g. baffling

WG1: Conventional signal-wall vacuum tube design (cont.)

- WG1 Recommendations
  - Wall thickness vs protective cover trade studies
    - Environmental, human-caused damage protection
  - Pursue further low carbon, mild steel approach
    - Coupon tests to validate low outgassing properties reported in literature
  - Al-system expansion joint studies to quantify requirements, assess costs
  - Further investigate commercially available piping options (driven by e.g., oil industry)

WG2: Non-conventional beam tube technology

- 2 concentric vacuum tubes
  - Inner: “thin” ~ ½ mm, UHV, clean
  - Outer: thicker, lower vacuum requirements
- Inner, outer vacuum envelopes either permanently separated or can communicate during pump down, venting
  - Either case the pressure differential must be carefully monitored & controlled to prevent thinner inner shell from buckling
- Inner tube: surface treatment to mitigate scatter
  - Treatment also has been shown to reduce outgassing properties of bare material – positive implications for bake-out
  - Treatments typically require high-temperature (high energy) activation
  - Possible to surface treat material as it is produced at the mill?

WG2: Non-conventional beam tube technology (cont.)

- WG2 Recommendations
  - Need a viable conceptual design how inner/outer vacuum can both be isolated during operation and communicate during pressure transients to prevent inner shell from buckling
  - Pumping strategies along 40 km lengths need to be analyzed
    - Use of non-evaporative getter (NEG) technology requires high activation temperatures – thermal stress in thin-walled materials
  - Small-scale testing of joining techniques, maintaining vacuum system integrity during pressure transients, etc.
  - Surface treatment studies for both scattered light and outgassing barrier are needed

WG3: Novel surface treatments for conventional & UHV materials

- Scope of this group overlapped with other WGs
- Modern steel foundry techniques have been shown to produce low carbon mild steels with low intrinsic H_2 outgassing
- Amorphous Si, TiN-coated stainless have been shown to reduce H_2O uptake, reducing bake out requirements (may also mitigate H_2 outgassing)
- Diamond-like coatings (DLC) may be an option to improve optical properties of the material
- Bakeout approaches for long beam tube systems
  - UV treatment of tube surfaces
  - Very dry hot gas purge as alternative to how initial LIGO baked its tubes

WG3: Novel surface treatments for conventional & UHV materials (cont.)

- WG3 recommendations
  - Perform outgassing tests on candidate materials with various surface treatments to qualify approaches
  - Will need to consider how to industrialize techniques that qualify…

WG4: Vacuum pumping for single-walled and nested vacuum tube systems

- For nested systems
  - Rough down & venting needs to be achieved while maintaining $\Delta p < 1$ Torr (133 Pa) to preclude buckling of internal thin-wall tube
  - Requires a valving mechanism to allow communication between inner, outer shells
- Single-walled system require no particular new solutions
- Bakeout:
  - NEG, ZAO(Zr-V-Ti-Al) pumps are an option today
- Steady-state:
  - 40 ion pumps or NEG(ZAO) along 40 km arm
  - Ti film on inside BT surfaces may be an option
    - Duration of gettering capacity with exposure needs to be considered

WG4: Vacuum pumping for single-walled and nested vacuum tube systems (cont.)

- WG4 recommendations
  - Details are dependent on vacuum tube technology choice, need to concurrently trade off vacuum tube design and pumping requirements
  - Nest tube design has a very tigh constraint on acceptable pressure gradient across inner tube – will drive design considerations, including valve designs
  - NEG technology today can accommodate the currently understood requirements
  - Ti sublimation pump technology may be applicable – need to understand requirements better

Conclusions/Recommendations:

- Both BT design concepts should be pursued to next level of detail – no serious issues identified at workshop
- Single walled BT design: low carbon mild steel or Al are viable options today
  - Non stainless approaches will require surface treatment
  - Al, mild steel will need transition welds/joints to accommodate expansion joints
- Nested BT concept
  - Inner vessel material of choice would be thin Al (better H_2O adsorption properties, easier in-situ bake)
  - Outer vessel would be mild steel or possible a polymer composite
- Inner surface treatment to reduce bake-out requirements seems compelling
  - May be possible to apply treatment at mill as part of the material fabrication process
- Pumping schemes will include NEG technology
- Ultra dry, ultra clean heated purge gas can significantly reduce the bake-out requirements prior to final pump down
- Industrial partnerships with relevant experience will be necessary in order to scale up/industrialize chosen technologies to ~80km of beam tube
- A follow-on workshop in about 1 year would be useful to continue to drive discussions among groups with similar needs and capabilities across the globe – EGO has offered to host the meeting