# Pipe Joining Techniques Workshop 2018

## CMS and Atlas Tracker Upgrades

## Enhanced Miniature Removable Coupling Development

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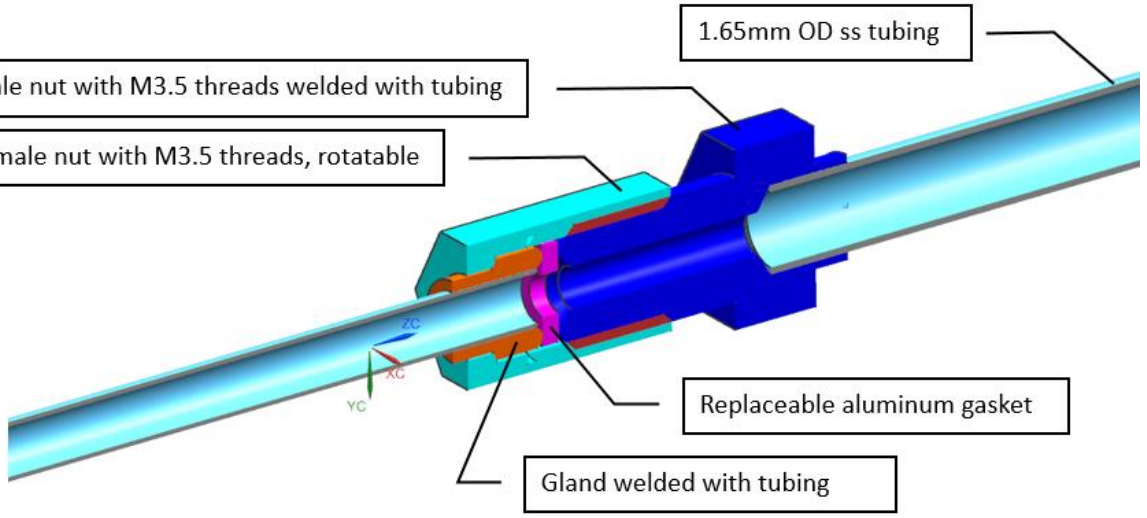
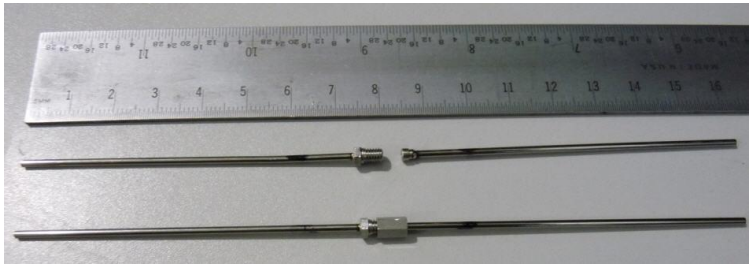
# Existing Version

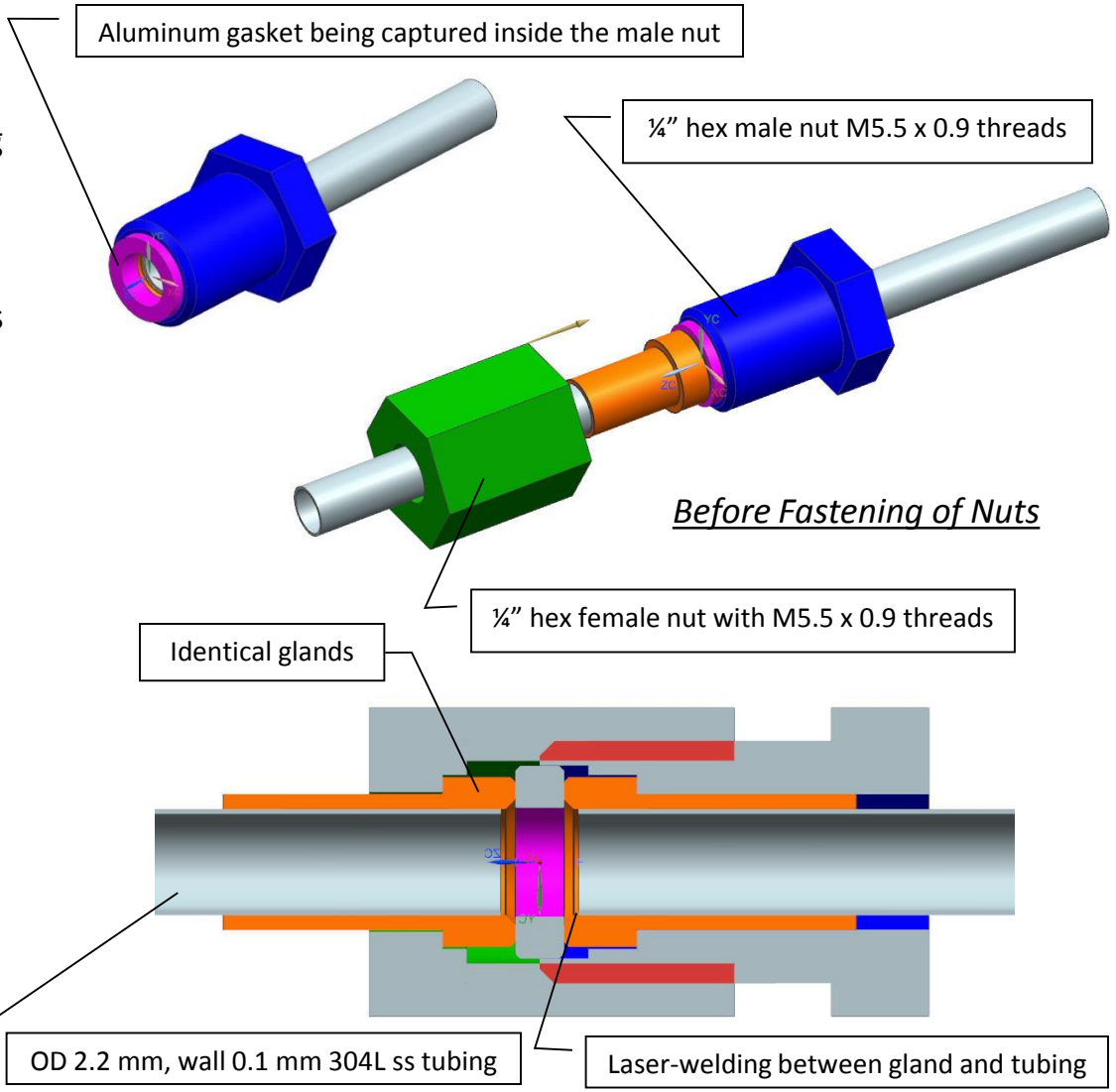
- The existing version for tubing OD 1.65 mm, wall 0.1 mm stainless steel (ss) tubing is being used in FPIX 1
- Similar to Swagelok VCR metal sealing technology
- Female nut rotatable
- Male nut and gland are laser-welded with ss tubing
- Male nut and gland are made of VIMVAR 304L ss to avoid weld solidification cracking
- Has been tested to pressure up to 276 bars (4,000 psi) without failure
- Pass intense quality control tests



# Enhanced Version

- Designed to serve ss tubing OD 2.2 mm
- Enhanced features
  - Both nuts are rotatable to minimize torque transfer to tubing during fastening
  - Gasket is captured in male nut before fastening >> extra handling to position this tiny part in place is avoided
  - "bulky" male and female nuts are both made of aluminum, weight reduction.
- Metal seal
- Two identical ss glands are used to laser weld at the front face with the ss tubing
  - Better weld cooling to minimize the chance of generating cracks.
- Gland is made of VIMVAR 304L ss to avoid weld solidification cracking
- Gasket is made of aluminum 6063 T6 with Brinell hardness 60
- Nuts are made of high-strength 2024 T4 aluminum with Brinell hardness 120 (similar to ss 304)



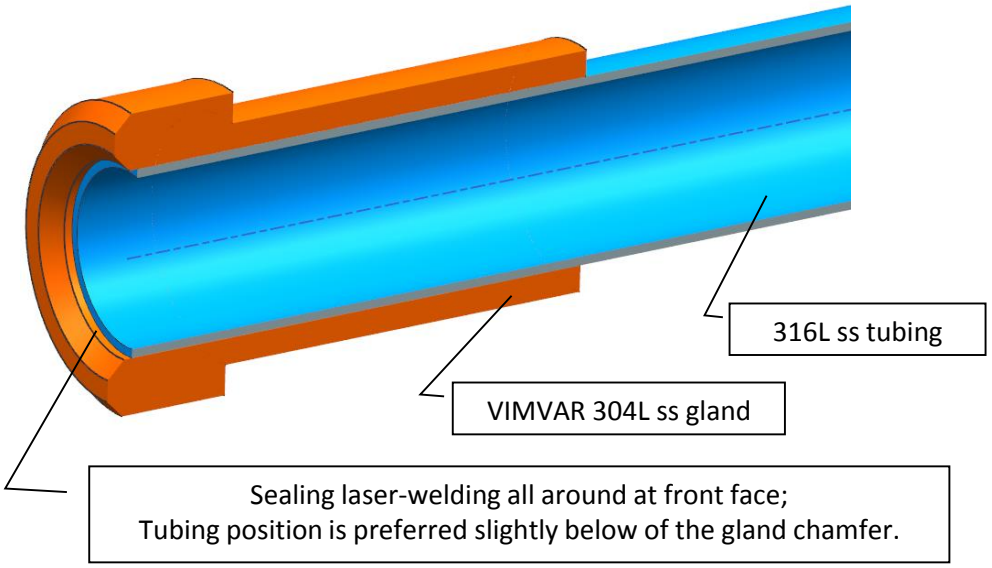

Notes: Yield strength of Al 2024 T4 = 47 ksi (324 MPa); SS 304L = 30 ksi (207 MPa).

# Laser Welding Parameters

- It is important to control the depth of weld penetration, and hence we need to carefully control the laser welding parameters like laser pulse power, pulse width, spot size, pulse frequency, and weld spot overlap.
- The optimal combination of parameters was determined by welding numerous test pieces and performing micrograph cross sections of welds.
- Since the laser power of the machine can degrade over time, the pulse power delivered was measured and calibrated before welding each batch of glands to ensure the consistency.

- Power % 34% (max power of machine)
- Pulse Width 4.0 – 4.2 ms
- Spot Size 3 (on machine dial)
- Frequency N/A (single pulse mode)
- Pulse Overlap Target 60 %

Welding Machine: LRS EVO Nd-Yag Laser (200 Watt)




Note: Power was calibrated at the beginning of every welding session. Other parameters were tweaked as needed as well. Welding of the thinner material into the thicker material, as in this case of face welding, is much more forgiving. It would be much more difficult to achieve a target weld penetration when welding the thicker material into the thinner. Because of the tubing complexity, it was a manual operation to rotate the parts and weld with the aid of some simple support fixtures.

# Anodization Coating on Aluminum Parts

- To prevent aluminum nuts from galling during fastening, 2 types of coatings were made
  - Aluminum 2024 nuts coated with Type II anodization with sulfuric acid
  - Aluminum 6061 nuts hard-coated with Type III anodization with sulfuric acid
- After 10 times of in-and-out fastenings for extra ¼ turn after hand-tightening, turning was still smooth and no galling was observed for Type II coating and for the nuts without coating. No test was done on Type III due to coating was too thick and difficult to initiate turning.

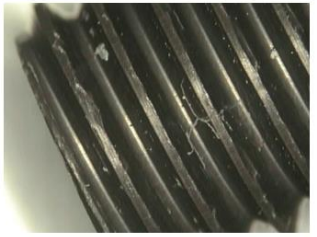
*2024-T4*
*No Coating*

*2024-T4*
*Type II Coating*

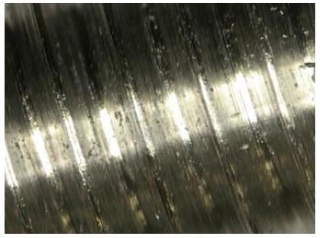
*6061-T6*
*Type III Hard Coating*

*2024-T4*
*No Coating, before*

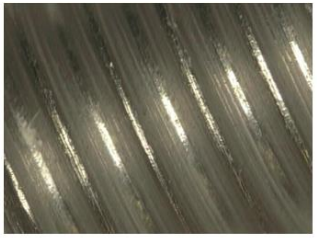
*2024-T4*
*Type II Coating, before*



*6061-T6*
*Type III Hard Coating, before*



*2024-T4*
*No Coating, after*
*No galling,*
*turning nuts still easy*



*2024-T4*
*Type II Coating, after*
*No galling,*
*turning nuts still easy*

*6061-T6*
*Type III Hard Coating,*
*No test*
*Due to coating too thick*
*Not easy to turn nuts*

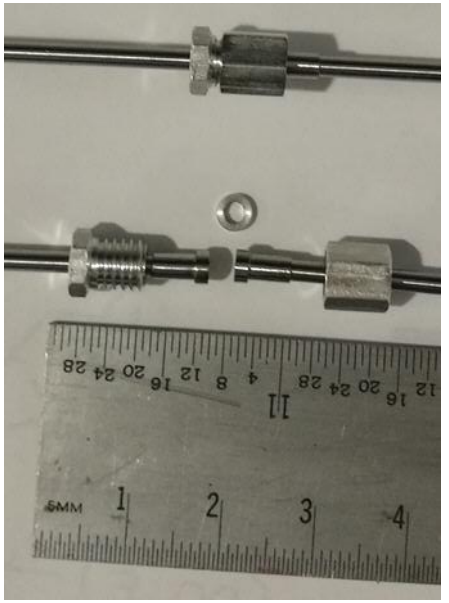
Note: The torque required to make an extra ¼ turn was about 0.8 to 1.3 N-m (7 to 12 inch-lbs) for uncoated nuts, and 0.8 to 2.0 N-m (7 to 18 inch-lbs) for coated nuts were observed.

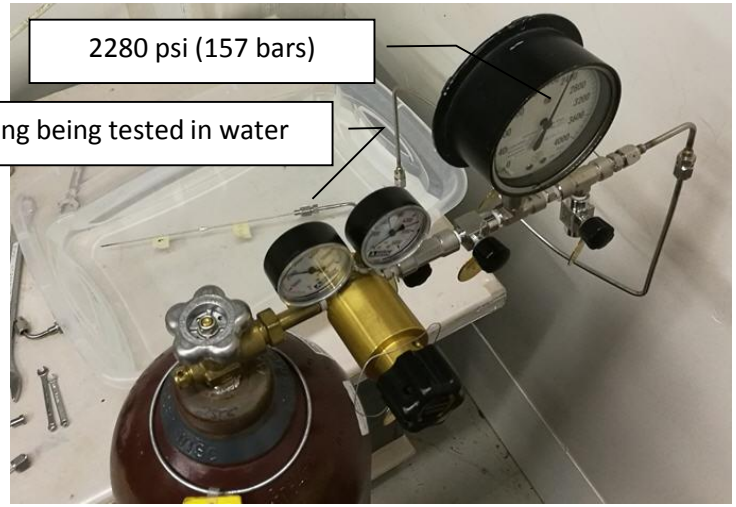
# Removable Coupling Testing

- Conducted a pressure hold-up test up to 4,000 psi (276 bars) for 2 minutes without failure and leakage.
- Conducted a durability pressure hold-up test successfully
  - Conducted an initial pressure test at 2,280 psi (157 bars) for 10 minutes
  - Went through 10 thermal cycles from liquid nitrogen to room temperature.
  - Repeated the pressure hold-up test at 2,280 psi in a water bath for 1 hour.
  - Continued the pressure hold-up test at 1600 psi (110 bars) in a water bath for 1 week.
  - No leak in final helium check.

*gland*

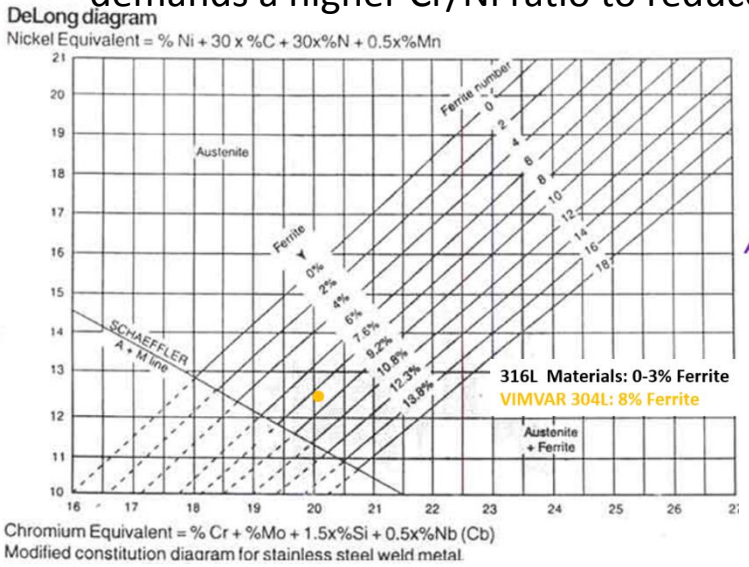
*gasket*

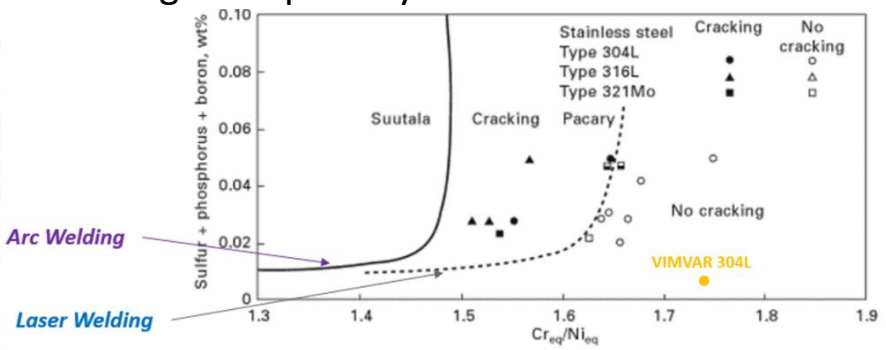




# More Notes on Laser Welding Stainless Steel

- Autogenous welds, no filler materials used.
- Needs zero gap (< 10% of thinnest material) between welding parts
- Parts must be cleaned, free of any contaminants and oxidation
- Material composition plays a role in final microstructure and cracking susceptibility
  - "L" grade is preferred for welding in order to lower the C content down to a max of .03% so to reduce sensitization, (precipitation of chromium carbides at grain boundaries) caused by the high temperatures involved in welding.
  - VIMVAR 304L with very low P & S contents is recommended as one of the welding part materials (the other welding part can be typical "L" grade.)
    - High P & S contents are susceptible to weld solidification cracking
  - Ferrite in 4%-8% is optimal for laser welding as P & S are soluble in ferrite
  - The higher cooling rates (on the order of ms) that occur under laser welding conditions demands a higher Cr/Ni ratio to reduce cracking susceptibility




*1.12* Cracking susceptibility diagram of stainless steels under laser beam processing conditions.

$Cr_{eq} = Cr + 1.37Mo + 1.5Si + 2Nb + 3Ti$ → Ferrite stabilizers

$Ni_{eq} = Ni + 0.31Mn + 22C + 14.2N + Cu$ → Austenite stabilizers

# Further Details on Laser Welding

See Stephanie Timpone's slides at FTDM 2016
on laser welding the existing FPIX1 miniature coupling.

https://indico.cern.ch/event/469996/contributions/2148019/attachments/1277061/1895241/FPIX_Laser_Welding_Bonn_Forum_2016.pdf

# Conclusions

Anodization coating is not really needed for the aluminum 2024 T4 nuts.
This enhanced design passes a series of intense tests.
This miniature removable coupling can be ready for production.

Thanks for your attention!