XELERA

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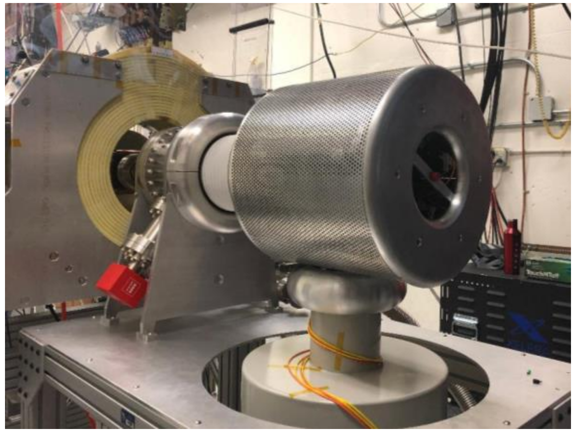
www.xeleraresearch.com

Company Overview

- Formed in 2013 by 5 partners – 210 years of accelerator design expertise
- Based in Ithaca, NY. Much of the personnel were from the Cornell ERL development team, who designed and built the world's highest current, high brightness photoinjector, which is now used in the 4-pass ERL: CBETA
- Now at 10 total employees

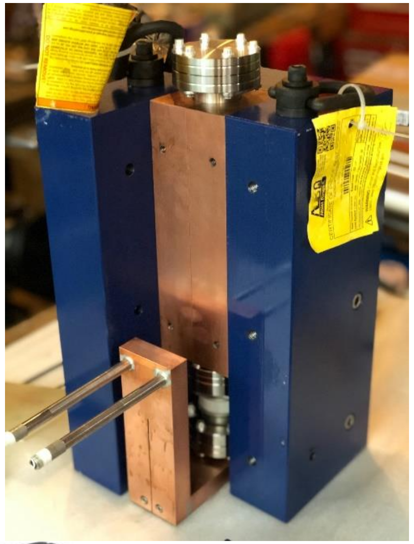
- Balanced Business: 1/3 SBIR Research, 1/3 Accelerator Design Consulting, 1/3 Component Manufacture

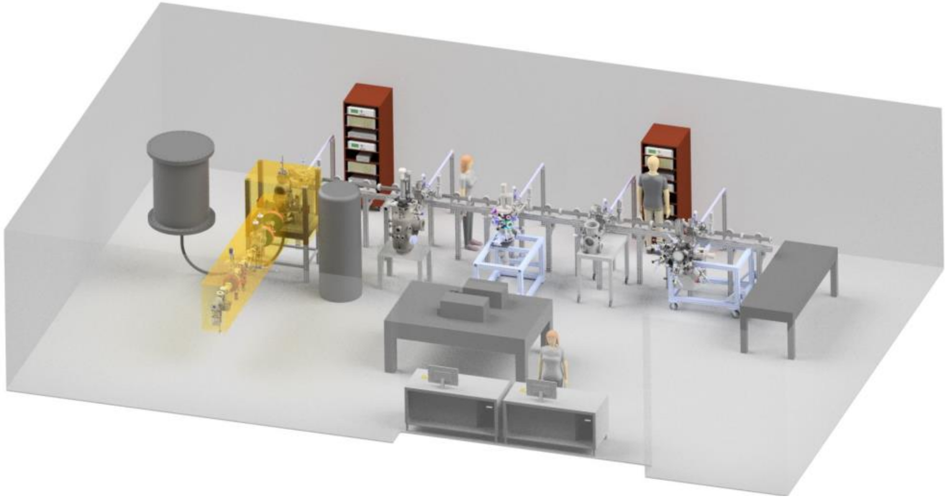
Company Overview



The Xelera team is experienced in designing and building a variety of particle accelerator components, including:

- Particle Sources (Electrons, Positrons, Neutrons)
- Beam stops, shutters, vacuum system components
- RF equipment





A high-power positron converter based on a recirculated liquid metal in-vacuum target

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Xelera Research LLC

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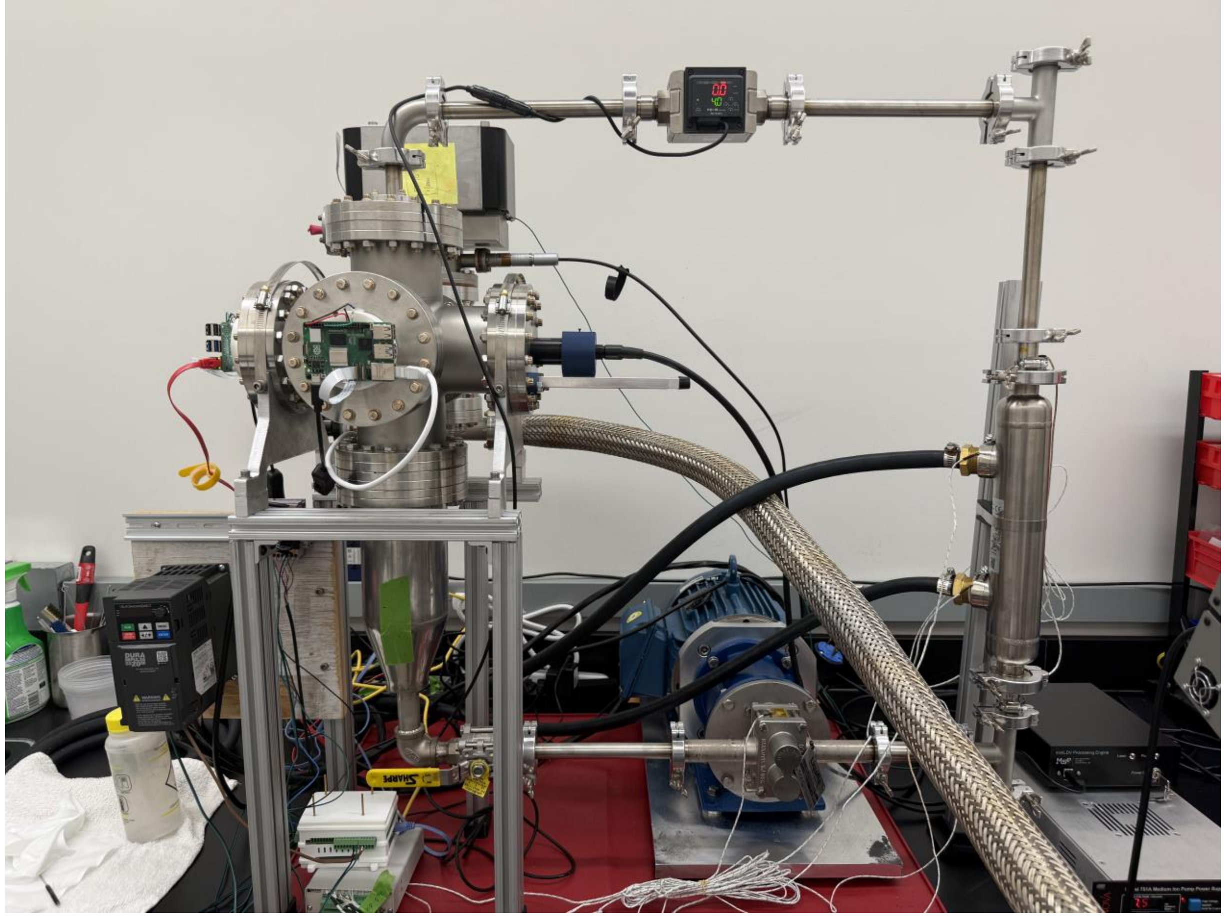
FY25 NP SBIR/STTR PI Exchange Meeting

Liquid metal (LM) targets: Introduction

- The very large power in electron beams needed to generate positrons require that solid tantalum or tungsten targets have some means of heat removal, e.g. by cooling high speed rotating discs of such materials.
- The mechanical complexity of such rotating discs in the ultra high vacuum of an accelerator beam line suggests that other target possibilities be considered.
- In particular, the free surface liquid metal jet target possesses some advantages. It is conceptually simple compared to a solid metal target, it can operate directly in an ultra high vacuum environment due to the very low vapor pressure of LMs used, it can handle very high heat loads and act directly as target coolant.
- There are three LMs available, Hg, and GaInSn and PbBi eutectics. Hg is toxic and has a high vapor pressure. GaInSn is a liquid at 20 ^oC while PbBi requires an operating temperature of 150 ^oC. Of the two, PbBi is preferable for positron production because of its much higher Z and greater density. However, since GaInSn is a liquid at room temperature, it was selected as the LM in our prototype.

View of the prototype positron converter



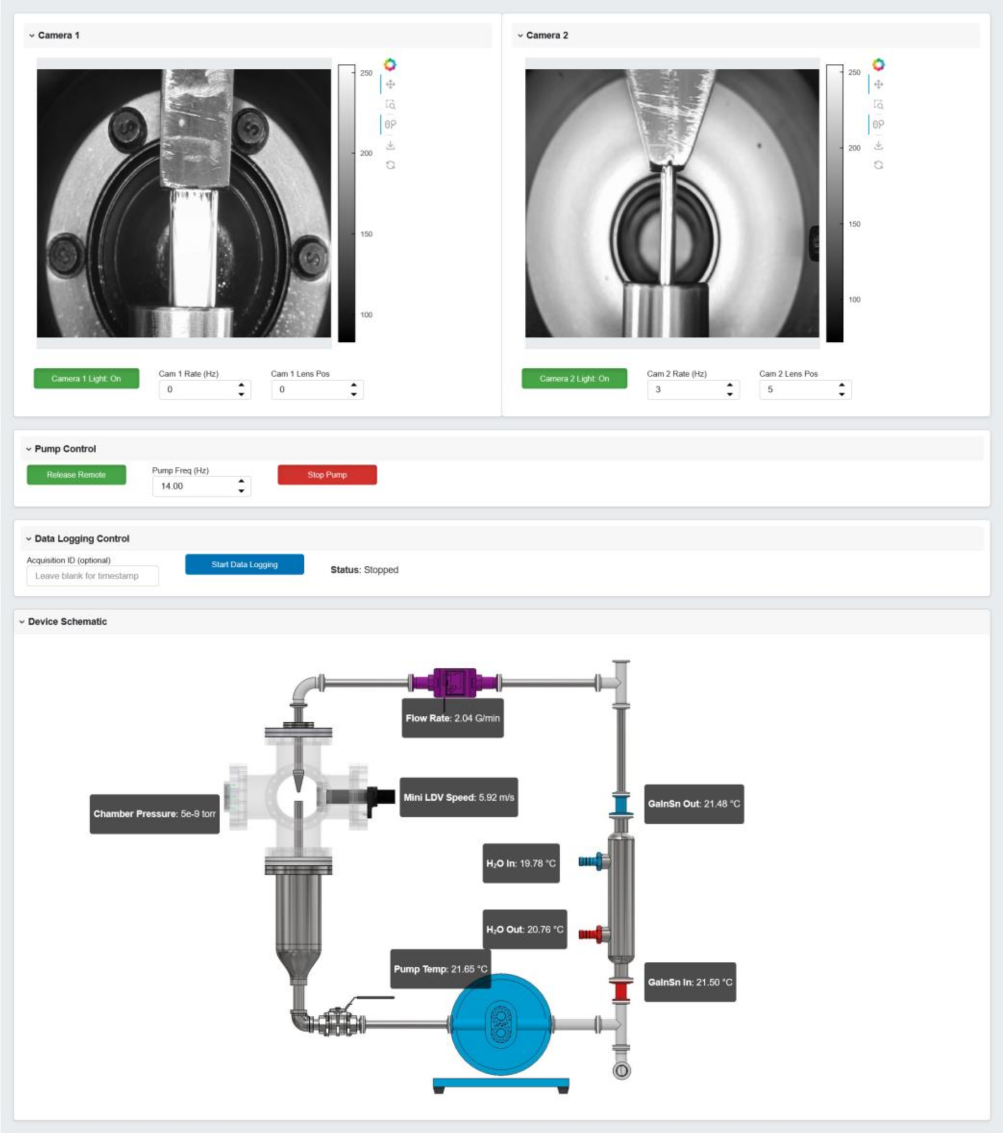
Experimental Physics and Industrial Control System

- Pythion-EIPCS implemented for real-time control of the protype converter system to read and control the following:

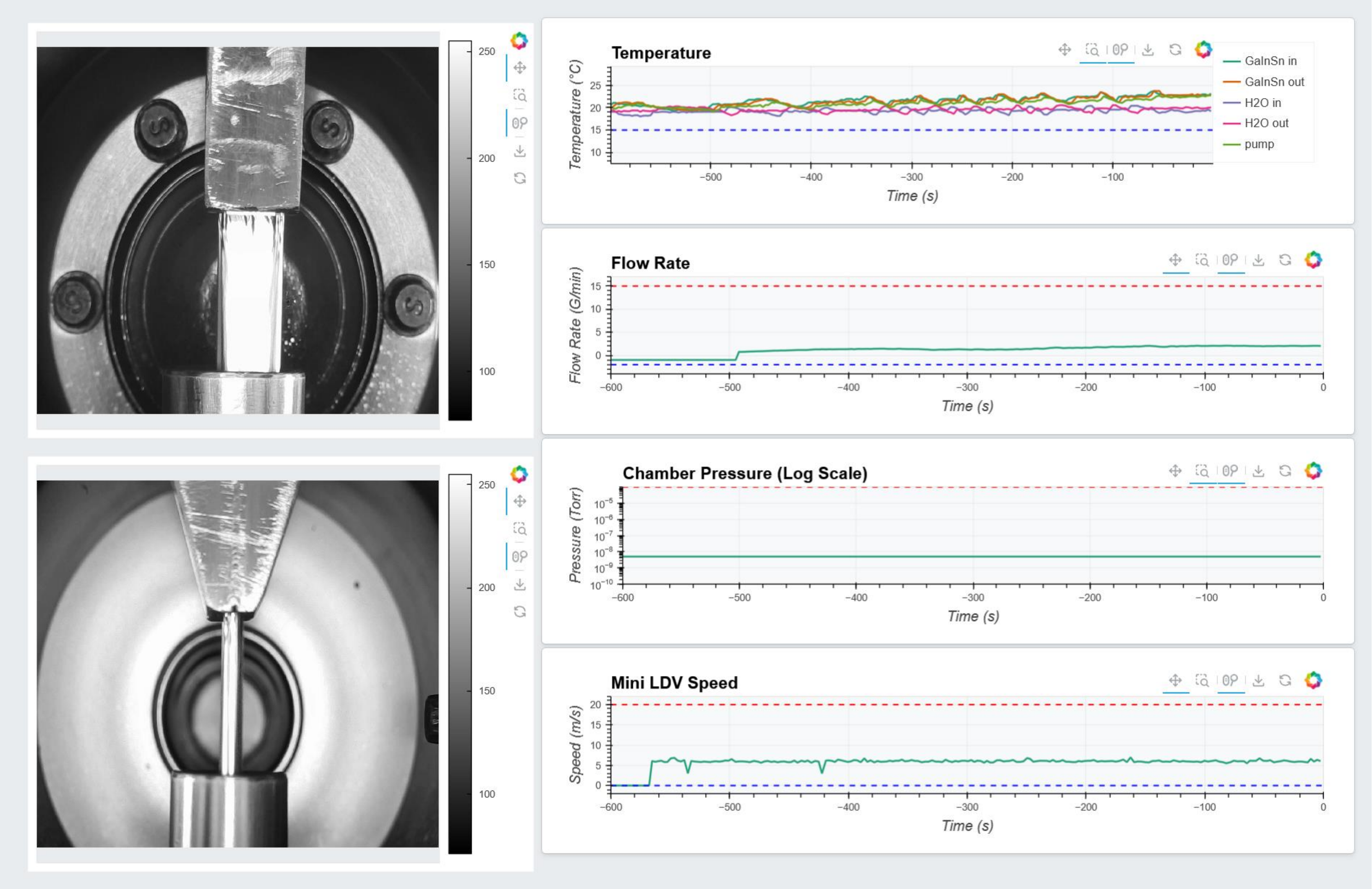
- K type thermocouples located at the heat exchanger at the GaInSn inlet and outlet, the cooling water inlet and outlet and the Liquiflo gear pump using the DataQ instruments Di808 Web-based Voltage and Thermocouple data logger. Also, the Keyence MD-MZ50AYK flow meter, the mag flowmeter and ion pump vacuum, the Measurement Science Enterprise miniLDV laser Doppler velocimeter and readout of two cameras, viewing the thickness and width of the GaInSn liquid metal flow.

- The data is logged and stored at adjustable time intervals that range from 1 to 10 seconds.

View of the Prototype Converter Control Screen

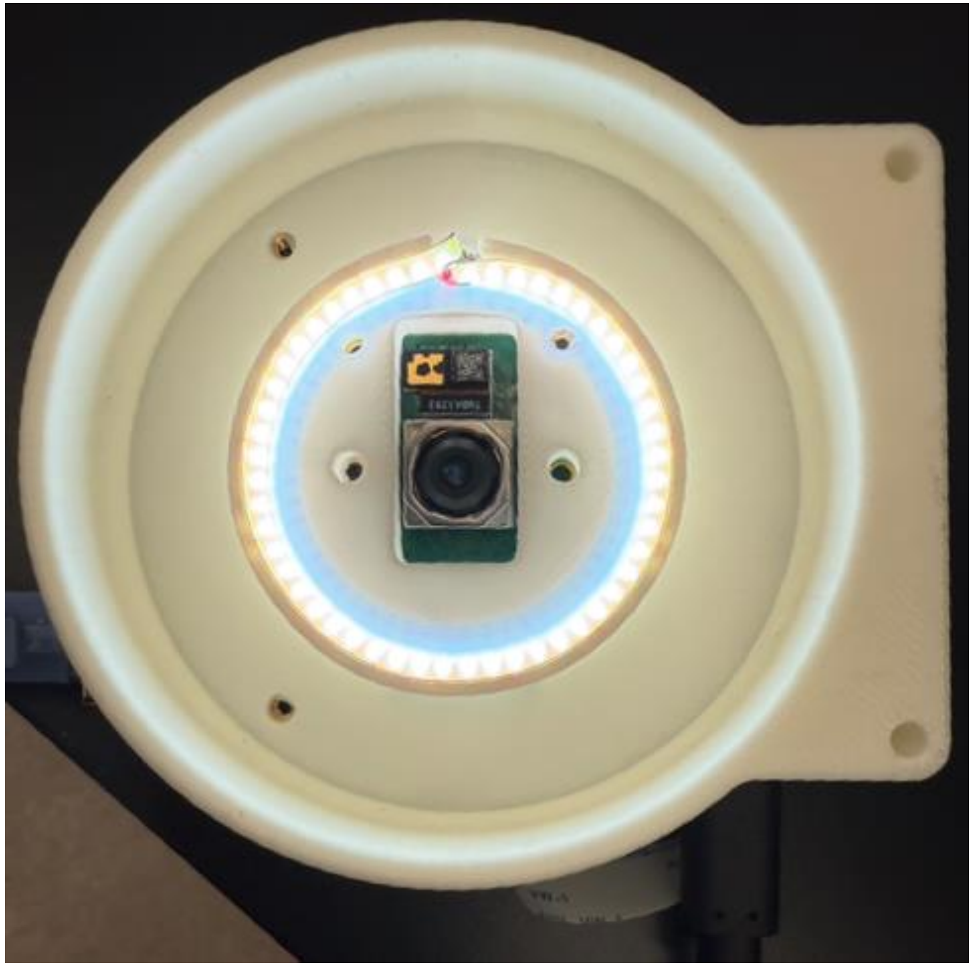


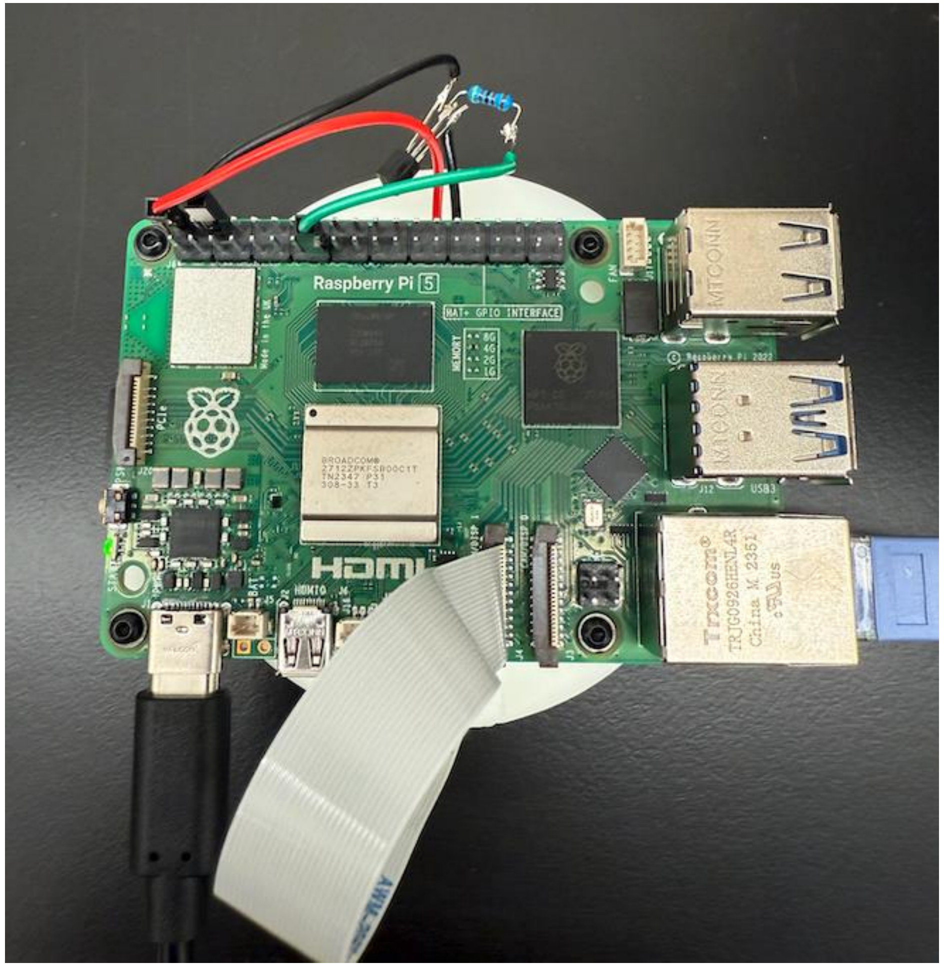
Example of Data Logged and Stored



Front and Back View of Cameras Used

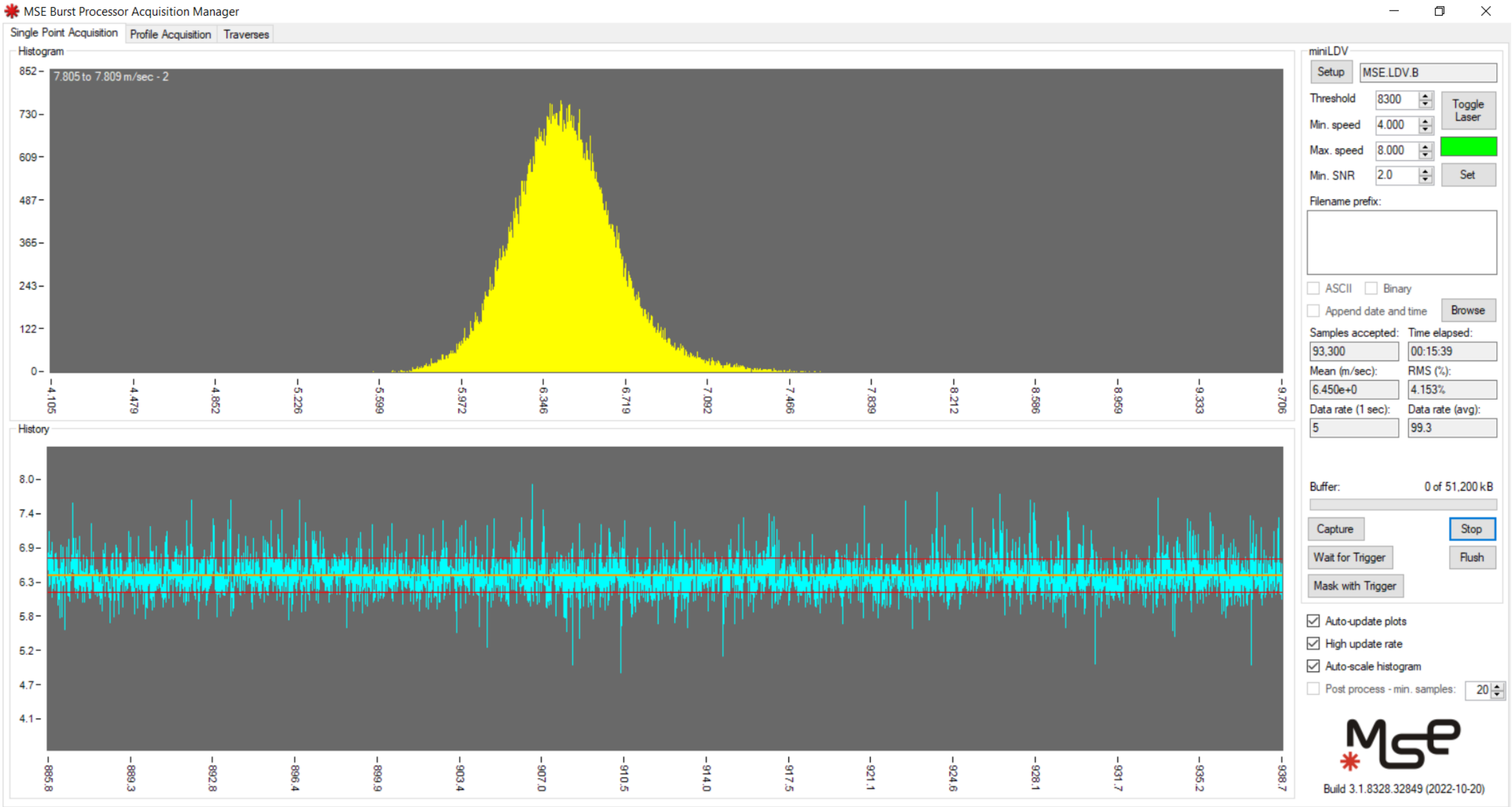
Each camera used is a Raspberry Pi Camera Module 3, 12MP IMX708 75°(D) Autofocus Pi Camera V3.





GaInSn flow at 6.5 m/s

Example of Liquid Metal Jet Velocity Measurement

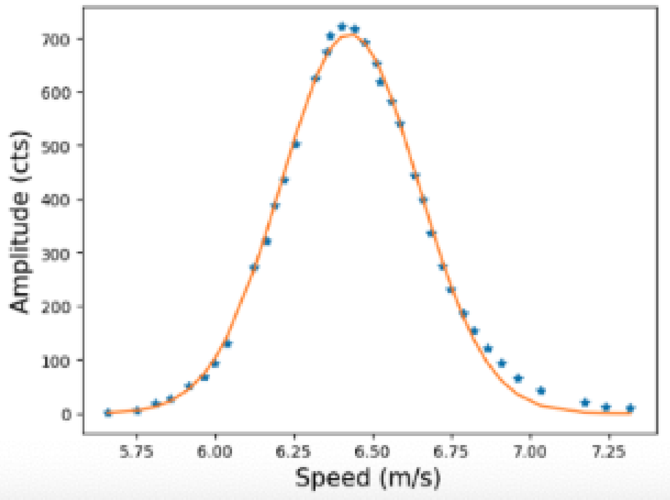


Digitized profile, fitted to

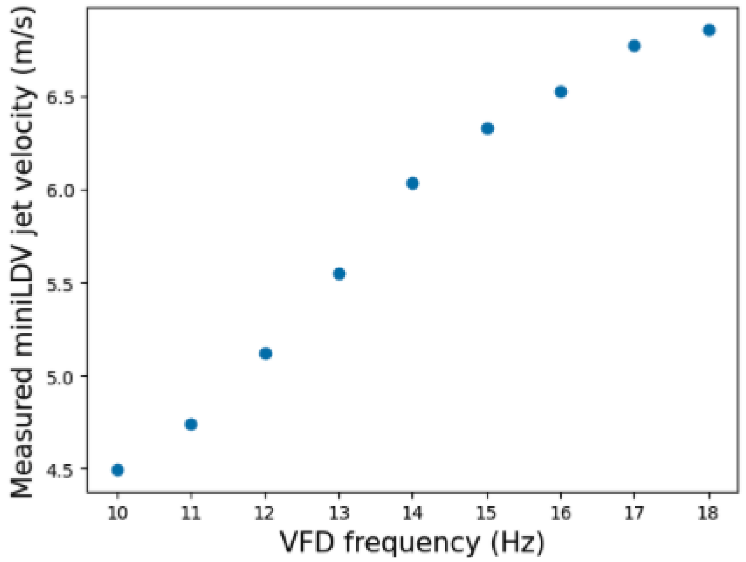
$$A = ae^{-\left(\frac{v - v_o}{b}\right)^2}$$

With a = 708, v_o = 6.427 m/s
b = 0.308

Fitted v_o = 6.427 (m/s), σ = 0.218
miniLDV = 6.450 (m/s), σ =0.268



GaInSn Jet

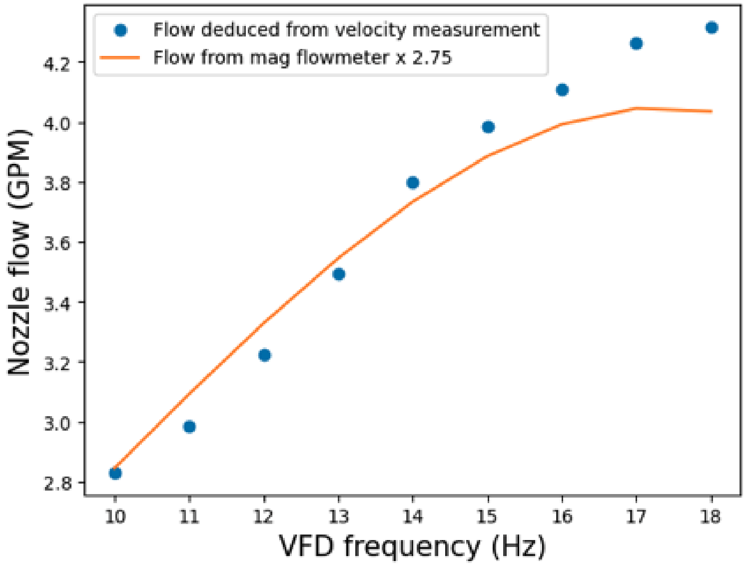


The jet flow in GPM is obtained from the measured jet velocity as follows:

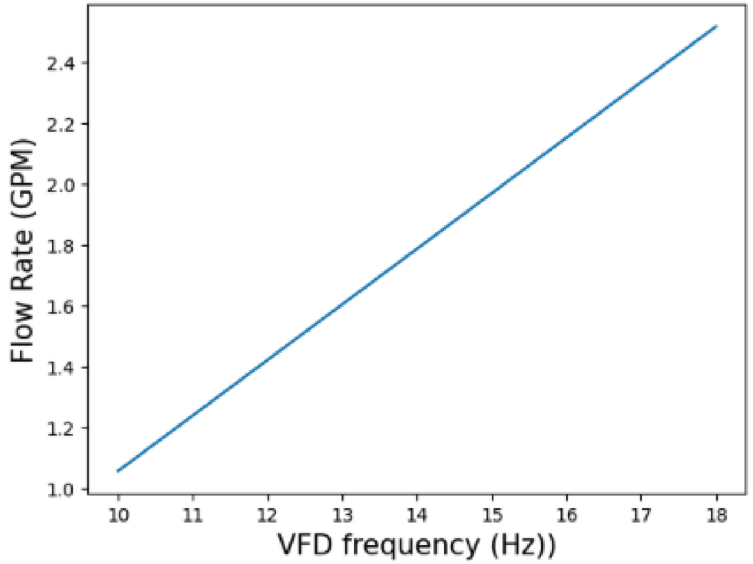
From the properties of the nozzle, $v_{in}A_{in} = v_{out}A_{out}$, so that $v_{in} = v_{out}A_{out}/A_{in}$ since $A_{out} / A_{in} = 0.150$, $v_{in} = 0.15 v_{out}$

Inflow(GPM) = $v_{in}A_{in} = 0.15 v_{out}A_{in}$
= 0.15 v_{out} (m/s) 100 (cm/m) A_{in} (cm^2) 60 (s/min) /1000 (cm^3/l)/2.7853 (l/gal)

Outflow = Inflow

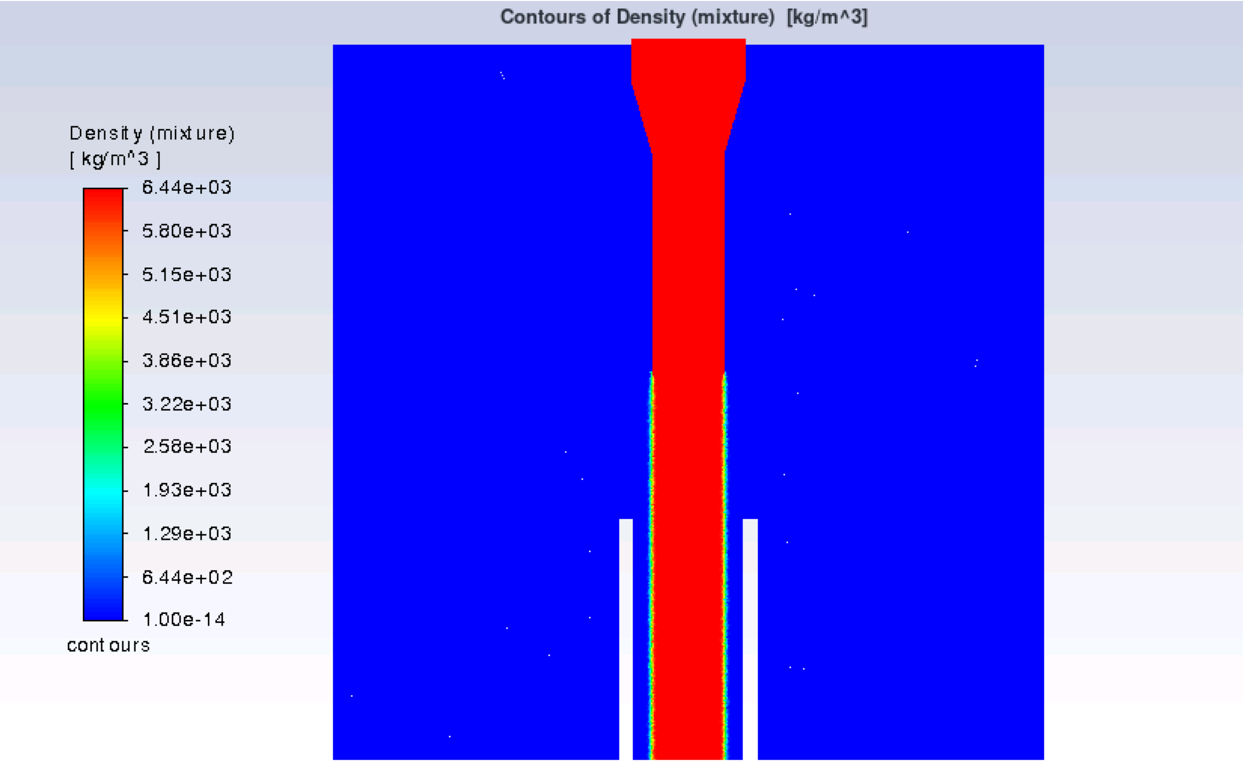


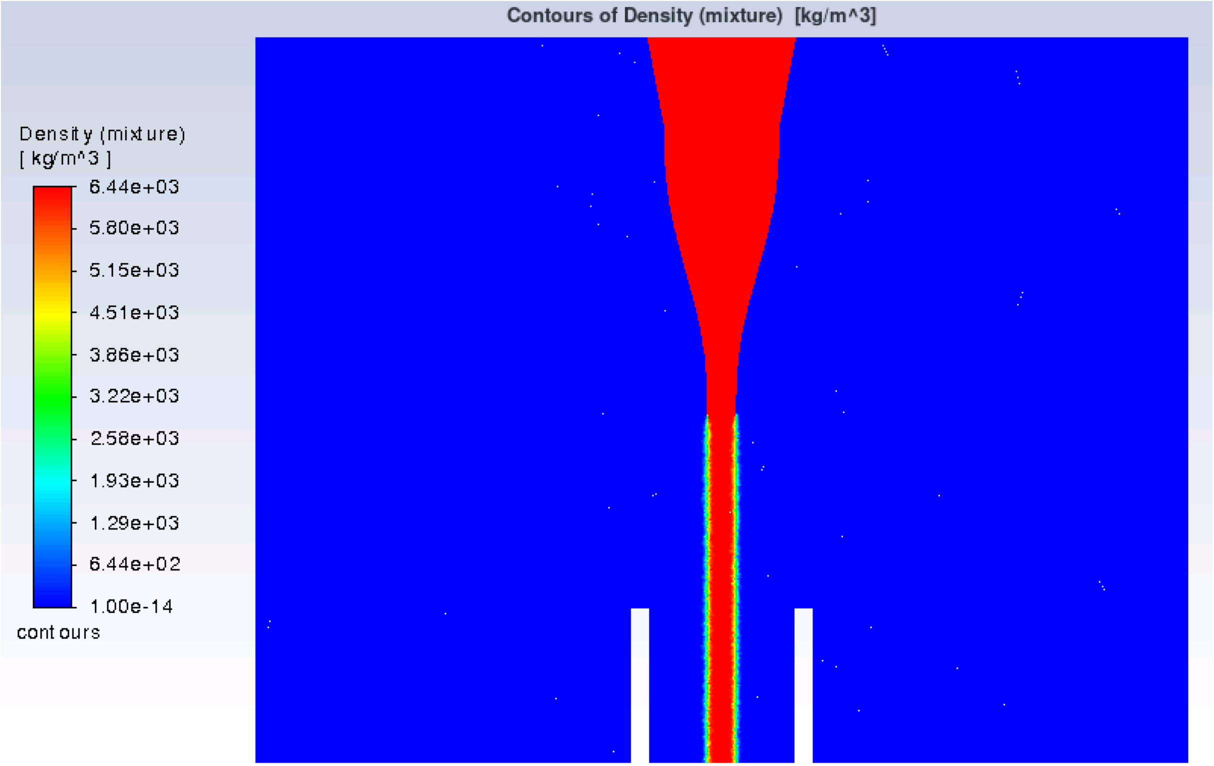
Problem:
Plot of Flow vs frequency at left does not agree with the plot of Flow vs Frequency derived from graph provided by Liquiflo and measurements.



CFD nozzle simulations

- CFD simulations of the nozzles were done by Silviu Covrig Dusa at JLab, using Fluent-ANSYS v2024R1 with a volume-of-fluid model, which is a multi-phase transport model. One phase is GaInSn and the other is air. The air fills the chamber at a pressure of 10^{-6} Pa (7.5×10^{-9} torr) and a density 1e-14 kg/m^3. The air is not treated as an ideal gas, but rather as a constant density fluid. The liquid metal comes in at inlet at 2 m/s, 293 K and pressure sufficient to overcome the nozzle resistance. The pressure is calculated by Fluent.

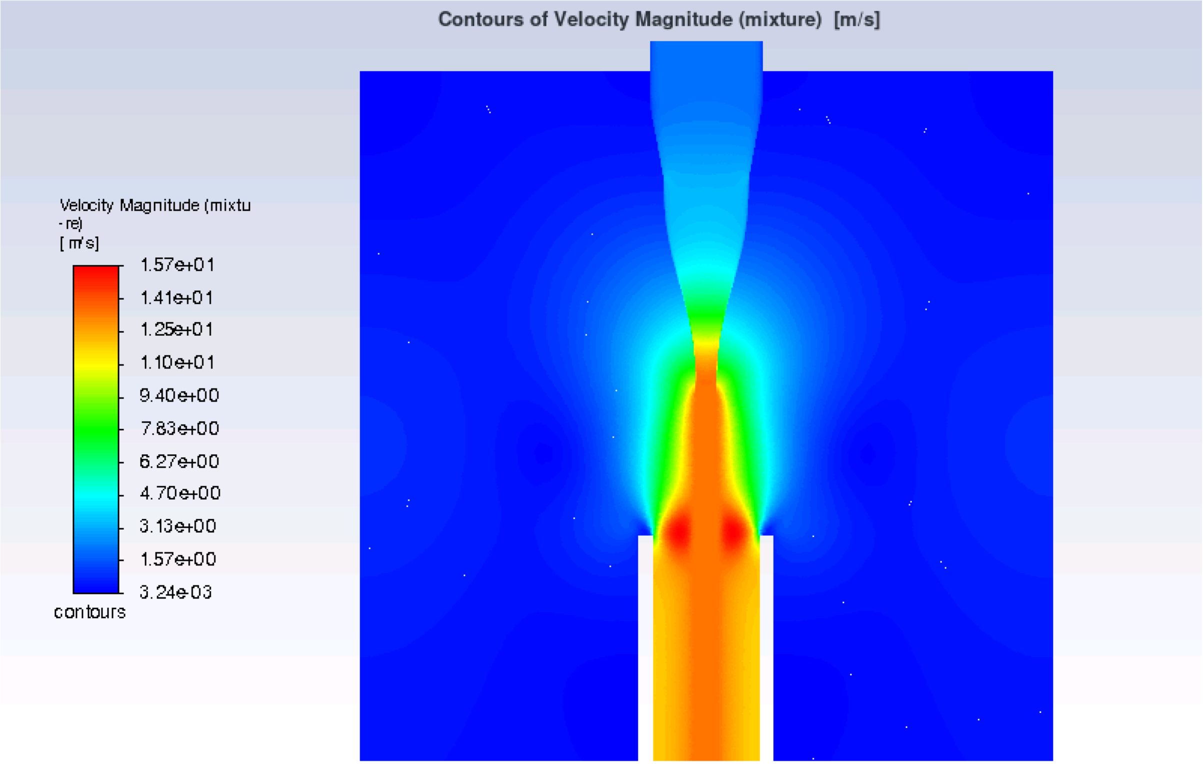


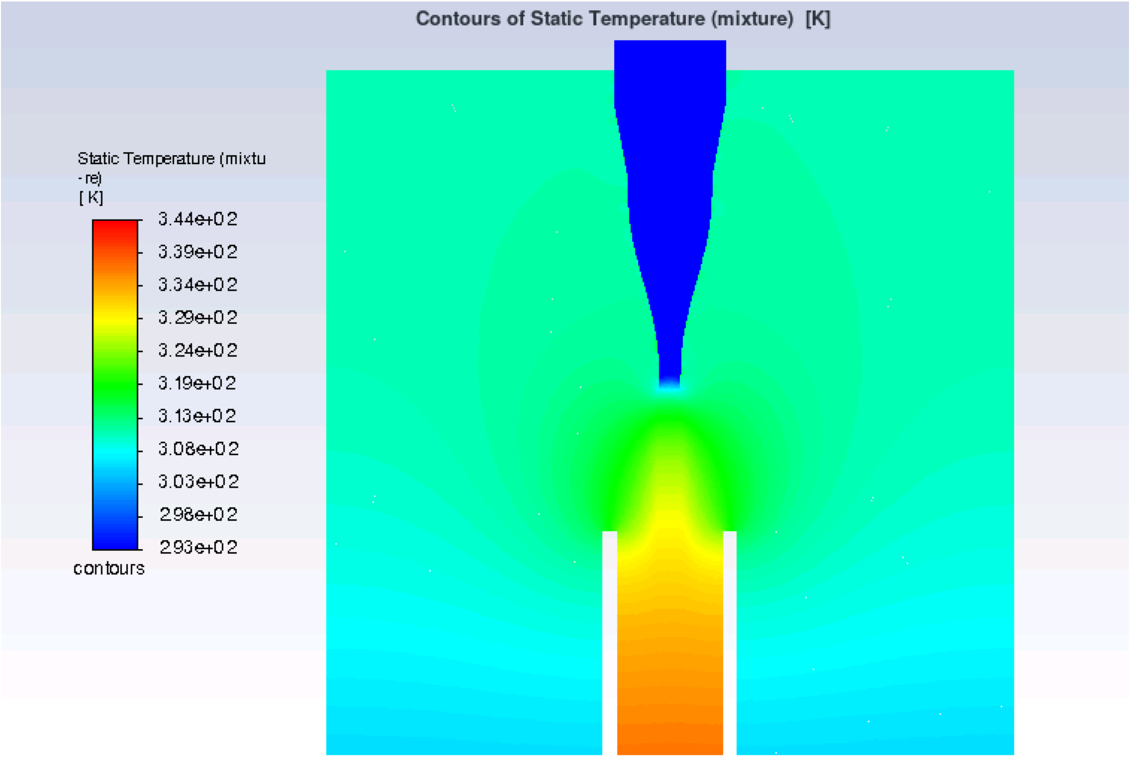


CFD nozzle simulations

Velocity profile, GaInSn velocity ~12.5 m/s, close to 2 m/s x 6.6

Temperature profile due to 40 kW deposited by beam (distribution calculated by GEANT4)

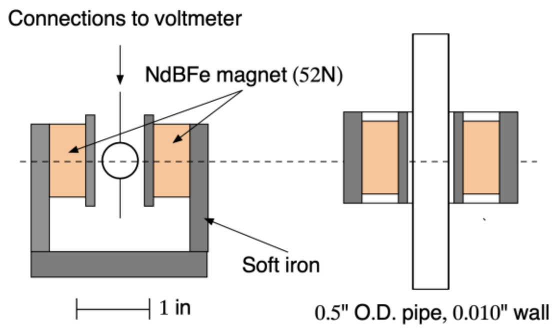


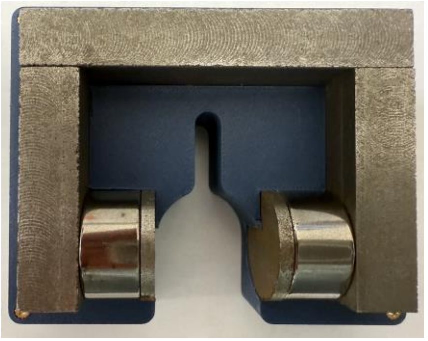


Magnetic flow meter

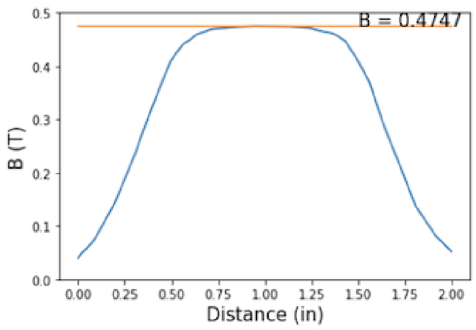
Purchased a model MD-MZ50AYK flow meter from Keyence and incorporated it into the system. Not much information about the device was available. This, combined with the fact that the device electronics probably would not survive in a high radiation field led to a design and construction of a device, based on the paper by
G.E. Turner, "Liquid Metal Flow Measurement (Sodium) State-of-the-Art Study", LMEC-Memo-68-9.

Magnetic flowmeter operation is based on the physical phenomenon that a potential is developed across a moving conductor in a magnetic field. This potential is proportional to the object’s velocity and magnetic field strength, and is developed at right angles to both the magnetic field and the direction of movement of the object.

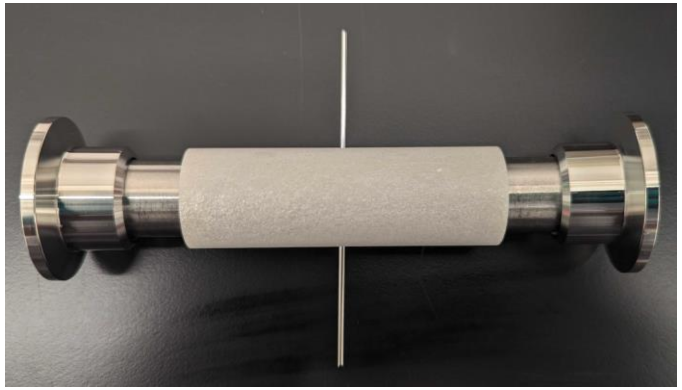




Magnet holder



B field from FEMM



Flow meter as constructed

Flow width measurement

In an accelerator experiment, it is important that the target thickness remains constant. Accordingly, the following method to measure the variation of the jet thickness in time was implemented.

The flow width computer algorithm implemented is a python algorithm that uses the camera feed from the Raspberry Pi's mounted on the prototype converter to measure the width of the liquid metal jet after the nozzle.

The algorithm first preprocesses the camera image to reduce noise and select the region of interest.

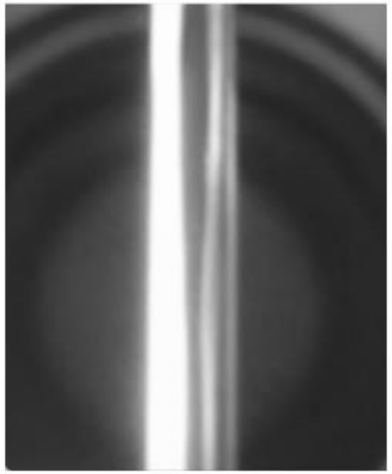
It then uses the Canny() function from the Open CV library to create a Canny Edge map of this region. This is a binary pixel map that highlights high contrast pixels.

Next, the HoughLinesP() function from Open CV is applied to the pixel map to detect probabilistic Hough Lines, that is, finding the straight lines in the Canny Edge map.

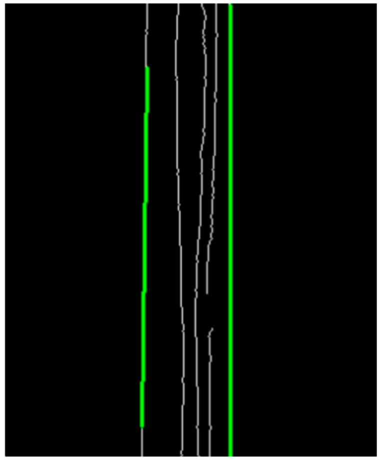
To calculate the width, lines that are the furthest apart are selected (reflections in the liquid metal can show up as lines in the middle of the flow). The change in distance with respect to height for the line pairs is then determined.

Assuming that the change in width is constant, the known starting width (3mm) and distance between the nozzle and the flow capturing tube (20mm) are then used to find the width halfway between the nozzle and the receptacle.

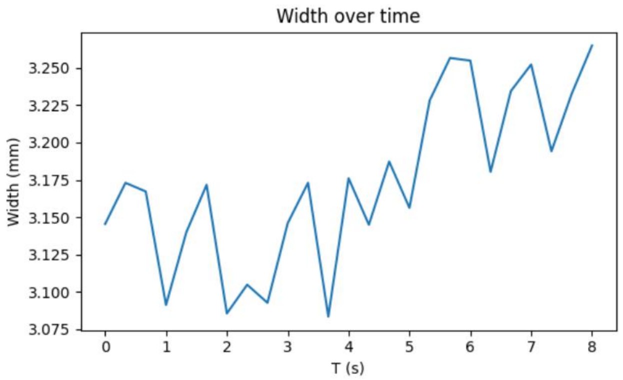
Flow width measurement cont’d



Typical cropped image used



Example of Hough Lines used.



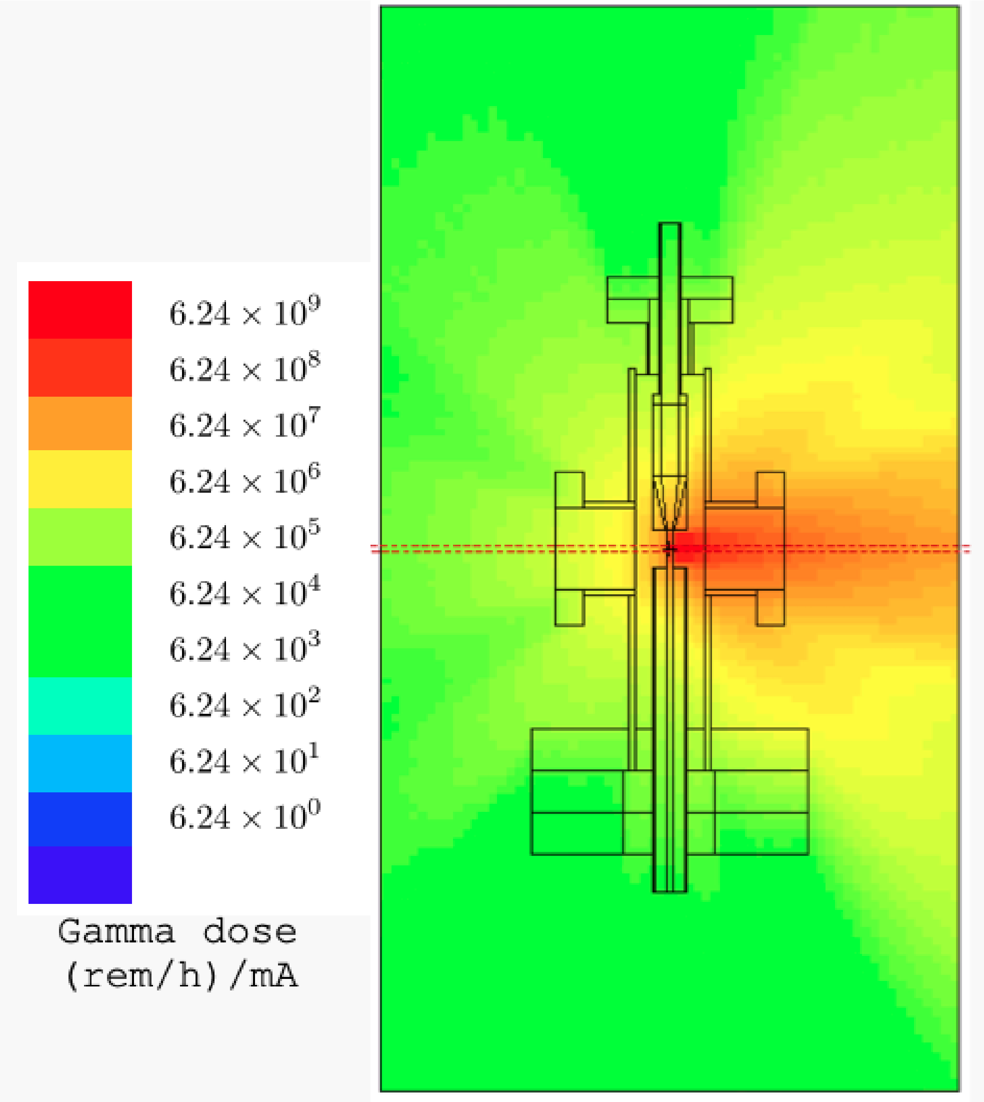
The approach seems to be fairly accurate. A preliminary test of 24 images, taken at a frequency of 3 Hz provided an average width measurement of 3.17 mm with a standard deviation of 0.057 mm(1.78%).

<u>A an issue that remains to be investigated:</u>

The length of the Hough Lines will occasionally cover only half of the flow length. This could be caused by three things: incorrect HoughLinesP() parameters, noise in Canny edges, or the flow itself does not follow a straight line.

Overall, this algorithm is a convenient and reliable method to measure changes in the width of the liquid metal jet after it exits the nozzle

Radioisotope production in the GaInSn target



- MCNP6 gamma dose rate in (rem/h)/mA calculated for a 10 MeV Gaussian electron beam with $\sigma_x = \sigma_y$ = 1mm
- Suppose that radioactive nuclides are formed at a constant rate R for a time τ, after which the irradiation stops and the nuclei decay. If no radio-nuclides are present initially, the activity at time τ is given by

$$A(\tau) = R(1 - e^{-\lambda\tau})$$

where $\lambda = \ln 2/T_{1/2}$, R is the saturation activity and given by Nσϕ where N is the number of target nuclides, σ is the microscopic cross section for the pertinent reaction and ϕ is the flux of particles initiating the reaction. After the irradiation is stopped,

$$A(t) = R(1 - e^{-\lambda\tau})e^{-\lambda t}$$

- The TALYS program for the simulation of nuclear reactions was used to calculate (γ,p), (γ,n) and (γ,γ') cross sections σ(E). These were convoluted with the 10 MeV bremsstrahlung flux ϕ(E) produced by electrons incident on a 3 mm thick GaInSn target and integrated to give R

$$R = N\int_0^\infty \phi(E)\sigma(E)dE$$

where N is the number of targets of each specie per g.

Radio isotope production

Reaction	$T_{1/2}$	Decay Mode	Gnd State Decay	R (Act g^{-1} el^{-1})
$^{71}Ga(\gamma,n)^{70}Ga$	21.14 m		$\beta^- \rightarrow$ Stable	4.959×10^{-10}
$^{113}In(\gamma,\gamma')^{113m}In$	99.5 m	.392 MeV γ	Stable	1.014×10^{-10}
$^{113}In(\gamma,n)^{112}In$	14.4 m		EC, $\beta^+, \beta^- \rightarrow$ Stable	3.128×10^{-13}
$^{113}In(\gamma,n)^{112m}In$	20.8 m	.155 MeV γ	EC, $\beta^+, \beta^- \rightarrow$ Stable	4.916×10^{-12}
$^{115}In(\gamma,n)^{114}In$	1.188 m		EC, $\beta^+, \beta^- \rightarrow$ Stable	4.063×10^{-11}
$^{115}In(\gamma,n)^{114m}In$	49.51 d	.190 MeV γ, EC	EC, $\beta^+, \beta^- \rightarrow$ Stable	5.962×10^{-11}
$^{112}Sn(\gamma,p)^{111}In$	2.805 d		EC $\rightarrow$ Stable	5.453×10^{-18}
$^{112}Sn(\gamma,p)^{111m}In$	7.7 m	.536 MeV γ	EC $\rightarrow$ Stable	2.060×10^{-18}
$^{117}Sn(\gamma,\gamma')^{117m}Sn$	14.0 d	.156, .159 MeV γ	Stable	9.972×10^{-12}
$^{118}Sn(\gamma,n)^{117m}Sn$	14.0 d	.156, .159 MeV γ	Stable	4.456×10^{-17}
$^{119}Sn(\gamma,\gamma')^{119m}Sn$	250 d	.089 MeV γ	Stable	1.033×10^{-11}
$^{120}Sn(\gamma,n)^{119m}Sn$	250 d	.089 MeV γ	Stable	6.728×10^{-15}
$^{122}Sn(\gamma,n)^{121}Sn$	27.1 h		$\beta^- \rightarrow$ Stable	2.786×10^{-11}
$^{122}Sn(\gamma,n)^{121m}Sn$	55 y	$\beta^- \rightarrow$ Stable	$\beta^- \rightarrow$ Stable	9.445×10^{-15}
$^{124}Sn(\gamma,n)^{123}Sn$	129.2 d		$\beta^- \rightarrow$ Stable	1.060×10^{-13}
$^{124}Sn(\gamma,n)^{123m}Sn$	40.1 m	$\beta^- \rightarrow$ Stable	$\beta^- \rightarrow$ Stable	1.199×10^{-10}

At 10 MeV, MCNP6 did not register any neutrons with a reasonable number of particles.

Next steps

- Install a permanent magnet with a 5 kG field next to flow in order to see effect on jet
- Prepare for and carry out a long run, 24 h or more
- Keep running experiments that investigate jet properties
- Investigate new designs for jet collector
- Construct final version of positron converter and incorporate lessons learned from the prototype