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REMOTE CRYO VALVE ADJUSTER– A NEW DEVICE TO IMPROVE SAFETY AND REDUCE COST

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Abstract

During the COVID-19 pandemic, non-essential businesses closed or reduced output, prices for products rose, and availability of products needed for research decreased significantly. Many cryogenic gas producers closed or significantly reduced production, causing cryogenic gas prices to rise. In 2022, liquid helium (LHe) cost $12.36; NSLS-II now pays $32.94/liter (as of August 2025). Much effort therefore focused on remote and multi-sample processing capabilities. When staff members were forced to work from home, equipment to facilitate efficient remote research with minimal on-site presence was developed. A prototype remote cryogenic transfer line valve adjuster was then developed that successfully cut LHe consumption to less than half in one week-long series of experiments, but it needed improvement. This paper describes the engineering efforts to develop, improve, and produce working remote cryogenic transfer line valve adjusters to retrofit existing cryogenic transfer lines.

INTRODUCTION

Remote processing capabilities at NSLS-II were developed during the COVID-19 pandemic due to the rising cost and decreased availability of cryogenic gases such as LHe (reference Fig. 1).

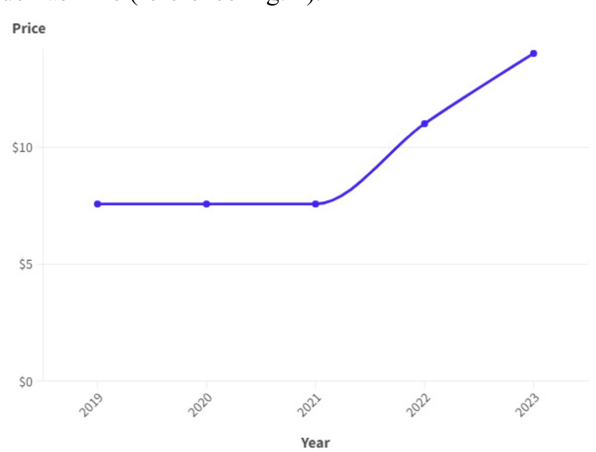

Figure 1: Grade A He price per m^3 (Source: USGS) [1].

At the NSLS-II PDF beamline, a series of week-long experiments using a magnet and cryostat containing samples cooled by an open-loop LHe system consumed three full 100-liter LHe dewars at a FY22 cost of $12.36/liter. The total LHe cost was >$3,700. Although this is just one series of experiments, the total amount of LHe used by NSLS-II in FY22 was 11,620 liters. The cost for this quantity exceeded $140k. As the cost for LHe continued to rise and its' availability continued to decline, three strategies were considered to mitigate this: 1, limit experiments performed requiring cryogens, 2, purchase closed-loop systems that recycle cryogens, 3, develop equipment to efficiently control LHe usage.

All three of these methods were used or initiated in FY22 including the design, production, and testing of a prototype Remote Cryo Valve Adjuster using a stepper motor, internal gears, and a metal housing (reference Fig. 2). The prototype was tested in a similar week-long series of experiments. The result: only one 100-liter dewar of LHe was needed. The LHe cost for this second series of experiments was approximately $1,200, a savings of over $2,500 (excluding labor to fill, transport, and change the additional dewars).

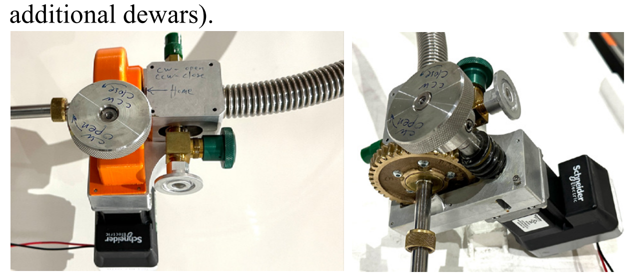

Figure 2: Prototype Remote Cryo Valve Adjuster (a) with, and (b) without the 3D printed plastic gear cover.

Although the first prototype worked well, it was heavy, expensive to produce, and difficult to set up and adjust. It used a NEMA 23 motor that was larger and heavier than needed. An improved, lighter, less expensive, easier to implement remote valve adjuster version was needed.

MATERIAL/PROCESS SELECTION

With the approval of Facilities Improvement Project (FIP) funds, efforts were undertaken to improve the original prototype to minimize weight and cost, then produce three completed devices for other NSLS-II beamlines. A NEMA 17 motor was selected, and the prototype was redesigned using 3D printed materials.

- Stereolithography (SLA) uses a laser to cure liquid resin,
- Fused Deposition Modeling (FDM) builds parts by melting/extruding thermoplastic filaments, and
- Selective Laser Sintering (SLS) uses a laser to fuse powdered polymers.

Both SLS and FDM equipment are available on-site, but SLS equipment was selected due for its' better resin material properties and higher accuracy levels (FDM: 0.20 mm vs. SLA: 0.10 mm). A 4-piece housing was

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designed to connect to existing cryogenic transfer lines, with a new hollow manual adjuster valve knob. Hollow internal cavities were used where practical to minimize plastic material and save weight. Housing components and adjuster knobs were made from both polycarbonate (PC) and Acrylonitrile Butadiene Styrene (ABS). Table 1 shows the 3D printed plastic material properties.

Table 1: Properties for 3D Printed Plastics [2]

PC & ABS Mechanical Properties	GREEN	POST-CURED	METHOD
Ultimate Tensile Strength	37 MPa, 5,366 psi	53 MPa, 7,687 psi	ASTM D 638-14
Tensile Modulus	1,697 MPa, 246 ksi	2,369 MPa, 344 ksi	ASTM D 638-14
Elongation at Break (X/Y)	19%	9%	ASTM D 638-14
Flexural Properties	GREEN	POST-CURED	METHOD
Flexural Strength	62 MPa, 8,992 psi	103 MPa, 14,939 psi	ASTM D 790-15
Flexural Modulus	1,520 MPa, 220 ksi	2,710 MPa, 393 ksi	ASTM D 790-15
Impact Properties	GREEN	POST-CURED	METHOD
Notched Izod	29 J/m, .551 ft-lbs/in	27 J/m, .511 ft-lbs/in	ASTM D 256-10
Thermal Properties	GREEN	POST-CURED	METHOD
Heat Deflection Temp @ 1.8MPa	56°C, 133°F	65°C, 149°F	ASTM D 648-16
Heat Deflection Temp @ 0.45MPa	49°C, 120°F	55°C, 131°F	ASTM D 648-16

Mechanical Properties			**Tough 200 Resin**
Tensile Properties	GREEN	POST-CURED	METHOD
Ultimate Tensile Strength	29 MPa, 4,206 psi	46 MPa, 6,671 psi	ASTM D 638-14
Tensile Modulus	1.2 GPa, 174 ksi	2.3 GPa, 329 ksi	ASTM D 638-14
Elongation at Break	74%	48%	ASTM D 638-14
Flexural Properties			
Flexural Strength	17 MPa, 2,465 psi	65 MPa, 9,427 psi	ASTM D 790-15
Flexural Modulus	0.45 GPa, 65 ksi	1.9 GPa, 275 ksi	ASTM D 790-15
Impact Properties			
Notched Izod	79 J/m, 1.5 ft-lb$_f$/in	40 J/m, .75 ft-lb$_f$/in	ASTM D 256-10
Unnotched Izod	208 J/m, 3.9ft-lb$_f$/in	715 J/m, 13.4 ft-lb$_f$/in	ASTM D 4812-11
Thermal Properties			
Heat Deflection Temp @ 1.8MPa	56°C, 133°F	65°C, 149°F	ASTM D 648-16
Heat Deflection Temp @ 0.45MPa	49°C, 120°F	55°C, 131°F	ASTM D 648-16
Thermal Expansion (0 - 150°C)	107μm/m°C, 59 μm/m/°F	91 μm/m°C, 50 μm/m/°F	ASTM E 831-13

Formlabs Tough 2000 ABS resin was the preferred choice for both housing components. This resin provides superior strength (e.g., 6.6 ksi versus 5.8 ksi UTS using standard ABS properties). This adds further conservativism to the results obtained and confirms lower strength ABS resins can also provide acceptable results. One unit was produced from clear resin for actual use and demonstrations.

ENGINEERING/DESIGN EFFORTS

The Remote Cryo Valve Adjuster FIP was funded in FY24 by NSLS-II. The engineering efforts focused on creating and testing three improved units for internal use. The initial redesign used a plastic housing with limit switches. This design was considered too complex during an internal review. The final design has no limit switches, lightweight 3D printed plastic, parts and a smaller motor with a manual adjuster knob for on-site adjustment *and* remote operation. Internal bearings were used extensively to ensure smooth operation and longevity. This version was easier to assemble and install (see Fig. 3).

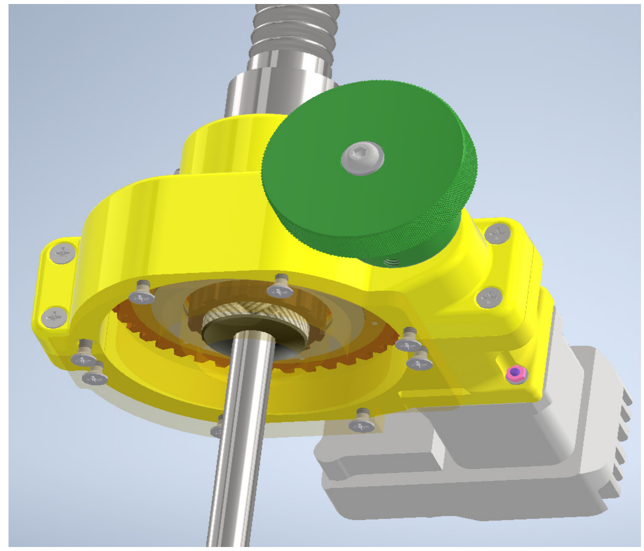

Figure 3: Remote Cryo Valve Adjuster (with transparent housing end plates).

Engineering calculations and analyses were undertaken to optimize the design, conservatively using the maximum torque produced by a double-stack NEMA 17 MDrive motor (even though a single-stack motor was intended). The double stack MDrive motor produces up to 60 ounce-inches of torque. It turns a single-lead worm gear that meshes with a 40-tooth pinion gear that connects to the helium flow control valve. A graph showing the motor torque is included in Fig. 4. Hand calculations (verified by a second engineer) were used to develop the applied FEA loads.

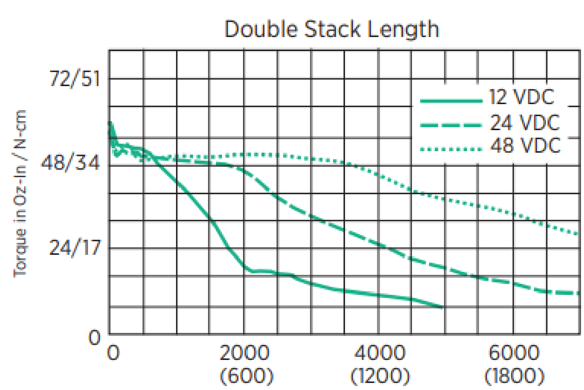

Figure 4: Torque curve for Novanta NEMA 17 Double-stack MDrive model LMDOE422 motor.

CALCULATIONS AND ANALYSES

Loads are created by the torque of the motor applied to internal gears. Forces on the housing components were calculated based upon the maximum torque the largest motor used could apply. The applied forces and finite element mesh of two housing components are shown in Fig. 5, one for each half of the housing and one for the split end plate that retain the gears. The two other housing components are essentially mirror images with only minor differences.

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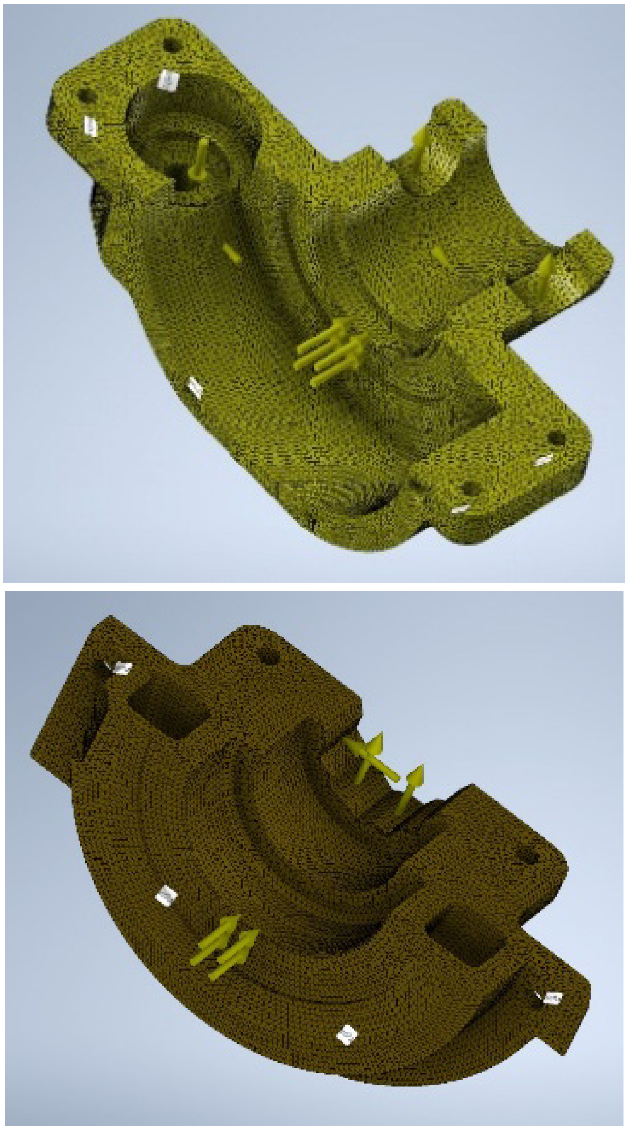

Figure 5: Finite Element mesh with applied force vectors for one half of (a) the housing and (b) housing plate that retains the worm and ring gear mechanism.

RESULTS

Three Remote Cryogenic Valve Adjusters were made using NEMA17 motors and plastic housings. Each unit tested performed similarly. During two sets of week-long tests, the Remote Cryogenic Valve Adjuster reduced liquid helium consumption from nearly 300 liters to less than 100 liters. At over $12 -13 per liter, the cost *savings* for a week-long series of experiments conducted in FY23 was approximately $2.5k. The new Remote Cryo Valve Adjusters are lighter, less expensive to produce, and make extensive use of low-cost plastic housing components designed to withstand the full torque of the largest motor tested compared to the original prototype. The new versions need no end stop switches and thus require fewer controls. Iterative finite element analyses (FEA) using conservative Factors of Safety and actual tests confirmed the housing could resist all internal forces. Factors of safety ranged from 2.86 minimum for the Upper Mounting Block housing to 8.18 for the 'Side A' End Plate housing. The upgraded housings can use standard ABS plastic with 5.8 ksi material strength (instead of 6.6 ksi for FormLabs Tough 2000 resin which is the preferred housing material). Both gears are lightly loaded, and the housings do not contact any moving parts other than the axles (which rotate slowly). Thrust bearings with alloy steel thrust washers surround each gear, thus minimal wear and long life is expected. Each of the three third-generation Remote Cryogenic Transfer Valve Adjusters operated successfully in FY24 without problems. These devices enable remote cryogenic fluid flow adjustment, enable accurate temperature control, and improve safety since no staff members are needed on site to make flow adjustments. The Remote Cryogenic Valve Adjusters can provide automatic temperature control without human intervention using temperature sensors and software.

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[2] FormLabs, `https://formlabs.com/store/materials/`