Component modeling and design for CrystaLiZe Experiment

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1 Abstract

Work is underway to make upgrades to the Crystalize experiment. The scope of this project is the design and verification of several physical components for the TPC assembly, including a molded PTFE test piece and a heatsink. All CAD and work was completed in Solidworks. A PTFE test piece is created using a 304 stainless steel mold, capable of withstanding the 4500 psi necessary to form PTFE (Teflon). The mold, assumed in three pieces, was validated using pressure load simulations. The second component designed was a copper and aluminum heatsink, designed to prevent room temperature Kapton cables from melting or boiling off the xenon held in the main assembly.

2 Acknowledgments

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3 Introduction

The LUX-ZEPLIN (LZ) experiment is a joint venture between many large institutions including Lawrence Berkeley National Labs (LBNL) to attempt to detect dark matter particles. The design of the experiment is heavily influenced by the LUX and ZEPLIN-III experiments, hence the name. Like the LZ experiment, the LUX and ZEPLIN-III experiments utilize xenon in the hopes of detecting a theorized elementary particle that would make up dark matter. This theorized particle would have a large mass and interact through a very weak force. It has been dubbed the Weakly Interacting Massive Particle (WIMP) (2; 3).

The LZ experiment is essentially a Russian doll of detectors, and its innermost mechanism is the Time-Projection Chamber (TPC), which contains 7 tonnes of active liquid xenon. The TPC is surrounded by an additional 2 tonnes of liquid xenon which acts as an insulator as well as another detector. Xenon is used because it is reliably stable, limiting internal radiation and is quite dense which prevents external radiation from penetrating to the center of the TPC (1).

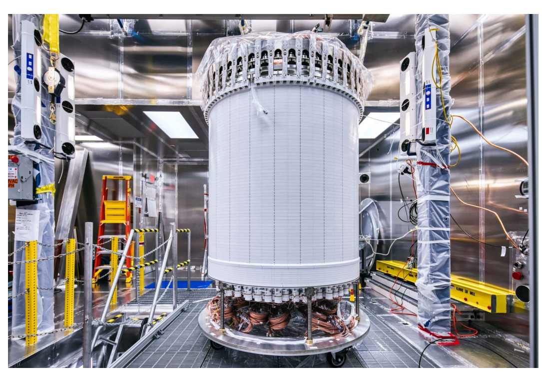

Figure 1: Assembled TPC for LZ (5)

The CrystaLiZe project is a probe into possible changes and/or upgrades to the LZ experiment, chief among them being the use of solid xenon instead of liquid in the TPC. This particular change will allow for a more precise detection of dark matter particles. Another possible change is the material of the containment vessel of the TPC.

4 Heat Sink Design

The solid xenon in the CrysaLiZe assembly is kept below -112°C in a vacuum chamber (the TPC) sealed by CF-flanges. Kapton cables run through the entirety of the assembly, parts of which are room temperature. When the Kapton cables enter the TPC, which contains the liquid xenon, the difference in temperature can cause it to boil off. In order to prevent this, one of the mini CF-flanges being used to seal the TPC was replaced with a flange machined to function as a part of the heat sink.

The original design of the heat sink was to tap threaded-holes though the CF-flange attached with nuts from the other side. The CF-flange had a drill-able area of about 0.32 in^2 which meant that not only did all the tapped holes need to fit in that 0.32 in^2 but the nuts needed to fit as well and there needed to be enough space for the tool to screw the nuts in.

Bolt type	Number of bolts	Space between nuts (in)	Cross-sectional area (in^2)
6-32	2	0.0413	0.0130
	3	0.0057	0.0195
4-40	3	0.0953	0.0133
	4	0.0435	0.0177
1/4-28	1	N/A	0.0302

This design was ultimately scrapped since there was concern about maintaining the integrity of the vacuum with tapped holes going all the way through the flange. The design that replaced it is made up of three main parts: the machined mini CF-flange, a machined copper rod, and a 1/4-28 threaded aluminium rod. The flange will essentially act as the nut for the threaded rod. This change in design will not have the tapped holes going all the way through.

The completely smooth side of the flange has three 8-32 holes tapped 1/8" deep so copper braids can be attached to the heat sink via ring terminals. The opposite side has one 1/4-28 tapped hole 1/8" deep through the center where the 1" threaded rod will attach. The 3" copper rod has two tapped holes. The first is a 1/4-28 hole through the axis of the rod and 7/8" deep. The other is a 1mm diameter hole perpendicular to the 1/4-28 tapped hole, 0.85" from the edge of the face the 1/4-28 tapped hole is drilled into and drilled through to the 1/4-28 hole. The 1" threaded rod is used to connect the two machined parts.

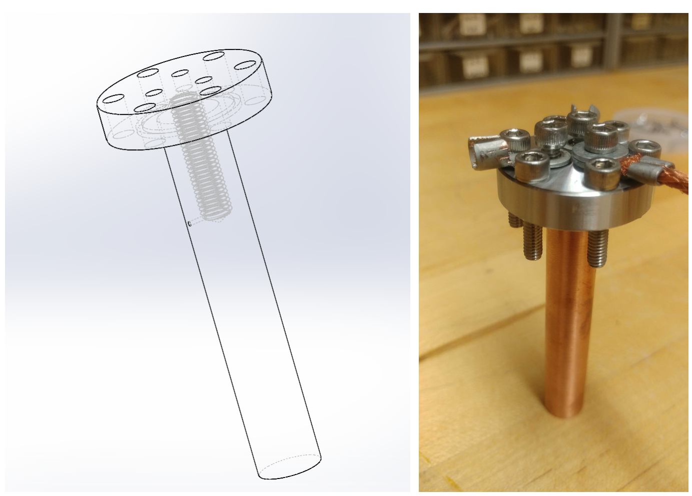

Figure 2: Assembled Heat Sink

5 PTFE (Teflon) Mold Design

Forming PTFE takes 3000-4500 psi of pressure followed by sintering at 363-382°C. Before committing to forming PTFE walls of a new composition for the TPC, a test piece needs to be made to make sure it will work as theorized. A mold for a $1 * 1 * 1$" cube that can withstand the needed pressure to form the PTFE. Another consideration that must be taken into account is that the PTFE must be able to be removed from the mold when it is done forming, meaning the mold has to be made out of at least two pieces. The preliminary design for the mold involves an inner piece that forms two walls of the mold and an outer piece that forms the other two.

Some back of the napkin calculations gave a ballpark for the general dimensions that the mold needs to be able to withstand at least 4500 psi. The mold as a whole can be assumed to be essentially a beam under the amount of pressure needed to exert the 4500 psi on the 1 in^2 part of the mold making contact with the top of the PTFE. The amount of strain on the part of the mold that contains the PTFE is much harder to calculate by hand than the part of the mold compressing it. It can be thought of as a pressure vessel problem however it is an atypical case in that regard considering that it is rectangular in shape and does not have spherical or cylindrical qualities like most pressure vessels. The formula for elastic deformation under axial load, $\delta = PL/AE$ where P is the load on the object, A is the area of the face the load is applied to, L is the length of the object and E is the modulus of elasticity was used to estimated the approximate size of the mold needed to minimize the strain on the part of the mold compressing the PTFE to $\leq$0.1 mm.

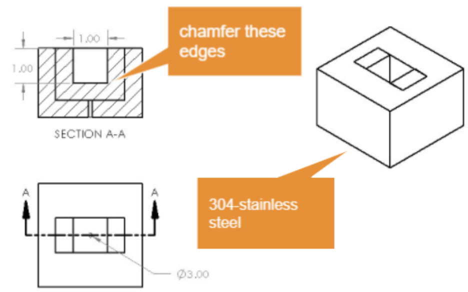

Figure 3: Preliminary PTFE mold design

Applying the dimensions to the preliminary design for the mold and simulating the pressure needed to form the PTFE yields results that expose an issue with the preliminary design. It must first be noted that there is no way to simulate the PTFE powder through its transformation under pressure in Solidworks so the simulations will be limited in that capacity. A cube the size of the cavity in the mold was assigned the average material properties of PTFE and placed in the mold as a substitute. When put through a simulation of the pressure need to for the PTFE the plunger piece of the mold tilted as show in the picture Figure 4.

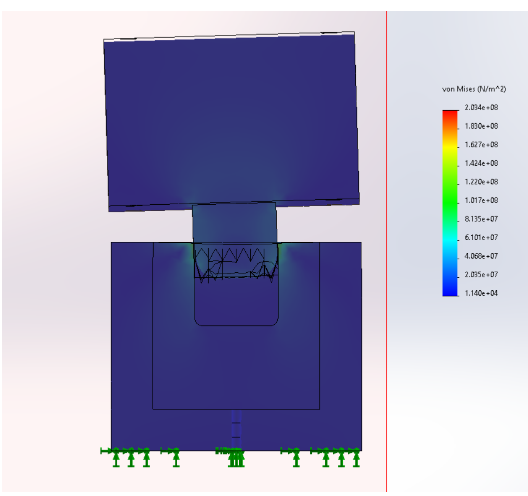

Figure 4: First PTFE mold simulation

There are two solutions to this issue. The first is to deepen the cavity in the center of the mold to allow the walls of the cavity to guide the plunger piece and prevent it from tipping. The other is to add guide pins to the corners of the mold to prevent the plunger piece from tipping.

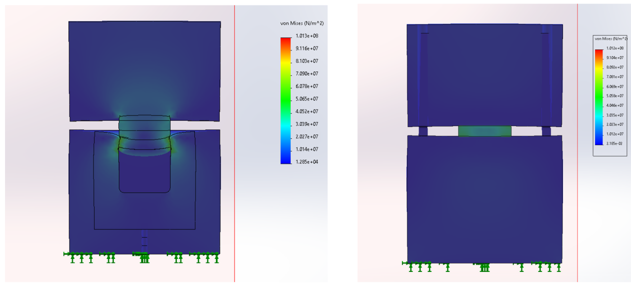

Figure 5: Deeper cavity simulation (left), Guide pin simulation (right)

When the cavity of the mold is made slightly deeper the plunger piece of the mold seems to go in without tipping in the simulation. The guide pins seem to also solve the problem of the plunger piece tilting. The problem with the guide pins is that because of the slight deformation of the mold the guide pins go into their holes at an angle (as seen in Figure: 5) and would likely cause them to bond with the plunger piece. Since both solutions seem to solve the issue of the plunger piece tilting and the guide pin solution seems to add a problem, it's clear that the mold should have a slightly deeper cavity to address the tilting problem instead of guide pins. As seen in Figure: 6, under the amount of pressure needed to form the PTFE the part of the plunger applying force to the PTFE in the mold will bond to the other parts of the mold.

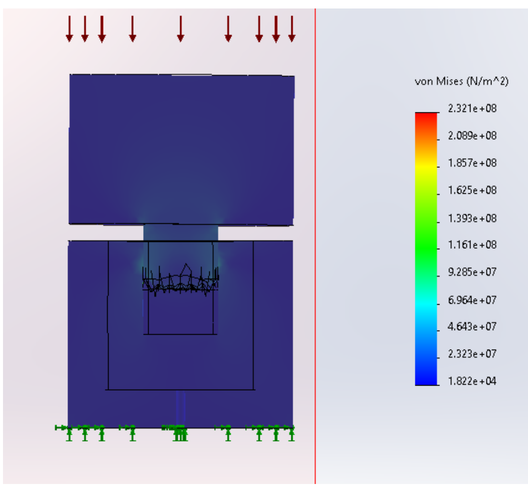

Figure 6: PTFE mold simulation with transitional fit clearance

In order to address the issue of the plunger piece bonding with the mold, the fundamental design was changed from a rectangular mold to a cylindrical mold to better distribute the load. Unfortunately, the plunger piece still bonds with the mold. There are two possible solutions to this that need to be explored further. The first is to make the cavity of the mold a threaded hole and use a threaded rod to apply to need pressure to the PTFE. The second solution is to split the mold into a top and bottom half so that even when the plunger piece bonds to the top half of the hold, the bottom half can be removed and the PTFE taken out.

After further investigation into the issue of the pieces of the mold bonding under pressure, there was a realization that the proper clearance between the plunger piece and mold cavity was not included in the models and by extension the simulations showing the pieces bonding. When transitional fit clearance was added to the cylindrical mold model, the simulation showed no bonding (4).

6 Conclusion

Although the heat sink design has been fabricated and the pieces fit together as anticipated it is unclear how effective it will be at cooling the Kapton cables before they enter the TPC. Three copper braids can be attached to the heat sink and it is predicted that using more than two would result in icing. Of course this is hard to know for sure until the heat sink is added to the assembly which likely won't happen for another month. There is reason to be optimistic that the heat sink will prevent the Kapton cables from melting and boiling off the solid xenon as intended.

While it is unfortunate that a not inconsiderable amount of time was spent trying to solve an issue that ended up being a flaw in the model and not in the design of the mold, now that the issue has been resolved focus can be directed toward the way the needed pressure will be applied. One possibility is by tapping threaded holes in the corners of the mold and tightening threaded rods until the needed pressure is achieved. Another by using some sort of mechanical press. Some of the considerations for this decision are the dangers of handling the PTFE powder outside of a controlled environment, the qualifications needed to handle certain equipment and how precise each method is. It is also worth investigating how to smooth out the surface of the PTFE that makes contact with the plunger piece since it seems so come out fairly jagged in the simulation. While the process of designing the PTFE mold is far from finished, confirming that the mold will be able to withstand the needed pressure is a clear success.

References

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