Fermi National Accelerator Laboratory

Fermilab

Gravity Offload Tool for PIP-II

Lilly Herbst
University of Wisconsin-Milwaukee - SIST

Supervisor: Curtis Baffes

Abstract

PIP-II cryomodules are supported on a kinematic strut system. These vertical struts carry a significant load and require high force to adjust. The gravity offload tool will facilitate the adjustment while providing enough compliance that the precise alignment of the cryomodules is not compromised.

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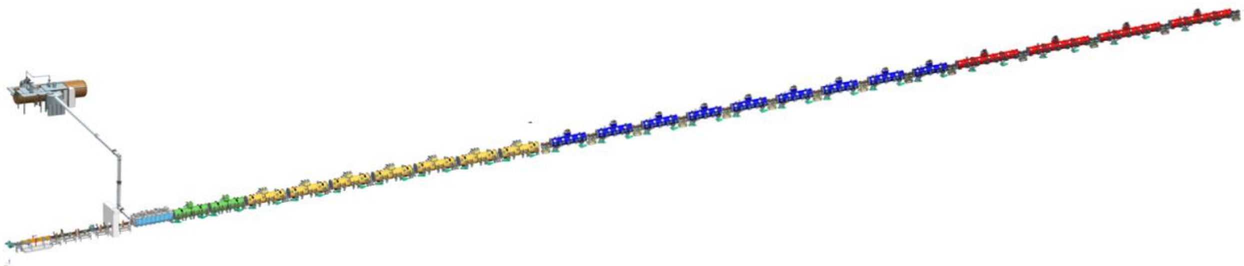
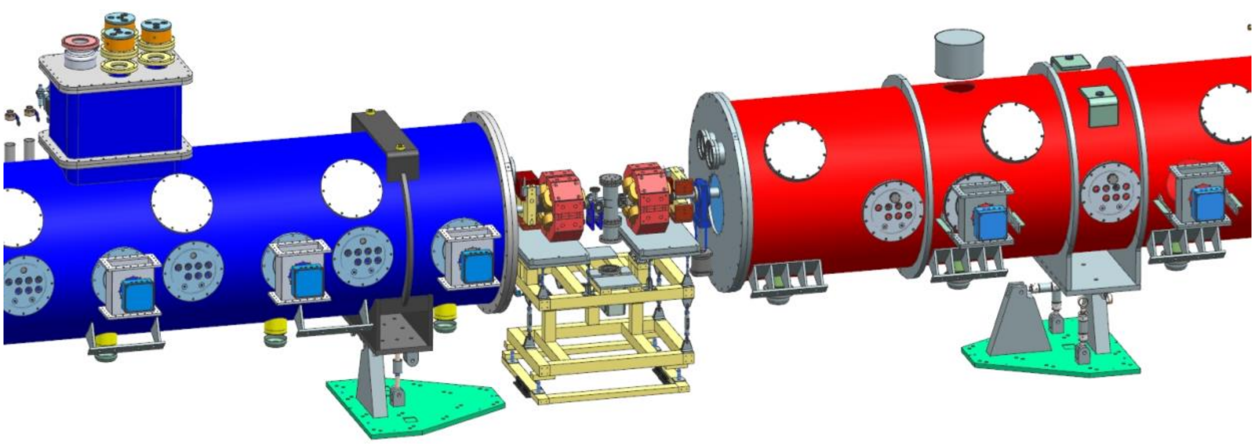
Background

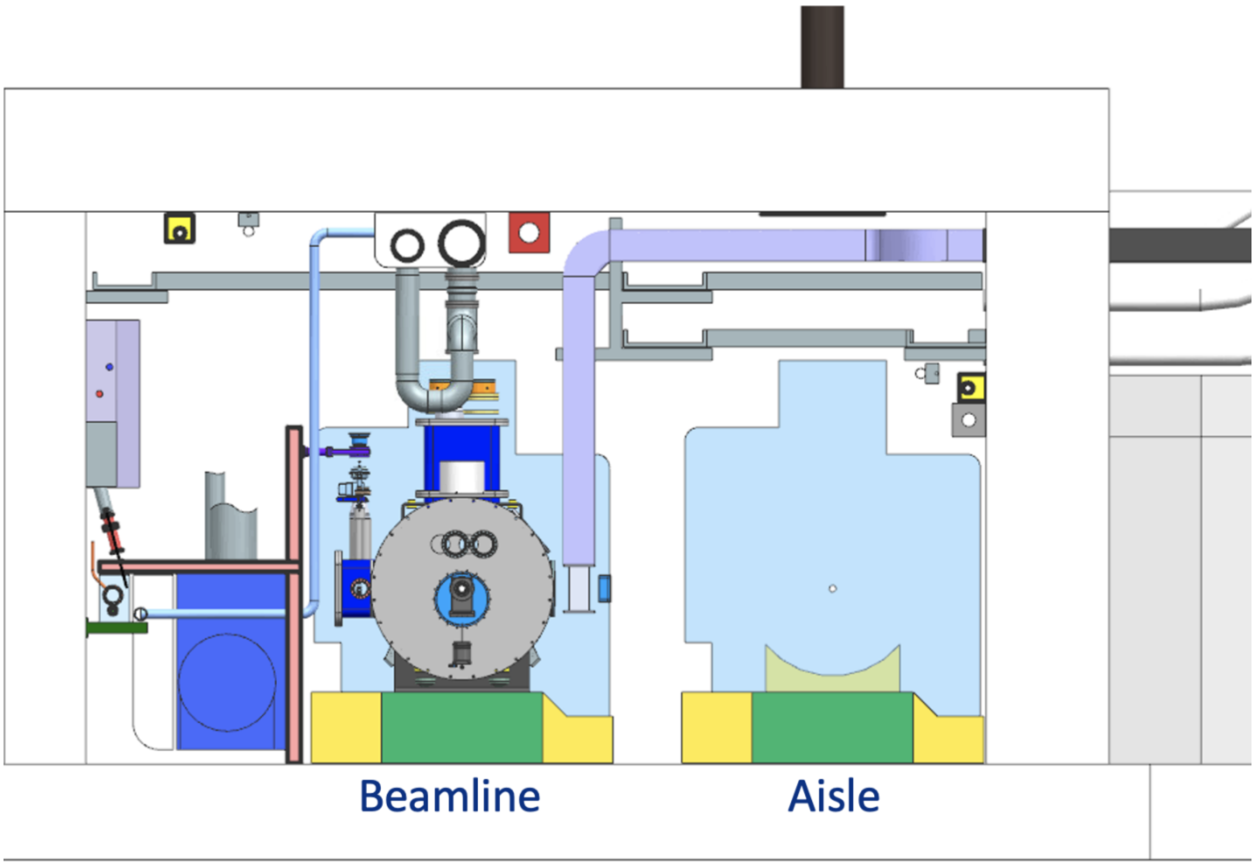
PIP-II will enable the world's most intense beam of neutrinos to the international LBNF/DUNE project, and a broad physics research program, powering new discoveries for decades to come. PIP-II is a superconducting particle linear accelerator that is comprised of twenty-three cryomodules that will operate in temperatures as low as two Kelvin. The cryomodules will be manually installed one at a time. Each cryomodule weighs approximately thirty thousand pounds, each having three vertical struts that will be used for final alignment – two vertical struts on the upstream side and one on the downstream side. With the first cryomodule installed, it was found to be difficult to adjust the vertical struts alone. Technicians were able to use a crane to lift the cryomodule for the struts to be adjusted easily.





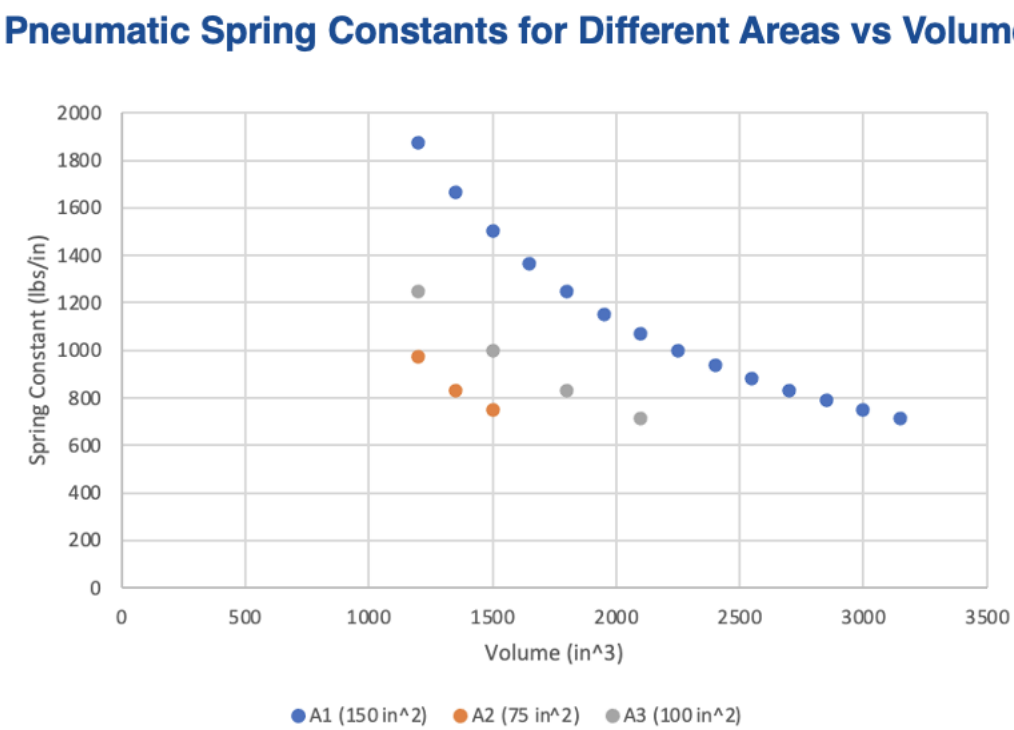
Motivation

Below is a cross-section model of the cryomodule tunnel transportation system that is being designed that will eventually get the cryomodules to the beamline location. There are many restrictions in these areas, so a crane is not possible to use. Considering the tight space of the cryomodule aisle and beamline, the gravity offload tool will need to be a small but powerful tool that will be able to temporarily lift some of the load from the cryomodule. Because the cryomodules will be approximately thirty-thousand pounds, the ideal range for the gravity offload tool was decided to be between five-thousand and ten-thousand pounds per inch.

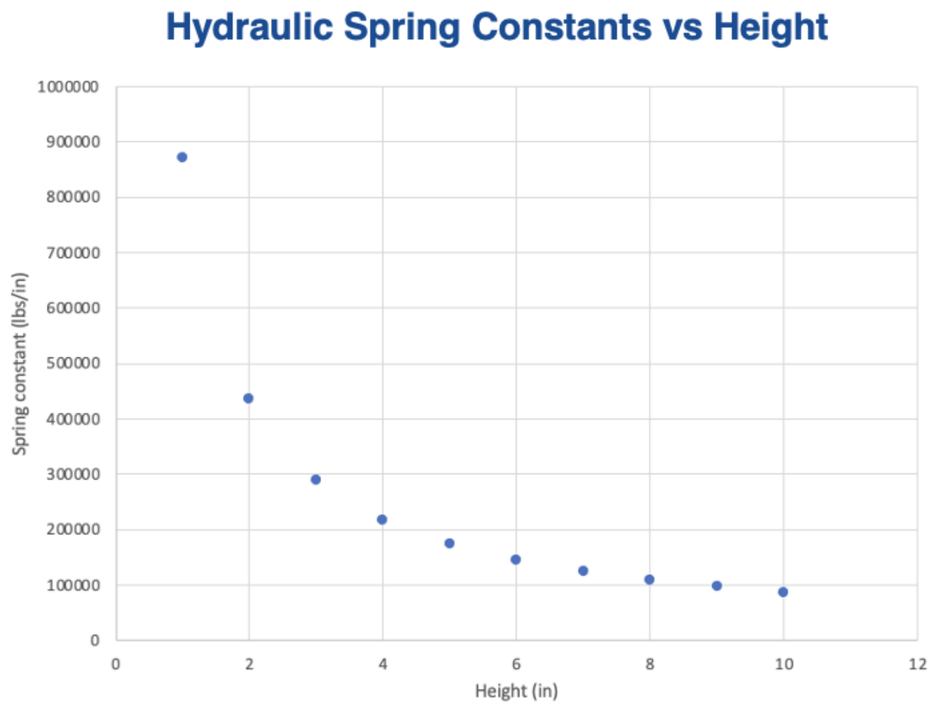


Methodology and Analysis

To study the possibilities of a gravity offload tool, calculations were made based on adjustability and ease of use. The difference between primary and secondary options were made – secondary meaning they cannot be used alone or are not easy to adjust or remove in a tight area. Focusing first on the primary ideas, the pneumatic cylinder's spring constant was calculated based on different areas vs volumes and it proved to be softer than the ideal range.



The hydraulic cylinder, however, was originally calculated using an estimated bulk modulus of hydraulic oil, not taking the hydraulic hose into account. The hydraulic spring constant was found to be the complete opposite – stiffer than the ideal range.



Combined Spring Constants

Next, we had to separately calculate the secondary options, which were compression springs, disc springs, and inflatable wedges. Because they cannot be used alone, we combined the primary options and the secondary options to see if the spring constant and adjustability could be in the ideal range. Below are the calculations with the combined spring constant between the pneumatic cylinder and every secondary option. Since the pneumatic spring constant is low, it made the combined spring constant even lower, which is not ideal.

Pneumatic + Disc Spring

	k (lbs/in)	pneumatic k	spring k	# of springs
ideal spring + pneumatic	1076.27	1500.00	3810.00	NA
disc spring1 + pneumaticH16	914.98	1000.00	10762.36	26
disc spring1 + pneumaticH17	870.43	937.50	12166.15	23
disc spring1 + pneumaticH18	830.01	882.35	13991.07	20
disc spring1 + pneumaticH19	790.93	833.33	15545.63	18
disc spring1 + pneumaticH20	757.42	789.47	18654.76	15
disc spring2 + pneumaticH16	882.35	1000.00	7500.00	32
disc spring2 + pneumaticH17	842.11	937.50	8275.86	29
disc spring2 + pneumaticH18	805.37	882.35	9230.77	26
disc spring2 + pneumaticH19	774.19	833.33	10909.09	22
disc spring2 + pneumaticH20	743.03	789.47	12631.58	19
disc spring3 + pneumaticH16	964.77	1000.00	27385.42	20
disc spring3 + pneumaticH17	909.48	937.50	30428.24	18
disc spring3 + pneumaticH18	860.18	882.35	34231.77	16
disc spring3 + pneumaticH19	815.95	833.33	39122.02	14
disc spring3 + pneumaticH20	776.05	789.47	45642.36	12
disc spring4 + pneumaticH16	908.50	1000.00	9929.45	27
disc spring4 + pneumaticH17	864.91	937.50	11170.63	24
disc spring4 + pneumaticH18	822.78	882.35	12186.15	22
disc spring4 + pneumaticH19	786.86	833.33	14110.28	19
disc spring4 + pneumaticH20	753.95	789.47	16755.95	16

Pneumatic + Inflatable Wedge

	k (lbs/in)	pneumatic k	wedge k	length (in)
wedgeH5 + pneumaticH16	847.46	1000.00	5555.56	16.75
wedgeH5 + pneumaticH17	802.14	937.50	5555.56	17.75
wedgeH5 + pneumaticH18	761.42	882.35	5555.56	18.75
wedgeH5 + pneumaticH19	724.64	833.33	5555.56	19.75
wedgeH5 + pneumaticH20	691.24	789.47	5555.56	20.75
wedgeH6 + pneumaticH16	779.51	1000.00	3535.35	17.75
wedgeH6 + pneumaticH17	741.00	937.50	3535.35	18.75
wedgeH6 + pneumaticH18	706.12	882.35	3535.35	19.75
wedgeH6 + pneumaticH19	674.37	833.33	3535.35	20.75
wedgeH6 + pneumaticH20	645.36	789.47	3535.35	21.75
wedgeH7 + pneumaticH16	735.29	1000.00	2777.78	18.50
wedgeH7 + pneumaticH17	700.93	937.50	2777.78	19.50
wedgeH7 + pneumaticH18	669.64	882.35	2777.78	20.50
wedgeH7 + pneumaticH19	641.03	833.33	2777.78	21.50
wedgeH7 + pneumaticH20	614.75	789.47	2777.78	22.50
wedgeH23 + pneumaticH16	829.38	1000.00	4861.11	17.00
wedgeH23 + pneumaticH17	785.93	937.50	4861.11	18.00
wedgeH23 + pneumaticH18	746.80	882.35	4861.11	19.00
wedgeH23 + pneumaticH19	711.38	833.33	4861.11	20.00
wedgeH23 + pneumaticH20	679.17	789.47	4861.11	21.00

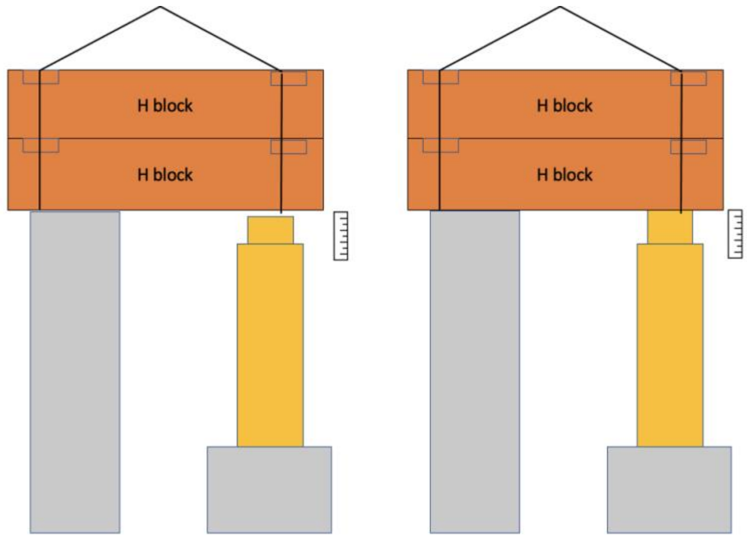
The disc springs proved to be the best adjustability-wise. The hydraulic cylinder and disc spring spring constants were combined with the same equation. Because the hydraulic cylinder is stiffer than the disc spring, the combined spring constant was lowered. The last row of the chart below proved to be the most ideal spring constant.

Hydraulic + Disc Spring

	k (lbs/in)	hydraulic k	disc spring k	length (in)	# of springs
disc spring1 + hydraulicH29	17144.29	870228	17488.84	20.99	16
disc spring2 + hydraulicH29	11836.78	870228	12000.00	20.98	20
disc spring3 + hydraulicH29	43367.78	870228	45642.36	20.84	12
disc spring4 + hydraulicH29	15489.60	870228	15770.31	21.00	17
disc spring5 + hydraulicH29	*10486.71*	*870228*	*10614.62*	*20.69*	*14*

Confirmation

Fermilab technicians assisted in an experiment to measure the spring constant of the Enerpac RC158 using H-blocks(concrete shielding blocks used at Fermilab) and a crane. On the leftmost side, the H-blocks sat on a rigid body, and on the rightmost side was the hydraulic cylinder and another smaller rigid body. At first, the load was being carried by the crane that lifted the H-blocks. The crane was then brought down until it transferred the full load onto the hydraulic cylinder. We ended up getting data such as the deflection and stroke, which let us calculate the spring constant of that hydraulic cylinder.



Potential Hydraulic Test Diagram

Enerpac RC158 Hydraulic Test at Fermilab

As the cylinder went from zero load to half of the load, it compressed by 3/16 of an inch. Using that as our deflection, we can now use this equation to find the spring constant. The stroke of the Enerpac RC158 when carrying the full load was 4.5 inches. Comparing that to the results of the original calculations, the hydraulic spring constant is less by a factor of three.

$$\frac{w_H}{\partial} = k$$

w_H = weight of 1 H-block
∂ = deflection
k = spring constant

Results from Calculations vs Hydraulic Test

stroke (in)	spring constant (lbs/in)
10	87022.80
9	96692.00
8	108778.50
7	124318.29
6	145038.00
5	174045.60
4	217557.00
3	290076.00
2	435114.00
1	870228.00

Hydraulic Test	
spring constant (lbs/in)	64000
deflection (in)	0.1875
stroke	4.5

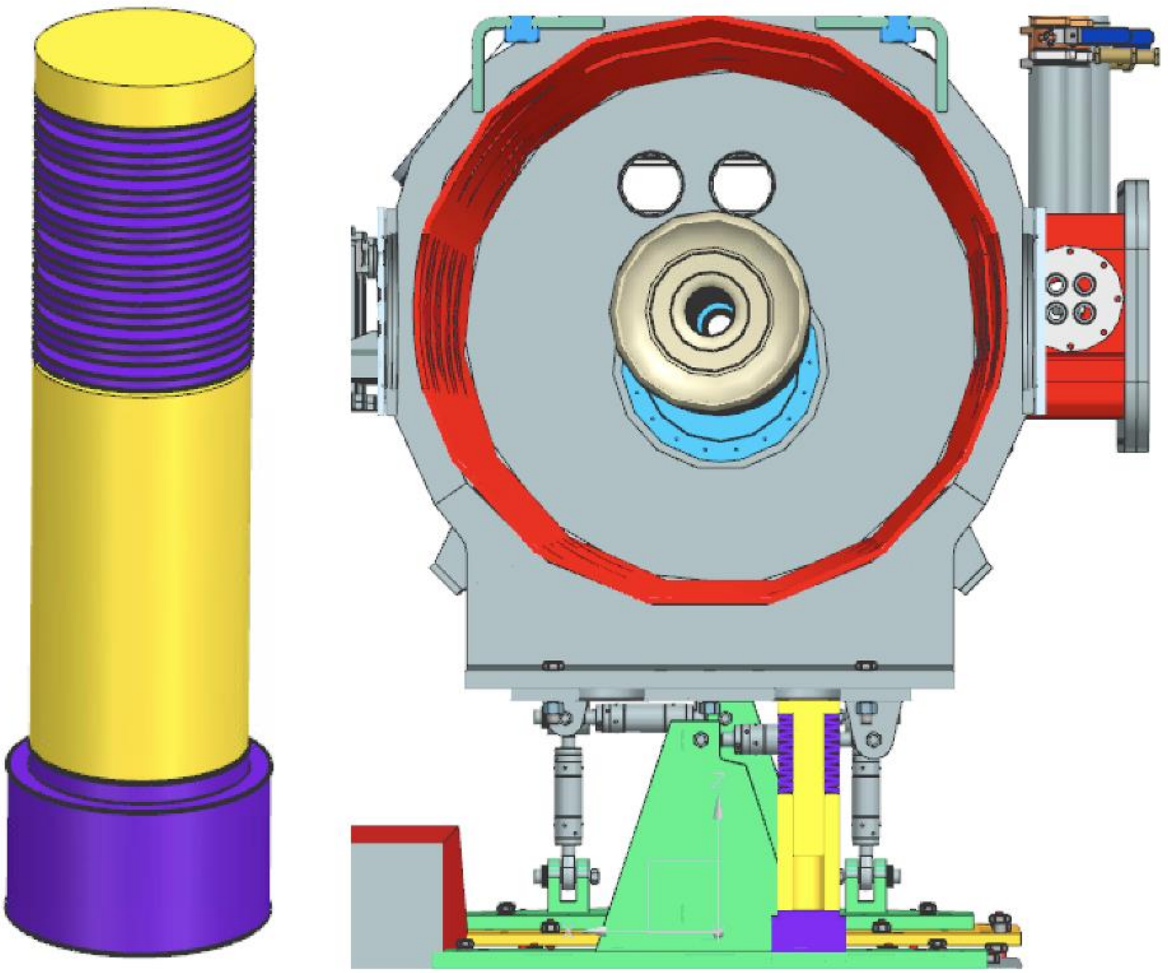
Placing the new tested spring constant into the combination equation, the final calculations resulted in nine-thousand pounds per inch, which is still in the ideal range.

Final Hydraulic + Disc Spring Calculations

	k (lbs/in)	hydraulic k	disc spring k	length (in)	# of springs
disc spring5 + hydraulicH29	*9104.59*	*64000*	*10614.62*	*20.69*	*14*

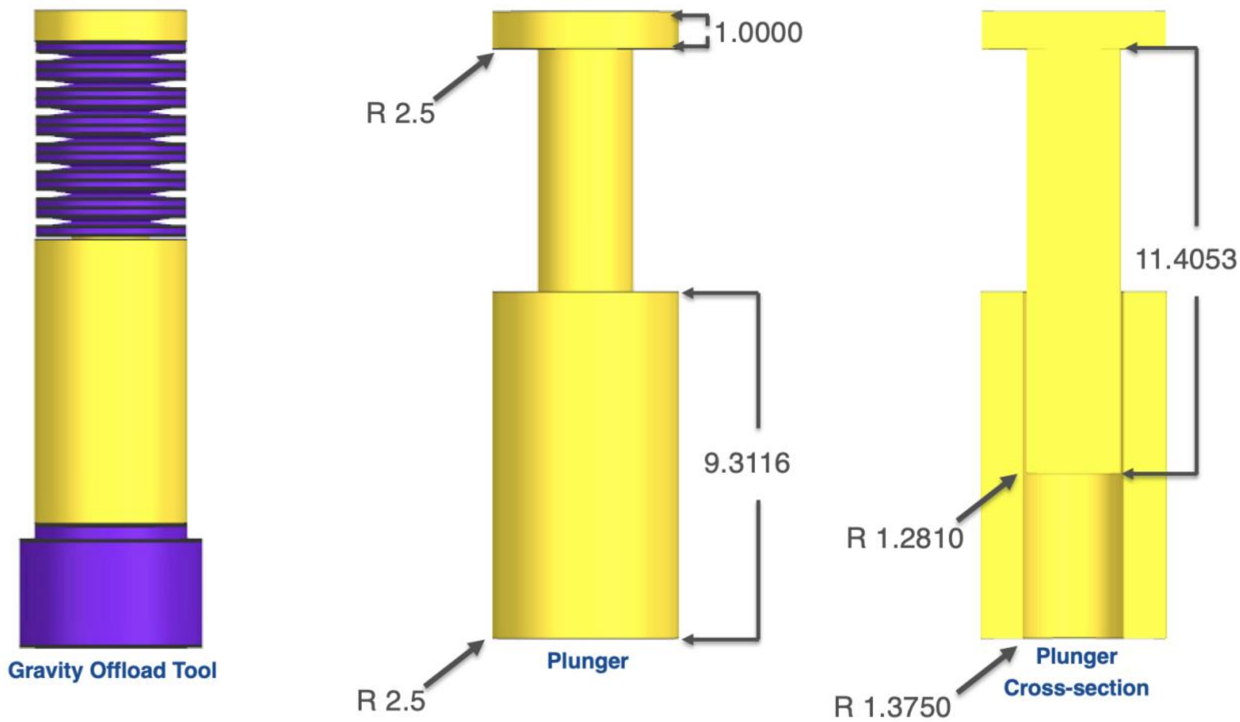
Concept Design

The Gravity Offload Tool will consist of an Enerpac SCL101TB, fourteen Belleville disc springs, and will be compressed and held together with the “plunger”. The disc springs will be stacked in a series and will be compressed when the stroke of the hydraulic cylinder increases. On both the upstream and downstream sides there will be two access holes. The gravity offload tool will be placed in the access holes under the cryomodule which are used for clearance in one of the four types of cryomodules. In the case of temporary adjustment, the placement of the gravity offload tool will not interact with problems.



NX 3D CAD Model of the Hydraulic Cylinder + Disc Spring System

Disc springs are commonly used with clevis pins, which hold the disc springs together through their inner diameter. The plunger will essentially replicate a clevis pin and will also compress the disc springs to their maximum compression state.



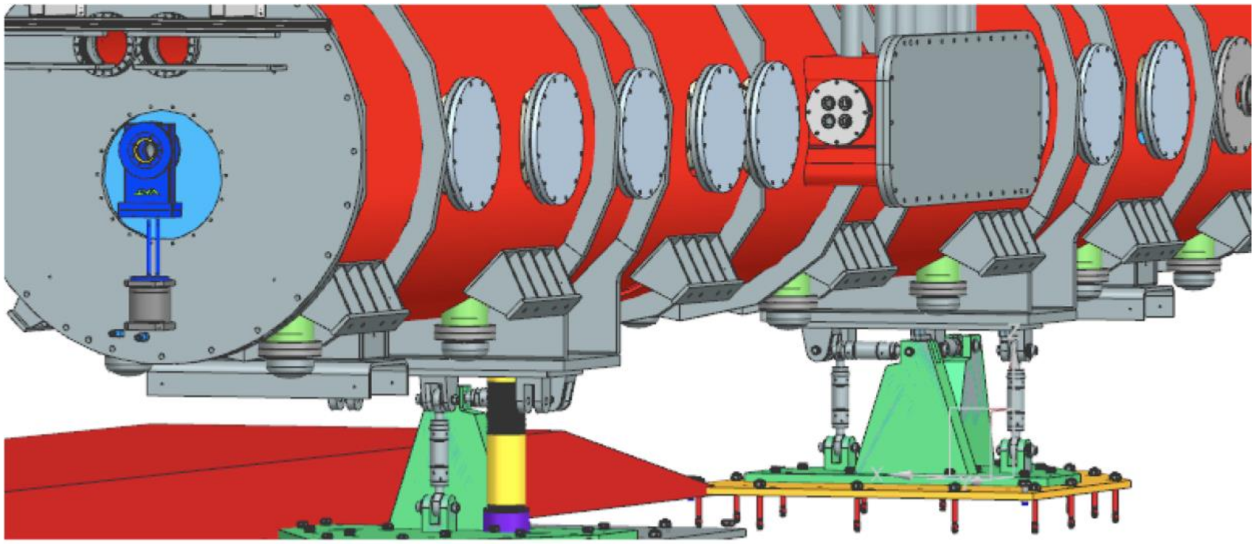
Conclusions and Future Work

This project presents the calculations for designing a gravity offload tool. There are still more steps to this design such as material selection for the plunger and base, FEA analysis, procurement, fabrication, and also to test and verify that the gravity offload tool is safe to use. In the future, we hope to conclude the gravity offload tool project and use it in the development of PIP-II and other future projects.

Acknowledgements

I would like to thank my supervisor Curtis Baffes and Michael Geelhoed for their guidance and support throughout this summer. I'd also like to thank Fermilab and the SIST internship for this opportunity of valuable experience.

Gravity Offload Tool Under Cryomodule



Gravity Offload Tool Under Cryomodule