G-2 Pulse Rate Scenario for Lithium Lens ANSIS Analysis:

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OverView:

From GM2-doc-17083

In March 2019, a modification to the operation of Lithium lens was put into place in an attempt provide longevity to the lens due to the fact there are limited number of lens spares. There have been 2 failures of lens in a short operational period. Table 1 below copied from GM2-Doc-17083 summarizes the agreed upon safe beam operational modes the lens can operate. The table outlines 2 acceptable beam scenarios to operate the lens for peak lens current and repetition rate.

Table 1:
Two acceptable safe beam operation modes were proposed for beam startup parameters:

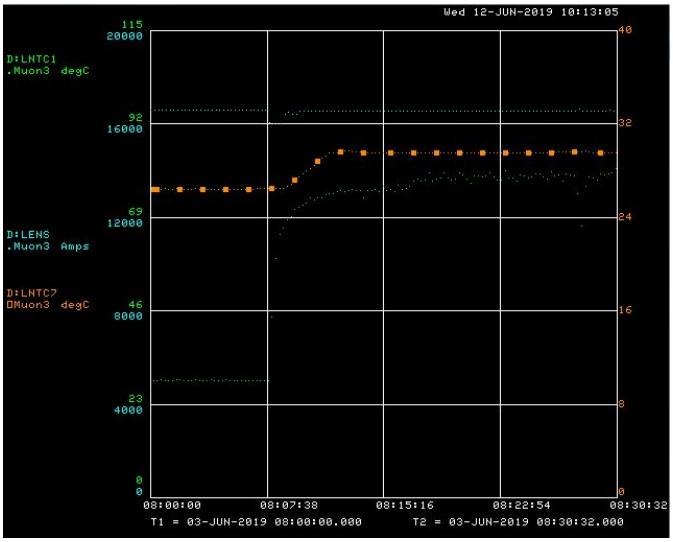
Operation mode	Current (Primary)	Current (Secondary)	Number of pulses per cycle	Effect on lens temperature		
				ΔT drop	Reduction in alternating T range	Peak T
#1	19.5 kA	156 kA	8 (1.33 s cycle time)	47.4%	44%	73 °C
#2	16.575 kA	132.6kA	16 (1.4 s cycle time)	28.4%	28.4%	88 °C

There has been a request to run an ANSYS analysis using these 2 modes of operating the lens to see if the 2 recent past failures and future needs for spares can be better understood.

Modeling Assumptions:

- Add beam heating for each pulse with assumption that beam intensity per pulse is 1.05E12 protons.
- The lens flow water flow rate is 3.3 GPM (D:LNWM1)
- The input water temperature to the lens
  - supply = 29° C (D:LNTC7)

- return = 37° C (D:LNTC8)



  - Plot of Lens during turning on and reaching temperature equilibrium
-
- Add affects for Ti lens body material between steel body lens. Ti is more resistive. Material Data for Ti body - Ti-6AL-4V or Ti-10V-2Fe-3Al

We would like to model all 3 of the following scenario. The #3 scenario is the g-2 design scenario. We would like to compare scenarios #1 & #2 to this results to see if the original ANSYS completed by Ryan had some big differences that would explain a reason for the limited number of pulses on the failed lens during g-2 running.

Operation mode	Current	Number of pulses per cycle	Effect on lens temperature		
			ΔT drop	Reduction in alternating T range	P
#1	19.5 kA	8 (1.33 s cycle time)	47.4%	44%	73
#2	16.5 kA	16 (1.4 s cycle time)	28.4%	28.4%	88
#3	19.5 kA	16 (1.4 s cycle time)			107

G-2 Pulse Rate Scenarios:

In order to start the ANSYS analysis there is some given operational information that will be needed. The g-2 pulse timing scenario in which the lens pulses will operate and fitted equation of a lens single pulse.

The g-2 pulse scenario can be seen in Figure 1 for the maximum reputation rate of 6 Hz corresponding to the #1 mode of operation. This means that in a 60sec operational timeline there would be 360 pulses in 60secs. Over the 1.33sec for the Numi cycle there are 8 event pulses where each pulse is separated by 10msec.

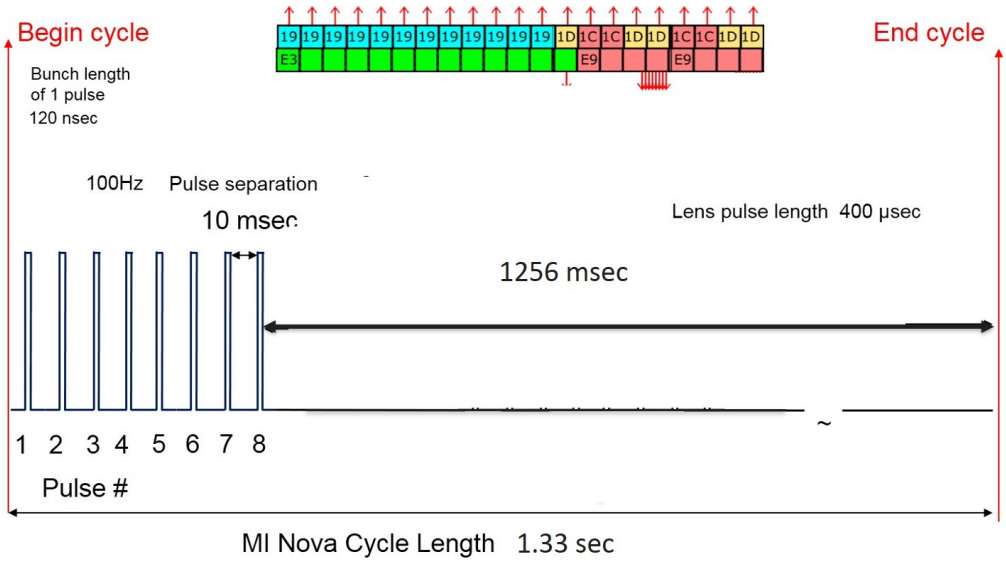


Figure 1:
Timing Scenario of maximum repetition rate of 6 Hz for 8 pulses in 1.33 sec for a lens secondary current of 156 kA

The g-2 pulse scenario can be seen in Figure 2 for the maximum reputation rate of 11.4 Hz. This means that in a 60sec operational timeline there would be 684 pulses in 60secs. Over the 1.4sec for the Numi cycle there are 16 event pulses where each pulse is separated by 10msec. There is a first set of 8 pulses that are separated by 193mesc before the 2nd set of 8 pulses occur. There is then 1057msec wait time until the cycle.

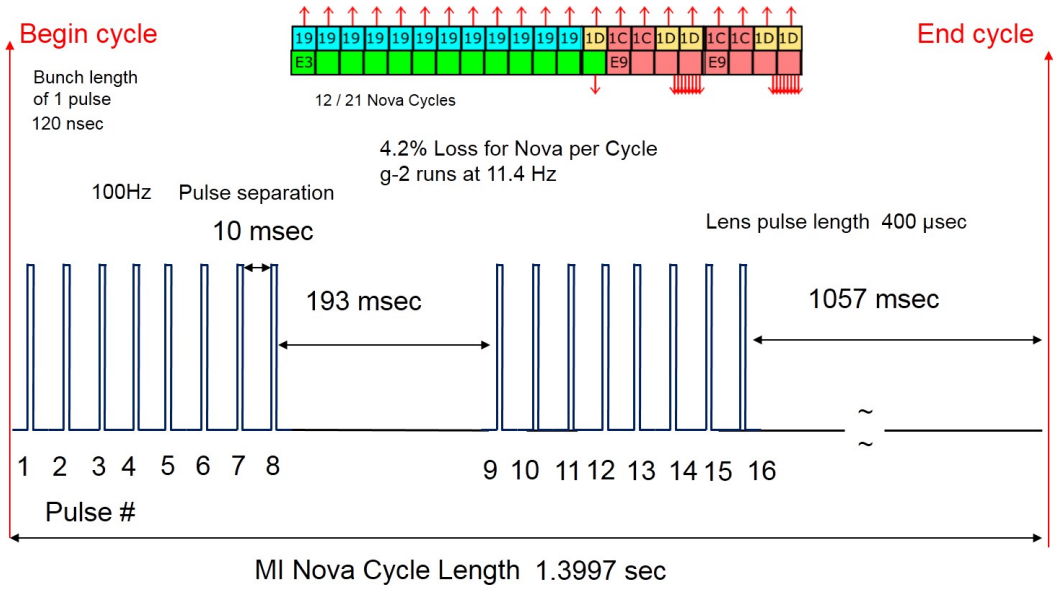


Figure 2:

Timing Scenario of maximum repetition rate of 11.4 Hz for a lens secondary current of 132.6 k

Lens and Pmag pulses with beam:

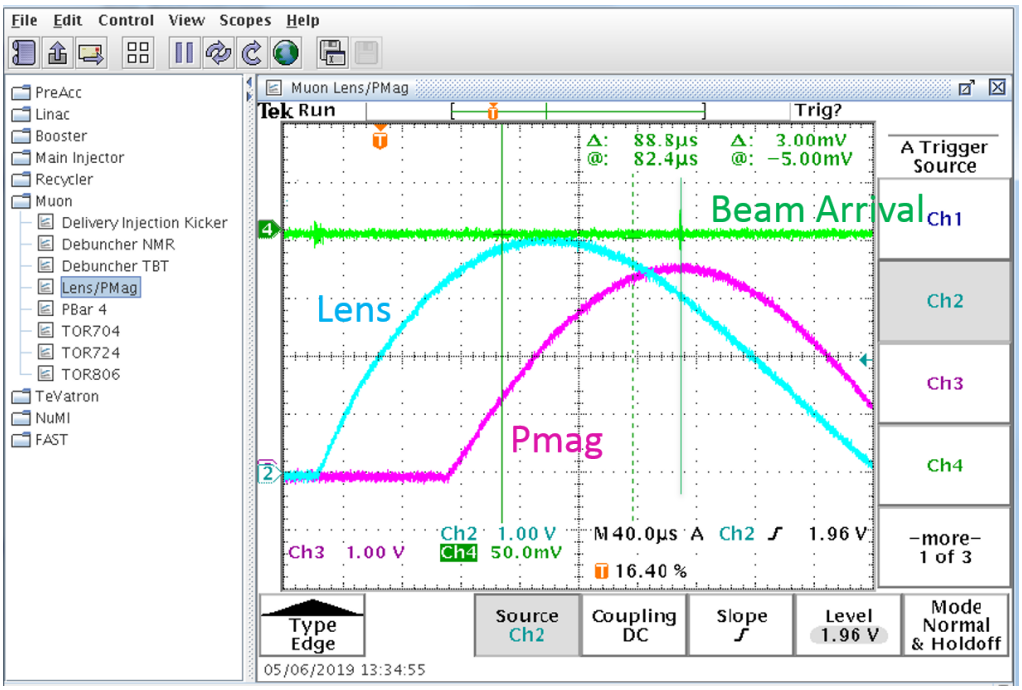


Figure 3:

Lens pulse in Cyan, Pmag pulse in Pink and toroid marking the arrival of beam in Green. The lens roughly has a pulse width of 375usec. The peak of the pulse precedes the moment the beam arrives by ~ 80us. This is the result of skin depth and the time it takes for the current to drive into the lithium conductor produce the peak magnetic field needed at beam time.

Fitting the Lens Pulse Shape:

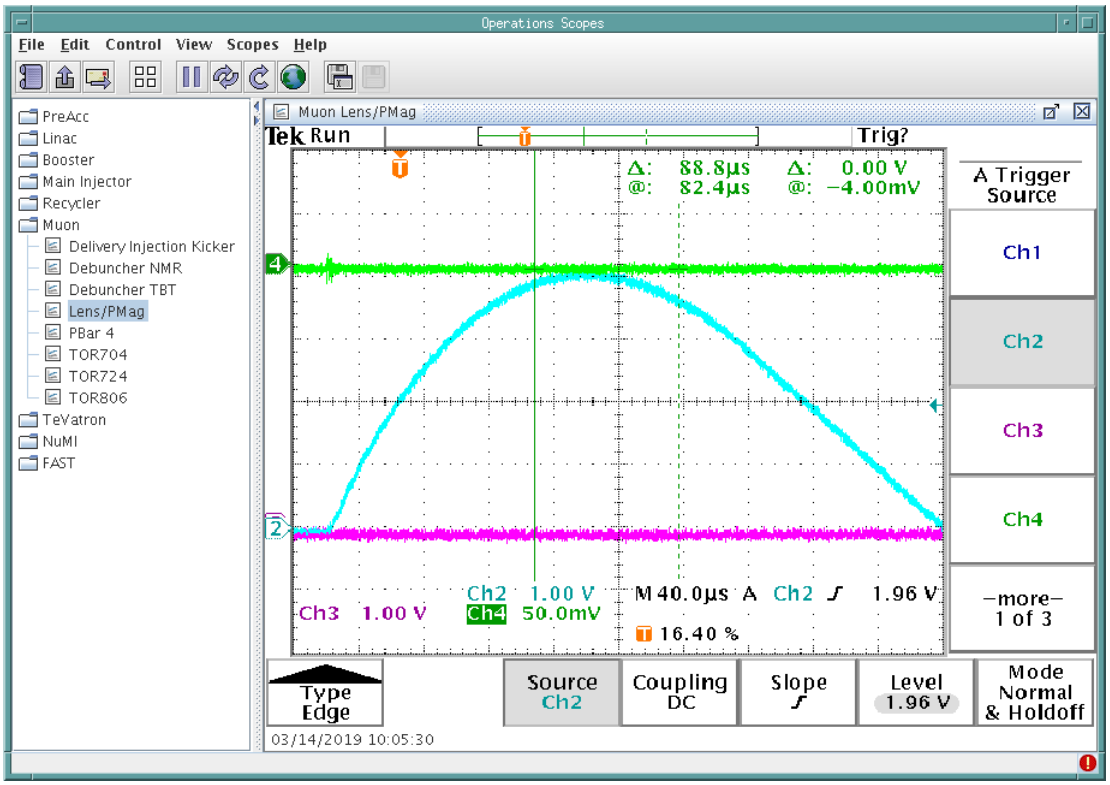


Figure 4:
Timing Scenario of maximum repetition rate of 11.4 Hz for a lens secondary current of 132.6 k

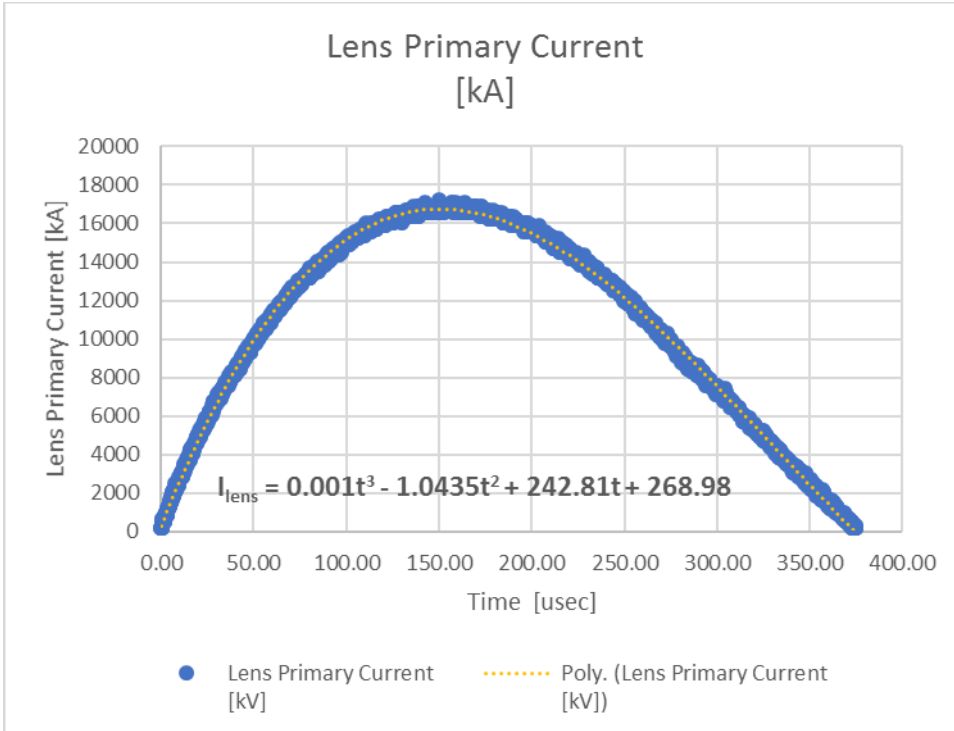


Figure 5:
Scope trace of the lens pulse at a primary current of 16.575kA – blue trace. The orange trace is the fit to the lens pulse scope trace.

In order to model the lens pulse the fit equation of the lens scope trace for primary current 16.575kA can be used (Eq 1).

$$I_{lens} = 0.001t^3 - 1.0435t^2 + 242.81t + 268.98 \qquad \text{(Eq 1)}$$

The equation was scaled to give the peak of the pulse a value of primary current of 16.575kA. The secondary current is a factor of 8 larger than the primary current resulting in 132.6 kA.

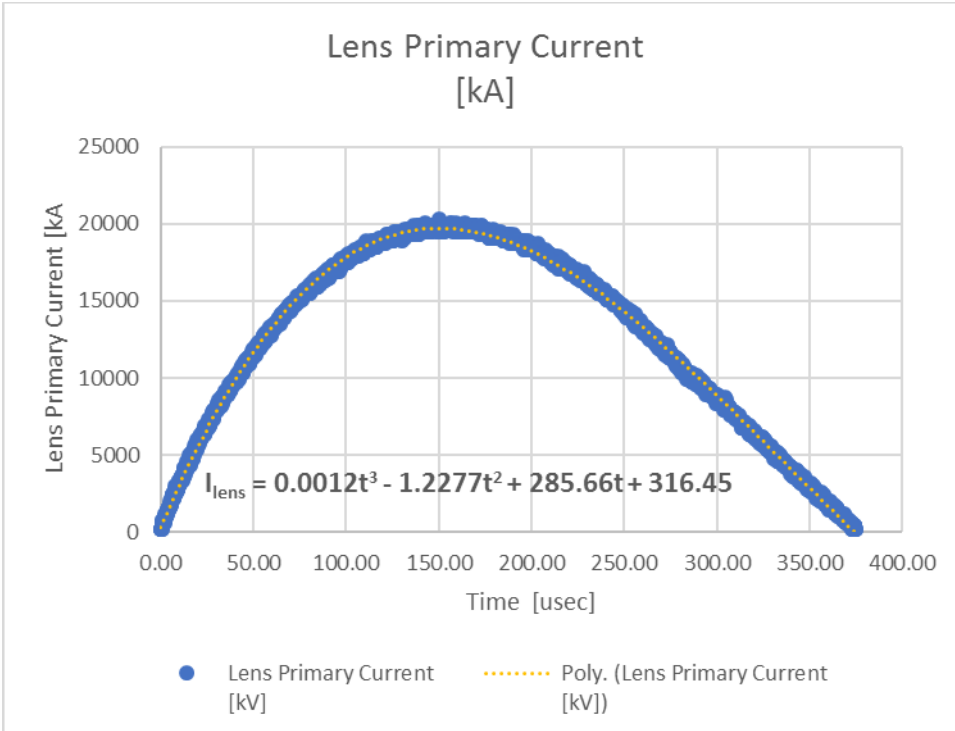


Figure 6:

Scope trace of the lens pulse at a primary current of 19.5kA – blue trace. The orange trace is the fit to the lens pulse scope trace.

In order to model the lens pulse the fit equation of the lens scope trace for primary current 19.5kA can be used (Eq 2).

$$I_{lens} = 0.0012t^3 - 1.2277t^2 + 285.66t + 316.45 \qquad \text{(Eq 2)}$$

The equation was scaled to give the peak of the pulse a value of primary current of 19.5 kA. The secondary current is a factor of 8 larger than the primary current resulting in 156 kA.

Lens PreLoad History:

Following up on our conversation yesterday, listed below are the preloads quoted in the old Target Station elog for the diffusion-bonded lenses. All of these are quoted for a temperature of 21 C, they made minor adjustments to the measured preload to normalize to that temperature. It looks like they were aiming for 4,000 psi or so. Note that 10mm-9 has not been filled yet and is one of the spare bodies that awaits final machining. As a historical note, the steel-bodied lenses had lower preloads than what is shown for the diffusion-bonded lenses. Back when you were involved with fills, lenses 21, 22, 23, 24 and 25 had preloads of 2,060, 2,440, 2,078, 1,850 and

1,823 respectively. The preload was then bumped higher, 27, 28, 29, 30 and 32 were 2,880, 2,950,

2,700, 3,273 and 3,300 respectively.

Lens #	Preload Setting [psi]
10mm-1	3,750
10mm-2	4,035
10mm-3	4,300
10mm-4	3,820
10mm-5	4,381
10mm-6	4,171
10mm-7	4,000
10mm-8	4,262
10mm-10	4,000
10mm-11	4,130