**Reviewer Comments/Recommendations for PIP Linac Laser Notch Review**

Nov 14-15, 2016

Reviewers

Russell Wilcox (LBNL)

Yun Liu (ORNL)

The reviewers are impressed with the progress made by the Laser Notcher team. They have solved a lot of problems and developed a workable system, using what’s currently commercially available in terms of fiber and YAG amplifiers. Just handing this task to some company would probably have been more expensive and there wouldn’t be as much accumulated knowledge at Fermilab, which is necessary for continuing operation and upgrade. A number of techniques demonstrated in this project, such as the temporal structure formation, multiple-reflection optical cavity, and beam spatial profile shaping, can be used in other applications in accelerator facilities where a laser based high efficiency H- neutralization is required.

The measurements of stripping efficiency using a different laser and preliminary results with this laser indicate that at the expected power levels, the system should achieve the desired performance. Problems with the seed laser appear to be well-understood, so that a simple swap of CW sources is expected to solve them. It will be interesting to see how the modified laser performs in its operational environment, running continuously. The reviewers are optimistic about the outcome since the chosen technologies are noted for reliability.

The recommendations below are mainly advice and suggestions, not an indication of some deficit in the effort. Each of these points has been discussed at our wrap-up meeting, and nothing appears as an outstanding problem.

Subjects:

1. Seed laser

2. SBS suppression

3. Machine protection (against SBS, lasing back reflection etc.)

4. Automatic laser beam path control

5. Diagnostics

6. Spares, maintenance

Seed laser

Present plan is to get a wavelength stabilized semiconductor diode laser from Innovative Photonics. This laser seems well specified in terms of amplitude stability, which is the key parameter. It is not adequate to spec in terms of linewidth, as this doesn’t capture the low adjacent longitudinal modes and their effect on the amplitude. Specifying the laser performance in terms of RIN (relative intensity noise) is the right way, and it appears the new laser has adequate RIN, though this needs to be verified here. We recommend a fast photo-detector and high bandwidth oscilloscope to do this, with enough bandwidth to capture oscillations at the mode separation frequency, which are typically several GHz.

There is another option if this new seed laser does not meet the RIN spec, which is the diode-pumped fiber laser, an example of which is the “Rock Laser Module” from NP Photonics which is used by SNS, or an NKT laser as used in NIF. These are more expensive, and may have only 20-40mW of power, although higher power versions are available, but they are very low noise (typically RIN < -100 dB/Hz) and robustly single mode. They can also be specified for a precise wavelength, accessible by temperature tuning and built-in piezoelectric transducer.

We also recommend a scanning Fabry-Perot interferometer to check the optical spectrum of the seed laser, and this is a commercial item from, for instance, Micron Optics, Thorlabs, Coherent, or others. This is good to have in case the laser starts to have a second mode or some other strange operation, which has been seen even with fiber lasers.

SBS

There is a well-founded suspicion that there is SBS happening in the fiber amplifiers, although an experiment can be carried out to definitively identify this. If the forward and backward scattered light are both captured and beat against each other on a photodiode, there should be the characteristic SBS offset frequency seen in the beat signal, as observed on an oscilloscope or RF spectrum analyzer.

Another signature of SBS may be the temporal signal observed at the fiber output. The SBS will build up through the gain length, which increases with pulse length. Thus, the pulse burst will be attenuated toward the later pulses, and this is easily observed with the existing diagnostics.

If this is indeed SBS (which plagues high power CW or other narrow band fiber lasers) it can be mitigated by phase modulation of the seed laser output, which is already planned for by the laser design team. Yet to be determined are the modulation depth and format which will be most successful in suppressing the SBS effect. Complicating this is the already existing amplitude modulation of the signal, square wave at 200MHz, plus the pulse burst duration. Not a lot of work has been done to investigate pulsed SBS in the literature, compared with the voluminous work on CW or continuous modulation for telecom applications. The modulation requirements need to be determined experimentally, and to aid in this we recommend the scanning Fabry-Perot again, so that the actual sideband structure can be observed. The existing optical spectrum analyzer is not adequate to resolve the sidebands, and might give misleading measurements. Since the modulation situation is somewhat complex, it is good to thoroughly understand and measure.

Machine protection

It is possible that SBS, unwanted lasing, back reflections etc. can cause damage to the laser system, particularly the fibers, and result in down time. We recommend a machine protection system that looks for trouble and shuts down the amps or modulators or whatever is necessary to prevent damage. (There are existing systems there, e.g. the “keep-alive” and the loops in the fiber amps themselves.) It is not clear to us exactly where the sensors or controls need to go, but many laser systems (including commercial amplifiers) have such protection. There can be multiple sensors and shut-down actuators, using simple and fast decision making electronics. It is probably not necessary to delay pulses in fiber to let the protection circuit do its work, but this is an option that is currently used on NIF, where SBS would be catastrophic. Sensors should be simple and fast. Even purely electronic sensors can be used, such as one which verifies that the phase modulator has adequate power.

Automatic beam path control

Since the system must work in a temperature environment where there could be tens of degrees variation, and since the mounting of the components cannot easily be made temperature insensitive, there will likely be thermal drifts in alignment of the beam into the cavity, and also other effects on the optics and electronics. For beam alignment, there can be an automatic control to maintain proper path through the zigzag cavity. We recommend implementing some kind of automatic laser beam path control loop, since the sensors and actuators are there now. This would not be a difficult task, and is a standard practice on many laser systems. It may be best to implement sensors before and after the zig-zag cavity, such as the camera looking through the stationary mirror, to see the multiple reflected spots, analyze their position, and control mirrors accordingly. This would feed back on the actual cavity alignment, which is what’s important. The determination of exactly how to implement these controls will have to follow operational experience.

There may be other parameters that are affected by temperature, so placement of temperature monitors in various parts of the system is a possible way to identify problems early. One can correlate thermal changes with the appearance of problems. There is currently one thermal sensor in the free space box, and maybe there should be others in the fiber chassis and burst generator also.

Diagnostics

There have been several diagnostics recommended in the sections above (scanning FP, fast photo-detector). There should be monitors of forward and backward power at various points in the system, which there appear to be currently. All these should be continuously monitored during operation, and logged, so that any problems that occur can be identified easily. It is our experience that there can’t be too many diagnostics, when one is operating a complex system and problems have to be identified quickly. There are commercial power monitors and digitizers which can have many channels available for digital archiving. One needn’t archive or continuously monitor the fast signals, but they should be quickly available to someone with a roll-around fast scope, for instance, without having to get inside a box and connect to a fiber connector.

Spares and maintenance

As some of the key components take a long time (months) to replace, and these active devices are liable to damage from a number of effects, there should be spares kept. These should be tested in the development area to verify their operation. An entire second set of hardware would provide tested spares for all components. A whole fiber amp module (suggested SBIR topic) is possible as a replaceable unit. It is also recommended to have a maintenance plan of the system during operation.