Contigency Plan if BPLS Is Unavailable

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Executive Summary

The Beam Power Limit System (BPLS) may not be available to support operations after the FY22C outage, which will install 2 additional cryomodules (CMs) and is expected to raise the beam energy to 1.1 GeV. It has been determined that it would be possible (but very difficult) to reach 2 MW of beam power at the First Target Station (FTS) with the additional beam energy. Administrative controls such as software interlocks and a more robust MPS trip system are available to prevent the remote possibility of achieving 2 MW at FTS if the BPLS is not ready before the end of the FY22C outage.
After 3 more cryomodules are installed in the FY23A outage, expected beam energy is 1.25 GeV and beam power 1.7 MW. An 18% increase in beam current would be required to reach 2 MW. Again, administrative controls, software interlocks, and a more robust MPS trip system can prevent inadvertent running at 2 MW.
When PPU is fully implemented and 2 MW operation is routine, compensatory measures could include limiting the beam power to a lower value, e.g. 1.8 MW, to provide a safety margin and use of similar interlocks used for the lower power operations.

Difficulty of Achieving 2 MW at 1.1 GeV After FY22C Outage

Beam power scales linearly with energy. A simple calculation for reliably achievable beam power is to multiply the current value of 1.4 MW by the 10% increase in beam energy added by the 2 CMs, which results in 1.55 MW of power. To realize 2 MW, the average beam current needs to increase by 30% (2/1.55).
2 MW and higher equivalent beam power transport in the linac at 1 Hz has been demonstrated in the past, therefore the risk cannot be ignored completely. However, the beam loading is so high that the linac can not sustain operation at 60 Hz without changes beyond just adding 2 cryomodules.

Several parameters would have to be changed to achieve 2 MW operation:

- The ion source is reliably providing PPU expected values of 55-60 mA. However the RFQ field must be raised from nominal to transport the required 38 mA of current through it. This requires deliberate action by operations to increase a saved setpoint far above its routine value.
- Several high voltage converter modulators (HVCMs) require increases in power output in order to supply enough power to the klystrons for 30% more beam loading. This requires deliberate action by operations to increase a saved setpoint and possibly support from HVCM experts. Alternatively, SCL cavity gradients and the ring energy setpoint can be lowered to accommodate the beam loading. This requires deliberate action by operations to change saved setpoints and support from RF personnel. The linked logbook entry shows that changes were required to to increase power from 1.4 to 1.7 MW equivalent. Similar changes would be expected to increase the power from 1.55 to 2 MW.
  (https://snsapp1.sns.ornl.gov/prod/f?p=161:22:484555469012:::RP,22:P22_ENTRY_ID:681457)
- Several beam loss monitor (BLM) trip settings would need to be raised. This requires deliberate action by the Control Room Shift Supervisor to increase a saved setpoint. The linked logbook entry shows changes required to go from 1.4 to 1.7 MW equivalent. Similar changes would likely be required if the beam power is raised from 1.55 to 2 MW.
  (https://snsapp1.sns.ornl.gov/prod/f?p=161:22:484555469012:::RP,22:P22_ENTRY_ID:681490)

This list of changes alone is enough to minimize the likelihood of achieving 2 MW by accident or by a simple “turn of a knob.” Administrative requirements to prevent changing of relevant parameters without authorization from management can be easily implemented and would be robust based on the number of people needed to make the changes.

Achieving 2 MW After FY23A Outage is Feasible but Not Likely

The FY23A outage will install 3 more cryomodules and raise the beam energy to ~ 1.25 GeV. Scaling the nominal 1.4 MW by the energy increase results in 1.75 MW being achieved without other parameters being changed. An 18% increase in beam current is required to realize 2 MW. This is still a significant increase over the routine expected operational value and therefore can be controlled via many of the same parameters as at 1.55 MW.

Interlocks Currently Available at < 2 MW

There are several ways already available to prevent the beam from reaching the proposed ASE limit of 2.145 MW averaged over 1 minute.

- The Machine Protection system (MPS) target dump power interlock reads an EPICS PV, calculates the power, and trips the MPS when it exceeds a setpoint. Changing the setpoint is done through PACE, which requires an operator to login and automatically generates an elog entry if a value is changed. This should be set to 1.6 MW for 1.55 MW running and to 1.75 MW for 1.7 MW running to give plenty of margin before hitting 2.145 MW.
- The DG-535 limits the maximum beam pulse length and rep rate. Changes to the DG are administratively controlled by an RS Hold.
- RF forward power limits are configured through PACE. These can be lowered close to the values required to run at 1.55 or 1.7 MW to prevent large changes in RFQ or SCL cavity power available.

Additional Interlocks can be Implemented at < 2 MW

Several additional interlocks can be implemented as well.

- The timing master has a hardware link to BCM 25 (presently used to determine the amount of beam on target for experiments and calibrated to 1% accuracy). A change to its code could be implemented to trip the beam on the next beam pulse if the readback exceeds a setpoint that is a calculated based on the final beam energy in the ring. Changes to the setpoint would be done through PACE, which requires an operator to login and automatically generates an elog entry if a value is changed. This is a more robust solution than the MPS target dump power interlock but requires more development and testing.
- Software limits can be put in place on the following parameters to prevent inadvertent changes that would affect the beam current. The limits can be set so that small adjustments are possible during routine running but would prevent the large changes required to reach 2 MW. This would be done on the EPICS .DRVH field (Drive High) through PACE, which requires a login for values to be changed and automatically generates an elog entry if a value is changed:
    - Ion Source 2 MHz RF drive setpoint maximum
    - LEBT Chopper PW On maximum
    - RFQ field setpoint maximum
    - HVCM voltage setpoint maximum
    - HVCM pulse width maximums
- Other possible interlocks include:
    - HVCM limits set in their controllers

- SCL Cavity amplitude setpoint maximums

Compensatory Measures at 2 MW

Once 2 MW beam power is reached, compensatory measures for the BPLS become more challenging as there is very little margin to limit beam current. If the BPLS fails during this time, one possibility is to lower the beam power and use the interlocks described above until the BPLS is restored.

Summary

The possibility of achieving 2 MW of beam on FTS after the FY22C outage is remote without significant effort by engineers, physicists, and operators. Administrative controls are sufficient to prevent reaching 2 MW.

After the FY23A outage, the beam power is expected to be 1.7 MW at 1.25 GeV. An 18% increase in beam current would be required to reach 2 MW. Administrative controls and additional software and hardware interlocks can be implemented to prevent inadvertently increasing the beam current.

After the FY24A outage, the beam power is expected to be 2 MW at 1.3 GeV. One possibility is to have a compensatory measure which requires lowering the beam power to provide safety margin and use the controls describe above to prevent beam from nearing the ASE limit.