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10 November 2000

To: R. Gerig
Cc: M. Borland, G. Goeppner, K. Harkay, S. Milton, J. Noonan, R. Rosenberg, S. Sharma, O. Singh, K. Thompson
From: J. Lewellen

Re: LEUTL and Top-Up: Interleaved operations

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APS Linac Upgrade for Interleaved Operation

John W. Lewellen

version 0.03

Introduction

The APS linac is presently a multi-purpose device. It is an essential part of the APS storage ring injection system. It is also used, when not required for APS injection, as a beam source for the Low-Energy Undulator Test Line (LEUTL) SASE-FEL experiment at the APS.

Presently the storage ring is typically filled once or twice per 24-hour period, depending on the fill pattern used in the storage ring. Injection for the storage ring is performed using one of two thermionic-cathode rf guns. An accumulator ring (PAR) is used for bunch stacking and is the device actually providing beam to the booster synchrotron. Presently, APS injection and LEUTL operation represent two completely different linac configurations and modes of operation. Switching from one mode to the other requires on the order of 10 – 20 minutes.

In October 2001, the APS is expected to switch to top-up mode. In this mode of operation, beam current is injected into the storage ring at frequent intervals (with current loss rates, lattices, and fill patterns, this is anticipated to be approximately one injection shot per 2 minutes). In order to successfully operate LEUTL, then, the booster injection cycle must be interleaved such that it may provide beam for both LEUTL and storage ring top-off effectively simultaneously.

The following outlines list the various components of the system which will require modification, and present a path-to-completion of the project. This is done for several possible upgrade paths. It is expected that this will be implemented in two main phases, first to enable booster injection at up to 450 MeV, and second to enable booster injection to the maximum projected linac energy of 1.65 GeV. Implementation of Phase I should be completed by the start of the July 2001 shutdown, so testing can occur before top-up mode commences in October 2001.

In the first phase of implementation, the LEUTL beam energy range will be limited to the range of 350 – 450 MeV (204 – 123 nm), with this range remaining fixed during SR operations. It may be varied during studies periods, during specified times of day when top-up operation is suspended, or if a reliable method of slow-ramping can be developed which will keep both the linac and booster well-synchronized so as to not affect injection capabilities. In order to operate at either higher or lower energies, LEUTL studies will be confined to machine-studies days. This mode of operations keeps the required modifications (both to the linac and to the booster) to a minimum, allowing time to develop the more comprehensive solutions.

In the second phase of implementation, the booster injection hardware (both before and after the booster injection magnet) will be upgraded to allow for a maximum injection energy of 1.65 GeV. This number corresponds to the maximum reasonable pre-booster-injection energy the APS linac could attain without significant tunnel extensions. Modifications to allow booster injection at 850 MeV (the anticipated maximum beam energy by 1 October 2001) will require

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about the same effort and level of redesign, so at present there are apparently no significant savings in time or money to be achieved by designing for this lower value first. The required modifications include new dipoles for LTP:B1 (to become the new linac spectrometer dipole), BB:BM1 and BB:BM2 (the LEUTL vertical pitching magnets). BB:BD:BM1 (booster bypass beam dump magnet) will be merged with BB:BM1 via a contactor arrangement. A new LEUTL hall dump magnet, with permanent magnetic field components, must be constructed also. The existing PTB:B2 (to be renamed LTB:B1) dipole will be replaced via a fast pulsed septum-like magnet, identical in construction with the booster injection magnet. They are required to operate at different angles, so separate supplies are required.

As part of the second-phase modifications, the Gun1 beamline will be redesigned as a double-bend achromat, with a fast-pulsed magnet as the second dipole of the achromat. This will provide the ability to interleave thermionic-cathode and PC gun beams in the APS linac. The layout will be tested in the injector test area. Also, a thermionic-cathode drive laser will be tested, with the intent of producing shorter pulses from the thermionic-cathode gun. The Gun2 beamline will remain unchanged from its present configuration.

Below is a brief version of the proposed initial implementation, with installation completed during the July '01 shutdown and full operation by October '01.

- linac energy
  - restricted to 350 - 450 MeV during SR operations
  - can be run up/down to whatever during machine studies times, as a dedicated study
- booster injection
  - PTB:B2 will be replaced with a laminated magnet, good to 450 MeV, as we originally discussed. We will hold off (unless otherwise directed) on modifications to LTP:B1, and the LEUTL vertical bend and dump magnets. The magnet will have a ramp time < 0.1 sec up and down.
  - booster-side hardware (kicker, kicker ps, etc.) will remain as-is until we have a better idea what we need to design for
  - we may still need an extra quad or two somewhere, however they should be placed so as to not require moving or extending any dipoles
- interleaved issues
  - we will still need a couple of fast-responding correctors to help deal with booster ramping; this is apparent in horizontal as well as vertical deflections (stray fields near the BB lines?)
  - to maintain 1% current stability, with a notional 0.3 nC per injection from the PCgun, we will need to top off every 40 seconds, not every 2 minutes.
    - diagnostics in the PTB and BTS need to accommodate this lower charge
    - this pretty much rules out repeated ramping of our existing supplies, as the majority of the time would be spent ramping from one setpoint to another

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<u>Initial Implementation</u>

This version will be used as a stop-gap of sorts, in order to allowed continued LEUTL operation under top-up while a more comprehensive solution is developed. This scheme does not require any magnet repositioning, a minimal number of new magnets, and imposes a limit on LEUTL beam energies on non-machine studies days.

- I. Linac and LET lines
  - A. general requirements
    - 1. bunch delivery rates
      - a) max. delivery rate to booster is 2 Hz
        - i) from any gun installed in the APS linac, to a specific booster bucket
          - *a)* guns are not interleaved
          - *b)* specified amount of time to change guns
            - *i)* < 5 minutes to go from PCgun to Gun1 or Gun2
            - *ii)* defined set of conditions calling for the change
            - *iii)* perhaps a set time or times of day for injector tune-ups?
        - ii) at specified booster energy
          - *a)* energy will not change during SR operations
      - b) max. linac rep rate is 10 Hz
        - i) nominal 6 Hz to maintain proper booster rep rate synchronization, PC gun drive laser operation
        - ii) selectable 2. 4. 6. 10 Hz operation
        - iii) core 2 Hz fundamental linac period remains unchanged
    - 2. linac / LET optics
      - a) capable of providing suitable beam for both LEUTL and booster injection, given LTB line optics setup
      - b) injection energy
        - i) initial modes of operation
          - *a)* booster and LEUTL run at the same energy
          - *b)* LEUTL does not run below 350 MeV
      - c) injector area redesign
        - i) decouple L1 structure and thermionic-gun rf power systems (see below)
        - ii) install new main injectors into present Gun1 and Gun2 positions
    - 3. booster loading compensation
      - a) booster ramping should not cause beam motion, or variations in beam energy or transverse properties
        - i) this requires further study
          - *a)* identification of main effects
          - *b)* development of compensation scheme
        - ii) implementation of correction will be restricted to adding fast-ramping correctors in suitable locations
  - B. systems
    - 1. machine controls (Controls and OAG)
      - a) timing
        - i) sequencing

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a) maintain present 2 Hz fundamental rep rate
ii) triggering capabilities
a) booster injection
i) PC gun drive laser resync. to have beam land in a specific booster bucket
ii) thermionic gun kicker or drive laser trigger to center beam on a desired booster bucket
iii) disable diagnostics triggering after LTB dipole
b) LEUTL operation
i) enable diagnostics triggering after LTB dipole
c) general
i) ramped supplies (e.g. LTB dipole) start ramp sequence
ii) pulsed magnets trigger sequence timed to booster bucket
b) bunch-level control
i) must provide enough "advanced warning" to pulsed and fast-ramped magnets to allow proper operation
ii) diagnostics & controllaw support
a) present linac readbacks, feedback and controllaws remain unaffected
iii) four fast-change corrector magnets in the post-LTB line to allow for booster-induced trajectory changes
c) overall control – effectively unchanged

2. RF systems
a) required reworking
i) L1 klystron to power both L1 structure and PCgun
a) uprated klystron tube (maybe)
b) high-power coupler
c) high-power phase shifter between coupler and L1 structure
ii) L3 klystron to power thermionic-cathode rf guns
a) isolator
b) rf switch to select between guns (in place already)
iii) other arrangements may be suitable, however the existing configuration is awkward as it is and serious consideration should be made for getting it changed

3. power supply and magnet systems
a) new magnets
i) stability to 10^{-4} of full-scale is the nominal specification
ii) classes of new supplies desired
a) quadrupole
b) corrector
c) dipole
b) existing magnets to be upgraded
i) at least two H & two V correctors following BB:BM1 dipole (presently three-magnet array)

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    ii) potentially, strategically placed quadrupoles after the last accelerating structure (new or revised presently-existing) to allow matching for both the booster and LEUTL line

4. diagnostics
   a) operational ranges
      i) 0.1 – 10 nC charge (integrated over bunch train)
      ii) 3 – 20 μm emittance (normalized)
      iii) bunch trains of 1 – 30 S-band buckets
   b) diagnostics sharing
      i) shared diagnostics – most of the linac diagnostics through the LTB dipole
         a) should be capable of being read out on a single-shot basis
      ii) non-shared diagnostics
         a) Gun1, Gun2 current monitors
         b) PCgun ICT, if the PC gun is not being used for top-up or fill
   c) imaging diagnostics – effectively unchanged
   d) non-imaging diagnostics – effectively unchanged, with the caveat that they must respond appropriately to the various bunch train and charge structures described above

II. Linac-to-Booster (LTB) line
   A. general requirements
      1. optics
         a) injection dipole
            i) must have a < 0.1-sec ramp-up time to max. energy
            ii) energy range: 350 MeV – 450 GeV
         b) quadrupoles
            i) must be capable of providing matched beam at all injection energies
            ii) ideally will not require additions to beamlines in line with LEUTL injection
      2. acceptance
         a) energy: 350 MeV – 450 MeV
         b) emittance: < 20 μm (normalized)
   B. systems
      1. machine controls (Controls and OAG)
         a) timing
            i) must provide appropriate triggers to rf gun systems
            ii) triggers to PCgun drive laser as appropriate
         b) bunch-level control
            i) not required, as the only bunches through this line will be for booster injection; no beamline settings should change unless the beam energy changes
         c) overall control
            i) trajectory controllaw
            ii) if some quads can be outfitted for cross-term measurement, rough beta-function control could be implemented

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2. power supply and magnet systems
    a) LTB dipole
        i) 0.1-sec ramp-up and ramp-down time
        ii) voltage and current specs – first cut has been completed
        iii) stability requirements
            a) +/- 0.04% (as per M. Borland)
                i) at what energy?
                ii) zero-point stability is to be determined
    b) booster-side kickers
        i) present status should be determined
            a) max. capable energy
            b) pulse duration
            c) structure (to determine possible damage from e-beam impacts)
        ii) if capable to 450 MeV, no changes for the present time
3. diagnostics
    a) no interleaving required for diagnostics in this part of the line
    b) operational ranges
        i) 0.25 – 10 nC charge (integrated over bunch train)
        ii) 3 – 20 µm emittance (normalized)
        iii) bunch trains of 1 – 30 S-band buckets, individual bunches on the order of 1 ps duration
    c) appropriate diagnostics for beam position at minimum, and preferably beam size monitors at specified locations also

III. Booster synchrotron
A. general requirements
1. beam acceptance
    a) the larger the dynamic aperture, the better
    b) 0.25 – 3 nC charge (captured)
    c) 3 – 20 µm emittance
    d) bunch trains (for bunch cleaning)
        i) minimum: 1 charge pulse of approximately 3 ps duration
        ii) maximum: 30 charge pulses, spaced at 2856 MHz, of approximately 0.5 pS duration each, and a max. charge per pulse of 0.3 nC
2. timing
    a) 2 Hz global rep rate will be maintained
    b) ramp rates will be the same as for present injection
    c) must provide appropriate signals to allow for proper PC, thermionic-gun triggering
B. systems
1. machine controls (Controls and OAG)
    a) ramps should be effectively the same as at present
    b) bunch cleaning should always be available for use
2. power supply and magnet systems
    a) beam kickers and injection requirements
        i) energy ranges

a) reliably accept beam at 325 – 1650 MeV

ii) accept bunch durations of up to 5 ns

3. diagnostics
   a) would be nice to get at least some BPMs working
   b) bunch purity monitoring is desired
   c) charge ranges of 0.25 – 3 nC for a single bucket (remaining after cleaning)

IV. BTS line

A. general requirements
1. beam repetition rate will remain the same
2. energy will remain the same

B. systems
1. machine controls (Controls and OAG)
   a) if one does not already exist, a BTS controllaw might be in order
2. power supply and magnet systems
   a) no modifications required
3. diagnostics
   a) diagnostics should be capable of responding to bunch charges of 0.25 nC

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Deluxe Version

This version will be considerably more flexible than the alternative, due to the control system, but will probably not be achievable in the given time

I. Linac and LET lines
  A. general requirements
    1. bunch delivery rates
      a) max. delivery rate to booster is 2 Hz
        i) from any gun installed in the APS linac, to a specific booster bucket
        ii) at specified booster energy
        iii) can deliver beam to booster interleaved with other beams, or all pulses for up to 10 sec every 2 min.
      b) max. linac rep rate is 10 Hz
        i) nominal 6 Hz to maintain proper booster rep rate synchronization, PC gun drive laser operation
        ii) selectable 2 – 10 Hz async. operation
    2. linac / LET optics
      a) capable of providing suitable beam for both LEUTL and booster injection, given LTB line optics setup
      b) injection energy
        i) initial modes of operation
          a) 350 – 405 MeV: booster and LEUTL run at same beam energy
          b) < 350 MeV LEUTL (L5 OFF), 350 MeV booster (L5 ON)
          c) energy changed only at predefined times
        ii) final modes of operation
          a) 350 – 1650 MeV: booster and LEUTL run at same beam energy
          b) no LEUTL operation below 350 MeV
          c) smooth transitions over 10 minutes from one energy to another, with magnets ramped and feedback trajectory tracking
      c) injector area redesign
        i) modify main injector beamlines to support new main injector design
        ii) replace Gun1 beamline with double-bend achromat
        iii) install fast-ramping magnet for second bend magnet, allowing interleaving of Gun1 with PCgun beam
        iv) retain Gun2 alpha magnet for beam quality considerations and short-pulse studies
        v) decouple L1 structure and thermionic-gun rf power systems (see below)
      d) ideally, there should be no difference in settings between LEUTL and booster injection modes; if necessary, additional magnets with fast-ramp capability shall be installed as required to allow matching in all circumstances
    3. booster loading compensation
      a) booster ramping should not cause beam motion, or variations in beam energy or transverse properties
        i) this requires further study

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a) identification of main effects
b) development of compensation scheme

ii) implementation of correction will be implicit in required modifications to other systems; see rf, controls, and magnets below

B. systems

1. machine controls (Controls and OAG)
   a) timing
      i) sequencing
         a) switch from the present ½-second basic time unit to a 1-seecond basic time unit
         b) keep track of which bunch can be capable of booster injection
            i) if at an even rep rate, booster injection can be at 2 Hz
            ii) if at an odd rep rate, booster injection can be at 1 Hz
      ii) capable of supporting integer linac repetition rates between 1 – 10 Hz
      iii) triggering capabilities
         a) booster injection
            i) PC gun drive laser resync. to have beam land in a specific booster bucket
            ii) thermionic gun kicker or drive laser trigger to center beam on a desired booster bucket
            iii) disable diagnostics triggering after LTB dipole
         b) LEUTL operation
            i) enable diagnostics triggering after LTB dipole
         c) general
            i) ramped supplies (e.g. LTB dipole) start ramp sequence
            ii) pulsed magnets trigger sequence
            iii) beam source determined on a bunch-by-bunch basis (e.g. can support interleaving Gun1 and PCgun)
   b) bunch-level control
      i) PV settings
         a) can vary based on bunch number and destination (e.g. LEUTL, booster, etc.)
            i) allows compensation for, e.g., position on booster ramp cycle
            ii) should allow linking a description to a bunch number
         b) settings for one destination may be changed without affecting settings for other destinations
         c) must provide enough "advanced warning" to pulsed and fast-ramped magnets to allow proper operation
         d) must be aware of which PVs can and cannot support different settings for different pulses
      ii) diagnostics & controllaw support
         a) must be able to provide readbacks and averaging for one destination or all shots (to avoid averaging difficulties)
         b) should be able to provide an "effective" beam rate indicator if a specific destination is selected for viewing

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        c) must be able to provide independent setpoint stabilization for different bunch number / destinations (beam trajectory comes immediately to mind)
  - c) overall control
    - i) must be able to save/compare/restore the bunch train structure
    - ii) must be able to save/compare/restore for a given bunch number
    - iii) should flag restoration of PVs that affect more than one destination (e.g. linac lattice quadrupoles)

2. RF systems
  - a) various systems will need to have parameter changes at up to 10 Hz rep rate; those that may currently be possible should be tested, those which are not currently possible (e.g. rf power) should have development started soon.
    - i) phase, definitely
    - ii) power, hopefully
    - iii) SLED timing
    - iv) rf start time, gate width
  - b) required reworking
    - i) L1 klystron to power both L1 structure and PCgun
      - *a)* uprated klystron tube
      - *b)* high-power coupler
      - *c)* high-power phase shifter between coupler and L1 structure
    - ii) L3 klystron to power thermionic-cathode rf guns
      - *a)* isolator
      - *b)* rf switch to select between guns (in place already)
    - iii) LLRF attenuators to solid-state design for rapid parameter changes
    - iv) verification of LLRF phase shifts at 10 Hz
    - v) parameter sample times required to (potentially) vary pulse-to-pulse
      - *a)* all powers
      - *b)* all phases

3. power supply and magnet systems
  - a) controllers and power supplies capable of performing magnet changes on 0.1-sec timescales will be required
    - i) stability to 10^{-4} of full-scale is the nominal specification
    - ii) classes of new supplies desired
      - *a)* quadrupole
      - *b)* corrector
      - *c)* dipole
  - b) magnets to be upgraded
    - i) at least two H & two V correctors between the last accelerating structure and the BB:BM1 dipole (three-magnet array)
    - ii) potentially, strategically placed quadrupoles after the last accelerating structure (new or revised presently-existing)

4. diagnostics
  - a) operational ranges
    - i) 0.1 – 10 nC charge (integrated over bunch train)

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        ii) 3 – 20 µm emittance (normalized)
        iii) bunch trains of 1 – 30 S-band buckets
    b) diagnostics sharing
        i) shared diagnostics – most of the linac diagnostics through the LTB dipole
            a) should be capable of being read out on a single-shot basis
            b) potentially, capable of displaying averaging based on bunch number or destination (e.g. LEUTL and booster may have different trajectories)
        ii) non-shared diagnostics
            a) Gun1, Gun2 current monitors
            b) PCgun ICT, if the PC gun is not being used for top-up or fill
    c) imaging diagnostics
        i) either the MV200 software or the processing / acquisition software needs to be aware of where the image is being taken, and apply appropriate selection rules
    d) non-imaging diagnostics
        i) BPMs must be capable of responding to interleaved beams with different charges and bunch train structures
        ii) current monitors must be capable of the same

II. Linac-to-Booster (LTB) line
  A. general requirements
    1. optics
      a) injection dipole
        i) must have < 0.1-sec ramp-up time to max. energy
        ii) energy range: 350 MeV – 1.65 GeV
      b) quadrupoles
        i) must be capable of providing matched beam at all injection energies
        ii) ideally will not require additions to beamlines in line with LEUTL injection
    2. acceptance
      a) energy: 350 MeV – 1.65 GeV
      b) emittance: < 20 µm (normalized)
  B. systems
    1. machine controls (Controls and OAG)
      a) timing
        i) LTB dipole ramp start according to bunch flag for booster injection
      b) bunch-level control
        i) not required, as the only bunches through this line will be for booster injection; no beamline settings should change unless the beam energy changes
      c) overall control
        i) trajectory controllaw
        ii) if some quads can be outfitted for cross-term measurement, rough beta-function control could be implemented

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2. power supply and magnet systems
   a) LTB dipole
      i) 0.1-sec ramp-up and ramp-down time
      ii) voltage and current specs
         a) final dipole capable of 1.65 GeV; may require other component location changes or replacement
      iii) stability requirements
         a) +/- 0.04% (as per M. Borland)
            i) at what energy?
            ii) zero-point stability is to be determined
   b) booster-side kickers
      i) present status: current capabilities of magnets, power supplies needs to be determined
      ii) capable of injecting to 1.65 GeV.
3. diagnostics
   a) no interleaving required for diagnostics in this part of the line
   b) operational ranges
      i) 0.25 – 10 nC charge (integrated over bunch train)
      ii) 3 – 20 µm emittance (normalized)
      iii) bunch trains of 1 – 30 S-band buckets, individual bunches on the order of 1 ps duration
   c) capable of 1 Hz, 2 Hz operation
   d) appropriate diagnostics for beam position at minimum, and preferably beam size monitors at specified locations also

III. Booster synchrotron
   A. general requirements
      1. beam acceptance
         a) the larger the dynamic aperture, the better
         b) 0.25 – 3 nC charge (captured)
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      2. timing
         a) 2 Hz global rep rate will be maintained
         b) ramp rates will be the same as for present injection
         c) must provide appropriate signals to allow for proper PC, thermionic-gun triggering
   B. systems
      1. machine controls (Controls and OAG)
         a) ramps should be effectively the same as at present
         b) bunch cleaning should always be available for use
      2. power supply and magnet systems
         a) beam kickers and injection requirements

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i) energy ranges
   a) initial: reliably accept beam at 325 – 450 MeV
   b) final: reliably accept beam at 325 – 1650 MeV
ii) accept bunch durations of up to 5 ns

3. diagnostics
   a) would be nice to get at least some BPMs working
   b) bunch purity monitoring is desired
   c) charge ranges of 0.25 – 3 nC for a single bucket (remaining after cleaning)

IV. BTS line
  A. general requirements
    1. beam repetition rate will remain the same
    2. energy will remain the same
  B. systems
    1. machine controls (Controls and OAG)
       a) if one does not already exist, a BTS controllaw might be in order
    2. power supply and magnet systems
       a) no modifications required
    3. diagnostics
       a) diagnostics should be capable of responding to bunch charges of 0.25 nC

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<u>"Simple" Version</u>

This has less flexibility and controls options than the deluxe version, but may be more achievable.

I. Linac and LET lines
- A. general requirements
  - 1. bunch delivery rates
    - a) max. delivery rate to booster is 2 Hz
      - i) from any gun installed in the APS linac, to a specific booster bucket
        - *a)* guns are not interleaved
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      - ii) implementation of correction will be restricted to adding fast-ramping correctors in suitable locations
- B. systems
  - 1. machine controls (Controls and OAG)
    - a) timing
      - i) sequencing
        - *a)* maintain present 2 Hz fundamental rep rate
      - ii) triggering capabilities

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- *a)* booster injection
  - *i)* PC gun drive laser resync. to have beam land in a specific booster bucket
  - *ii)* thermionic gun kicker or drive laser trigger to center beam on a desired booster bucket
  - *iii)* disable diagnostics triggering after LTB dipole
- *b)* LEUTL operation
  - *i)* enable diagnostics triggering after LTB dipole
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  - *i)* ramped supplies (e.g. LTB dipole) start ramp sequence
  - *ii)* pulsed magnets trigger sequence

b) bunch-level control
- i) must provide enough “advanced warning” to pulsed and fast-ramped magnets to allow proper operation
- ii) diagnostics & controllaw support
  - *a)* must be able to provide readbacks and averaging for one destination or all shots (to avoid averaging difficulties)
  - *b)* should be able to provide an “effective” beam rate indicator if a specific destination is selected for viewing
  - *c)* must be able to provide independent setpoint stabilization for different bunch number / destinations (beam trajectory comes immediately to mind)
- iii) four fast-change corrector magnets in the post-LTB line to allow for booster-induced trajectory changes

c) overall control – effectively unchanged

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    1. optics
        a) injection dipole
            i) must have a 0.1-sec ramp-up time to max. energy
            ii) energy range: 350 MeV – 1.65 GeV
        b) quadrupoles
            i) must be capable of providing matched beam at all injection energies
            ii) ideally will not require additions to beamlines in line with LEUTL injection
    2. acceptance
        a) energy: 350 MeV – 1.65 GeV
        b) emittance: < 20 µm (normalized)
  B. systems
    1. machine controls (Controls and OAG)
        a) timing
            i) must provide appropriate triggers to rf gun systems
            ii) triggers to PCgun drive laser as appropriate
        b) bunch-level control
            i) not required, as the only bunches through this line will be for booster injection; no beamline settings should change unless the beam energy changes

7.

3.

c) overall control
    i) trajectory controllaw
    ii) if some quads can be outfitted for cross-term measurement, rough beta-function control could be implemented

2. power supply and magnet systems
    a) LTB dipole
        i) 0.1-sec ramp-up and ramp-down time
        ii) voltage and current specs
            a) initial dipole for PTB:B2 drop-in replacement
            b) final dipole capable of 1.65 GeV; may require other component location changes or replacement
        iii) stability requirements
            a) +/- 0.04% (as per M. Borland)
                i) at what energy?
                ii) zero-point stability is to be determined
    b) booster-side kickers
        i) present status: current capabilities of magnets, power supplies needs to be determined
        ii) capable of injecting to 1.65 GeV.

3. diagnostics
    a) no interleaving required for diagnostics in this part of the line
    b) operational ranges
        i) 0.25 – 10 nC charge (integrated over bunch train)
        ii) 3 – 20 µm emittance (normalized)
        iii) bunch trains of 1 – 30 S-band buckets, individual bunches on the order of 1 ps duration
    c) capable of 1 Hz, 2 Hz operation
    d) appropriate diagnostics for beam position at minimum, and preferably beam size monitors at specified locations also

III. Booster synchrotron

A. general requirements

1. beam acceptance
    a) the larger the dynamic aperture, the better
    b) 0.25 – 3 nC charge (captured)
    c) 3 – 20 µm emittance
    d) bunch trains (for bunch cleaning)
        i) minimum: 1 charge pulse of approximately 3 ps duration
        ii) maximum: 30 charge pulses, spaced at 2856 MHz, of approximately 0.5 pS duration each, and a max. charge per pulse of 0.3 nC

2. timing
    a) 2 Hz global rep rate will be maintained
    b) ramp rates will be the same as for present injection
    c) must provide appropriate signals to allow for proper PC, thermionic-gun triggering

B. systems

7.

3.

1. machine controls (Controls and OAG)
    a) ramps should be effectively the same as at present
    b) bunch cleaning should always be available for use
2. power supply and magnet systems
    a) beam kickers and injection requirements
        i) energy ranges
            a) reliably accept beam at 325 – 1650 MeV
        ii) accept bunch durations of up to 5 ns
3. diagnostics
    a) would be nice to get at least some BPMs working
    b) bunch purity monitoring is desired
    c) charge ranges of 0.25 – 3 nC for a single bucket (remaining after cleaning)

IV. BTS line
  A. general requirements
    1. beam repetition rate will remain the same
    2. energy will remain the same
  B. systems
    1. machine controls (Controls and OAG)
        a) if one does not already exist, a BTS controllaw might be in order
    2. power supply and magnet systems
        a) no modifications required
    3. diagnostics
        a) diagnostics should be capable of responding to bunch charges of 0.25 nC

7.