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EFFECT OF 805-MHZ LINAC RF STABILITY ON BEAM LOSSES IN LANSCE HIGH-ENERGY BEAMLINES*

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Abstract

Operation of an accelerator facility critically depends on stability of the field amplitudes and phases of the accelerating cavities. The LANSCE linear accelerator consists of a 201.25-MHz, drift-tube linac and an 805-MHz, side-coupled-cavity linac (SCL). Beam losses in the high-energy beamlines of the 800-MeV facility were measured versus variation of the amplitudes and phases of the 805-MHz, SCL, RF cavity fields. The study confirms that to achieve low losses, the stability of the amplitudes and phases should be kept within 0.1% and 0.1°, respectively. This agrees with a previous study of beam losses generated by variation of amplitude and phase of 201.25-MHz linac [1]. Details of the measurements and results are presented.

LANSCE ACCELERATOR FACILITY

The LANSCE Accelerator facility currently operates with four 800 MeV H^- beams and one 100 MeV proton beam (see Fig. 1). The highest power beam, an 80 kW H^- beam with average current 100 µA, is accumulated in the Proton Storage Ring (PSR) and is extracted to the Lujan Neutron Scattering Center facility for production of moderated neutrons with meV-keV energy. Another H^- beam, as a sequence of short pulses, is delivered to the Weapon Neutron Research (WNR) facility to create un-moderated neutrons in the keV-MeV energy range. The third H^- beam is shared between the Proton Radiography Facility (pRad) and the Ultra-Cold Neutron (UCN) facility. The proton beam is used for isotope production in the fields of medicine, nuclear physics, national security, environmental science and industry.

High-energy part of facility includes multiple beamlines delivering beams to experimental areas. Beam after linac enters Switchyard (SY) followed by Line XD. H^- beams going to PSR and WNR are directed to Line D - North where they travel approximately 100 m until they are separated by fast kicker magnet. Beam going to Lujan facility travels an additional 80 m along the Ring Injection (RI) beamline before entering the Proton Storage Ring. WNR beam travels 50 m along Line D - South before entering Target 2 experimental area. Another H^- beam is bend from Swithyard by fast kicker magnets to enter Line X, where the beam is divided by two beams entering either Line C going to pRad area, or Line B going to UCN target.

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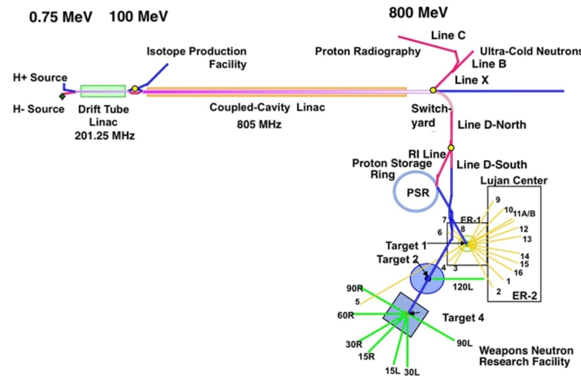

Figure 1: Layout of LANSCE Accelerator Facility.

CONTROL OF BEAM LOSSES

Beam losses at LANSCE are detected by various types of loss monitors. The linear accelerator and high-energy beamlines are equipped with scintillators, while high-energy part includes also ion-chamber detectors. The main control of beam losses is provided by Activation Protection (AP) detectors, which are one-pint size cans with a photomultiplier tube immersed in scintillator fluid. AP detectors integrate the signals and shut off the beam if the beam losses around an AP device exceed 100 nA of average current for an 800 MeV beam, which corresponds to 100% AP reading. Response of AP devices is proportional to beam current losses for a fixed beam energy.

Figures 2, 3 illustrate typical distribution of beam losses in linac and in the high-energy section of the accelerator facility. Most beam losses are observed in the Switchyard and the Line - D North area. Total beam losses in that area are around 300 nA, or 0.3%. Losses in linac are less significant than that at the high-energy part of accelerator facility. From day-by-day operation of accelerator complex it follows, that small variation of amplitudes and phases in the 805-MHz linac strongly affect losses in high-energy beamlines. Low-Level RF control system has trip fast protect limits of 1% in RF amplitude and 1° in RF phase. Actual variation of RF amplitude and phase are one order of magnitude smaller than fast protect limits.

Random errors in RF amplitude and phase result in increase of amplitude of longitudinal oscillations. Amplitude of phase oscillation Φ and that of relative momentum $g_a = \Delta p / p$ are related as [2]

$$g_a = \gamma^2 \Phi (\frac{\Omega}{\omega}) , \qquad (1)$$

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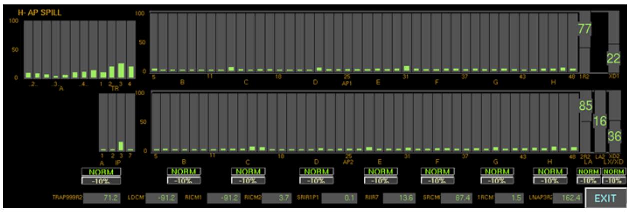

Figure 2: Beam losses along linear accelerator.

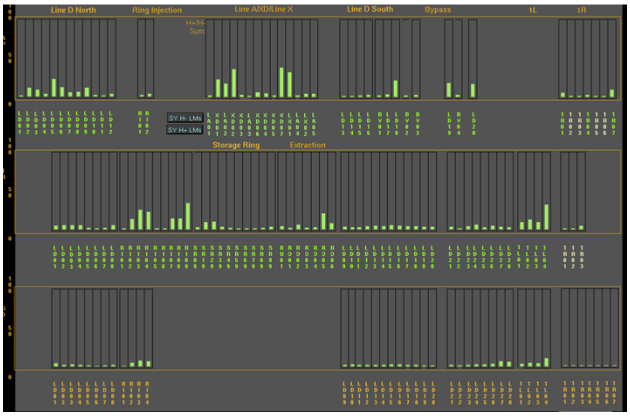

Figure 3: Beam losses in high-energy beam transport.

where γ is the relativistic energy, and Ω/ω is the dimensionless longitudinal oscillation frequency:

$$\frac{\Omega}{\omega}=\sqrt{\left(\frac{qE\lambda}{mc^2}\right)\frac{|\sin\varphi_s|}{2\pi\beta\gamma^3}}\,. \tag{2}$$

Increase of amplitude of relative momentum spread in a sequence of N accelerating sections with relative error in RF amplitude $\delta E_o/E_o$, and error in RF phase $\delta\psi$ is estimated as [2]:

$$<\Delta g_a>=\sqrt{\frac{N}{2}[<\Delta g>^2+\left(\frac{\Omega}{\omega}\right)^2<\delta\psi>^2]}\,, \tag{3}$$

where

$$<\Delta g>=\frac{W_\lambda}{\beta_N}\sqrt{<\frac{\delta E_o}{E_o}>^2+tg^2\varphi_s<\delta\psi>^2}\,, \tag{4}$$

$W_\lambda=eE_oT\lambda\cos\varphi_s/(mc^2)$ is the dimensionless acceleration rate, β_N is the average effective beam velocity in linac, and φ_s is the synchronous phase. Substitution of 805-MHz linac parameters into Eqs. (3) - (4) gives an estimation of increase of momentum spread due to RF field instability:

$$<\Delta g_a>=\sqrt{\frac{N}{2}(1.5\cdot10^{-7}<\frac{\delta E_o}{E_o}>^2+4.6\cdot10^{-6}<\delta\psi>^2)} \tag{5}$$

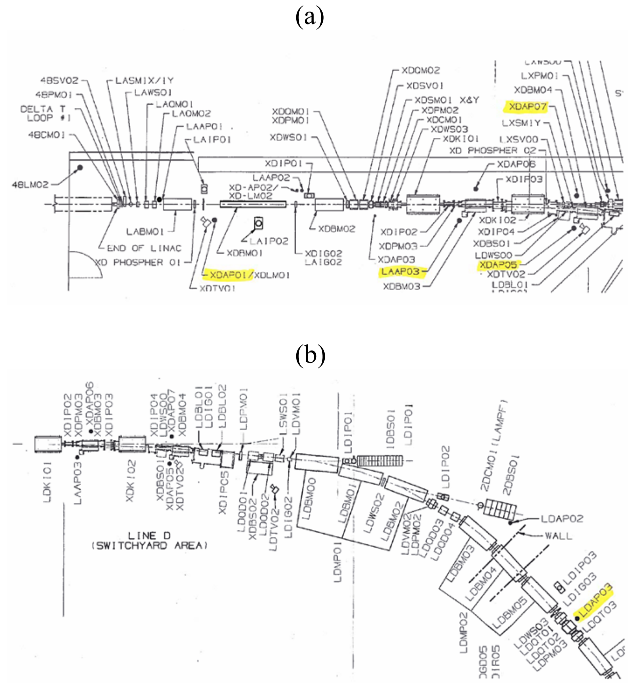

Figure 4: Location of Activation Protection devices (a) in Switchyard and (b) in Line D-North areas.

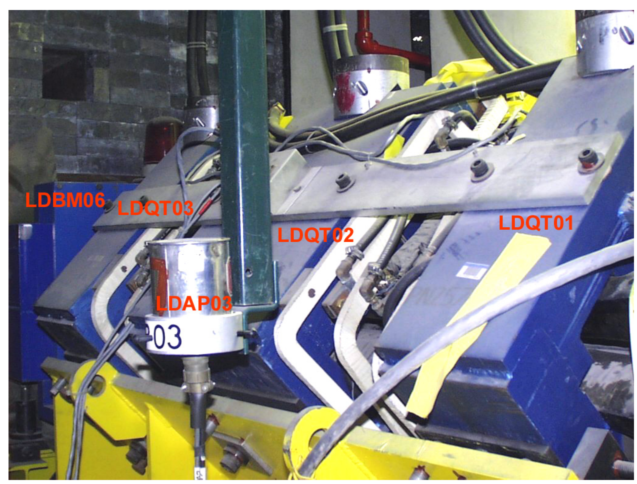

Figure 5: Position of LDAP03 monitor with respect to LDQT01-03 quadrupole triplet.

This estimation, Eq. (5), indicates that for instability of the RF field amplitude $<\delta E_o/E_o>\approx 1\%$ and that of phase $<\delta\psi>\approx 1^o$, increase of momentum spread of the beam is around $<\Delta g_a>\approx 1.7\cdot10^{-4}$, which is a significant addition to regular momentum spread of the beam $\Delta p/p\approx 8\cdot10^{-4}$ and confirms the applicability of fast-protect thresholds. Random errors in RF field result in formation of energy and spatial tails in beam distribution, which create additional beam losses after the linac in dispersive high-energy parts of the accelerator facility.

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RESULTS OF MEASUREMENTS

Most of beam spill in the accelerator facility is generated by the 80 kW, 100 μA H^- beam delivered to Lujan Center. This beam has a repetition rate of 20 Hz and pulse length of 625 μs. In order to perform measurements of extra beam spill generated by RF field instability without interruption of accelerator operation, average beam current was reduced to 5 μA using beam pulse length of 150 μs and repetition rate of 4 Hz.

Measurements were performed for modules 6-14, where beam energy increases from 113 MeV to 240 MeV. Perturbations of the beam due to variation of RF parameters are most significant at lower energy [2]. Extra beam spill generated by modules 8, 10, 11, 12, 13, 14 was larger than that generated by other modules, and measurements with these modules were done with additional reduction of beam current by a factor of 2.

Measurements were performed in two stages. After selection of accelerating module, RF amplitude of the module was changed until significant spill was generated. Then, RF amplitude was returned to nominal value, and RF phase was varied until significant spill was generated. Observed level of beam spill was not a regular function of amplitude and phase change. All results were finally normalized by 1% of variation of RF amplitude, and 1^o of variation of RF phase at maximum beam current of 100 μA.

The most significant increase in beam spill was observed in the following monitors placed in high-energy part of facility: XDAP01, XDAP04, XDAP05, XDAP07, LAAP04, LDAP03. Locations of AP monitors are displayed at Figures 4-5. Figure 6 illustrates increase of beam spill in high-energy part of accelerator facility with variation of amplitude and phase of module 13. Figures 7-8 show normalized results of variation of beam spill generated by 1% variation in RF amplitude and 1^o variation in RF phase at average beam current of 100 μA. Highest value of extra beam spill under that conditions found to be around 500 - 1000 nA. Radiation protection regulations and fast protect limits restrict beam spill per AP module by the value of 100 nA. The results of this study confirm that the stability of the RF amplitudes and phases should be kept one order of magnitude smaller than (1%, 1^o), or within 0.1% and 0.1^o, respectively, in order to provide safe operation of accelerator facility.

ACKNOWLEDGEMENTS

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REFERENCES

[1] L.J. Rybarcyk, R.C. McCrady, Proceeding of LINAC2016, East Lansing, MI, USA, MOPLR072, p.301.

[2] I.M. Kapchinsky, "Theory of Resonance Linear Accelerators", Harwood, 1985.

(a)

XDAP001R02:H- SPILL AVG	--	0.25000 PCNT
XDAP004R02:H- SPILL AVG	--	0.20000 PCNT
XDAP005R02:H- SPILL AVG	--	3.0500 PCNT
XDAP007R02:H- SPILL AVG	--	5.3000 PCNT
LAAP004R02:H- SPILL AVG	--	0.55000 PCNT
LDAP002R02:LBEG SPILL AVG	--	1.0500 PCNT
LDAP003R02:LBEG SPILL AVG	--	0.25000 PCNT

(b)

XDAP001R02:H- SPILL AVG	--	0.35000 PCNT
XDAP004R02:H- SPILL AVG	--	0.80000 PCNT
XDAP005R02:H- SPILL AVG	--	20.100 PCNT
XDAP007R02:H- SPILL AVG	--	11.850 PCNT
LAAP004R02:H- SPILL AVG	--	23.400 PCNT
LDAP002R02:LBEG SPILL AVG	--	1.0500 PCNT
LDAP003R02:LBEG SPILL AVG	--	2.1000 PCNT

(c)

XDAP001R02:H- SPILL AVG	--	0.35000 PCNT
XDAP004R02:H- SPILL AVG	--	1.1000 PCNT
XDAP005R02:H- SPILL AVG	--	25.500 PCNT
XDAP007R02:H- SPILL AVG	--	15.050 PCNT
LAAP004R02:H- SPILL AVG	--	35.400 PCNT
LDAP002R02:LBEG SPILL AVG	--	1.1000 PCNT
LDAP003R02:LBEG SPILL AVG	--	3.0000 PCNT

Figure 6: (a) Nominal beam spill in high-energy beamlines generated by H^- beam with average current 2.5 μA, (b) change of beam spill after increase of amplitude of module 13 by 2.6%, (c) change of beam spill after increase of phase of module 13 by 2.9^o.

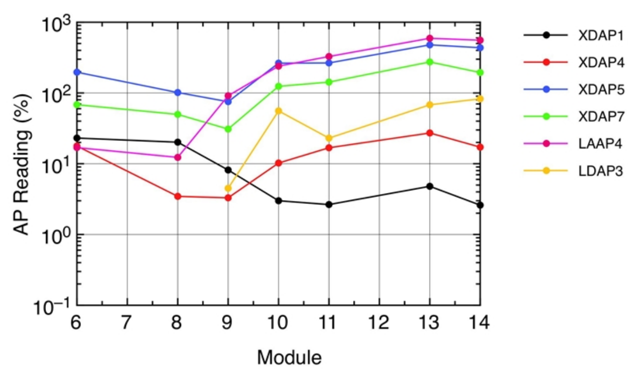

Figure 7: Beam spill normalized by 1% variation in RF amplitude.

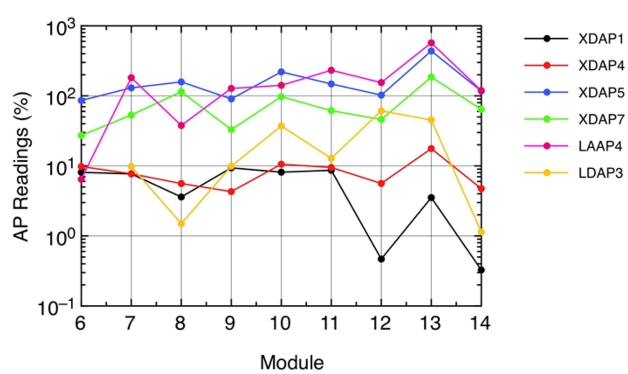

Figure 8: Beam spill normalized by 1^o variation in RF phase.