Beam Injection Operation for Particle Physics and Photon Science Experiments with Pulse-to-Pulse Beam Modulation

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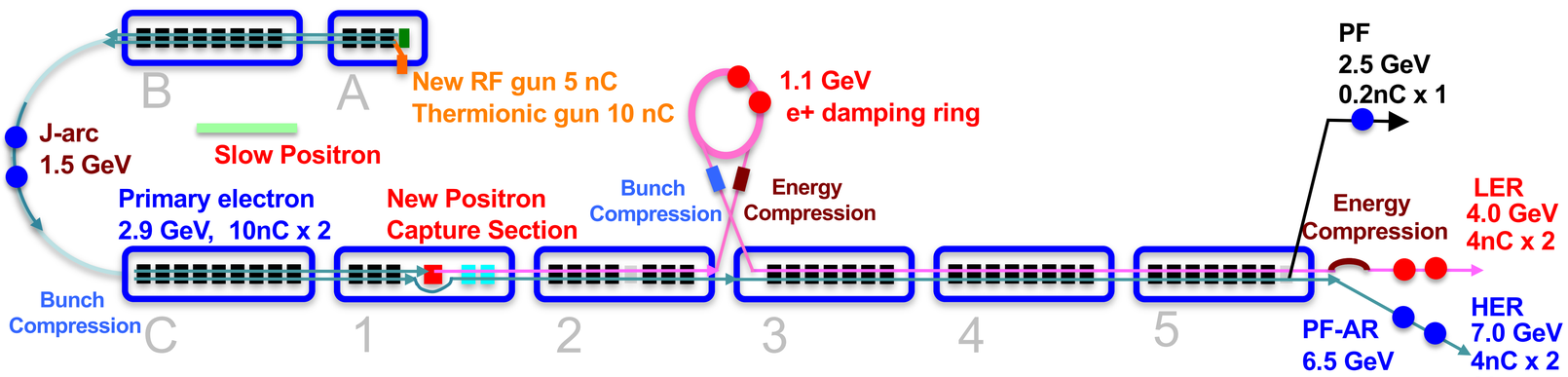
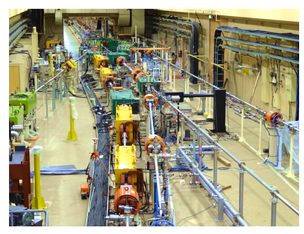
The electron and positron accelerator complex at KEK offers unique experimental opportunities in the fields of elementary particle physics with SuperKEKB collider and photon science with two light sources. In order to maximize the experimental performances at those facilities the injector linac employs pulse-to-pulse modulation at 50 Hz, injecting beams with diverse properties. The event-based control system effectively manages different beam configurations. This injection scheme was initially designed 15 years ago and has been in full operation since 2019. Over the years, a number of enhancements have been implemented. As the event-based controls are tightly coupled with microwave systems, machine protection systems and so on, their modifications require meticulous planning. However, the diverse requirements from particle physics and photon science, stemming from the distinct nature of those experiments, often necessitate patient negotiation to meet the demands of both fields. This presentation discusses those operational aspects of the multidisciplinary facility.

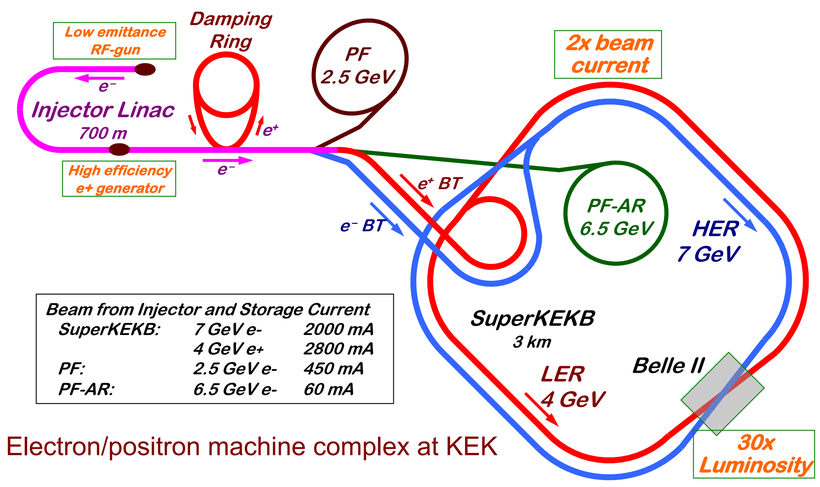
KEK e^- / e^+ injector LINAC delivers multi-disciplinary beam injections for 4 + 1 storage rings of light sources and a particle physics collider even with higher beam charge and lower beam emittance

Injector LINAC Configuration



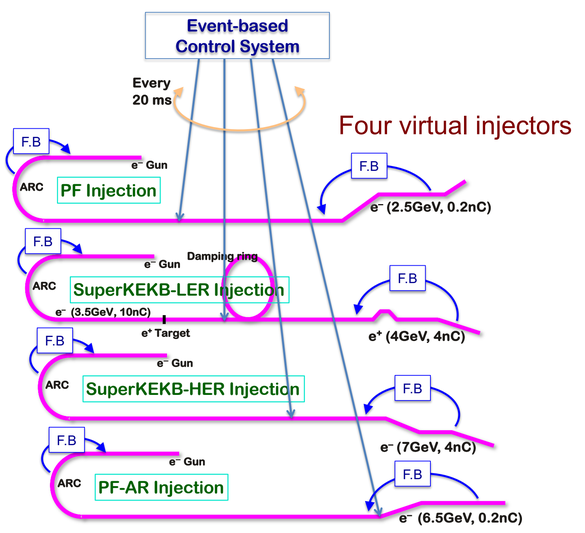


Simultaneous Top-up Injections into 4 + 1 Rings

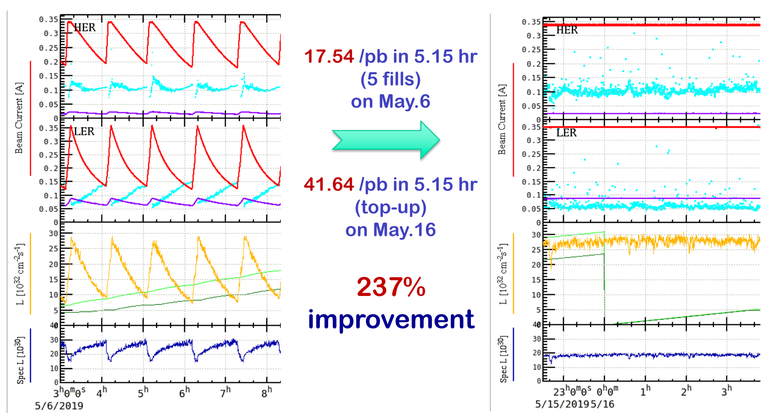


Beam from Injector and Storage Current		
SuperKEKB:	7 GeV e-	2000 mA
	4 GeV e+	2800 mA
PF:	2.5 GeV e-	450 mA
PF-AR:	6.5 GeV e-	60 mA

Electron/positron machine complex at KEK

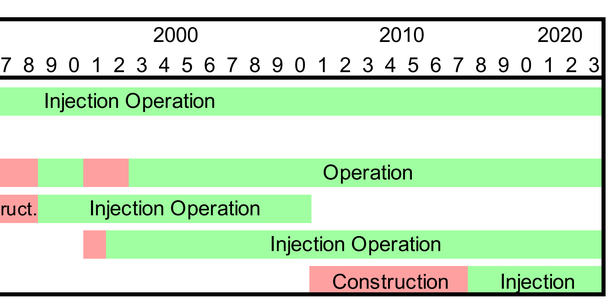


Improved SuperKEKB performance by 237%

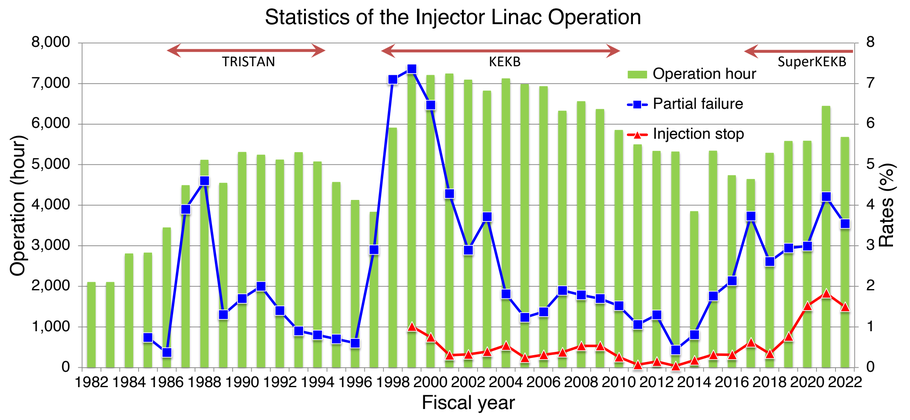


Historical Linac Beam Deliveries

Project	Injection Energy	Exp. Energy
Photon Factory	2.5 GeV	2.5 GeV
TRISTAN	2.5 GeV	32 GeV
Slow Positron	2.5 GeV - 55 MeV	0.1 - 35 keV
KEKB	8 / 3.5 GeV	8 / 3.5 GeV
PF-AR	2.5 GeV - 6.5 GeV	5 - 6.5 GeV
SuperKEKB	7 / 4 GeV	7 / 4 GeV



Beam Injection Statistics



Dual Disciplinary Beam Injection

PF / PF-AR photon science

- ◆Short-term in many user groups
- ◆Stability intensive
  (Hates failures)
- ◆Meticulous scheduled maintenance
- ◆Invests on maintenance
- ◆Formal common objective between users
- ◆Fixed procedures
  Difficult to train operators against failures

SuperKEKB particle physics

- ◆Long-term and fixed single user group
- ◆Performance intensive
  (Integral performance during a year)
- ◆Minimum preventive maintenance
- ◆Invests on improvements
- ◆May share common goal with the user
- ◆Everyday is new
  On-the-job training for operators

◆Injector linac arbitrates between downstream accelerators with incompatible disciplines for long-term plans, yearly maintenance and improvements, and daily beam deliveries

Top-up injections for dual disciplines

Required Beam Performance

Stage	KEKB (final)		Phase-I (achieved)		Phase-II (achieved)		Phase-III (interim)		Phase-III (final)	
Beam	e+	e–	e+	e–	e+	e–	e+	e–	e+	e–
Energy	3.5 GeV	8.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV
Stored current	1.6 A	1.1 A	1.0 A	1.0 A	–	–	1.8 A	1.3 A	3.6 A	2.6 A
Life time (min.)	150	200	100	100	–	–	–	–	6	6
Bunch charge (nC)	primary e- 10 →1	1	primary e- 8 →0.4	1	0.5	1	2	2	primary e- 10 →4	4
Norm. Emittance (γβε) (mrad)	1400	310	1000	130	200/40 (Hor./Ver.)	150	150/30 (Hor./Ver.)	100/40 (Hor./Ver.)	100/15 (Hor./Ver.)	40/20 (Hor./Ver.)
Energy spread	0.13%	0.13%	0.50%	0.50%	0.16%	0.10%	0.16%	0.10%	0.16%	0.07%
Bunch / Pulse	2	2	2	2	2	2	2	2	2	2
Repetition rate	50 Hz		25 Hz		25 Hz		50 Hz		50 Hz	
Simultaneous top-up injection (PPM)	3 rings (LER, HER, PF)		No top-up		Partially		4+1 rings (LER, HER, DR, PF, PF-AR)		4+1 rings (LER, HER, DR, PF, PF-AR)	

Summary

- ◆ KEK injector LINAC continues simultaneous top-up injections to support the both photon science and particle physics experiments.
- ◆ It often carries administrative and operational negotiations to a successful conclusion to enable short-term and long-term optimizations and to enhance performances for the both disciplines.