KEK Insight through Accelerators.

IPAC26 TUP7628

PRECISE FREQUENCY TUNING OF S-BAND PULSE COMPRESSORS AT HIGH-POWER OPERATION IN THE ELECTRON AND POSITRON INJECTOR LINAC OF KEK

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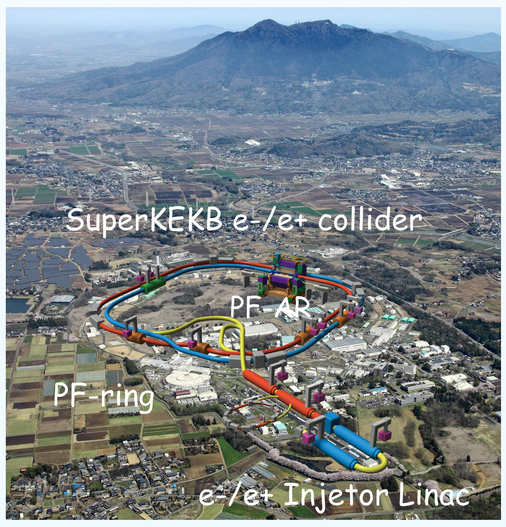
Abstract

The KEK electron-positron injector linac employs **pulse compressors** to amplify high-power radio frequency waves generated by **S-band** 40-MW klystrons. Accurate tuning of these compressors during high-power operation is essential to minimize their voltage standing wave ratio and maximize output power. We developed **a real-time, labor-saving tuning system** that consists of a waveform analyzer and a removable remote-controlled tuner driver. The analyzer calculates **frequency deviations and waveform distortions in real-time** by comparing the compressor's output waveform to an optimal waveform derived from fourth-order Runge–Kutta calculations. The tuner eliminates frequency deviations, whereas the analyzer monitors **pulse-to-pulse adjustments**. Consequently, all compressors were tuned efficiently and precisely.

KEK electron/positron S-band Injector Linac

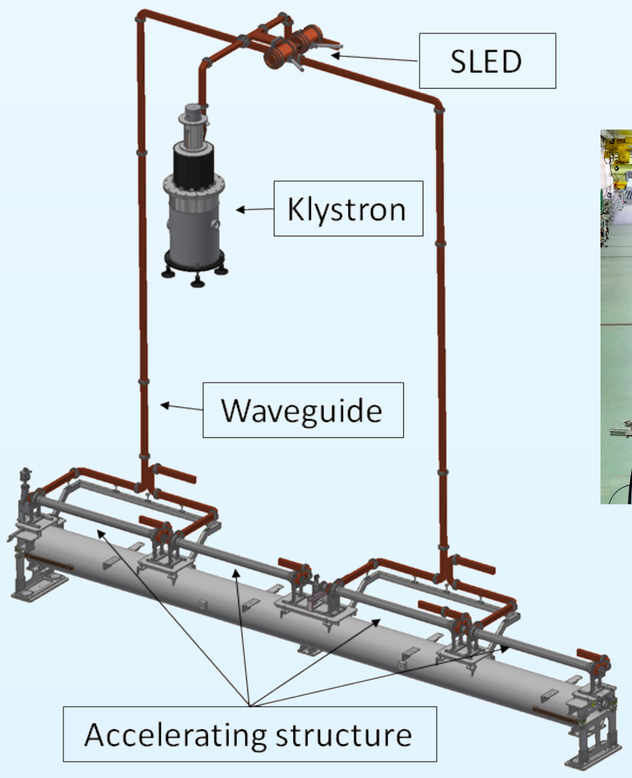


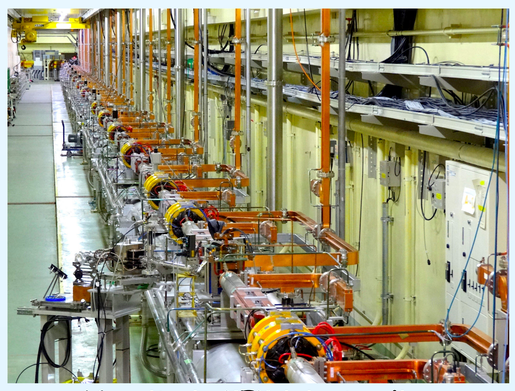
	Electron	Positron
Energy [GeV]	7	4
Number of S-band accelerating structures	230	
Operating frequency [MHz]	2,856	
Klystron	40 MW 4 μs 50 Hz	
Charge [nC]	4	4
Normalized emittance H/V [μm]	40/20	100/15
Energy spread [%]	0.07	0.16

The linac supplies electron and positron beams to four storage rings, SuperKEKB 7-GeV HER / 4-GeV LER for particle physics, 2.5-GeV PF Ring, and 6.5-GeV PF-AR of SR facilities via simultaneous top-up injection switching operating parameters at 50 Hz to generate and accelerate beams as required by each ring.

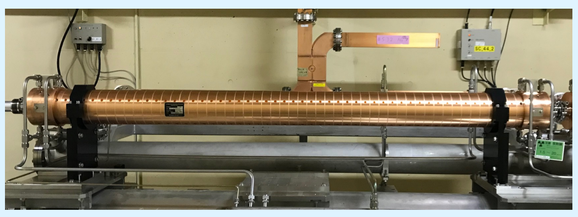
S-band beam accelerating unit

40-MW Klystron + Pulse compressor (SLED or SCPC)
+ Four accelerating structures + WR-284 Waveguide system

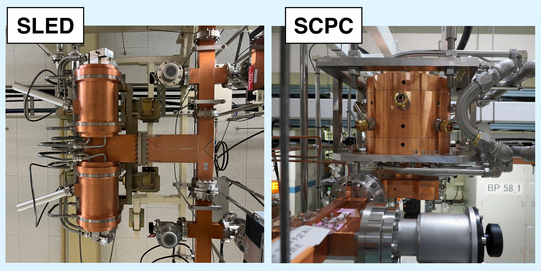




61 units in KEK injector linac



S-band accelerating structure
(IPAC23, WEPA118)



Two types of pulse compressors
SLED (left) and SCPC (right)

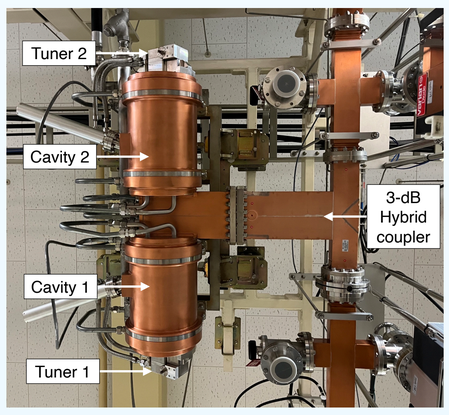
RF properties

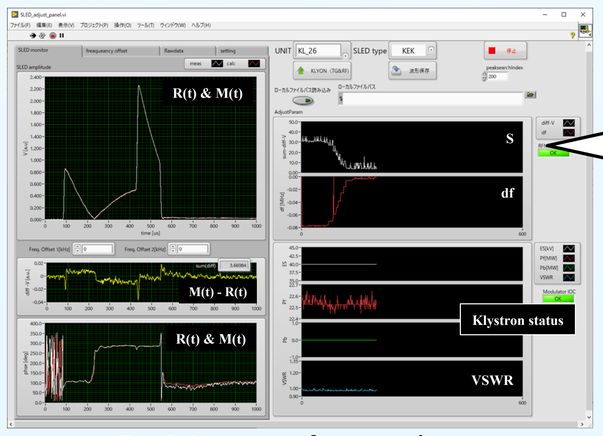
Accelerating structure	
Operating frequency [MHz]	2,856
Accelerating mode	TM01 - 2π/3
Type of structure	Quasi-CG
Cell iris diameters [mm]	23.340 - 19.234
Mean group velocity / c	0.0117
Filling time [μs]	0.570
Unloaded-Q	14,000
Attenuation parameter [Neper]	0.366
Mean shunt impedance [MΩ/m]	61.7
Energy gain [MeV/MW$^{1/2}$]	7.87
Operating gradient [MV/m]	20

	SLED	SCPC
Operating frequency [MHz]	2,856	
Resonant mode	Cylindrical TE_{015}	Spherical TE_{112}
Unloaded-Q	100,000	
Coupling constant	6.4	
Peak compression ratio	6.2	
Input pulse length [μs]	4.0	
Phase-reversed length [μs]	1.0	
Input power [MW]	40	
Number of the compressors	56	2

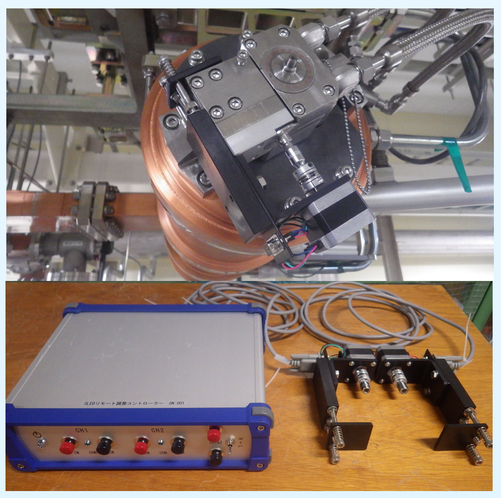
Precise frequency tuning of pulse compressors at high-power operation

- Tuning for the pulse compressors at the rated high-power operation
- Real-time waveform analyzer taking the waveform data and estimating the optimal waveform and frequency deviation
- Remote tuner-driver enabling precise frequency adjustment at the step of 0.055 kHz





Real-time waveform analyzer



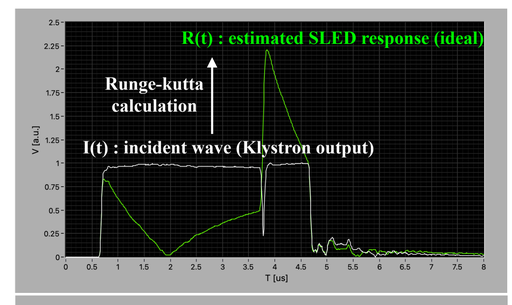
New removable tuner-driver with stepping motors

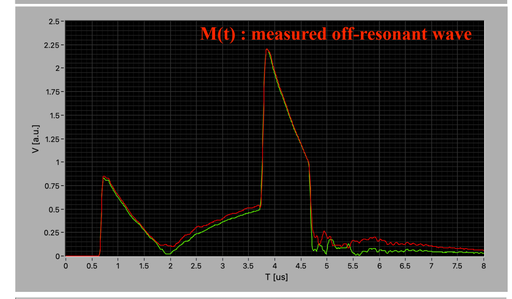
Response estimation on SLED

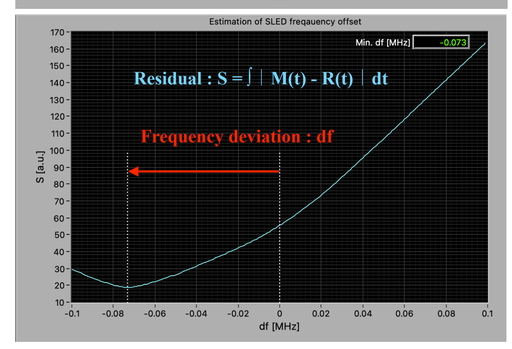
$$\left(1+\frac{\omega_{c,1}^2}{\omega^2}\right)\frac{dV_{c,1}}{dt}+\left\{\frac{\omega_{c,1}}{Q_{L,1}}+j\omega\left(1-\frac{\omega_{c,1}^2}{\omega^2}\right)\right\}V_{c,1}=\frac{2\omega_{c1}\beta_1}{Q_{0,1}}\frac{V_i}{\sqrt{2}}$$

$$\left(1+\frac{\omega_{c,2}^2}{\omega^2}\right)\frac{dV_{c,2}}{dt}+\left\{\frac{\omega_{c,2}}{Q_{L2}}+j\omega\left(1-\frac{\omega_{c,2}^2}{\omega^2}\right)\right\}V_{c,2}=\frac{2\omega_{c,2}\beta_2}{Q_{0,2}}\frac{jV_i}{\sqrt{2}}$$

$$V_o=\frac{1}{\sqrt{2}}\left(jV_{c,1}+V_{c,2}\right)$$



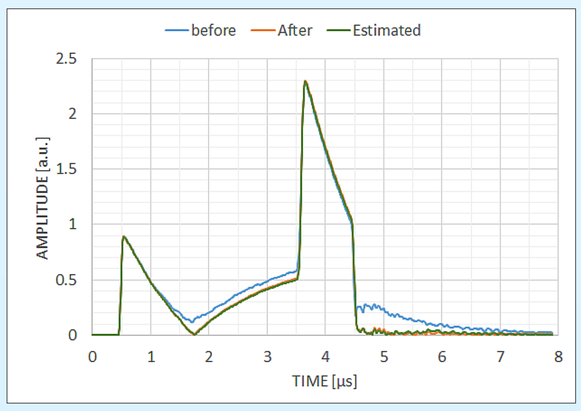


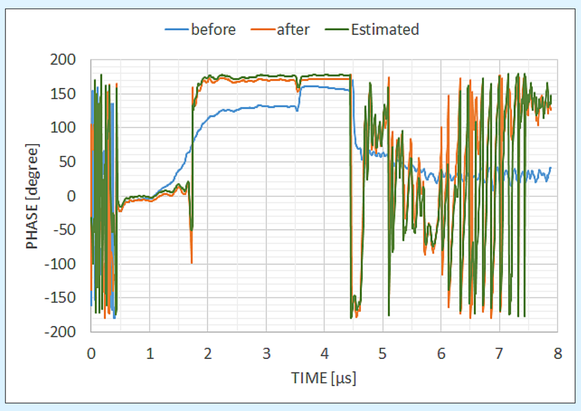


Pulse-to-pule real-time estimation at 50 Hz

Tuning : S → minimum

Tuning results





- Measured waveform amplitude and phase closely matched the estimated optimal waveform.
- Single operator performed the measurement and tuning work in approximately 10 to 15 min per SLED. This represents a notable reduction in manpower and time compared to conventional methods that involve oscilloscopes and require four operators.

Summary

To address the limitations of previous SLED tuning methods, we developed a waveform analyzer and implemented remote-controlled tuners for the SLED cavities. This innovation has led to a notable reduction in tuning time compared to conventional methods and confirmed that optimal SLED tuning can be readily achieved.