Possibility to save the operation power with pulse magnet at RTML

Toshiyuki OKUGI
2022/02/02
IDT WG2 DR/BDS/DUMP group meeting

Sustainability Issues of ILC

International Development Team

Sustainability Issues
Benno List, DESY
25th IDT WG2 Meeting
19.10.2021

IDT **Upcoming Conference: IAEA**

- IAEA Conference on accelerators for research and sustainable development
- Vienna, May 23-27, 2022
- Submitted an abstract for ILC and CLIC: "Sustainability studies for linear colliders"
  - Authors: S. Stapnes, S. Michizono, BL
- Intent: Provide an overview over measures to increase sustainability of ILC and CLIC
  - Overall design
  - Energy saving components
  - Renewable energy sources
  - Waste heat usage
  - …
- If accepted, writeup is expected

https://conferences.iaea.org/event/264/

IDT **Reduced Damping Ring Operation**

- Damping Rings consume 14MW (13%) of total power
- At 2.5Hz operation, beams circulate for 400ms instead of 200ms
  -> longer damping time sufficient?
- Can wiggler fields be reduced and RF power saved?
- Damping rings consume
  - 7.4MW RF power
  - 1.5MW cryo power
  - How much could be saved at 2.5Hz operation?

	500 TDR	250-A	250-A' w/R&D	250-A Lx2
Rep-Rate / Hz	5	5	5	5
Bunches / Pulse	1312	1312	1312	2625
Lumi / 10^{34}	1.8	1.35	1.35	2.7
Gradient / MV/m	31.5	31.5	35	31.5
Q_0/1E10	1.0	1.0	1.6	1.0
ML E-gain / GeV	470	220	220	220
ML Power / MW	107.1	50.1	49.3	53.5
e- Src / MW	4.9	4.9	4.9	5.6
e+ Src / MW	9.3	9.3	9.3	10.2
DR / MW	14.2	14.2	14.2	22.2
RTML / MW	10.4	10.4	10.4	13.3
BDS / MW	12.4	9.3	9.3	9.3
Dumps / MW	1.2	1.2	1.2	1.2
IR / MW	5.8	5.8	5.8	5.8
Campus / MW	2.7	2.7	2.7	2.7
Gen. Margin/MW	5.1	3.3	3.2	4.0
Total	**173**	**111**	**110**	**138**

From ILC-CR-0018

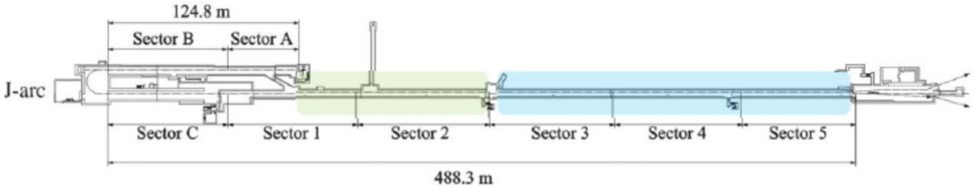
Can we reduce the operating power for RTML by using the pulsed magnet ?

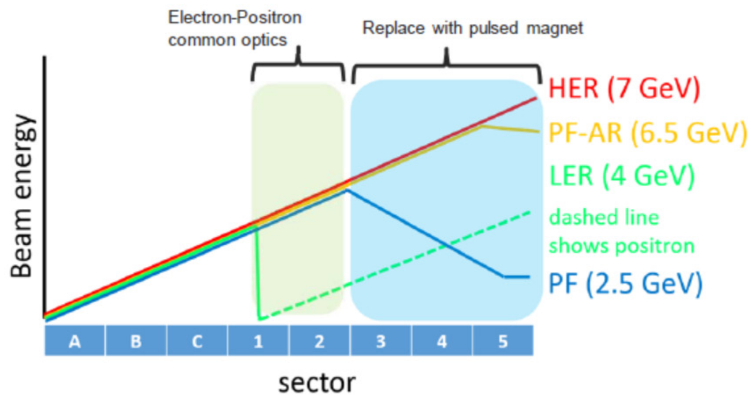
The possibility of operating power reduction for the warm magnet of RTML is roughly evaluated with the pulse magnet used in SuperKEK linac.

Pulse magnet used in SuperKEK linac

Beam energy and structure of our linac

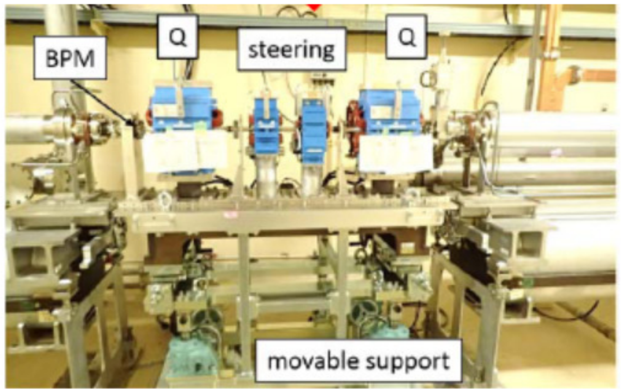
Y. Enomoto @LINAC2018





- 600 m long, 8 sectors
- Maximize common energy section to use DC magnets as much as possible
- Install pulsed magnets mainly in sector 3 to sector 5

26 quads and 26 steerings @ sector 3-5
10 steerings @ sector 1,2
2 quads @ positron production target



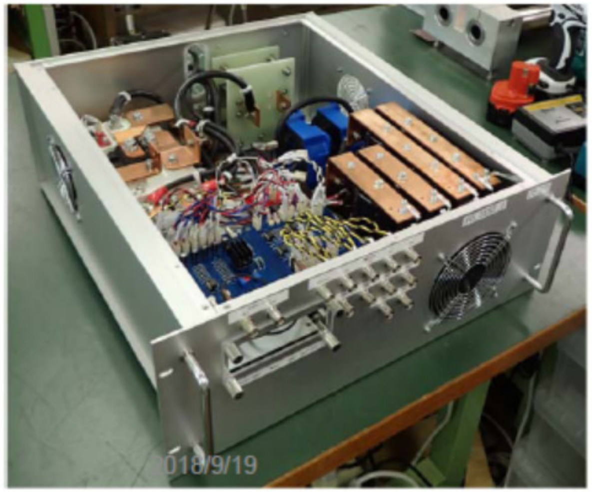
type	L@1 kHz	R	max current	magnetic field	gap	Installed Num.
PX_16_5	2.4 mH	71 mohm	40 A	1040 AT	72 mm	1
PY_16_5	2.4 mH	71 mohm	40 A	1040 AT	72 mm	1
PX_17_2	2.6 mH	127 mohm	40 A	1440 AT	39 mm	4
PY_17_2	2.6 mH	126 mohm	40 A	1440 AT	39 mm	4
PX_32_4	2.9 mH	115 mohm	40 A	1440 AT	20 mm	13
PX_32_4	2.9 mH	115 mohm	40 A	1440 AT	20 mm	13
PM_32_4	1.0 mH	8 mohm	330 A	60 T/m	ϕ 20 mm	28

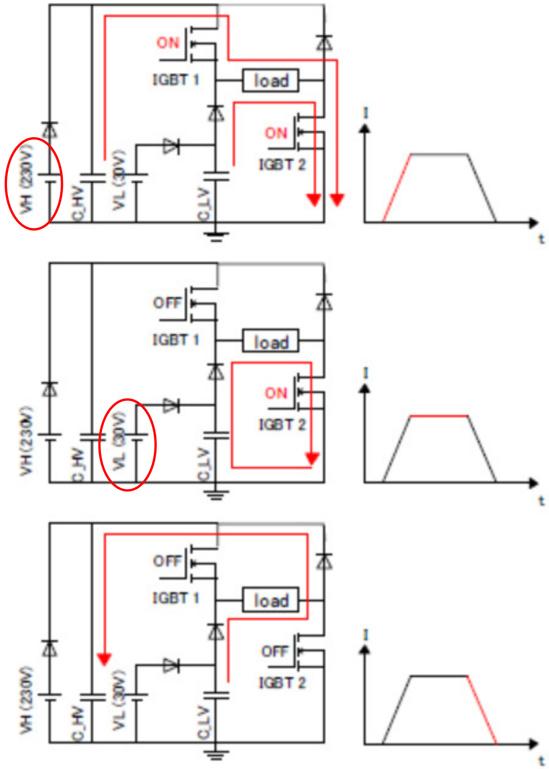
Maximum design current of steering magnets are 40 A but operated at 10 A

Y. Enomoto @LINAC2018

Energy recovery pulse driver for Q magnet

parameter	value
max current	330 A
max voltage	230 V
stability	0.1%
cooling	water cooled
power consumption	1500 W
repetition	50 Hz





Charging of magnetic field

- Power is supplied from HV PS.

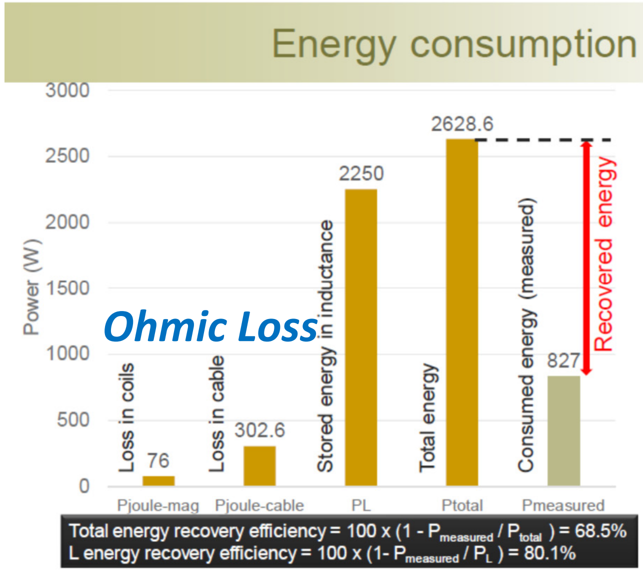
Keeping the flat-top

- 6 ms flat-top
- 0.1% stability
- Power is supplied from LV PS.

Energy recovery circuit

- Reduction of the supplied power for next pulse

Operating power of the pulse magnet



	Q (PM_32_4)
t_1 (s)	2.5 m
t_2 (s)	0.5 m
I_{max} (A)	300
L (H)	1 m
R_{mag} (Ω)	7.8 m
R_{total} (Ω) incl. cable	38.83 m
$P_{joule\text{-}mag}$ (W) @ 50 Hz	76
$P_{joule\text{-}cable}$ (W) @ 50 Hz	302.6
$P_{joule\text{-}total}$ (W) @ 50 Hz	378.6
P_L (W) @ 50 Hz	2250
P_{total} (W) @ 50 Hz	2628.6

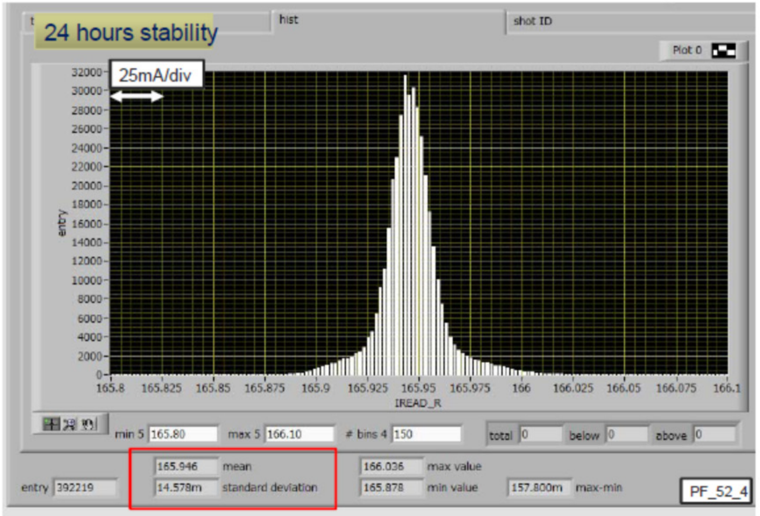
Y. Enomoto @LINAC2018

	rep. rate	gradient	bore diameter	Current	Ohmic loss	Stored energy	recovery rate	Total Power		
								no recov.	with recov.	
LINAC Pulse Magnet	50 Hz	55 T/m	20 mm	300 A	380	2250	0.800	2630	830	*50% duty factor*
	5 Hz				38	225	0.107	263	239	*5% duty factor*
ATF2 CW magnet		35 T/m	32 mm	75 A				750		

- In 5Hz operation, energy recovery efficiency is not high because of the time interval between the arrival of the next pulse.
- Compared to the power consumption of similar size magnet in ATF, the power consumption can be **reduced to roughly 1/3**.
- However, since the Ohmic Loss of the cable accounts for a large percentage of the power consumption of the pulse magnet, the exact value cannot be determined without a trial calculation that includes the power supply layout.

Stability of the pulse magnet

Pulse-by-Pulse Stability measurement



0.014578 / 165.946 = 0.0088% (requirement 0.1 % @ 330 A)

Y. Enomoto @LINAC2018

Stability of the pulse magnet of SUperKEKB Linac

Pulse-by-pulse stability (measurement)	0.0088%
Flat-top stability (design)	0.1%

- RTML simulations have been performed assuming a magnet stability of 1e-5 at the ILC.
- It is difficult to require a stability of 1e-5 for many pulsed devices, not just pulsed magnets.
- This value was assumed during the simulation, and is not the tolerance that is actually required for the magnet.
- **It is necessary to estimate what level of stability is acceptable.**

Summary

The possibility of operating power reduction for the warm magnet of RTML is roughly evaluated with the pulse magnet used in SuperKEK linac.

It was found that the power consumption can be reduced to roughly 1/3 by comparing to that of similar size magnet in ATF.

However, the strength stability of the pulse magnet is about 1e-3 at flat top, and the pulse-by-pulse stability is just under 1e-4, which is larger than the 1e-5 used in the ILC RTML simulation.

The value of 1e-5 was assumed during the simulation, and is not the allowable value that is actually required for the magnet.