Investigation on the Ultra-high Field Flux Pumped superconducting magnets

Chao Li
University of Cambridge
Outline

1. Why is flux Pumping
2. What is flux pumping
3. How is flux pumping
1. Why is flux Pumping
2. What is flux pumping
3. How is flux pumping
Why is flux pump

superconducting maglev train

Large Hadron Collider

superconducting coil gun
Why is flux pump

MRI: 1-10T

the uniformity of magnetic field: 0.1ppm/h

400 Amp Cu Vs YBCO

Limitation of HTS: 1. low-resistance joints 2. flux creep
Why is flux pump

LTS: wire, low-resistance joint

HTS: coated conductor, high resistance joint

NMR: above 20T, LTS plus HTS or copper

World record: 45.5T national laboratory in USA
Outline

1. Why is flux Pumping
2. What is flux pumping
3. How is flux pumping
Travelling wave flux pump

Rotating magnets type

Linear type:
Transformer-rectifier flux pump

\[ V(t) = iR_2(t) - v_2(t) = \frac{v_1(t) + v_2(t)}{R_1(t) + R_2(t)} R_2(t) - v_2(t) \]

\[ V_{DC} = \frac{1}{T} \int_0^T v(t) \, dt = \frac{1}{T} \int_0^T \frac{-d\Phi}{dt} \, dt \]

**Resistance constant**

\[ V_{DC} = \frac{1}{T} \frac{R_2(t)}{R_1(t) + R_2(t)} \int_0^T -d\Phi \, dt = 0 \]

**Resistance inconstant**

\[ V_{DC} = (p_{\text{dec}} - p_{\text{inc}}) \Delta \Phi \neq 0 \]

Transformer-rectifier flux pump

\[
\Delta \phi_{on} = (I_p - i_L)R_{dyn}pT - i_L R_L pT
\]

\[
\Delta \phi_{off} = -i_L R_L (1 - p)T
\]

\[
\frac{\Delta \phi}{T} = L \frac{i_L}{dt} = I_p R_{dyn} p - i_L (R_{dyn} p + R_L)
\]

\[
A = I_p / (1 + R_L / R_{dyn} p)
\]

\[
\tau = L / (R_L + R_{dyn} p)
\]
Outline

1. Why is flux Pumping
2. What is flux pumping
3. How is flux pumping
Key technology in flux pumping

1. Novel design for persistent current switch (PCS)

Key technology in flux pumping

2. Second harmonic analysis to avoid the quench of PCS

\[ \Phi_{\text{per_cycle}} = 2(B_a - B_{a,th})aI_tw/I_c \]

\[ V_{\text{DC}} = f \Phi_{\text{per_cycle}} = 2f(B_a - B_{a,th})aI_tw/I_c \]

\[ R_{\text{dyn}} = V_{\text{DC}}/I_t = 2awf(B_a - B_{a,th})/I_c \]

J Geng, C Li, “AC field controlled impedance: Response speed and electric field value”, IEEE Trans. Appl. Supercond. 27 (6), 2017

C Li, Tim, “Second harmonic in the voltage of dc-carrying YBCO tape under alternating magnetic field”, Physica C 2019
Key technology in flux pumping

3. The secondary resistance

\[ \phi_{out} < \phi_{in} \leq \phi_{out} + \phi_{load} \]

Thank you