Development of Very-Short-Period Undulators

1. Target & Circumstances
2. Formation of a “very short period” field
3. Field measurement & characterization
4. Magnet elongation
5. Observation of the first light

Photon Factory, KEK
Shigeru YAMAMOTO
1. Target & Circumstances

Development of very-short-period undulators

Target: Produce the higher energy photons by the shorter period of an undulator ($\lambda_u$) with the lower (1st) harmonic and the lower energy LS

If $\lambda_u = 4\text{mm}$ possible, 12keV-photons by 1st harmonic @ 2.5GeV LS

Background: In KEK we invented and constructed the In-Vac Undulators to reduce $\lambda_u$

In other institutes: 3G LS (SPring-8, ESRF, APS): In-vac Us ($\lambda_u$~several cm)
Compact 3G LS: In-vac Us ($\lambda_u$~2 cm)
1. Target & Circumstances

In KEK we constructed the In-Vac Us to reduce the period length:

- In-vac Us ($\lambda_u=4\text{cm}$)
  @ 6.5GeV PF-AR (since 1989)

- In-vac Short Gap Us ($\lambda_u\sim 2\text{cm}$)
  @ 2.5GeV PF (2003-08)

What is the next target of $\lambda_u$?

Very short $\lambda_u = \text{several mm (4mm)}$

= several cm (ordinary type) $\times 1/10$
1. Target & Circumstances

Reduction of $\lambda_u$ at PF/KEK

History of the undulator development in PF/KEK

- Out-vac @ 2.5GeV PF
- Out-vac @ 6.5GeV AR
- In-vac @ 6.5GeV AR
- In-vac @ 2.5GeV PF

Target of Very-Short-Period U $\lambda_u=4\text{mm}$

10 times shorter $\lambda_u$
2. Formation of a “very short period” field: multi-pole magnetization

How to fabricate very short period undulator magnets

Direction of pulsed current

Electromagnet (2600V x 15kA)

Magnet plate made of NdFeB (NEOMAX)

Perpendicular geometry:
Similar to a perpendicular magnetic recording method in a recording media
2. Formation of a “very short period” field: multi-pole magnetization

In a gap between a pair of the magnets

Magnetization #1
Magnetization #2

$\lambda_{\text{u}}$
To achieve a simple development, a step-wise multipole magnetization was adopted in the perpendicular geometry.

The plate magnet is driven stepwise by a linear motor and the plate is magnetized at each step by the fixed head, which is excited by the pulsed current.

The step width of the linear motion is set to a half of the period length (2mm). At each step of the plate movement, the current direction is reversed to form the 4mm period length.
2. Formation of a “very short period” field: *multi-pole magnetization*

Plate type undulator magnets with a very-short-period undulator field

Field pattern seen through a magnetic viewer sheet

(a) 100mm long, 20mm wide, 2mm thick; 25 periods

(b) 152mm long, 20mm wide, 2mm thick; 38 periods

NMX-39EH TiN coated (Br =12kG, iHc=25kOe)
20mm wide, 2mm thick

Reduction of magnet volume enables the downsizing & weight reduction of the total undulator system
3. Field measurement & characterization

Measurement @ fixed gap=1.6mm

Hall probe ~1.3mm thick with 0.05 x 0.05 mm² resolution
Gap > 1.6mm
3. Field measurement & characterization

Measured ($\lambda_u=4\text{mm}$) @ gap = 1.6mm

Electron orbit @ 2.5GeV
3. Field measurement & characterization

Measured ($\lambda_w=4\text{mm}$) @ gap =1.6$^+\text{mm}$

Electron orbit @ 2.5GeV
3. Field measurement & characterization

Measured field is compared to ideal field with the same strength.

Undulator field ($\lambda_u = 4\text{mm}$) of 3800G @ gap=1.6mm
4. Magnet elongation

We need a new method to elongate the undulator length by connecting magnets, since the magnets longer than 200mm may not easy to fabricate.

Two plates are magnetized independently and then connected longitudinally.

NMX-39EH TiN coated (Br =12kG, iHc=25kOe)
100 long, 20mm wide, 2mm thick
4. Magnet elongation 1

Connection of magnet plates magnetized independently

Measured ($\lambda_u=4\text{mm}$) @ gap = $1.6^{+1}_{-1}\text{mm}$

Electron orbit @ 2.5GeV
4. Magnet elongation 2

Magnet plates magnetized as one plate

F7F8&F9F10; (100+100) x 20x 2mm³, λu = 4mm

Electron orbit @ energy of 2.5GeV
4. Magnet elongation 2

Measured field is compared to ideal field with the same strength.

Undulator field ($\lambda_u = 4\text{mm}$) of 4720G @ gap=1.2mm
4. Magnet elongation 2

(a) Magnetic field $B_y$ (T) as a function of $z$ (m).

(b) Electron orbit at energy of 2.5 GeV as a function of $z$ (m).

F1-F5 & F6-F10: $(100 \times 5) \times 20 \times 2 \text{mm}^3$, $\lambda_u = 4 \text{mm}$

Gap = 1.6 mm
4. Magnet elongation 2

Measured field is compared to ideal field with the same strength.

Undulator field ($\lambda_u = 4\text{mm}$) of 4230G @ gap=1.6mm
4. Magnet elongation 2: construction of mechanical frames

Very-short-period Undulator#1 for use @ Tohoku Univ.
Very-short-period Undulator#3 for the use in Laser-wake filed acceleration facility @ SP-8
5. Observation of the first light

First beam observation @ Tohoku Univ. t-ACTS S-band linac

Linac: 2Hz operation
E = 34MeV
1 macro-pulse =3.5pC x 5700 μbunch
εₙ = 1mm mrad (H), 3mm mrad (V)
σₚ = 250μm

Beam trans. > 90% @ gap = 1.7mm
5. Observation of the first light

Installation of 100-mm long magnets into the frame of the Very-short-period Undulator #1

- Magnet holder
- Cu mask for protection
- Plate magnet
- e-beam
We have been resolving major subjects and taking the right direction to develop the very short period undulators.

We have very clear perspective to make a very-short-period but long undulator magnet.

Also, we believe that the present successful result of the first light observation will be followed by the experiments combined with a laser-accelerated electron beam in the near future.

I am happy if this technology is useful to compactify light source system including FEL & ring type SR sources.
R&D for the very short period undulators

supported by:

First light observation @ Tohoku Univ. supported by

H. Hama, S. Kashiwagi, F. Hinode, T. Mutoh, K. Nambu