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EXTENDING OK5 WIGGLER OPERATIONAL LIMIT AT DUKE FEL/HIGS FACILITY*

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Abstract

Since 2007 the HIGS facility has been operated to produce both linearly and circularly polarized gamma-ray beams using two FELs, the planar OK-4 FEL and helical OK-5 FEL. Presently, with the OK-5 FEL operating at 192 nm, we can produce circularly-polarized gamma-ray beams between 1 and 100 MeV for user applications. Gamma-ray production between 80 and 100 MeV required an extension of the OK-5 wiggler operation beyond the designed current limit of 3.0 kA. In 2009, we upgraded cooling and machine protection systems to successfully extend OK-5 operation to 3.5 kA. To realize HIGS gamma-ray operation beyond 100 MeV and ultimately toward 150 MeV (the pion-threshold energy), with various limitations of the VUV mirror technology, the OK-5 wigglers will need to be operated at an even higher current, between 3.6 and 4.0 kA. In this paper we present our technical solution to further extend the operation range of the OK-5 wigglers, and report our preliminary results with high-current wiggler operation.

BACKGROUND

Need for Higher Wiggler Current

The energy of gamma-rays produced in the Duke Free Electron Laser (FEL) depends on the FEL lasing wavelength, the energy of the stored electron beam, and the magnetic field strength of the wiggler magnets [1]. The maximum gamma energy at the High Intensity Gamma Source (HIGS) currently available for users is 100 MeV, using 190 nm FEL mirrors and operating with 1.05 GeV electrons and a current of 3.5 kA in the OK-5 wigglers. There are important experiments which need higher energy gammas (eg. proton spin polarizability), up to 110–120 MeV. Having no expectation in the short-term of obtaining robust and highly reflective mirrors for shorter wavelengths, nor of a significant increase of the electron beam energy in the storage ring, we need to identify ways to operate the wigglers at higher currents.

The main design and operational parameters of the OK-5 wigglers are given in Table 1.

Table 1: Parameters for OK-5 Wigglers

Polarization	Circular
No. of wigglers	4
No. of regular periods	30
Wiggler period [cm]	12
Maximum current [kA]	3.5
Maximum magnetic field [kG]	3.17
Maximum K_w	3.53
FEL wavelength [nm]	190 - 1064

Figure 1: T-Rex power supplies at Duke FEL.

2009 Upgrade

Prior to 2009, operating the wigglers at the design maximum of 3.0 kA, and using the shortest wavelength of conventional mirrors (240 nm), the maximum gamma energy was limited to 60 MeV. Raising the wiggler current up to 3.6 kA, gamma energies of 70 MeV would be achievable. Testing showed that operation above 3.0 kA tripped the magnet over-temperature switches (65 °C Klixons), and a new set was installed (90 °C). Next, we found that long-term operation above 3.5 kA increased the resistance of the magnet coils and connecting bus bars enough that the TRANSREX (T-Rex) power supply (see Figure 1) reached the maximum output voltage limit (about 100 V) when driving two wigglers in series, which limited wiggler current to 3.5 kA. The final steps of the upgrade were to add water flow switches to the cooling water return flows as protection against sudden loss of water flow, and to install new, faster response-time

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temperature sensors on the cooling water return flows to allow real-time monitoring of wiggler heating.

Wiggler Cooling Water

Each wiggler contains 8 coils of hollow square copper tubing which wind through the 120 poles in the magnet, and cooling water flows through each of these coils (see Figure 2). The cooling water supply has been controlled at 29 °C, and the temperatures of the return flows range from 40 to 59 °C with 3.5 kA of wiggler current. This range of return flow temperatures is thought to arise from the different lengths of the coils (average 20 m long each), and from differences in the inner cross-sectional areas at different points resulting from the fabrication process of bending the coils to fit around the wiggler magnet poles. Raising wiggler currents from 3.5 to 4.0 kA will increase resistive heating by 30%, and could raise the return flow maximum temperature another 10 °C or more.

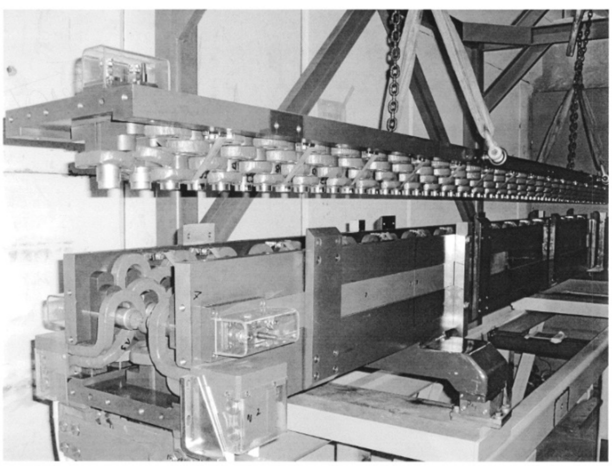

Figure 2: OK-5 Wiggler Coils.

Reconfiguration of Bus Bars

During the installation of a mechanical switchyard for the wigglers in 2012 [2], the bus bars and cables connecting the T-Rex power supplies to the wigglers were reconfigured to allow much more flexibility (see Figure 3). In the new arrangement, we can configure which of the two T-Rex power supplies would drive current through which of the four wigglers. Possible scenarios are linking two T-Rex in series to drive four wigglers linked in series, down to each T-Rex driving only one of the four wigglers.

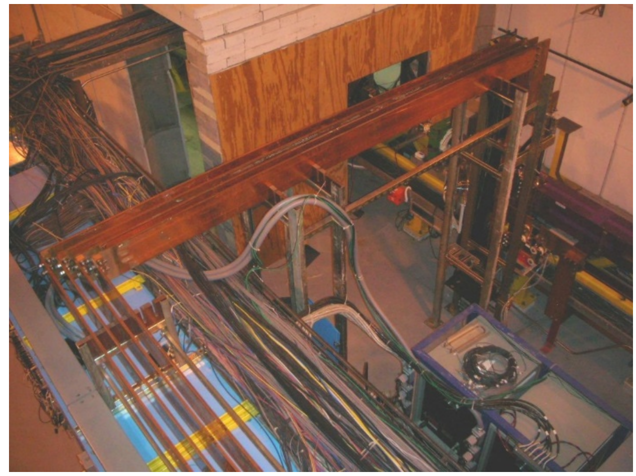

Figure 3: Section of copper bus bars between T-Rex and wigglers.

2014 TEST

OK-5 wiggler operation with currents over 3.5 kA requires that one T-Rex drives current through only one wiggler, due to the T-Rex voltage limitation. To keep the wiggler return flow temperature well under 100 °C, as well as under the 90 °C klixon temperature trip point, we ran the first test by reducing the cooling water control point (the supply temperature) to 21 °C (8 °C below the routine operational temperature).

Tests at 3.5 kA and 4.0 kA

Data were collected on cooling water supply and return temperatures, and the temperatures of all return flows in two OK-5 wigglers and in the two T-Rex power supplies. Figure 4 shows a graph of the temperatures of the eight wiggler coil cooling water return flows in one wiggler operating at 3.5 kA and 4.0 kA with the control temperature set to 21 °C, and then at 3.5 kA with the control temperature set to 29 °C. The temperature rise of the eight return flows with 3.5 kA wiggler current and supply temperature set to 29 °C vs. 21 °C averages 6.2 °C (range from 5.0 to 7.7 °C). The return flow temperature rise with 21 °C supply temperature of 4.0 kA vs. 3.5 kA wiggler currents averages 8.9 °C (range from 5.5 to 12.2 °C). There were no magnet over-temperature interlock trips during the hour of operation at 4.0 kA.

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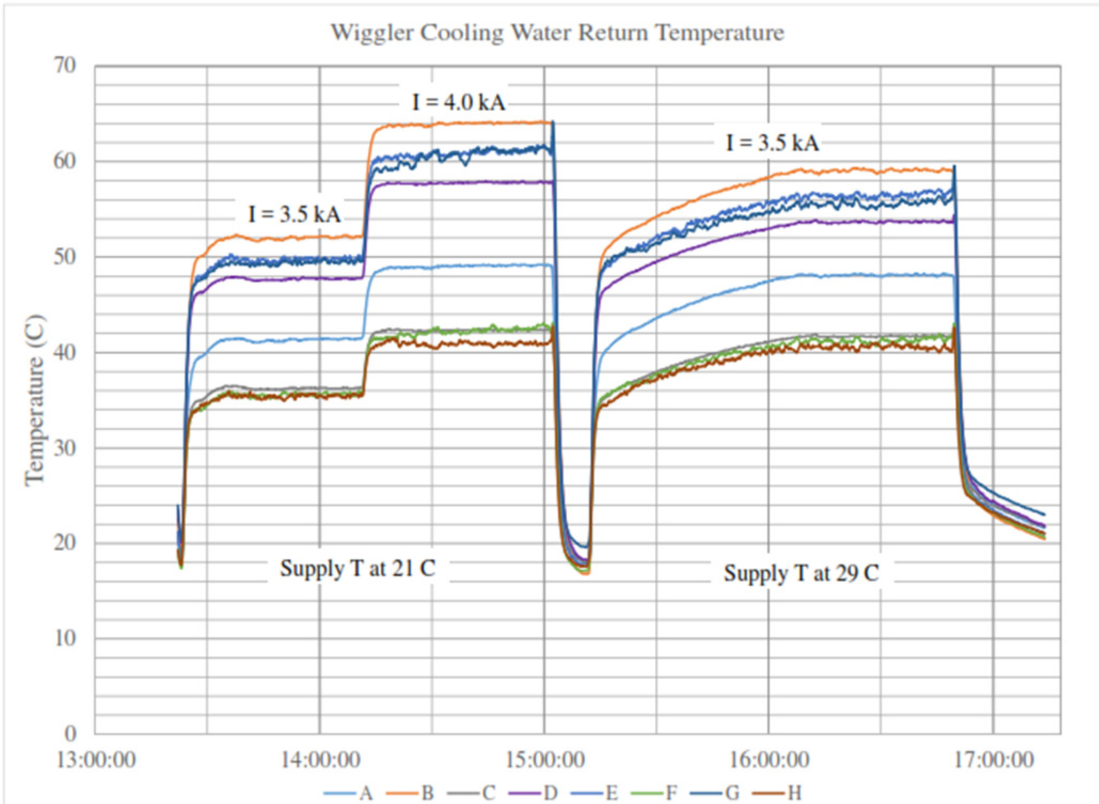

Figure 4: Return temperatures of eight wiggler coils (A-H) in one wiggler. In the left half, the supply temperature was set at 21 °C and the wiggler currents were set to 3.5 and 4.0 kA respectively. In the right half, the supply temperature was set at 29 °C and the wiggler current was set at 3.5 kA.

CONCLUSIONS

There will need to be further tests at 4.0 kA before we can provide routine operation at this setting. Additional tests will use longer test times (over 4 hours) and simultaneous operation of the storage ring at high energy (> 1.0 GeV), while studying potential difficulties with the electron beam orbit and achieving lasing of the FEL. Also, since lowering the cooling water temperature will change the temperature in all magnets, power supplies and accelerator vacuum chambers, there will need to be a major re-tuning of the storage ring and injection booster.

For long term operation with the control point set to 21 °C, we must also upgrade the cooling water system, switching from a conventional evaporative cooling tower to the campus-wide Duke University Chilled Water system. Implementation of the cooling system change is expected in the later part of 2015.

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