ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPM125

STUDY ON A SELF-RESONATING OPTICAL CAVITY FOR HIGH-BRIGHTNESS LASER-COMPTON SCATTERING X-RAY SOURCES

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Abstract

Laser Compton Scattering (LCS) is a technique to produce quasi-monochromatic X-rays and gamma rays by colliding a laser with a high-energy electron beam produced by an accelerator. Although LCS light sources are expected to produce photons of the same quality in a small (6 m x 8 m) device as those from large synchrotron radiation facilities, the low number of scattered photons is an issue for practical use. To solve this problem, we have developed an optical cavity to generate colliding lasers with high repetition rate and high peak power. However, the operation of an optical cavity in an accelerator environment with high noise limits the stored optical power by maintaining resonance through resonator length control. Therefore, we have devised and are developing a self-resonating optical cavity in which the resonance is maintained spontaneously by connecting the optical storage resonator and the laser oscillator in a closed loop. In this talk, I will report on the status of self-resonating optical cavity and its temperature dependence.

INTRODUCTION

Laser Compton Scattering (LCS) is a technique to produce X-rays by collision of a high-energy pulsed electron beam produced by an accelerator and a pulsed laser. The LCS light source is expected to realize high quality X-ray generation with energy tunability and high directivity in a small device (about 6 m x 8 m), which has been possible only in large synchrotron radiation facilities. Since the amount of scattered light in the LCS is proportional to the intensity of the colliding pulse laser and the number of collisions per unit time, it is necessary to develop an optical cavity that can generate intense and highly repetitive pulsed laser pulses. Figure 1 shows a schematic diagram of the LCS.

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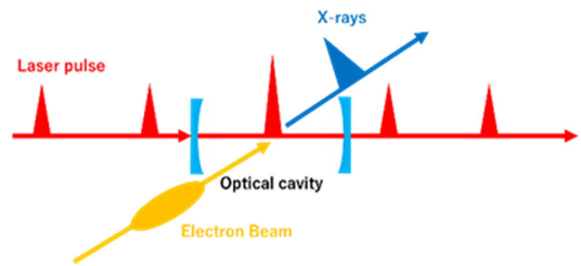

Figure 1: Schematic of laser-Compton scattering using an optical cavity.

However, it is difficult to maintain resonance for a long period of time in a high-magnification optical storage resonator by means of cavity length feedback control due to high environmental noise in accelerator facilities, and this has been a challenge. The required control accuracy is on the order of pm.

SELF-RESONATING OPTICAL CAVITY

Conventional optical cavity work by storing and increasing light from an oscillator in an external resonator [1]. In this method, the position of the resonator mirror is controlled by a piezoelectric element or the like, and the resonance condition.

$$L_{cav} = n\left(\frac{\lambda}{2}\right), (n: integer) \quad (1)$$

Equation (1) is satisfied to accumulate light. If the rate of increase of the resonator is increased to accumulate more light, it becomes sensitive to disturbances such as vibration and temperature changes, and maintaining resonance by controlling the cavity length becomes extremely difficult. To solve this problem, we have been developing a self-resonating optical cavity that incorporates a new mechanism called "self-resonating". As shown in Fig. 2, this resonator uses a system in which the cavity and amplifier are integrated. The spontaneous emission from the amplifier (gain medium) is used as the starting point of oscillation, and when this is injected into the cavity, a component satisfying the resonance condition is accumulated. Since the light transmitted through the cavity always satisfies the resonance condition, the light is amplified and repeatedly injected back into the cavity, and only light that satisfies the resonance condition spontaneously oscillates and resonates.

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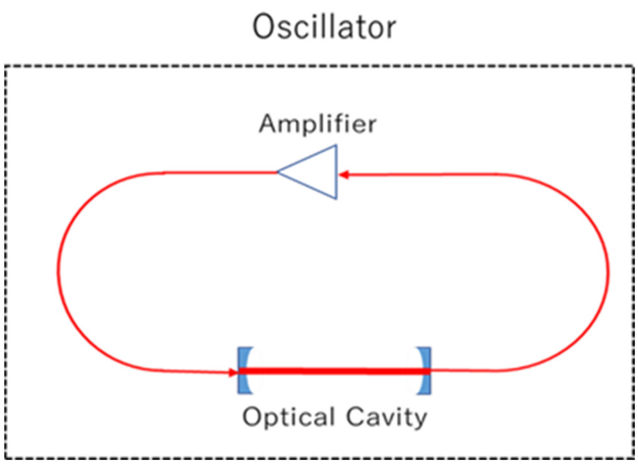

Figure 2: Schematic of a Self-Resonating Optical Cavity.

EXPERIMENATAL SETUP

For application to LCS light sources, it is necessary to accumulate a pulsed laser with high peak power that matches the repetition rate of the electron beam. In other words, it is necessary to perform pulsed oscillation in a self-resonating optical cavity. To achieve this, a supersaturation absorption mechanism that selects only the high-intensity pulse component in the fiber (blue line in Fig. 3) and a pulse overlap condition, in which the pulse that travels back and forth in the cavity and the pulse that travels once around the outer loop overlap in the cavity, are required. This pulse overlap condition is expressed as follows using the cavity repetition frequency f_{cav}, the fundamental repetition frequency f_{loop} of the outer loop, the cavity length L_{cav}, and the outer loop length L_{loop}.

$$f_{cav} = n\, f_{loop} \Leftrightarrow L_{loop} = n \times 2L_{cav}, (n: integer) \qquad (2)$$

In this study, with a view to LCS with a 357 MHz repetition rate electron beam, we constructed an experimental setup aiming at self-resonating mode-locked oscillation at around 357 MHz, which is a higher repetition rate than in the previous study [2]. A schematic diagram of the experimental setup is shown in Fig. 3.

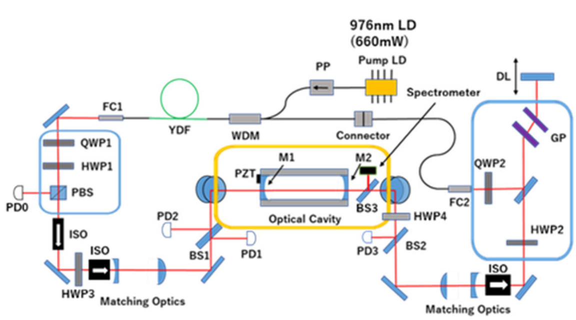

Figure 3: Schematic of the experimental setup.

MODE-LOCKED OSCILLATION AND ENVIRONMENATAL TEMEORATURE

In order to discuss the environmental temperature dependence of the spontaneous resonant mode-locked oscillation, we show here the oscillation without the environmental temperature stabilization mechanism. Figure 4 below shows the stored light intensity accumulated in the resonator over 4000 s, and Fig. 5 shows the laboratory temperature at the same time.

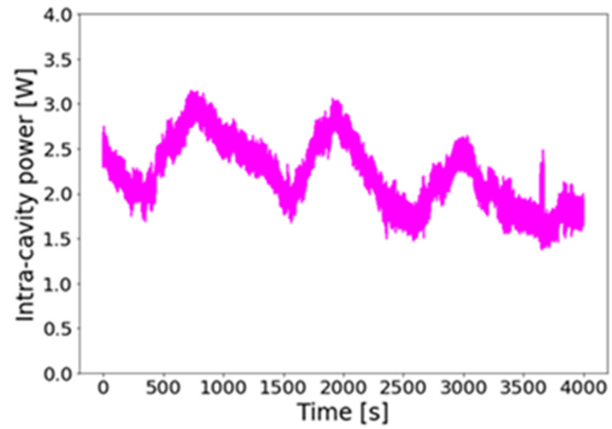

Figure 4: Time stability of Intra-cavity power.

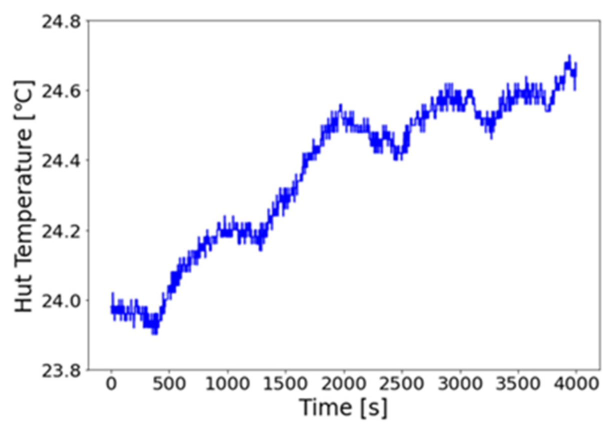

Figure 5: Room temperature log.

Figure 5 shows that the laboratory temperature during the same time (4000 s) changed in a similar manner to the stored light intensity. This result suggests that changes in environmental temperature may affect the stability of laser oscillation. The following considerations are made. First, changes in environmental temperature cause changes in the cavity length and external loop length, resulting in deviations from the pulse overlap condition in Eq. (2). Next, a deviation occurs between the FSR (Free Spectral Range) of the entire loop and the FSR of the resonator, and among the longitudinal modes that can oscillate in the entire loop, the longitudinal modes that deviate from the center frequency are not accumulated in the cavity as much. The more longitudinal modes that are shifted from the center frequency among the longitudinal modes that can be oscillated in the entire loop, the less they are stored in the cavity. Based on this consideration, we have been working on

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stabilizing the environmental temperature to further stabilize the oscillation.

Mode-locked Oscillation after Temperature Stabilization

Considering that changes in ambient temperature affect the stability of laser oscillation, we took two measures to stabilize the ambient temperature in our experimental setup. The first was the installation of water-cooled heat sinks. Nineteen of them were placed on the optical table to stabilize the temperature by water cooling. The second was the installation of Styrofoam in the box covering the optical table. The Styrofoam provides thermal insulation, and thus the temperature of the experimental setup is not affected by the external ambient temperature. The results obtained after these measures were taken are shown below; Fig. 6 shows the evolution of the stored light intensity for 4000 seconds, and Fig. 7 shows the evolution of the ambient temperature at the same time [3]. The temperature change at each location of the experimental setup was successfully suppressed to less than 0.14°C. The RMS stability of accumulated light intensity improved from 12.9% to 5.9%. Currently, further environmental temperature stabilization has been carried out and environmental temperature changes have been successfully suppressed to less than 0.1°C.

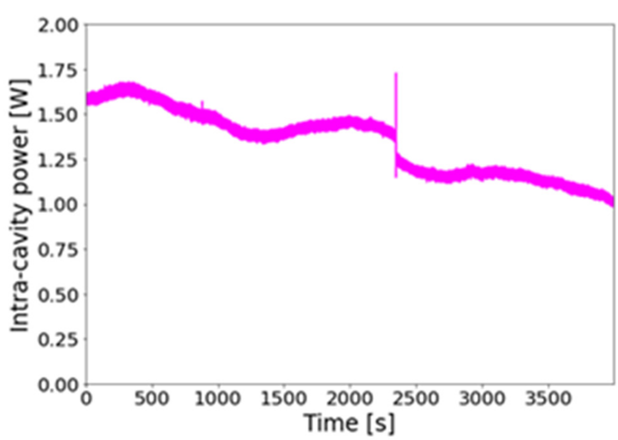

Figure 6: Time stability of Intra-cavity power after stabilizing setup's temperature.

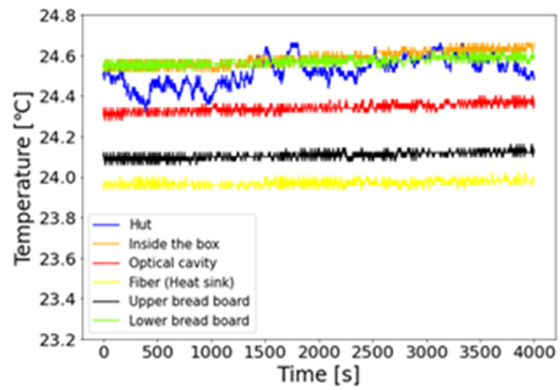

Figure 7: Temperature log of 6 points of experimental setup.

CONCLUSION

In this study, we are developing a self-resonating optical cavity for laser Compton scattering light sources. Currently, using a cavity mirror with a reflectivity of 99.0 %, we have successfully achieved 4000 s of self-resonating mode-locked oscillation with a stability of 5.9 % in the mode-locked oscillation part. To improve the stability of the oscillation, efforts toward temperature stabilization were made and the ambient temperature was suppressed to 0.1 °C or less. In the future, we would like to reproduce the mode-locked oscillation with the current setup, in which the temperature stabilization efforts have been completed, and conduct an experiment in which the laser is sent to the LUCX (small electron accelerator) at KEK to be used as a master oscillator.

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