IMPROVEMENT OF THE POSITION MONITOR USING WHITE LIGHT INTERFEROMETER FOR MEASURING PRECISE MOVEMENT OF COMPACT ERL SUPERCONDUCTING CAVITIES IN CRYOMODULE

Hiroshi Sakai[#], Kazuhiro Enami, Takaaki Furuya, Masato Satoh, Kenji Shinoe, Kensei Umemori, KEK, Tsukuba, Ibaraki, Japan
Masaru Sawamura, JAEA, Tokai, Naka, Ibaraki, Japan
Enrico Cenni, The Graduate University for Advanced Studies, Tsukuba, Ibaraki, Japan
Tomohiro Aoto, Kyohei Hayashi*, Tsutomu Kanzaki, Tokyo Seimitsu Co. LTD, Tsuchiura, Ibaraki, Japan

Abstract

Alignment of superconducting cavities is one of the important issues for linear collider and/or future light source like ERL and X-FEL. To measure the cavity displacement under cooling to liquid He temperature more precisely, we newly developed the position monitor based on the measurement of the interference of light between the measurement target and the reference point. We applied this monitor to the main linac cryomodule of Compact ERL (cERL) and successfully measured the displacement during 2 K cooling with the resolution of 10 µm [2]. However, some drift come from outer temperature were observed. In this paper, we describe the upgraded version of this monitor.

INTRODUCTION

R&D of superconducting cavity and cryomodules are in progress for next generation light source like energy recovery linac (ERL) and a future linear collider. For these accelerators, the precise cavity alignment is necessary to keep highly stable beam operation. Wire monitor is one of the candidates for monitoring cavity displacement. However, wire monitor have some disadvantages of, for example, wire break and measured accuracy limitation [3]. To monitor the displacement of cavity under cooling precisely and stably, we newly developed the position monitor based on the interference of white light, named as WLI monitor.

We first installed this WLI monitor to the cERL main linac cryomodule and successfully measured the cavity displacements under 2 K cooling within +-10 µm level in Dec. 2012 [2]. In principle, this WLI monitor was based on the peak detection of the interference pattern when distances of the measured target and the reference mirror are the same. While we keep the peak detection under scanning the reference mirror precisely, we know the relative displacement of the target at every second as shown in Figure 1. Detailed setup was expressed in Ref.[1]. It makes possible to measure precise cavity position from the outside of the cryo-vessel, through a small view port. From these measurements, the displacements of cavity center from room temperature to 2 K were estimated to be less than 0.4 mm. And we found that this value was within our alignment tolerance. During first measurements in Dec. 2012, this WLI monitor was set on the cERL beam line, shortening the fiber length from WLI control unit to the target and/or reference mirror to overcome the measured position error comes from the thermal drift of the spectrum change of ASE light source with temperature and temperature dependence of the optical path lengths between the reference fiber and the target. Therefore, we needed to set the whole system including PC inside the cERL beam line. During high power test, unfortunately, we had to stop the measurement to escape them from the radiation come from the cryomodule. In order to measure the displacements during high power test and beam operation for a long time, we need to lengthen the fiber to set the whole system including PC to the outside of the beam line. This situation led us to improve this WLI monitor.

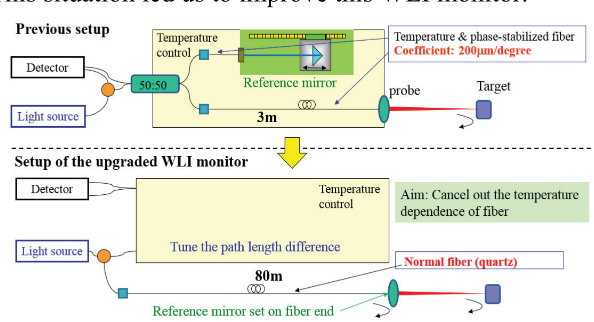

Figure 1: Setup of the previous WLI monitor (above) and upgraded WLI monitor (below).

Our idea to improve this WLI monitor is that the reference mirror was set on the same path to cancel the temperature dependence come from the deference path of the reference mirror and the target as shown in the below figure of Figure 1. Our requirements of improvements of this monitor are summarized in Table.1.

Table 1: Requirements of Upgraded WLI Monitor

Parameters	Achieved value	Requirements of new WLI monitor
Stability	+-10µm @25°C+-0.5°C	+-10µm @25°C+-5°C
Fiber length	3 m	More than 80 m
Measurement points	2ch (1 position of x-y values)	4ch (2 positions of x-y values)

[#]hiroshi.sakai.phys@kek.jp, *kyohei.hayashi@accretech.jp

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PERFORMANCE OF THE UPGRAGED WLI MONITOR

Figure 2 shows the picture of the setup of the upgraded WLI monitor at a test bench [4].

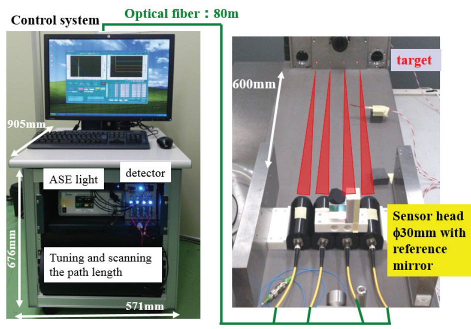

Figure 2: Setup of upgraded WLI monitor at test bench.

We used the same ASE light source of 100 mW for a white light source. All optical paths are given by the optical fiber made of quartz. One of the differences from the previous setup are the reference mirror point set the end of fiber of the sensor head. Four measured sensor heads were equipped on upgraded WLI monitor to increase the monitor points in cryomodule. This is another upgraded point of this monitor. Finally the path length of reference line was controlled by the scanner with less than 1 μm resolution and reproducibility at control system as shown in the left of Figure 2. The interference of the reflected lights between the reference and the target was measured by the AD counter on PC via the balanced detector with the electric filter as a function of the position of the reference light scanner.

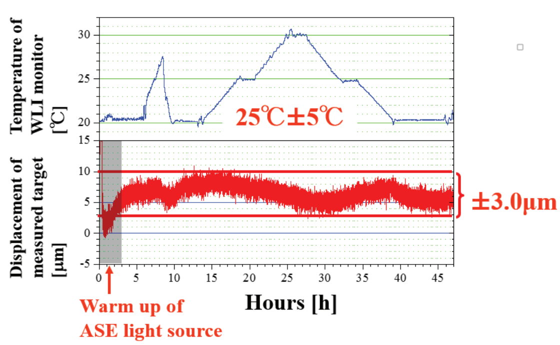

Figure 3: Measured results of upgraded WLI monitor at a test bench. Vertical axis shows the measured temperature at WLI monitor (top) and the displacement (down) of this monitor corresponding with the elapsed time (hour).

Figure 3 shows the measured displacement under changing the room temperature of 25°C+-5°C when the target was fixed at the table made of invar to keep the distance within 1μm under temperature control. We found that the temperature dependence was much reduced within +-3μm level for more than 40 hours even if the length of the optical fiber of 80 m was much longer than previous setup of 3 m and the temperature of WLI monitor was changed from 20 °C to 30 °C. We expressed that the temperature dependence of the different path length between the target and reference mirror was drastically cancelled out by setting the reference mirror point on the same path to the target.

MEASUREMENTS OF THE CAVITY DISPLACEMENTS IN CRYOMODULE

After the performance test, we installed the upgraded WLI monitor to the cERL main-linac cryomodule again. Figure 4 shows the detailed cryomodule structure of cERL main-linac with 8 alignment targets [2]. The detailed setup was same as the previous one expressed in Ref[1]. Not only the target of #1 set on the upstream of the cryomodule but also the target of #4 on the downstream were used for monitoring the movement of cavities by the WLI monitor to monitor not only the displacement of two cavities set on the 5K frame but also the tilting of the 5K frame in the cryomodule as shown in Figure 4 under 2K cooling and beam operation.

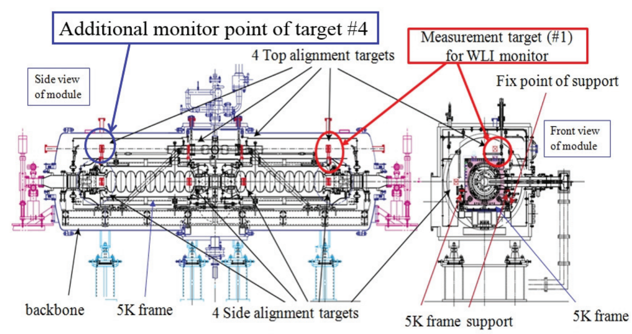

Figure 4: Detailed cross sections of the cERL main linac cyomodule with 8 alignment targets including the monitoring target (#1) & (#4) by upgraded WLI monitor.

In 2013, we constructed the injector parts and the return loop of cERL[5]. Before the beam commissioning, we cooled down the cERL main-linac cryomodule again in Nov. 2013. First beam commissioning with energy recovery started in 16. Dec. 2013 [6][7] and after one week the cryomodule was warmed up to room temperature in 2013. We continued the beam commissioning again and main linac cryomodule was cooled down to 2 K from 2014.Jan.7 to 2014.Mar.15 and warm up again after beam commissioning.

Figure 5 shows the measured horizontal displacements of target #1 and #4 by the upgraded WLI monitor from 2013.Nov.1 to 2014.Apr.7 under two-times thermal cycles from room temperature to 2 K, respectively. Figure 6 also shows the measured vertical displacements of target #1 and #4 in the same time range of Figure 5, respectively. First of all, this upgraded WLI monitor kept monitoring the cryomodule every 5 seconds for half year during high power test and beam operation including two-times thermal cycles from room temperature to 2 K. We found that the horizontal displacements of target #1 and #4 from room temperature to 2 K were 0.2 mm and 0.3 mm, respectively. The vertical displacements were found to be 1.3 mm. At the previous measurements in 2012, we did not take the continuous data under high power test and warm up to the room temperature. By upgrading the WLI monitor, we could take long-time data during beam operation and found the reproducibility of the cavity displacements with about 50 μm level between after warming up and cooling to 2 K. These values almost agreed well with the measured displacements of target by using the alignment telescope within 0.1mm. We noted that these measurements were carried out under heavy radiation environments come from the field emission of more than 100mSv/h in the cERL beam line for half year.

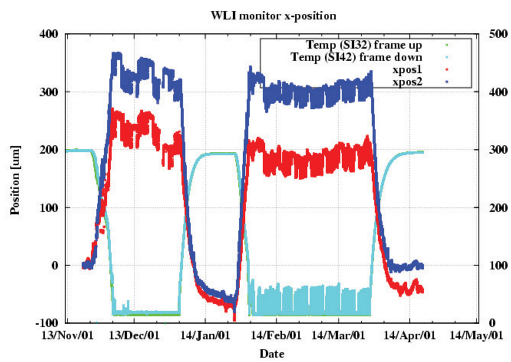

Figure 5: Measured horizontal displacements of the target (#1) (red) and (#4) (blue) under cooling by upgraded WLI monitor with temperature of 5K frame (upper) (light green) & (lower) (light blue), respectively.

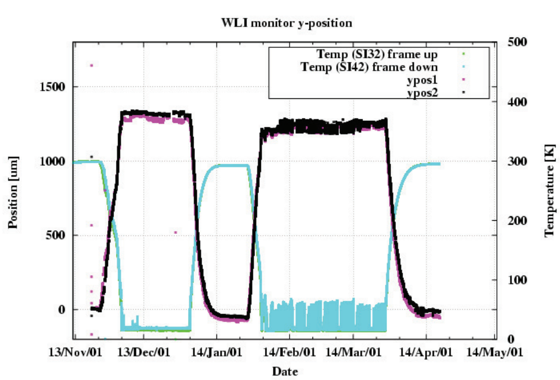

Figure 6: Measured vertical displacements of the target (#1) (pink) and (#4) (black) under cooling by upgraded WLI monitor with temperature of 5K frame (upper) (light green) & (lower) (light blue), respectively.

Figure 7 shows the measured displacements under 2K cooling in detail for 2 days at first beam commissioning. The clear temperature correlations between horizontal displacements and temperature under 2K cooling from 4K were observed. The pumping of the He liquid of cavity for 2K cooling would add finite force to the cavity and make some displacements of the cavity and/or 5K frame. If the temperature was stable to 2K, horizontal position of the superconducting cavity with 5K frame was stably set within +-3 μm, which was as same as the test bench results, for 12 hours. This means our WLI monitor has +-3μm resolution for 12 hours during beam operation. On the other hand, the measured vertical displacement has some drift during beam operation under 2K condition. However, this drift was within 20 μm in 2 days, whose values was much smaller than the requirements of the alignment of cavity. We noted that the vertical drifts was reduced to less than +-5μm at the next cool-down between 2014.Jan and 2014.Mar.

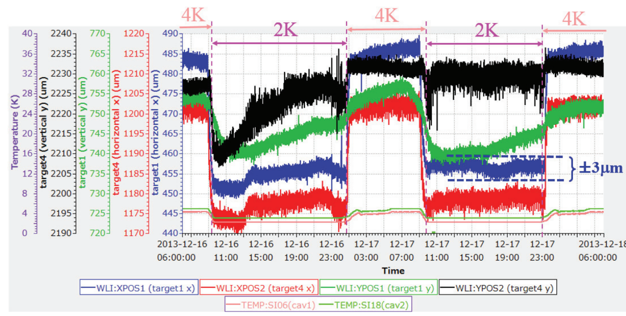

Figure 7: Measured displacements of target #1 and #4 by the upgraded WLI monitor in detail. (Red) horizontal one of target #1, (Blue) horizontal one of target #4, (Green) vertical one of target #1 and (Black) vertical one of target #4 were shown in 2 days. Light green and pink lines show the temperatures of cavities near the target #1 and #4, respectively.

SUMMARY

We upgraded the WLI monitor to escape the monitor system from the field emission come from cryomodule in cERL beam line. By setting the reference mirror on the way from the light source to the target, we drastically cancelled thermal drift come from the fiber of the WLI monitor and found that the resolution of this monitor was 3 μm at a test bench, in spite of the fiber length of 80 m. After the performance test, we installed the WLI monitor to the cERL main-linac cryomodule again. By improving this monitor, we kept monitoring the cryomodule every 5 seconds for half year during high power test and beam operation including two-times thermal cycles from room temperature to 2 K. We found that the horizontal and vertical movements of target set in cryomodule from room temperature to 2K were 0.2-0.3 mm and 1.3 mm, and found the reproducibility of the cavity displacements with 50 μm level between after warming up and cooling to 2 K. The upgraded WLI monitor could monitor the displacements for a long time with +- 3 μm resolutions

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