CAVITY BPM SYSTEM FOR DCLS*

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Abstract

Dalian Coherent Light Source (DCLS) is a new FEL facility under construction in China. Cavity beam position monitor (CBPM) is employed to measure the transverse position with a micron level resolution requirement in the undulator section. The design of cavity, RF front end and data acquisition (DAQ) system will be introduced in this paper. The preliminary measurement result with beam at Shanghai Deep ultraviolet (SDUV) FEL facility will be addressed as well.

INTRODUCTION

In order to meet the growing demands of the biological, chemical and material science research, an increasing number of FEL user facilities have been constructed and being proposed in the world. Dalian Coherent Light Source is a extreme ultraviolet (EUV) coherent light source based on ultra-fast lasers and electron accelerator techniques, it will be the first FEL user facility operating exclusively in the EUV wavelength region based on the principle of high-gain harmonic generation (HGHG) scheme and the aim is to generate the FEL radiation with wavelength range from 50 to 150 nanometer [1].

The DCLS facility is located in the northeast of China and under commission now. The entire facility consists of the following parts:

1. A photo-injector will produce electron pluses of 500 pC with normalized emittance below 1 mm • mrad.
2. The linear accelerator will accelerate the electrons to 300 Mev which consists of 6 S-band accelerator structures and a movable chicane for electron bunch compression.
3. The undulator complex where the seed laser induces an energy modulation for the electron beam in the modulator and then converted into a density modulation in the dispersion chicane, a selected higher harmonic is then amplified in the radiator to generate the FEL radiation with wavelength of 50 ~ 150 nm.
4. The photo beam line and diagnostic line.

For the electron beam in the undulator section, the demanded position resolution is less than 1 um@0.5nC because the electron beam and the generated photo beam must be overlapped in the undulator section for sufficient FEL interaction between them. In SXFEL and DCLS, a C-band cavity BPM worked at 4.70 GHz for both position cavity and reference cavity is employed in order to achieve this requirement. In total, 10 CBPMs were utilized in the undulator sections of the DCLS. The schematic layout is shown in Fig. 1.

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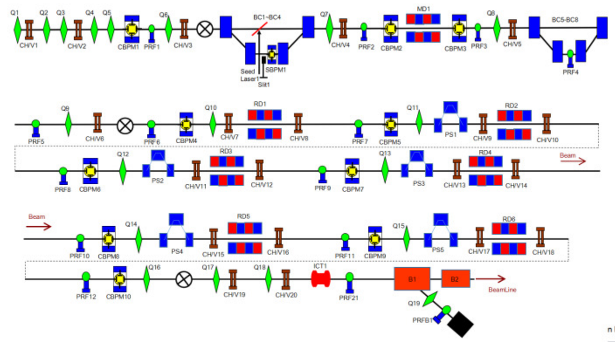

Figure 1: Schematic layout of CBPMs in the undulator section.

The CBPM system of DCLS is comprised of cavity pickup, a dedicated RF front end and DAQ system. Fig. 2 show the diagram of the system. More details and relevant results are described in the following section.

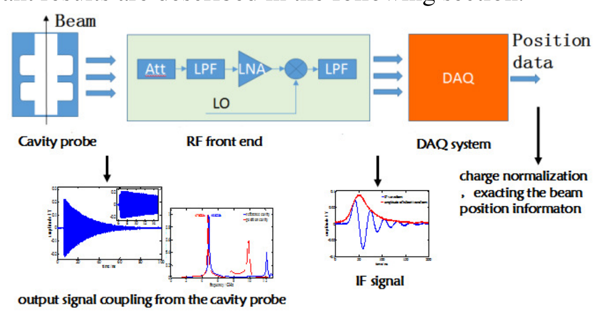

Figure 2：Diagram of the CBPM system.

DESIGN AND FABRICATE OF THE CAVITY PICKUP

A low Q factor cavity BPM was designed and tested in the last year [2,3], although it has the strengths of high efficient coupling structure and better SNR but the performance was limited by the DAQ system due to the short duration time about 2~5 ns. Considering the single-bunch working mechanism both in SXFEL and DCLS, we redesigned a high Q factor CBPM to matching with the electronics for getting a better performance. Table 1 illustrate the high Q factor CBPM design parameters.

Table 1: Design Parameters of the CBPM

Parameter	TM110	TM010
Frequency	4.70 GHz	4.70 GHz
Q	~ 8000	~ 8000
Number of ports	4(X:2, Y:2)	2

Comparing to the low Q cavity we designed before, the material changes from stainless steel of 304 to oxygen-

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free copper so as to raise the Q value. The distance of the two cavities also increased from 35 mm to 45 mm in order to reduce the possibility of signal coupling between position cavity and reference cavity. The three-dimension structure of the cavity is shown in Fig. 3.

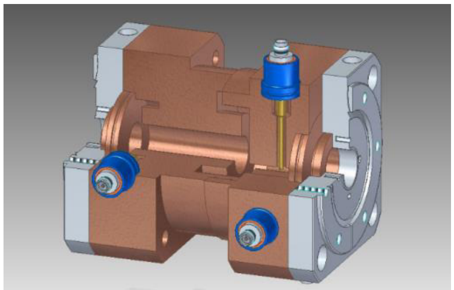

Figure 3: Three-dimension structure of the high Q CBPM.

In terms of fabricating, three sets of cavity prototype was processed and tested by Agilent N5230A PNA-L network analyzer. Analyzing the resonant frequency and correspondent Q factor by measuring the S21 parameter of the symmetric output port. Fig. 4 illustrate the S21 parameter of the one of the prototype measured by network analyzer.

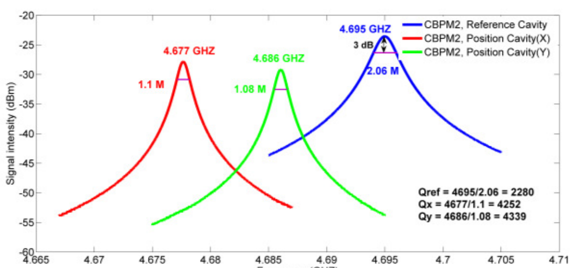

Figure 4: S21 parameter of the CBPM2 measured by network analyzer.

Combing with the designed parameters and processing technology, the specification of the cavity processing are determined and listed in Table 2.

Table 2: Specification of the Cavity Processing

	Working frequency	Q factor
Reference cavity	4693±3 MHz	2230±10%
Position cavity (X)	4680±3 MHz	4250±10%
Position cavity (Y)	4688±3 MHz	4250±10%

RF FRONT END

Design of the Front End

The RF signal coupled from the cavity will be converted to IF signal by the dedicate RF front end and then processed, the simplified block diagram is illustrated in Fig. 5.

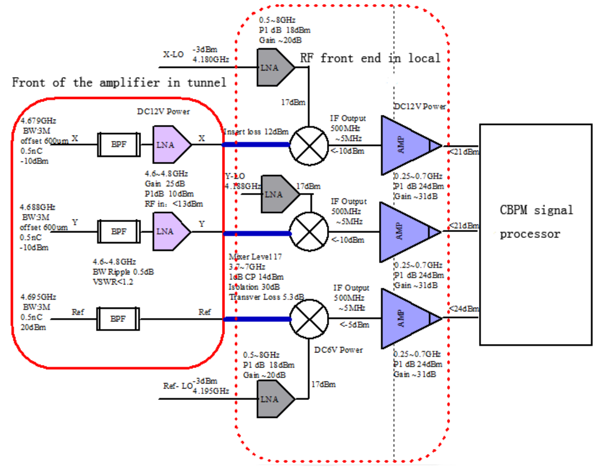

Figure 5: Block diagram of the RF front end.

The RF front end adopts two-stage amplifier structure, a cavity BPF filter with center frequency of 4.7 GHz and a LNA with gain of 25 dB make up the front of the amplifier which located in the accelerator tunnel, as close as possible to the pick-up to minimize the RF signal losses from the connected cables. The amplified RF signal then transfer to the RF front end in local station, down-convert to IF signal about 500 MHz by the mixer with the Lo signal which phase is locked to a machine reference signal that has a stable phase relative to the electron bunch. The IF amplifier accomplishes the last gain adjusting to fulfill the input requirement of ADCs.

Test of the Front End

The RF front end including the front of the amplifier was tested in laboratory, Fig. 6 is the diagram of the test. A signal generator simulate the output of the cavity (attenuation of 12dB from cables located in tunnel also included) and another simulate the machine frequency of 2856 MHz which can generate Lo signal and sampling clock by Lo signal generator.

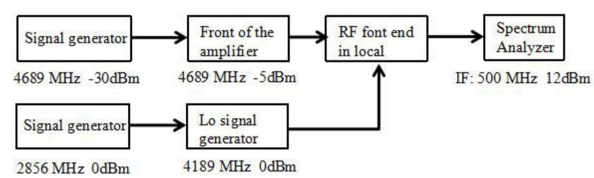

Figure 6: Diagram of the RF front end test in laboratory.

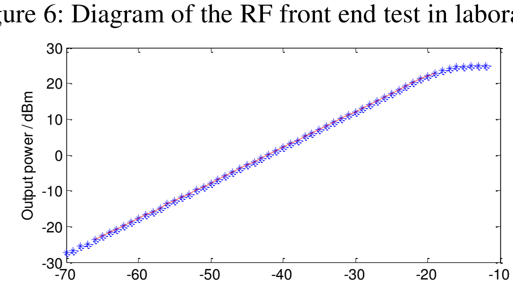

Figure 7: Gain line test of the RF front end.

The gain line test of the whole RF front end also have been done as shown in Fig .7. Because the attenuation of the cable between the two parts of the RF front end is put into the simulated cavity output signal in tested and com-

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bine with the output saturation of the front of the amplifier, the input power should be less than -7 dBm which can easily achieve for cavity coupling signal.

DAQ SYSTEM

The IF signals from RF front end need to be digitized and processed by processor. Our group start the research on the digital BPM (DBPM) processor a few years ago [4], base on the requirements of the cavity BPM signals process we optimized the performance and then used in the CBPM system. Fig. 8 show the simplified diagram of the DBPM processor. The requirement of the cavity BPM processor is that the resolution of the ADC better than 12 bit and the sampling rate lager than 100 MHz, real time signal processing can be done in the FPGA and the data achieves the long-distance communication and remote control by EPICS channel access.

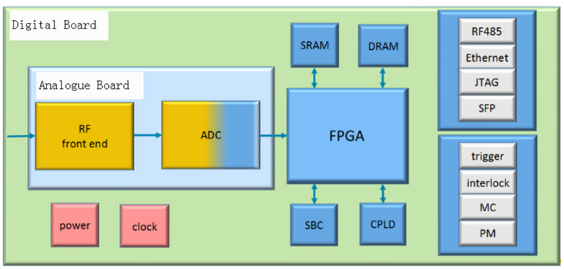

Figure 8: Simplified diagram of the DBPM processor.

The performance evaluation of the DBPM prototype also has been done in laboratory, the power of 0 to 200 mV input by using a signal generator to simulate the IF signal. Fig. 9 illustrate the gain line test result of the DBPM prototype by change the gain of the IF amplifier. And the mapping of the signal intensity and the gain setting also can be seen in Fig. 10.

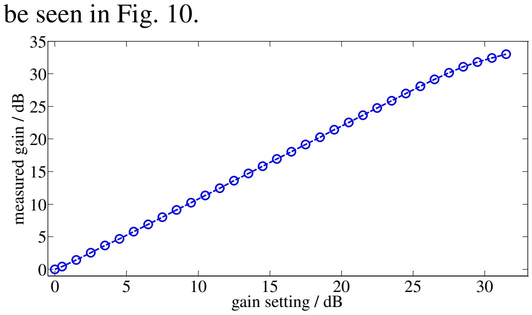

Figure 9: Gain line test result of the DBPM prototype.

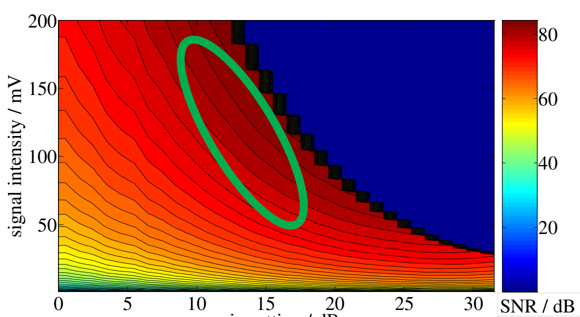

Figure 10: SNR mapping of the signal intensity and the gain setting of the DBPM prototype.

From the test results mentioned above, the DBPM prototype has a better linear gain response and the SNR is better than 75 dB when the intensity of the IF signal lager than 25 mVpp, which can meet the requirement of the cavity BPM processor.

The batch processing and test of the DBPM for DCLS has been accomplished now. Fig. 11 show the photograph of the DBPM processor.

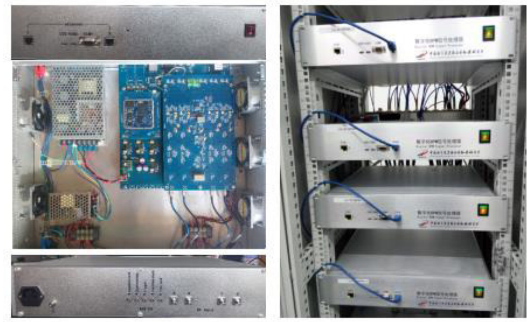

Figure 11: Photograph of the DBPM processor.

BEAM TEST AT SDUV

The cavity BPM system had also been tested with beam at SDUV facility to verify the physical design of the cavity and the performance of the whole system.

Cavity Evaluation

A broadband oscilloscope is used to test the working frequency and the Q factor of the cavity pick-up with beam and comparing with the results of the cold test, not only can evaluate the performance of the cavity but also can determine the acceptance standard of the batch processing. Fig. 12 and 13 show the RF signals and correspond frequency spectrum of the one of the CBPM.

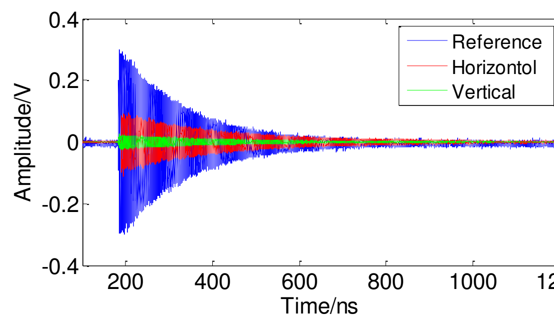

Figure 12: RF signals of the CBPM.

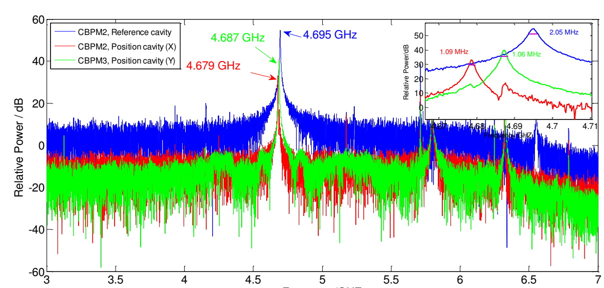

Figure 13: Frequency spectrum of the CBPM.

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The results show that the waveform and frequency spectrum of the RF signals are consistent with the expectations. Furthermore, the results with beam are agree with the cold test very well. Therefore, the measurement results of S21 parameter can be the acceptance standard for cavity batch process to meet the requirement of the project.

Noise Assessment of the CBPM System

For the sake of finding the influence of the environment background noise to the resolution of the CBPM system, we did the experiment of using DBPM to collect the environment noise data when beam on and off respectively. The level of the noise are shown in Fig. 14.

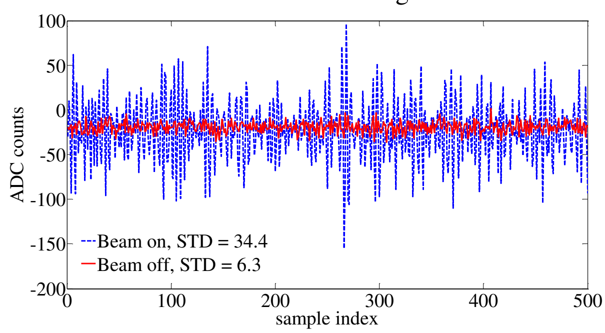

Figure 14: The level of the noise when beam on and off.

From the results we can see that the amplitude of the interference signals with beam on is lager than the condition of beam off about 6 times, which will become the one of the biggest restriction to promote the resolution of the CBPM system. In addition, one of the port of the RF front end was split by power divider and then sampled by the two channels of the DBPM to evaluate the path of the noise coupling. Fig. 15 illustrate the linear dependence of the noise picked up by different channels which indicate that the noise coupling to the system in the part of the RF front end.

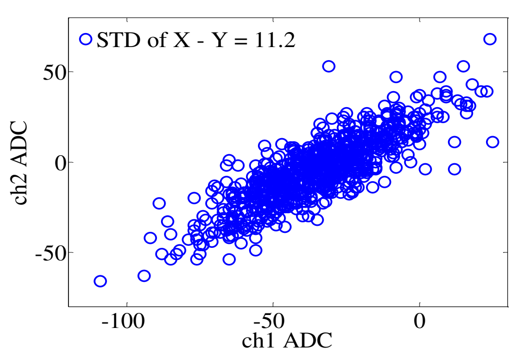

Figure 15: The linear dependence of the noise picked up by different channels.

From the assessment of the CBPM system, the suppression of the environment background noise is one of the most important roles for the CBPM system. So the electromagnetic shielding, grounded of the electronics and the test of the background noise should be considered in the scene of installation.

CONCLUSION

The cavity BPM system of DCLS is comprised of a cavity pick up, dedicated RF front end and DAQ system and the design and preliminary test with beam has been completed. The experiment results show that the performance of the CBPM system accord with the expectation and the batch processing is in progress.

The performance evaluation of the whole cavity BPM system show that:

1. Test results with beam in cavity pick-up evaluation are consistent with the cold test with S21 parameter, which can be the acceptance standard of the batch processing to meet the requirement of the project.
2. The output signal amplitude of the RF front end should be optimized within 100~200 mV to get the best SNR.
3. The electromagnetic shielding, grounded of the electronics and the test of the background noise should be considered in the scene of installation.

DCLS is under the commission stage, more experiment and further evaluation of the cavity BPM system will be made in the near future. And we are looking forward more better results after optimize the condition of beam.

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