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CSNS LINAC BEAM COMMISSIONING TOOLS AND EXPERIENCE

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Abstract

The China Spallation Neutron Source (CSNS) successfully accelerated the H- beam to 80 MeV in January 2018, marking a key progress in the beam commissioning. One of the keys to success is the development and use of software tools. XAL, a Java-based software infrastructure originally developed by SNS was applied for CSNS beam commissioning. We have developed and transplanted many applications based on XAL. Some of the applications for the LINAC are described, and some experiences are shared.

INTRODUCTION

The CSNS [1] accelerator complex consists of an H- injector, a linear accelerator, a RCS ring and associated beam transport lines. The LINAC is 200m with the output energy of 80 MeV in CSNS-I and 250 MeV in CSNS-II. The LINAC commissioning initiated April 2015 and completed in January 2018, was performed in 4 discrete runs with interruption of DTL tank installation and the faults of CPI klystron and DTL vacuum. The beam commissioning for the Front-End to MEBT was form April 2015 to July. The beam transmission of the RFQ is more than 90% and the parameters of MEBT are also accurately measured. DTL-1 beam commissioning was completed in January 2016. The beam transmission is 100% and the peak current is 18 mA, which is higher than the design value of 15 mA. In April 2017, the DTL-2 and DTL-3 beam commissioning was completed, and the beam energy reached 60MeV. In January 2018, the beam commissioning for DTL-4 was finished. The beam energy reached the design value of 80 MeV with the error of $\pm$0.01 MeV, and the overall beam transmission of DTL reached over 97%.

Beam commissioning for LINAC is generally smooth regardless of hardware installation and the major faults. The software tools play an important role for this successful beam commissioning. The XAL [2, 3] and Open XAL were selected as our software development platform. XAL was originally developed and used by SNS for accelerator physics commissioning. It consists of upper applications, physics model of the beam and other toolkit. The XAL was confirmed as our tuning software development platform at the end of 2012, and a large number of physical applications were developed based on the SNS / XAL version between 2014 and 2015 and officially used in April 2015. A lot of useful applications have been developed in subsequent beam commissioning. OPEN XAL is an upgrade of XAL, which is a collaboration among several laboratories, including CSNS. XAL and OPEN-XAL are used simultaneously in our control room now and XAL is used more.

In this paper, the physical applications used in LINAC beam commissioning including longitudinal and transverse were introduced firstly. Then the problems and solutions during the development and use of the software tools will be shown later.

THE APPLICATIONS

Applications for LINAC beam commissioning are mainly divided into three aspects: longitudinal、 transverse and machine management related applications.

RF Phase Scan and Tuning Application

The longitudinal tuning is the first and the most important step for LINAC beam commissioning. To achieve the design value, accurate RF phase and amplitude settings are required. A software application called PASTA [4] in XAL has been written to perform RF phase setting using the signature matching method. The PASTA of CSNS version has been modified in two ways. First, SNS uses Beam Position Monitor (BPM) to measure the phase of the beam, but we use Fast Current Transforms (FCTs), so the corresponding components are replaced. In addition, due to the great difference between CSNS-DTL and SNS-DTL in the relationship between the transition time factor and Beta, we also revised the underlying energy calculation code to make it consistent with the CSNS-DTL acceleration characteristics. Figure 1 is the analysis panel of the PASTA application with the result of DTL-4 tank. It shows the error is very small in the range of 70 degrees and the calculated energy is very close to the design energy. The energy of LINAC is also measured using the Time-of-Flight (TOF) method, which is also close to the design value and the maximum difference is less than 0.5%.

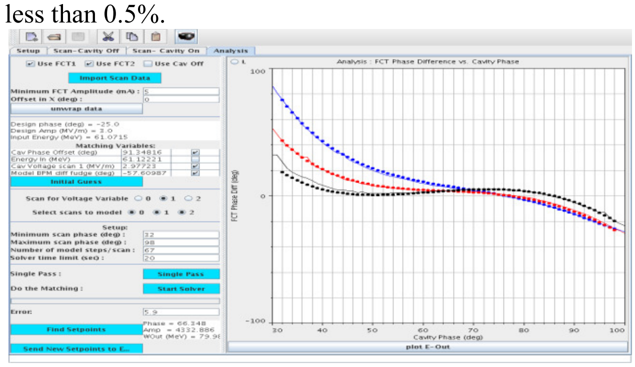

Figure 1: The analysis panel of the PASTA application.

Orbit Correction

Due to the small aperture of the vacuum beam pipe in LINAC, the beam orbit distortion should be small and smooth. The “orbit correction” application in XAL can realize orbit distortion measurement and correction [5]. Based on the response matrix of BPM to corrector (theoretical or measurement response matrix), the Solver calculation module was used to fit the measured orbit and predicted orbit. After repeated iterations, the correspond-

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ing corrector values and orbits are found. In the beginning of beam commissioning, the measured response is usually used firstly.

The figure 2 is the result of orbit correction for LINAC. The left is for MEBT and the orbit can be corrected from ±1.5mm to ±0.5mm. LRBT is on the right and the orbit can be adjusted from ± 13mm to near 1mm. After the corrections, the orbit deviations are suppressed and beam loss is also greatly reduced. The orbit correction for DTL is not carried out due to no corrector and only one BPM inside.

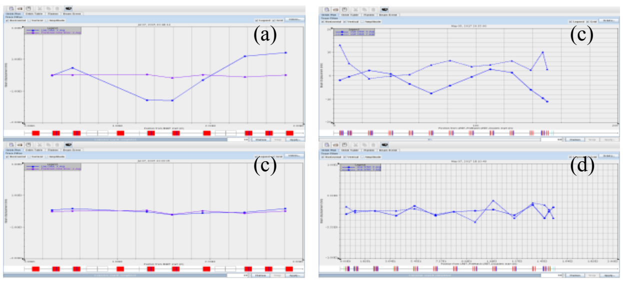

Figure 2: Orbit correction of LINAC (The left is the orbit of MEBT. The right is LRBT).

Emittance and Twiss Parameters Measurements

The emittance of LINAC can be given in two ways. One method is to use the slit-slit scanning to get the beam position and angle distribution in phase space directly. The other is indirect method which measure the transverse beam size with more than three wire scanners and give the emittance, that is, the three-grid method.

Two slit-slit instruments are installed in the middle of the MEBT to measure the horizontal and vertical emittance respectively. The application for processing the original measurement data is developed. Figure 3 is the interface of the application. The beam RMS emittance ε and Twiss α, β parameters were calculated by statistical and Gaussian fitting methods. In addition, the relationship between the threshold value and emittance and Twiss parameters can be given, from which the threshold value can be inferred. Figure 3 shows the MEBT emittance obtained with slit-slit scan.

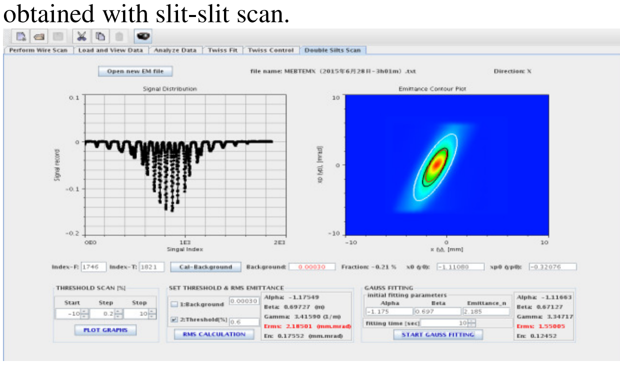

Figure 3: MEBT emittance obtained with slit-slit scan.

The three-grid method can be used to calculate the emittance and Twiss parameters. Four wire scanners were installed in MEBT and 6 were installed in LRBT straight line. There is a "wire analysis" application in the original XAL, which can be used to fit the raw data of wire scanners in various ways. Then the emittance and the Twiss parameters at entrance are given by iteration with the algorithm package of XAL. Figure 4 shows the beam envelope of LRBT before and after matching with 6 wire scanners. The beam envelope oscillation is large before matching, and the beam loss is large too. According to the calculated entrance parameters, we can rematch the beam and make a new lattice. As can be seen from the following figure, after matching, the envelope of the measured beam is close to the design value, the oscillation is small, the beam loss were greatly reduced too.

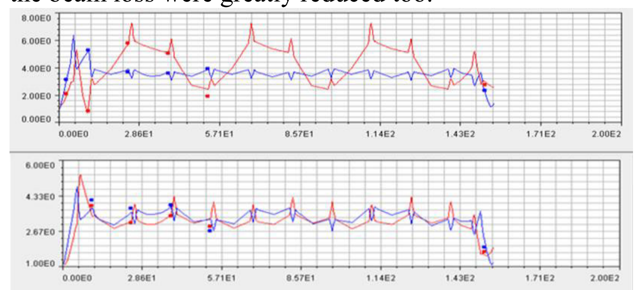

Figure 4: Beam envelope of LRBT before and after matching.

Machine Parameters Management

The energy span for LINAC beam commissioning is large, involving 3 MeV, 20 MeV, 40 MeV, 60 MeV and 80 MeV. The magnets settings are not exactly the same for different energy, especially the magnets for matching function. To master the state of the machine and restore the machine quickly, we need save the magnetic field, cavity parameters, even the beam parameters, timing and other important parameters.

"Model management" and "SCORE" applications can realize the management of machine parameters with a little difference in function. The former application only stores magnetic field and cavity parameters, but it can do lattice calculation and give the Twiss parameters in the form of graphs. Figure 5 is the interface of management application developed by ourselves. This program plays a great role in the early beam commissioning and remote control operation for power supply.

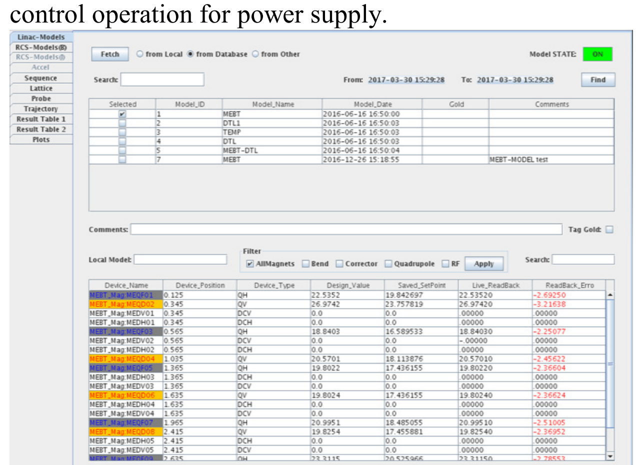

Figure 5: The interface of the Model Management application.

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The SCORE (Save-Compare and Restore) [5] application was developed by SNS, which really realized machine parameter management. Figure 6 is the interface of SCORE application that stores a large number of parameters to database by PV (Process Variables) key-value pairs which is composed of any two PVs. Usually, we give the set and read back signals, for example, the setting value and the read back value of current of power supply. With the great advance of beam commissioning, more and more important signals are stored in the database. The program can not only record the signal related to the current model, but also make on-line comparison and machine recovery. Each model also provides annotations with 250 words.

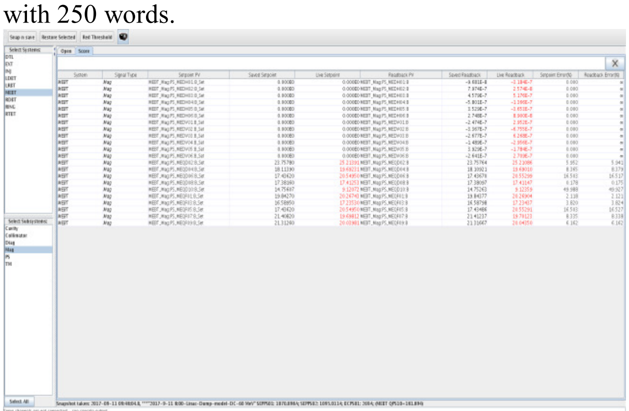

Figure 6: The interface of the SCORE application.

PROBLEMS AND EXPERIENCE

Since the selection of XAL as the CSNS accelerator physical tuning software in 2012, a large number of physical applications have developed and tested on the basis of XAL, which played a key role during beam commissioning. However, there are many problems encountered in the development and use of application programs. Many important applications in the XAL / SNS version contain the SNS specific parameters, some of which are hidden at the bottom, requiring a lot of patience and repetition to adapt to the needs of CSNS. For example, our RF frequency is 324MHZ, and SNS is 402.5MHZ, so this parameter needs to be changed. Other problems happened when transplanting the applications to CSNS. For example, SNS uses Oracle database, and we use the free MySQL database, so SCORE and PV Logger applications can not directly used, which need to modify the relevant interface functions. Some applications were normal with the use of virtual accelerator debugging, but were in trouble in beam commissioning. For example, the "orbit correction" application could not display the track normally at first. It was found that the BPM timestamp was not synchronized. The BPMs in LRBT are distributed in two sub-stations and two different electronic systems were selected, which resulting the BPM timestamp asynchrony. After the synchronization, orbit correction can work normally. So we need test the key applications repeatedly and be familiar with the underlying algorithm and its suitable conditions for direct transplantation applications before the beam commissioning.

CONCLUSION

From April 2015 to January 2018, CSNS completed the beam commissioning for LINAC with energy of 80 MeV. As a physical software tool, XAL plays a key role in the beam commissioning. We have accumulated a lot of experience to learn from during the development and employment of these applications. With the increasing beam power, there are still many physical problems to be studied in LINAC, and more and more convenient applications need to be developed in the next several years.

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