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OPERATION EXPERIENCE OF THE CSNS DTL*

Huachang Liu[1,2,3†], Jun Peng[1,2,3], Keyun Gong[1,2],Ahong Li[1,2,3], Bo Li[1,2], Qiang Chen[1,2], Xiaolei Wu [1,2] ,Mengxu Fan[1,2], Yun Wang[1,2] , Peihua Qu[1,2], Shinian Fu[1,2,3]

[1] Institute of High Energy Physics, Chinese Academy of Sciences (CAS), Beijing, China
[2] Dongguan Neutron Science Center, Dongguan 523803, China
[3] University of Chinese Academy of Sciences, Beijing, 100049, China

Abstract

The China Spallation Neutron Source (CSNS) Drift tube linac (DTL) accelerates H- beam from 3 to 80MeV with 4 independent tanks. The 80MeV beam acceleration was achieved in January 2018. The linac is a key to the reliability of the whole CSNS facility since all the beams stop when these upstream facilities fail. Many efforts have been made for DTL reliable operation. This paper presents the operation experience learned in DTL commissioning.

INTRODUCTION

The China Spallation Neutron Source (CSNS) is an accelerator-based multidisciplinary user facility constructed in Dongguan, Guangdong, China [1]. The CSNS complex consists of an H- linear accelerator, a rapid cycling synchrotron (RCS) accelerating the beam to 1.6 GeV, a solid-tungsten target station, and instruments for spallation neutron applications. Construction and commissioning has been completed so far. The facility operates at 25 Hz repetition rate with an initial beam power of approximately 20 kW on target. It can be foreseen that the beam power on target will reach 100kW within 2~3 years. The facility will provide scientists with a world-leading platform for studies in fields such as materials science and technology, life sciences, and new energy, etc.

The 324MHz drift tube linac (DTL) is the main part of CSNS accelerator linac complex (Fig.1). It can provide 15mA peak current beam with energy gain from 3 to 80MeV [2]. It consists of four independent tanks with ~9m in length. Each tank is divided into three short unit sections for ease of fabrication and assembly. A hollow coil based electromagnet is accommodated in each drift tube for its compact structure. The main design parameters of DTL are listed in table 1.

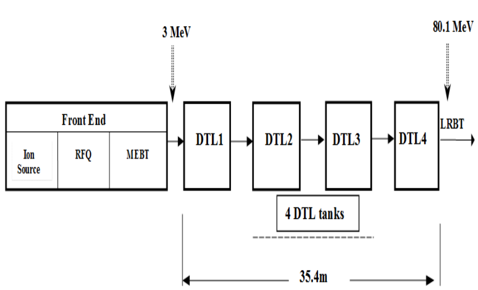

Figure 1: Layout of the CSNS LINAC.

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† email address:liuhc@ihep.ac.cn

The commissioning of the first DTL tank started in January 2016. The first 20MeV@18mA beam was achieved within ten days. Based on the experience of DTL1 commissioning, the three successive DTL tanks were progressively installed and commissioned. Final 80 MeV acceleration was successfully obtained in January 2018. During the commissioning and operation, the performance of DTL gradually improved owing to a series of prompt action to the troubles.

Table 1: Major Parameters of CSNS DTL

Tank number	1	2	3	4	total
Output energy (MeV)	21.67	41.41	61.07	80.1	80.1
Length (m)	8.51	8.56	8.78	8.8	
Number of cells	64	37	30	26	157
RF driving power (MW)	1.35	1.32	1.32	1.34	5.33
Total RF power (MW)@30mA	1.91	1.92	1.92	1.93	7.68
Accelerating field (MV/m)	2.86	2.96	2.96	3.0	
Synchronous phase (degree)	-35 to -25	-25	-25	-25	
RF frequency(MHz)	324	324	324	324	324
Max. repetition rate(Hz)	25	25	25	25	25
Peak surface field(Kilpatrick)	/	/	/	/	<1.3

BEAM COMMISSIONING

The DTL consists of four accelerating tanks with final output energy 80MeV. The transverse focusing was arranged in a FFDD lattice utilizing electric-magnet quadrupoles. Because no drift tube is empty, diagnostics have to be imbedded between tanks. After each tank, a FCT and a CT were installed to monitor beam phase and current. Between DTL 3 and DTL 4, a Beam Position Monitor (BPM) was added for monitoring beam orbit.

For DTL tanks, it is essential to find the correct tank RF field amplitude and phase to minimize energy spread and mismatch, which are highly required by the following

RCS. "Phase scan signature matching" method was adopted for determining the RF set points of DTL tanks [3], Time of flight measurement was also performed (Fig.2). For each tank, three FCTs were used to form two short pairs and a long pair. The two short pairs were used to determine the number of integer periods and the long pair was used to calculate beam energy. The beam energy measured by TOF method are summarized in Table 2. The deviation of measured beam energy from the design value is less than 0.5%.

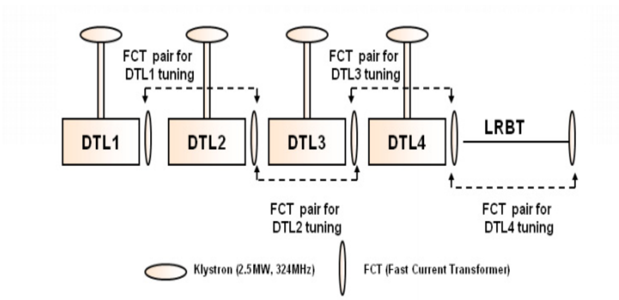

Figure 2: Phase Scan Signature Matching Technique using FCT pairs

Table2: Beam Energy From Time-of-flight Measurements

	Design [MeV]	Measured[MeV]	Deviation (%)
DTL1	21.67	21.73	+0.28
DTL2	41.41	41.54	+0.31
DTL3	61.07	61.36	+0.47
DTL4	80.09	80.34	+0.3

WATER LEAKAGE IN DRIFT TUBE

Each DTL tank is equipped with one 1000Litre/s turbomolecular pump, and 7~8 1000Litre/s ion pumps, the pressure in operation is in an order of 10^{-6} Pa. In May 2017, the vacuum in DTL1 became worse, and the trip rates of DTL1 increased in the meantime. The beam commissioning was not interrupted by this problem because the speed of vacuum deterioration was relatively slow at the beginning. After nearly one month operation, the poor performance of DTL1 forced us to stop the beam commissioning. External vacuum leak was not found by using a helium leak detector. But the RGA (Residual Gas Analyser) shows an abnormal spectrum (Fig.3) which indicates a great suspicion of water leakage in the drift tube (DT). In order to find the specific location of the leakage area, we shut down the water cooling of DT, heating up the electro-magnetic quadrupole (EMQ) one by one and check the vacuum pressure change in the cavity. An intensive vacuum fluctuation was found while heating the 13th EMQ. This problem was traced to bad e-beam welds.

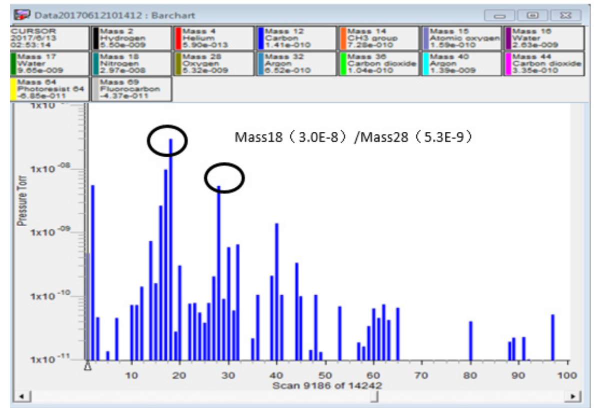

Figure 3: Residual gas spectrum in DTL1.

A spare DT with an EMQ inside was manufactured, new leak testing method was introduced to confirm the electron beam welding (EBW) quality. The water channels are pressurized with He gas while drift tube body is in vacuum chamber. However, to replace a DT inside DTL tank is a very complicated and time consuming engineering subject. The top priority at that time is to restart the beam commissioning as soon as possible, instead we modify the DTL focusing lattice and EMQ's gradient to compensate the malfunctioning DTQ-13.Fig.4 shows the beam envelope without Q13 before and after optimization. The transmission is almost 100% according to the simulation results [4].

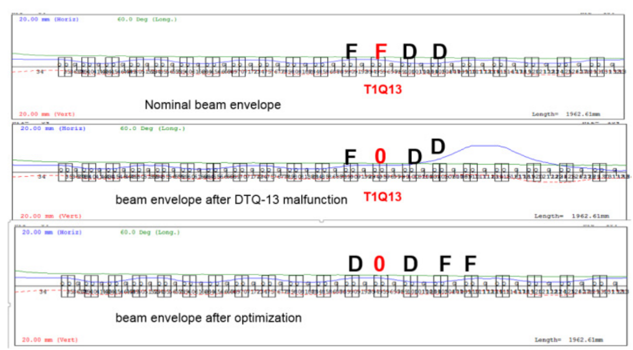

Figure 4: Beam envelope simulation results.

VSWR PROTECTION

The VSWR interlock protection is incorporated into the MPS system in order to protect the high-power components in case of an excessive reflected power. The RF power must be shut off within 2~3 µs if the reflected power is higher than the pre-set threshold. During the initial operation, all RF cavity run stable, no sign of electron activities was observed. The trip rate of DTL2 unexpectedly increased by frequent VSWR protection since January 5th 2018. Experiments have been done to figure out the reason of cavity degradation. It is found based on the machine research that the VSWR interlock protection has behaved erratically, with a response which is not correlated at all with vacuum pressure in the cavity. This false alarm is mainly due to the poor contact of the power plug to the LLRF control circuit board. After replacing the related power plug

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(Fig.5), the VSWR protection issue was successfully solved.

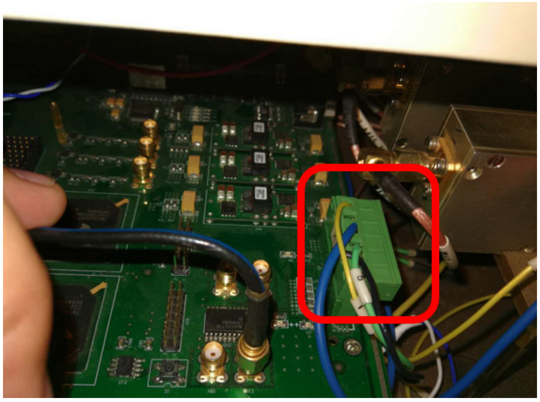

Figure 5: DTL LLRF controller.

COOLING COMPONENTS FAILURE

Under normal operation (beam on), approximately 80% of the RF power is dissipated in the DTL copper structural components. The water cooling system is responsible for removing the undesired RF waste heat. All the RF components include tanks, drift tubes, fixed tuners, movable tuners, post couplers, EMQs, end-plates need sufficient water cooling. In the return of each cooling circuit just prior to the return manifold is a float type flow switch (Fig.6) to detect insufficient flow. The flow switches are monitored by the control system, which annunciates all flow alarms that can provide an MPS signal to shut down the power source and the beam in case of any malfunctions. Flow meters are used on sub manifold return lines. These flow meters will allow operators to detect significant flow blockages.

Figure 6: Flow switch placing on the Drift tube cooling channels.

During the operation, nearly half of flow meters were blocked by the residual scrap in the cooling channel ascribe to the nature of turbine flow meter (Fig.7). These flow meters have advantages of high accuracy, fast response. On the other hand, they are sensitive to the water impurity, and the rotor may easy to get stuck. The water flow in the entire sub manifold line reduced significantly and the related flow switches would trigger the MPS protection. In the maintenance, all the flow meters in the return lines are replaced by straight pipes to improve the reliability of cooling distribution system (Fig.8). All other flow meters in the intake lines are still remained to detect the water flow of each sub manifold.

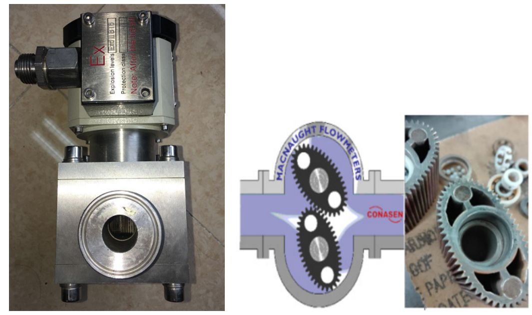

Figure 7: Schematic of flow meter.

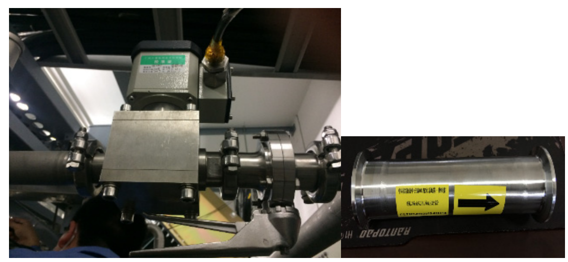

Figure 8: Flow meter and straight pipe.

CONCLUSION

Four DTL tanks were constructed for CSNS facility. The success of DTL beam commissioning verifies the design and manufacturing process. We have experienced many troubles, and all these troubles have been solved. The DTL accelerator shows a stable performance at present, a lot of experience and operation data were learned. We will continue our effort to further increase the beam availability of accelerator facility and to upgrade the system.

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