THE ALIGNMENT OF THE DRIFT TUBE LINAC FOR THE COMPACT PULSED HADRON SOURCE

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Abstract

This paper presents the alignment result of the drift tubes inside the cavity and the DTL cavity in the beam line, together with the progress of the Compact Pulsed Hadron Source (CPHS) project. The CPHS at Tsinghua University is one multi-purpose pulsed neutron source. The linac of the CPHS mainly consists of a proton source, a low energy beam transport line (LEBT), a radio frequency quadrupole (RFQ), and a drift tube linac (DTL). The DTL is positioned downstream the RFQ accelerator and accelerates the beam from 3 MeV to 13 MeV with the peak current of 50 mA to meet the energy demands for the beam bombarding the target. The main structure of the DTL consists of 2 cavities, 39 drift tubes, 2 pedestals and 2 flanges. A total of 41 permanent magnet quadrupoles (PMQs) are mounted in drift tubes and flanges to focus the beam. After the final assembly, the position of each PMQ magnetic center needs to be within the tolerance of ±0.2 mm in the transverse direction and ±0.3 mm in the beam line direction. The alignment measurement of the DTL is one of the key technologies of the CPHS DTL.

INTRODUCTION OF CPHS

The Compact Pulsed Hadron Source (CPHS) project at Tsinghua University was launched in 2009 [1]. CPHS project consists of a high-current proton linac (13 MeV, 16 kW, peak current 50 mA, 0.5 ms pulse width at 50 Hz), a neutron target station, a small-angle neutron scattering instrument and a neutron imaging/radiology station. The facility will provide the proton beam, together with the neutron beam by delivering the proton beam to bombard the beryllium target. The layout of CPHS is shown in Fig. 1. The CPHS is aimed at becoming an experimental platform for education, research, and innovative applications at Tsinghua University.

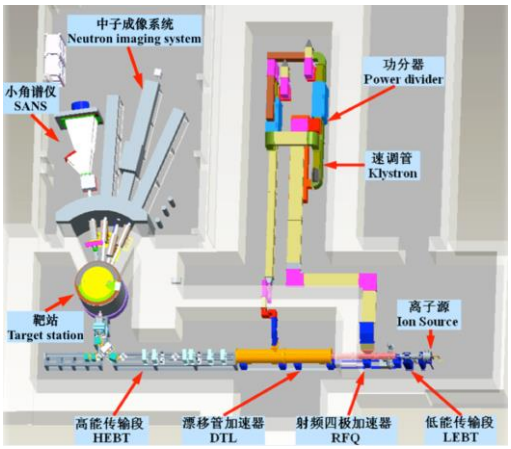

Figure 1: CPHS project layout

The linac of CPHS mainly consists of an ECR ion source, a low energy beam transport line (LEBT), a radio frequency quadrupole (RFQ), a drift tube linac (DTL), and a high energy beam transport line (HEBT). The DTL will accelerate 50 mA proton beams from 3 MeV to 13 MeV to bombard the target [2][3]. The permanent magnet quadrupoles (PMQs) are mounted in the drift tubes with an FD lattice to focus the beam.

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DTL ALIGNMENT REQUIREMENTS

The DTL cavity structure mainly consists of 2 cavities, 2 pedestals, 2 flanges and 39 drift tubes. 24 drift tubes are installed in the first cavity and 15 drift tubes are installed in the second cavity. The cavity is shown in Fig. 2, and the drift tubes are shown in Fig. 3.

Figure 2: DTL cavity

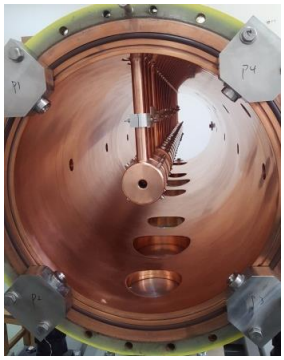

Figure 3: Drift tubes installed in the cavity

The CPHS beam line coordinate system is defined as follows: the beam direction is Z+; the vertical upward is Y+, and then X+ can be inferred as shown in Fig. 4.

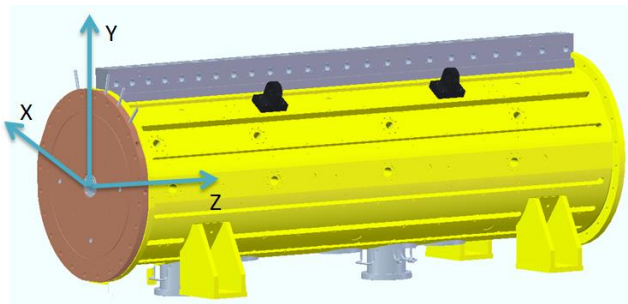

Figure 4: Definition of coordinate system

According to the electromagnetic field simulation and the beam dynamics simulation, the position requirement of drift tubes is illustrated in Table 1. The position requirement of cavities is illustrated in Table 2.

Table 1: Position tolerance of drift tubes

Position		Tolerance
Magnetic center	△X	±0.20 mm
	△Y	±0.20 mm
	△Z	±0.30 mm
Axis deviation	△θx	±3°
	△θy	±3°
	△θz	±0.6°

Table 2: Position tolerance of cavities

Position	Tolerance
△X	±0.20 mm
△Y	±0.20 mm
△Z	±0.30 mm
△θz	±0.6°

Several factors that can influence alignment: foundation, environment stability, device precision, and transportation, etc [4][5]. To ensure the precision and convenience of installation, all parts of DTL are stored, installed and measured at constant temperature and humidity environment. The main procedures of CPHS DTL alignment are as follows: (1) fiducialization of drift tubes; (2) pedestal-cavity alignment; (3) installation of drift tubes and alignment measurement in cavity; (4) connection and alignment of the two cavities in the laboratory; (5) transit to the CPHS beam line site and alignment in beam line.

CPHS DTL drift tubes are designed to be installed onto pedestals without any adjustment devices. In mechanical design, we have allocated the tolerances to mechanical tolerances and assembly tolerances of cavities, pedestals, and drift tubes so as to meet the requirements in Tables 1 and 2. Based on measurement results, the drift tube position deviation of several independent installations should be within ±0.1mm.

FIDUCIALIZATION OF DRIFT TUBES

The DTL is designed to be operated at 25°C. Thus, compensating thermal expansion during manufacturing is necessary. Alignment measurements are also conducted at room temperature of 25°C and relative humidity of ＜ 40%， so as to keep the dimension at steady state and slow down the oxidation of copper surface.

The first step of DTL alignment is the fiducialization of the drift tube, which aims at establishing a document containing the relative position of fiducial points and key points of the drift tube (low energy end center, high energy end center and stem center). The fiducialization document can be used by the best-fit method to obtain the key points in the cavity. We perform the fiducialization through the following procedures.

First, the drift tube is mounted onto the aluminum holder on one marble platform. Four refractor holders for 0.875″ diameter refractor are glued on the drift tube cylinder surface and one is installed on the stem as shown in Fig 5. The relative position of drift tube and laser tracker is adjusted so that the axis of drift tube is about to be coaxial to the incident direction of laser and the low energy end plane is perpendicular to the laser, which is illustrated in Fig. 5.

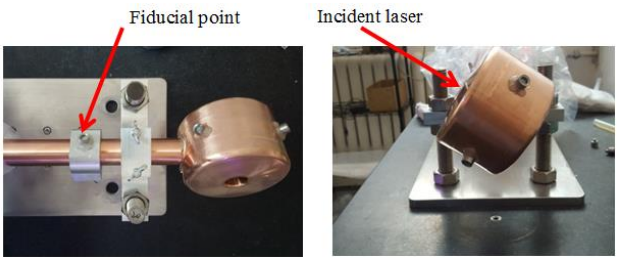

Figure 5: Fiducialization of drift tube

The surface points of the drift tube cylinder and low/high energy end plane are measured, and the coordinate system of the drift tube is established. Then we add the magnetic center position offset to obtain its magnetic center.

The final fiducialization document can be established with positions of key points and fiducial points under the same coordinate system.

PEDESTAL AND CAVITY ALIGNMENT

This alignment adjustment aims to keep the pedestal axis parallel to the Z axis of the cavity. The procedures are as follows.

After mounting the pedestal onto the cavity, we use the level gauge to measure the top surface of the pedestal and adjust the cavity support to ensure that the top surface is horizontal; therefore the drift tube stem can be vertically installed to avoid bending deformation on stem [6].

Four refractor holders are installed on the two flanges of the cavity respectively, which work as the local engineering control network for the laser tracker relocation, as shown in Fig. 6. The inner surface of the cavity is measured to obtain its Z axis, and then we intersect with low and high energy end to obtain key points. Besides, we measure the top plane of pedestal and then establish the coordinate system of the cavity.

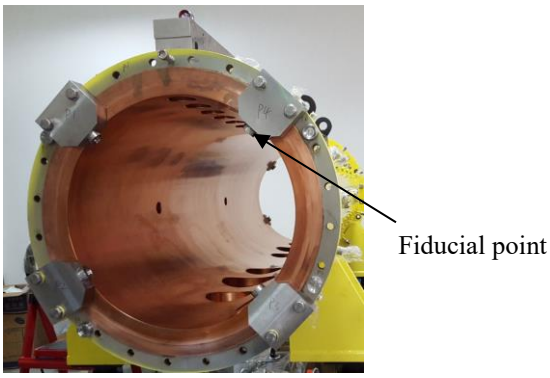

Figure 6: Fiducial points on the cavity flange

The pedestal position under the cavity coordinate system can be obtained by measuring the installation hole on top of the pedestal. Two refractor holders are glued on each end of the pedestal, and then the live monitoring feature of the Spatial Analyzer can be applied to monitor the adjustment amount of the pedestal. After adjustment, finally the axis of the pedestal installation hole is parallel to the Z axis of the cavity within ±0.10 mm, and the distance between the first installation hole and low energy surface is within ±0.10 mm. Then the adjustment device is firmly locked and the drift tubes can be installed on reliable pedestal which will not cause conspicuous alignment error.

DRIFT TUBES ALIGNMENT

Considering the difficulty of installing drift tubes in the 2.2-meter-long cavity, we decide to install from the center of the cavity to the outside. After every 5 drift tubes are installed, positions of the refractor holder points are measured and best-fit is conducted to obtain their key points position. Then the results are evaluated to see whether obvious error far out of the required tolerance exists, in case too many drift tubes need to be uninstalled.

The fiducial points on drift tubes inside the cavity can be difficult to reach as shown in Fig. 7. The survey crew member needs to lie down under the cavity and extends the arm through the vacuum or tuner port to place the refractor on the fiducial points. One measurement needs at least 2 locations for the laser tracker to fully measure the 5 fiducial points on each drift tube.

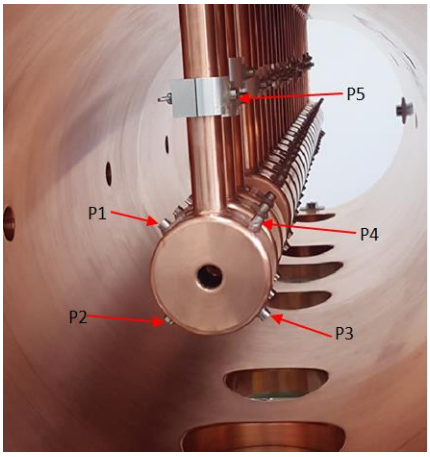

Figure 7: Fiducial points on drift tube in cavity

After all drift tubes are installed in one cavity, the final results are thoroughly measured. Based on the fiducialization documents, the magnetic center of each drift tube is located in the cavity coordinate system. Then all of the magnetic centers are best-fitted to obtain a new Z axis, and the cavity coordinate system is amended by the new Z axis. This axis will be set as the align base of the cavity in beam line.

The laser tracker is relocated to fully measure the fiducial points on the cavity, and the fiducialization document of one cavity is obtained.

The statistics of the alignment result in the first cavity is illustrated below. As shown in Fig. 8, most of the positions of the magnetic centers of drift tubes locate within ±0.20 mm in first cavity. The X position of the 11st drift tube slightly exceeds the tolerance. As shown in Fig. 9, all of low/high energy end Z deviations of drift tubes in the first cavity fall within ±0.30 mm.

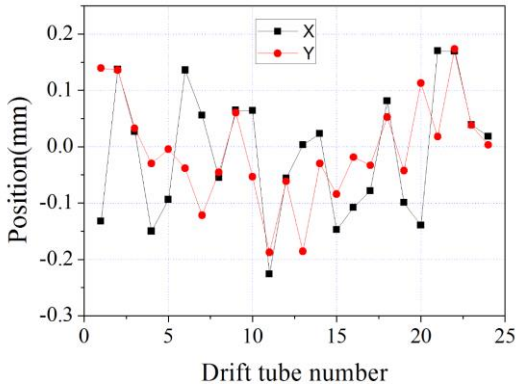

Figure 8: Transverse positions of the magnetic centers of drift tubes in the first cavity

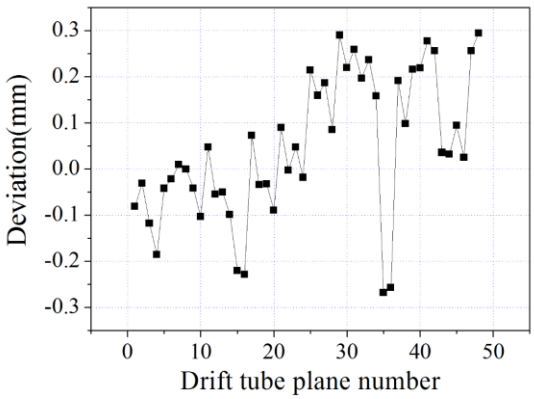

Figure 9: Low/high energy end Z deviation of drift tubes in the first cavity

As for the alignment result in the second cavity, it is observed that the X position of the 32nd drift tube slightly exceeds the requirement, and the position of the 34th drift tube at the high-energy end exceeds the tolerance, as shown in Figs. 10 and 11, respectively. Results show that the rotating angles of drift tubes are relatively easy to meet the requirement.

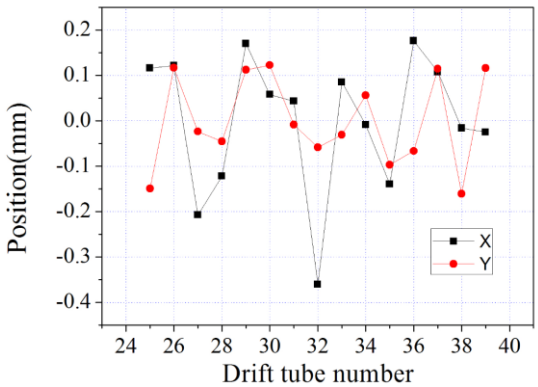

Figure 10: Magnetic center traverse position of drift tubes in second cavity

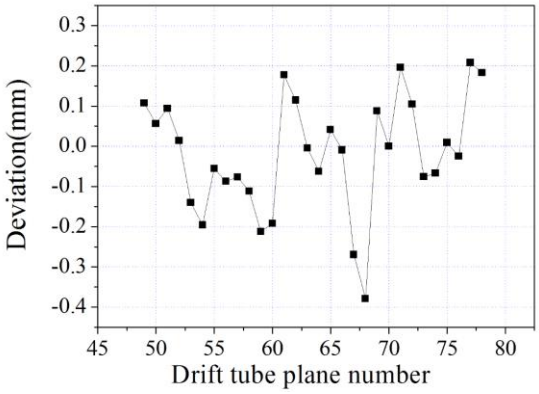

Figure 11: Low/high energy end Z deviation of drift tubes in second cavity

SIMULATION AND TUNING

The beam simulation with the alignment results is performed by the TraceWin code [7]. The alignment results of the PMQs strongly affect the beam envelope of the DTL, which is shown in Fig. 12.

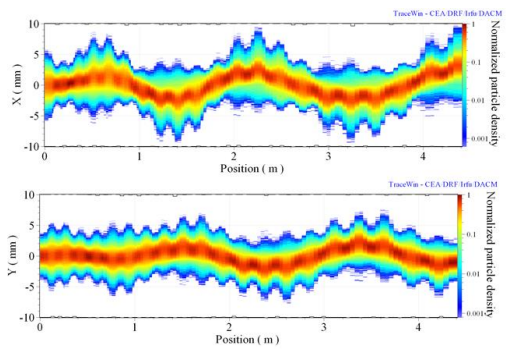

Figure 12: Beam envelop in the DTL cavity by the TraceWin code (up: x-direction; low: y-direction)

With the current alignment result, a combined error study is conducted considering varies of possible errors. The transmission rate of DTL is above 99% with a probability of 99%.

After the alignment, the DTL-tuning process is conducted. The result shows that the relative error of the field distribution is within ±1.6% compared with the designed value, and the tilt sensitivity which indicates the stability of DTL is within ±32.6%/MHz as shown in Figs. 13 and 14. Both of them can meet the tuning requirement, which is ±3% for the field error and ±150%/MHz for the tilt sensitivity.

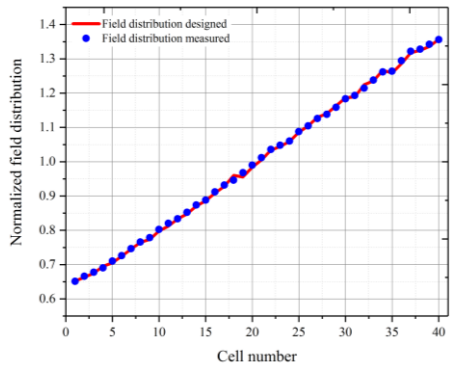

Figure 13: Measured and designed field distribution of the DTL cavity

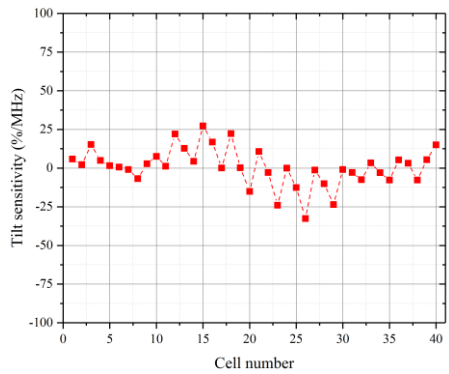

Figure 14: Tilt sensitivity of the DTL cavity

DTL ALIGNMENT IN BEAM LINE

After all the drift tubes and flanges in DTL are installed and aligned, the DTL cavity is transferred to the accelerator hall and needs to be aligned in the beam line, as shown in Fig. 15. The engineering control network contains control points along the beam line with the interval of 3~4 m in horizontal direction and 2~3 m in

vertical direction. The control network is measured thoroughly by relocating the laser tracker for 4 times, and then we use the method of USMN (Unified Spatial Metrology Network) in Spatial Analyzer to combine the control network points into one beam line coordinate system.

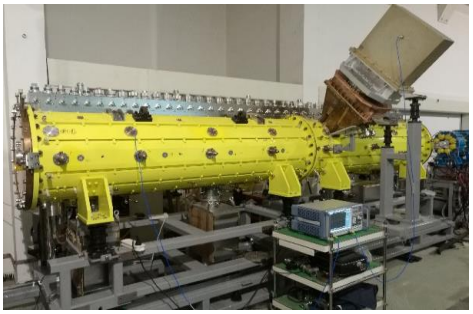

Figure 15: DTL cavity aligned in beam line

We have evaluated the precision of relocating the laser tracker in the control network, and the result comparison of two independent measuring and processing methods shows that a probability of 95% can be achieved for the positions of the RFQ and HEBT magnets to be within ±0.12 mm, and 90.5% to be within ±0.10 mm, as shown in Fig. 16. It can be concluded that under the confidence coefficient of 2δ, a measurement precision of ±0.12 mm can be obtained in the beam line.

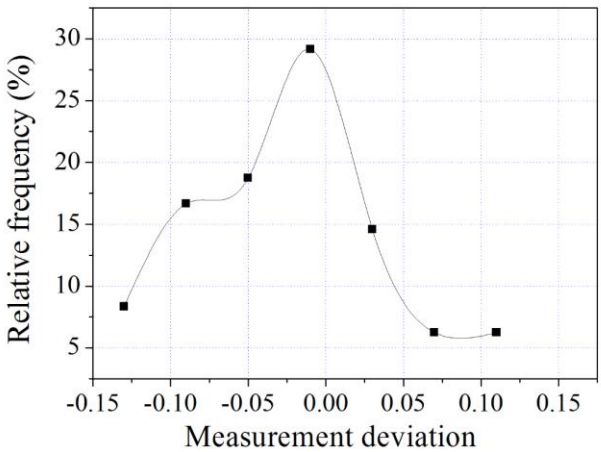

Figure 16: Location deviation distribution of 2 measurements

CONCLUSION

An Alvarez-type permanent magnetic DTL is designed and manufactured for CPHS at Tsinghua University. The drift tubes have been successfully installed and aligned in the DTL cavity. The alignment result shows that the positions of three drift tubes exceed the requirement in X, Y, Z direction respectively. Beam dynamic simulation and tuning of DTL cavity have been conducted based on the current alignment result.

By far the two cavities have been installed and aligned in the beam line. The 13MeV proton beam commissioning is expected at the end of this year.

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