ISBN: 978-3-95450-194-6 doi:10.18429/JACoW-LINAC2018-THPO029

QUALITY FACTOR AND POWER LOSS OF THE CSNS DTL*

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Abstract

An Alvarez-type Drift tube linac (DTL) was utilized to accelerate the H^- ion beam of up to 15mA peak current from 3 to 80MeV of China Spallation neutron source (CSNS). For ease of manufacturing and measurement, the CSNS DTL was divided into four independent cavities. The Q factor of four cavities were given, including the measurement results of low-power [1] and high-power [2], and several reasons for the low Q factor of the cavity in the measurement process were analysed. During the operation of the DTL, the frequent alarm of the water flow switch causes the power of the cavity to fall to 0. Estimate the power loss of each component, under the circumstances of ensuring adequate water flow, reduce the alarm threshold of the water flow switch of some components to improve the stability of the system.

INTRODUCTION

Injectors for CSNS include a 50KeV H- ion, a LEBT, a 3MeV Radio Frequency Quadrupole (RFQ), a MEBT and an 80MeV Drift Tube Linac (DTL) as shown in Fig. 1. The Q factor is an important parameter in the DTL cavity design specifications. The Q factor of the hollow cavity reaches more than 89% of the theoretical value, and the cavity copper plating process meets the high-frequency requirement. The hollow cavity does not include stems, drift tubes (DTs), post couplers (PCs) and slug tuners. Each DTL cavity was powered by a 3MW klystron, the Q factor of total cavity which includes stems, DTs, PCs and slug tuners reached more than 75% of the theoretical value, the power loss of each cavity is within the working range of the klystron. In the course of cavity running, the water flow switch warning question becomes prominent day by day. Through two methods of experimental measurement and CST software simulation [3] to estimate the power loss of each component, especially the PCs and slug tuners. Optimized water cooling system, reducing the system failure rate.

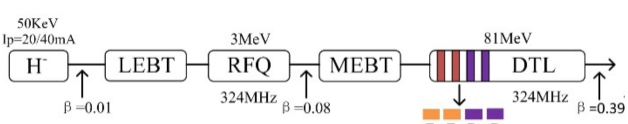

Figure: 1: CSNS Linac injectors.

* Work supported by National Natural Science Foundation of China (11105166), and Youth Innovation Promotion Association of CAS (2015011).
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Q FACTOR OF HOLLOW CAVITY

The length of first tank DTL1 is 8.5 meters, a total of three units. The first unit DTL1-1 has a length of about 2.8 meters. The unloaded Q factor which called Q_0 of the DTL1-1 hollow cavity which shown in Fig. 2(a) was tested. Hollow cavity of DTL1-1 has no stems, DTs, PCs and slug tuners. The openings of the cavity were sealed with copper plugs as shown in Fig. 2(b) and (c).

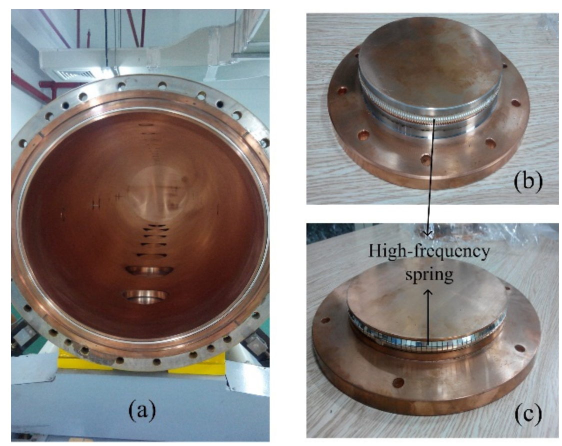

Figure 2: Hollow cavity of DTL1-1 and copper plugs.

Table 1 shows the results of Q_0 of DTL1-1. The final Q_0 was taken as the average of 89.88% of the theoretical value. It shows that the inner wall copper plating process meets the high-frequency requirements. The loaded Q factor Q_L was measured by a vector network analyser using the two-port network method [1]. The Q_0 can be calculated by Q_L, and the formula is shown in Eq. (1).

$$Q_0 = Q_L \cdot (1+\beta_1+\beta_2) = Q_L \cdot \left(1+ {1}/{VSR_1} + {1}/{VSR_2}\right) \quad (1)$$

The factors that influence the measurement result of Q_0 are as follows. The better the high-frequency spring (shown in Fig. 2) seal of copper plugs, the larger the Q_0 measurement. Partial copper plug diameter is too large to install, milling part of the copper layer, bare iron exposed as shown in Fig. 2 (b), due to a part of the material from copper to iron, which makes a little drop in the measured value of Q_0. During the measurement, the standing wave ratio is reduced, which makes the received signal relatively strong. The three results in table 1 are not much different and the measured Q_0 is more accurate.

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Table 1: Q Factor of DTL1-1 Hollow Cavity

$VSWR_1$	$VSWR_2$	Q_L	Q_0	Q_0 (design)	Q_0/Q_0 (design)
9.48	13.57	59400	70043	78032	89.77%
9.37	18.68	60500	70195	78032	89.96%
20.28	18.04	63500	70151	78032	89.91%

Q FACTOR OF FOUR DTL CAVITY

The CSNS DTL contains four cavities and the respective Q_0 of them at RF low-power measurements was obtained (see Fig. 3). The specific results are shown in table 2. The results show that the Q_0 are all above 75% of the design value, which ensures that the 3MW klystron can meet the power requirements. The input cavity power of DTL1~4 during operation was 1.53MW, 1.5MW, 1.42MW and 1.35MW respectively.

Table 2: Q_0 of DTL in RF Low-power Measurements

	DTL1	DTL2	DTL3	DTL4
Q_0	44935	46016	45074	49512
Q_0(design)	53828	58313	58894	58936
Q_0/Q_0(design)	83.4%	78.9%	76.5%	84%

Figure 3: RF low-power measurement of DTL cavity.

The Q factor of the four cavity were also tested using the ring-down method [2] when they were loaded with high power. The calculation method of Q_L is shown in Eq. (2) and (3). In formula (3), A(t) represents the amplitude of the electric field at time t in the attenuation curve of the electric field tail.

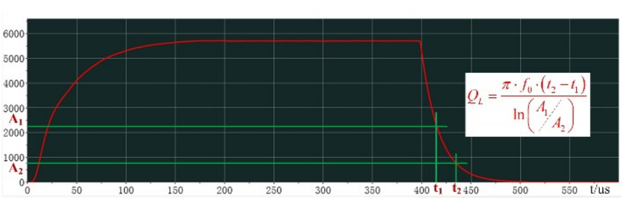

Figure 4: Selecting two A(t) values for calculating Q_L.

As shown in Fig. (4), the Q_L can be calculated by selecting two A(t) values on the attenuation curve tail of the electric field. The ridge waveguides of the DTL cavity are all over-coupled and the calculation method of Q_0 is shown in Eq. (4).

$$Q_L = \pi \cdot f_0 \cdot T \tag{2}$$

$$A(t) = A_0 \cdot \exp(-t/T) \tag{3}$$

$$Q_0 = Q_L \cdot (1+\beta) = Q_L \cdot (1+VSWR) \tag{4}$$

The Q_0 of the four cavity at high-power is shown in Table 3. There are some errors in the high-power measurements in Table 3 and the low-power measurements in Table 2. DTL is such a large cavity that it is indeed difficult to accurately measure its Q_0. However, the measurement results of both methods show that the ratio of the Q_0 of the cavity to the design value exceeds 75%, indicating that the manufacturing process of the cavity meets the engineering requirements.

Table 3: Q_0 of DTL in RF High-power Measurements

	DTL1	DTL2	DTL3	DTL4
VSWR	1.58	1.38	1.49	1.57
Q_L	17888	18756	20105	16725
Q_0	46151	44639	50063	42985
Q_0(design)	53828	58313	58894	58936
Q_0/Q_0(design)	85.7%	76.5%	85%	72.9%

ESTIMATE THE POWER LOSS OF EACH PART OF THE CAVITY AND OPTIMIZE THE WATER COOLING SYSTEM

The drift tube coils of the CSNS DTL and the main heating components such as the drift tube housing, the cavity and the end plate, the slug tuners, the movable tuners, the PCs, the ceramic window, and the ridge waveguide all need to be cooled by circulating water. In order to ensure the normal operation of DTL, the structural layout, mechanical design, manufacture, and stable and reliable operation of its water-cooled distribution system are all very important. Cavity and other components distribution system water supply temperature adjustable 21-28℃, water temperature control accuracy ±0.1℃。 In order to monitor the water flow of each component, in addition to the molecular pump fence and the ion pump fence, all components are equipped with a flow switch.

Figure 5: DTL water cooling interlock system.

Each water flow switch is linked to high frequency system. Below the alarm threshold, the power in the cavity

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will be reduced to zero. Fig. 5 displays the DTL water cooling interlock system. Because the flow switch alarm threshold is relatively strict, the frequency of the fault is high during the operation of the cavity. The power loss of each part of the cavity was estimated, the temperature rise before and after the drift tube with power was counted, and the alarm threshold of most water flow switches was reduced. The power loss of each part of the cavity was estimated by superfish [4] and the result was displayed in Table 4. There are a few things to note here. First, the bucket does not include the front plate and end plate. Second, the front plate and end plate includes the half DT. Finally, others include post couplers and slug tuners.

Table 4: Power Loss of Each Part of Cavity by Superfish

Power Loss/KW	DTL1	DTL2	DTL3	DTL4
Front plate	13.2	16.0	17.8	19.9
End plate	17.2	23.5	25.7	27.8
Cavity bucket	539.4	567.7	570.7	574.4
Drift tube	349.5	358.6	372.6	391.7
stem	175.4	118.1	101.2	92.8
others	250.4	235.8	234.5	237.6
Total	1345.1	1319.7	1322.6	1344.2

Since superfish cannot estimate the power loss of the post couplers and slug tuners respectively, the CST software simulation and the low-power test data can be used to estimate their values.

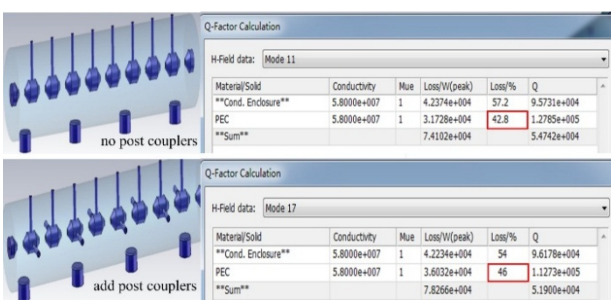

Figure 6: The power loss ratio before and after the PCs were added in the CST.

Figure 6 displays the power loss ratio before and after the PCs were added in the CST. The ratio of Q_0 to its theoretical value before and after adding PCs in low-power test data was shown in Table 5. The simulation and measurement power loss of slug tuners and PCs was shown in Table 6. The measurement value is closer to the actual situation. According to the estimated power loss of each component, some flow switch alarm thresholds are lowered. The specific value are shown in Table 7. Since the drift tube and the internal magnet coil are in a strong electric field region, the alarm threshold does not decrease. After optimizing the water cooling system, the alarm frequency of the water system is greatly reduced when the water supply is stable, and only three alarms occur in about six months.

Table 5: The Ratio of Q_0 to its Theoretical Value before and After Adding PCs in Low-power Test Data

Cavity state (DTL4)	f/MHz	Q_0/Q_0(design)
All slug tuner length is 50mm, no PCs	322.924	79.63%
Average length of slug tuner is 74.4mm, add PCs	323.902	72.03%

Table 6: Power Loss of Slug Tuners and PCs of Simulation and Measurement

Power Loss/KW	simulation	measurement
Slug tuners	191.7	157.9
Post couplers	42	79.6

Table 7: The Water Demand of Each Component and the Switch Alarm Threshold

	Water requirement(L/min)	Flow switch initial alarm threshold(L/min)	Flow switch optimized alarm threshold(L/min)
Drift tube coil	1	0.8	0.8
Cavity bucket	30	25	10(↓)
Front/end plate	6	5	3(↓)
Pcs	2.3	1.5	1(↓)
Ion pump fence	5	/	/
Molecular pump fence	5	/	/
Slug tuners	5	5	2(↓)
Ceramic window	10	10	10
Auto tuners	5	4	4
Ridge waveguide	5	5	5
Drift tube	5	3.5	3.5

CONCLUSIONS

The unloaded Q factor of the DTL1-1 hollow cavity was measured and the final result of Q_0 was taken as 89.88% to its theoretical value. The results of Q_0 of four DTL cavity were given out and the measurement results show that they were all above 75% to its design value. The cavity inner wall copper plating process meets the high-frequency requirement. The power loss of each part of the cavity was estimated and the water cooling system was optimized and the cavity operation failure rate was reduced.

REFERENCES

[1] Z.Y Shen, "Microwave technology," Beijing, National Defense Industry Press, 1980, pp.228.

[2] C.Zhu and Dr. Todd Hubing, "Q-Factor and resonance in the time and frequency domain", Technical Report.

[3] P.H Qu, "3D model analysis of cavity for CSNS DTL", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 4236-4238, doi:10.18429/JACoW-IPAC2017-THPIK061

[4] J Peng, "Physics design and study of the CSNS drift tube linac," Beijing: Institute of high energy physics, Chinese Academy of Sciences, 2008.