THREE-DIMENSIONAL MULTI-PHYSICS ANALYSIS OF A DUAL-BEAM TYPE LINAC

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(1) INTRODUCTIONS

The DB-DTL project has been proposed to proof the feasibility of multi-beam type linac in middle energy region acceleration [2] [3], which will apply to the design of new heavy ion inertial confinement fusion (HIF) facility [4]. The layout of the DB-DTL test bench is shown in fig.1. The main parameters of the prototype DB-DTL is listed in Table.1. The prototype DB-DTL will be operated in room temperature. The power dissipated on the internal surface on the DB-DTL will make cavity temperature rise, which also result in structure deformation and resonant frequency shifting. It is important to simulate the temperature rise, deformation and frequency shifting of DB-DTL cavity. Actually, the prototype DB-DTL will be operated in pulse mode with a duty of 1/1000, with cooling-water channels but without cooling-water because of the limitation of funds. The multi-physics analysis is performed to explore the maximum operating pulse duty factor, which will apply to the beam experiment. The detailed three-dimensional multi-physics analysis of the DB-TL will be presented in this paper, which is a coupled electromagnetic, thermal and structural analysis.

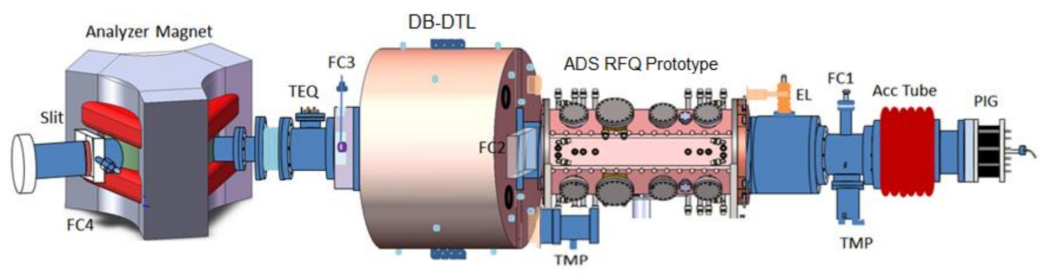

Fig.1: The layout of the DB-DTL beam test bench

Table 1: Main parameters of the DB-DTL

Parameters	Value
Charge to mass ratio q/A	1
Frequency (MHz)	81.25
Beam current (mA)	1
Input/output energy (MeV)	0.56/2.5
Radius of beam-aperture (mm)	10
Maximum gap voltage (kV)	389.06
Transmission rate	34%
Operation mode	pulse
Cavity length	919.43
Shunt impedance (MΩ/m)	200.02
Normalized power dissipation (kW)	35.83

(2) MULTI-PHYSICS ANALYSIS OF THE DB-DTL

1. The procedure and goal of multi-physics analysis:

As shown in fig.2 [6], the procedures of multi-physics analysis include electromagnetic, thermal, structural and frequency shifting analysis. The deformation and stress of cavity and corresponding resonant frequency shifting should be within a proper range.

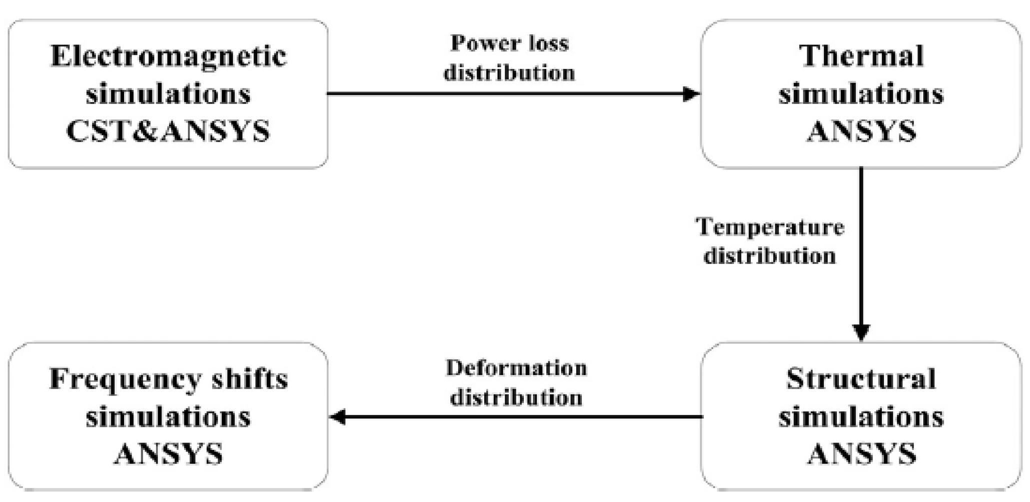

Fig.2: The multi-physics analysis scheme with MWS and ANSYS (Cited [6]).

2.. Heat transfer theory and parameters of cooling-water

$$h_c = \frac{KN_u}{D} \quad (1)$$

$$N_u = 0.023 R_e^{0.8} P_r^{0.4} \quad (2)$$

$$P_r = \frac{\mu C_p}{K} \quad (3)$$

$$R_e = \frac{\rho v D}{\mu} \quad (4)$$

Table 2: Main parameters of cooling-water

Parameters	Ridges Cooling-water	Walls Cooling-water
D (mm)	15	*15*
v (m/s)	2	*2*
Re	*30000*	*30000*
Pr	6.6349	6.6349
Nu	187.14	187.14
Hc (W/m²/⁰C)	7860	7860

3. Structure model of the DB-DTL and the layout of cooling-water channels:

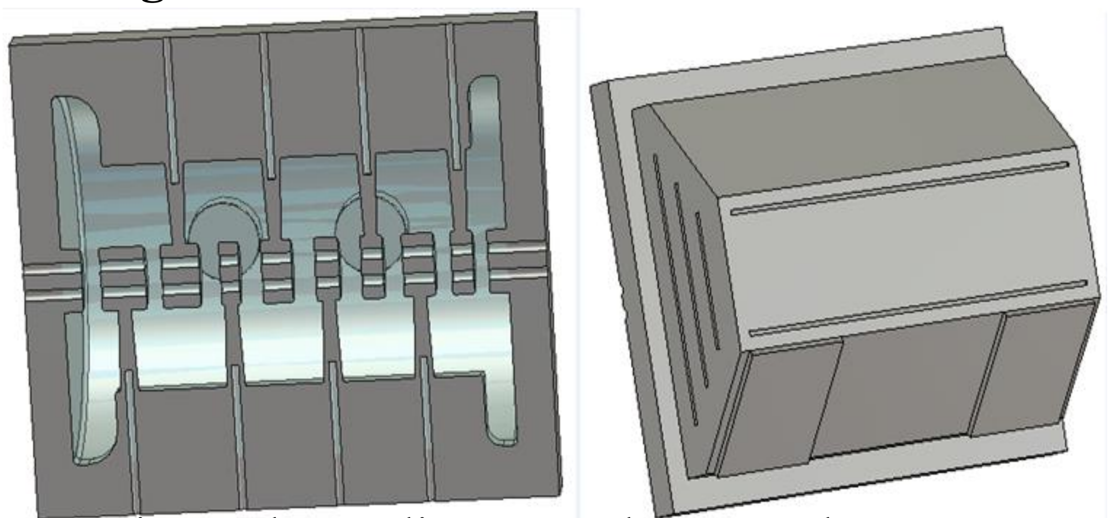

Fig.3: The cooling-water layout and structure model of the DB-DTL.

4. The multi-physics analysis results of the DB-DTL with a duty of 1/100:

The power dissipation of the half model of the DB-DTL is set to be 18.915*1/1000 kW in thermal simulation. In addition, there isn't cooling-water in the cooling-water channels because of the limitation of funds. The simulation results show that the maximum temperature is 21.38 ⁰C located at drift tube, the maximum deformation is 23.4 um located at upper cavity edge, and the maximum stress is 22.942 MPa located at fixed supporting plane edge, as illustrated in fig.4. The deformation of DB-DTL cavity will cause frequency shifting. The frequency shifting is 0.9 kHz. All the simulation results are within an acceptable range, which meet the designing goal of the DB-DTL operated in pulse mode with a duty of 1/1000.

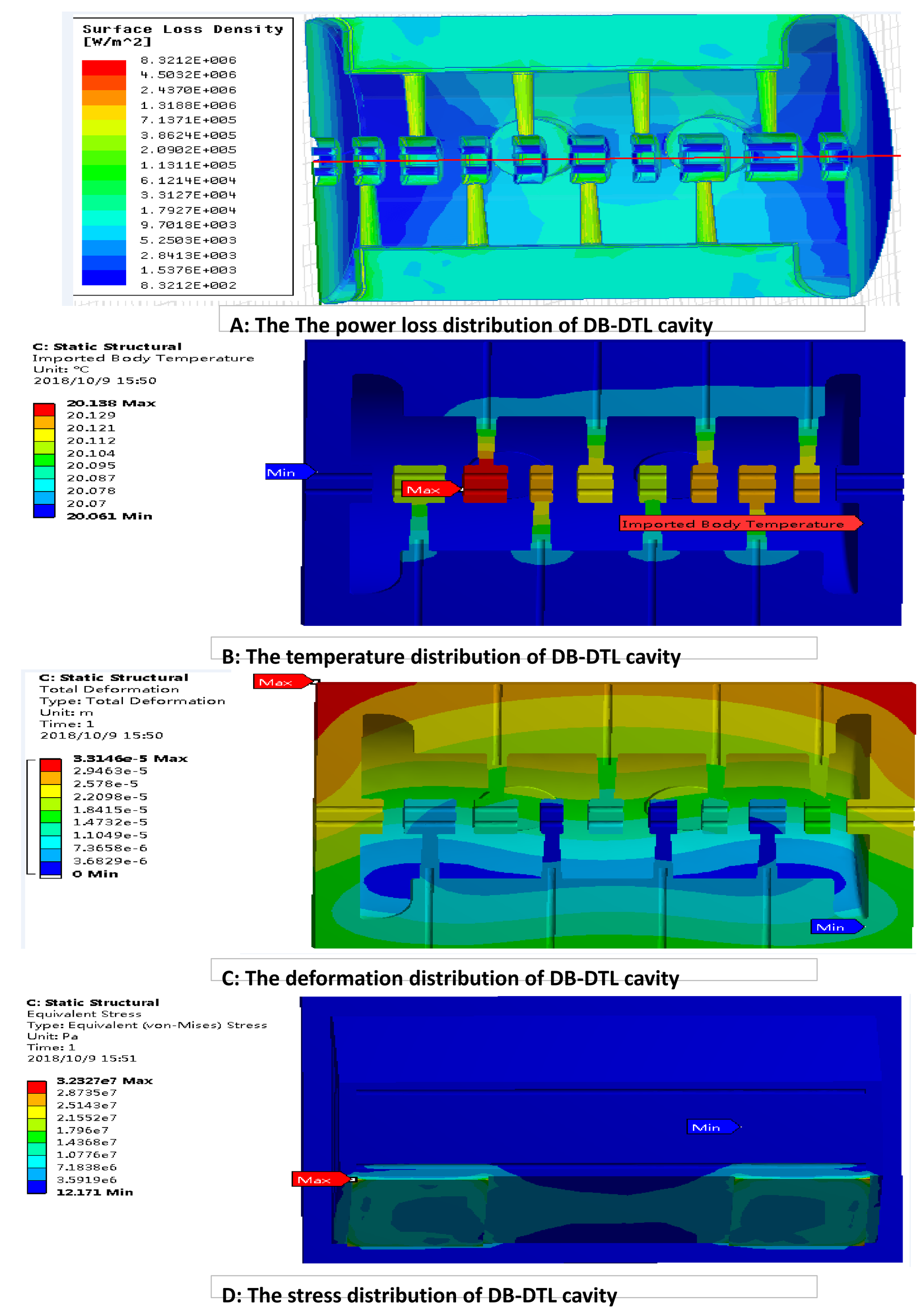

Fig.4: The power loss, temperature, deformation and stress distribution of the DB-DTL

5. The biggest beam duty factor is explored for beam experiment: 1/100.

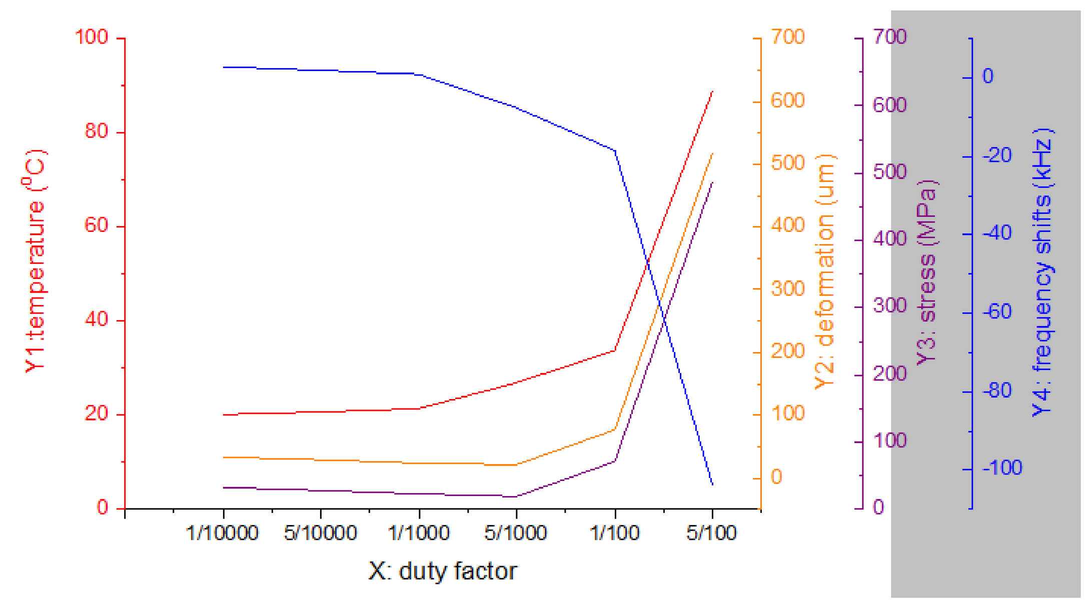

Fig.5:Without cooling-water system, the variation of the maximum cavity temperature, deformation stress and corresponding frequency shifts with duty factor.

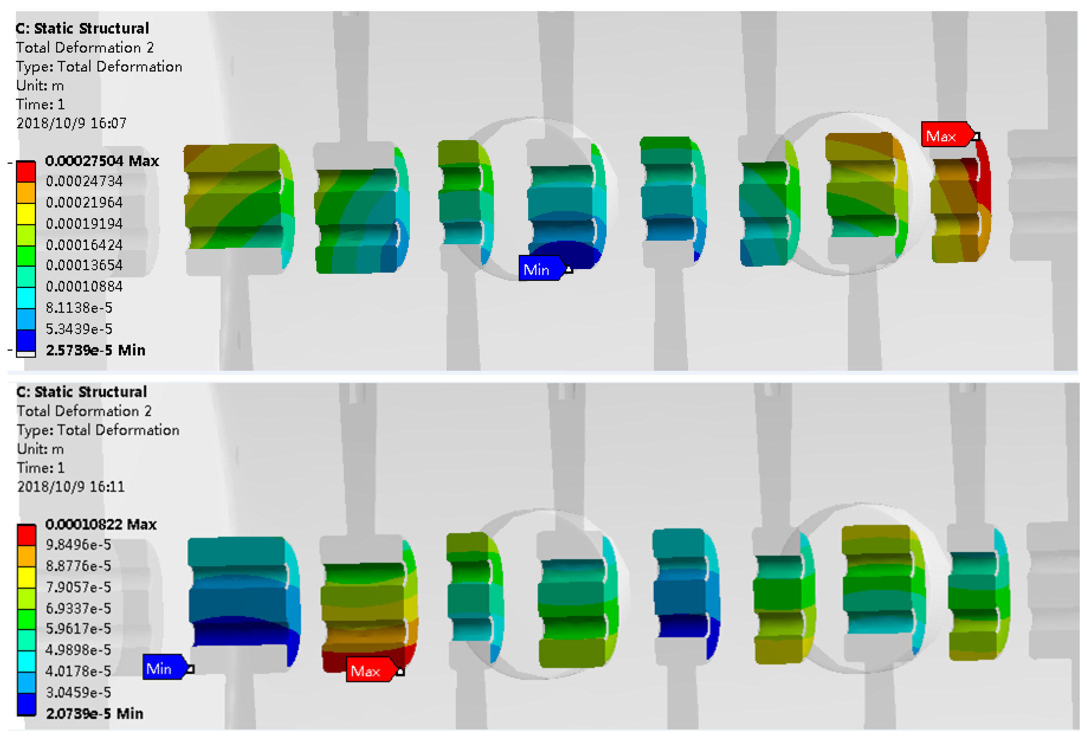

Fig.6: Without (above) and with (below) cooling system, the deformation distribution of drift tubes with 5/100 duty factor.

Table 4: The multi-physics analysis results with or without cooling-water system

Parameters				
Cooling-water	With-out	With	with-out	With
Duty factor	1%	1%	5%	5%
Temperature (0C)	33.798	25.795	88.99	48.973
Deformation (mm)	76.551	32.123	519.46	108.22
Stress (MPa)	70.912	34.498	488.04	29.009
Frequency shifts (kHz)	-18.5	-6	-103.9	-41.9

(3) Conclusion

Three dimensional multi-physics analysis of the DB-DTL has been performed, which is a coupled procedure including electromagnetic, thermal, structural and frequency shifting analysis. The designing goal is that the DB-DTL is operated in pulse model with a duty of 1/1000. There isn't cooling-water in the cooling-water channels of the DB-DTL for the limitation of funds. The simulation results show that the maximum temperature is 21.38 0C located at drift tube, the maximum deformation is 23.4 um located at upper cavity edge, the maximum stress is 22.942 MPa located at fixed supporting plane edge and The frequency shifting is 0.9 kHz caused by the cavity deformation. All the simulation results are within an acceptable range, which indicate that the designing goal of DB-DTL is achieved. The maximum loadable duty factor has been studied and the maximum duty factor is 1/100 during the beam experiment in the future. In addition, the multi-physics analysis of the DB-DTL with cooling-water system and the frequency sensitivity of cooling water temperature also have been performed if the cooling system is required in the future.