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Tuner Design for PEFP Superconducting RF Cavities

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1. Introduction

A superconducting radio frequency (SRF) cavity will be used to accelerate a proton beam after 100 MeV at 700 MHz in a linac of the Proton Engineering Frontier Project (PEFP) and its extended project [1]. In order to control the SRF cavity's operating frequency at a low temperature, a new tuner has been developed for the PEFP SRF cavities.

Each PEFP superconducting RF cavity has one tuner to match the cavity resonance frequency with the desired accelerator operating frequency; or to detune a cavity frequency a few bandwidths away from a resonance, so that the beam will not excite the fundamental mode, when the cavity is not being used for an acceleration [2,3].

The PEFP cavity tuning is achieved by varying the total length of the cavity. The length of the cavity is controlled differentially by tuner acting with respect to the cavity body. The PEFP tuner is attached to the helium vessel and drives the cavity Field Probe (FP) side to change the frequency of the cavity, as shown in Fig. 1.

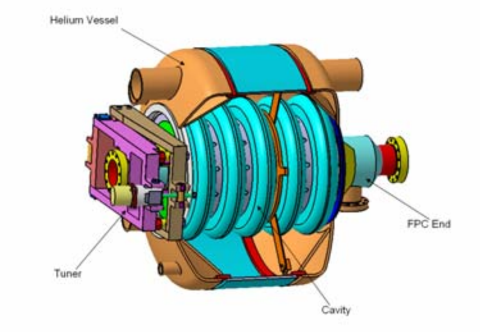

Fig. 1. An assembly of a PEFP low-beta cavity, a tuner and a helium vessel.

2. Tuner Requirements

The role of the tuner is to adjust the cavity frequency to an accuracy of 1/20th of the cavity bandwidth [4]. From the Q_{ext} of 8.0×10^5 of the input power coupler for the low-beta cavity, the expected bandwidth is 875 Hz, this result in a required resolution of 43 Hz.

A desirable tuner must have a good tuning quality, be stable and have a long lifetime. So, the components of such tuner should be highly reliable, maintainable and repairable, these are the number one priorities that need to be considered [5]. Based on the SNS tuner operation experiences, the specifications of a PEFP tuner for a low-beta SRF cavity are listed in Table I.

Table I . PEFP tuner specifications for a Low-beta SRF cavity.

Parameters	Value
Tuning range (kHz)	470
Resolution (Hz)	<43
Cyclic life (Times)	29×10^3
Radiation limit (rads)	$>10^6$
Tuning method	Tension
Load at full stroke (kN)	25
Travel (mm)	2.5
Temperature range (K)	2~300
Vacuum Environment (Torr)	10^{-7}

3. Tuner Design

A PEFP tuner is generally composed of a stepping motor, a gear reduction, a screw-and-nut assembly and a lever arm with a flex mechanism attached, as shown in Fig. 2. The material of the lever is 316L stainless steel and all the components work in a vacuum space and an extreme environment.

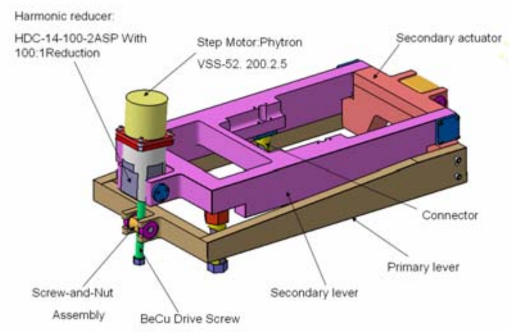

Fig. 2. PEFP tuner structure.

The step motor for the PEFP tuner is Phytron VSS 52.200.2.5. This kind of step motor has good work characteristics in a vacuum space and the work temperature range is -270 °C to 40 °C. The step motor can deliver a torque up to 0.405 N·m and provide 200 steps per revolution. In order to obtain a large driving torque for a tuner, a gear reduction is necessary. The PEFP tuner gear reduction adopts a harmonic reducer, because the harmonic reducer is known for its zero backlash, high torque, compact size, excellent positional accuracy and high reduction ratio. In addition, the harmonic reducer has good characteristics in a vacuum space. The PEFP tuner's harmonic reducer provides a gear reduction of 100:1 between the step motor and the drive screw. The drive screw material for the PEFP tuner is BeCu, chosen for its strength, hardness and high thermal conductivity.

The PEFP tuner is designed based on the leverage principle. Figure 3 shows its detailed work principle. The step motor delivers the torque to the harmonic reducer. The harmonic reducer amplifies the torque to drive the screw rod. The screw rod transfers the torque to be the drive force *F*. The *F* works on the active point *D* of the primary lever. The other end of the primary lever is hinged to the helium vessel at point *C*. For the secondary lever, one end is hinged to the primary lever at point *B*, and the other end is hinged to the helium vessel at point *A*. The primary lever movement induces a secondary lever movement to produce a secondary drive force F_1 at point *B*. Two connectors on the middle of the secondary lever (point *O*) connect the cavity and deliver the tuning force F_2 to it. F_2 is 25000 N for a PEFP low-beta cavity.

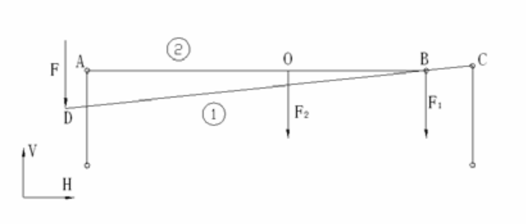

Fig. 3. Diagram of the tuner work principle

According to the lever structure shown in Fig. 3, and after made a detailed calculation we got F=1000.48N. Base on the relevant equations, we can get *T*=0.022 N·m which is output torque of step motor.

PEFP tuner step motor can output a maximum torque of 0.405 N·m, therefore, the step motor that we chose can match the PEFP tuner system requirements. After a further calculation, the cavity frequency tuning sensitivity is 112.73 Hz per motor revolution and 0.56 Hz per motor step. Therefore, this precision can satisfy the PEFP tuner system requirements.

4. Mechanical Analysis

The tuner's mechanical framework delivers the tuning force from the motor to the cavity. The tuning force is up to 25000N, which is a large load for the forced parts. Because all the parts are located in a vacuum and a low-temperature environment, the tuner is not easy to repair. A detailed mechanical analysis for the whole tuning mechanical system is necessary during design.

PEFP cavity frequency tuning is achieved by using a tuner to stretch and press the total length of the cavity. In order to know the tuner stress distribution after a large load acts on it, we analyzed the tuner working in a stretched and pressed status by ANSYS, respectively. The material of the PEFP tuner framework is 316L stainless steel which yield strength is 480 MPa. So, if the stress surpasses 480MPa, the 316L stainless steel will experience a plastic deformation which is a result we don't want.

In a stretched status at low-temperature, the analysis results show that the whole tuner mechanical assembly's maximal equivalent stress is 214.79 MPa, as shown in Fig. 4. In a pressed status at low-temperature, the whole tuner mechanical assembly's maximal equivalent stress is 214.89 MPa, as shown in Fig. 5. The results of the two situations show, that the maximal equivalent stress of the main components under force is below the 316L stainless steel's yield strength 480 MPa. Therefore, a plastic deformation will not happen in both situations

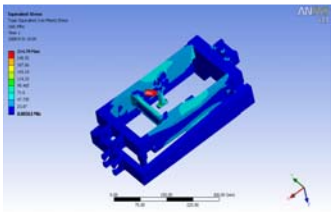

Fig. 4. Equivalent stress distribution of a PEFP tuner under a maximum stretch load.

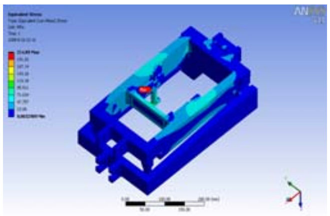

Fig. 5. Equivalent stress distribution of a PEFP tuner under a maximum press load.

According to the above analysis, the new PEFP tuner mechanical structure is able to work at low-temperature stably.

5. Conclusions

A detailed calculation and mechanical analysis have been completed. Every model from the step motor to the mechanical structure has been chosen and designed carefully. They can meet our requirements. The whole tuner mechanical system's stress distribution is rational and the maximal stress is much lower than 316L stainless steel's yield strength. Therefore, the developed PEFP tuner system is safe and rational. Thus PEFP tuner can be used to qualify the tuning work for the PEFP superconducting RF cavity.

REFERENCES

[1] Y. S. Cho and K. Y. Kim, J. Korean Phys. Soc. 48, 721 (2006).
[2] Sun An, Y. S. Cho, B.H. Choi, and J. H. Jang, J. Korean Phys. Soc. 50, 1421(2007).
[3] Sun An, H. S. Kim, Y. S. Cho, and B. H. Choi, J. Korean Phys. Soc. 52, 793 (2008).
[4] J. Preble et al., in Proceedings of the PAC2003 (Portland, Oregon U.S.A. May 12 to 16, 2003), p. 457.
[5] E. F. Daly, G. K. Davis and W. R. Hicks, in Proceeding of PAC 2005, (Knoxville, Tennessee, U.S.A, May 16 to 20), p.3910.