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STATUS OF SUPERCONDUCTING TRAVELLING WAVE CAVITY FOR HIGH GRADIENT LINAC*

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Abstract

The use of a travelling wave (TW) accelerating structure with a small phase advance per cell instead of standing wave may provide a significant increase of accelerating gradient in a superconducting linear accelerator. The TW section achieves an accelerating gradient 1.2-1.4 times larger than TESLA-shaped standing wave cavities for the same surface electric and magnetic fields [1]. The final stage of a 3-cell superconducting travelling wave cavity development is presented. This cavity will be tested in travelling wave regime at cryogenic temperature.

INTRODUCTION

Accelerating gradient in RF cavities is one of the most important parameter of particle accelerator. It determines particle energy and accelerator length which is crucial for multi-kilometres accelerators such as International Linear Collider (ILC) [2]. The cost of this project highly depends on it. In order to reduce the cost with determined particle energy one should have a greater accelerating gradient. TESLA style superconducting standing wave (SW) cavity (180 degree phase advance per cell) is considered to be used as a current ILC design. Accelerating gradient shows the efficiency of acceleration and includes the multiplication of electric field gradient in a cavity and transit time factor which is around 0.7 for 180 degree phase advance. Standing wave cavities length is restricted to 1 meter in order have field flatness degradation less than 5% because of strong dependence on the cavity length. Thus, there is a gap between cavities (220 mm) which reduces accelerating rate by 22%. Superconducting traveling wave accelerating structure was proposed before in our previous publications [3, 4]. It requires feedback waveguide (WG) from one end of accelerating structure to another in order to make a closed loop for power distribution. Although, this cavity has more complicated design (additional waveguide) and tuning procedure (two tuners are required to tune operational frequency and compensate reflections along the loop) it has two urgent advantages. Firstly, field flatness has lower dependence on cavity length. If surface treatment and manufacturing process allow to build 10 meter long (cryomodule length) traveling wave cavity it will have better field flatness than 1 meter long standing wave cavity. This fact increases accelerating gradient by 22%. Secondly, traveling wave does not need to have 180 degree phase advance as it is required for standing waves cavities in order to have each cell filled with EM energy. Accelerating wave travels along the cavity together with accelerated particle. The geometry of TW cavity was optimized in order to obtain a higher accelerating gradient. 105 degree phase advance was found to have 24% higher accelerating gradient than in TESLA style SW cavity. The detailed information can be found in the following article [3, 4].

A 3-cell cavity was chosen to demonstrate traveling wave regime. It was optimized and is manufacturing in AES, Ink. This cavity will be processed and tested at Fermilab in the end of summer 2015. 3-cell tuning studies were presented in publications [5, 6]. They are the following for -30 dB reflections: WG deformation range is 90 um; WG deformation step is 20 nm; longitudinal position range ±4 mm, and longitudinal position step 0.5 um. WG deformation range was extended to 1 mm after some investigations with tuner design and tuning procedure. WG wall deformations were calculated by Ansys and 15 kN force was found to be required for 1 mm wall deformation at 2 K.

3-CELL TRAVELING WAVE CAVITY TUNER DESIGN

As was discussed in [6] 3-cell traveling wave cavity tuner must have the possibility to move the point of force application to the WG. This is the main feature which distinguishes it from conventional SW cavity tuners and the first attempt to make a design became SW tuners review. Cryogenic stepper motor actuator for vacuum application with a reinforced axial load was found in one of Fermilab tuner design. It consists of 200/1 stepper motor, 50/1 gearbox and a shaft with 1 mm thread. That means that 1 step of this actuator produce a 100 nm longitudinal displacement. This motor can withstand 1.3 kN of axial load (Fermilab experience shows 4 kN of axial force before nut failure), i.e. if 12/1 lever is involved 15 kN force and 8 nm step can be achieved by this motor. These numbers satisfy almost all of the requirements. The rest of them is the possibility of moving along the WG. That was solved by additional unit, called traverse, which is mounted to the active lever through linear guides and movable by the second actuator. The 3-cell tuner is depicted in Figure 1 with hidden front rib.

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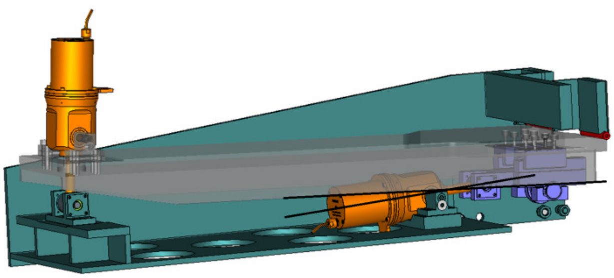

Figure 1: Tuner design.

It is a single lever tuner with reduction ratio 12/1. It has two identical actuators (orange part in Figure 1): 200/1 stepper motor, 50/1 gearbox and "shaft-nut" unit with 1 mm thread. This actuators can provide 100 nm step and 8 nm if 12/1 lever is involved. Active lever is transparent and has a grey colour in the figure. Passive lever is green (one of the ribs is hidden). Two levers are connected to each other through a joint junction – red rods in the picture. Joint junction was chosen instead of ball bearing because it is more simple, occupies less space and the force is better redistributed in it. The last important unit in this figure is the traverse (purple part) which is needed to deform the WG at a particular point. It is connected to active lever through two linear guides which allows it to move along the WG by the actuator. But the actuator axis is not collinear to traverse axis, it has some angle (see black lines in Figure 1). This angle never changes sign. This was done to minimize shaft-nut junction play because of small step value requirement (20 nm).

The tuner design in Figure 1 is in the end of range position. In this position tuner just touch the WG without any force. The work point of tuner is in the middle of range, this fact will allow to deform the WG in both directions as soon as there are elastic deformations in the range of tuner. Thus, the tuner always works against the WG wall spring constant. This will decrease the backlash significantly in pushing direction only.

Traverse linear guides were successfully tested in liquid nitrogen to check thermal shrinkage. After that, tuner test stand was designed and tested at room temperature and liquid nitrogen in order to check traverse-actuator unit feasibility at cryogenic temperatures.

TUNER TEST STAND DESIGN AND MEASURED DATA

Tuner test stand was designed to prove the feasibility of actuator-traverse movement and was successfully tested at room temperature and in liquid nitrogen. Tuner test stand after liquid nitrogen testing is depicted in Figure 2. Tuner test stand has the actuator-traverse unit. Traverse is not seen in this figure, it is inside metal cage. This cage mimics the tuner and transfer load from screwed springs to the traverse. This stand has 6 springs with 50 kg stiffness, which were fully screwed, i.e. 300 kg force was obtained by these springs. Only 30 kg of axial load were transferred to the actuator taking into account friction coefficient of rolling. Nevertheless, it is enough to make a "prove of principle". Traverse was moved by the actuator in liquid nitrogen by similar current as at room temperature. The data can be found in Figure 3.

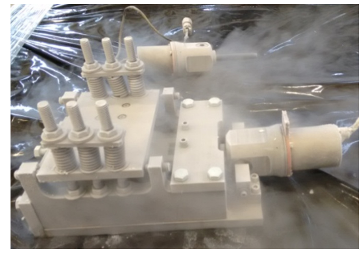

Figure 2: Tuner test stand after liquid nitrogen testing.

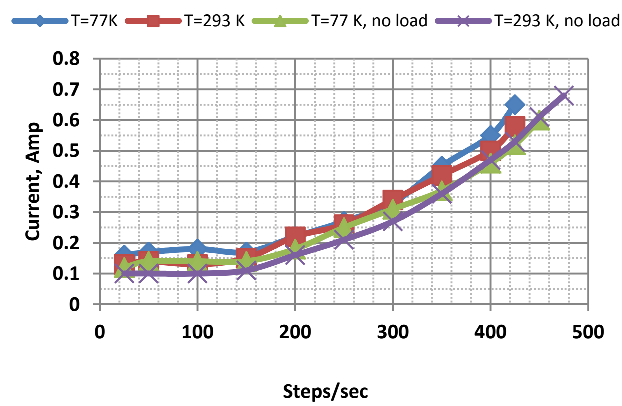

Figure 3: Minimal required current to move Phytron actuator shaft with 300 kg load on the traverse and without load at room temperature and in liquid nitrogen.

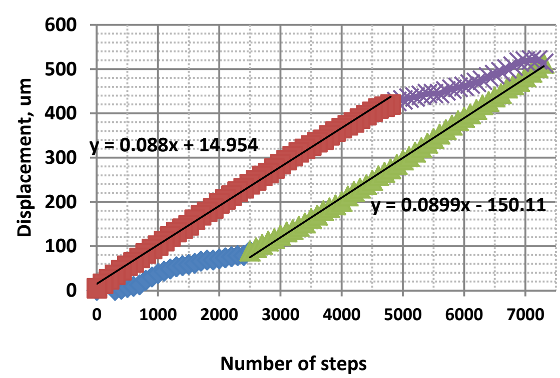

Figure 4: Hysteresis loop of the tuner test stand at room temperature. Sample rate = 500 steps/sec, current = 0.5 Amp, sample = 200 steps

The current indicated in Figure 3 is the current from JOVA controller, which can provide only 1 Amp current for each actuator coil. The actuator has two coils and requires 1.2 Amp current for each coil to show a declared torque (350 mN/m). Torque is linear proportional to current. Figure 3 shows almost the same required current in all four cases: with and without load, at room temperature and in liquid nitrogen. It means that the load is too low for this type of actuator. The data showed that the required current is the same for the speeds less than 150 steps/sec. An increased current is needed after this

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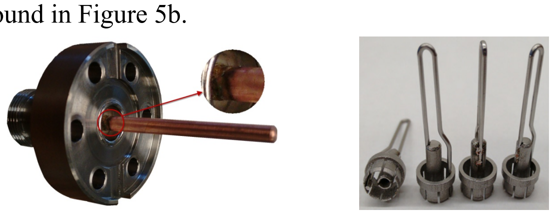
point to move the actuator shaft. This shows a lack of torque because there is not enough time for a given current to rise.

Tuner test stand was tested at room temperature with the goal to determine a backlash and hysteresis loop. It was done by dial indicator with 0.0001" resolution. The data can be found in Figure 4. These data shows around 200 steps backlash and 2500 steps – non-linear regime of displacement. The slope is around 90 nm/step for a linear regime. Calculated slope is 100 nm/step. Each sample in this figure corresponds to two hundred motor steps. If longer sample is employed slope coefficient becomes 100 nm/step.

3-CELL TRAVELING WAVE CAVITY COUPLERS

Both main and measure couplers for 3-cell superconducting travelling wave cavity were designed and manufactured. Only 200 W is considered for each power coupler as soon as the cavity will be tested at Fermilab with existing power supply. The required circulating power is 680 MW in the cavity. The regime is strongly over-coupled, β is around 100, Q_L is 10^8, and S_{12}= -65dB for power coupler. There is a need to redistribute power in two power couplers up to 30/70 in order to make a fine tuning of travelling regime. Thus, 280 W is the maximum power for one coupler. Standard N-type Kyocera feedthrough with 1-1/3" NbTi flange was considered for main and measure couplers. Main coupler can be found in Figure 5a, measure coupler loops can be found in Figure 5b.



a b

Figure 5: a. 3-cell main coupler after electrical breakdown; b. 3-cell measure coupler loops.

Main couplers have antenna shape as soon as they will be mounted on the wide wall of the feedback waveguide in the maximum of electric field. Good electrical contact is required for power coupler because of significant power level. Copper was chosen as a material for antenna. Antenna was soldered to inner conductor by usual soldering iron. This coupler was tested in liquid helium at Fermilab. Electrical breakdown occurred at 263 W for the first time and around 220 W for the following ones. Breakdown track can be seen in Figure 5 (see zoomed in circle region). One of the reasons is 10^{-4} mbar vacuum. Additional test will be done with better vacuum. Lower power level will be used with the same circulating power in the case of the test failure. Shorter antenna will be required which is quite easy to do.

Power level of 100 mW was considered for measure coupler taking into account attenuations along the way to power meter. This is more than enough for power meter with 1 uW sensitivity. S_{12} is -98 dB for measure couplers. Measure couplers will be mounted on the narrow wall of the feedback waveguide. Loop shape is required due to absence of electric field. Measure coupler loops can be found in Figure 5b. They consist of two collets connected together by a wire. Collets provide tight contact in order to get clean signal free from vibration noise. Non-magnetic 316L stainless steel was used in order not to contribute additional magnetic field to Nb cavity. Direct Metal Laser Sintering (DMLS) was used for collets because of much cheaper price. No gassing was found from these parts. The loop is detachable and can be rotated if needed. Equal power levels are required from measure couplers which will be obtained by variable attenuators before operation.

CONCLUSION

Superconducting traveling wave accelerating structure may provide 1.2-1.4 times higher accelerating gradient. Reflections along the structure are needed to be compensated in order to obtain TW regime. 3-cell superconducting traveling wave structure was considered to demonstrate traveling wave regime. Electromagnetic and structural design of this structure was optimized. TW regime adjustment was modeled with the influence of microphonics and Lorentz Force. Tuner requirements were determined from these simulations.

This paper shows our investigations in tuner design. One active lever tuner was designed with 2 actuators in order to deform the WG with the possibility of moving along the WG. Backlash and non-linear dependence of displacements from number of steps in the beginning of moving were found for test stand at room temperature. Liquid nitrogen tests show no thermal shrinkage.

The obtained information from the simulations and tests prove the design feasibility and open the way to build the tuner with the required parameters.

Power and measure couplers are also presented in this paper. Power coupler was tested in liquid helium. 263 W was obtained before the breakdown. The next test will be done with better vacuum.

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