ACCELERATED LIFE TESTING OF LCLS-II CAVITY TUNER MOTOR

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Abstract

An Accelerated Life Test (ALT) of the Phytron stepper motor used in the LCLS-II cavity tuner is being carried out at JLab. Since the motor will reside inside the cryomodule, any failure would lead to a very costly and arduous repair. As such, the motor will be tested for the equivalent of five lifetimes before being approved for use in the production cryomodules. The 9-cell LCLS-II cavity will be simulated by disc springs with an equivalent spring constant. Hysteresis plots of the motor position vs. tuner position – measured via an installed linear variable differential transformer (LVDT) – will be used to determine any drift from the required performance. The titanium spindle will also be inspected for loss of lubrication. This paper outlines the ALT plan and latest results.

INTRODUCTION

The LCLS-II Cavity Tuner is a lever-style tuner, consisting of the frame, two piezo actuators and a Phytron stepper motor, the LVA 52-LCLS II-UHVC-X1 (Fig. 1). In the current testing setup, the piezo actuators are not present, and replaced by solid cylinders. Table 1 describes the working parameters of the tuner and motor.

The motor itself consists of four main components: the stepper motor, gear box, titanium spindle and traveling nut. A copper collar is located at the edge of the motor section to attach to a thermal strap. The planetary gear box has a ratio of 1:50. The spindle is a titanium M12x1 thread, which attaches to a similarly sized stainless steel traveling nut. The traveling nut has a TECASIN insert which mates to the M12x1 thread [1].

TESTING SETUP

The cavity is simulated via two sets of disc springs, designed to imitate the cavity's stiffness of 3kN/mm. The tuner frame and springs are attached to an Aluminium base plate (Fig. 2), which is positioned inside the Tuner Test Can.

The can is evacuated and lowered into a vertical test area (VTA) dewar for cold testing at ~4K. Unlike the cryomodule, there is no active pumping on the test can.

An LVDT is positioned between the main lever arm of the tuner and the Aluminium base plate. The LVDT is the primary means of recording and measuring the tuner arm's movement, and the motor's operation. The feedback voltage of the LVDT is used to define the tuner arm displacement. In the provided graphs, the zero-position of the LVDT is at a readback value of 0.016V.

The motor is fitted with a thermocouple for recording the running temperature. However, its readings were found to be too noisy due to the close proximity of other wiring. Instead, a resistance temperature diode (RTD) is attached to the side of the motor portion of the assembly.

A set of limit switches are attached adjacent to the spindle to act as a safety mechanism. The limits are set just inside the maximum mechanical travel of the traveling nut. The motor is stopped once either of the switches is tripped.

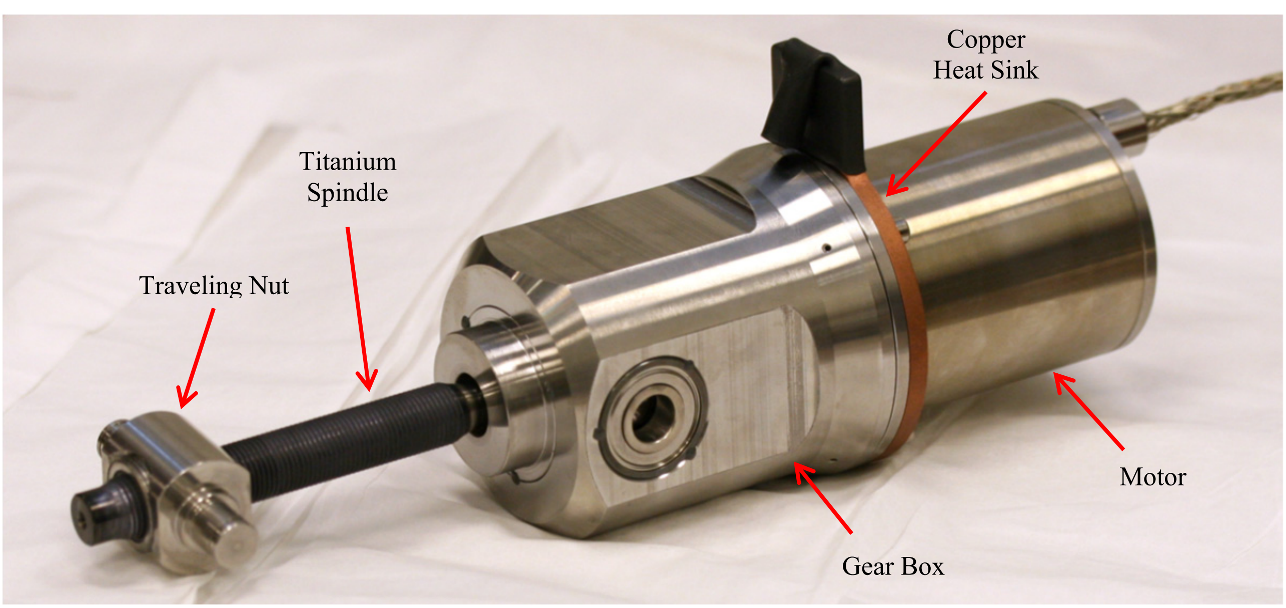

Figure 1: Phytron motor assembly, showing the main components.

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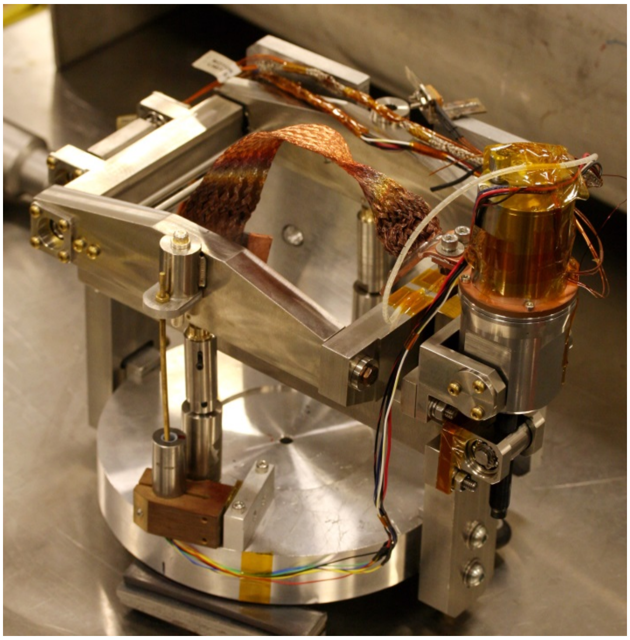

Figure 2: Tuner assembly attached to Aluminium base plate and spring stack for testing

Table 1: Tuner and Motor Operating Specifications

Description	Value
Slow Tuner Frequency Range	Nominal 250 kHz Max 420 kHz
Slow Tuner Dimensional Range	Nominal 740 mm Max 1300 mm
Motor Operating Condition	Insulating Vacuum
Motor Operating Temperature	20K – 60K
Motor Lifetime	1000 revs (20 years)
Motor Current	1.2A
Motor Force	+ 1300N, -200N

TESTING PLAN

Tuner Ranges

It is estimated that the tuner motor will run once a day during regular operation. This part of the testing will involve travel along a small portion of the motor's spindle. For each year of life, this motion is estimated at ~330 cycles (once a day, minus down time). The length of travel is specified to be +/-10 Bandwidths. As each bandwidth is 30Hz, the total motor travel will encompass 600Hz of cavity tuning. Twice a year, the cryomodule is expected to be warmed up, and the tuner motor will travel the full range of its spindle stroke (+/- 13 mm).

From the tuner testing at FNAL, the response from the cavity was found to be 1.4 Hz/step. This leads to a total cavity stroke of ~43 microns (~0.0017 inches). Each spindle rotation requires approximately 200 steps of the stepper motor. As each step changes the cavity frequency by 1.4 Hz, 429 steps (or 2.14 spindle rotations) are required per +/- 300Hz bandwidth (as well as per cycle for the test). The motor driver works at 256 micro-steps per step; in conjunction with the 1:50 gear ratio, this leads to a value of ~ 5.5×10^6 micro-steps per cycle. The total time taken for the five lifetime test will depend on the highest motor speed allowed by temperature increase [2].

The tuner will initially move to a position 13mm from the neutral; it will then cycle with the aforementioned 2.14 revolutions. The small movements will be interceded by a larger stroke movement, corresponding to when the cryomodules are warmed up. This process will utilize the tuner's full stroke of 26mm [2].

Simulated Lifetimes

Table 2 summarizes the motor operation for the test for one simulated year. Each simulated lifetime of testing will encompass 20 years, and a total of five lifetimes will be covered. Table 3 summarizes the testing and inspection schedule.

Table 2: Cycles of Tuner per Simulated Year of Operation

Stroke (mm)	Cycles
+ 13	1
+/- 2	165
+/-13	1
+/- 2	165

Table 3: Testing and Inspection Schedule

Inspection Name	Cycles
Initial Parameter Test	50 – 100
Initiation Failure	~3300
Single Lifetime	~6600
Four Lifetimes	~26,400
Five Lifetimes	~33,000

Parameters

An initial test run was conducted to determine the running parameters which would be used for the remainder of the testing. The following parameters were investigated:

- Motor Speed
- Motor Acceleration
- Motor Deceleration
- Motor Current
- Dwell time between cycles

The parameters were tested with regard to the effect on the temperature rise in the motor.

RESULTS

Test Run 1

Table 4 outlines the parameters used in the first test run. Figure 3 shows plots comparing the LVDT position and Temperature against Time, as well as a hysteresis plot of the first and last cycles.

Table 4: Parameters of 1st Test Run

Parameter	Value
Motor Velocity	10 rev/s
Motor Acceleration	2 rev/s^2
Motor Deceleration	2 rev/s^2
Dwell Time	0 s
Motor Current	1.4 A
Cycles	45

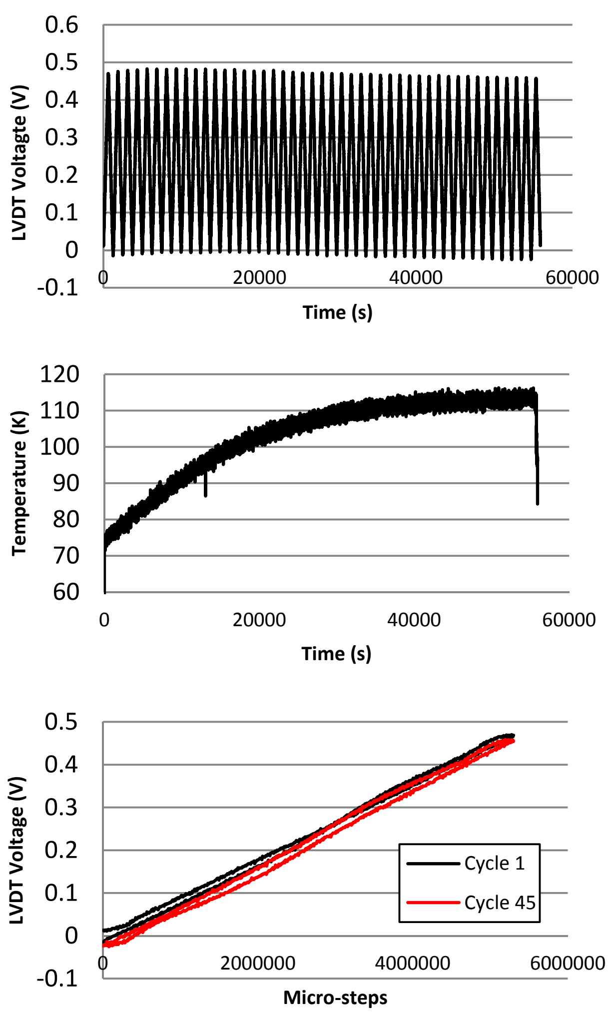

Figure 3: LVDT Voltage vs. Time (top), Temperature vs. Time (middle) and LVDT Voltage vs. Micro-steps (bottom).

The initial test saw a rise in temperature far higher than that allowed for the cryomodule operation, at ~112K. Some positional drift can also be seen in the hysteresis plot shown in Figure 3.

Test Run 2

Table 5 outlines the parameters used in the second test run. Figure 4 shows plots comparing the LVDT position and Temperature against Time, as well as a hysteresis plot of the first and last cycles.

Table 5: Parameters for 2nd Test Run

Parameter	Value
Motor Velocity	5 rev/s
Motor Acceleration	0.5 rev/s^2
Motor Deceleration	0.5 rev/s^2
Dwell Time	0 s
Motor Current	1.4 A
Cycles	30

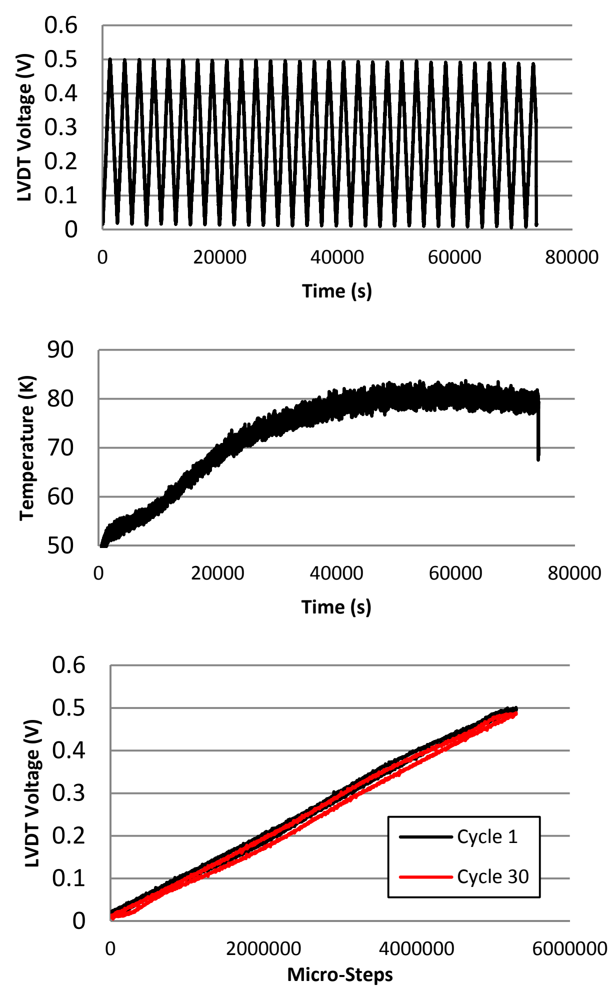

Figure 4: LVDT Voltage vs. Time (top), Temperature vs. Time (middle) and LVDT Voltage vs. Micro-steps (bottom).

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Decreasing the velocity, acceleration and deceleration of the motor greatly reduced the operating temperature of the motor to ~80K. However, it was still higher than that allowed. In addition, the slower speed would make the time frame for the full ALT too large.

Test Run 3

Table 6 outlines the parameters used in the third test run. Figure 5 shows plots comparing the LVDT position and Temperature against Time, as well as a hysteresis plot of the first and last cycles.

Table 6: Parameters for 3rd Test Run

Parameter	Value
Motor Velocity	10 rev/s
Motor Acceleration	2 rev/s^2
Motor Deceleration	2 rev/s^2
Dwell Time	5 s
Motor Current	1.2 A
Cycles	100

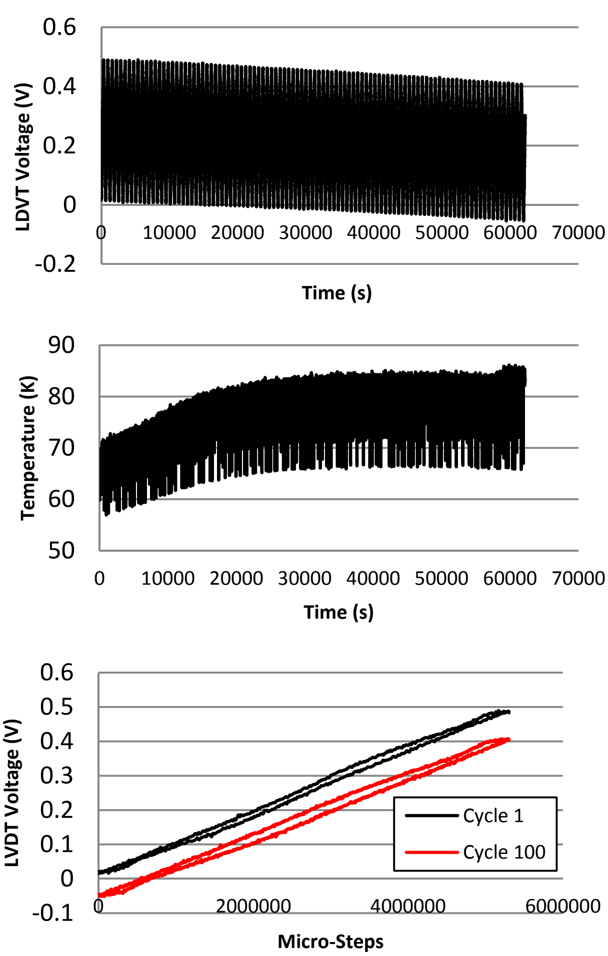

Figure 5: LVDT Voltage vs. Time (top), Temperature vs. Time (middle) and LVDT Voltage vs. Micro-steps (bottom).

A drop in temperature was found when the current was dropped to 1.2 A, and a dwell time of 5 seconds was added between the cycles, while increasing the motor velocity and acceleration. The temperature plateaued at ~83K; this is still higher than desired, but much improved from Test Run 2 in terms of speed. The instantaneous drops in temperature visible in the Temperate vs. Time plot correspond to these dwelling periods. However, as can be seen from the LVDT Voltage vs. Time and hysteresis plots, a large amount of positional drift of the tuner was found. This could possibly be due to non-linear behaviour of the disc springs simulating the cavity, or small thermal contractions.

Spindle Inspection

One of the major inspection criteria for the motor is the condition of the titanium spindle after cycling at 4K.

Previous tests of similar motor/spindle combinations have found the spindles stripped of lubrication after the cycling [2]. The motor was run ~200 cycles during this first testing phase, and no damage or loss of lubrication was found on the spindle (Fig. 6).

Figure 6: Motor spindle after initial test runs, showing no damage or loss of lubrication.

CONCLUSION

The tuner and motor went through initial ALT testing in the JLab VTA at an ambient temperature of 4K. The testing determined that the data logging and testing procedures would function for the full ALT. However, the motor's running temperature was found to be too high at the tested speeds and current, and the tuner's drifting issue also needs to be resolved. A second set of parameter testing runs needs to be carried out before the full ALT can begin in earnest.

FURTHER WORK

The following are changes to the design of the test and apparatus which will be carried out to improve results:

1. A copper strap will be attached to the motor collar, and connected to the inside surface of the test can. The latter is conductively cooled by liquid helium on the outside. The presence of this strap reflects the tuner's actual operating condition inside the cryomodule.
2. A second RTD will be added to the tuner frame. The current diode's close proximity to the motor leads to unsteady temperature readings.
3. The operating current of the motor can be dropped significantly. It was found that the tuner lever arm will move at a minimum current of 0.70 A. This should lower the motor's operating temperature.
4. An analysis will be conducted of the spring constant of the disc spring currently in the test setup. Discrepancy in the force put on these springs may be the cause of the tuner's drift.

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REFERENCES

[1] Y. Pischalnikov, B. Hartman, J. Holzbauer, W. Schappert, S. Smith, J.C. Yun, "Reliability of the LCLS II SRF Cavity Tuner", *these proceedings*, THPB065, Proc. SRF15, Whistler, Canada (2015).

[2] Y. Pischalnikov, "LCLS-II Tuner – Internal Review of the Modified Design", FNAL, December, 2014.

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