Fiber Positioning System Results: General Behavior, Creep Mitigation, and a Set Start Point

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I. Introduction

This is a technical report that will cover the general behavior we have learned about the Piezo-Electrically controlled Fiber Positioner System. This includes the maximum range of movement of the Fiber Positioner and more details on creep behavior of the system. There was also progress made on determining a known start point that can be used as reference for any fiber motion. Before we go into the results, there will be a brief overview of the system as it stood for these measurements.

II. System Introduction

The piezo-electrically controlled Fiber Positioner System is designed to precisely position an optical fiber for the purposes of image acquisition for a spectroscopic telescope. The piezoelectric tube actuator[i], which will be referred to simply as the piezo tube or piezo, is controlled by applying voltages on 4 segments which cause an expansion and contraction which leads to a curve in the piezo tube. The segments are referred to as a North-South(X) and East-West(Y) poles and each pairing are rough opposites of each other. An important note is that the segments are not perfectly symmetric, so they are not evenly divided into 4 quadrants. The voltage range is from 250V to -250V and is controlled from LWDAQ via the A2057H[ii] board. To apply the voltages we send a DAC value to the A2057H board, where 255 DAC will apply 250V on one side of the pole and -250V on the opposite pole, 0 DAC value will apply -250V on one pole and 250V on the opposite. A DAC value of 128 will result in 0 volts applied on either side. The piezo tube has a thin steel[iii] tube emerging from the end, the fiber is contained in this tube and runs to a contact injector which supplies light during DAQ. The steel tube was picked so that it would be as light and as stiff as possible to minimize sagging when the system is inclined as it will be in a telescope. The requirements for this system is that we can send the tip of the fiber to a location within its maximum range with 10µm and when it is at that location it must stay at the location within 10µm for 1 hour.

Due to the material properties of piezo-electric ceramic there are two effects that make this difficult. The first requirement is complicated by hysteresis, there is no simple 1-1 map of voltage to position as the movement from one position to another is affected both by the start and end position. The second requirement is complicated by creep affects, as after a voltage is applied the piezo continues to deform resulting in constant long-term movement.

III. Results

A.

Figure 1 shows the maximum range of motion on the Sony ICX424[iv] CCD, the units are in µm in X and Y. It is important to note that the range in real space is larger than on the CCD; each 1µm change on the CCD is equivalent to ~6µm in real space which holds for all data that shows microns on the CCD. This data set was taken by applying the largest magnitude voltages on each pole to establish the corners, then keeping one polarity constant while varying the other to get the edges. We see that the maximum range is rectangular as there are only 4 directions to control the piezo motion. Originally calculations were done assuming a circular maximum range, however we clearly see below that this was an incorrect assumption. This gives a larger viewing area than previously expected.

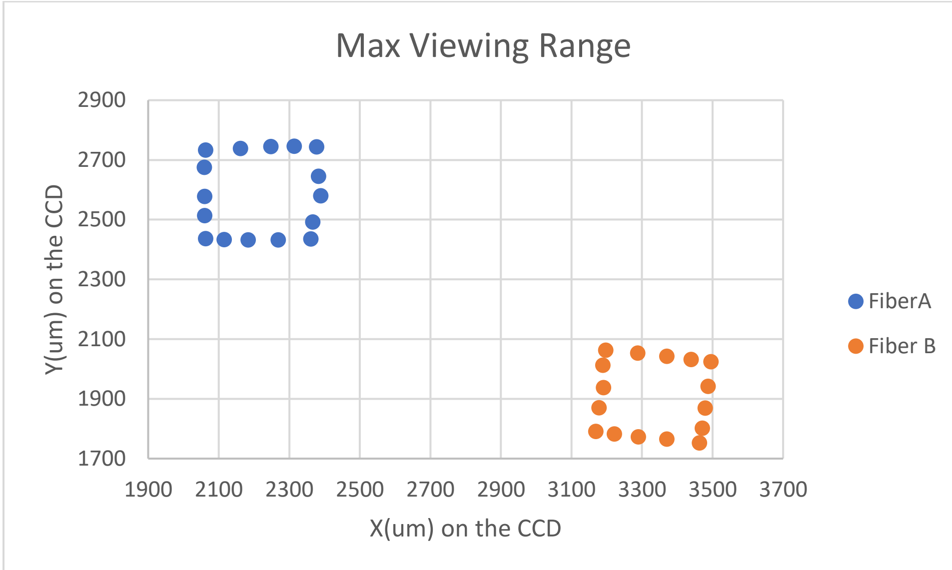

Figure 1: Max Viewing Range

We can also see that Fiber B has its piezo placed not directly parallel to the north-south east-west direction. Due to uneven nature of the piezo segments each piezo will need to be placed and then calibrated as even with consistent placement the directional movement may not be consistent with the NS & EW directions.

B. This short discussion on creep behavior is supposed to serve as supplemental information to prior research done by Guadalupe Duran. We already know that creep rate decreases as a function of time[v]. We will discuss observations about creep with respect to research we have done concerning creep mitigation. The first topic we touch on is how creep rate changes as a function of the voltage change when moving from one point to another. It appears that when the magnitude of the change in voltage is larger, the creep, especially in the first 30 seconds, is larger.

We will see a simple example of this in Figure 2 and Figure 3. These two plots show displacement of the fiber within two seconds of a voltage change. Figure 2 shows the displacement when applying the maximum DAC value on both the NS EW poles followed the minimum DAC value on the poles, this is the maximum voltage change that can be placed on the piezo. The second plot has the same maximum value at the start but is then changed to the 128 DAC value or 0 volts on the poles. We can see below the displacement is larger when the total voltage change is also larger. This holds regardless of whether we are going from low to high DAC value.

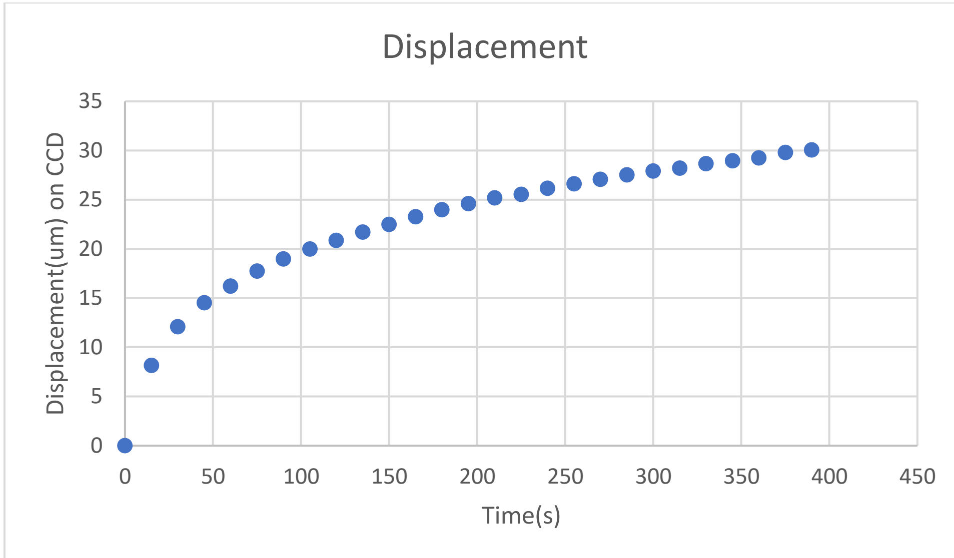

Figure 2: 255,255-0,0 DAC Change

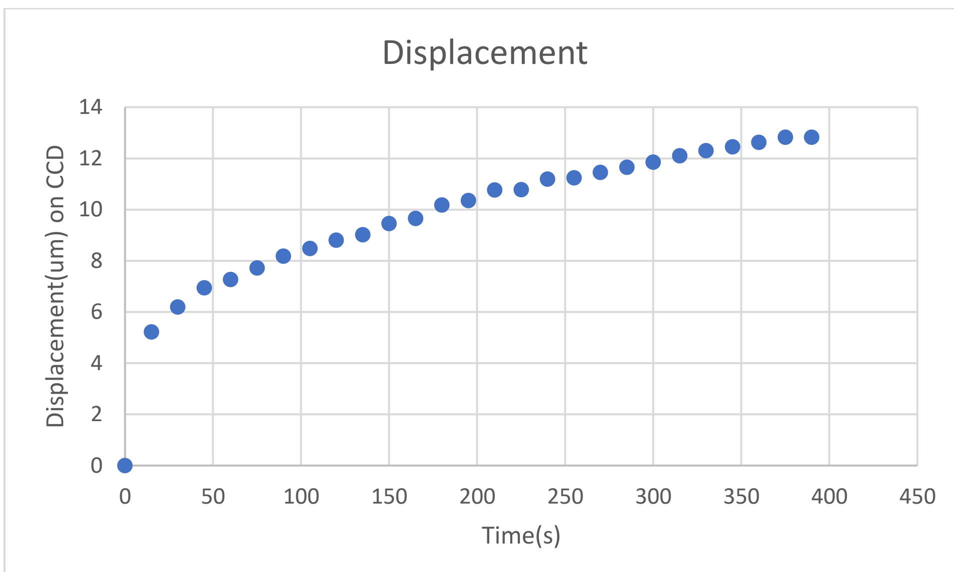

Figure 3: 255,255-128,128 DAC Change

Another piece in understanding the movement of creep is noting the correlation between the direction of the movement during a voltage change and the direction of creep motion after the change. We will demonstrate this by showing displacement on the CCD from 255,255 to 128,128 DAC and 0,0 to 128,128 DAC. As you can see below in figures Figure 4 and Figure 5 though the second voltage applied in both plots are identical that the creep directions are opposite. This holds for all the changes in location we have checked.

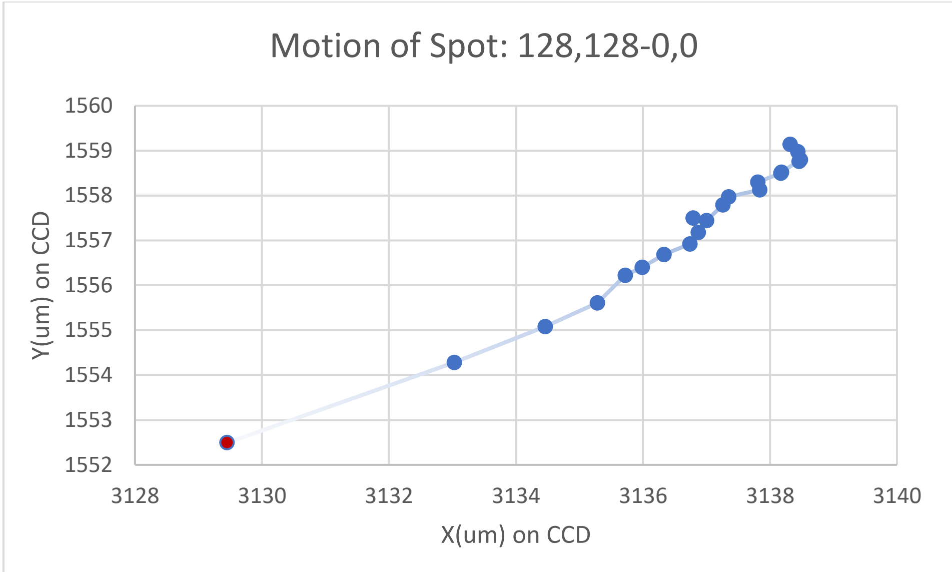

Figure 4: 255,255-128,128 DAC Change

The point with the red fill in figure 4 is the first acquisition of the fiber spot after 128,128 DAC value is applied prior to the acquisition 255,255 DAC was applied to the fiber. The point on figure 5 is the first acquisition at 128,128 following the application of a 0,0 DAC value. Figure 4 clearly shows that the creep is in the positive direction of both X and Y while figure 5 is the opposite. The only difference between the two plots is the voltage that had been applied previously.

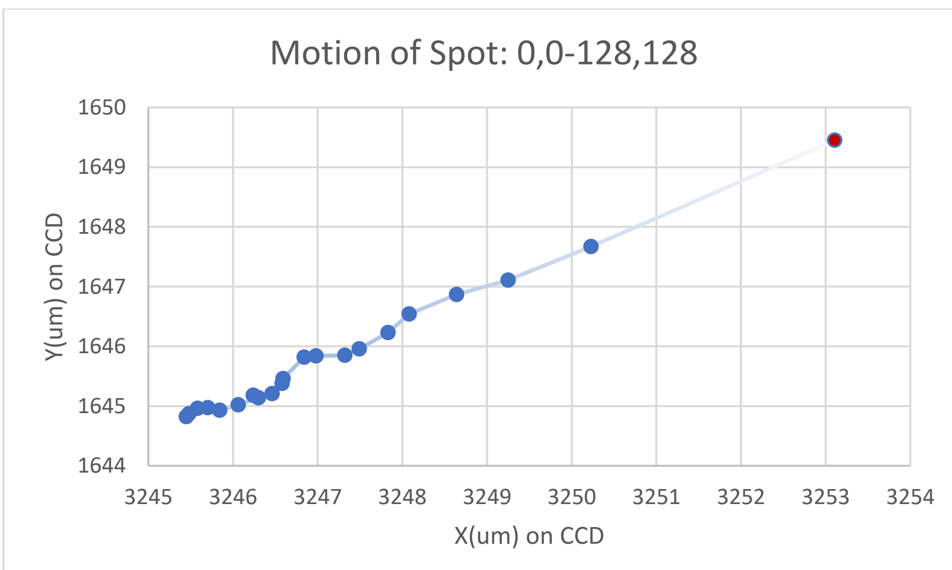

Figure 5: 0,0-128,128 DAC Change

C.

The method that we have been developing for creep control relies on small voltage adjustments that occur after the fiber is moved to the desired position. As we have seen in both the brief examples of creep shown as well as Guadalupe's paper most of the creep motion occurs within the first few minutes after the voltage is applied, and the rate of movement decreases over time. This along with the information we have shown above, creep continues in the direction of the piezo motion and magnitude of motion affects magnitude of creep, gives us a template for what variables need to be controlled or monitored to mitigate creep using voltage adjustments. Using this information, we made a few scripts that control DAC value and we had reasonable success in controlling creep within the setup. The rules we used to generate the scripts are as follows: the largest DAC adjustments were to occur 10s after moving the fibers, followed by subsequently smaller and less frequent adjustments. If adjustments were made too quickly it would overcorrect or start going in the opposite direction of where the creep would normally take it. The other key rule is that all adjustments were made in the opposite "direction" of the DAC change, e.g., if we were changing the DAC from 0-128 the adjustments would be made by subtracting DAC value from 128.

I will not go over the scripts in detail; however, they follow the general rules outlined above. We will briefly go over the results of a few of those scripts to show the moderate success we had in mitigating creep. The scripts that controlled DAC also dictated when the images were acquired. The procedure for the experiments were as follows. First, the piezo had some specific voltage applied for a time longer than five minutes. A different set of voltages are applied on the piezo, there is a 10s delay and then the first image is acquired followed by an immediate voltage adjustment. A large portion of the motion happens in the first 10 seconds, so it is simpler to wait before attempting to control the creep. If the waiting time is consistent the fiber will still be consistently located on the first acquisition. After the immediate larger magnitude adjustment, there is another acquisition followed by another adjustment. The rate of adjustments reduces which corresponds with the slower creep rate. We will write out briefly what the DAC values look like during these adjustments. If we were sending the piezo from 0,0 to 255,255 DAC, the adjustment of DAC would look like this: 255,255—250,250—250,250—247,247—247,247—247,247—246,246—246,246—246,246 and so on. We did not do creep adjustments for the full hour, but we believe that using that my demonstration of creep control using small adjustments is a good proof of concept of this method.

The plots we will show are only one fiber and in the X direction only. Each image acquisition is taken 15s apart, Figure 6 shows unmitigated creep while figures Figure 7, Figure 8,Figure 9, and Figure 10 show creep with the DAC adjustments. The descriptions of the DAC changes are below each plot.

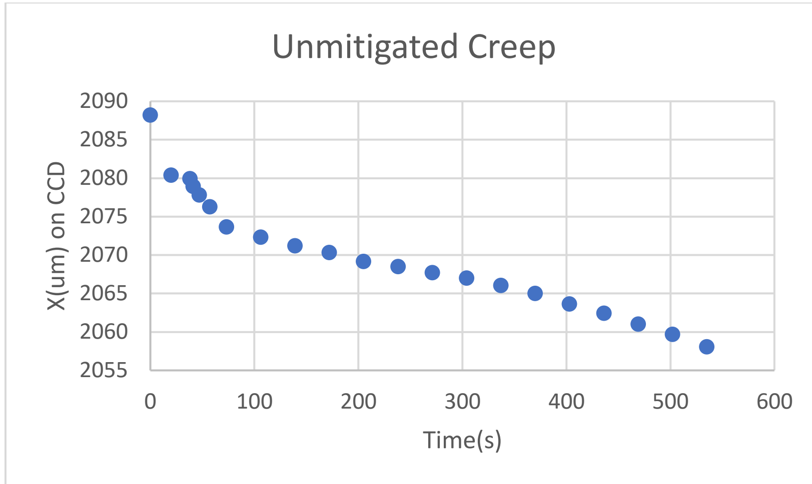

Figure 6: 0,0-255,255 DAC Change Control Test

The plots below show the same magnitude of voltage change, yet the scripts were not just simple opposites of each other. The script for the 255,255-0,0 has a larger initial adjustment. This could suggest some non-uniformity in the piezo, however we have not done more research to determine the root cause at this point. Nonetheless, we can see that over an equivalent time span of around 500 seconds there is a ~180µm shift from starting point in the control test and ~12µm and ~25µm in the first and second plots.

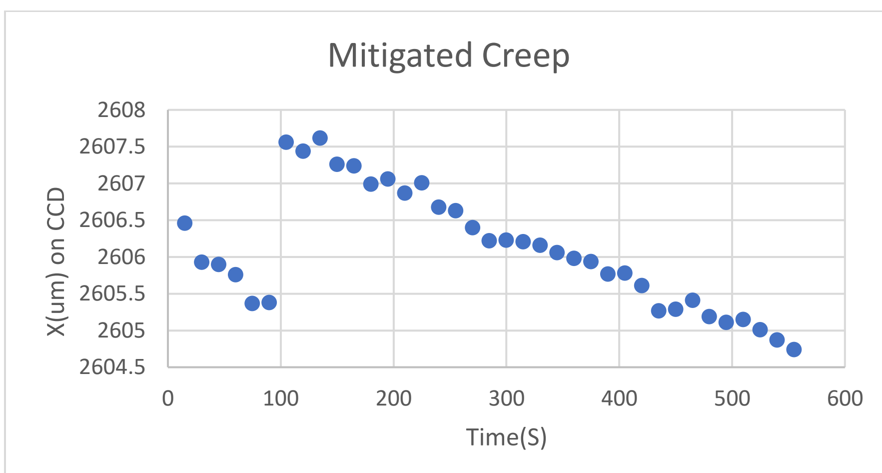

Figure 7: 0,0-255,255 DAC Change Mitigated

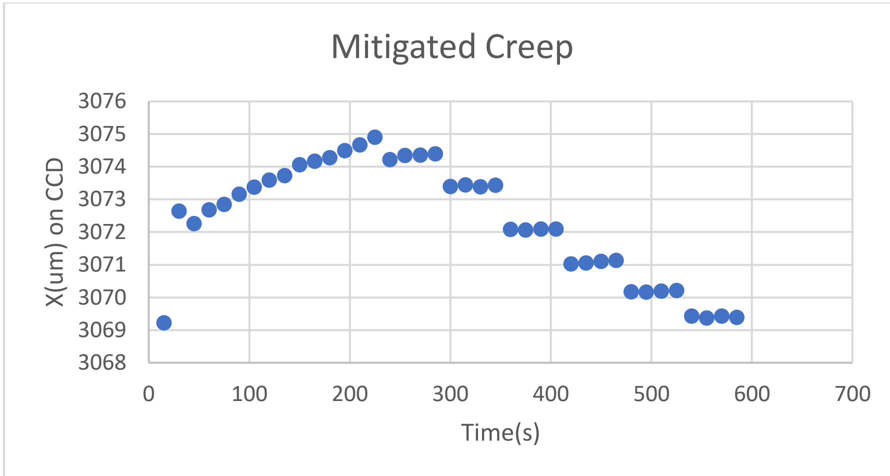

Figure 8: 255,255-0,0 Change Mitigated

The plots below show a smaller magnitude change in both directions and show even greater success in creep mitigation. The largest deviations for both plots are ~12µm in real space in that time window. We think this demonstrates that creep control is possible using these methods, however some more fine tuning is needed.

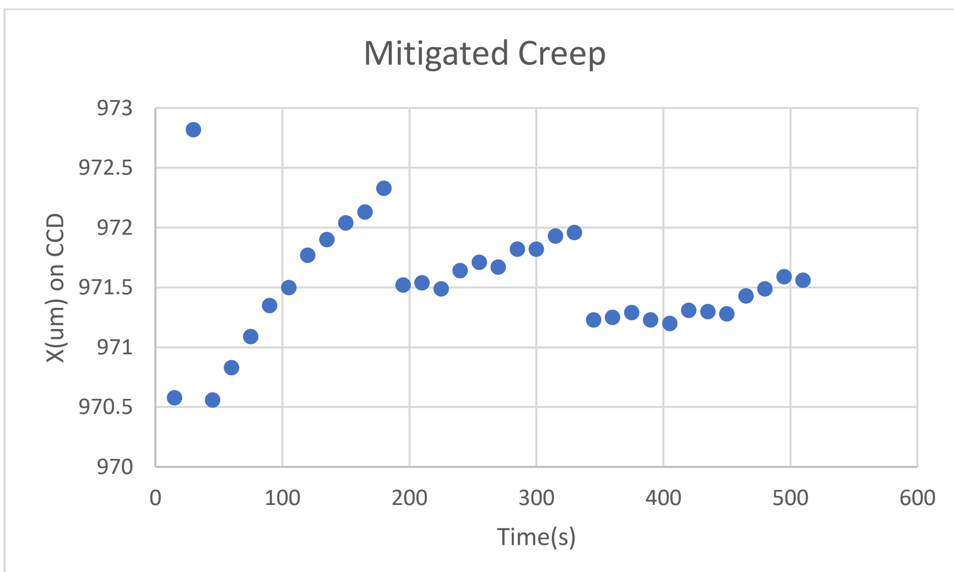

Figure 9: 255,255-128,128 Change Mitigated

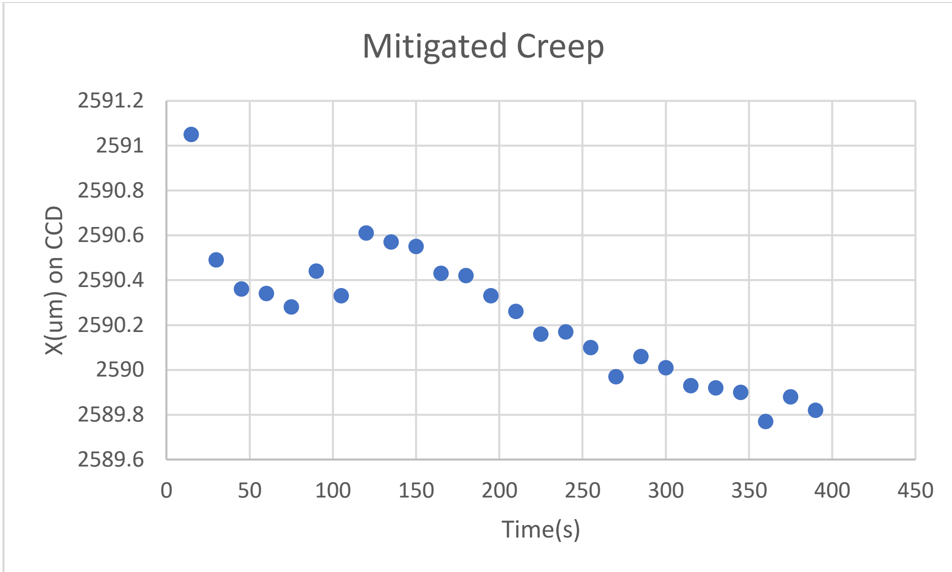

Figure 10: 128,128-255,255 Change Mitigated

D.

This last section covers the attempt to determine a set start point. The goal is to find an algorithm of various voltages and/or timings that will always send the fiber system to the same location. This point can then be calibrated for each individual fiber in the system and used as the point that is always moved from when positioning a fiber for an acquisition. Instead of having to determine the relationship between any point and any other point you would like to move to, the only relationship that would need to be determined is between the set point and the point the fiber was moving too. This reduces the complexity of making a map significantly and it is worth determining whether a set point is possible.

I had some early success using a simple algorithm which involved applying voltages at the min and max of the DAC values repeatedly. First, we tried a simple 255,255-0,0-255,255 which was not successful but discussing. These tests were carried out by first starting the voltage at some arbitrary value to represent the location of the fiber on the prior acquisition. We held the fiber at this voltage for five or more minutes at a time, then the algorithm was run where we changed the DAC values as shown above in 20s increments and took an image after the final move. We used a variety of different initial voltage and saw a spread in the final position which can be seen in Figure 11.

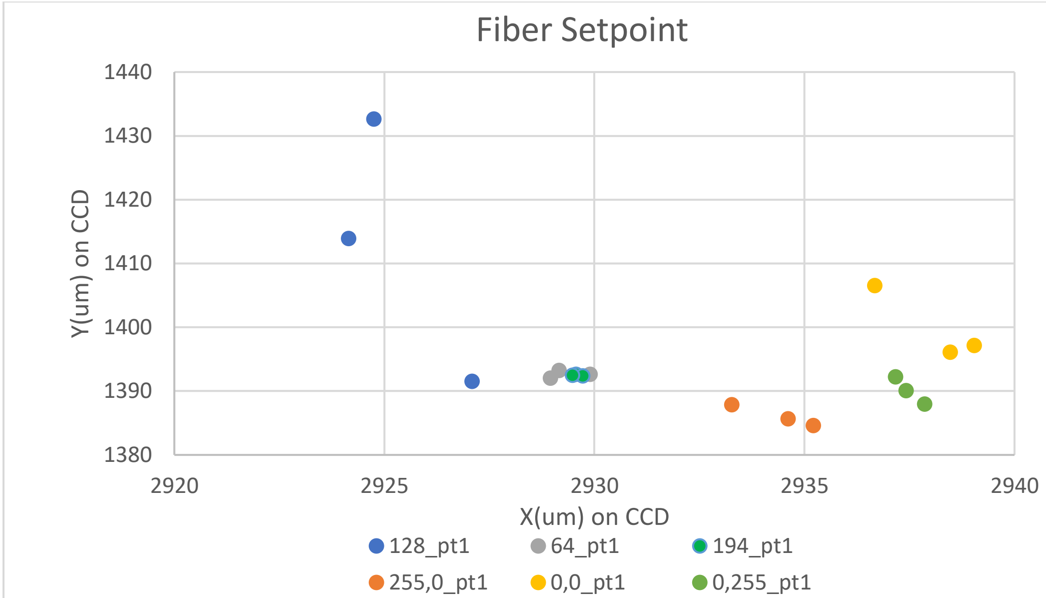

Figure 11: First Algorithm Set-Point

As we can see there is a significant spread, all points ideally would be within 10µm of each other. We see a range almost 300µm in Y and 60µm in X in real space. This is clearly too large of a spread. We tried a second algorithm which was closely related to the first, the difference between the two was simply adding another set of DAC changes. The new algorithm was 255,255-0,0-255,255-0,0-255,255 with the same time difference between each DAC change. We will see below in Figure 12 that the spread shrinks significantly.

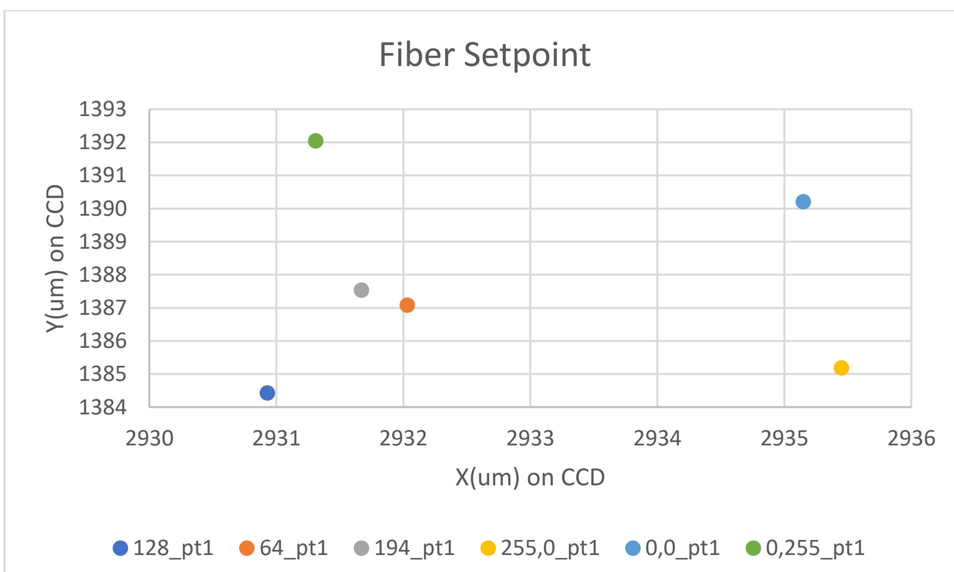

Figure 12: Algorithm with Extra Pair of DAC Changes

As we can see our range in both X and Y is smaller, the max range in X is ~27µm and in Y is ~45µm in real space. While it does not meet the requirements, it suggests that this method could potentially get us within the tolerance we are looking for. In a brief check of the set points' dependence on the time between DAC changes we ran an experiment with the same DAC changes but only 10s in between each. We saw a similar range which suggests that this set point algorithm may be somewhat independent from time between DAC changes. We can see the plot below demonstrating this. The range we see in X is ~18µm and the range in Y is ~36µm in real space, this change in fact results in a smaller spread than seen previously.

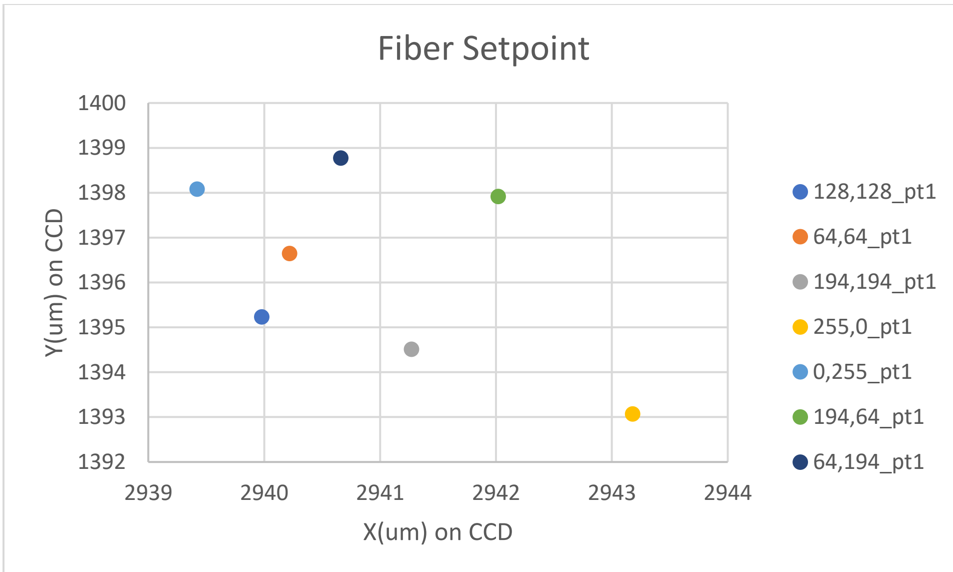

Figure 13: 10s Between DAC Changes

IV. Conclusion and Future Research

There is still important work left to do as we currently do not have a working map from a set point to a specific position. However, this work suggests that the system can be well understood, and it should be possible to determine a map that would allow us to send fiber to specific positions within10µm and have them remain there. The current precision of the set point is not within the requirement of 10µm which will be the goal of future work. Using the creep behavior rules that have been discovered we was able to make scripts that held creep over a shorter time scale to within 10µm. While there is some fine tuning to be done on some of the scripts this method of mitigation seems to be a potential solution to the creep problem.

The future experiments that need to be performed are as follows: how does temperature affect piezo motion, how does the angle of inclination of the system affect its motion, and the map from set point to a certain location must be made. This last experiment is the critical final step in determining the efficacy of the system.

[i] CERAMIC, P. Piezoelectric Actuators, 1 ed. PI Ceramic GmbH, Lindestrasse, 07589 Lederhose, Germany, Feb. 2019. A full MANUAL entry.

[ii] "Input-Output Head", Hashemi et al. (2008-2020), http://www.bndhep.net/Electronics/A2057/M2057.html

[iii] *Hypodermic Tubing,* 304H13X, Microgroup, https://www.microgroup.com/product/304h13x/

[iv] *Solid-state CCD Image Sensor*, ICX424, Sony, https://www.1stvision.com/cameras/sensor_specs/ICX424.pdf

[v] "Properties of Piezoelectric Tube Actuators for use in a Fiber Positioner for a Spectroscopic Telescope", Duran et al. (2020), http://www.bndhep.net/Electronics/A2089/FPS_Feasability.pdf