Senior Project

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Abstract

In order to characterize an open loop piezoelectric motor stage, an attempt has been made to incorporate the stage into an arm of a Michelson interferometer with hopes to to count the fringes passing by a detector as the stage changed the length of the arm. While the goal of achieving accurate movement measurements of the motor was not met, a rudimentary system was constructed as a basis for understanding what kinds of issues the project brought about. Between unstable optics, nonlinear motion of the piezoelectric stage, difficult to control stage accelerations as well as an unfortunate instrumentation failure, a set of information has been gathered on the current state of the effort as well as a number of ideas of where to move next have been compiled.

I. INTRODUCTION

In order to incorporate a piezoelectric motor stage into a larger project, understanding it's characteristics is critical. A Physik Instrumente (PI) M-662.4V0 Vacuum ready piezoelectric motor stage coupled with a PI C-185.161 analogue drive controller box is the particular set of instruments that is of interest in the project. This pair operates using an open loop control system, as apposed to other models that include a position encoder. Consequently, any information about the position or motion of the motor has to be incorporated externally into the control system. The spec minimum incremental motion is listed as 0.1μm[1] although because there is no encoding system, there does no appear to be a standard control signal that can replicate these short movements in a repeatable fashion and in order to move the stage with some degree of accuracy, it is important to have a full characterization for its given application. This project aimed at observing the motion of the stage using a Michelson interferometer constructed with a standard educational optics kit, and a standard 1.5mW HeNe 633nm laser. By attaching a mirror to the stage, the goal is to be to characterize different types of control signals and count the number of fringes that pass by a detector as the motor changed the length of arm. While a configuration has been constructed, not all the pieces of the project have been developed into a practical and accurate observational system due to a number of unseen issues, instrumentation failure, and insufficient time. Currently, an interferometer is setup and can produce clear, steady fringe patters that can be counted when the mirror is slowly moved manually using a micrometer stage. An electronic data acquisition and signal generation system has been developed in LabVIEW. With these items in place, due laser failure, a new laser had to be incorporated into a data acquisition system that was designed for the previous equipment which has resulted in a number of issues. It has also been discovered that moving the stage is harder than previously understood, which has lead to vibrational problems in the optics system due to large accelerations that are hard to avoid. Information on different types of control signals as well as some rudimentary measurements to observe what the system is currently capable of will be the main topic of this paper in addition to discussion on suspected sources of error.

II. PROCEDURE

There are three major parts to this project. The ultimate goal is to develop a way to move the motor in a predictable way. This requires understating a bit about the piezoelectric motor such as the mechanisms behind its motion as well as the specifications provided in order to use it. Interferometery, the method in which we hope to observe the motion of the motor with, offers a very high degree of accuracy and feedback (but is also very susceptible to noise!). This requires some understanding of what is happening with our optics as well as understanding some theory to calculate distances from collected data. The third major part of the project is developing tools in LabVIEW to collect data and generate control signals for the motor. In addition to these main parts of the project, designing custom mounting pieces to be custom machined was a requirement (and thanks to David Shook for his Solid works assistance!).

A. Piezoelectric Motors

The Pi M-662.4V0 is a piezoelectric translation stage. It can move its top plate very short distances. It works using a piezoelectric oscillator that slides back and forth along a friction bar that pushes the above stage along. Depending on how the oscillator is exited, is pushes in one direction, and slides back the other allowing the stage to move in that direction. The actual oscillation signal sent to the oscillator or "stator", is provided by the driver electronics. Piezoelectric have a relationship between their electric charge and mechanical stress. If you apply a strong electric field, you can cause the shape of the piezoelectric to change shape by a small amount. There are quite a number of different applications piezoelectric's have in optics (between tuning a laser wavelengths and positioning mirrors in laser cavities).[2] The C-185.161 analogue drive controller box accepts a -10 to 10 Volt analogue signal. It is documented that when the voltage passes across 0, the motion of the stage reverses direction. There is also some kind of control voltage versus stage velocity relationship, as in the more input voltage you send the driver, the faster the stage moves. When purchasing the motor, it is tuned with the driver box to work optimally. When designing the project, the assumption was made that moving the stage at low velocities would not be a challenge. It turned out that controlling the motor was not quite as simple as it sounded. Motion at

FIG. 1. The Piezoelectric Stage

low voltages do occur. The first visible signs of motion begin around 2.3-2.5 volts. Around 2.3 volt pulses, a small but noticeable waver occurs in the interferometer fringes indicating some motion is disturbing the stable system. No motion occurs however and its effectively appears as a slow vibration in the fringe pattern. Around 2.5 volts, at certain positions, the there is translational motion, until the motor hits a position at which point gets stuck. There are a number of positions that the motor appears to get stuck or experience more friction attenuating its motion. If the stage get's stuck, applying a larger signal voltage of 3volts, the motor will unstick and continue to move. These spots of friction are most apparent between 2.5 and 3.5 volts. At higher input voltages, these friction spots become less apparent and the velocity seems fairly uniform, but also very fast. The uniformity of the velocity however is purely based on personal observation and has not been observed by the interferometer. This lack of reliable control of the speed at low voltages results in a number of issues regarding vibrations that end up disturbing the optical setup.

It is completely possible to move the motor in very small steps, but in doing so measurements have not been possible yet. Sending it very short pulses at low voltages will result in a very small stepping action. The distance of each step appears susceptible to the apparent friction at different positions. Having the interferometer step a short distance quickly caused a lot of vibration in the optics, which were visibly disturbed well after the motion had ended. Enabling the pneumatic table helped reduce this.

Instead of sending pulses, ramping the voltage seemed to help reduce some of the vibrations, but even with a very low slope vibrations seemed to appear in the data when the motor stopped moving. Charts of these ramped, trapezoidal control siginals are shown in Figure 5.

B. Interometry

The interferometer was modeled after an example given in the projects guide that accompanied optical kit.[3] It consists of a Galilean beam expander, a beamsplitter, as well as two mirrors and a convex lens to enlarge the target pattern. A diagram is shown in Figure 2. The motor was mounted on a custom built mount for an optics table and the mirror was then mounted to a quarter inch screw mount that was also made for the motor. These mounts can be seen in Figure 3.

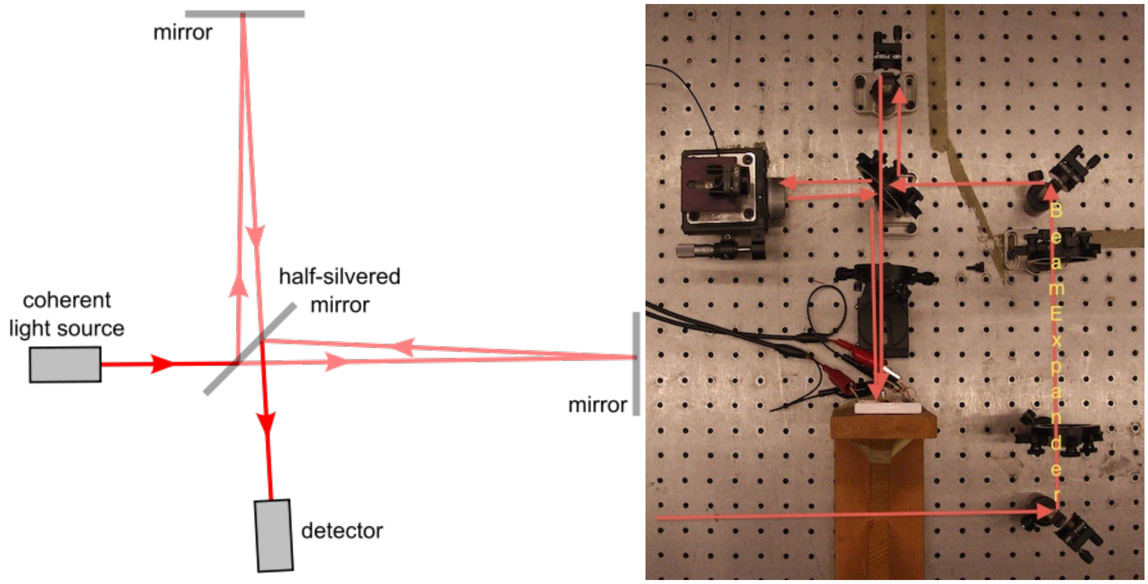

FIG. 2. The Michelson Interferometer Setup

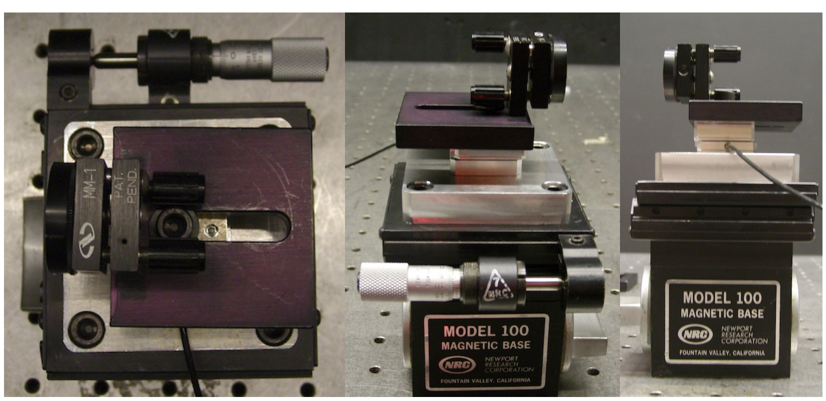

FIG. 3. The motor and mirror mount

As a mirror is moved by $\lambda_0/2$, each fringe will move to the position previously occupied by an adjacent fringe. If we are able to count the fringes that go by we can know the change in distance.[4] This is given by

$$\Delta d = N(\lambda_0/2) \tag{1}$$

Difficulties arise when the fringe pattern is disturbed by vibrations. These vibrations can appear to be fringes moving across our detector, but really are just oscillations within our system. Also, unless the mirror moves in exactly one dimension, our fringe pattern can change shape, orientation and width as the mirror distance is changed. Because the system is aligned by hand using adjustable hardware, this appears to be an issue present in the optics.

C. Data Acquision

Developing a detector required a simple phototransistor circuit and adjusting resistor values until the optimal reading was achieved. Developing a LabVIEW program devoured a significant amount of time as original design plans for the program attempted to accommodate fringes moving at a slower speed. With the assistance of version control, prototyping a range of different control and acquisition vis helped develop what is seeming to work out well. The best way of collecting data it seems is to begin collecting data as the control voltage is less than the movement threshold, and continue recording data as you ramp the voltage back to zero. This way a manageable amount of data is collected for a known instruction. Because this is done simultaneously, it makes it very easy to save all of the settings and control waveforms with the phototransistor data.

Given the data collected, it appears we are having a number of issues ranging from possible aliasing, exceeding the capabilities of the transistor potentially. During this process the laser originally being used malfunctioned and is no longer operable. As a last minute attempt at collecting data, a different laser with reported power fluctuations was implemented to replace the old. Because of this, the signal got weaker and noisier. A suspicious oscillation in the data when no movement was occurring could indicate that the power output of this laser was inherently less stable.

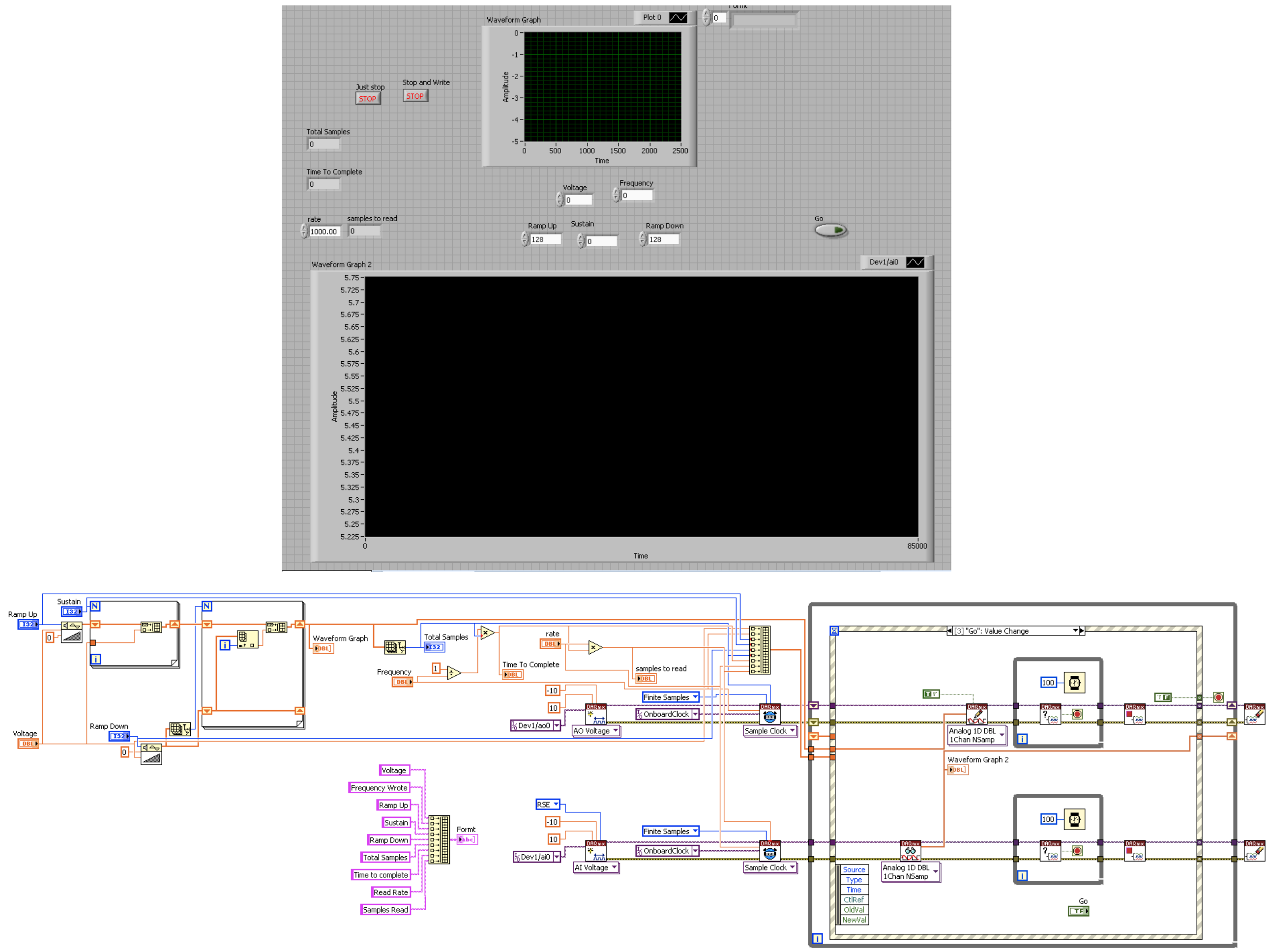

FIG. 4. Current State of the developed LabVIEW Program

III. RESULTS

In Figure 5, the control signal voltage versus time is plotted alongside the collected data. Observation indicate that motion is not possible until approximately 2.3V. With this in mind, when the control voltage reaches this value you can see a distinct swing that oscillates a few times and quickly tapers off to the width before there was any movement. The average value it sits at is approximately right in the middle of our range capable by our phototransistor. We are likely not sampling fast enough, but also the power output (looking at its variance when there is no motion as reference) might be making the sampling more difficult. When Vc reaches 2.5 volts on the way back down we see the oscillations like the beginning come back and continue on until the instruction is done writing. While the initial oscillation at the beginning seems quite plausible as a fringe reading, the behavior at the end of the movement seems less decreeable. Its some likely some kind of vibration in the system, but weather its from rapid deceleration or the actual motor stuttering as it slows down, its hard to tell.

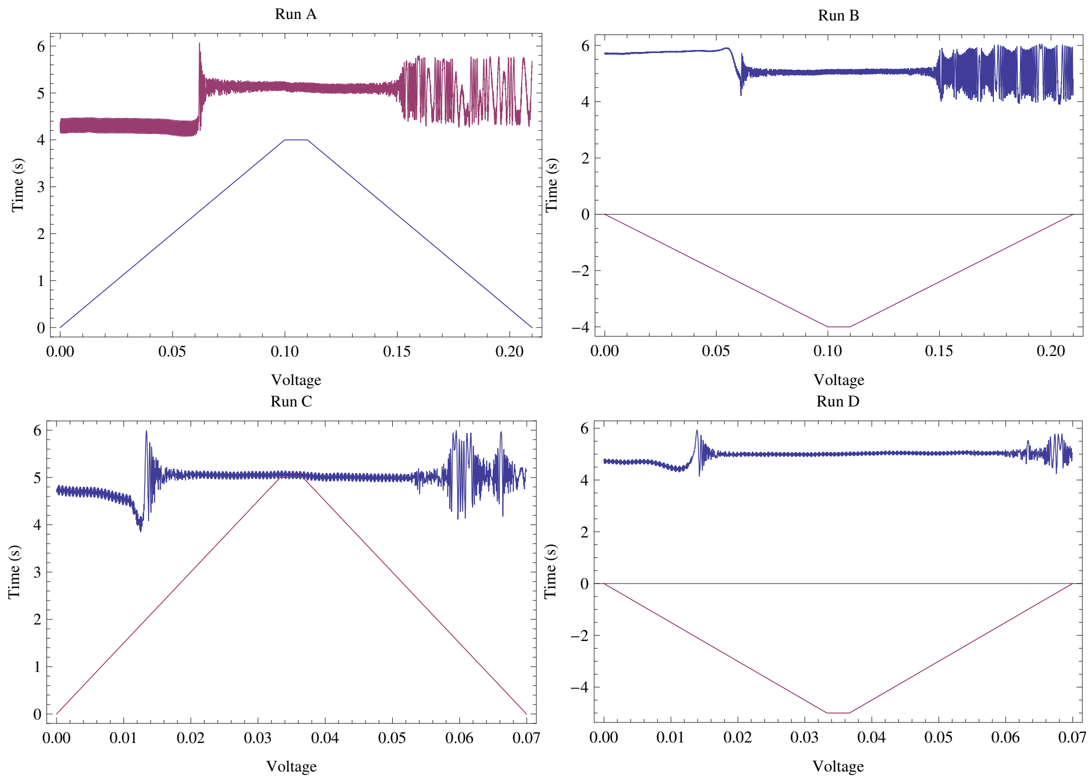

FIG. 5. Plots of the control signal and the resulting data for a few different timings and control signals. Motion begins around 2.3-2.5 Volts on the control signal. (Note: the acquired data is not yet representative of the number of passing fringes)

IV. CONCLUSION

This project is by no way complete, as the instrumentation are barely in a workable state. I expect to continue working on this during the summer, and depending on it's success, look into a similar experiment with angular interferometry with professor Monty Mola.

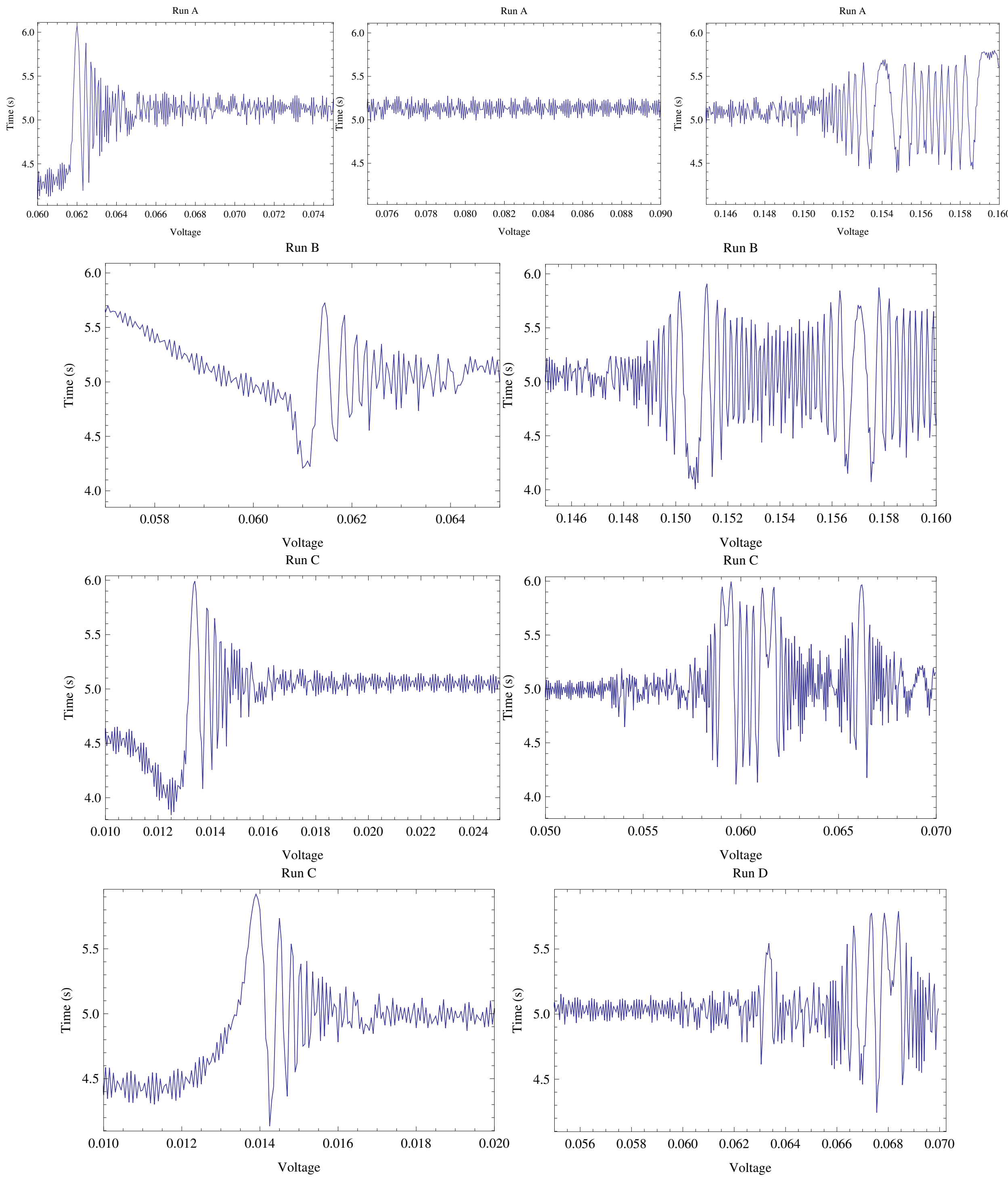

FIG. 6. Run A: Looking at the data during acceleration, motion and deceleration.

[1] *MP 69E User Manual M-661 / M662 PILine Linear Piezo Motor Stages*, Physik Instrumente (PI) GmbH Co. KG, Auf der Römerstr. 1, 76228 Karlsruhe, Germany (2005).

[2] Piezoelectricity, Wikipedia (2010).

[3] D. D. C. O'Shea, *Projects in Optics Workbook*, Newport, g ed.

[4] E. Hecht, *Optics*, 4th ed. (Addison Wesley, 2002).