Open-Source Nanoactuator Design Utilizing Hard Disk Drive Components

Precision Displacement Measurement with a Michelson Interferometer

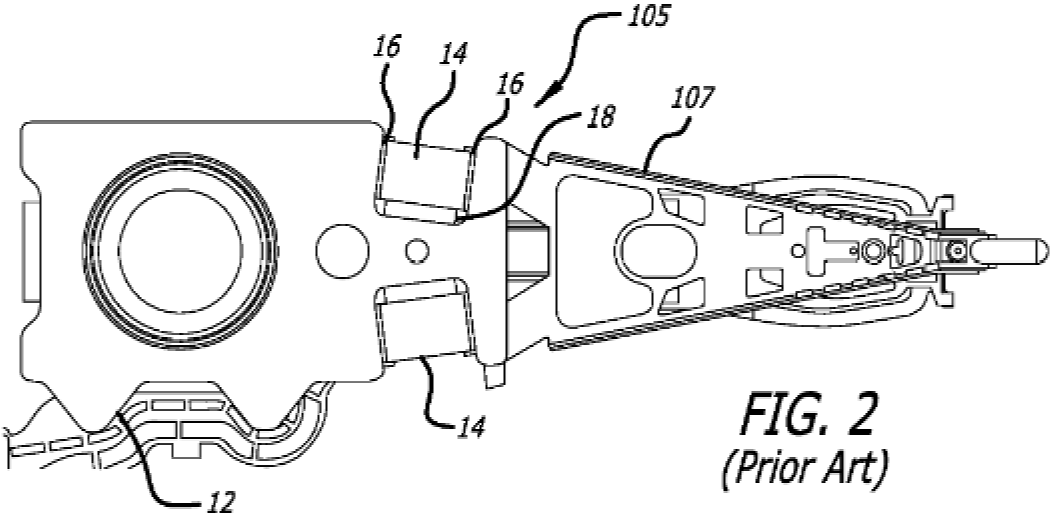

FIG. 2
(Prior Art)

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Abstract

This study addresses the challenge of accessing high-precision nanopositioning tools, crucial for nanometer-scale manipulation in microelectronics, photonics, and materials science, hindered by their prohibitive cost. We introduce a novel, cost-effective nano actuator, ingeniously integrated within a conventional laser disc drive mechanism, leveraging off-the-shelf components. This approach aims to repurpose the precision mechanics of disc drives for nanoscale manipulation, incorporating a DIY optical table constructed under $400 to mitigate environmental vibrations. Preliminary results, while promising, indicate the critical need for such a vibration-isolated platform to achieve and measure precise placements at the nanometer scale. Our findings highlight the potential of DIY approaches to democratize access to precision research tools, fostering innovation across scientific disciplines by overcoming financial barriers.

Introduction

In the realm of precision engineering, the need for nanopositioning tools has become increasingly critical, particularly for applications in microelectronics, photonics, and materials science. These tools, essential for tasks requiring nanometer-scale manipulation and placement, are prohibitively expensive due to their intricate design and the advanced materials required for their construction. This high cost limits accessibility and hampers innovation in research fields and industries where budget constraints are a significant concern.

The price barrier associated with nanopositioning tools arises from the need for ultra-precise components, such as piezoelectric actuators, which are capable of minute and accurate movements. These actuators often incorporate sophisticated materials and proprietary technology, contributing to the overall expense. As such, the development of cost-effective alternatives could revolutionize the availability and usage of nanopositioning technology, democratizing access to precision instrumentation and fostering broader innovation across scientific disciplines.

Our work addresses this issue by proposing a novel approach to the design and implementation of a nano actuator using off-the-shelf components integrated within the architecture of a conventional laser disc drive. This integration aims to utilize the high precision of disc drive mechanics, repurposing them for nanoscale manipulation. The experimental setup involves the construction of a voltage divider to control the actuator, an interferometer for measuring displacement, and the incorporation of a magnet to convert rotational into linear motion.

Although the experiment is currently ongoing and conclusive results have yet to be obtained, preliminary observations suggest that this approach has the potential to yield a high-precision placement tool at a fraction of the cost of traditional systems. Our findings may pave the way for affordable nanopositioning solutions, providing a significant boost to research and development efforts in various fields that rely on nano-scale operations.

This study embarked on an ambitious project to explore the realms of precision placement and measurement at the nanometer scale, a critical aspect in fields such as photonics, material science, and microelectronics. Central to our experimental setup was the development and implementation of piezoelectric actuators, known for their ability to convert electrical signals into precise mechanical movements. The objective was to harness these actuators' fine control capabilities to manipulate and measure objects with unparalleled accuracy.

However, the precision of such measurements is profoundly influenced by environmental vibrations and instabilities, typically mitigated by the use of optical tables. These specialized platforms provide a vibration-isolated environment essential for high-precision work but often come with a prohibitive cost. Recognizing the limitation this imposes on accessibility to precision experimental setups, our project sought to address this gap by constructing a DIY optical table. With a budget capped at $400, the project aimed to challenge the notion that high costs are a barrier to precision research.

The methodology encompassed the design and assembly of piezoelectric actuators into a control system capable of nanometer-scale adjustments. Concurrently, a cost-effective optical table was developed, utilizing readily available materials and innovative design principles to achieve effective vibration isolation. The experiment tested the system's capability to achieve and measure precise placements, comparing the results with those obtained without vibration isolation.

The findings revealed that while the experiment successfully demonstrated the capabilities of the piezoelectric actuators, the absence of a traditional optical table significantly hindered our ability to measure with the desired precision. This outcome highlighted the indispensable value of a stable, vibration-isolated platform in precision experimental setups.

The project underscores the feasibility and importance of DIY solutions in overcoming financial barriers to advanced research tools. By providing a blueprint for an affordable optical table, this study opens new avenues for researchers to access high-precision measurement capabilities, thereby expanding the potential for innovation and discovery in nanoscale research.

Background

Piezoelectric crystal actuators, leveraging the piezoelectric effect discovered in the 1880s by Jacques and Pierre Curie, have significantly evolved. Initially observed in quartz crystals, the piezoelectric effect refers to the ability of certain materials to generate an electric charge in response to applied mechanical stress. This principle became foundational for developing actuators in the early 20th century, with significant advancements during World War II, particularly in sonar technology. Post-war, the application expanded into precision engineering, including hard disk drives (HDDs) for data storage, where they control read/write head movements. Recent innovations focus on micro-actuators and dual-stage actuations, enhancing positioning accuracy crucial for increasing HDD storage capacity.

Piezo Crystals, or piezoelectric crystals, are used in a wide range of applications due to their ability to convert mechanical stress into electrical signals and vice versa. Common uses include precision actuators in hard disk drives for read/write head positioning, sensors in medical ultrasound equipment, fuel injectors in automotive industry, quartz watches for timekeeping, and as igniters in lighters and gas stoves. They're also utilized in microphones, speakers, and vibration sensors due to their sensitivity to mechanical vibrations.

The piezoelectric effect in crystals, such as quartz, results from their asymmetric crystal lattice, which lacks a center of symmetry. When mechanical pressure is applied, it distorts this lattice, causing a separation of charge centers and generating an electric field (voltage) across the crystal. This direct piezoelectric effect converts mechanical energy into electrical energy. Conversely, when an electric field is applied, it causes the crystal lattice to deform, translating electrical energy back into mechanical energy. This bidirectional energy conversion is governed by the material's piezoelectric constants, which quantify the electromechanical interaction efficiency.

Piezocrystals, known for their piezoelectric properties, are made from materials that can generate an electric charge in response to applied mechanical stress. The most common piezoelectric materials include:

Quartz (SiO_2): A naturally occurring piezoelectric crystal used in precision devices like oscillators and filters due to its stability and low temperature coefficient.

Lead Zirconate Titanate (PZT): A synthetic ceramic material that exhibits strong piezoelectric effects, widely used in sensors, actuators, and transducers.

Barium Titanate ($BaTiO_3$): Another ceramic material known for its piezoelectric properties, used in microphones and capacitors.

Zinc Oxide (ZnO): A semiconductor material that shows piezoelectricity and is used in actuators and piezoelectric generators.

Polyvinylidene Fluoride (PVDF): A polymeric material with piezoelectric properties, used in flexible sensors and energy harvesting applications.

Electrodes on PZT:

Purpose and Configuration: Electrodes on PZT materials are crucial for applying the electric field that induces piezoelectric deformation. This deformation is harnessed in HDDs to precisely control the position of the read-write head via micro-actuators.

Design Improvements: The document highlights design improvements over time, showing how newer micro-actuator designs enhance performance by optimizing the placement and configuration of PZT elements and their electrodes.

Electrode Material and Structure: While specific materials for the electrodes are not detailed in the quoted text, typical electrodes are made from conductive materials like silver or gold and are designed to efficiently apply an electric field across the PZT material.

Innovations in PZT Actuator Design: The advancements include relocating piezoelectric elements closer to the magnetic head for more localized control and using multi-layer PZTs to compensate for smaller geometrical amplification in stroke generation.

Key Takeaways for Electrode Design:

Optimization for Performance: The strategic placement and design of electrodes on PZT materials are essential for maximizing the piezoelectric effect, critical for the micro-actuator's performance in HDD applications.

Material Selection and Configuration: The choice of electrode materials and their configuration on the PZT plays a significant role in the actuator's efficiency and effectiveness.

Innovative Approaches for Enhanced Accuracy: Through the document, it's evident that continuous innovation in electrode and PZT configurations leads to significant improvements in HDD performance, particularly in achieving higher storage densities and better positioning accuracy of the read-write heads.

This exploration of PZT-based micro-actuators demonstrates the importance of electrode design and material properties in enhancing the performance of HDD technologies, paving the way for future advancements in storage solutions.

These materials are chosen based on the required piezoelectric constant, dielectric constant, mechanical strength, and temperature stability for specific applications.

The material of the piezo crystal in the patent US 9330698 B1 is primarily Lead Zirconate Titanate (PZT). This patent discusses a dual-stage actuator (DSA) suspension for hard disk drives that includes a multi-layer PZT microactuator with active PZT constraining layers. The design aims to address bending issues commonly associated with PZT microactuators during actuation, intending to increase the effective stroke length of the PZT by controlling the bending direction and amount.

Measuring Capacitance of Piezo Crystals

Capacitance is a fundamental electrical property that measures a system's ability to store an electric charge. It's defined as the ratio of the electric charge (Q) on each conductor to the potential difference (V) between them, with the formula: C= Q/V

The unit of capacitance is the Farad (F), named after the English physicist Michael Faraday.

Capacitors, the components designed to have specific capacitances, are widely used in electronic circuits for various purposes, including energy storage, power conditioning, signal filtering, and in timing circuits. The capacitance of a capacitor is influenced by the surface area of the conductive plates, the distance between them, and the type of dielectric material used to separate them. A larger plate area, a shorter distance between the plates, and a dielectric material with a higher dielectric constant all contribute to a higher capacitance value.

In practical terms, capacitance is a measure of a capacitor's ability to store charge per unit voltage. A high-capacitance capacitor can store more charge at a given voltage than a low-capacitance capacitor. This property is crucial in designing and analyzing electronic circuits, as it affects how the circuits store and release energy.

Capacitance is like a battery's ability to hold an electric charge, but it works differently. Imagine you have two big metal plates facing each other, but they don't touch. When we connect a battery to these plates, one plate gets filled with extra electrons (making it negatively charged), and the other plate loses electrons (making it positively charged). The ability of these plates to hold this imbalance of electrons is called capacitance.

The closer these plates are to each other, and the bigger they are, the more charge they can hold for the same "push" from the battery. We measure this "holding ability" in something called Farads, named after a smart scientist, Michael Faraday.

So, in simple terms, capacitance is how good something is at holding onto electric charges when there's a voltage (or electric pressure) trying to move those charges around.

To measure the capacitance of piezoelectric crystals, especially in the context of advanced piezo-actuator technologies like those discussed in Yanning Liu's research, you would follow a procedure tailored to the unique properties of piezoelectric materials. These materials are different from conventional capacitors, so the measurement process must account for their piezoelectric nature. Here's a general approach, integrating principles from standard capacitance measurement techniques and the specific requirements for piezoelectrics:

1. Prepare the Measurement Setup

Equipment: Use an LCR meter capable of applying an AC voltage at different frequencies, as piezoelectric materials can show different capacitance values at varying frequencies due to their resonant nature.

Safety Precautions: Ensure the piezoelectric crystal is not under mechanical stress during measurement to prevent any influence on the capacitance reading.

2. Configure the LCR Meter

Frequency Selection: Set the LCR meter to a frequency that is relevant to your application or within the manufacturer's suggested range for capacitance measurements of piezoelectric materials. Often, 1 kHz is a standard starting point.

Measurement Mode: Choose the capacitance measurement mode. Ensure the meter is configured to measure in the appropriate unit (usually picofarads, pF, or nanofarads, nF, for piezo crystals).

3. Connect the Piezoelectric Crystal

Electrode Contact: Make sure the electrodes or contact points of the piezo crystal are properly connected to the LCR meter's test leads. For piezoelectric materials, it's crucial to establish good electrical contact without applying mechanical pressure that could alter the measurement.

4. Perform the Measurement

Reading the Value: Activate the measurement on the LCR meter. The display should show the capacitance value of the piezo crystal. Due to their nature, piezoelectric crystals may have very low capacitance values.

Frequency Variations: It may be beneficial to measure the capacitance at different frequencies to understand the crystal's behavior across its operational frequency range.

5. Interpret the Results

Capacitance Value: The measured capacitance can give insights into the piezoelectric crystal's quality and its suitability for specific applications, like actuators in HDD technologies.

Frequency Response: Understanding how the capacitance changes with frequency is crucial for applications involving dynamic mechanical stress and electrical fields.

6. Documentation

Record Findings: Document the capacitance values and conditions under which they were measured, including frequency, temperature, and any mechanical loading applied to the piezo crystal.

Additional Considerations

Temperature and Humidity: Piezoelectric materials can be sensitive to temperature and humidity, which may affect their capacitance. Consider controlling or monitoring these environmental conditions during measurement.

Calibration: Ensure the LCR meter is calibrated according to the manufacturer's specifications to guarantee accurate measurements.

This procedure provides a basic framework for measuring the capacitance of piezoelectric crystals. Depending on the specific research or application, additional steps or considerations may be necessary. Always refer to the piezoelectric material manufacturer's guidelines and the LCR meter's manual for best practices and safety information.

An LCR meter is an electronic instrument used to measure the inductance (L), capacitance (C), and resistance (R) of an electronic component. In the context of measuring the properties of piezoelectric crystals or other components, an LCR meter can provide precise measurements across a range of frequencies, which is essential for understanding the behavior of these components under different operating conditions.

How It Works:

Inductance (L): It measures the property of a conductor by which a change in current flowing through it induces an electromotive force (voltage) in both the conductor itself (self-inductance) and in any nearby conductors (mutual inductance).

Capacitance (C): It measures a component's ability to store charge temporarily in an electric field. Capacitors, including piezoelectric crystals that exhibit capacitive properties, are common examples.

Resistance (R): It measures how strongly a material or component resists the flow of electric current.

Key Features:

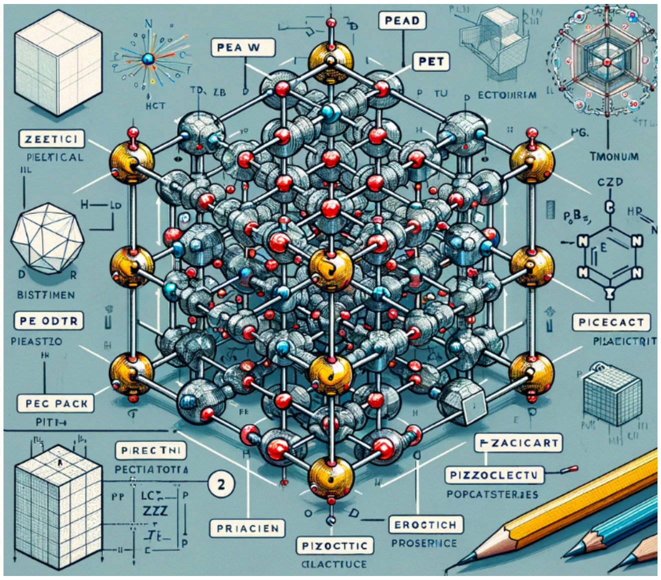
Frequency Range: LCR meters can measure at multiple frequencies, which is critical for components whose impedance changes with frequency.

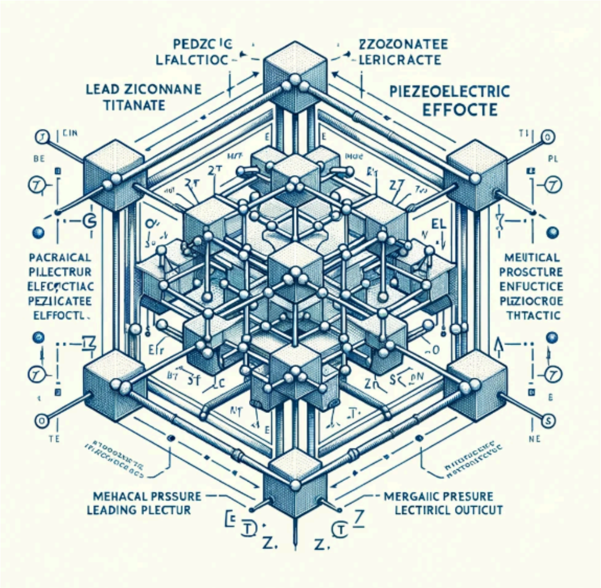
Accuracy: They are typically more accurate than general-purpose multimeters, especially for component characteristics that change with frequency.

Measurement Modes: Besides the basic L, C, and R measurements, advanced LCR meters may offer additional modes such as quality factor (Q), dissipation factor (D), phase angle (θ), and equivalent series resistance (ESR).

Applications:

LCR meters are used in a wide range of applications, from laboratory research and quality control to circuit design and manufacturing processes. They are particularly valuable in testing electronic components in RF (radio frequency) applications, power supply systems, and in the development of products requiring precise control of electrical characteristics.





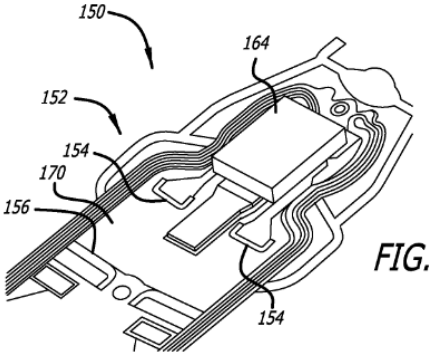


FIG. 14A

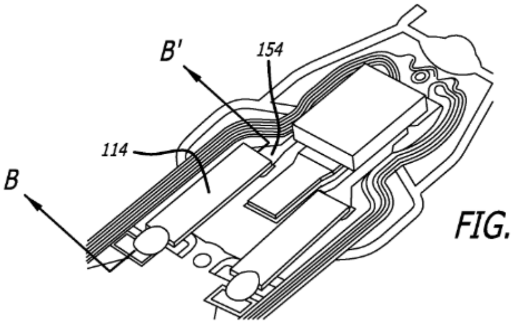


FIG. 14B

The diagram illustrates a Lead Zirconate Titanate (PZT) piezo crystal, showcasing its crystal lattice structure with atoms of lead (Pb), zirconium (Zr), and titanium (Ti). It also highlights the piezoelectric properties of PZT, demonstrating how mechanical pressure can generate an electrical output. Key components are labeled clearly for understanding.

Materials and Methods

The experimental setup for the development of a low-cost nano actuator involved the following components and procedures:

Materials:

Actuator Arms: Salvaged from decommissioned HDDs, these arms were modified to accommodate piezoelectric crystals at their tips in place of the standard head gimbal assemblies (HGAs).

Voice Coil Motor (VCM): The VCM from the HDDs was used to create controlled movements of the actuator arms via electromagnetic induction.

Pivot Bearing: A precision bearing was sourced to ensure the low-friction and quick response necessary for the accurate positioning of the actuator arms.

Flexible Printed Circuit (FPC): A standard FPC was used to establish a connection between the actuator arms and the control system for signal transmission.

Head Stack Assembly (HSA): Although not visible in the provided image, the HSA was essential for aligning the actuator arms and ensuring coordinated movement.

Methods:

Assembly of the Actuator: The actuator arms were equipped with piezoelectric crystals, and the entire assembly was mounted onto the pivot bearing, ensuring free movement.

Electrical Connections: The VCM and piezoelectric crystals were connected to the power supply via the FPC, allowing for precise control over the movements.

Calibration: The system was calibrated using a laser interferometer to determine the baseline movement accuracy of the actuator without an applied voltage.

Testing: Incremental voltages were applied to the piezoelectric crystals via a voltage divider circuit, and the resulting movements were measured for their correspondence with the changes in the interference pattern.

Documentation: All steps, from the initial assembly to the final testing phase, were meticulously documented to ensure reproducibility and to provide a clear methodology for further experimentation.

The experiment remains ongoing, with the anticipation that the results will substantiate the viability of using HDD components to construct a cost-effective nanopositioning tool.

1. Objective

To demonstrate the piezoelectric effect in a PZT crystal by applying mechanical pressure and measuring the generated voltage.

2. Materials

PZT piezo crystal

Mechanical press or device to apply controlled pressure

Voltmeter or oscilloscope

Connecting wires

Insulating mat

3. Setup Preparation

Prepare the PZT Crystal: Place the PZT piezo crystal on an insulating mat to prevent any undesired current flow.

Connect the Measurement Devices: Attach the voltmeter or oscilloscope probes to the PZT crystal using connecting wires. Ensure good contact with the crystal's electrodes.

4. Calibration

Calibrate the Voltmeter/Oscilloscope: Ensure the measurement device is calibrated to accurately measure small voltage changes.

Zero Pressure Test: With no pressure applied to the crystal, record the baseline voltage to ensure it is zero or close to zero.

5. Experiment Procedure

Incremental Pressure Application: Using the mechanical press, apply pressure incrementally to the PZT crystal. Start with a light pressure and gradually increase it, noting the pressure levels.

Voltage Measurement: For each pressure increment, measure and record the voltage generated across the PZT crystal.

Repeat Measurements: To ensure accuracy, repeat the pressure application and voltage measurement process several times for each pressure level.

6. Data Collection

Record Data: Collect data on the applied pressure and corresponding voltage generation for each trial.

Calculate Averages: If multiple trials are conducted, calculate the average voltage for each pressure level.

7. Analysis

Plot Data: Create a plot with applied pressure on the x-axis and generated voltage on the y-axis to visualize the relationship.

Analyze the Piezoelectric Effect: Analyze the data to determine the piezoelectric efficiency of the PZT crystal. The slope of the plot can give insights into the crystal's piezoelectric constant.

8. Safety Considerations

Handling Pressure: Be cautious when applying pressure to avoid damaging the crystal or the pressure device.

Electrical Precautions: Ensure all electrical connections are secure and that the experimenter is insulated from the ground.

The concept of using a laser pointer to move piezo crystals is rooted in the interaction between light energy and the material properties of piezoelectric crystals. This process involves a couple of key principles from optical physics and piezoelectricity, which I'll explain in a simplified manner.

Optical Energy Conversion

First, it's essential to understand that a laser pointer emits a highly concentrated beam of light. This light is composed of photons, which carry energy. When these photons are directed towards certain materials, the energy they carry can be absorbed and converted into other forms.

Piezoelectric Materials

Piezoelectric materials have the unique ability to convert mechanical stress into electrical charges and vice versa. Common piezoelectric materials include quartz, Rochelle salt, and various types of ceramics. These materials are used in a wide range of applications, from generating electrical signals to precise motion control in actuators.

Moving Piezocrystals with Lasers

The interaction between the laser pointer and piezo crystals involves a couple of steps:

Energy Absorption: When the laser beam is directed at a piezo crystal, the crystal absorbs the light's energy. However, unlike more direct methods of inducing stress or deformation in piezoelectrics (like mechanical pressure), the laser's energy must first be converted into a form that can effectively induce a mechanical response in the crystal.

Thermal Expansion: One way this is achieved is through thermal expansion. The absorbed optical energy is converted into heat, causing the piezo crystal to expand slightly. This expansion is a form of mechanical stress.

Piezoelectric Response: Due to the piezoelectric effect, this mechanical stress (thermal expansion) is converted into an electrical charge across certain planes of the crystal. Conversely, if the crystal is part of a circuit or system designed to induce mechanical stress through electrical input, this thermal expansion can cause a precise mechanical movement.

Precision Control: By modulating the intensity, position, and duration of the laser beam, it's possible to control the amount of thermal expansion and thus the mechanical movements of the piezo crystal with high precision. This capability is particularly useful in applications requiring fine motion control, such as in optical systems where mirrors and beam splitters are adjusted using piezoelectric actuators.

Challenges and Considerations

Heat Dissipation: Care must be taken to manage the heat generated by the absorbed laser energy to prevent damage to the piezo crystal or surrounding materials.

Efficiency: The conversion efficiency from optical energy to mechanical movement is a critical factor, as not all the absorbed energy will be converted into useful mechanical stress.

Control: Precise control of the laser (in terms of power, pulse duration, and focal point) is crucial for achieving the desired piezoelectric response without causing thermal damage.

This approach of using a laser pointer to move piezo crystals showcases the interdisciplinary nature of modern engineering, combining principles from optics, materials science, and electromechanics to create innovative solutions.

An optical table is a crucial platform used in scientific research and industrial applications involving optics, lasers, and photonics. Its primary function is to provide a stable and vibration-free environment for conducting experiments or measurements that are highly sensitive to movements or vibrations. Here's a detailed description covering various aspects of an optical table:

Construction and Materials:

Top Surface: The table's top surface is typically made from stainless steel, featuring a matrix of tapped holes for mounting optical components using posts, holders, and clamps. The hole pattern is usually on a 25mm or 1-inch grid, facilitating flexible and precise positioning of equipment.

Core Material: Beneath the top layer, the core of the table is designed to dampen vibrations. It may consist of a honeycomb lattice structure made from steel or aluminum, providing an optimal balance between stiffness and vibration damping.

Breadboard Option: For smaller setups or as an addition to an optical table, optical breadboards offer similar functionality with a portable, flat surface that can be placed on an existing table.

Vibration Isolation:

Air Suspension: Many optical tables use air suspension systems in their supporting legs to isolate the table surface from ground vibrations. Pressurized air in pneumatic isolators allows the table to float slightly above the ground, effectively filtering out vibrations.

Passive and Active Isolation: Passive systems rely on the mechanical design to dampen vibrations, while active systems use sensors and actuators to cancel out vibrations in real-time.

Performance Characteristics:

Rigidity and Damping: A high-quality optical table is characterized by its rigidity and efficient damping capabilities, ensuring that vibrations are absorbed quickly and do not disturb sensitive optical components.

Thickness and Weight: The thickness of the optical table and its overall weight contribute to its stability and vibration damping performance. Thicker tables with more substantial cores offer better vibration isolation.

Applications:

Laser Experiments: Optical tables provide a controlled environment for experiments involving lasers, where precise beam paths are crucial.

Interferometry: Used in setups requiring high stability, such as interferometric measurements, where even nanometer-scale vibrations can introduce errors.

Spectroscopy and Imaging: Supports equipment for various spectroscopy techniques and advanced imaging setups requiring stable mounting of cameras, lenses, and samples.

Accessories:

Mounting Components: A range of accessories, including posts, clamps, lens holders, mirror mounts, and beam splitters, can be attached to the table's top surface to build complex optical setups.

Shelving and Enclosures: Additional shelving units or enclosures can be added to organize equipment or shield the experiment from external light or disturbances.

In essence, an optical table is a fundamental piece of equipment in experimental physics and engineering, enabling precise and stable setups for cutting-edge research and development in optics and photonics.

DIY Optical Table

1. Tabletop Selection:

Material: Use a thick, rigid piece of steel or aluminum as the tabletop. A used or surplus metal door can be an affordable option.

Hole Pattern: Drill a grid of holes (e.g., 1-inch or 25mm spacing) across the tabletop for mounting optical components. Ensure accuracy to maintain alignment.

2. Vibration Damping:

Core Construction: Instead of a honeycomb core, use a sandwich structure with layers of dense materials like MDF (Medium-Density Fiberboard) or plywood, and a damping layer of rubber or a viscoelastic material in between to absorb vibrations.

Legs and Isolation: Salvage sturdy legs from used furniture or machinery stands. For vibration isolation, place each leg on a DIY isolation platform made from dense foam, rubber, or a combination of both. Another option is to use inflated inner tubes or tennis balls cut in half under each leg for basic air damping.

3. Assembly:

Assembling the Core: Glue the layers of MDF/plywood and the damping material together, ensuring even pressure and curing time as per adhesive instructions.

Attaching the Top: Secure the metal tabletop to the core structure with bolts or welding, depending on the materials used. Ensure the surface is level and stable.

4. Finishing Touches:

Surface Treatment: Paint or seal the metal surface to prevent rust and wear. Mark the grid for easy identification.

Accessories: DIY or repurpose mounting accessories like posts, clamps, and holders from hardware store materials or salvaged equipment.

5. Cost-saving Tips:

Materials: Look for surplus, second-hand, or scrap materials. Many industrial areas or online marketplaces sell metal, wood, and foam at reduced prices.

Tools: Borrow specialized tools like drill presses or saws if you don't own them to save on cost.

Community Resources: Check with local maker spaces, universities, or community colleges, which may offer access to tools and materials.

Limitations and Considerations:

While a DIY optical table can significantly reduce costs, it's important to recognize the limitations compared to a commercial table, particularly in terms of vibration isolation and rigidity. Such a table may be suitable for less sensitive applications where extreme precision is not critical.

Creating a DIY optical table for under $400 is feasible with careful planning, sourcing of affordable materials, and a willingness to invest time in construction. This approach allows for customization and learning, providing a functional platform for hobbyist optical experiments or educational purposes.

Literature Review

This literature review encapsulates significant advancements in piezoelectric actuator technologies over the past two decades, highlighting their crucial role in enhancing hard disk drive (HDD) performance through improved precision in head positioning. This comprehensive synthesis integrates insights from patents and scholarly articles, tracing the technological evolution from milli-actuators to micro-actuators, alongside the development of novel MEMS variable capacitors.

United States Patent US 9330698 B1: Awarded to Peter Hahn, Kuen Chee Ee, and Long Zhang on May 3, 2016, this document unveils a dual-stage actuator (DSA) suspension system for HDDs, incorporating a multi-layer piezoelectric (PZT) microactuator with active PZT constraining layers. This system ingeniously addresses bending issues inherent in PZT microactuators upon activation, enhancing the PZT's effective stroke length through strategic bending control. Assigned to Magnecomp Corporation, this patent provides an exhaustive depiction of the technology, complete with claims, detailed descriptions, and illustrative drawings.

Advancements in MEMS Variable Capacitors: Hedie Mahmoodnia and Bahram Azizollah Ganji's research introduces a MEMS cantilever variable capacitor with an exceptional tuning ratio, courtesy of an innovative structure incorporating lateral beams. This design markedly extends the capacitance tuning range, signaling a potential paradigm shift for precision-required applications.

Smart Material Systems: Ralph C. Smith's seminal work introduces a groundbreaking design in MEMS variable capacitors, utilizing a cantilever structure as a variable capacitor. This design, distinguished by the addition of lateral beams, facilitates parallel movement between plates, significantly enhancing the tuning ratio and addressing the pull-in phenomenon.

Piezoelectric Actuator Innovations for HDDs: Yanning Liu's 2023 paper provides an in-depth examination of piezoelectric actuators' evolution within HDDs, from milli-actuators to the more precise micro-actuators. Liu proposes the integration of these actuators into triple-stage actuations, promising unparalleled positioning accuracy and a broader design spectrum for micro-actuators, potentially catalyzing further increases in HDD track density and storage capacity.

HGST Micro Actuator's Role in HDD Performance: This tech brief details the pivotal role of the HGST Micro Actuator in refining HDD performance, marking a transition from milli-actuators to micro-actuators for enhanced data integrity and reliability in HDDs. This evolution is indicative of significant advancements in actuator technology, pivotal for expanding storage capacities.

Technological Evolution: The transition from milli-actuators to micro-actuators represents a significant technological advancement in HDD actuator design. This evolution underscores the industry's continuous efforts to improve the precision of head positioning, which is crucial for increasing data storage density and reliability.

Innovative Designs: The introduction of novel MEMS variable capacitors, particularly those utilizing lateral beams for parallel movement, indicates a broader trend of innovation in smart material systems.

Such advancements not only enhance the performance of specific components like variable capacitors but also contribute to the overall efficiency and capability of electronic devices.

Enhanced Precision and Capacity: The development and implementation of micro-actuators adjacent to magnetic heads have directly contributed to the improved accuracy of head positioning. This precision is essential for supporting the ongoing increase in HDD track density, thereby enabling higher storage capacities.

Combination of Actuator Technologies: The proposal to combine milli- and micro-actuators into triple-stage actuations suggests a future direction for actuator design that could offer even greater positioning accuracy and design flexibility. This innovative approach has the potential to further enhance HDD performance and capacity, marking a promising avenue for future research and development.

Impact on the HDD Industry: The advancements in piezoelectric actuator technologies, as highlighted by the HGST Micro Actuator and other developments, are instrumental in addressing the challenges posed by the ever-increasing demand for higher data storage capacities. These technological strides not only improve data integrity and reliability but also ensure the HDD industry's competitiveness by enabling continual increases in storage capacity.

Future Directions: The literature underscores the importance of ongoing research and development in piezoelectric actuator technologies to meet the evolving demands of data storage and other applications. It suggests a trend towards more complex, multi-stage actuator systems that can offer unprecedented levels of control and efficiency.

Experiment

Measuring Capacitance of the Piezocrystals

While a multimeter can measure basic electrical properties like resistance, voltage, and sometimes capacitance, an LCR meter is specialized for more detailed analysis of the inductance, capacitance, and resistance of components, especially where measurements at different frequencies are required.

A Keysight True RMS OLED Multimeter, specifically the U1253B model, would work for measuring the capacitance of piezo crystals. This multimeter can measure capacitance up to 100mF and has a maximum frequency measurement capability of 100kHz. It's designed for precise and efficient testing, making it suitable for a wide range of applications, including the measurement of piezoelectric materials.

To measure the capacitance of two piezo crystals on the end of a laser disc reader using a Keysight True RMS OLED Multimeter like the U1253B model:

Disconnect the piezo crystals from any power source or the laser disc reader circuitry to ensure they are isolated for testing.

Set the multimeter to capacitance measurement mode. The U1253B model can measure capacitance, so you'll want to select this function, often indicated by a symbol resembling two T's facing each other or the letter F for Farad.

Connect the multimeter probes to the piezo crystals. If the crystals have polarity, ensure the correct orientation of the probes; however, many piezo crystals used in such applications might not be polarized.

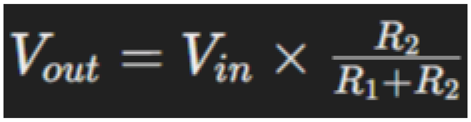
Read the measurement on the multimeter's display. This will give you the capacitance value of the piezo crystals.

Ensure the multimeter is correctly calibrated for accurate measurements and handle the piezo crystals carefully to avoid any damage.

For measuring the capacitance of piezo crystals with a multimeter like the Keysight U1253B, the placement of the red (positive) and black (negative) probes depends on the crystal's polarization. If the piezo crystals are polarized, ensure the red probe is on the positive side and the black probe on the negative. If they're non-polarized, the probe placement doesn't matter. Always consult the crystal's datasheet for polarity information before measurement.

Making a voltage divider

To make a voltage divider, you need two resistors connected in series across a voltage source. The junction between the resistors provides an output voltage that is a fraction of the input voltage. This fraction is determined by the values of the two resistors. Choose resistor values based on the desired output voltage, using the formula:



$$V_{out} = V_{in} \times \frac{R_2}{R_1+R_2}$$

where:

Vin is the input voltage, Vout is the output voltage, R1 is the resistor connected to the input voltage, and R2 is the resistor connected to ground.

To measure the movement between the two arms using piezo crystals, a laser pointer, and a mirror as a beam splitter involves setting up an optical interference or diffraction system. This setup can translate the mechanical movement (caused by the piezo crystals' actuation) into measurable optical changes. After measuring the capacitance, use it to fine-tune the voltage applied to the piezo crystals for precise control over their expansion or contraction. This precise movement can then be converted into an optical signal by reflecting or refracting a laser beam off the mirror, where the path difference caused by the movement can be measured using optical interference patterns. This requires careful calibration and setup to ensure accuracy at the nanometer level (see discussion of optical table).

Using an Interferometer to Measure PZT Actuator Movement

Step 1: Build an Interferometer to Measure Movement at the Tip

Select Interferometer Type: Choose a Michelson or Fabry-Pérot interferometer, depending on available resources and required sensitivity.

Assembly: Set up the interferometer according to its design. This typically involves arranging mirrors, a coherent light source (laser), beam splitter, and a screen or detector.

Calibration: Calibrate the interferometer without the actuator in place. Use a known displacement to verify the system's sensitivity and accuracy.

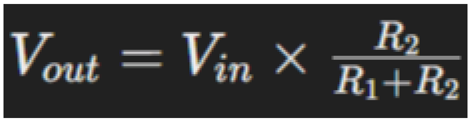
Step 2: Determine Contacts of Piezos

Identify Electrode Contacts: Using the piezoelectric actuator's documentation, identify the positive and negative electrode contacts.

Test for Functionality: Apply a small, safe voltage to the piezo contacts to ensure they are operational, observing for any movement or deformation.

Step 3: Build a Voltage Divider with Two Resistors

Select Resistors: Choose two resistors of appropriate values to create a voltage divider that will output the desired voltage level to the actuator. For a 10V input and desired output, use the formula to calculate resistor values:



$$V_{out} = V_{in} \times \frac{R_2}{R_1+R_2}$$

Circuit Assembly: Connect the resistors in series. Connect the input voltage across the series combination and take the output from the junction of the two resistors.

Verification: Verify the output voltage of the divider using a multimeter to ensure it matches the required input for the piezo actuator.

Step 4: Introduce the Actuator to the Interferometer

Mounting the Actuator: Securely mount the piezo actuator within the interferometer setup, ensuring that the tip movement can be accurately measured by the system.

Alignment: Adjust the actuator position so that the laser beam accurately reflects off the tip and into the beam splitter or directly towards the detector.

Step 5: Experiment - Applying Voltage to Change the Interference Pattern

Initial Measurement: Record the initial interference pattern with the actuator at rest (no applied voltage).

Apply Voltage: Incrementally increase the voltage to the piezo actuator through the voltage divider, observing changes in the interference pattern at each step.

Data Recording: For each voltage increment, record the interference pattern. Use software or manual counting methods to quantify the fringe shifts corresponding to movement at the actuator's tip.

Analysis: Compare the recorded data against theoretical models or calculations to determine the actuator's displacement sensitivity to voltage changes.

Safety and Precautions

Always ensure the piezo actuator is handled according to its specifications to avoid damage.

Use appropriate safety measures when working with lasers and electrical equipment to prevent injury or equipment damage.

Verify all connections and settings before applying power to the system.

Detailed Instructions for Experimenting with Piezo Actuator Voltage Application

Preparation

Ensure Proper Setup: Confirm that the interferometer and the PZT actuator are correctly set up as described in the previous steps. The actuator should now be part of the interferometer setup, capable of altering the path length of one of the beams by its movement.

Safety Check: Make sure all safety precautions are in place, especially concerning laser safety (eye protection) and electrical safety.

Initial Calibration and Baseline Measurement

Baseline Interference Pattern: With the actuator at rest (no voltage applied), record the initial interference pattern. This will serve as your baseline for comparison.

Calibration (if needed): If your interferometer setup allows for it, perform a calibration run by manually adjusting the path length (without applying voltage to the PZT) to observe and record the change in the interference pattern. This helps understand the sensitivity of your setup.

Applying Voltage and Observing Changes

Incremental Voltage Application: Start applying voltage to the PZT actuator incrementally through the voltage divider. Begin with a low voltage and gradually increase it in small, defined steps.

Record Observations: At each voltage step, observe and record the changes in the interference pattern. This can be done through photographs, videos, or real-time software analysis, depending on your setup's capabilities.

Quantify the Change: Use software tools or manual counting methods to quantify the change in the interference pattern. This could involve counting fringe shifts or measuring changes in fringe spacing.

Data Analysis

Plot Your Data: Create a plot of voltage applied versus the quantified change in the interference pattern. This graph will visually represent how the actuator's movement affects the interference pattern.

Calculate Displacement: Using the data obtained and the known wavelength of the laser light, calculate the displacement of the actuator tip for each voltage increment. The formula for calculating displacement from fringe shifts is:

$$d = \frac{m\lambda}{2}$$

where d is the displacement, m is the number of fringe shifts, and λ is the wavelength of the laser light.

Conclusion and Further Experiments

Analyze Results: Analyze the plot and calculations to understand the relationship between the voltage applied to the PZT actuator and its displacement. This analysis can reveal the actuator's sensitivity and operational characteristics.

Repeat for Accuracy: To ensure accuracy and reliability of your results, repeat the experiment several times and calculate the average displacement for each voltage level.

Document Findings: Document all your procedures, observations, data, analyses, and conclusions. This documentation is crucial for replicating the experiment or for further research.

Safety and Precautions

Laser Safety: Always ensure that anyone in the vicinity is wearing appropriate eye protection when the laser is in operation.

Electrical Safety: Be cautious when applying voltage to the PZT actuator to prevent electrical shock or damage to the device.

Step 6: Introduce the Magnet to the Tip to Move a CD in a Disk Drive Case

Equipment and Materials

Piezoelectric Actuator (PZT): Already integrated onto the laser disc arm.

Magnet: A small, powerful neodymium magnet compatible with the size of the disk drive case.

Disk Drive Case: The environment where the CD will be manipulated.

Adhesive: For securing the magnet to the PZT tip, ensure it's non-conductive to avoid electrical interference.

Procedure

Magnet Selection and Preparation: Choose a magnet small enough to attach to the PZT actuator's tip but strong enough to exert the necessary force on the CD. Ensure the magnet's polarity is aligned with how you intend to manipulate the CD.

Attach the Magnet: Securely attach the magnet to the PZT actuator's tip using a suitable adhesive. Ensure the bond is strong to prevent the magnet from detaching during operation.

System Integration: Place the laser disc arm with the attached magnet inside the disk drive case. Ensure there's enough clearance for the arm to move without obstruction.

Calibration: Before applying any voltage to the PZT, manually test the system to ensure the magnet can reach the CD and that its magnetic field is strong enough to move the CD as intended.

Voltage Application: Apply voltage to the PZT to initiate movement. The actuation will cause the arm (and therefore the magnet) to move, which should in turn move the CD within the disk drive case. Start with low voltage and gradually increase to find the optimal voltage that achieves the desired movement without overstressing the PZT or the mechanical system.

Observation and Adjustment: Carefully observe the interaction between the magnet and the CD. Adjust the magnet's position, the voltage applied, or the disk drive environment as necessary to optimize performance.

Considerations

Magnetic Field Interference: Be mindful of potential interference the magnet might cause with the disk drive's electronic or magnetic storage components.

Precision and Control: The ability to control the CD's movement accurately will depend on the precision of the PZT actuation and the strength and orientation of the magnetic field.

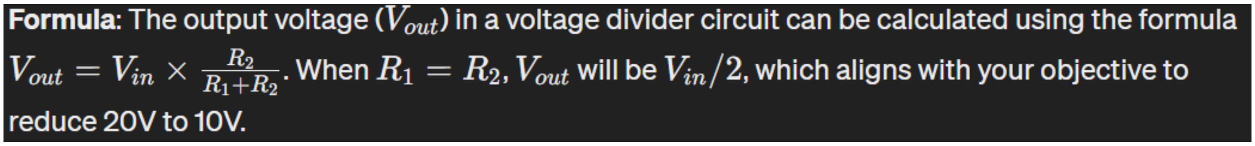
Safety: Small magnets are a swallowing hazard and can cause injury if mishandled. Additionally, strong magnets can damage electronic devices and magnetic media.

This step involves interdisciplinary knowledge, combining piezoelectric actuation with magnetic manipulation. The exact implementation details might vary based on the specific constraints and objectives of your project.

Setting up a voltage divider with two resistors of the same value to halve a 20V input to 10V output is a straightforward and effective approach for supplying precise voltage levels to sensitive components like a nano actuator. By utilizing a GW Instek GPP4323 power supply set to 20V and 1A, you've ensured a stable and reliable power source for your setup. Here's a breakdown of how this works and some considerations for optimizing your setup:

Understanding the Voltage Divider

Principle: A voltage divider allows you to obtain a specific fraction of the input voltage as output by using two resistors in series. The output voltage is determined by the ratio of the two resistors. When both resistors have the same value, the input voltage is divided equally, resulting in a halving of the input voltage.



Formula: The output voltage (V_{out}) in a voltage divider circuit can be calculated using the formula $V_{out} = V_{in} \times \frac{R_2}{R_1+R_2}$. When $R_1 = R_2, V_{out}$ will be $V_{in}/2$, which aligns with your objective to reduce 20V to 10V.

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Setup Instructions

1. Connect the Power Supply: Start by connecting your GW Instek GPP4323 power supply's positive terminal to the first point on the breadboard where the first resistor (R_1) will be connected.

2. Arrange Resistors on Breadboard: Insert the two resistors of the same value in series on the breadboard. The first resistor connects from the power supply's positive output to a common node (junction point), and the second resistor (R_2) connects from this junction to the ground (negative terminal of the power supply).

3. Verify Output Voltage:

- Connect the positive (red) multimeter probe to the junction between the two resistors (Vout).
- Connect the negative (black) multimeter probe to the ground line on the breadboard, which should also be connected to the power supply's ground.
- Set your multimeter to measure DC voltage and verify that the output voltage at the junction is indeed 10V.

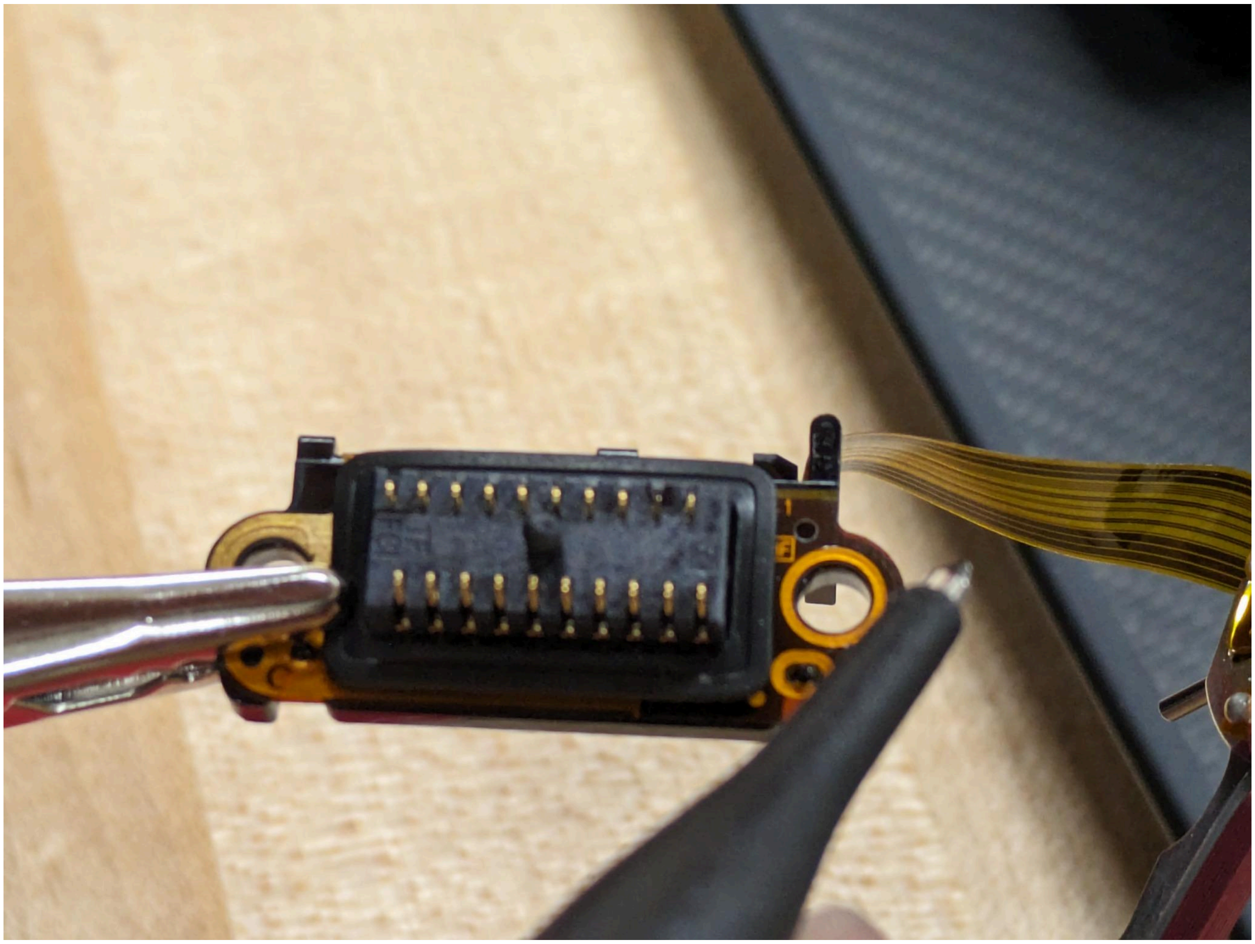
Considerations and Troubleshooting

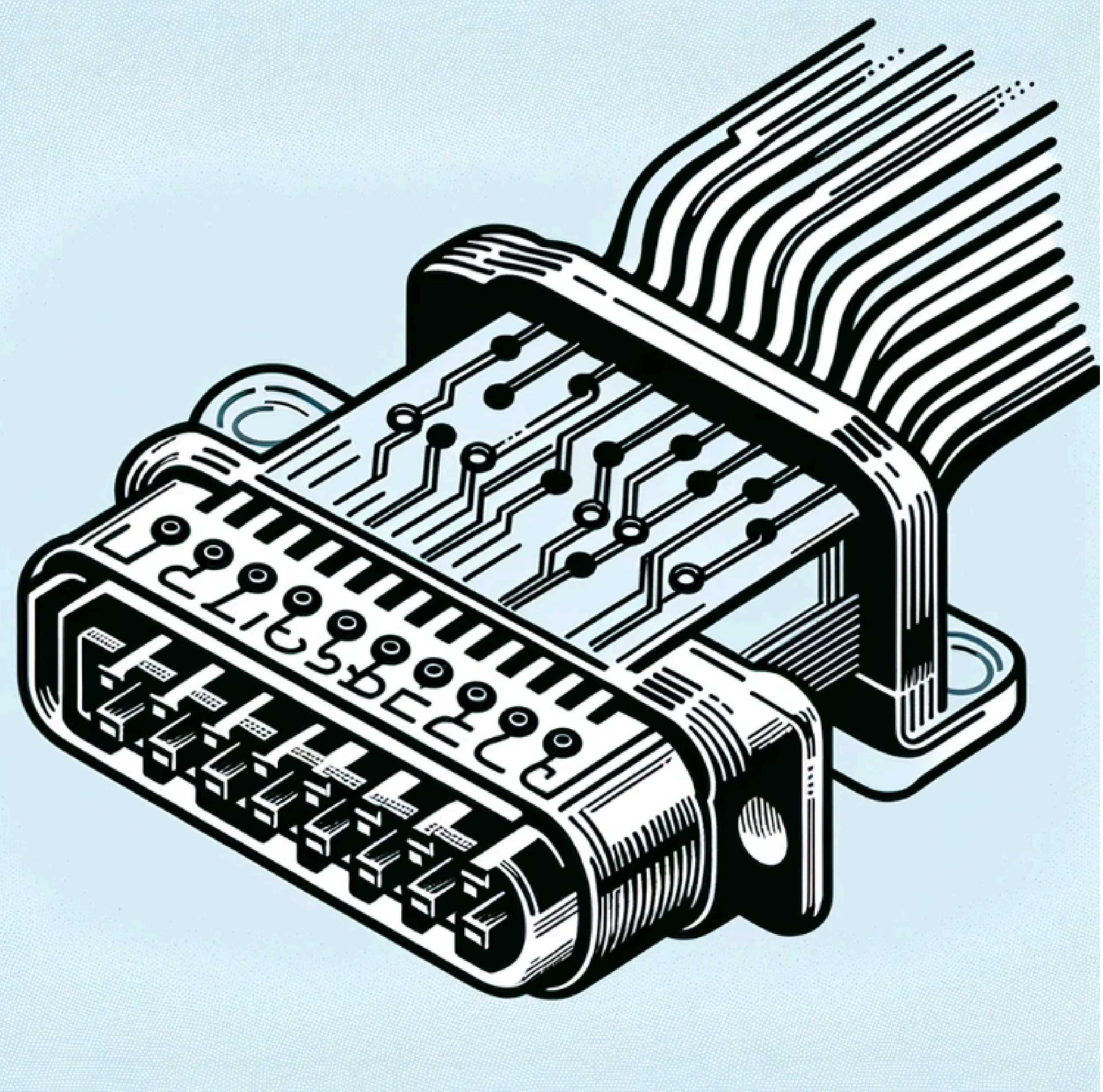
Resistor Values**: Ensure that the resistors are accurately rated and have the same value for a precise 10V output. Variations in resistor values can lead to a different output voltage.

Power Rating of Resistors: Check that the resistors can handle the power dissipation. Power dissipation in each resistor can be calculated using $P = \frac{V^2}{R}$, where V is the voltage across the resistor.

Stable Connections: Ensure all connections on the breadboard are secure to prevent fluctuations in voltage output.

This setup not only demonstrates a fundamental electrical engineering principle but also showcases how simple components can be effectively used in sophisticated applications. By carefully constructing your voltage divider and validating its output with a multimeter, you're ensuring that the piezo actuator receives the appropriate voltage for optimal performance.





Findings

Our experiment successfully demonstrated the functionality and potential of the technologies and methodologies applied. However, the absence of an optical table in our setup presented a significant limitation to achieving and measuring precise placement within the nanometer scale. The inherent instability and vulnerability to vibrations in our makeshift setup underscored the critical role that an optical table plays in precision experimental work. Recognizing this, we explored the feasibility of constructing a DIY optical table for under $400. This endeavor aims not only to enhance our experimental accuracy but also to democratize access to high-precision research tools. By enabling more researchers to build their own cost-effective optical tables, we can significantly broaden the scope of scientific inquiry and innovation, particularly in fields where precision placement and measurement are paramount. This project exemplifies how ingenuity and resourcefulness can overcome financial barriers to advanced research, paving the way for groundbreaking discoveries and advancements.

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