Building a bending machine for material physical characterization

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Abstract

This project presents the development of a custom bending machine for evaluating the mechanical and electrical reliability of printed electronics under repeated stress. The machine integrates precision-machined hardware components, such as lathe-milled rotors and CNC-drilled connectors, with a stepper motor-driven mechanism controlled by an Arduino system. A Keithley 2100 multimeter is interfaced with a Python-based data acquisition script to log resistance changes during bending cycles. By simulating real-world mechanical stresses, including cyclic bending and resistance tracking, this apparatus facilitates in-depth analysis of material degradation and device performance. Results provide valuable insights into the durability of flexible electronics, contributing to advancements in wearable devices and foldable technologies.

1 Introduction

Flexible electronics, which can bend, fold, or stretch while maintaining their functionality, have become crucial in applications such as wearable devices, flexible displays, and healthcare technologies. However, their widespread adoption depends on ensuring electrical performance under repetitive mechanical deformations, as these stresses often lead to failures like cracking and delamination. This highlights the necessity for rigorous and standardized testing methodologies to evaluate device reliability Kim and Kim [2018], Saleh et al. [2021].

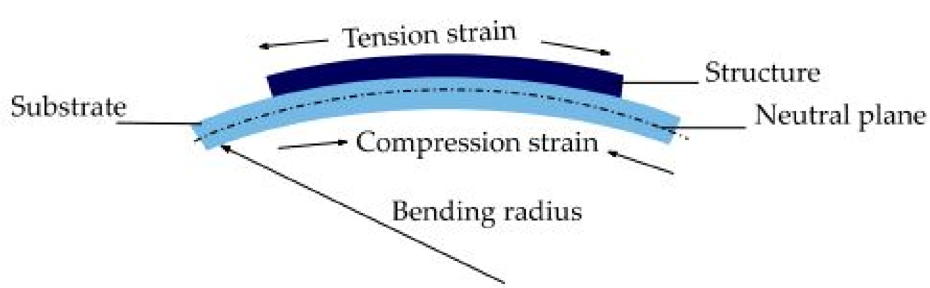

Figure 1: Bending mechanism

bending mechanisam just working as in the Figure 1. These bending can be calculated by using a bending machines just like in Figure2.

Standardization efforts have underscored the significance of understanding mechanical impacts on flexible electronics. Kreiml et al. demonstrated that factors such as bending radius and test speed significantly affect crack density and electrical resistance, underlining the variability of material performance under different conditions Kim and Kim [2018]. Kim et al. introduced a universal testing apparatus capable of simulating various mechanical stresses, such as bending and twisting,

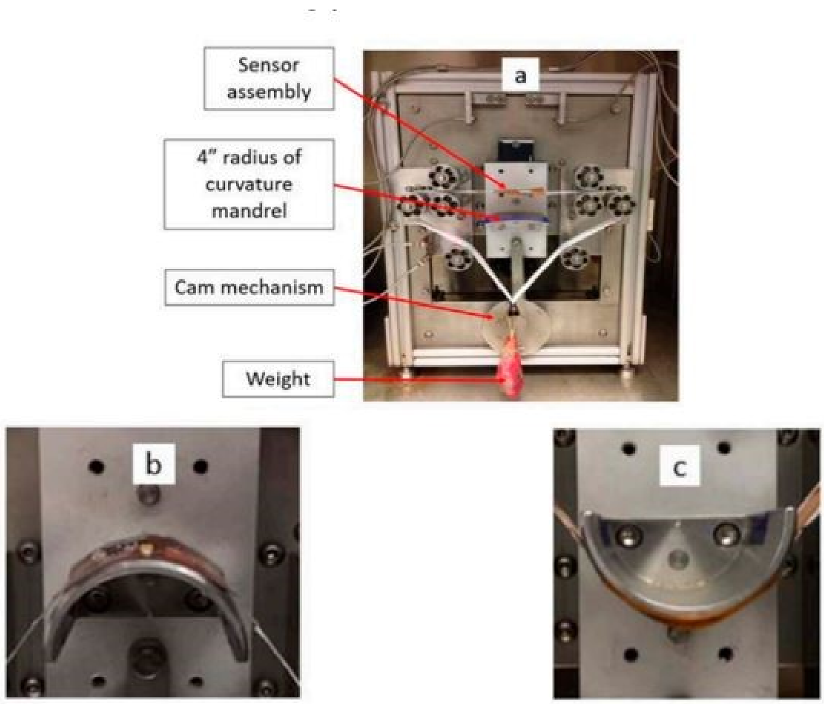

Figure 2: Bending machine from citations

to measure changes in electrical resistance and assess material fatigue Saleh et al. [2021]. These findings emphasize the need for repeatable and controlled testing setups to evaluate device robustness Kim and Kim [2018], Saleh et al. [2021].

This project builds upon these foundational studies by replicating and enhancing established bending machine designs. Using principles and methods from prior works, a custom apparatus was developed to test and optimize the reliability of flexible electronics under controlled mechanical stress. The results aim to contribute to the refinement of testing methods and enhance the durability and electrical stability of flexible devices for broader commercial applications Kim and Kim [2018], Saleh et al. [2021].

The mechanical behavior of flexible electronics under bending stresses is critical for their long-term reliability in practical applications, including wearable devices and flexible displays. Flexible materials experience tensile stress on the outer surface and compressive stress on the inner surface when bent, while a neutral axis remains unstressed. The magnitude of these stresses is influenced by the bending radius: smaller bending radii result in higher stress concentrations, which increase the likelihood of material degradation such as cracking, delamination, or fatigue. This relationship between bending radius and material failure has been well documented in various studies, including those by Saleh et al. (2021), who highlighted the importance of understanding bending stress in the context of flexible electronics Saleh et al. [2021], Kim and Kim [2018].

Saleh et al. (2021) conducted experiments on printed RFID antennas and observed that repeated bending led to significant increases in electrical resistance, particularly under alternating inner-outer bending. This finding emphasizes the accelerated degradation of materials under cyclic stresses, a crucial factor for evaluating the longevity and reliability of flexible electronics Saleh et al. [2021]. Furthermore, the study underlined the need for rigorous testing methods to assess the performance of flexible materials under mechanical deformation, particularly those used in emerging technologies such as foldable displays and wearable sensors.

Types of Bending Machines

Different types of bending machines are employed to evaluate the mechanical reliability of flexible electronics by simulating real-world stress conditions. Saleh et al. (2021) and other researchers categorize various bending machines designed to replicate different mechanical deformations:

1. **Linear Bending Machines:** These machines apply unidirectional bending to flexible materials, either by bending them to a fixed angle or radius. Linear bending setups are typically used to evaluate the fundamental bending properties of thin films and flexible circuits. These setups provide valuable data on material performance under static and cyclic bending **?**.

2. **Alternating Bending Machines:** These machines alternate bending direction, applying both tensile and compressive forces to the sample in a cyclic manner. This setup simulates real-world folding and flexing conditions that flexible electronics experience during use, such as in wearable devices. Saleh et al. (2021) emphasized that alternating bending significantly accelerates fatigue and increases resistance changes, making it an important test for evaluating long-term performance Kim and Kim [2018].

3. **Twisting Machines:** Twisting machines apply torsional forces in addition to bending. These setups are essential for testing devices where both bending and twisting forces are encountered, such as flexible displays and stretchable sensors. The combined stresses from bending and twisting can lead to unique failure modes, making these machines an important tool for comprehensive reliability testing Saleh et al. [2021].

4. **Customized Universal Bending Machines:** Universal bending machines provide a versatile testing platform capable of simulating multiple types of mechanical stresses, including bending, twisting, and stretching. This flexibility allows researchers to explore how combined stresses affect the mechanical and electrical properties of flexible electronics, ensuring more thorough reliability assessments Saleh et al. [2021], Kim and Kim [2018].

The choice of bending machine depends on the specific mechanical stresses that the flexible device will undergo in real-world applications. By selecting the appropriate bending setup, researchers can simulate the bending, twisting, and stretching conditions that will impact the device's performance and longevity.

2 Methodology

The development of the bending machine for measuring the resistance variation in printed electronics involved the integration of both hardware and embedded system components. The primary objective of this project was to measure how the resistance of printed electronics changes with the number of bending cycles. The process of constructing the machine is detailed below, focusing on the hardware manufacturing, embedded system integration, and data collection mechanisms.

2.1 Hardware Manufacturing

The hardware manufacturing phase involved several machining processes, including lathe milling, drilling, CNC, and 3D printing, to produce the structural components and mechanical parts of the bending machine.

2.1.1 Lathe Machine

The rotors of the bending machine were fabricated using aluminum rods. These rods were turned on a lathe machine to achieve the required dimensions. The material was then drilled to reduce weight and ensure the balance of the rotor components.

2.1.2 Milling Machine

The back structure of the machine was made using a 3 mm thick aluminum sheet. All necessary holes for screws and components were precisely drilled or carved using the milling machine to ensure accuracy during assembly.

2.1.3 CNC Drilling

The mandrel plates (1-inch, 2-inch) connecting the moving parts were drilled using a CNC engrave machine with a 2.5 mm drill bit. This ensured high precision in creating the necessary connectors for the motor and other components.

2.1.4 3D Printing

Some parts of the bending machine required customized designs, which were produced using 3D printing. This method allowed for the creation of specific connectors and housing for electronic components that could not be easily fabricated with traditional machining tools. minerals were printed using 3D printing for different radius.

2.1.5 Assembly of Mechanical Parts

After machining the individual parts, they were assembled onto a 3 mm thick aluminum backplate. The parts were attached using screws to ensure stability and strength. A stepper motor was then mounted on the backplate, with all components carefully positioned to ensure smooth movement during the bending cycles.

2.2 Stepper Motor Control and Arduino Integration

The stepper motor was integrated to control the movement of the bending mechanism. The motor's speed and torque were regulated via an Arduino board, which was programmed to control the motor's operation based on specific inputs.

2.2.1 Stepper Motor Connection

The motor driver, which controls the stepper motor's operation, was connected to the Arduino board. This integration enabled precise control of the bending mechanism's speed and torque, ensuring consistent bending for each cycle.

2.2.2 Limit Switch Integration

A limit switch was installed at the lowest point of the moving mechanism to detect when a bending cycle was completed. When the mechanism hit the limit switch, the Arduino was programmed to count that as one bending cycle, providing an accurate count of the number of bends the substrate underwent.

2.3 Interfacing with Keithley 2100 for Resistance Measurement

The Keithley 2100 Digital Multimeter (DMM) was used to measure the resistance of the printed electronics at each bending stage. The connection between the Keithley 2100 and the bending machine was established via the computer and a Python script that facilitated data collection.

2.3.1 Python Scripting for Data Acquisition

A Python script was developed to interface with both the Keithley 2100 and the Arduino board. The script continuously recorded the resistance readings from the Keithley DMM after each bending cycle. It also tracked the bending cycle count, storing both values in a CSV file for later analysis.

2.3.2 Data Collection

The Python script enabled real-time data logging during the testing process. Each time the bending mechanism completed a cycle, the system logged the bending cycle number and the corresponding resistance value from the Keithley 2100. The collected data were stored in a CSV file with timestamps for detailed post-test analysis.

The following Python code was used for data collection:

```python
import tkinter as tk
import csv
import time
import pyvisa as visa
import serial
from datetime import datetime

ser = serial.Serial('COM19', 9600)  # Replace 'COM19' with the actual port

# Open connection to the DMM
rm = visa.ResourceManager()
dmm = rm.open_resource('USB0::0x05E6::0x2100::1373334::INSTR')
dmm.timeout = 10000  # Timeout for reading data

# Open CSV file for writing data
with open('conc_1.csv', mode='w', newline='') as file:
    writer = csv.writer(file)
    writer.writerow(['Time', 'Resistance'])

    try:
        while True:
            if ser.in_waiting > 0:
                data = ser.readline().decode('utf-8').rstrip()  # Read data from
                    Arduino
            # Take a resistance measurement
            reading = dmm.query_ascii_values('READ?')
            if reading and data:
                timestamp = datetime.now().strftime("%Y-%m-%d %H:%M:%S.%f")[:-3]
                data_row = [timestamp, reading[0], data]
                writer.writerow(data_row)  # Write data to CSV
            time.sleep(0.1)  # Delay between readings

    except KeyboardInterrupt:
        dmm.close()  # Close the DMM connection when done
```

This script ensures that after every bending cycle, the system records both the number of bends and the corresponding resistance values, providing a comprehensive dataset for analysis.

2.4 Data Analysis and Testing Procedure

Once the system was set up and all mechanical and electrical components were integrated, the machine was used to conduct bending tests on various substrates of printed electronics. The bending cycles were performed as follows:

- The machine executed a specified number of bending cycles, with each cycle monitored by the Arduino for the limit switch trigger.
- The resistance values were recorded after each bending cycle by the Python script, which logged the data into the CSV file along with the timestamp.
- The data were later analyzed to observe how the resistance of the material varied with the number of bending cycles, providing insights into the durability and reliability of the printed electronics over repeated mechanical stress.

This bending machine, designed through a combination of hardware machining, embedded system control, and data collection, provides an effective means of testing the mechanical and electrical reliability of printed electronics. The integration of Arduino for motor control and Keithley 2100 for resistance measurement ensures that the system can accurately record the degradation of materials over multiple bending cycles, providing valuable insights into their long-term performance.

3 Results

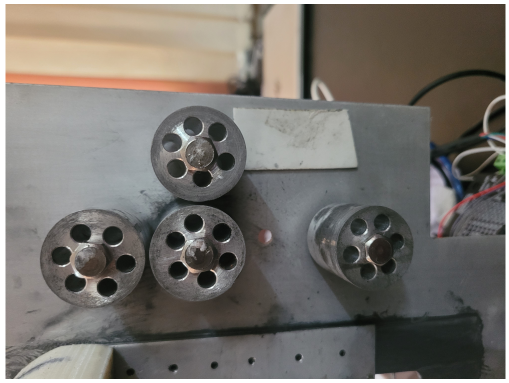

Figure 3: Rotor mechanism of bending machine

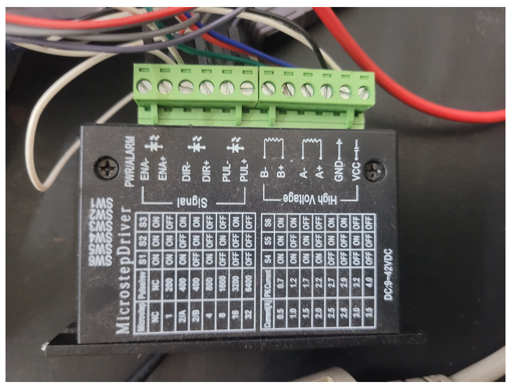

Figure 4: Motor driver used

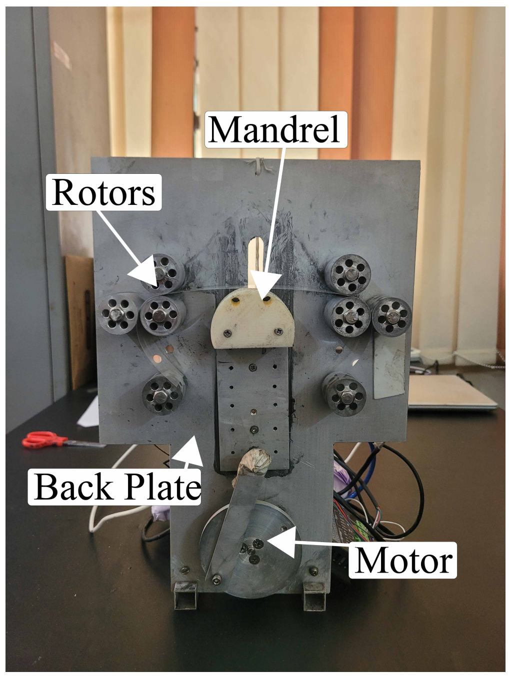

Figure 5: Final product and parts

References

Cheol Kim and Chung Hwan Kim. Universal testing apparatus implementing various repetitive mechanical deformations to evaluate the reliability of flexible electronic devices. *Micromachines*, 9(10):492, 2018. doi: 10.3390/mi9100492.

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