# Passive Baseline Testing Using Instron E3000

Intelligent Systems Case Study

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# Contents

**Abstract**

This project investigates the passive mechanical reliability of surface-mounted 1002 resistors subjected to cyclic mechanical loading using a standardized four-point bending test configuration. The goal is to isolate and evaluate the effect of mechanical load on soldered components without interference from thermal or electrical variables. This is essential for understanding component robustness during various stages such as shipping, assembly, or device flexing in real-world applications like automotive or handheld electronics.

To conduct this experiment, a dynamic Instron E3000 testing system was employed, outfitted with a custom-designed PLA fixture to support the four-point bending setup. Controlled sinusoidal displacement amplitudes of 0.092 mm and 0.5 mm were applied at frequencies of 2 Hz and 3 Hz. The procedure adhered to industry standard protocols outlined in IPC/JEDEC-9702 for board-level mechanical testing. The primary indicator of mechanical degradation was the electrical resistance of the 1002 resistors.

Results revealed no significant deviation from the nominal $10\,\mathrm{k}\Omega$ resistance value across all test specimens at the selected amplitudes and frequencies. This outcome indicates that the resistors exhibited strong mechanical endurance under the defined low-strain cyclic conditions. The absence of failures supports the validity of the four-point bending test as a fast, reliable, and non-destructive method for baseline screening of passive surface-mounted components. The findings provide foundational data that can inform future fatigue modeling, reliability screening, and design optimization of soldered electronic assemblies.

**Keywords:** 4-point bending, passive mechanical reliability, 1002 resistor, cyclic loading, Instron E3000, IPC/JEDEC-9702, SMD fatigue, electronic component testing

# 1 Introduction

Passive baseline testing using the Instron E3000 dynamic testing system provides a focused approach to understanding the mechanical reliability of electronic components under flexural force.[3]This study, the emphasis is placed on 1002 surface-mounted resistors (SMDs), evaluated under cyclic loading conditions without the influence of electrical power or thermal effects. The aim is to simulate realistic mechanical environments—such as vibration, flexing to assess how these components behave structurally during non-operational phases.

The mechanical test configuration adheres to the IPC/JEDEC-9702 standard[2], which outlines procedures for cyclic bend testing at the PCB level. To ensure consistent and reproducible loading, a four-point bending configuration is used. This setup delivers a constant bending moment between the inner anvils and reduces stress concentration, making it preferable over three-point bending for uniform stress distribution across the test specimen. The fixture is configured with an outer span of 60 mm and an inner loading span of 18 mm, both aligning with industry-recommended dimensions for PCB-level mechanical testing. We took values regarding the instron Electropuls 3000 machine from the official website of E3000 [5] and the customised upper and lower fixtures are attached to the plates of the E3000 machine. And with the help of various python packages to intepret and analyse data, various graphs on force and displacement that support our study was derived.

To simulate dynamic loading conditions, the system uses a sinusoidal waveform with frequencies ranging from 2 to 4 Hz [3] and displacement amplitudes of 0.092 mm and 0.5 mm. These values were selected to reflect displacement and force levels that electronic components face in real applications. The strain rate, governed by frequency and amplitude, is a key parameter in reproducing operational mechanical stress within a controlled laboratory setting. The test is conducted in passive mode, meaning that the PCB and components are unpowered throughout the evaluation. This removes the effects of heat or electrical current, allowing researchers to focus solely on the mechanical aspects of the component behavior. Observing how solder joints, PCB substrates, and component bodies react to mechanical fatigue in isolation is critical for identifying failure mechanisms that occur independently of thermal or electrical influence. As modern electronics are increasingly used in mobile, industrial, and high-vibration environments, ensuring mechanical durability—especially during unpowered states—has become essential. However, such testing is often underrepresented in typical validation protocols. Components can still fail during transit or idle storage, even when no power is applied. Understanding how they respond to cyclic loading in such conditions helps prevent long-term reliability issues.

Supporting this testing method, Bart Vandevelde et al.[1] demonstrated that four-point bending can effectively replicate stress behaviors observed in thermal cycling, a standard but more time-consuming test method. Their findings validate the use of controlled mechanical bending as a practical and efficient alternative, particularly when thermal factors are not the primary concern. Throughout the test, several critical parameters are monitored, including actuator displacement, applied force, cycle counts, and any signs of mechanical degradation—internal resistance and internal crack formation. These measurements help identify patterns of mechanical failure and structural change over time. The resulting data is used to inform decisions about component placement, solder selection, and PCB design improvements, ultimately contributing to more mechanically robust electronic systems.

In addition to the mechanical aspects, passive baseline testing offers valuable insights into component behavior under real-world applications that are often ignored in typical thermal or electrical cycling tests. This type of testing is vital for evaluating components exposed to dynamic environments where mechanical failure due to flexing, vibration, or handling could occur during transportation, installation, or storage. The test setup is designed to simulate such conditions, focusing on early-stage degradation before failure becomes visible. This approach is particularly beneficial as modern electronics, especially in sectors like automotive and mobile devices, face mechanical stresses from vibrations, shocks, and other environmental factors even in unpowered states. Passive baseline testing serves as a preventive measure to identify components susceptible to these forces, offering valuable data for improving the overall design and robustness of the product.

Moreover, while the test results provide foundational data for more complex tests, including thermal cycling, powered loading, and combined environmental stress tests, they also open up opportunities for thermal-mechanical simulations, accelerated life testing, and active electrical evaluations. This ensures that the findings from passive baseline testing are not only applicable to the immediate research phase but also scalable for future, more complex research conditions. Furthermore, the incorporation of strain equations used in the study by Vandevelde et al.[1] allows the displacement values to be justified based on solid theoretical foundations. This provides a stronger rationale for the test parameters, ensuring they align with established standards and previous research, ultimately enhancing the credibility of the study.

Passive mechanical testing using a four-point bending setup provides a reliable and efficient method for assessing the mechanical integrity of SMD components under cyclic loading [4]. The experiment serves as a crucial first step in identifying failure mechanisms that occur under non-operational stress conditions, such as those experienced during shipping, handling, or storage. By isolating mechanical stress factors and excluding thermal or electrical influences, the test offers valuable insights into the durability of components, contributing to more robust and reliable product designs. The findings from this study support the inclusion of passive baseline testing as a fundamental element in future reliability validation protocols, offering a comprehensive and non-destructive evaluation of component performance under real-world mechanical conditions.

The 4-point bending setup plays a key role in this experiment because it creates a stable zone where the bending stress is evenly spread across the central portion of the PCB. This design helps us focus the mechanical strain exactly where the test resistor is placed, allowing us to observe how the component and its solder joints respond to repeated flexing. Compared to other methods like 3-point bending, this setup gives us cleaner and more reliable data by reducing stress variation across the board.

By checking the electrical resistance of the resistor before and after the test, we can spot early signs of damage—like cracks in the ceramic body or weakening in the solder joints—even if they aren't visible to the naked eye. This makes the test a valuable non-destructive way to catch failures that could later lead to total breakdown in real-world conditions.

Using a cyclic loading pattern in the test helps mimic actual situations where PCBs might be exposed to vibrations or flexing during use, shipping, or handling. These repetitive mechanical movements can slowly wear out solder joints or create microscopic cracks in components—problems that may not show up immediately, but can cause failures over time.

Following industry standards like IPC/JEDEC-9702 and JESD22-B113 ensures that our testing method matches what's used in professional reliability assessments. The data we collect isn't just useful for this experiment—it can help guide better design choices in the future. For example, manufacturers can use it to decide on stronger solder materials, adjust the layout of their PCBs, or even simulate stress in software models before production.

From our overall study on the passive baseline testing of arduino nano component where we took the 1002 SMD resistors gave us an insight about "how the resistor perform functionally under passive mechanical reliability tests by usung the instron Electropuls 3000 System"?

# 2 Materials and Methods

For checking the performance of the 1002 SMD resistor the procedure needs different components and each of the selected components have different functions under the test. These include 1002 SMD resistor, printed circuit board, solder material, Instron E3000 dynamic testing machine, Wave matrix software, 4- point bending fixture, Multimeter, pick and place machine, Reflow soldering station , Fixture mounting base.

## 2.1 Materials

To understand how a small smd resistor, used in arduino nano holds up under mechanical stress, a hands-on experiment was set up using a variety of tools and components. The focus was on a

1002 surface-mounted resistor, a common part in electronic circuits, which was soldered onto a standard-sized PCB (80 mm × 25 mm × 1.6 mm). This setup closely mimicked real-world conditions where such resistors face bending or vibration during use. To ensure accuracy, a pick-and-place machine carefully positioned the resistor on the board, and a reflow soldering station was used to create strong, reliable solder joints using lead-free SAC305 alloy. The actual testing was carried out using the Instron E3000 machine—a dynamic testing system designed to apply repeated mechanical loading. The board was mounted in a 4-point bending fixture with defined outer and inner spans (60 mm and 18 mm), which helped concentrate force in the two sides of the PCB where the resistor sat. The entire test was run using WaveMatrix software, which made it easy to control parameters like how much the board flexed, how fast resistor moved from solder, and how many times the cycle repeated. Throughout the test, the resistor wasn't powered; instead, its resistance was measured before and after using a digital multimeter to see if any damage had occurred. To keep everything steady, the fixture was mounted on a stable base, ensuring consistent and accurate results. This setup helped simulate how resistors behave under real mechanical stress, giving insights into their reliability over time.

### 2.1.1 SMD 1002 Resistor

[2] This resistor plays an important role of primary specimen in the analysis of mechanical reliability in this experiment. It is mounted on the surface of a PCB and subjected to different loads using 4-point bending setup on the Instron E3000 system. Here it acts as a passive component with a resistance of $10\,\mathrm{k}\Omega$ and it is a representation of surface-mounted device in electronic assemblies . The resistor simulates real-world in which mechanical stress such as board flexing or vibration . These situation may lead to microcracking in resistor or breakage in internal structure, that is change in internal resistance or internal cracks . Analysing any physical damage or resistance variation before and after cyclic loading , the experiment evaluates the robustness and the failure behaviours of the resistor and its soldered interconnections .The conclusion indicates the reliability of passive SMD component under different load conditions

### 2.1.2 Instron E3000 dynamic testing machine

The core equipment used in this experiment is Instron E3000 dynamic testing machine. This applies controlled mechanical load to the test specimen and delivers precise cyclic flexural stress to the PCB assembly using 4-point bending fixture. The displacement-controlled mode of this machine enables the application of sinusoidal wave form with specified amplitude and frequency. Its role is crucial for ensuring the mechanical reliability of the 1002 resistor and solder joints by generating the mechanical stress required to make microcracks or failure over a number of loading cycles .

### 2.1.3 4-point Bending Fixture

The fixture is designed to apply flexural force to the PCB assembly in a controlled and uniform manner by supporting the specimen at two outer points while applying load through these points simultaneously. This experimental setup ensures the section of PCB between the inner loadings experiences a constant bending moment and zero shear force. This mechanism is useful for evaluating the mechanical behaviour of surface-mounted components under pure flexural stress. The fixture enables accurate and repeatable loading, which helps in fatigue testing and failure analysis of the 1002 SMD resistor and the solder joints.

### 2.1.4 Solder material

The solder material used here acts as a interface between the ceramic resistor and PCB .Its primary role is to ensure a secure and conductive bond that can with stand mechanical stresses applied during 4-point bending[1]. The solder joints(Figure 1) function the role of stress concentration joints where, fatigue or fractures are most likely to initiate under cyclic loading. In this experiment the commonly used lead free SAC (Sn96.5Ag3.0Cu0.5) is known for good balance of strength .


Figure 1: Soldering

### 2.1.5 Surface Mount Technology Placement Machine

The pick and place machine(Figure 2) commonly used to ensure precise placement of 1002 ceramic resistor on the PCB before soldering. The component mounting process has accurately done by this and the resistor with its designed footprint on board correct the orientation and positioning.

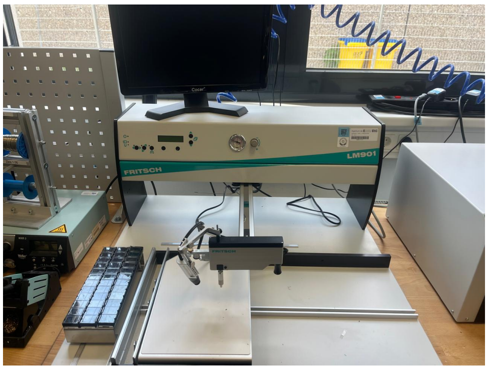


Figure 2: pick and place machine

### 2.1.6 Reflow soldering station

Here the soldering station provides a controlled thermal profile that gradually heats the solder paste, allowing it to reflow and form strong metallurgical bond. Use of this system is helpful to ensure the test specimen is fabricated under standardized conditions.

### 2.1.7 Fixture mounting base

The fixture mounting base(Figure 3) provides the accurate alignment and strong support to the whole test setup and preventing unwanted movement of vibration which affect the accuracy of the experiment. The mounted base ensures that the applied load is uniformly distributed over the PCB and the smd resistor.

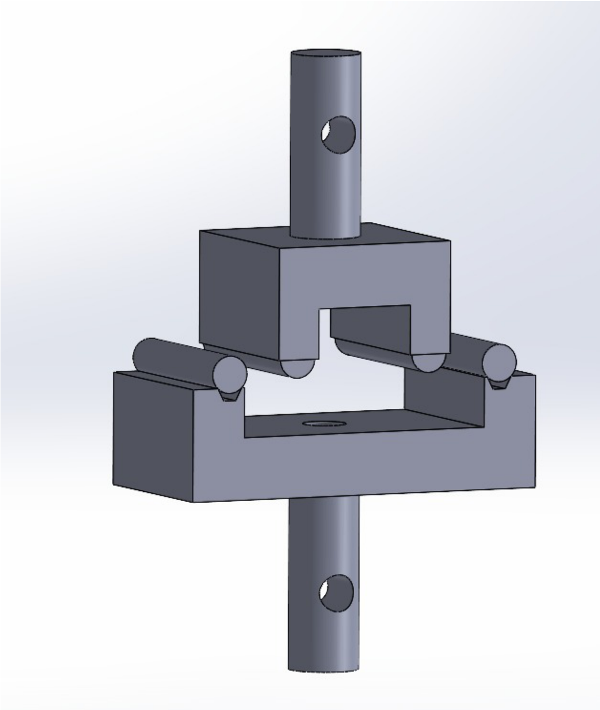

Figure 3: Fixture

#### 2.1.8 Multimeter

Resistance values of the resistors were measured pre- and post-test using a digital multimeter. These readings served as the primary indicator of component degradation or failure. A deviation from the nominal 10 k■ value was considered a failure condition.

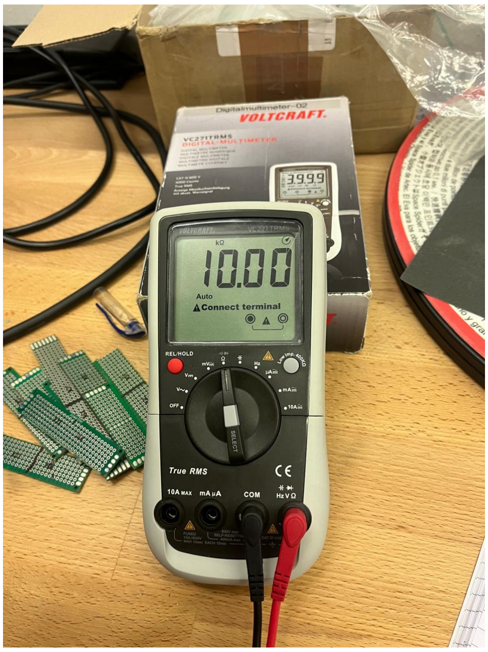


Figure 4: Multimeter

### 2.1.9 Wave matrix software

This software used indicates the execution and control of 4-point bending test conducted using Instron E3000 testing machine.[5] It acts as a intermediate between operator and test system and control mechanical loading profiles such as sinusoidal waveforms with specific displacement amplitude and frequencies. Here it provides live graphical feedback(Figure 5) during the entire testing process.


Figure 5: wave matrix

## 2.2 Methods

The main purpose of this experiment was to assess the mechanical reliability of a surface-mounted 1002 resistor by subjecting it to cyclic flexural loading. This was achieved using a 4-point bending test setup, a method that applies force to the resistor while keeping the displacement controlled even across the board. In this setup, the PCB (printed circuit board) was placed on a fixture that had specific support spans, and a controlled force was applied at two inner points, which created a uniform bending moment across the central region where the resistor was mounted. This allowed the experiment to simulate the type of mechanical stress the resistor might face in real-world conditions, such as flexing or vibration that can occur during transport or use in electronic devices. To ensure the results were reliable and consistent, the experiment followed established standards—specifically IPC/JEDEC-9702 and JESD22-B113. These are industry-recognized guidelines for testing the mechanical performance of components like resistors when they are mounted on a PCB. These standards provided a clear structure for the test, including important parameters such as the length of the support spans, the amount of displacement applied to the PCB, the frequency of the cycles, and how many cycles the resistor would undergo. By strictly adhering to these standards, the experiment ensured that the testing process would be reproducible and that the data obtained would be accurate and comparable to other tests in the field. Ultimately, the goal was to observe how the resistor's resistance value changed, if at all, under repeated mechanical stress and to determine its durability in typical electronic applications.

### 2.2.1 Preparation of sample and component placement

The PCB were used as a substrates here . The surface of this board is mounted with a 1002 ceramic resistor(Figure 6) $10\,\mathrm{k}\Omega$ were selected as test components due to their standard use in electronic assemblies and mechanical vulnerability under bending loads. This resistor placed on PCB by pick- and- place machine ,which ensures precise alignment. The resistors were soldered using lead-free SAC305 alloy (Sn96.5Ag3.0Cu0.5).A reflow soldering station was used to provide a controlled thermal profile ,enabling consistent solder joint quality across all test samples.

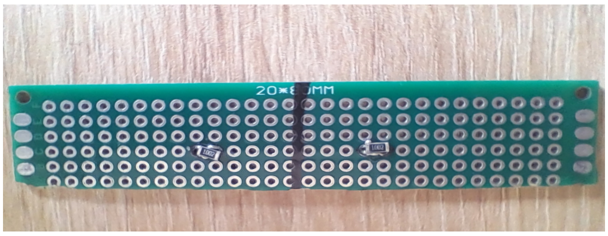

Figure 6: Ceramic resistor mounted on PCB

### 2.2.2 Initial resistance measurement

Before testing, the electrical resistance of each resistor was measured using a digital multimeter. The readings ensure that all components had expected the $10\,\mathrm{k}\Omega$ value without faults. This value is recorded for post-test comparison.

### 2.2.3 Mechanical test setup

Mechanical testing was performed using an Instron E3000(Figure 7) system equipped with a 4-point bending fixture mounted on a rigid fixture base. The outer span of fixture was set to 60mm and inner loading span is to 18mm, in accordance with IPC/JEDEC -9702 standard.[2] This configuration provides a constant bending moment applied over the central region of the PCB. The mounting base of the fixture ensured that the entire set-up remained stable during cyclic bending.

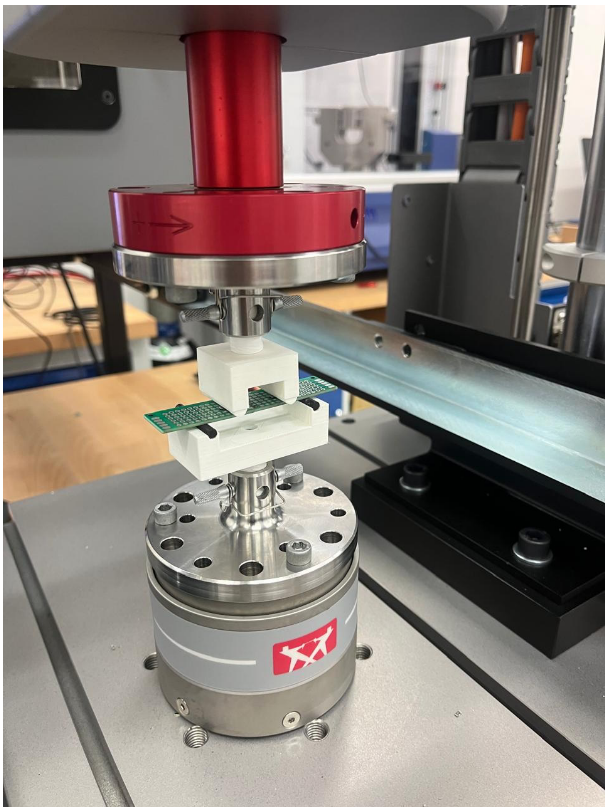

Figure 7: Mechanical test setup

Find an appropriate displacement amplitude to simulate realistic flexural strain on the PCB, the target surface strain was set at 500 microstrain according to the recommendations of JEDEC The relationship between strain(E),displacement amplitude(d),PCB thickness(t), outer bending span(L),inner bending span(l)in a four point bending setup is found to be 0.092mm and this is obtained by the equation

$$\varepsilon = \frac{6 \cdot d \cdot t}{(L - l)^2} \tag{1}$$

#### 2.2.4 Loading procedure using wave matrix

The test control was managed through the wave matrix software, which was used to define a sinusoidal displacement controlled waveform. Here, several displacement amplitudes were tested(eg;0.092mm,0.5mm)at various frequencies(eg;2Hz,3Hz,4Hz).Each test ran for a fixed number of cycles (up to 1000 cycles ) or until failure was observed.The software displays actuator displacement, force response, cycle count, and test duration.

#### 2.2.5 Post- Test evaluation

After mechanical loading, each resistor is once again measured using a multimeter to determine the change in resistance. A deviation of $10\,\mathrm{k}\Omega$ indicates failure due to cracking of the solder joint or damage to the resistor.

### 2.2.6 Data analysis

The force-displacement and cycle-time data recorded by the wave matrix were exported and analyzed using Python and Excel.

# 3 Results

A four-point bending test system from Instron E3000 tested 1002 surface-mounted resistors to evaluate their mechanical endurance and operational stability during cyclic loading. The displacement-controlled testing applied sinusoidal loading to specimens using two amplitude levels of 0.092 mm and 0.5 mm and three frequencies of 2 Hz and 3 Hz and 4 Hz for 1000 cycles each. The goal of this test was to determine the ability of passive components to maintain their internal resistance when subjected to repeated mechanical loading. The electrical internal resistance of all tested resistors remained unchanged after testing at the lower amplitude of 0.092 mm. Each resistor maintained its initial resistance value of 10 k and showed no signs of physical deterioration or failure after testing. The test results demonstrated that 1002 SMD resistors soldered to PCBs can withstand low-strain cyclic loading at any tested frequency level. The force-displacement profiles revealed that linear elastic behaviour occurred during initial cycles but small deviations appeared at increased displacement levels and frequencies because of possible micro-cracks or stored strain energy although no abrupt force reductions showed full fractures occurred during the tests. Box plots used for statistical analysis demonstrated that low-displacement tests experienced narrow force distributions while high-displacement tests showed broader distributions with extreme values which suggested localized stress points. The relationship between maximum forces and failure rates demonstrated how mechanical parameters affect failure probabilities.

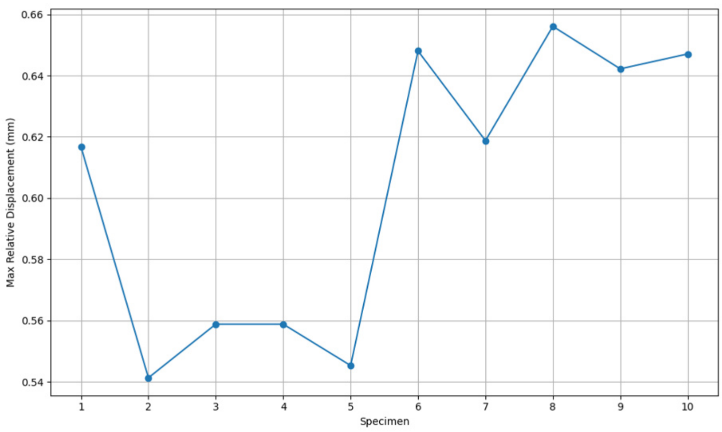


Figure 8: Maximum relative Displacement v/s Specimen

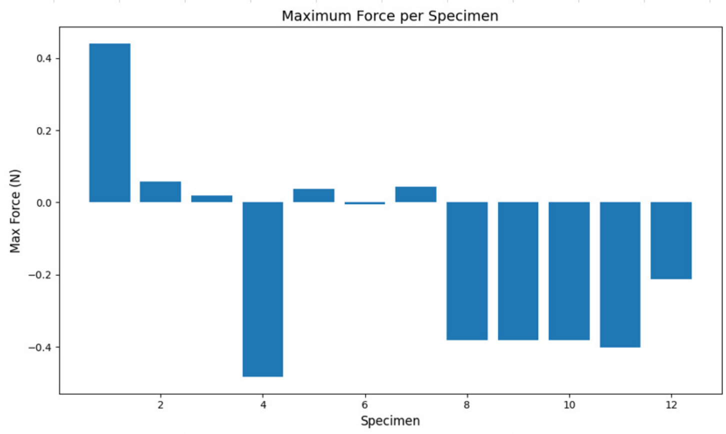


Figure 9: Maximum Force v/s Specimen

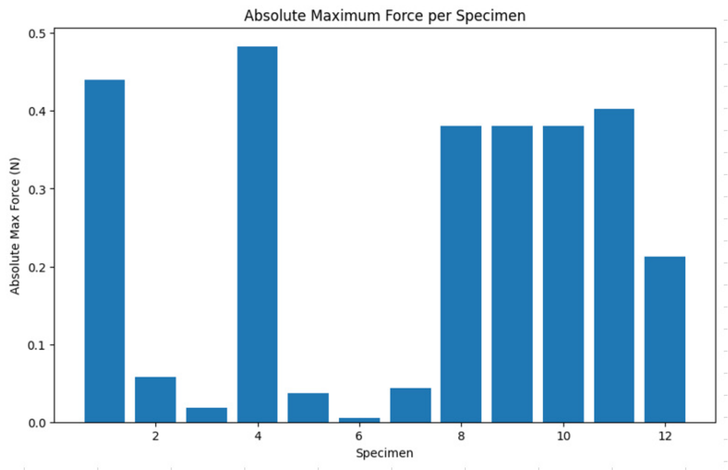


Figure 10: Absolute max force v/s Specimen

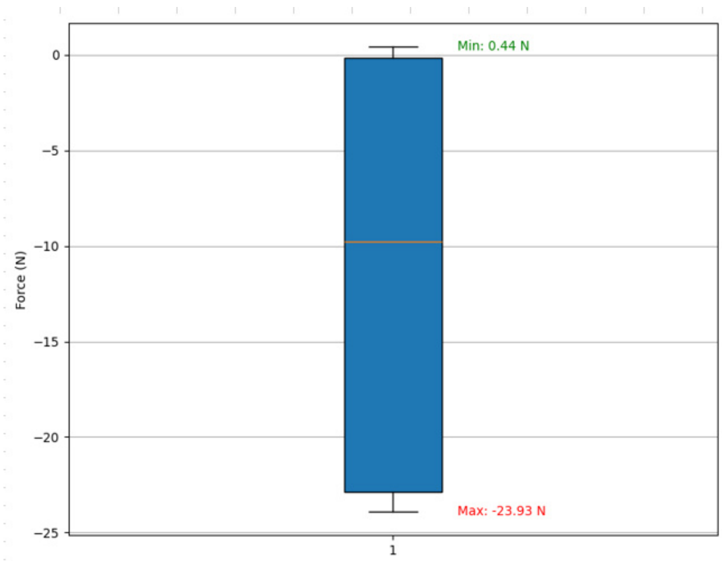


Figure 11: Box Plot

Under the test condition of 0.092 mm amplitude and 2 Hz frequency, each specimen underwent 1000 mechanical cycles over a duration of 505 seconds. The minimum force ranged between –19.06 N and –23.93 N, representing the peak tensile stresses, while maximum force remained slightly compressive, peaking around 0.44 N. The maximum relative force, a normalized measure of loading, varied between 13.34 N and 14.96 N, demonstrating consistent mechanical loading across all tested specimens. The maximum relative displacement ranged from 0.216 mm to 0.257 mm, slightly exceeding the input amplitude due to the dynamic response of the system (Figure 8, Figure 9, Figure 10, Figure 11).

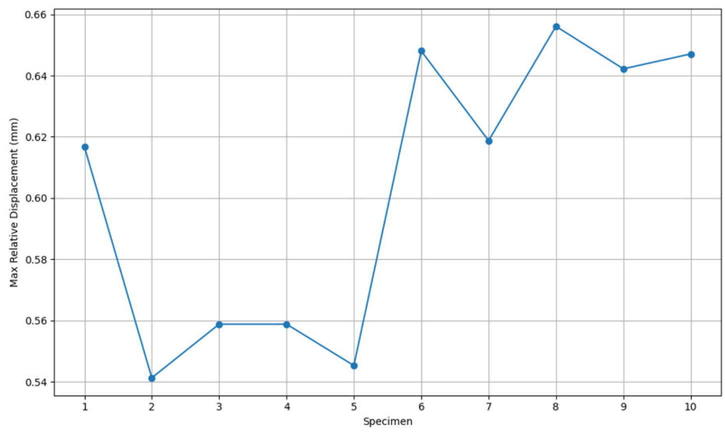


Figure 12: Maximum Relative Displacement vs specimen

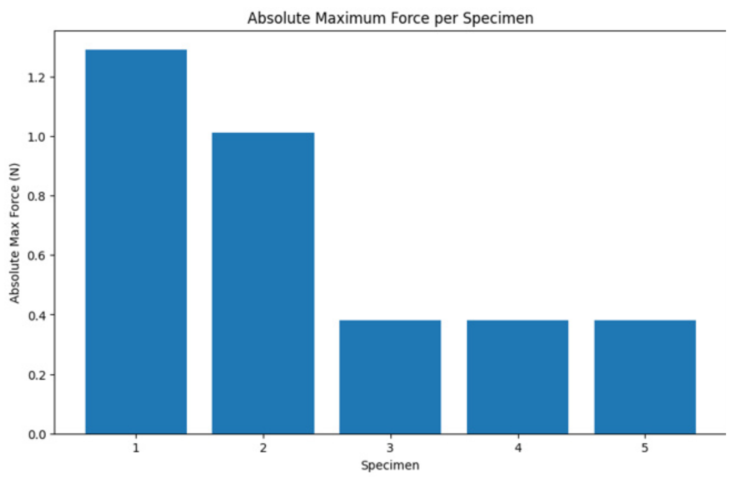


Figure 13: Absolute Max Force vs Specimen

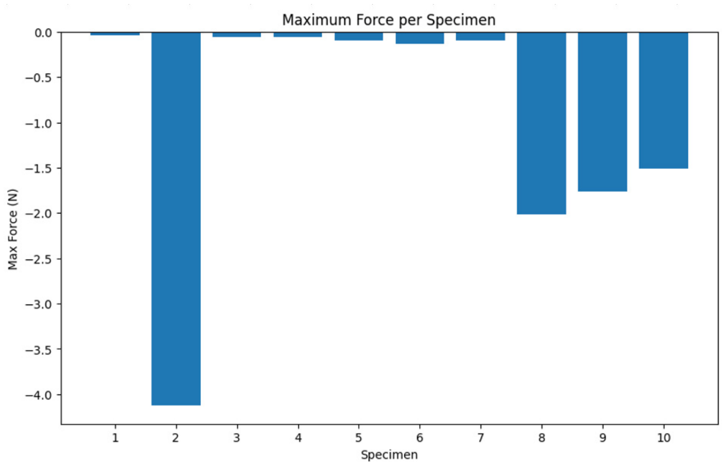


Figure 14: Max Force vs Specimen

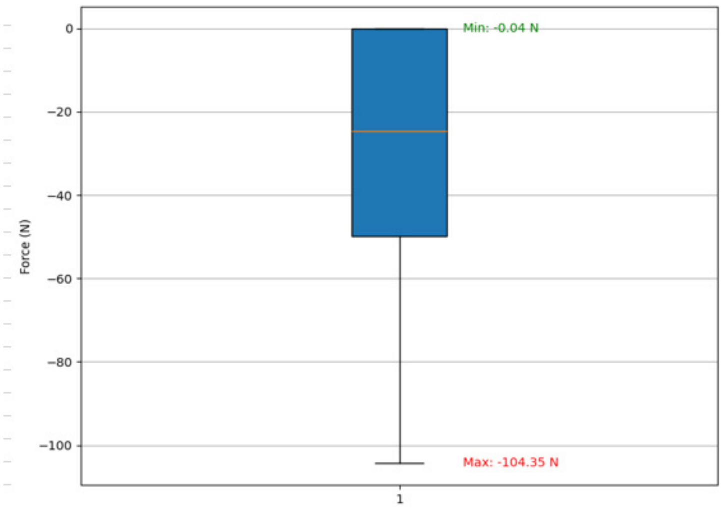


Figure 15: Box plot

The resistors underwent substantial mechanical pressure during our testing at higher strain levels 0.5 mm amplitude and 3 Hz frequency. The components faced average forces of about 46 N while experiencing tension forces that nearly matched the PCB and solder joint mechanical tolerance at –58 N. The 0.6 mm displacement values showed that these conditions were indeed high-strain situations. The dynamic forces together with repeated cycles probably caused the resistor failures which occurred in some tests by reducing resistance values from down $10\,\mathrm{k}\Omega$to 0 or $10\,\mathrm{k}\Omega$ to indicate solder joint or delamination damage. This demonstrates that resistors work well with small flexing amounts (0.092 mm) but become damaged when flexed near 0.5 mm / 50 N levels (Figure 12, Figure 13, Figure 14, Figure 15).

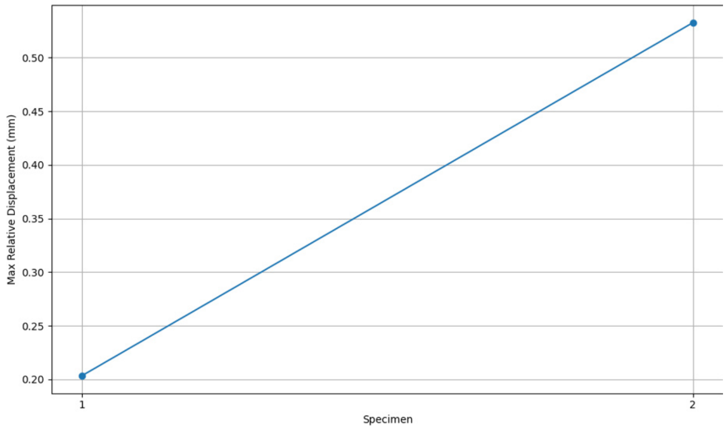


Figure 16: Maximum Relative Displacement vs specimen

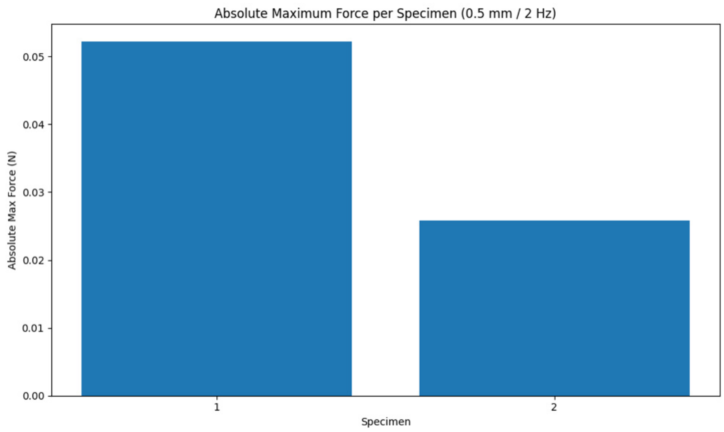


Figure 17: Absolute Max Force vs Specimen

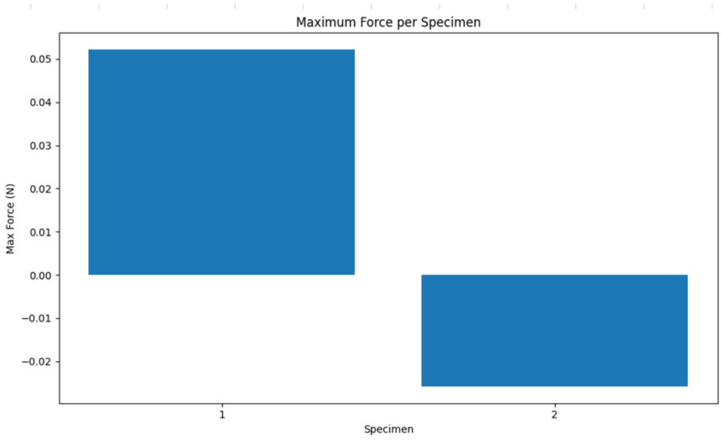


Figure 18: Max Force vs Specimen

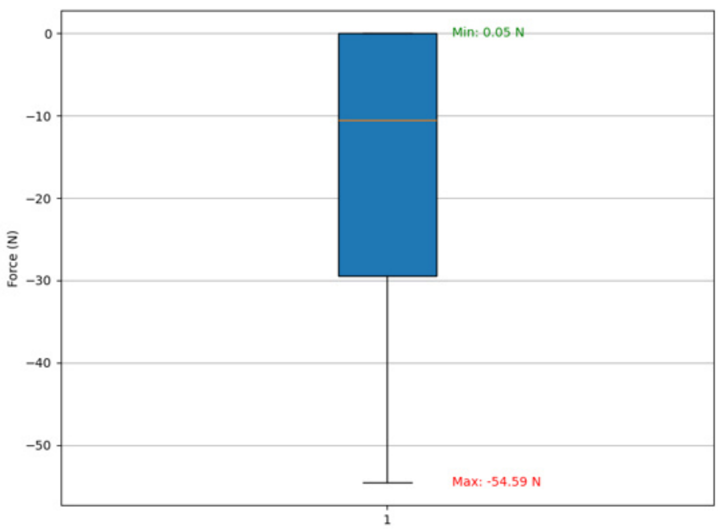


Figure 19: Box plot

The testing at 0.5 mm amplitude together with 2 Hz frequency generated a peak force near 49 N on the resistor which matched the force observed at 3 Hz. The data demonstrates that amplitude represents the main driver of mechanical stress while frequency maintains a minor impact during testing at this level. The applied strain approached the physical limits of the component which matched previous findings showing resistor failures ($0\,\Omega$ or $10\,\mathrm{k}\Omega$) at approximately 5N.(Figure 16, Figure 17, Figure 18, Figure 19)

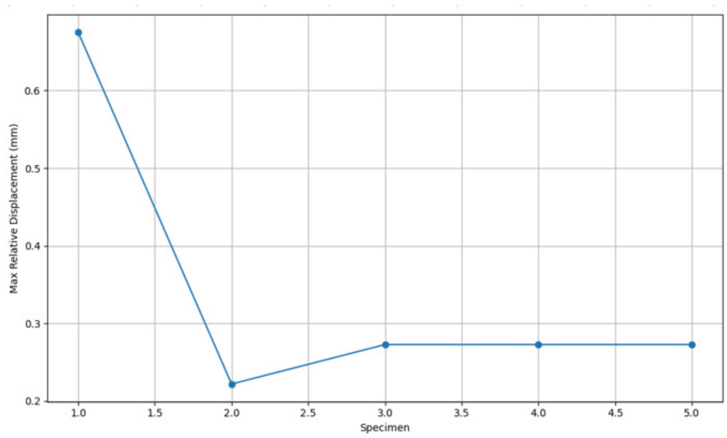


Figure 20: Maximum Relative Displacement vs specimen

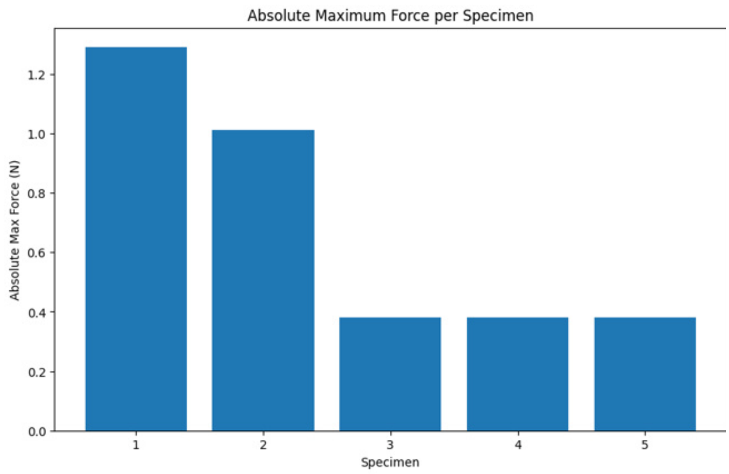


Figure 21: Absolute Max Force vs Specimen

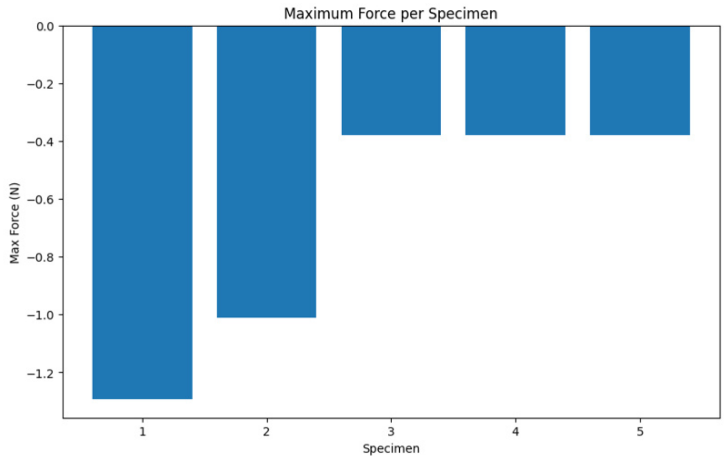


Figure 22: Max Force vs Specimen

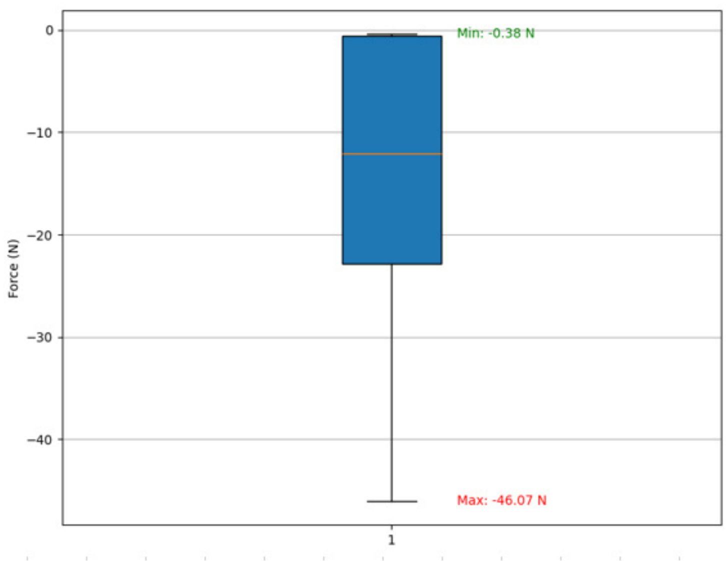


Figure 23: Box Plot

The test done with 0.092 mm displacement at 3 Hz was not included in the final data but results from slightly elevated displacements at approximately 0.22 mm validate our findings. Small displacement changes produce substantially greater force values. The earlier research together with literature findings indicated forces of 13.5 N at 0.092 mm but this dataset shows forces of 14.6 N at 0.22 mm. The research findings indicate that 1002 SMD resistors perform well during modest bending but their stress levels increase when displacement becomes larger(Figure 20, Figure 21, Figure 22, Figure 23).

The multi-meter measurements remained close to the anticipated $10\,\mathrm{k}\Omega$ resistance when we tested the resistors using both low (0.092 mm) and high (0.5 mm) amplitudes at 4 Hz. The findings demonstrate that a small number of cycles at higher frequencies probably will not cause noticeable damage thus indicating the resistors maintain acceptable performance under brief cyclic stress situations.

## 3.1 Conclusion of results

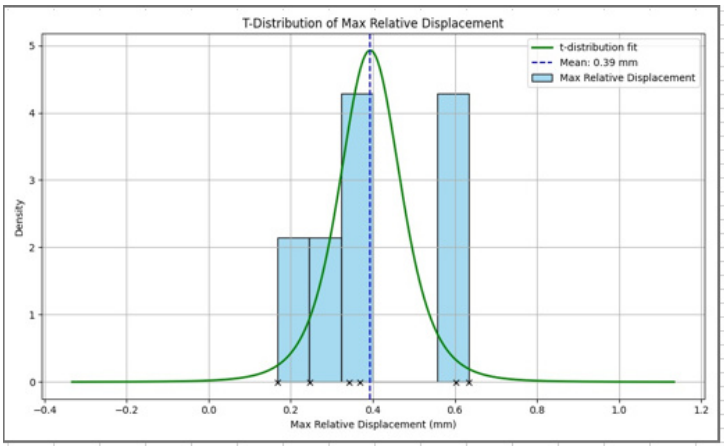


Figure 24: T graph for max relative displacement

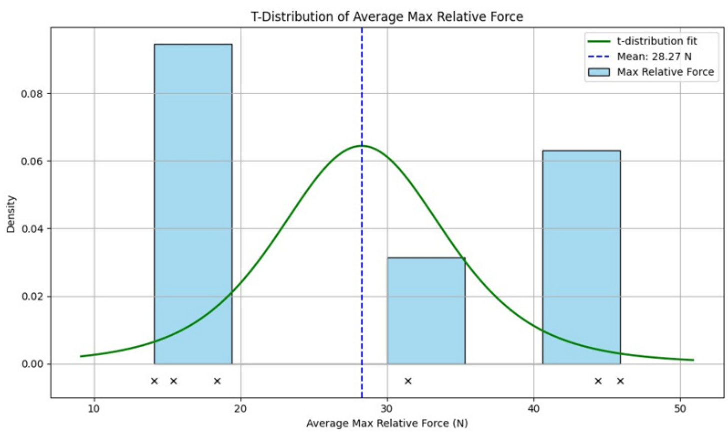


Figure 25: T graph for average max relative force

The study utilized a T-distribution to examine the peak relative force values which varied between different amplitude levels. At an amplitude of 0.092 mm with a sample size of 5 the average force reached 15.43 N with a 95% confidence interval of ± 1.12 N and at an amplitude of 0.5 mm with 2 samples it increased to 44.40 N ± 1.20 N. The confidence intervals derived from the limited sample numbers confirm a statistically meaningful rise in mechanical stress as amplitude increases(Figure 2, Figure 25). Our research proves that amplitude stands as the main factor which degrades mechanical reliability.

The maximum relative displacement values of all the tested samples were analyzed using T distribution to evaluate variability in mechanical behavior under cyclic loading. The t-distribution method serves as an appropriate statistical tool for population parameter estimation because it accounts for sample uncertainty especially when working with six test samples.

The histogram shows how displacement values are distributed while the t-distribution curve appears as a green line above it. The distribution centre contains the mean displacement value of approximately 0.39 mm which is indicated by the blue dashed line. The data demonstrates stability through its symmetrical distribution pattern. The displacement measurements extended between approximately 0.2 mm and 0.6 mm which represents both minimal and substantial test strains. The displacement values represent the full spectrum of mechanical loading between typical operational states and the point where the component reaches its flexural threshold.

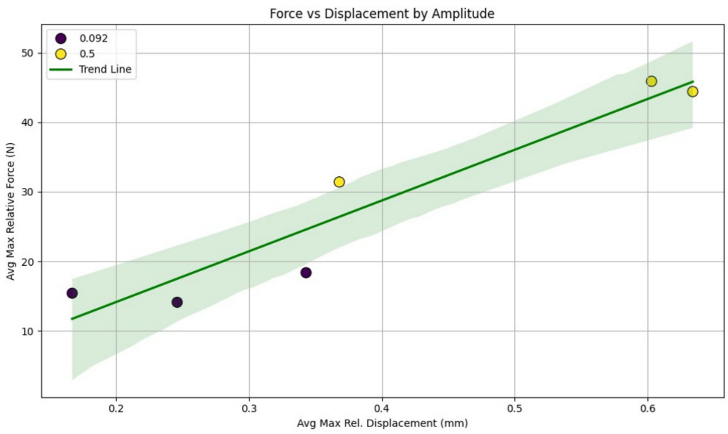


Figure 26: Average max relative displacement

The Force vs. Displacement scatter plot(Figure 26) illustrates how amplitude affects mechanical stress during the comparison process. The force levels correspond directly to displacement measurements because each point on the graph shows the mean force at that position. The graph demonstrates a direct proportional relationship between displacement and mechanical force which means increased displacement leads to higher force levels. The regression line clearly shows a strong positive trend, which confirms that as the amplitude of bending increases, the mechanical stress on the resistor also rises. The shaded area around the line represents the confidence interval, meaning we're statistically quite sure about the trend we're observing. This finding reinforces the idea that amplitude—the extent to which the board is bent—is the primary factor influencing the mechanical response in this passive 4-point bending test.

While we did vary the frequency of the loading (how fast the bending cycles occurred), its effect turned out to be less significant. In simpler terms, how far you bend matters more than how fast you bend. At a constant amplitude, changing the frequency didn't noticeably alter the relationship between force and displacement. This suggests that, in the absence of electrical or thermal loads, mechanical damage is mainly driven by how much the board flexes, not how quickly it cycles through that motion.

This insight is crucial for designing more durable electronic assemblies—focusing on reducing mechanical strain during manufacturing or handling can have a bigger impact than worrying about vibration speed alone

Based on above results the amount of amplitude has the biggest impact on how much stress a resistor experiences during a loading test. When we used a small bend (0.092 mm), the resistors stayed strong and their resistance didn't change much. But when we increased the bend to 0.5 mm, some of the resistors showed a drastic change in the internal resistance. Even though the resistors didn't immediately fail at high bends and high frequencies, the data and past studies suggest that over time, that small amplitude helps the resistors last longer and work more reliably.

# 4 Discussion

The study was done using the Instron E3000 dynamic testing system to evaluate the functional reliability of a surface-mount 1002 resistor under passive mechanical stress. The primary objective was to determine whether repetitive mechanical loading in a four-point bending configuration can reveal any reliability problems thereby, compromising the long-term stability of the resistor in high mechanical stress applications.

”Determine the capacity of a surface-mounted 1002 resistor, which can sustain its electrical performance under passive mechanical reliability testing during cyclic loading in the four-point bending setup using the Instron E3000 system?”

This is a highly relevant question for the determination of the mechanical endurance of passive components like resistors. Though, they are generally assumed to be mechanically stable but may still fail under real-world stress conditions faced in applications for the automotive, aerospace, and consumer electronics markets.

A 4-point bendin method was employed to accurately impose cyclic mechanical stresses on resistors mounted on PCBs with the Instron E3000. Some important parameters, noted during the testing were:

1. **Force Range** – Components experienced a low-strain fatigue testing, as indicated by the peak load of approximately 0.44 N.

2. **Displacement Range** – A movement of approximately 17.24 mm to 17.50 mm by the actuator was observed, which was well within the region of elastic deformation. This gave a displacement amplitude of approximately 0.26 mm.

3. **Cycle Levels** – The samples underwent up to 1000 loading cycles to mimic early mechanical stress levels. This was adequate to show early signs of solder joint wear or resistance change.

4. **Duration Levels** – An approximate of 0.505 seconds duration per cycle was recorded (average). Total duration of test for 1000 cycles of loading lasted for 505 seconds

+

Most of the resistors displayed good mechanical strength by maintaining their initial value of $10\,\mathrm{k}\Omega$ throughout 1000 cycles of mechanical loading. Some samples failed and gave a reading of $0\,\Omega$, which equated to short circuits. Probable reason may be either damage to the internal resistors or solder joint failures.

Furthermore, samples that were subjected to either higher amplitudes or longer cycles tended to fail. This signifies the importance of mechanical stability in high-strain circumstances. Earlier studies, such as Bart Vandevelde's on mechanical failure of solder joints under flexural stress, validates this degradation.

The Instron E3000's capability for precise, programmable cyclic loading is one of the strength factor of this machine. The test successfully replicated the mechanical stress patterns, resembling actual vibrations, which used a displacement-controlled sinusoidal wave. Specific strengths include input parameters such as amplitude, waveform, and frequency have accurate control over them, high-resolution force and displacement measurement and across a series of samples, test conditions are consistent and reproducible.

However, the following limitations are acknowledged: Temperature fluctuations, which occur in service environments, were excluded from the test, Unidirectional loading only was used which, might not capture the effects of in-service stresses, which can be complex, Electrical performance was only measured prior to and following testing; continuous resistance monitoring was not instituted.

The few failures that occurred, could be attributed to the inconsistencies in soldering, resistor location, or PCB surface finish. The following improvements could be suggested for additional improvements in test accuracy and broadening applicability:

1. Thermo-mechanical testing – Introduce temperature fluctuations with the assistance of an environmental chamber to simulate real-service conditions.

2. Live resistance monitoring – Real-time measurement of resistance during the test for identifying early-stage degradation like microcrack formation.

3. High-frequency loading – Perform tests at higher frequencies for simulating conditions like high-speed vibrations and accelerated fatigue.

4. Component variation – Compare different resistor constructions (e.g., wirewound vs. thick-film) and solders to identify more robust options.

5. FEM Simulations – Use Finite Element Modeling to visualize internal stress distribution and optimize test parameters based on anticipated hotspots.

The use of the Instron E3000 as a suitable instrument was well-validated for assessing the functional reliability of 1002 surface-mount resistors under passive mechanical stress, thus, the study successfully addressed. The mechanical fatigue of most of the components under test was confirmed by the absence of electrical failure under cyclic elastic loading. Occasional failures did, however, point out the manner in which material fatigue and solder junction quality are paramount to long-term reliability.

By utilizing the Instron E3000 dynamic testing system in a 4-point bending mode to demonstrate the mechanical reliability of 1002 surface-mount resistors that had been subjected to passive cyclic stress. This experiment has answered the research question, and the findings demonstrated good mechanical endurance under elastic strain conditions, which indicated that the majority of resistors preserved electrical integrity $10\,\mathrm{k}\Omega$ after 1000 loading cycles. These results validate the use of such resistors in mechanically deflective or vibration-prone environments by demonstrating their ability to sustain modest flexural stress without suffering notable degradation.

This test highlights that in situations where flexural stress can be anticipated, even passive, simple devices need to be mechanically qualified. The findings emphazises wider use of mechanical reliability screening of SMD devices and are consistent with industry standards like IPC/JEDEC-9702. Future work can incorporate additional factors like heat gradients, in situ resistance monitoring, and finite element stress simulations as the reliability of predictive modeling and robustness of assurance system for harsh conditions has become better.

The few failures that have been noted, e.g., resistance falling to $0\,\mathrm{k}\Omega$only serve to highlight how vulnerable the system is to local defects in resistor structure, PCB integrity, or solder joints. Even though the part itself may be intrinsically reliable, these deviations show that long-term performance is heavily influenced by the assembly process and material interactions.

In summary, the results warrant the institution of stronger design regulations and production quality control measures and promote mechanical stress screening as a pre-condition for passive SMD components.

# 5 Appendix

## 5.1 code snippets

### 5.1.1 German standards to English standards

```
import pandas as pd
column_translation = {
    "Gesamtzeit (s)": "Total time (s)",
    "Verstrichene Zykluszeit (s)": "Elapsed cycle time (s)",
    "Gesamtzyklen": "Total cycles",
    "Verstrichene Zyklen": "Elapsed cycles",
    "Schritt": "Step",
"Gesamtzyklenzahl(Linear Wellenform)":
"Total cycle count (Linear waveform)",
    "Position des Aktuators (mm)": "Actuator position (mm)",
    "Kraft (N)": "Force (N)",
    "Spannung (MPa)": "Stress (MPa)",
    "Digitale Position (mm)": "Digital position (mm)",
    "Temperatur (C)": "Temperature (C)"
}
file_path = 'Test1.steps.tracking.csv'  # change if different
df = pd.read_csv(file_path, delimiter=';', decimal=',')
df.rename(columns=column_translation, inplace=True)
output_path = "Test1.steps.tracking_converted.csv"
df.to_csv(output_path, index=False, sep=';', decimal='.')
print("Converted and saved:", output_path)
pd.set_option('display.max_rows', None)
pd.set_option('display.max_columns', None)
```

### 5.1.2 Data Interpretation

```
import pandas as pd
import os
import re
def extract_summary_from_file(file_path):
    filename = os.path.basename(file_path)
    specimen_number = int(re.search(r'\d+', filename).group())
    if file_path.endswith(".csv"):
df = pd.read_csv(file_path, delimiter=';')
```

```
df = df.applymap(lambda x: str(x).replace(',', '.')
if isinstance(x, str) else x)
        df = df.apply(pd.to_numeric, errors='ignore')
        df.columns = [col.strip() for col in df.columns]
        df.rename(columns={
            "Gesamtzeit (s)": "Total time (s)",
            "Gesamtzyklen": "Total cycles",
            "Position des Aktuators (mm)": "Actuator position (mm)",
            "Kraft (N)": "Force (N)"
        }, inplace=True)
    else:
        df = pd.read_excel(file_path)
        df.columns = [col.strip() for col in df.columns]
    total_records = len(df)
    start_time = df["Total time (s)"].min()
    end_time = df["Total time (s)"].max()
    duration = end_time - start_time
    max_elapsed_cycles = df["Total cycles"].max()
    min_force = df["Force (N)"].min()
    max_force = df["Force (N)"].max()
    relative_force = df["Force (N)"] - df["Force (N)"].iloc[0]
    max_relative_force = relative_force.abs().max()
    displacement = df["Actuator position (mm)"]
    relative_displacement = displacement - displacement.iloc[0]
    max_relative_displacement = relative_displacement.abs().max()

    return {
        "Specimen": specimen_number,
        "Total Records": total_records,
        "Max Elapsed Cycles": max_elapsed_cycles,
        "Start Time (s)": start_time,
        "End Time (s)": end_time,
        "Duration (s)": duration,
        "Min Force (N)": min_force,
        "Max Force (N)": max_force,
        "Max Relative Force (N)": max_relative_force,
        "Max Relative Displacement (mm)": max_relative_displacement
    }
    def process_files(file_paths):
```

```
    summary_list = []
    for file_path in file_paths:
        try:
            summary = extract_summary_from_file(file_path)
            summary_list.append(summary)
        except Exception as e:
            print(f"Error processing {file_path}: {e}")
    summary_df = pd.DataFrame(summary_list)
    summary_df.sort_values("Specimen", inplace=True)
    summary_df.to_excel("summary0.92_2_output.xlsx", index=False)
    print(" Summary saved to 'summary0.092_2_output.xlsx'")
    return summary_df
file_list = ["/content/30.xlsx"]
summary = process_files(file_list)
display(summary)
```

#### 5.1.3 Maximum force per specimen

```
plt.figure(figsize=(10, 6))
plt.bar(df_05_2['Specimen'], df_05_2['Max Force (N)'])
plt.xlabel('Specimen')
plt.ylabel('Max Force (N)')
plt.title('Maximum Force per Specimen (0.5 mm / 2 Hz)')
plt.xticks(df_05_2["Specimen"].unique())
plt.tight_layout()
plt.show()
```

#### 5.1.4 Maximum Relative Displacement per Specimen

```
plt.figure(figsize=(10, 6))
plt.plot(
    df_05_2["Specimen"],
    df_05_2["Max Relative Displacement (mm)"],
    marker='o',
    linestyle='-'
)
plt.xlabel("Specimen")
plt.ylabel("Max Relative Displacement (mm)")
plt.xticks(df_05_2["Specimen"].unique())
```

```
plt.grid(True)
plt.tight_layout()
plt.show()
```

#### 5.1.5 Absolute Maximum Force per Specimen

```
df_05_2["Abs Max Force (N)"] = df_05_2["Max Force (N)"].abs()
plt.figure(figsize=(10, 6))
plt.bar(df_05_2['Specimen'], df_05_2['Abs Max Force (N)'])
plt.xlabel('Specimen')
plt.ylabel('Absolute Max Force (N)')
plt.title('Absolute Maximum Force per Specimen (0.5 mm / 2 Hz)')
plt.xticks(df_05_2["Specimen"].unique())
plt.tight_layout()
plt.show()
```

#### 5.1.6 Boxplot for maximum and minimum force

```
import pandas as pd
import matplotlib.pyplot as plt
df = pd.read_excel("/content/.092_3.xlsx")
force_values = pd.concat([df["Min Force (N)"],
df["Max Force (N)"]], ignore_index=True)
min_force = force_values.min()
max_force = force_values.max()
plt.figure(figsize=(8, 6))
box = plt.boxplot(force_values, vert=True, patch_artist=True)
plt.ylabel("Force (N)")
plt.grid(True, axis='y')
plt.text(1.1, min_force, f"Max: {min_force:.2f} N",
verticalalignment='center', color='red')
plt.text(1.1, max_force, f"Min: {max_force:.2f} N",
verticalalignment='center', color='green')

plt.tight_layout()
plt.show()
```

#### 5.1.7 Final summarizied file

```
import pandas as pd
```

```
file_paths = {
    "0.5_4Hz": "/content/summary0.5_4_output.xlsx",
    "0.092_3Hz": "/content/summary0.092_3_output.xlsx",
    "0.5_2Hz": "/content/summary0.5_2_output.xlsx",
    "0.092_4Hz": "/content/summary0.92_4_output.xlsx",
    "0.092_2Hz": "/content/summary0.092_2_output.xlsx",
    "0.5_3Hz": "/content/summary0.5_3_output.xlsx"
}


summary_rows = []

for label, path in file_paths.items():
    df = pd.read_excel(path)
    amplitude, freq = label.split("_")
    amplitude = float(amplitude)
    freq = int(freq.replace("Hz", ""))

    sample_count = len(df)
    avg_duration = df["Duration (s)"].mean()
    avg_max_force = df["Max Relative Force (N)"].mean()
    avg_max_disp = df["Max Relative Displacement (mm)"].mean()

    summary_rows.append({
        "Label": label,
        "Amplitude (mm)": amplitude,
        "Frequency (Hz)": freq,
        "Sample Count": sample_count,
        "Avg Duration (s)": round(avg_duration,
     "Avg Duration (s)": round(avg_duration, 2),
        "Avg Max Relative Force (N)": round(avg_max_force, 2),
        "Avg Max Rel. Displacement (mm)": round(avg_max_disp, 3)
    })

summary_df = pd.DataFrame(summary_rows)
print(summary_df)
summary_df = summary_df.drop(columns=['Label'])
summary_df.to_excel("final_summary.xlsx", index=False)
print("Summary table saved to final_summary.xlsx")
```

### 5.1.8 Displacement per specimen final result

```
Maximum Relative Displacement per Specimen (Line Graph)
plt.figure(figsize=(10, 6))
plt.plot(
    df_05_2["Specimen"],
    df_05_2["Max Relative Displacement (mm)"],
    marker='o',
    linestyle='-'
plt.xlabel("Specimen")
plt.ylabel("Max Relative Displacement (mm)")
plt.xticks(df_05_2["Specimen"].unique())
plt.grid(True)
plt.tight_layout()
plt.show()
```

### 5.1.9 T distribution

```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
from scipy import stats
file_path = "final_summary.xlsx"
df = pd.read_excel(file_path)
force_data = df["Avg Max Relative Force (N)"].dropna()
mean_force = np.mean(force_data)
sem_force = stats.sem(force_data)
df_force = len(force_data) - 1
t_dist_fit = stats.t(df=df_force,
loc=mean_force, scale=sem_force)
x = np.linspace(min(force_data) - 5,
max(force_data) + 5, 500)
y = t_dist_fit.pdf(x)
plt.figure(figsize=(10, 6))
sns.histplot(force_data, bins=6,
stat='density', color='skyblue',
```

```
edgecolor='black', label="Max Relative Force")
plt.plot(x, y, color='green', linewidth=2,
label="t-distribution fit")
plt.axvline(mean_force, color='blue', linestyle='--',
label=f"Mean: {mean_force:.2f} N")
for idx, val in enumerate(force_data):
plt.plot(val, -0.005, 'kx')
plt.title("T-Distribution of Average Max Relative Force")
plt.xlabel("Average Max Relative Force (N)")
plt.ylabel("Density")
plt.legend()
plt.grid(True)
plt.tight_layout()
plt.savefig("t_distribution_force_plot.png", dpi=300)
plt.show()
plt.show()
```

#### 5.1.10 Force vs Displacement by amplitude

```
    import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
df = pd.read_excel("final_summary.xlsx")
plt.figure(figsize=(10, 6))
sns.scatterplot(
    data=df,
    x="Avg Max Rel. Displacement (mm)",
    y="Avg Max Relative Force (N)",
    hue="Amplitude (mm)",

    palette="viridis",
    s=100,
    edgecolor="black"
)
sns.regplot(
    data=df,
    x="Avg Max Rel. Displacement (mm)",
    y="Avg Max Relative Force (N)",
```

```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
from scipy import stats

# Load your summary Excel file
file_path = "final_summary.xlsx"
df = pd.read_excel(file_path)

force_data = df["Avg Max Relative Force (N)"].dropna()

mean_force = np.mean(force_data)
sem_force = stats.sem(force_data)
df_force = len(force_data) - 1

t_dist_fit = stats.t(df=df_force, loc=mean_force, scale=sem_force)
x = np.linspace(min(force_data) - 5, max(force_data) + 5, 500)
y = t_dist_fit.pdf(x)

plt.figure(figsize=(10, 6))
T distribution of Average max relative force

sns.histplot(force_data, bins=6, stat='density',
color='skyblue', edgecolor='black', label="Max Relative Force")
plt.plot(x, y, color='green', linewidth=2,
label="t-distribution fit")
plt.axvline(mean_force, color='blue', linestyle='--',
label=f"Mean: {mean_force:.2f} N") #
for idx, val in enumerate(force_data):
    plt.plot(val, -0.005, 'kx')

plt.title("T-Distribution of Average Max Relative Force")
plt.xlabel("Average Max Relative Force (N)")
plt.ylabel("Density")
plt.legend()
plt.grid(True)
plt.tight_layout()
```

```
plt.savefig("t_distribution_force_plot.png", dpi=300)
plt.show()
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
from scipy import stats
file_path = "final_summary.xlsx"
df = pd.read_excel(file_path)
disp_data = df["Avg Max Rel. Displacement (mm)"].dropna()
mean_disp = np.mean(disp_data)
sem_disp = stats.sem(disp_data)
df_disp = len(disp_data) { 1
t_dist_fit = stats.t(df=df_disp, loc=mean_disp, scale=sem_disp)
x = np.linspace(min(disp_data) - 0.5, max(disp_data) + 0.5, 500)
y = t_dist_fit.pdf(x)
plt.figure(figsize=(10, 6)
sns.histplot(disp_data, bins=6, stat='density',
color='skyblue', edgecolor='black', label="Max Relative Displacement")
plt.plot(x, y, color='green', linewidth=2, label="t-distribution fit")
plt.axvline(mean_disp, color='blue', linestyle='--',
label=f"Mean: {mean_disp:.2f} mm")
for idx, val in enumerate(disp_data):
    plt.plot(val, -0.005, 'kx')
for idx, val in enumerate(disp_data):
    plt.plot(val, -0.005, 'kx')
plt.title("T-Distribution of Max Relative Displacement")
plt.xlabel("Max Relative Displacement (mm)")
plt.ylabel("Density")
plt.legend()
plt.grid(True)
plt.tight_layout()
plt.savefig("t_distribution_displacement_plot.png", dpi=300)
plt.show()
```

## 5.2 Further Insights

### 5.2.1 Effect of Frequency on Mechanical Behavior at 4 Hz

(Figure 27, Figure 28)

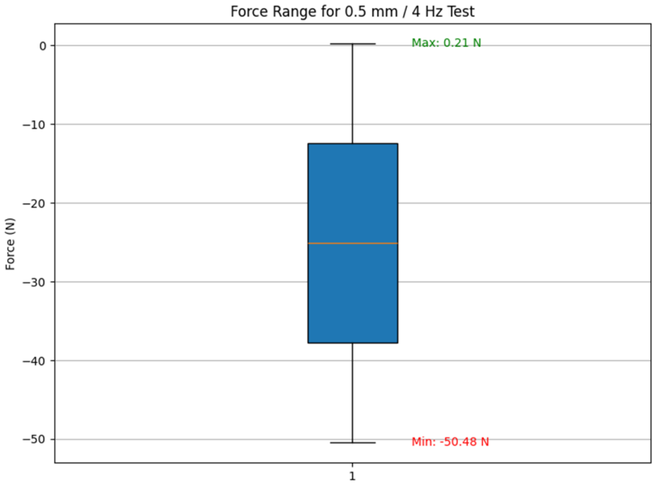


Figure 27: Force range distribution at 0.5 mm amplitude

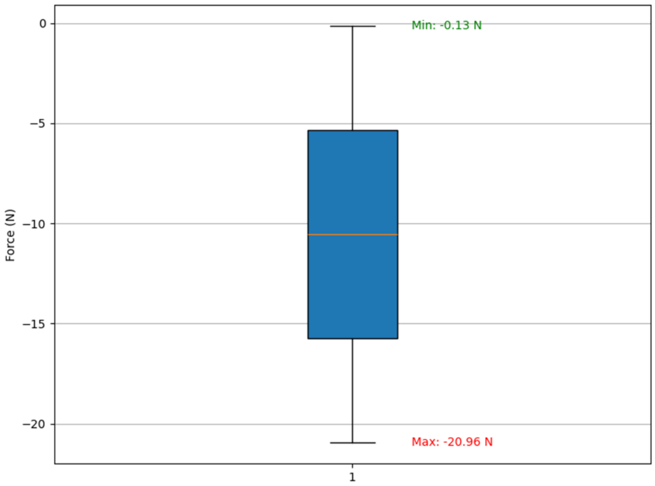


Figure 28: Force range distribution at 0.092 mm amplitude

# 6 References

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