DESIGN OF MULTIFUNCTIONAL CYCLIC BENDING AND CYCLIC STRETCHABILITY TEST RIG FOR STRETCHABLE CONDUCTIVE INK

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ABSTRACT: The reliability of flexible and stretchable printed circuit using conductive ink is important due to rapid growth of technology and demands of flexible and stretchable electronic products. The reliability assessment of the stretchable conductive ink (SCI) are important to ensure high functionality and durability over the designated operation lifetime. Thus, the development of cyclic bending test and cyclic stretchability test rig is required to investigate the functionality SCI under repeated loadings. The developed test rig has three main parts which are the movable end arm, adjustable fixed end arm and data gathering. The movable end arm is moving with help from stepper motor which controlled by power supply. Furthermore, the position of adjustable fixed end arm can also be adjusted according to the experiment percentage of stretchability. The test rig is attached with LCR meter to measure the resistivity of the printed circuit and the results are fully monitored by using computer. The development of multifunction reliability test rig for SCI in this project is able to offer a compact, simple and precise results based on the IPC 9204 test requirements.

KEYWORDS: *Stretchable Conductive Ink; Test Rig; Cyclic Bending Test; Cyclic Stretchability Test*

1.0 INTRODUCTION

The world economic growth leads to the technological advances that result in progress of future devices which more complex compares to the past technology. This kind of growth lead to the advance electrical and electronic devices in producing product based on consumer demands. Everything need to be simple, compact and futuristic in achieving consumer's requirement [1]. Towards the future technology, printed electronic devices is periodically growing stronger due to time saving and cost effectiveness [2]. The growth of flexible and stretchable printed electronic devices also leads to elimination of lengthy, material intensive and expensive old manufacturing process [3].

The flexible and stretchable printed circuit is the advanced and alternative way to develop electric circuitry instead using traditional printed circuit board (PCB). The traditional PCB is good but the rigidness of board limiting its application for non-curvy shape product only. This is the purpose of introducing flexible and stretchable substrate with conductive ink, to replace the rigid PCB, in order to allow higher degree of shape flexibility. The component can operate in many conditions, such as when bend, twist and stretch, without degrading the electrical performance.

In order to achieve the best performance, the flexible and stretchable printed circuit with conductive ink must be defect free and have good adhesion between substrate and the ink as well as the mounted components especially to ensure the circuitry can withstand all the loads (bending, vibration, thermal, shock and stretching) during application [4]. During operation, the component is also subjected to similar load but with repeated or cyclic conditions, such as cyclic bending loads. Stretching and cyclic loadings required the assessment of the performance in term of its reliability. Among the study conducted in assessing the reliability performance is through cyclic bending and cyclic stretchability tests, in order to handle the intrinsic problem in increase of resistivity and lack of adhesion between the ink and the substrate [5, 11-13].

However, dedicated test facility to perform such examinations is still limited, and often required the design and fabrication of customized cyclic bending and cyclic stretching test rig. This paper is aimed to develop a new customized test rig capable of performing cyclic bending and cyclic stretchability tests to check the reliability of the flexible and stretchable printed circuit with conductive ink, in term of resistivity and adhesion performance. The cyclic bending and cyclic stretchable tests are fundamental to eliminate the limitation of the printed circuit [6]. The test rig development process involved product design specifications, and creating design solution and producing detail design of the test rig. The detail design includes schematic diagram, 3D CAD modelling and test measurement electrical circuitry.

2.0 METHODOLOGY

2.1 Product Design Specifications (PDS)

PDS is purposely done to specify the requirement of the product design [7]. It to ensure the design and development of product meets the specification given. Table 1 shows specification need to be meet by the manufacturer in developing the test rig.

Table 1: Product design specification of cyclic bending and stretchability test rig

Product design specification	
Cyclic bending and cyclic stretchability test rig	
No.	**Requirements**
1	Performance
	1.1 Able to do cyclic bending and stretchability movement
	1.2 Able to collect data automatically
2	Dimension
	2.1 Maximum height: 150mm
	2.2 Maximum width: 600mm
	2.3 Maximum length: 900mm
3	Weight
	3.1 Total Weight: 10kg
4	Material
	4.1 Material should be lightweight and corrosion resistance
5	Standard and Specifications
	5.1 Follow Standard IPC 9204
6	Safety
	6.1 The wiring is well insulated
	6.2 Stepper motor is fully covered
7	Ergonomics
	7.1 Simple and easy to use
8	Cost
	8.1 Low fabrication cost
	8.2 Minimum maintenance cost

According to Association Connecting Electronics Industries (ACEI), the guideline on flexibility and stretchability testing for printed electronics have been introduced in detail in the IPC 9204 [8]. This standard is followed precisely in developing the test rig. In this study, the test rig produced is multifunctional which it can do cyclic bending test and cyclic stretchability test within the same equipment. For cyclic bending test, the standard is according to Section 7, bending test principles for printed electronics, and the details test procedure is referred to Subsection 7.3 which is free arc bending test. This test can be used to evaluate the functionality of the printed electronic devices under repeated bending conditions with variable bending radius. Next for cyclic stretchability test, the standard is according to Section 6 which is stretchability testing principles for printed electronics, the procedure and requirement for testing is referred to Subsection 6.2 which is cyclic stretchability test. This test method can be used to verify if a stretchable printed electronics device can withstand repeated elongation cycles under tensile load. Figure 1 shows the diagram set up to hold the circuit or specimen for testing.

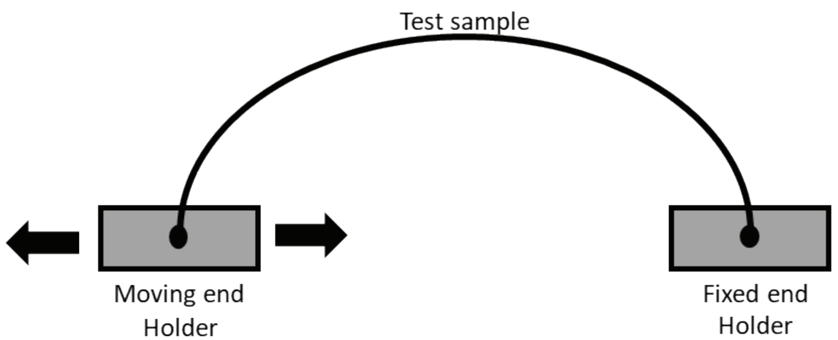

Figure 1: Setup of specimens according to IPC 9204 guideline

During test, the specimen is affixed to two holders at the same horizontal level. One holder is stationary, while the other one is movable. By moving back and forth the movable holder, the specimen can be bent in constantly changing bending radius with repeating cycles. The test needs to be monitor the functionality or resistance of the circuit before and after testing. For cyclic stretchability test, the fixed end holder is modified to be adjustable to make it suit with the second testing. According to IPC 9204 [8], the setup of the specimens precisely the same as free arc bending test which one holder fixed and the other one movable but the different is the specimens is stretch repeatedly. In this case, the stretchability percentage of the specimen will be control before conducting experiment. Therefore, the test specimens will experience the stretched when the movable holder moving back and forth.

2.2 Detail Design of Test Rig

The test rig can be divided into three parts which is movable end arm, adjustable fixed end arm, and data gathering. Every part of rig has its own functions and crucial for this system. The complete schematic diagram of system of test rig is shown in Figure 2. The diagram shows a detail connection between three parts of the test rig. Power supply is used to control the current flow inside the stepper motor which it will results to the speed of movable end arm movement.

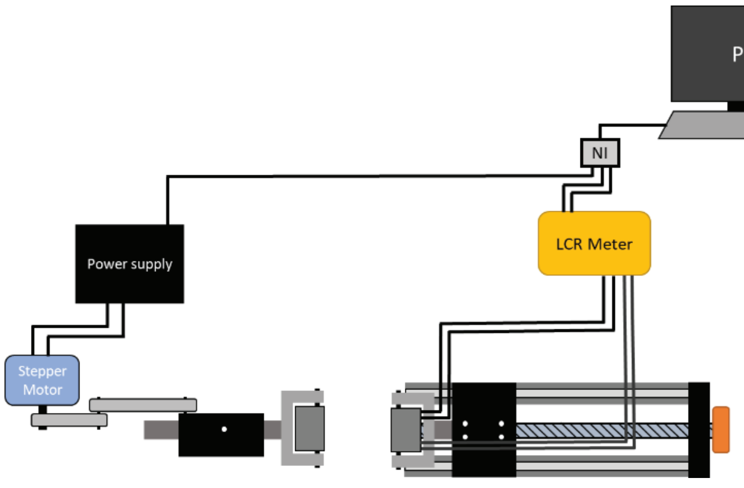

Figure 2: The complete schematic diagram of test rig

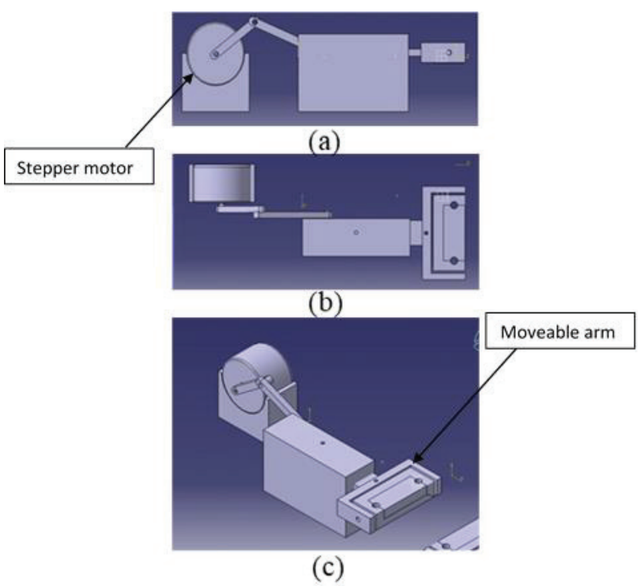

Figure 3: 3D CAD of movable end arm attached with stepper motor: (a) side view, (b) top view and (c) isometric view

The used of stepper motor is needed to help the movement of the arm. In this case, some arrangement need to be done to change the rotational movement stepper motor into translation movement of the movable end arm. The concept of the movement is same as crankshaft and piston in the engine, piston moves back and forth results from rotational movement of crankshaft. The overall 3D picture of movement end arm can be seen in Figure 3. As can be seen in the Figure 3, there have two connectors between stepper motor and movable end arm. these connectors play a rolled to change the rotational movement of stepper motor to translation movement of movable end arm.

The speed of movable end arm can be controlled by adjusting the voltage input into stepper motor. The recommended condition of stepper motor for the testing is speed, 4.2 seconds cycling time or 0.24 Hz cycling frequency. This variable will be controlled using LabView software by connecting it to computer through national instruments device.

For adjustable fixed end arm, some modification had been done to make it multifunction test rig for conductive ink testing. For information, the focus of this arm is to hold the specimen at a fixed position while conducting the test. This arm also attached the measurement electrode to get the real-time resistance reading of printed circuit while testing. The connection of electrode between fixed end arm and LCR meter is shown in Figure 2. The complete 3D design of adjustable fixed end arm is shown in Figure 4.

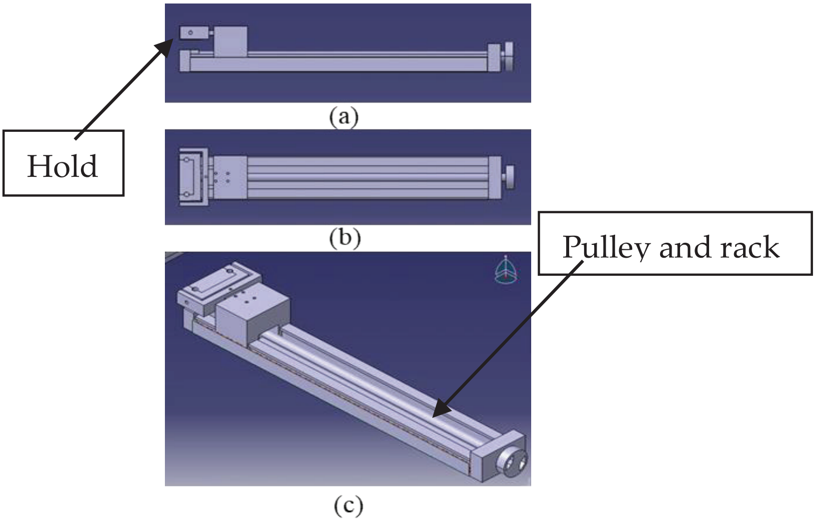

Figure 4: 3D CAD of adjustable fixed arm: (a) side view, (b) top view and (c) isometric view

As shown in Figure 4, there has a pulley at the opposite of specimen holder. The function of the pulley is to adjust the position of the holder. When pulley is rotated, the fixed holder will be moved back and forth depends on direction of rotation. This action involved the mechanical movement from rotation to translation movement that make the fixed end move. The position of fixed end arm is depending on percentage of stretchability of the conductive printed circuit. The metre rule also been attached on the side of this part to be a reference while repositioning the fixed holder according to percentage of stretchability defined.

In data gathering part, device involved is LCR meter. LCR meter can be used to measure the inductance, capacitance and resistance of printed circuit at various frequencies. The reading of resistance is the most important variable to be measured in this study, the inductance and capacitance is additional input that can be obtained for further study about electrical behaviour of the printed circuit. In this development of test rig, the LCR meter used is type HIOKI 3522-50 LCR Hi-Tester [9]. This device will be controlled by using LabView that monitored by computer. Due to small specimen, the LCR meter used to measure resistance with 1V test signal at direct current (DC). This type of LCR meter used Kelvin Connection method to measure the test current towards conductive ink. This method is established by 4 measurement leads attached to the adjustable fixed end arm. It enabled a 4-point measurement method of resistance as shown in Figure 5. It consists of 4 leads which is high force, high sense, low sense and low force lead. In addition, the function of force lead is to feed the test current through a specimen under testing while sense lead is to measure the voltage over the specimen tested.

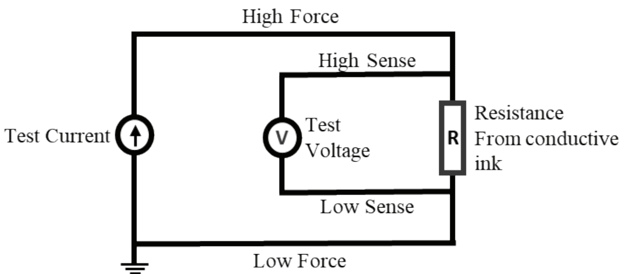

Figure 5: Kelvin Connection consists of high force, high sense, low sense and high force which complete the 4-point measurement in LCR meter

Furthermore, sense leads of kelvin connection does not carry current due to the high input impedance of voltmeter [10]. Thus, it will give an accurate definition of the resistance of a resistor under measurement by Ohm's law. The main three parts of the test rig have been discussed in section. The functionality of each part is unique and different from each other. By using this test rig, the cyclic bending and stretchability test can be conducted easily.

3.0 DESCRIPTION OF PROPOSED DESIGN

3.1 Mechanism of Operation

The cyclic bending and stretchability test rig is easy to use, the mechanism of operation is simple. This test rig involved three external components which is power supply, LCR meter and computer. Before running the test, the components stated need to switch ON. Then, printed circuit that been prepared for the test need to clip on the holder of movable end arm and adjustable fixed end arm. The printed circuit terminal must be attached with electrode of LCR meter which is high force, high sense, low sense, and low force electrode. In this experiment, it involved the cyclic bending test due to PET substrate. Next, the input stepper motor of movable end arm need to be setup in LabView software by setting the power input to the motor. For this test, the stepper motor is setup to 4.2 seconds cycling time or 0.24 Hz cycling frequency. Then, start the test. When the test is running, the movable end arm will move back and forth, result in repeated bending arc towards the specimen. Every cycle of the test, the data obtained by LCR meter is recorded in LabView. The data obtained is time against resistance. The functionality of the test rig is as shown in Table 2.

Table 2: The function of test rig

Functionality	Check
ON/OFF	/
Arm move	/
Adjustable arm	/
Resistivity Reading	/
Speed	/

The test rig is completely functional, it can be switch ON and OFF. When the switch is ON, the speed of stepper motor need to be set before start the test. The speed of stepper motor can be adjusted by controlling the power supply enter stepper motor. The adjustable fixed arm can be adjusted to fit with the testing. For stretchable specimens, the adjustable fixed arm can be adjusted according to percentage of stretchability of the experiment by rotating the pulley. Then, the movable end arm will start to move when the test is start. The arm moving back and forth while the test is running. During the test, the resistivity reading of specimen will be measured by LCR meter and the data is recorded. The data obtained is real-time result during the testing. After finish the test, the data can be taken in .csv format from the computer. The data is ready to be analysed and discussed for further study about the printed conductive ink. Lastly, after completely using the test rig, turn OFF the machine and computer of the test rig. From the testing, the resistance behaviour of the printed circuit is observed. From the data obtained, the prediction of lifetime printed circuit can be done. Therefore, the test rig is valuable to the electric and electronic industry since it gives result of reliability of the printed circuit. Printed circuit need to be durable and low resistance, if the industry wants to commercialize it to the market.

3.2 Advantages of Design Test Rig

The cyclic bending and cyclic stretchability test rig is 2 in 1 test machine which undergo two types of test. The modification made toward adjustable fixed end arm is to make the test rig fit with both type of testing. Adjustable fixed end arm can be adjusted to stretch the sample according to the percentage of stretchability decided. During the test, the LCR meter will detect the changes in resistance against time. Data recorded is in real-time data obtained while conducting the test. Besides, the test rig also can be used to test the capacitance and inductance of the printed circuit if necessary because the LCR meter used can measure three type of parameters which is inductance, capacitance and resistance. In addition, this test rig is compact, simple and precise. It said to be compact and simple because it can conduct two types of test with using this test rig. The functionality of the test rig is also precise because this machine is developed by following standard IPC 9204 [8] which the method of experiment is undeniable and follow the standard. The data recorded by the test rig also precise and accurate because the LCR meter can measure up to 4 decimal places which it can detect even slight changes of resistivity of printed circuit.

4.0 CONCLUSION

This paper is successfully demonstrated the development of multifunction test rig for printed conductive ink circuit. The cyclic bending test and cyclic stretchability test can be conducted by using the test rig. The development of the test rig followed the requirements as designated by the Association Connecting Electronics Industries (ACEI) IPC 9204 standard for flexibility and stretchability testing of printed electronics. The data collection for the system is done using HIOKI 3522-50 LCR Hi-Tester due to its capability to provide precise measurement up to 4 decimal places. It is suitable device to measure the resistivity of conductive printed ink since it can measure even slight changes of resistivity inside the printed circuit.

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