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A two-scale force sensor for power device wire-pull test

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Abstract

This paper presents a new method for the power device wire-pull test. Our method measures the pull force through measuring the displacement of a movable member suspended by a compliant mechanism. The compliant mechanism is specially designed to have two different stiffness values in its workspace. The low stiffness is used for small force measurement while the high stiffness is for larger force. The major advantage of this method is that it can measure large range pull force with different scales in one setup.

1 Introduction

Wire-pull tests are an important operation in the power device wire bonding process, where bonding strength needs to be evaluated. The strength of different types of bonding is much different due to variety of wire materials and diameters, normally ranging from several mN to several tens of Newton. Operators often need to change over cartridges to cater for different wires, thus resulting in a low throughput in the process. Therefore, there is a strong demand in industry for the force measurement devices with a large range and a high resolution.

Conventional force measurement techniques exist the following drawbacks: i.e. their resolutions depend on the measuring range. They are used either for micro range or for macro range due to the limitation of single resolution. When an application includes both micro and macro force measurements, different force cartridges change-over are often needed.

Our method measures an external force through measuring the displacement of a movable member suspended by a compliant mechanism. We specially design the compliant mechanism to have two different stiffness values in its workspace. The low stiffness is used for small force measurement while the high stiffness is used for larger force measurement. Due to adopting different stiffness scales for the different force ranges, the force measurement with a high resolution is therefore achieved.

2 Force sensor system

Our force sensor system consists of a double compound parallelogram flexural mechanism (CPFM) and a grating-based displacement measurement unit as shown in Figure 1. The movable plate in CPFM is linked to the base frame through two sets of leaf-spring flexures (named respectively flexural joint A and flexural joint B) connected serially. Joining the two sets of flexures is an intermediate plate. A probe is attached on the movable plate to interface with the external force.

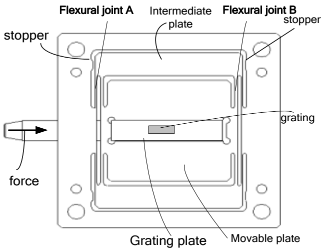

Figure 1: Force sensor system

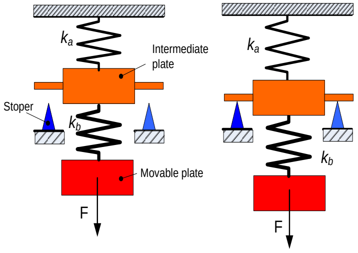

Figure 2: Movable plate kinematics model

The displacement measurement unit includes a grating plate (scale) and a detecting head. The grating plate is mounted on the movable plate while the detect head is fixed on the base frame. A merit of adopting grating scanning technique is that the displacement signal is digital, which is immune to the outside electromagnetic noise, therefore allows a more stable and precise force measurement.

3 Stiffness analysis

The elastic-kinematics model of the movable plate can be simplified as shown in Figure 2. The movable plate movement includes two phases. The first phase is from the balance position (or original point) to the position that the intermediate beam touches the stopper which is part of the base frame. The second phase starts from the position of the intermediate beam touching the base frame until the movable plate reaches its linear motion limit. The stiffness of the movable plate in phases 1 and 2 can be calculated respectively by

$$k_1 = \frac{k_a k_b}{k_a + k_b}, \text{ and } \quad k_2 = k_b \tag{1}$$

where k_a and k_b are overall stiffness of the flexural joints A and B. The value of k_a and k_b in the linear range can be calculated by [2]

$$k_{a\ or\ b} = 0.5Ew(h/l)^3 \tag{3}$$

where E is young's module, w, h and l is the width, thickness and length of the leaf spring, respectfully. Referring to Figure 3, if the stiffness of the movable plate is known, the applied force F will be obtained from

$$F = k_1 d \text{ when } F \leq F_0 \text{ or } d \leq d_0 \tag{4}$$

$$F = k_1 d_0 + k_2 (d - d_0) \text{ when } F > F_0 \tag{5}$$

where d is the displacement of the movable plate with respect to the balanced position, d_0 is the displacement that the intermediate beam moves until touching the stopper. Obviously, the small force will be expressed by (4) whereas the large force is expressed by (5). The force resolution change is force-dependent. If the displacement resolution is Δ, it will be $k_1\Delta$ for the small force or $k_2\Delta$ for the large force.

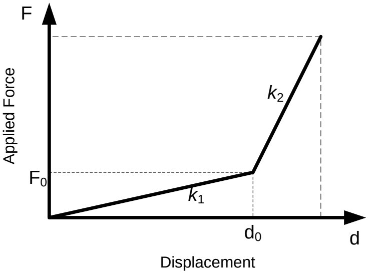

Figure 3: Force-displacement profile

Figure 4: Pull testing with the force sensor

4 Prototype, calibration and pull test

The double CPFM is made of AL7075, and overall dimension is 30 x 30 x 10 mm. The leaf-spring flexure parameters are: w = 10 mm; h = 0.31 mm and l = 10 mm for joint A, w = 10 mm; h = 0.51 mm and l = 10 mm for joint B. The displacement sensor uses a Micro-E M3500 encoder [3], which consists of a read head and a grating scale. The calibration for the force sensor is conducted through a set of standard weights and a laser interferometer (Renisaw, RLD 10). A total of 100 points within the range of 0 to 1 kg are measured, and a lookup table is then generated. The reading of other points between two calibrated points is obtained through linear interpolation.

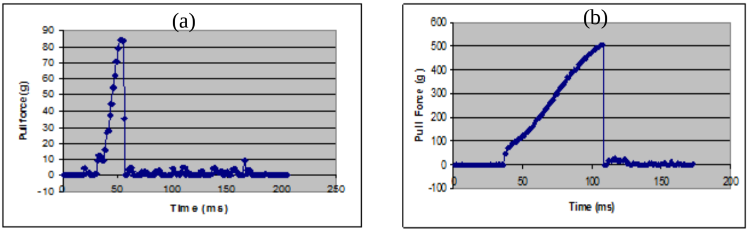

Figure 5: Pull force profiles: (a) wires of ø 20 µm, (b) wires of ø50 µm

The force sensor was applied to measure the AL wire bonding strength of a power device as shown in Figure 4. There are two types of AL wires on the device. One has a diameter of 20 µm and another has a diameter of 50 µm. According to the requirement, the force resolutions of the first type and the second type of wires should be 0.2g and 1.0g, respectively. Conventional pull testers generally need two force cartridges to complete such tasks.

Thanks to our force sensor's two-resolution feature, two pull tests are implemented consequentially without extra setup needs. Pull force profiles of the two wires are illustrated in Figure 5. In the pull test of the first type wire, the force sensor shows a nominal break force of 84.0g with a force resolution of 0.09g. In the pull test of the second type wire, the force sensor gives a nominal break force of 500.2g with a force resolution of 0.4g. The force profiles and nominal break force values obtained from our force sensor agree with the results obtained from a commercial tester of the XYZTEC Co.

References:

[1] US patent, No. 2008/0053249 A1, "Force-measuring device and reference unit," Aug 28, 2007.

[2] Stuart T. Simth, *Flexure: Elements of Elastic Mechnisms,* Gordon and Breach Science Publishers, 2000.

[3] US patent No 5165045, "Method and apparatus for measuring displacement having parallel grating line," Oct 10, 1991.