Research on Mechanical Constitutive Model of Fuzz Button Connector

Ran Huang[1], Zhigang Kong[1],*, Baoyou Wang[2], Lei Zhang[3], Ming Zhu[2], Fan Yang[2] and Xinhang Li[4]

[1]Research Laboratory of reliability of electrical connection and connector, Beijing University of Posts and telecommunications, Haidian District, Beijing, China
[2]China Electronics Standardization Institute, Dongcheng District, Beijing, China
[3]AVIC Optoelectronics Technology Co., Ltd, Luolong District, Luoyang City, China
[4]Beijing University of Posts and telecommunications, Haidian District, Beijing, China

*Corresponding author email: zgkong@bupt.edu.cn

Abstract. In this paper, the mechanical constitutive model of fuzz button connector was studied from a theoretical perspective. Based on the structure of the fuzz button, the spatial configuration and contact mode of the metallic protofilament were analyzed, and the meso structural unit of the single metallic broken-line segment based on the simply supported beam structure was proposed. From meso to the unit structure, the constitutive model of the fuzz button connector subjected to a certain compressive load was derived. Some basic parameters such as the diameter and the elastic modulus of the metallic protofilament, relative density of the fuzz button, the length and winding angle of broken-line segment, which were all included in the model. It fills the blank of the mechanical research of the fuzz button connector, and provides a theoretical basis for further research on the mechanical characteristics of the fuzz button connector and guiding the practical application.
Keywords: Fuzz button; Constitutive model; Metallic protofilament; Simply supported beam.

1. Introduction

With the advent of the 5G era and the rapid development of the wireless communication field, the problems of signal transmission quality, skin effect, and device miniaturization have become increasingly prominent, therefore, it is needed for a new type of electrical connector which has an ideal signal transmission effect and is easy to use and maintain. The fuzz button connector is pre-processed by a very thin metallic wire, randomly wound and then pressed to form. Finally, after tempering and plating, a cylindrical connector with a certain diameter and length is formed, as shown in Figure 1. Due to its random winding, small size, elasticity and other structural characteristics, it has broken the mutual induction effect of the signal inside the connector. Reduced the transmission signal path length and the skin effect of high-frequency signals. Multiple signal paths are created internally to form a "redundant" transmission with higher reliability. And the signal can pass the shortest path, reducing distortion, resistance, inductance, which is conducive to the transmission of high-frequency signals. Finally, due to the elasticity of the fuzz buttons, it is possible to realize the elastic connection of the end face without welding.

Figure 1. Fuzz button connector.

At present, there are few researches about fuzz buttons and most of them are focused on electromagnetics. Harris[1] explores the reliability of fuzz button connectors from an experimental perspective. Pan[2] found the transmission line model of the fuzz button connector, and Cater[3] verified the application of the fuzz button connector in the microwave field. However, there are few studies on fuzz button connectors in China. The current researches are mainly concentrated in the field of electromagnetic applications[4-6], and in terms of mechanical properties, Rui Zhang[7] and Xuguang Guo[8] summarized the mechanical properties of the fuzz button connector through experiments, and proposed that the fuzz button has three states during compression: no contact, sliding contact and squeezing contact. Therefore, from the theoretical point of view, the research on the relationship between the structural parameters and mechanical properties of the fuzz button connector, that is, the constitutive relationship is still in the exploratory stage.

In this paper, starting from the main characteristics of the change of the metallic protofilament during the compression deformation of the fuzz button connector, then the simply supported beam is introduced to simulate the meso structure of the fuzz button connector, at last the modified parameters are proposed according to the structural characteristics of the fuzz button disorderly winding. By these deriving a constitutive model that reflects the mechanical properties of the fuzz button connector when it is subjected to a compressive load between the circuit boards.

2. Mesoscopic Deformation Model of Fuzz Button

2.1. Theoretical Assumptions and Determination of Research Objects

The fuzz button are wound and compressed by the metallic protofilament. The partial enlarged view is shown in Figure 2. In processing and manufacturing, the metallic protofilament is processed and bent into a metallic broken line, and then randomly winded, at last compressed into a fixed shape. The metallic line as shown in Figure 3. It is not difficult to find from Figure 2 and 3 that the fuzz button can be regarded as being constituted by a series of broken-line segments, which at an angle to the forming direction, which are in contact with each other and intertwined with each other. The elastic deformation force and the interaction force between the broken lines jointly determine the compression performance of the fuzz button connector. Because the structure of the fuzz button connectors, which currently produced and used, is extremely small, it is difficult to macroscopically define the internal force between the fuzz buttons. Therefore, it is necessary to establish a meso-structure model so that it can accurately summarize the interaction force between broken lines on a certain scale.

Figure 2. Fuzz Button connector partially enlarged.
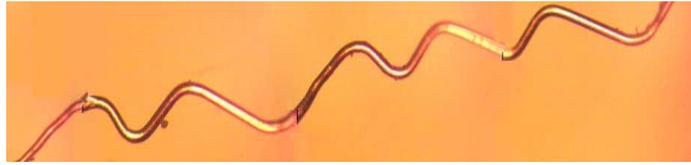
**Figure 3.** The metallic broken line is enlarged.

Due to the random winding between the broken lines which constituting the fuzz button connector, the research on the internal structure of the fuzz button has always been difficulted. Therefore, it is necessary to make some basic simplified assumptions for the fuzz button connector. Assumptions are as follows:

①The broken-line segment which is the basic component of the button connector is regarded as a simply supported beam with the diameter d and the length L_0 . And it is assumed that in the process of compression load, only one contact point is formed on each broken-line segment.

②The broken lines are randomly distributed, and there is no friction between the broken lines, and only elastic deformation occurs.

③During the compression process, the compression deformation of the fuzz button mainly comes from the bending deformation of the broken line, ignoring the axial deformation and torsional deformation of the broken line.
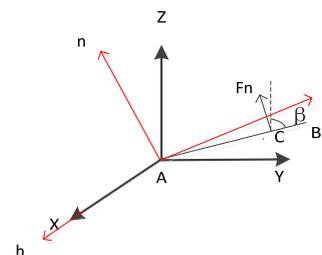
Combining the above assumptions, the paper proposes a meso-deformation model of fuzz button. Firstly, a single broken-line segment is taken as the research object, and the broken line is divided into several broken-line segements, which is seen as simply supported beam, then the fuzz button is equivalent to a compound body, which is formed by a series of simply supported beams connected in series and parallel. The process of bearing the compression load of the fuzz button is regarded as the process of bending deformation of the simply supported beam at the contact point, which forms the mechanical characteristics of the fuzz button connector.

2.2. Equivalent Stiffness of Simply Supported Beam

Combining the processing technology and theoretical assumptions of the fuzz button connector, the broken line is simplified into a broken-line segments of equal length, as shown in Figure 4. Determine that the AB broken-line segment in the spatial position is the research object, and the two ends of A and B are equivalent to the fixed end of the hinge of the simply supported beam, another broken-line segment are in contact with this segment at point C, point C is stressed, and point C is randomly distributed on AB.
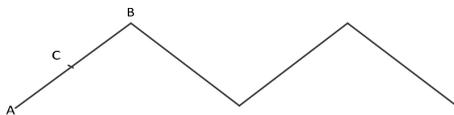

Figure 4. Simplified broken line model.   **Figure 5.** Spatial force model of folded-line segment.

The force model of the metal folded-line segment AB in the overall three-dimensional coordinate *Axyz* and the local coordinate system *Ahin* is shown in Figure 5. The metallic broken-line segment is located in the *hi* plane, and the angle with the *Z* axis is β, where AB is fixed at two points, and point C receives the force F_n along the *n* direction.

The load diagram of the broken-line segment in the *hi* plane, as shown in Figure 6, the length of the broken-line segment is L_0, the distance between the force point and the left endpoint is a, and the other is b.
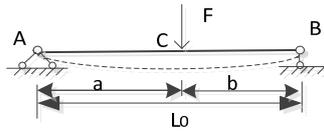
Figure 6. Load distribution on beams in the *hi* plane.

From the Castigliano second theorem[9]:

$$U = \int \frac{M(x)^2}{2EI} dx \tag{1}$$

$$W = \frac{1}{2} P \Delta n \tag{2}$$

According to the principle of function conversion, U=W, the *n*-direction deformation of the broken-line segment AB is derived:

$$\Delta n = \frac{Fab}{6EIL_0}\left(L_0^2 - a^2 - b^2\right) \tag{3}$$

The broken-line segment AB stiffness:

$$K_n = \frac{6EIL_0}{ab\left(L_0^2 - a^2 - b^2\right)} \tag{4}$$

Where *I* is the moment of inertia of section: $I = \dfrac{\pi d^4}{64}$

Therefore, the stiffness of the broken-line segment is:

$$K_n = \frac{3EL_0 \pi d^4}{32ab\left(L_0^2 - a^2 - b^2\right)} \qquad \left(a + b = L_0\right) \tag{5}$$

Among them, L_0 is the length of the broken-line segment, d is the diameter of the metallic protofilament, E is the modulus of elasticity of the metallic protofilament, a is the distance from the contact point to the end point.

According to the Saimoletano model[10], the contact action model of the simply supported beam AB is established at the contact point, as shown in Figure 7, AB is in contact with another section of simply supported beam CD at the normal direction of contact point C. The simply supported beam CD is parallel to the compressive load Z direction.
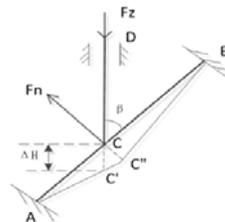
Figure 7. Contact action model of simply supported beam.

Elastic force of simply supported beam AB in Z direction:

$$F_z = F_n \sin \beta \tag{6}$$

After the simply supported beam is deformed by force, the contact point moves from point C to point C'. According to the displacement relationship, we can obtain:

$$F_n = K_n \Delta H \sin \beta \tag{7}$$

Available from formulas (6) (7):

$$F_z = K_n \Delta H \sin^2 \beta \tag{8}$$

Therefore, the effective stiffness in the **Z** direction of the compressive load is:

$$K_z = K_n \sin^2 \beta \tag{9}$$

$$K_z = \frac{3E\pi d^4}{64a^2 \left(L_0 - a\right)} \sin^2 \beta \qquad (0 < a \le L_0) \tag{10}$$

3. Establishment of the Constitutive Model of the Fuzz Button Connector

The fuzz button is elastic in a certain compression range, which can be regarded as a series and parallel connection of springs with a certain rigidity. In order to derive the mechanical model of the fuzz button, a representative unit body is taken from the structure of the fuzz button connector, as shown in Figure 8, in this unit body, according to the second assumption that fuzz button broken line are evenly distributed, and consistent with continuum model[11]. Suppose that there are **m** layers broken-line segments per unit thickness, each layer has **n** broken-line segments, the segments between each layer are parallel to each other, and each layer is in series with each other. According to the series-parallel relationship of springs[12] the stiffness relationship is obtained as in formula (11):
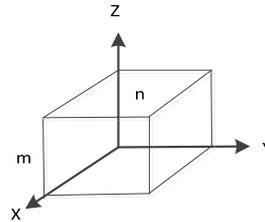
Figure 8. Unit body of the fuzz button connector.

$$K_v = \frac{\prod_{i=1}^{m} K_{in}}{\sum_{i=1}^{m} \prod_{j=1, j\neq i}^{m} K_{jn}} = \frac{n}{m} K_z \tag{11}$$

For a unit volume of the fuzz button connector, the fuzz button's constitutive relationship is:

$$\sigma = \frac{nK_z}{m} * \varepsilon \tag{12}$$

The relative density of the fuzz button connector is: $\bar{\rho} = \frac{\rho_{fb}}{\rho_s}$ (ρ_{fb} is the density of the fuzz button, ρ_s is the density of the metallic protofilament).When the volume of fuzz button is V, the total number (N_V) of broken-line segments AB can be calculated according to the equal mass:

$$N_v = \frac{4V\bar{\rho}}{d^2 L_0 \pi} \tag{13}$$

The number **N** of metal broken-line segments in a unit volume is:

$$N = \frac{4\bar{\rho}}{d^2 L_0 \pi} \tag{14}$$

The total number of broken-line segments per unit volume is the product of **m** and **n**:

$$N = m * n = \frac{4\bar{\rho}}{\pi d^2 L_0} \tag{15}$$

Since the micro-element springs in the fuzz button connector are evenly distributed, and the distribution in the three perpendicular directions is equally probabilistic[12], then from formula (15), we can know:

$$\frac{n}{m} = N^{\frac{1}{3}} = \left(\frac{4\bar{\rho}}{\pi d^2 L_0} \right)^{\frac{1}{3}} \tag{16}$$

By those formulas (10) (12) (16), the constitutive model of the fuzz button connector is:

$$\sigma = \left(\frac{4\bar{\rho}}{\pi d^2 L_0} \right)^{\frac{1}{3}} \frac{3E\pi d^4}{64a^2 (L_0 - a)} \sin^2 \beta * \varepsilon \tag{17}$$

In view of the complexity of the deformation process of the fuzz button connector under stress, other factors including friction, uncertainty of the number of contact points formed on the broken-line segment, etc, so introducing the comprehensive proportional coefficient A of various factors, then formula (17) can be expressed as:

$$\sigma = A \left(\frac{4\bar{\rho}}{\pi d^2 L_0} \right)^{\frac{1}{3}} \frac{3E\pi d^4}{64a^2 (L_0 - a)} \sin^2 \beta * \varepsilon \tag{18}$$

4. Conclusion

The process of establishing the constitutive model is described, and then based on some assumptions, the stress-strain model of the fuzz button is derived from a theoretical perspective. From the constitutive model, the influence of some parameters, such as the diameter and the elastic modulus of the metallic protofilament, the winding angle and the length of the broken-line segment, on the stress-strain relationship can be explored separately.

From the constitutive model we can see, when the strain ε is constant, the stress σ is proportional to the relative density $\bar{\rho}$ of fuzz button, the elastic modulus E and the diameter d of the metallic protofilament, and the winding angle β.The stress σ is inversely proportional to the length L_0 of the broken-line segment and the length a which is the distance between contact point and left end point

The research on the structural parameters of the fuzz button is of guiding significance for industrial design. So, in future work, the effects of these parameters on the constitutive model will be explored through experiments, and the experimental results will be compared with the mechanical model to explore the feasibility of the constitutive model deduced in the article.

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