*This article is a translation of a Japanese article published on the JAE website at the end of March 2022.

JAE Technical Report

1 Electrical Reliability of a Film Type Connector by Vibration Test

Junya Sato	Technology Manager, Product Development Center
Naoki Shibata	Product Development Center
Kousuke Matsuo	Assistant Manager, Product Development Center
Ryosuke Mitsui	Ph.D. (academic) and Assistant Manager, Product Development Center
Atsushi Kira	Ph.D. (engineering) and Senior Technology Manager, Product Development Center

Keywords: Film Type Connector, Elastic, Vibration Test

Abstract

Efforts on improvement of the efficiency of various systems by connecting all kinds of objects and utilizing the acquired information have gradually been spread. In these efforts, electronics are being mounted on things and in places that were previously unpredicted. In this trend, flexible electronics, which are lightweight, thin, and can be used in various shapes, are attracting attention, and various devices are being developed. It is assumed that connectors that connect to these devices will also be required to be portable, flexible, thin, and lightweight. This paper introduces the connection reliability of film-type connectors through the vibration test, which enable electrical connection without compromising the functionality of flexible electronics.

1. Introduction

There is increased activity in initiatives to connect objects and systems of all kinds and utilize information from these connections to make a variety of mechanisms more efficient. For instance, Industry 4.0, proposed by Acatech and the German Federal Ministry of Education and Research in 2011, aims to optimize manufacturing technology, including supply chains, by thoroughly automating manufacturing work and digitalizing information. This initiative seeks to achieve this goal by acquiring big data from IoT (Internet of Things) and using AI (Artificial Intelligence) to precisely reproduce actual spaces in virtual space (digital twins).[1] Therefore, it is necessary to integrate sensors into more objects than ever to realize this initiative. Electronics are being mounted on things and places where electronics did not previously need them.

Conventional electronics have driven the way in portable devices such as smartphones by keeping pace with the miniaturization and integration of semiconductors to achieve higher functionality, performance, and lower cost. Meanwhile, flexible electronics, in which highly integrated electronic circuits and miniaturized sensors are mounted on flexible and lightweight film, have attracted attention in the above trend. The development of various devices such as sensors,[2, 3] RFIDs,[4] and batteries[5] has been advancing energetically. Furthermore, there is increased activity in initiatives directed at new value creation through the development of wearable devices[6] oriented toward the healthcare field.

In these flexible electronics, it can be imagined that there will be a demand for flexibility, portability, thinness, and lightness in electrical connections. There is also a need to respond to demands for heat resistance in the films that serve as substrates. Generally, in electrical connections for flexible printed circuits (FPCs), FPC connectors are used. Still, there is a danger that flexibility can be lost in electrical connections using connectors. Moreover, high-reliability electrical connections have been achieved with connectors by using mechanical contact loads achieved through mating mechanisms. Thus the requirement for a sufficient contact force and mechanical designs for miniaturized connectors are limited. To solve these problems, the authors have been making efforts to develop a film-type connector that utilizes the elastic restoring force of the adhesive.[7–10] The film-type connector can connect electrodes without applying heat, and electrical contact can bend them in any shape. It is an electric connection technology in harmony with flexible electronic device functions. In the next section, we will describe these connectors in detail.

Film-type connectors

Film-type connectors feature a structure in which electrodes are formed on an elastic material with adhesive properties, and contact loads that originate in the shape-restoring force of the elastic body produced at the time of connection are produced on the electrodes. Figure 1 shows a method of connecting to an FPC as an example of an electrical connection method utilizing a film-type connector. First, the film-type connector and the electrodes of the FPC are aligned, and the matching electrodes are brought into contact by applying pressure. Further pressurization pushes the adhesive out from between the wires of the film-type connector. The extruded adhesive deforms to fill the spaces between the wires and adheres to the polyimide substrate of the FPC. The film-type connector retains its connection even when unloaded during contact, thus enabling electrical connection. We can modify the materials used in our film-type connectors according to the required properties, such as adhesives that laminate at room temperature or UV-curable adhesives.

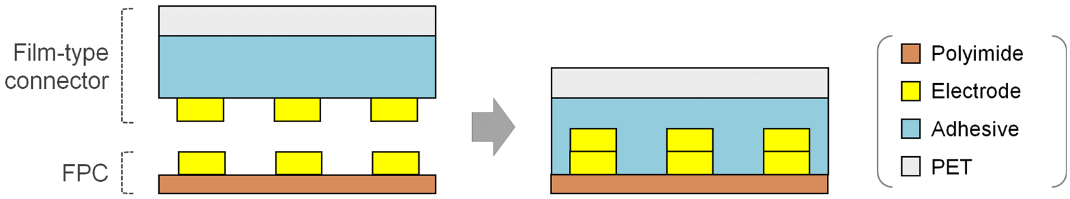

Figure 1. Connection process for film-type connector

In film-type connectors, the adhesive is deformed in the thickness direction by pressure applied at the time of connection. A contact load is produced in the direction of pressing together opposing electrode surfaces by the elastic restoring force and the cohesive force acting to restore the deformed adhesive to its original shape. The film-type connector achieves an electrical connection because the adhesive force between the adhesive and the substrate maintains the contact load. Standard connectors utilize a contact load produced by a mating mechanism made of metal, resin, or the like. A stable electrical connection is achieved by making the electrode surface contact area large. On the other hand, in film-type connectors, the elastic force produced by the deformation of the viscoelastic material is utilized, the contact area is maintained, and the electrical connection is achieved by pressing the electrodes to follow the surface shapes of the opposing electrodes. Previously, the authors have reported that film-type connectors have stable electrical connections even after constant temperature and humidity tests and thermal shock tests. They have also said that film-type connectors can maintain a stable electrical contact even when bent to a radius of curvature of 2.5 mm, for reasons that ① the low-profile connection structure, ② the flexibility of the viscoelastic material, ③ adhesion to the substrate, and ④ contact of electrode surfaces.[7–8] In this paper, we will introduce the connection reliability of film-type connectors based on vibration testing.

2. Electrical reliability of film-type connectors by vibration test

We thought that flexible film-type connectors could provide a stable electrical connection for both bending and vibration motion. We performed vibration testing on a sample in which an FPC and a film-type connector were connected and evaluated the reliability of the connection.

2.1. Evaluation sample

The configuration of the evaluation sample used in this study is shown in Table 1. The connection process consisted of temporary adhesion and UV irradiation processes. In the temporary adhesion process, the film-type connector electrode and the evaluation substrate electrode were aligned, and the crimping machine applied pressure of 1.0 MPa at room temperature. After conduction was confirmed, irradiating the sample with ultraviolet rays at 4000 mJ/cm^2 using a high-pressure mercury vapor lamp (Figure 2).

Table 1. Configuration of evaluation sample (thickness)

	Evaluation substrate	Film-type connector
Electrode	Au/Ni/Cu (Au: > 0.03 μm) (Ni: 3–5 μm) (Cu: 18 μm)	Au/Ni/Cu (Au: > 0.03 μm) (Ni: 3–5 μm) (Cu: 18 μm)
Substrate	FR-4 (0.8 mm)	PI (25 μm)
Adhesive		Adhesive 80 μm PET 25 μm

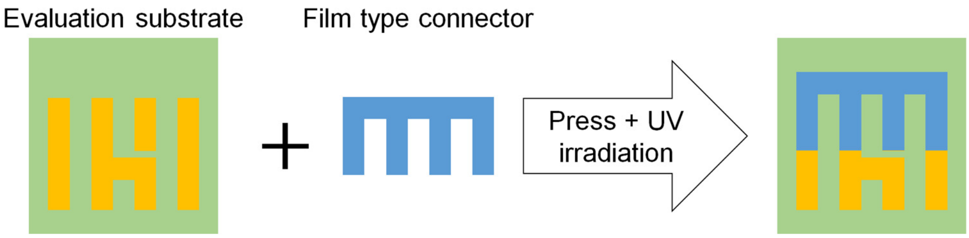

Figure 2. Connection process for film-type connector

2.2. Evaluation method

2.2.1. Contact resistance measurement method

An example of the measurement method[11)] for contact resistance when the film-type connector and the evaluation substrate were connected is shown in Figure 3. We connected a source meter (Keithley Instruments) with the evaluation substrate using a four-point probe method, as shown in Figure 3. The voltage values were measured while sweeping current values. The data was plotted, and we calculated contact resistance based on an approximating curve's slope.

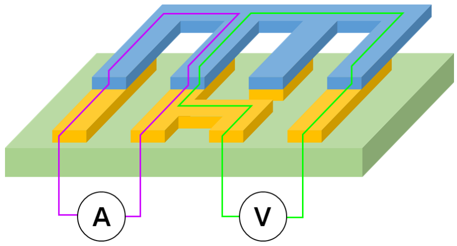

Figure 3. Measurement by the four-point probe method

2.2.2. Vibration testing method

The reliability of a sample formed by connecting a film-type connector and an evaluation substrate was investigated by vibration testing. The evaluation sample was fixed to the sample stand of an electromagnetic vibration device VTS100 (Vibration Test Systems) (Figure 4a), and we performed vibration testing. We defined the pitch direction concerning the wiring of the film-type connector to be the x-direction, the wiring direction to be the y-direction, and the vertical direction to be the z-direction (Figure 4b).

We decided on the conditions for vibration testing following the stipulations of JIS C 60068-2-6 for standard testing procedures for determining the ability to resist sine-wave vibrations.[12)] This vibration test aimed to assess the mechanical weak points or the deterioration of specific functions of the product and prove the product's mechanical sturdiness or investigate the product's kinetic behavior.

A ten-cycle sweeping vibration test was performed with an acceleration of 50 m/s^2, ranging from a lower-limit frequency of 11 Hz to an upper-limit frequency of 500 Hz. The lower-limit frequency listed in the standard is 10 Hz, the frequency tolerance is ±1 Hz, and the lower-limit set value for the electromagnetic vibration device is 11 Hz. So we the sweeping frequency range of the vibration test from 11 Hz to 500 Hz. We calculated changes in resistance values by subtracting the resistance value of the sample before the vibration test from the resistance value after the vibration test. Table 2 shows the results of calculating velocity and displacement from the frequency and acceleration set for the electromagnetic vibration device. Because the vibration test was performed at a constant frequency, it is presumed that the vibration velocity and displacement become more significant as the frequency decreases. The load applied to the sample increases.

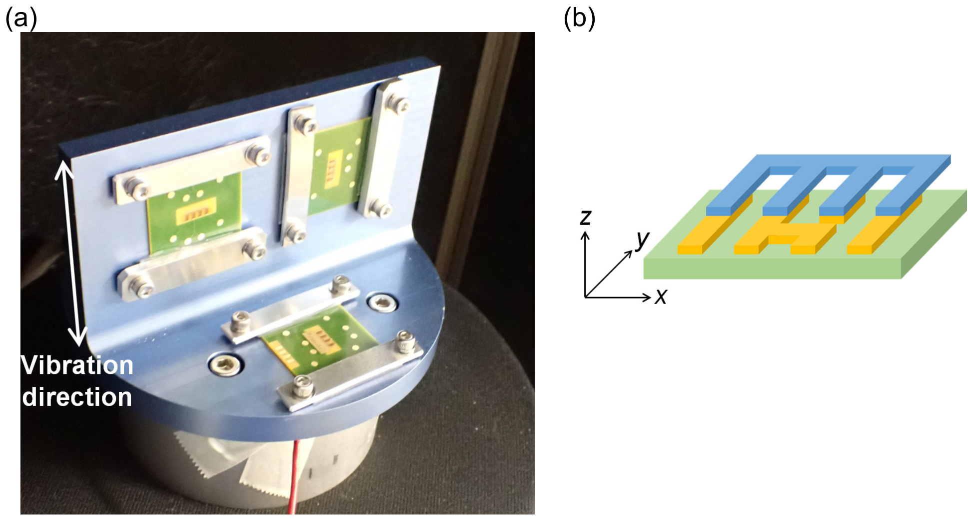

Figure 4. Example of vibration test method
(a) method for fixing sample, (b) axial direction of sample

Table 2. Vibration conditions for electromagnetic vibration device

Set frequency (Hz)	Set acceleration (m/s^2)	Velocity (m/s)	Displacement (mm)
11	50	0.723	10.467
12	50	0.663	8.795
100	50	0.080	0.127
300	50	0.027	0.014
500	50	0.016	0.005

2.2.3. Vibration measurement method

Using a laser Doppler vibrometer LV-1800 (Ono Sokki), the velocity power spectrum density was measured while vibrating the evaluation sample in the *z*-direction at an acceleration of 50 m/s^2 and frequencies of 12 Hz, 100 Hz, 300 Hz, and 500 Hz. An example of the measurement method is shown in Figure 5. The electrode section of the evaluation substrate (Figure 5c) and the electrode section of the sample with the film-type connector connected (Figure 5d) was used as measurement sites. Based on Table 2, displacement from an acceleration of 50 m/s^2 and a frequency of 11 Hz is 10.467 mm, exceeding the 10-mm measurement range of the laser Doppler vibrometer, so the sample was evaluated by vibrating it at a frequency of 12 Hz.

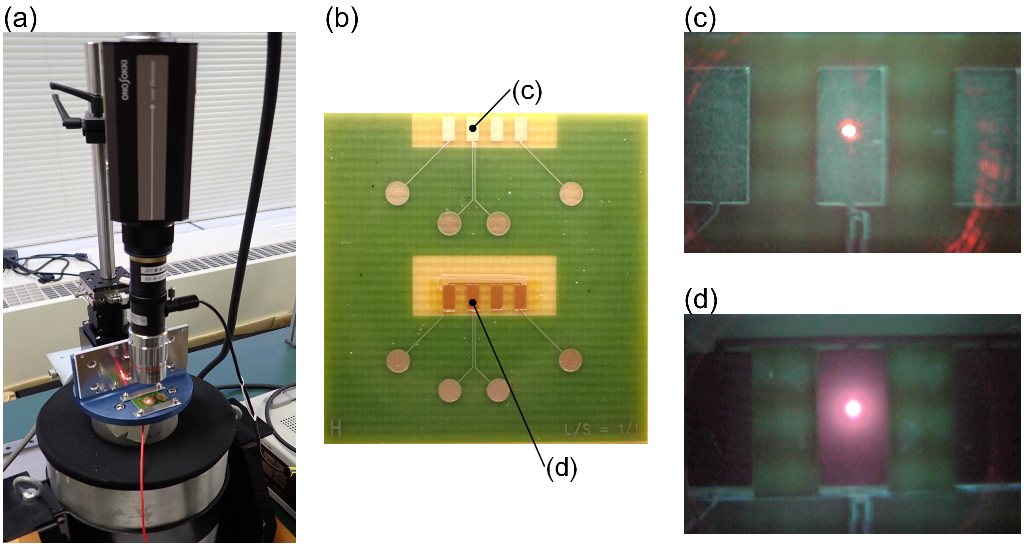

Figure 5. Vibration measurement using laser Doppler vibrometer
(a) external view of vibrometer, (b) external view of sample, (c) measurement site on substrate, (d) measurement site on film-type connector

2.3. Results and discussion

We evaluated changes in the contact resistance in vibration testing of a sample in which we connected a film-type connector with an electrode width of 1.0 mm and an evaluation substrate. Results from before and after the sample were vibrated in the *x*-direction are shown in Figure 6(a), the *y*-direction in Figure 6(b), and the *z*-direction in Figure 6(c). The results of calculating contact resistance before and after the vibration test from the slope of an approximating curve using the results in Figure 6 are shown in Table 3. It was confirmed that the change in the contact resistance value was 0.3 mΩ or less in all vibration directions and that the electrical connection was stable against vibration.

Table 3. Contact resistance of film-type connector

Vibration direction	Contact resistance (mΩ)		
	Before test (a)	After test (b)	Difference (b–a)
x	11.96	12.09	0.13
y	11.11	11.11	0.00
z	10.85	11.11	0.26

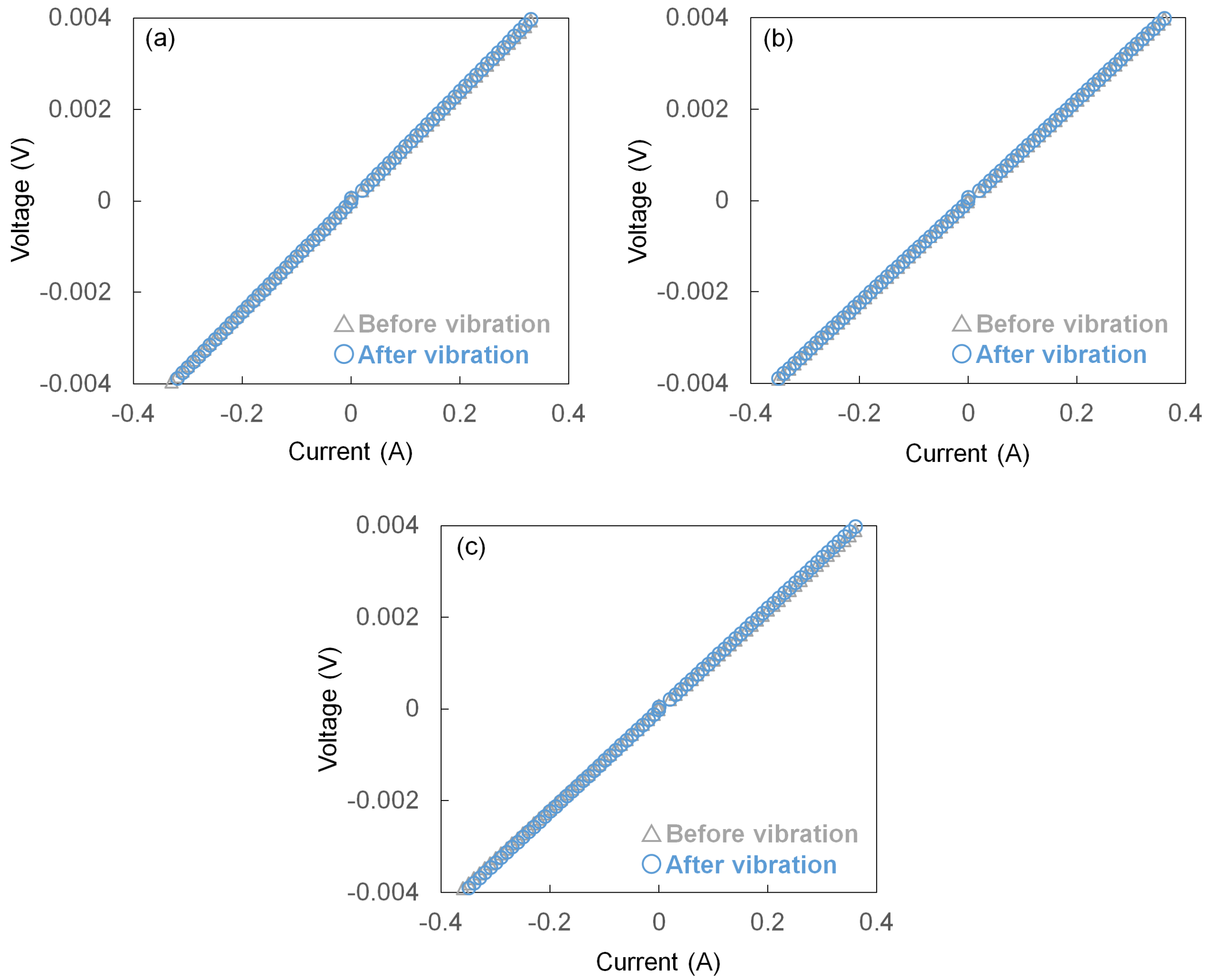

Figure 6. Electrical characteristics before and after vibration testing
(a) *x*-axis vibration, (b) *y*-axis vibration, (c) *z*-axis vibration

We evaluated the degradation of film-type connector connections by measuring the velocity power spectral density of vibration-tested samples. The results of measurement when the sample was vibrated at 12 Hz are shown in Figure 7(a), 100 Hz in Figure 7(b), 300 Hz in Figure 7(c), and 500 Hz in Figure 7(d).

Based on Table 2, a velocity of 0.663 m/s is considered to be applied when the set frequency of the vibration device is 12 Hz. When vibrating at 12 Hz, the frequency at which the velocity power spectral density of the substrate and film-type connector is at its maximum is 12 Hz. This frequency is the same value as the setting of the vibrometer. Furthermore, the spectral width between the board and the film-type connector does not change significantly and is the same as the value set by the vibratory apparatus. This result indicates that the substrate and film-type connector vibrate at the vibrometer's frequency and speed.

For vibration at 100 Hz, 300 Hz, and 500 Hz, the measured frequency values were equivalent to the set values, and there were no significant changes in spectrum width for the substrate or the film-type connector. Accordingly, we confirmed that the film-type connector was displaced to follow the vibration of the vibrometer.

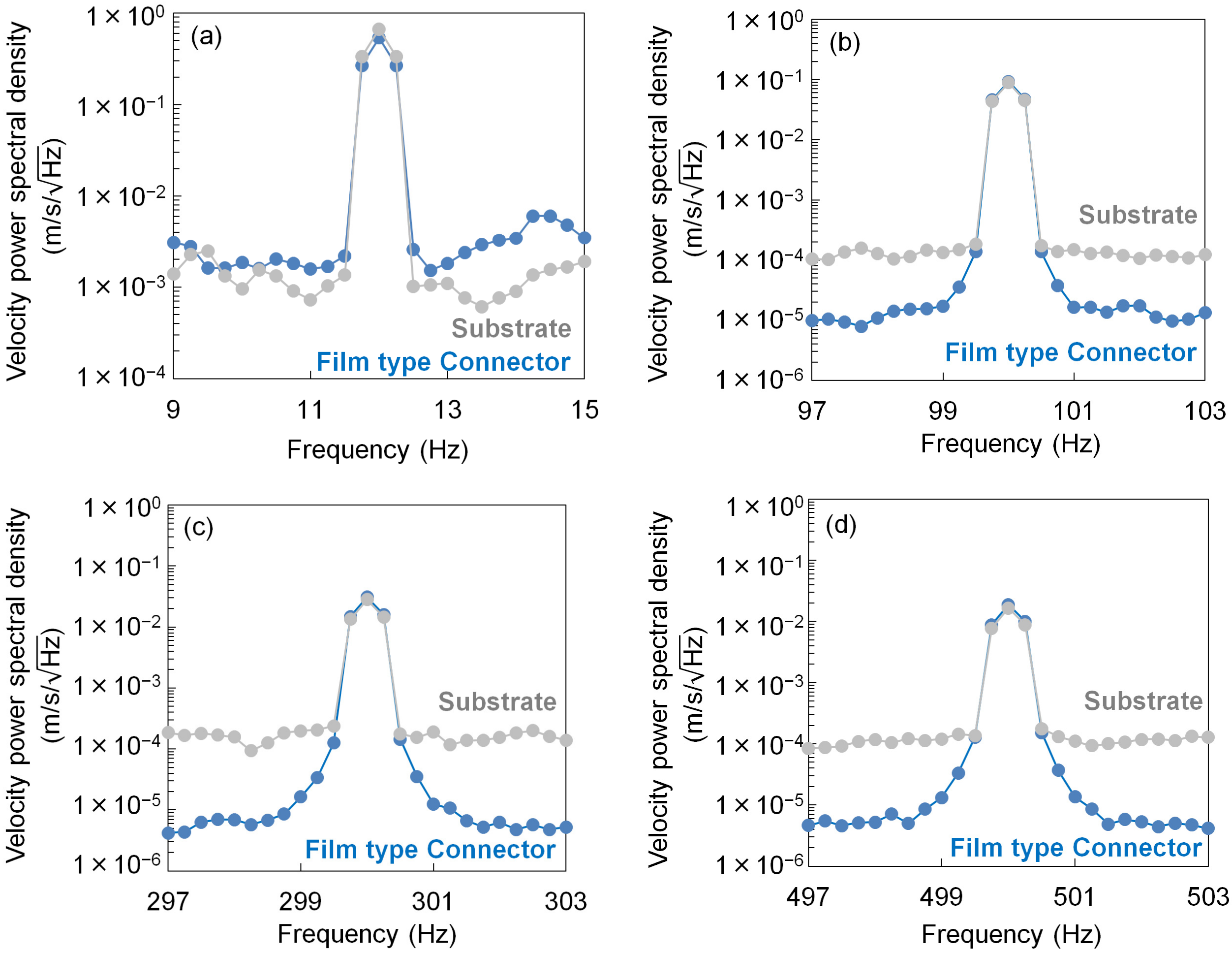

Figure 7. Results of velocity power spectrum density measurement at each vibration frequency
(a) 12 Hz, (b) 100 Hz, (c) 300 Hz, (d) 500 Hz

We conducted vibration tests on samples connected with film-type connectors at accelerations of 50 m/s^2 and in the range of 11 Hz to 500 Hz. We measured the samples' resistance and velocity power spectral density after the vibration tests. The change in resistance before and after the vibration test was less than 0.3 mΩ, confirming that the samples connected with film-type connectors have a stable electrical connection with a slight change in resistance. We consider that samples connected by film-type connectors provide a highly reliable electrical connection because the film-type connectors displace following the vibration of the vibratory apparatus, even when a load is applied.

3. Summary

In this paper, we checked for deterioration of a film-type connector through vibration testing. The film-type connectors were subjected to a vibration test following JIS C 60068-2-6, with ten-cycle sweeps from 11 Hz to 500 Hz at an acceleration of 50 m/s^2. The results confirmed no significant change in contact resistance before and after the test. We confirmed that the film-type connectors are mechanically stable. We also found from the results of Doppler vibrometer measurements that the film-type connectors followed the vibration of the substrate under the vibration conditions described above. We found that the film-type connectors' adhesive strength met the vibration testing requirements applicable to parts of ground-mounted transport machinery, land transport vehicles, small speed boat, and aircraft. The flexibility and stability against movement of film-type connectors are expected to expand the application of electronics. Film-type connectors are expected to be one of the electrical connection technologies contributing to constructing sensor networks to promote the Internet of Things.

(References)

1) A. Padovano, F. Longo, L. Nicoletti, and G. Mirabelli, IFAC PapersOnLine **51**, 631 (2018).
2) S. Lee, S. Franklin, F. A. Hassani, T. Yokota, M. Nayeem, Y. Wang, R. Leib, G. Cheng, D. W. Franklin, and T. Someya, Science **370**, 966 (2020).
3) D. Maddipatla, B. B. Narakathu, and M. Atashbar, Biosensors **10**, 199 (2020).
4) Y. Wang, C. Yan, S. Y. Cheng, Z. Q. Xu, X. Sun, Y. H. Xu, J. J. Chen, Z. Jiang, K. Liang, and Z. S. Feng, Adv. Funct. Mater. **29**, 1902579 (2019).
5) G. Lee, M. Kim, Y. W. Choi, N. Ahn, J. Jang, S. M. Kim, J. G. Lee, D. Kang, H.S.Jung, and M. Choi Energy Environ. Sci. **12**, 3182 (2019).
6) K. Kim, B. Kim, and C. H. Lee, Adv. Mater. **32**, 1902051 (2020).
7) R. Mitsui, S. Takahashi, S. Nakajima, K. Nomura, and H. Ushijima, Jpn. J. Appl. Phys. **53**, 05HB04 (2014).
8) R. Mitsui, J. Sato, S. Takahashi, and S. Nakajima, Electronics **4**, 827 (2015).
9) R. Mitsui, J. Sato, and S. Nakajima, Aviation Electronics Technical Report **39**, 1 (2017)
10) R. Mitsui, R. Goto, J. Sato, A. Kira, and S Nakajima, Aviation Electronics Technical Report **41**, 1 (2019)
11) K.W. Jang and K.W. Paik, IEEE Trans. Compon. Packag. Technol. **32**, 339 (2009).
12) Japanese Industrial Standards Committee, *Environmental Testing Methods: Electricity and Electronics: Part 2-6: Sine-Wave Vibration Testing Methods* (Japanese Standards Association, Tokyo, 2010), p. 5

