Evaluation of a Spring-Finger Based, Magnetic Connector Concept for Reliable E-textile Interconnects

Tom Greig, Kai Yang, Russel Torah

Abstract—Reliable, impermanent connectors are a significant challenge in the development of e-textile devices, needed to increase their modularity, a key factor in their ability to be repaired or recycled. The combination of spring loaded contacts and magnetic fastenings is a promising option as these components exhibit the small size and mechanical compliance necessary for use in flexible devices.

This paper details the evaluation of a 5 pin, spring finger connector held in place by two pairs of 1 mm thick NdFeB button magnets. The connector is subjected to bending and straightening around a 9 cm diameter to analyse its suitability for use in an e-textile device. The results show that with 1.3 mm high springs and a backing with a flexural rigidity of 1.16×10^{-4} N m^2, 100% reliability can be achieved on that test. These results indicate a necessity to use small springs that can easily be flattened. However, their small working range means that they may not be as reliable when connecting to uneven surfaces.

I. Introduction

E-textile devices hold promise in several areas, however the aim of completely integrating electronic components into the textile host has led to devices that are hard to repair or separate for recycling [1], [2]. Taking a more modular approach to designing e-textile devices would lead to improvements in these areas, but doing so requires reliable, impermanent electrical connectors between modules.

A number of different approaches to this problem have been considered in the past [3]. Some use a permanent fixture such as an eyelet [4] or crimp [5] to attach to the textile, then use a standard rigid connector to attach to that. This system allows the connection to the textile to be much more robust than if it had to be removable, though it does require adding rigid components to the device, the boundaries of which are known to be a common point of mechanical failure for electrical conductors [6].

Other designs have adapted components native to textiles which share their flexible properties, for example, creating conductive Velcro. However, the conductive coating used on Velcro has been shown to wear off after repeated use [7]. The opening and closing of a zip has been employed as an electrical switching mechanism [8], but zips are not useful for increasing modularity as the parts of an e-textile device are rarely just two sheets needing to be joined edge to edge.

An alternative basis for e-textile connectors is the combination of magnets and spring loaded contacts. Magnetic fastenings are attractive because they are self-aligning and, with judicious use of polarity, can enforce correct orientation. Magnets have been used directly as connectors [9], but their inability to be soldered without demagnetising makes this challenging. Using magnets to hold sprung connectors in place solves this problem and has the advantage that the receiving side of the connector is simply an exposed conductive pad. This makes manufacturing easier and increases the flexibility afforded to the design. It also means that when disconnected, the connection mechanism is completely unobtrusive.

Thus far, such systems have only been realised using spring loaded “pogo” pins [3], [10]. Shown in figure 1, these consist of a spring loaded pin inside a hollow metallic cylinder. As a result, pogo pins cannot compress to less than half their original height. This creates a compromise between the total thickness of the device and the working contact range of the connector. Because the spacing between the tips of the pins needs to remain the same as that of the bases, at least one side of the connector must also be rigid.

An alternative that is more suited to connections between two flexible devices is spring finger connectors. These are ‘C’ shaped metal contacts, the bottom of which is soldered to a PCB. When compressed onto an opposing contact pad, they form a reliable, electrical connection. While this system occupies more lateral space than one based on pogo pins, it can compress almost flat so is better suited for devices where a low profile is a requirement.

Such a connector would itself have properties beneficial for sustainability: the easily accessible spring fingers contacts can be replaced in situ if broken and the encapsulated magnets are unlikely to demagnetise

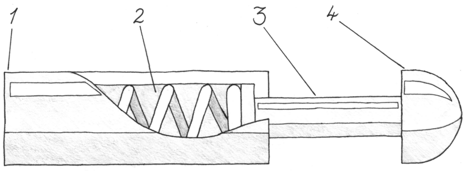

Fig. 1: Pogo pin mechanism. (1) Fixed barrel which is permanently attached to one side of the connector, (2) Spring, (3) Movable pin, (4) Contact head.

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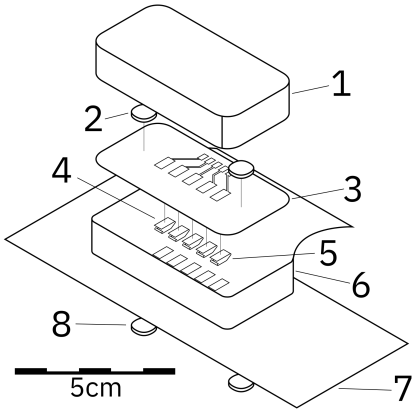

Fig. 2: Design of the test device. (1) Foam backing, (2) Magnets × 2, (3) Flexible PCB connecting contacts to test pads, (4) Spring finger connectors, pin 1, (5) pin 5, (6) Fabric cover, (7) Copper sheet, (8) Magnets used to hold device down × 2.

during standard use and can be easily recovered at the end of the product's lifetime. The metallic construction, using materials already present in most electronic devices, means that the recycling process is not complicated by the connector's inclusion.

This paper details the evaluation of such a system, identifying the key requirements of its design to allow development of future reliable connectors for e-textiles.

II. Method

A. Test Device Design

The proposed connector system was tested using the design shown in figure 2. A flexible, copper coated polyamide (GTS Flexible Materials Ltd.) circuit board (F-PCB) was produced, using the photolithographic etching technique described in [6], with five pads 5 mm apart to which the spring finger contacts were soldered. Two different spring contacts were tested, both from TE Connectivity: the smaller 1447360-8 (1.3 mm high) and the larger 1438259-6 (4 mm high). The F-PCB connected each spring contact to a copper pad, to which a length of litz wire was soldered to connect to an oscilloscope.

Either side of the contacts, N850 cylindrical magnets (Eclipse Magnetics, UK) were attached using double sided tape. The magnets were 6 mm in diameter, 1 mm high and had a pull force of 0.3 kgf. Their small size allowed them to be incorporated into the device without noticeably impacting its flexibility.

Above the PCB, was a 10 mm thick layer of foam (Anyfoam Ltd. UK). This was used to add some rigidity to the device so that the middle pins did not completely fold up and lose contact. Five different types of foam, described in table I, were tested.

	Density kg/m^3	Hardness N	Flexural Rigidity Nm^2
1 (Softest)	21 - 24	86 - 110	1.62×10^{-5}
2	31 - 34	100 -130	1.07×10^{-4}
3	38 - 40	180 - 220	1.16×10^{-4}
4	48 - 52	225 - 265	1.51×10^{-4}
5 (Hardest)	20 - 22	225 - 275	1.83×10^{-4}

TABLE I: Backing foam properties [11].

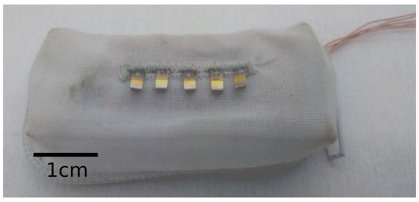

Fig. 3: Test device with spring finger contacts protruding from the underside. A zip was included in the cover to allow the backings to be easily swapped but would not be required in a real application.

The whole device was enclosed in a polyester-cotton cover with holes cut in the bottom to allow the contacts through (figure 3). This design was chosen for the purpose of easier testing, in a final application it could be significantly more compact.

A sheet of copper coated polyamide was used as the other side of the connector for all five pins. Two more N850, 6 × 1 mm magnets were placed underneath it. It was given a fabric backing and litz wire was used to connect the sheet to the oscilloscope.

B. Testing Procedure

Methods for testing e-textile devices are slowly becoming standardised [12], [13], however, no completed standard exists describing the type of test needed here. As such, a testing methodology was devised to simulate the conditions the connector would endure as part of a wearable, e-textile device, optimised to reveal the differences between the various configurations. Since this work began, a draft standard for measuring the resistance of e-textiles during bending has been published [14] which has some similarity with the method presented here, but it focuses on conductive materials rather than the connection between modules.

The method used here involved mounting the copper sheet into a bespoke bending rig [6], shown in figure 4. The bending rig holds a length of fabric under tension while pulling it back and forth over a cylindrical axle. In this case, a 90 mm diameter axle was used. During each test, the connector was passed across the axle at approximately 1.25 Hz for 5 s.

Data was collected on whether a connection occurred between the copper sheet and the each pin of the connector via a potential divider connected to an oscilloscope. If the pin made contact, the voltage between it and the copper sheet would be zero, if not, a voltage would appear. The reliability of each pin was quantified as the fraction of the time it maintained a connection as it moved over the axle of the bending rig.

III. Results & Discussion

The reliability values for each pin in each configuration are shown in figure 5. The most common failure mechanism observed during the experiment,

Fig. 4: Test device mounted on the bespoke bending rig [6]. The real time connection between the copper sheet and each pin of the device was tested as it was pulled back and forth over the grey cylindrical axle.

illustrated in figure 6, was when the magnets, pulling the connector down on either end, combined with the outer two pins to lever the central pins up, preventing them from making contact. This is shown in results as pins 1 and 5 being always more reliable than pins 2 and 4 respectively. With the softest backing (foam 1) and the smaller pins, the dent in the foam caused by this effect reached far enough to affect pin 3 as well.

In the case of the larger springs, pin 1 was sufficiently large for the levering effect to affect every other pin. With the more flexible backings, the magnet at the far end was able to bend the connector and make pin 5 connect some of the time, but with more rigid backings, this happens less frequently. At the points where pin 5 does make contact, that end of the connector is at a sufficiently steep angle that pin 4 is still much farther up, keeping its reliability at 0. Despite the symmetry of the connector, pin 1 is always favoured because it was initially the farthest from the axle of the bending rig: as the copper sheet was bent, it peeled away from pin 5 first, allowing pin 1 to establish a reliable connection at the expense of the pins at the other end.

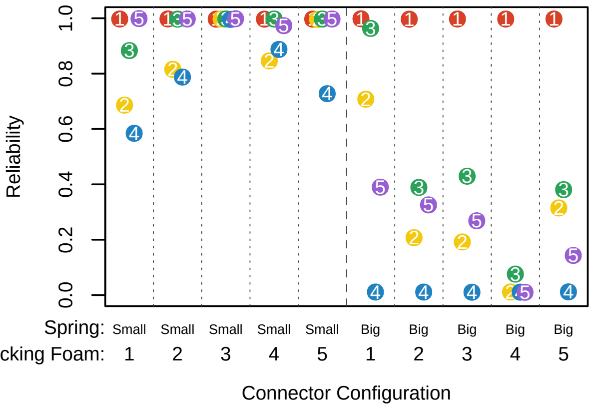

Fig. 5: Pin reliability for each connector configuration. Reliability is the fraction of the time a connection was made. The result for each pin is shown by the position of the corresponding number.

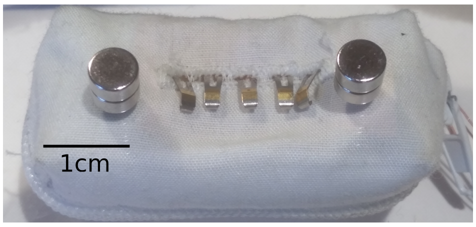

Fig. 6: Underside of the test device with backing foam 1, shown through glass. The magnets pull the ends of the connector down to the surface, creating an angle that lifts the central pins away.

Using the optimal backing, the smaller pins were able to reach 100% reliability in this test, however, the smooth surface of the copper sheet they were connecting to is not necessarily representative of a real e-textile application. Were the contact surface less uniform, the small working range of these pins may have caused them to become less effective. A solution to this would be to use spring finger contacts with a larger size but a lower spring constant. This would allow the pins near the magnets to simply compress, rather than levering the inner contacts upwards. However, because spring finger contacts are primarily used in rigid electronics [15], the spring constant is not often specified, making suitable versions difficult to identify.

The need to control the rigidity of the connector's backing can reduce the overall flexibility of the device slightly. Using contacts with a lower spring constant would help here too as softer springs will need a less rigid backing to hold them down.

IV. Conclusions

Magnetically secured, spring finger connectors have several properties that make them appealing as e-textile connectors: their small size, mechanical compliance and simplicity make them good candidates for integration into e-textile devices.

However, the results presented here show that size of the springs and the rigidity of their backing must be carefully chosen in order to ensure reliability in the dynamic environment in which e-textile devices can be used. If the device's backing is too soft, pins near the fixing magnets can push their neighbouring contacts upwards, causing their connection to break. A backing that is too rigid however, is unable to respond when the surface to which it is connected bends.

Using larger contacts increases the risk of them lifting each other up, but smaller ones have a smaller working range, which would cause them to be less reliable when placed on uneven surfaces. Pins which require less force to compress would circumvent this trade-off, but due to the usual applications of spring finger connectors, these are not currently widely available.

While greater care is needed to ensure that this form of connector is electrically reliable, the complete lack of rigid components in the conducting path significantly reduces mechanical stress compared to standard electronics connector designs.

References

[1] D. Hardy, R. Wickenden, and A. McLaren, "Electronic textile reparability," Journal of Cleaner Production, vol. 276, p. 124328, 2020.

[2] A. R. Köhler, "Challenges for eco-design of emerging technologies: The case of electronic textiles," Materials & Design, vol. 51, pp. 51–60, 2013.

[3] J. Stanley, J. A. Hunt, P. Kunovski, and Y. Wei, "A review of connectors and joining technologies for electronic textiles," Engineering Reports, p. e12491, 2021.

[4] J. Leśnikowski, "Research on poppers used as electrical connectors in high speed textile transmission lines," Autex Research Journal, vol. 16, no. 4, pp. 228–235, 2016.

[5] M. Liu, T. Ward, D. Young, H. Matos, Y. Wei, J. Adams, and K. Yang, "Electronic textiles based wearable electrotherapy for pain relief," Sensors and Actuators A: Physical, vol. 303, p. 111701, 2020.

[6] A. Komolafe, R. Torah, Y. Wei, H. Nunes-Matos, M. Li, D. Hardy, T. Dias, M. Tudor, and S. Beeby, "Integrating Flexible Filament Circuits for E-Textile Applications," Advanced Materials Technologies, vol. 4, no. 7, p. 1900176, 2019.

[7] H. G. Joo, Y. H. Jang, and H. S. Choi, "Electrical contact resistance for a conductive velcro system," Tribology International, vol. 80, pp. 115–121, 2014.

[8] L. Stark, "Soft switches." http://thesoftcircuiteer.net/soft-switches/, 2018. Accessed: 2022-06-01.

[9] X. Righetti and D. Thalmann, "Proposition of a modular i2c-based wearable architecture," in Melecon 2010 - 2010 15th IEEE Mediterranean Electrotechnical Conference, pp. 802–805, 2010.

[10] R. Freire, B. R. Glowacki, R. R. Williams, M. Wonnacott, A. Jamieson-Binnie, and D. R. Glowacki, "Omg-vr: Open-source mudra gloves for manipulating molecular simulations in vr," 2019.

[11] Anyfoam ltd. https://anyfoam.co.uk/. Accessed: 2022-06-01.

[12] "BS IEC 63203-204-1. wearable electronic devices and technologies. part 204-1. electronic textile. washable durability test method for leisure and sportswear e-textile system," 2018.

[13] S. Rotzler, M. von Krshiwoblozki, and M. Schneider-Ramelow, "Washability of e-textiles: current testing practices and the need for standardization," Textile Research Journal, vol. 91, no. 19-20, pp. 2401–2417, 2021.

[14] "BS IEC 63203-204-2. wearable electronic devices and technologies. part 204-2. electronic textile. test method to characterize resistance change in bending test of e-textile systems," 2022.

[15] TE Connectivity. https://www.te.com/global-en/products/connectors/pcb-connectors/board-to-board-connectors/spring-finger-contacts.html. Accessed: 2022-06-08.