27
3-24-77
25 to 27

BDX-613-1479

SOLID STATE CONNECTOR

PDO 6989239, Final Report

R. A. Hayes, Project Leader

Published March 1977

Prepared for the United States Energy
Research and Development Administration
Under Contract Number EY-76-C-04-0613
USERDA

MASTER

**Kansas City
Division**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America

Available From the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Price: Microfiche \$2.25
Paper Copy \$3.50

BDX-613-1479
Distribution Category UC-38

SOLID STATE CONNECTOR

Published March 1977

Project Leader:
R. A. Hayes
Department 131

PDO 6989239
Final Report

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Technical Communications

**Kansas City
Division**

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

fy

SOLID STATE CONNECTOR

BDX-613-1479, UNCLASSIFIED Final Report, Published March 1977

Prepared by R. A. Hayes, D/131, under PDO 6989239

This report covers the results of development work on a soft-contact tester-to-product interface capability. Primary emphasis is placed in the examination of a solid state connector material capable of producing scratchless distinct isolated electrical contacts. Material characteristics are examined and applications are presented. Implementation suggestions and considerations are listed.

WPC-pls

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

THE BENDIX CORPORATION
KANSAS CITY DIVISION
P.O. BOX 1159
KANSAS CITY, MISSOURI 64141

A prime contractor with the United States Energy Research and Development Administration
Contract Number EY-76-C-04-0613
USERDA

CONTENTS

Section	Page
SUMMARY.	5
DISCUSSION	6
SCOPE AND PURPOSE.	6
ACTIVITY	6
<u>Material Description</u>	6
<u>Material Characteristics and Specifications.</u>	6
ACCOMPLISHMENTS.	15
FUTURE WORK.	17
REFERENCES	18
DISTRIBUTION	19

ILLUSTRATIONS

Figure		Page
1	20-Mil (508 μm) Conductive Elastomer (13X) (P-91097)	7
2	Edge Views of 5-, 10-, and 20-Mil (127, 254, and 508 μm) Conductive Elastomers (30X) (P-91099)	8
3	Conductivity of Metal-Filled Elastomers.	9
4	Conductive Elastomer Contact Resistance Versus Pressure.	10
5	5-Mil (127 μm) Conductive Elastomer Arcover (13X) (P-91106)	12
6	Conductive Elastomer Connection Reliability Nomograph.	13
7	Permanent Deformation of 5-Mil (127 μm) Conductive Elastomer (13X) (P-91100)	14
8	85-Mil (2.2 mm) Electroplated Solid Coaxial Cable (25X) (P-91104)	16

SUMMARY

This report covers the results of development work on a soft-contact tester-to-product interface capability. Primary emphasis is placed on the examination of a solid state connector material capable of producing scratchless distinct isolated electrical contacts. Material characteristics examined included thru-resistance, leakage-resistance, current density, breakdown voltage, capacitance, contact area, contact density, temperature, cleaning, and mounting. This material should be considered for implementation in applications requiring any or all of the following characteristics: low capacitance, scratchless connector, or multipath conductor. A list of application considerations and limits is included in the report.

DISCUSSION

SCOPE AND PURPOSE

The objective of this work was to develop a soft-contact tester-to-product interface capability suitable for use in future test equipment design. Primary emphasis was placed on the evaluation of a solid state connector material exhibiting characteristics suitable for the desired tester-to-product interface application. This report covers an explanation of the material (conductive elastomer) as well as a discussion of characteristics which exploit the feasibility for interface applications.

ACTIVITY

Material Description

The material, called a conductive elastomer¹, is a metal-polymer composite capable of producing distinct isolated electrically conductive paths. The polymer acts as a binder for small metal particles (nickel balls) which are non-uniformly distributed throughout the medium. Figure 1 is a top view of a 20 mil thick (508 μm) sample. The coarseness of the material is a result of the metal particles near the surface. Figure 2 is an edge view of three samples, 5, 10, and 20 mil (127, 254, and 508 μm). The difference in particle size between the three samples is quite noticeable.

In the static state, the resistance between surfaces is that of the polymer binder because no conductive path exists between opposite sides of the material. When sufficient force is applied to an area, the percentage metal per volume increases to the point of electrical conduction, whereas resistance to adjacent areas remains high. Thus, an electrical conductive path can be established by probing an area, yet can maintain isolation from other contacts. Quantitative pressure and distance requirements between conduction areas are discussed in the following section.

Material Characteristics and Specifications

A number of characteristics are strategic to the nature of the material and to interface applications. Three sample thicknesses were used in this study: 5, 10, and 20 mils (127, 254, and 508 μm). Unless specifically noted, the following characteristics apply to all thicknesses.

Figure 1. 20-Mil (508 μm) Conductive Elastomer (13X)

Thru-Resistance

A CE model for a system consisting of a metallic filler in a non-conductive binder is presented in the literature.² The characteristic curve associated with this model is shown in Figure 3, which plots mean conductivity versus volume percent metal. Of particular interest is the extreme slope at $V_m = 23$. In this area the material is on the verge of conduction, and a very slight increase in compaction results in the completion of a continuous chain of particles from one surface to the other and thus forms an electrical path.

Although the model is based on spherical particles uniformly distributed in a homogenous binder, results indicate good correlation between the physical material and the theoretical model.² For the specific thicknesses (and thus particle concentration and size) under investigation, the knee of the curve designated as A in Figure 3 is examined in detail to determine the pressure required to reduce the resistivity ($1/\text{conductivity}$) sufficiently for a

Figure 2. Edge Views of 5-, 10-, and 20-Mil (127, 254, and 508 μm) Conductive Elastomers (30X)

satisfactory electrical connection. The results of this examination are shown in Figure 4.

Surface-to-surface resistance as a function of pressure was measured with calibrated weights and an ohmmeter. The exact duplication of a resistance-pressure measurement is improbable because of the statistical nature of CE. For this reason Figure 4 illustrates regions of resistance versus pressure probability rather than an exact functional relationship as typified by a curve. Data for the curves was obtained by taking a large number of measurements at different pressures. Average value and standard deviation were then calculated for each pressure.

Average values were used to construct the curves in Figure 4 and standard deviations were used as a check on the data. Standard deviation decreased as the pressure increased. The top line was constructed using average values with 10 mil (2.54 mm) material while 5 mil (127 mm) material data was used for the lower line.

Figure 3. Conductivity of Metal-Filled Elastomers

Because of the illustrative nature of the graph, no exact information should be extracted, but it was seen that with sufficient pressure (10 lb/in.² or 68.49 kPa) the contact resistivity can be reduced to less than 0.1 Ω -in.²). No extrapolation should be attempted from pressures less than 0.22 lb/in.² (15.167 kPa). In this region incremental changes in pressure cause order of magnitude changes in resistance, but are not predictable. The zero-pressure (gage) resistance is greater than 10^{10} ohms, which is indicative of the magnitude of resistance change below 0.22 lb/in.² (15.167 kPa). These results are valid for applications where contact areas are typically less than 2500 square mils (1.61 mm²).

It should be noted that the contact resistance can be reduced further by increasing the contact area, therefore increasing the number of parallel conduction paths; however, the increase in area requires a proportional increase in force to maintain the same pressure.

The statistical nature of CE prevents its use as a pressure sensitive switch, except in a very broad sense, where wide variations in pressure are to be measured in a go/no-go response.

Figure 4. Conductive Elastomer Contact Resistance Versus Pressure

Leakage Resistance

Leakage resistance tests were performed on samples using a megohm meter. A layer of CE was sandwiched between outer holding surfaces; probes were then inserted with probe spacing from 0.125 to 0.375 inch (3.175 to 9.525 mm). Measurements were obtained using two voltage levels: 85 V and 500 V. In all cases the leakage resistance exceeded 10^{10} ohms.

Current Density

Current density is determined by probing an area of the material and passing a current through the surface. Using a 0.095 inch diameter (2.4 mm) probe, currents to 2 amperes were safely passed and resulted in current densities of 282 A/in² (43.7 A/cm²).

Voltage Breakdown

Breakdown potential was determined on a 5 mil (127 μm) sample using a flatpack integrated circuit (IC) chip holder and clamp. The sample was inserted between the lead connections and the clamp with the test voltage applied to the lead connections spaced at

20 mils (508 μm). With no material inserted, breakdown occurred at 1700 V. With material inserted, arcing was experienced at 1400 V. The result of the arcing is shown in Figure 5.

Capacitance

Material capacitance is a measure of cross-coupling between conductive paths. The capacitive effect of the material is determined by using a monostable multivibrator. Pulse duration is determined by an external resistor and capacitor. If the multivibrator is triggered with the external capacitance pins (adjacent pins) open circuited, the resulting width has capacitive contributions from internal package capacitances as well as socket and pin-to-pin capacitance. This pulse width was measured, the IC package was connected to the IC flatpack socket through CE, and the measurement was repeated. The difference in pulse widths between the two measurements is then attributable to CE. Because the difference in pulse widths (nanoseconds) approached the accuracy of the pulse width measurement device, only an upper bound could be found. This bound is one picofarad for a 20 mil (508 μm) distance between conducting areas of 500 mil² (323 mm²).

Contact Area and Density

The size and distribution of particles limit the minimum contact area of CE (Figure 2). A probe diameter smaller than the distance between particles cannot provide a high probability of contact. As the contact area decreases, the probability of making a connection decreases. The user thus requires a minimum contact area which, if observed, will provide assurance of a good contact. The results³ of a probing test in the form of a nomograph are shown in Figure 6. The nomograph illustrates the reliability (probability/100) of all valid connections as a function of the material thickness and number of contacts. As an example, consider a printed circuit board to be tested by probing at 100 points through 5 mil (127 μm) material. If the area of each probe is 105 mil² (0.0645 mm²), one can find the probability that all 100 points will provide a valid connection. Assuming a sufficient distance between probes to prevent shorting, the probability of 100 valid connections is greater than 0.99999 (Figure 6).

The question of minimum distance between contacts is also a statistical problem. The manufacturer has suggested a minimum distance between contacts to be 1.2 times material thickness. As a matter of practical experience, it has been shown that a more practical figure to use is 1.5 times material thickness.

As a final example, using 10 mil (254 μm) material and 15 mil (381 μm) spacing between circular probes of diameter 25 mils (635 μm) each, a contact density of approximately 625 contacts/in²

Figure 5. 5-Mil ($127\ \mu\text{m}$) Conductive Elastomer Arcover
(13X)

(96 contacts/cm²) may be established. Application of the nomograph in Figure 6 yields a probability of approximately 0.999993 that all 625 contacts will provide a valid connection.

Temperature Characteristics

The material was examined in two types of temperature environments: high temperature, and cycling from high to low temperature. The material was placed in an oven with the resistance monitored on a strip chart recorder using a four-wire connection.

For the high temperature test, material was exposed to temperatures from 125°C to 250°C for 30 hours with no sign of connection failure. The material was also held at 300°C for 7 hours with no connection degradation. The high temperature test left the material charred and brittle and unsuitable for future use.

Results of the cyclic test (150°C to -55°C to 150°C....) showed that the material provided a reliable connection. Temperature cycling also left the material in its natural texture.

Figure 6. Conductive Elastomer Connection Reliability Nomograph

The cyclic temperature test demonstrated an ability to shape the material. Figure 7 shows how the material underwent permanent deformation, yet remained in a natural texture. The ridges were made by sandwiching the CE under pressure between two surfaces, one of which had two holes drilled.

Figure 7. Permanent Deformation of
5-Mil (127 μm) Conductive
Elastomer (13X)

Cleaning

Contaminants on the polymer surface such as solder flux, fingerprints, and hand lotion may be effectively removed using trichloroethylene. Although it suffices as a cleaning agent, it acts to partially or completely dissolve plastics which may be found close to the CE in a fixture, so care should be taken when it is used near foreign materials.⁴

Mounting

CE may be mounted in a fixture restrained by surrounding surfaces. If a more permanent mounting is required, a silicone based adhesive should be used to ensure that the polymer binder is not degraded.

ACCOMPLISHMENTS

In general, conductive elastomers may be considered for implementation where any or all of the following characteristics are required: low capacitance, scratchless connector, or multipath conductor.

- CE has been successfully used in an IC tester adapter for an interface between the tester and test fixtures containing the IC. The original configuration employed *fuzz buttons*. CE application provided a low capacitance, low resistance, positive interface between fixture and tester.
- CE may also be used to eliminate spring loaded contact pins such as those found in printed circuit board testers. The spring-loaded pins may be replaced by solid pins of equal length and interfaced with CE.
- CE may also be used as a scratchless connector for interface between probes and delicate surfaces. CE may be used as a scratchless connector to gold lines deposited on a thin wafer. Application for CE has been planned for use in testing flat cables which have conductive 2 mil (50.8 μm) aluminum layers. CE provides a scratchless connection for testing, whereas previous probing techniques tended to scratch the surface and degrade performance.
- CE makes an excellent interface for a Kelvin connection. Small diameter solid coaxial cables provide a rigid probe as well as a two wire contact. If CE is used as the interface, the four-wire contact may be extended to the desired probing point. The coaxial interface surface may be prepared by electroplating a small layer of shiny copper to provide sufficient contact area for the CE (Figure 8).

There are several considerations and limitations the engineer should be concerned with when considering the use of CE.

- A scratchless connection can be made with CE.
- Pressure is required to provide a thru connection; the magnitude of pressure can be determined by using the graph in Figure 3. Although a thru connection is easily made with sufficient pressure, isolation is maintained for adjacent

Figure 8. 85-Mil (2.2 mm) Electroplated Solid Coaxial Cable (25X)

contacts with a minimum distance (1.5 times CE thickness) requirement.

- Statistical properties of CE limit the minimum contact area. The nomograph (Figure 5) provides an aid in selecting contact areas.
- When multiple probes are used, steps should be taken to ensure equal force probe heights (and equal pressures), thereby providing equal pressure to all areas being probed. The distance between probe surface and probe holding medium must be only a few mils to provide a good contact area.
- CE is not tolerant to twisting. Thinner 5 mil (127 μ m) material is less tolerant of twisting than thicker 20 mil (508 μ m) material.
- Current pricing of CE is \$50 to \$60 for a 5 inch by 5 inch (127 by 127 mm) area, depending on the thickness.

FUTURE WORK

An application may require that the conductive elastomer be permanently affixed to a probing or testing surface. Such a capability does not exist. Two problems arise: if a conductive adhesive is used, extreme care must be exercised not to short adjacent contacts. And if nonconductive adhesive is used, steps must be taken to ensure that after drying, a nonconductive layer does not form between probe and material or testing surface and material and thus prevent an electrical path.

Another area which needs to be explored is the ability to mold conductive elastomer. The feasibility to mold became apparent in the cyclic temperature and is shown in Figure 6.

REFERENCES

¹Manufactured by Chromerics, 77 Dragon Court, Woburn, MA 01801.

²Charles H. Kuist, "Anisotropic Conduction in Elastomeric Composites", *Connector Symposium*, Cherry Hill, NJ, October 1974.

³Private communication, Charles H. Kuist, Chromerics, Woburn, MA 01801.

⁴Lloyd C. Jackson, *Contaminant Removal Using Solubility Parameter Technology*. Unclassified. Bendix Kansas City: BDX-613-1200, August, 1974.

DISTRIBUTION

	Copy
R. Bulcock, ERDA-KCAO	1
V. C. Vespe, ERDA-ALO	2
J. A. Freed, LASL	3
S. J. Buginas, LLL	4
H. M. Brinkmeier, Monsanto	5
D. H. Weingarten, SLA	6
J. A. Knuth, D/100, BC38	7
D. H. Bahm, D/131, FC39	8
J. A. Dimarco, D/131, FC39	9
R. A. Hayes, D/131, FC39	10-14
D. R. Lemon, D/131, FC39	15
W. E. Simes, D/131, FC39	16
G. A. Yocum, D/131, FC39	17
J. D. Corey, D/554, BD50	18-19
L. Stratton, D/554, 2C44	20-22
R. F. Pippert, D/700, 1A42	23
R. P. Frohmberg, D/800, 2A39	24
E. A. Kroencke, D/812, 2A27	25
W. H. Deterding, D/814, 2C43	26
R. E. Kessler, D/865, 2C40	27