SEPARABLE ELECTRICAL CONNECTORS FOR SPACE: A TRIBOLOGICAL AND ELECTRICAL ASSESSMENT

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ABSTRACT

The electrical and tribological properties of separable electrical connectors have been examined in air and vacuum. Two types of commercially available connector were tested, each of which utilised gold-plated pins and sockets. It was observed that contact resistances of each pin/socket connection remained essentially constant throughout testing and was the same in vacuum and air. However insertion and extraction forces in vacuum were significantly higher than the corresponding forces in air at atmospheric pressure. Examination of pins following accelerated life testing showed some wear attributable to the ploughing action of socket retainer springs. Nevertheless, wear over 500 insertion/extraction cycles was acceptably low. Connectors subjected to fretting tests (over 10^6 cycles) showed no electrical degradation and no discernible contact wear. The paper also reports some preliminary studies aimed at determining whether there exists a need to screen pins and sockets for space connectors.

Key words: electric contacts, vacuum, tribology.

1. INTRODUCTION

With the envisaged increase in the use of retrievable space modules (eg. Columbus), a need has arisen for reliable and re-usable electrical connectors. Such connectors must be capable of providing reliable power and data links between, say, an orbital space platform and a retrievable test module during the course of several docking manoeuvres. Thus connectors of this type will be required to undergo several couplings and de-couplings in space and during ground testing.

Whilst separable connectors have been extensively and successfully employed on spacecraft, they have hitherto played a static role inasmuch as they have not been subjected to repeated matings and dematings. Their employment has therefore been undemanding in a tribological sense and their ability to withstand repeated connect and disconnect operations in space is not known. A need has therefore arisen to examine and characterise the behaviour of separable electrical connectors when operating in both high vacuum and air at atmospheric pressure. To this end tests have been carried out aimed at determining the tribological and electrical properties of candidate connectors. This paper reports electrical and tribological measurements made in air and high vacuum on two types of commercially available connector.

In addition the pins and sockets of one of the connectors tested were subjected to individual measurements of insertion force and contact resistance **prior** to insertion in the connector body. The implications of these data, and their statistical distribution, with regard to the possible need for screening of pins and sockets is discussed.

2. CONNECTOR TYPES

For the purposes of this work the following terminology will be employed. The term "connector" shall apply to a plug and its receptacle, both bodies being fitted with either pins or sockets. The term "contact" or "contact pair" shall apply to a single pin and socket.

The two connector types employed in testing are designated Type 1 and Type 2. The Type 1 connector is intended for medium-to-high current transmission whereas the Type 2 connector is intended for low-current, signal transmission.

Type 1 connector

The Type 1 connector, shown in Fig.1, consists of a body manufactured from diallyl phthalate into which are fitted gold-plated pins or sockets. No screening shields were fitted to the connector tested. The pins (16 gauge) and sockets are manufactured from brass with a finish of gold plate over copper. The spring retainer, which imparts a retention force to the pin, consists of a collar and tongue, as shown in Fig. 2a. The collar is formed of

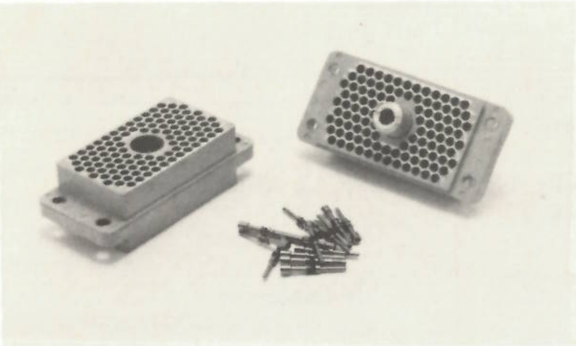

Fig.1 Type 1 Connector.

beryllium copper with a finish of gold plate over copper. For the present tests the connector halves were fitted with eight pins and sockets.

The connector is fitted with a removable polarising boss which is manufactured from aluminium alloy, its surface being anodised. In the main, tests were carried out with the boss removed so as to obtain the frictional properties of the pins and sockets alone.

Type 2 connector.

The Type 2 unit, shown mounted on support plates in Fig.3, is a 37-way, shielded, signal connector. The connector under test was fitted with 20 AWG pins and sockets (Fig. 2b), these being finished in gold over nickel. The pins and sockets were held within the connector by means of an insert made from fluorinated silicone. The shells (shields) were manufactured from aluminium alloy and were coated with nickel. Electrical continuity between the shells is maintained by means of spring fingers. A feature of the Type 2 connector is a self-aligning spring (see Fig.3) against which one of the connector halves is mounted.

3. APPARATUS

A schematic drawing of the test rig is shown in Fig. 4 (see also Fig.5 for photograph of rig). The arrangement allows a connector block retaining the pins to be moved towards, or away from, a fixed connector block containing the sockets. The movable connector block was inserted and extracted by means of a linear motion drive unit. This drive unit consisted of a linear motion screw driven by a stepper motor via a gear train. For tests involving insertion/extraction cycling the stepper motor was powered via control electronics controlled using pulse trains from a signal generator: control of insertion speed was effected by varying the frequency of these pulse trains, with the drive distance set using micro-switches. Fretting action (oscillating pin displacement: amplitude of oscillation 40 microns) was achieved by computer control of the stepper motor.

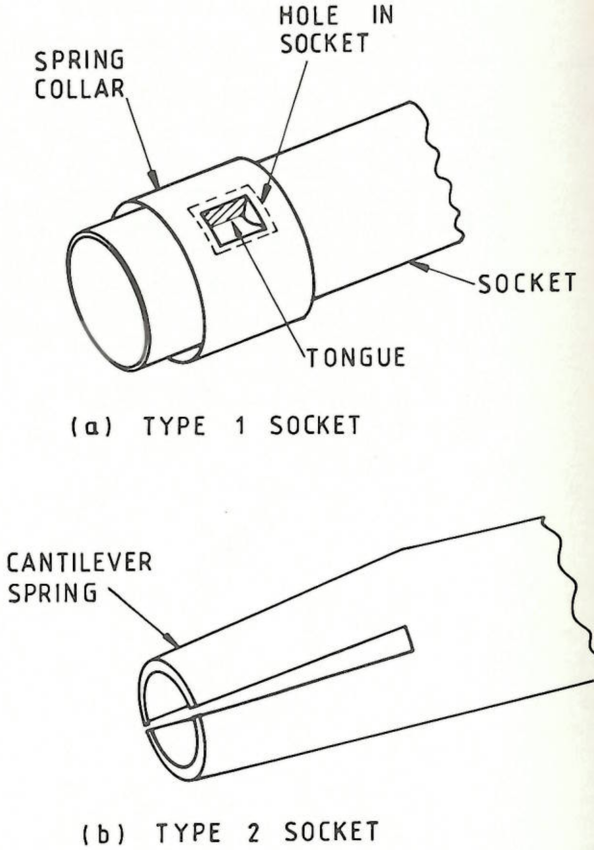

Fig. 2 (a) depicting the socket of a Type 1 connector socket (b) depicting the socket of a Type 2 connector socket.

Travel of the pin connector block was measured using a linear variable differential transformer (LVDT). A load cell attached to the socket connector block measured insertion and extraction forces. The output from the load cell and the LVDT were fed into an X-Y recorder via suitable filters to produce force/displacement curves.

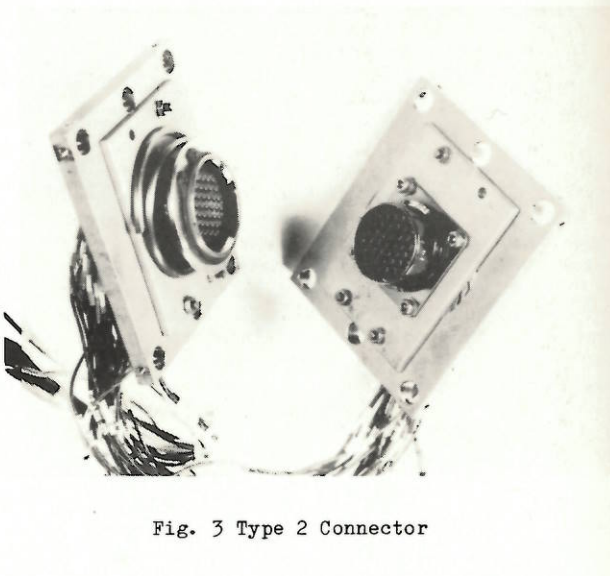

Fig. 3 Type 2 Connector

Two force balance accelerometers were mounted on the connector block support plates to allow measurement of rotational misalignment (rotation about boss axis) of the connector blocks. Accelerometer output is proportional to the sine of the angle of inclination thus the rotational misalignment angle could be calculated from the difference in the voltage outputs of the two accelerometers.

Electrical measurements of contact resistance were made as follows. Eight contact pairs were placed in series with a two ohm resistor and a variable constant current source. The current flowing in this circuit was calculated from the voltage drop across the 2 ohm resistor. Contact resistances were then calculated from the measured voltage drop across each pin/socket contact.

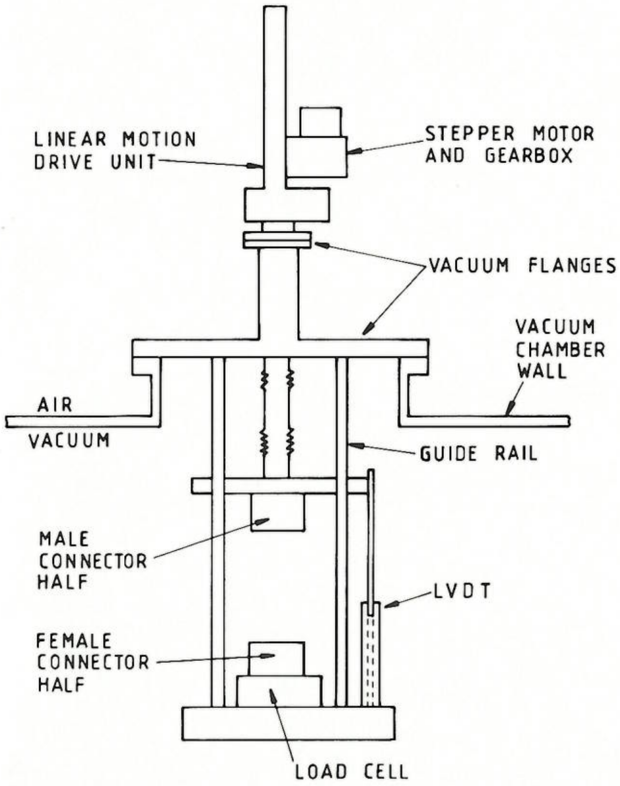

Fig. 4 Schematic drawing of test rig to measure insertion/extraction force as function of insertion distance.

The apparatus was mounted in a high vacuum chamber. Initially this was evacuated by means of a turbo-molecular pump and the pressure further reduced to $1X10^{-6}$ torr by means of ion-pumping.

4. TEST METHODS

To determine the operating characteristics of the connector, three types of test were carried out:-

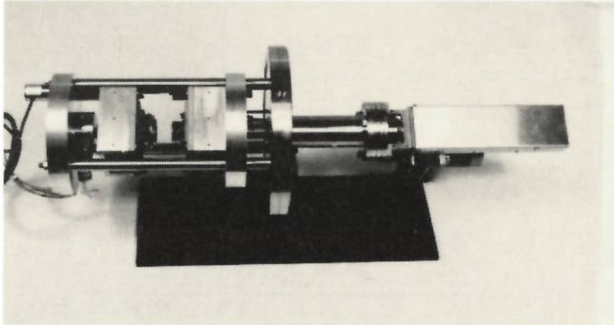

Fig. 5 Photograph of test rig to measure insertion/extraction force.

4.1 Insertion/extraction cycling: life test

Insertion/extraction cycling was carried out by repeatedly driving the pin connector block in and out of contact with the socket connector. Regular measurements of contact resistance were made and force/displacement curves taken over 500 cycles, a number considered representative of the total connections made during the operational lifetime of the connector.

Testing was carried out in air and high vacuum using a current of 0.01 amps. The insertion speed was kept constant at $0.23mms^{-1}$.

The Type 1 connector was subjected to life testing at ambient temperature whereas the Type 2 connector was operated at high temperature (60 deg.C) and low temperature (-10 deg.C) in addition to room temperature in the course of its life test.

4.2 Fretting

To simulate the effect of fretting (low amplitude displacement between two normally loaded metal surfaces) the pin connector was brought into electrical contact with its socket counterpart and the pin block cycled to and forth over a displacement (wipe) of 40 microns. Contact resistance was measured at frequent intervals over the test duration (10^6 fretting cycles). Testing took place under high vacuum conditions only ($1X10^{-6}$ torr). The Type 1 connector only was submitted to this test.

4.3 Alignment testing

Alignment testing involved measuring the insertion and extraction forces produced by the connector in various states of rotational misalignment about the boss axis. Testing was carried out in air only over a rotational angle range of $\pm$ 3 degrees. Again this test was restricted to the Type 1 connector.

4.4 Individual screening measurements on pins and sockets.

Prior to the connector testing described above, pins and sockets of a Type 2 connector were subjected to screening-type measurements. The pins were sorted according to size and the sockets sorted according to the forces needed to insert and extract a steel pin of chosen diameter: this measurement being made with an Instron pull-test machine. Two groups of pin and

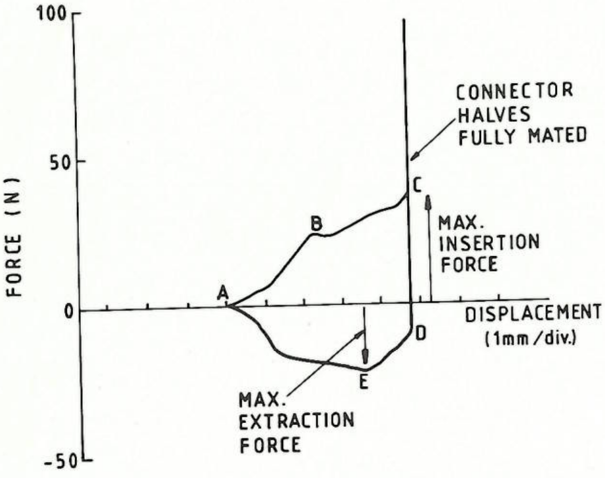

Fig. 6 Typical curve of insertion/extraction force vs. displacement for Type 1 connector.

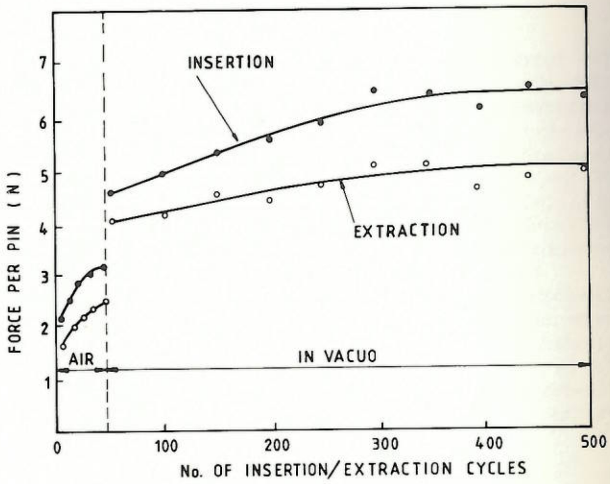

Fig. 7 Plot of maximum insertion and extraction forces vs. number of matings for Type 1 connector.

socket pairs were selected to obtain the lowest and the highest loads from the batch. Insertion and extraction force measurements were made of the chosen pairs. The contact resistance of the pairs with the worst characteristics (that is the smallest diameters and lowest insertion force) were measured by the four-wire method in air.

5. RESULTS

5.1 Insertion/extraction cycling

5.1.1 Contact resistance

Average contact resistance (ie. the mean of all measurements of resistance of individual pin/socket contacts) measurements varied little over the test period of 500 insertions. Type 1 contacts exhibited an average contact resistance of 1.75 mohms whilst the equivalent value for Type 2 was 2.9 mohms.

The average contact resistance associated with both types of connector was found to be essentially the same in both air and high vacuum.

5.1.2 Force/displacement characteristics

Type 1 connector.

It was observed that the general shape of the insertion/extraction force versus displacement curves is as shown in Fig.6.

Measurements were made of maximum insertion force and maximum extraction force as defined in Fig.6. Fig.7 indicates that on going from air to high vacuum both the (maximum) insertion and extraction forces increase sharply. Thereafter, with increasing number of contact make and breaks, the forces increase gradually reaching an essentially constant value upon the completion of about 300 cycles. Note that over the test duration the maximum insertion force increases from about 2N (in air) to about 6.5N (in vacuo).

A test aimed at establishing the dependence of insertion force on electrical current showed no discernible dependence in the current range 0.01 - 3 Amps.

Measurements of insertion and extraction forces were also made with the polarising boss fitted but with the pins removed. These showed that both the insertion and extraction forces increased gradually (there was no rapid rise on going from air to vacuum) with increasing cycles, reaching constant values following completion of about 300 cycles. Maximum insertion forces ranged from 46N to 75N whereas the maximum extraction forces ranged from 45N to 65N.

Type 2 connector.

An example of a force-displacement curve for the Type 2 connector is shown in Fig. 8. The curve shown is for a connector containing no pins or sockets.

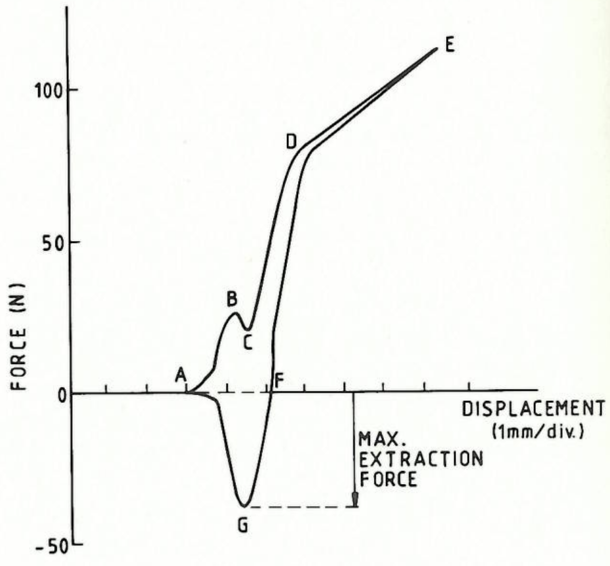

Fig. 8 Typical curve of insertion/extraction force vs. displacement for Type 2 connector (less pins).

The shape of the curve between A and C is accounted for by friction between the connector shells. The two-stage rise in insertion force CD and DE is due solely to compression of the self-alignment spring. On extraction, the spring extends and the force decreases along the line EF. EF does not, and would not be expected to, follow CE faithfully because of spring hysteresis. On further extraction the force-displacement curve is dominated by the frictional forces accompanying the sliding of the male connector shell against its female counterpart. This part of the curve is characterised by a maximum extraction force (G).

On carrying out similar measurements with a connector which was fully complemented with pins and sockets the overall curve shape of Fig. 8 is repeated. However there is now a tendency for the peak B to shift towards, and indeed to merge with, that part of the curve designated CD. Thus the accurate measurement of maximum insertion force proved difficult and such measurements are not reported here. However the peak G representing the maximum extraction force was unaffected and remained distinct. The manner in which this maximum extraction force changed with number of insertion/extraction cycles is shown in Fig.9. In general the shape of this curve is similar to that observed with the Type 1 connector in that (a) there is a twofold rise in extraction force on going from air to vacuum and (b) the extraction force increases on cycling in vacuum, reaching a stable value following some 300 cycles. Changes in temperature do not therefore appear to affect significantly this trend.

Note that the forces shown in Fig. 9 differ from those of Fig. 7 in that they represent the friction associated with the extraction of the shells as well as the pins and sockets. Measurements made with the shells only (i.e connector less pins) indicate that shell-to-shell rubbing contributes in the region of 20% to the frictional forces plotted in Fig.9. This implies that the maximum extraction force **per pin** varies between about 0.9N (in air) to about 2.6N (in vacuo following 300 cycles). These values are approximately half the corresponding values observed on the Type 1 connector.

5.2 Fretting Tests

No change in connector (Type 1) performance was observed over a million fretting cycles. Contact resistance remained unchanged with an average value of 1.73 mohm per pin contact. Similarly, force/displacement characteristics before and after fretting were essentially the same.

5.3 Alignment testing

The effect of rotational misalignment on the insertion/extraction force of the Type 1 connector is shown in Fig 10 The graph indicates that a margin of +/- 1.5^{o} in angle of rotation is allowable with this type of connector before the forces increase appreciably.

5.4 Screening measurements

A batch of 37 contacts (Type 2 only) were examined individually in air (prior to testing in connector). Insertion force ranged from 0.49N to 1.10N with a mean force of 0.66N and a standard deviation of 0.12N. The contact resistances varied between 2.91 and 3.35 mohms and exhibited a mean value of 3.15 mohms and a standard deviation of 0.11 mohms.

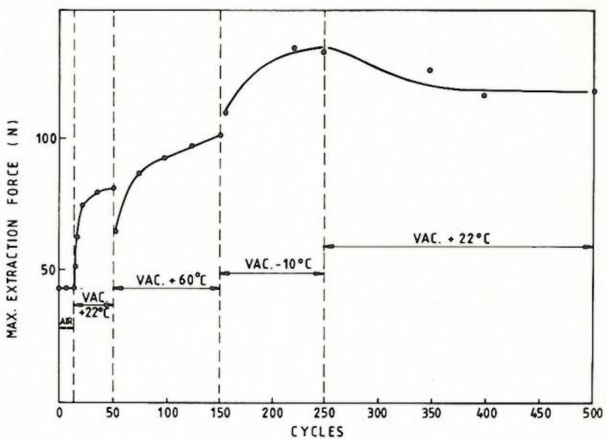

Fig. 9 Plot of maximum extraction force vs. matings for Type 2 connector.

It might be expected that the contact resistance would decrease with increasing insertion force (since an increasing insertion force implies an increasing contact load which in turn would bring about a decrease in contact resistance) but, surprisingly, there exists no such correlation. In view of this it is intended that the method of measuring insertion forces of individual pins and sockets be re-examined and checked for validity. Thereafter additional measurements will be performed with further batches of contact pairs in order to determine at what point the reduction in insertion force, and hence contact load, leads to increases in contact resistance beyond acceptable limits.

In the batch examined these limits were not exceeded and indeed the variation of contact resistance was remarkably small.

6. POST TEST EXAMINATION

6.1 Insertion/Extraction cycling

Type 1 connector

The pins and sockets of the Type 1 connector were examined for wear following life testing.

Wear scars were found on several pins and socket tongues. Wear scars on pins were found by travelling microscope to be typically 0.1mm deep, 0.4mm wide and 5mmm long. Although dimensional measurements on the scars observed on the tongues proved impossible to carry out, such scars were perceived to be shallower than those observed on the pins. Similar scars were discovered on 65% of the contact pairs subjected to vacuum testing, with the position of the pin scar corresponding to the location of the tongue on the spring collar of the socket.

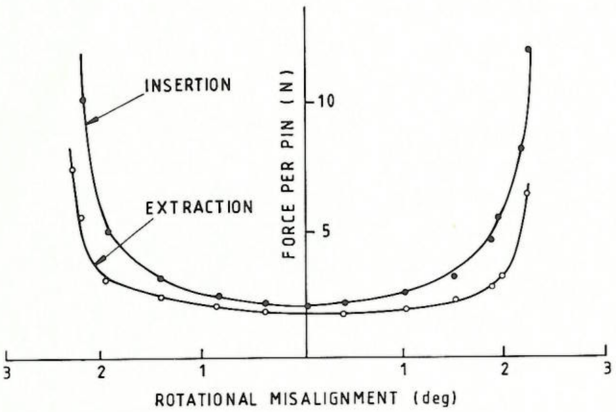

Fig. 10 Effect of rotational misalignment on insertion and extraction force of Type 1 connector.

Significant amounts of gold-coloured debris were found deposited on the rig in close proximity to the connectors. Similarly, small flakes of the red paint used on the retaining collar of the connectors were seen in the recesses of the connector block.

Pins and sockets subjected to fretting tests exhibited no signs of wear after $1X10^6$ cycles. However it was noticeable that again specks of red paint had been liberated.

Examination of the contacting surfaces of the polarising boss following life testing revealed wear scars on some faces. The anodised finish in the region of this scarring appeared to have worn away so as to reveal the underlying aluminium substrate. There was however little wear debris evident on the connector block halves.

Type 2 connector

Examination of the pins and sockets of the Type 2 connector following life testing revealed very little evidence of wear. The shells however did show signs of wear, in particular in and around the locating key where there was evidence of ploughing of the female shell by the key of the male shell. This ploughing action had resulted in the displacement of material rather than the formation of free debris.

7. DISCUSSION

Electrically the performance of the contacts was generally satisfactory in that the mean contact resistance did not change appreciably throughout the life tests or during the fretting tests or as a result of changing the environment from air at atmospheric pressure to high vacuum. The lower contact resistances observed on the Type 1 connector (1.75 mohms cw. 2.9 mohms on Type 2) can be attributed to higher contact loads associated with the heavier duty connector. Indeed this is consistent with the observation of higher insertion and extraction forces on the Type 1 connector in that the frictional force accompanying the sliding of a pin within a socket is proportional to contact load.

Tribologically, the performance of the connectors may be summarised as follows.

a) In vacuum the insertion and extraction forces exceed those in air and increase with increasing number of mating/de-mating cycles. The insertion and extraction forces appear to reach constant values following about 300 cycles.

b) Pins of the Type 1 connector wear primarily as a result of the ploughing action of the tongue of the spring collar but the degree of ploughing wear varies considerably from pin to pin. No detectable wear arose as a result of fretting tests. Contact pairs of the Type 2 connector showed little sign of wear though some wear was evident on the shells.

c) The connector halves (Type 1) can tolerate a rotational misalignment (about boss axis) of about ± 1.5 degrees before insertion/extraction forces increase significantly.

We attribute the increase in insertion and extraction forces, on going from air to high vacuum, to the evaporation of water and, possibly, other volatile surface contaminants. Such substances will act as lubricants if they are of low shear strength or if they reduce adhesion between contacting asperities. The increase in insertion force with increasing number of cycles in vacuum may be due to the gradual removal, by wear, of non-volatile surface contaminants. This reasoning applies both to the gold contacts and the nickel plated shells.

We propose that axial play in the sockets accounts for the lack of detectable wear and, indeed, the constancy of contact resistance during fretting tests on the Type 1 connector. Such results might be expected if, on subjecting the connector half containing the pins to small-amplitude oscillatory motion, the sockets move in unison with the pins ie. with no relative sliding between pin and socket. This would arise if the sliding force needed to separate the contacting asperities of the pins and sockets exceeded that needed to displace the socket in a direction along its axis. As discussed above socket displacement is known to occur (that is, there is some "play" associated with the sockets) and therefore it is conceivable that true fretting action may not have taken place during our test. However even if this be the case, this type of test remains valid as it is representative of the type of motion such connectors may experience during operation.

8. CONCLUSIONS

The following conclusions are drawn.

1. Insertion and extraction forces of gold-plated connectors are up to 3.5 times higher in high vacuum than in air.

2. Contact resistances remain low and constant when connectors are subjected to 500 or less mating/de-mating cycles in vacuum.

3. The contact resistance is the same in vacuum as it is in air.

4. Small-amplitude oscillatory motion of the pin connector half (over one million cycles) of the Type 1 connector does not affect contact resistance or give rise to appreciable wear.

5. Life testing (over 500 cycles) in vacuum indicates that pin and socket wear are at an acceptably low level.

ACKNOWLEDGEMENTS

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