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ADVANCED HIGH-POWER TRANSFER THROUGH ROTARY INTERFACES

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ROLL-RING CONFIGURATION

The successful flights of space shuttles Columbia and Challenger initiated an entirely new generation of space research. The opportunity now exists to build and maintain a variety of strategically important space structures. A large percentage of these spacecraft will have one or more rotating interfaces through which signal and/or power current must be conducted. New demands for high-voltage and high-current transfer, at up to 200-kilowatt (kW) power levels, have been forecast, particularly in the area of solar power arrays.

Considerable research has been conducted to determine the operational advantages and disadvantages of a variety of rotating electrical interface devices. The majority of this effort has been expended on a wide variety of slip-ring designs, power rotary transformers, and the roll ring. The latter device is the subject of this paper.

The patented roll ring, a concept with over 550,000 circuit hours of test in 400 circuits, is a device that performs the same function as a slip ring/brush assembly, but does so by means of rolling instead of sliding electrical contact. The roll ring consists of two concentric conductive rings and at least one rolling flexible conductive element. This latter flexure is fitted to and captured in the annulus space between the two rings. When the rings are suitably attached to two structures aligned with a common axis, the flexure provides a precise electrical coupling between the two. Figure 1 shows a photograph of the circuit components of a typical roll-ring circuit. This particular design has been used to conduct up to 15 amperes of current.

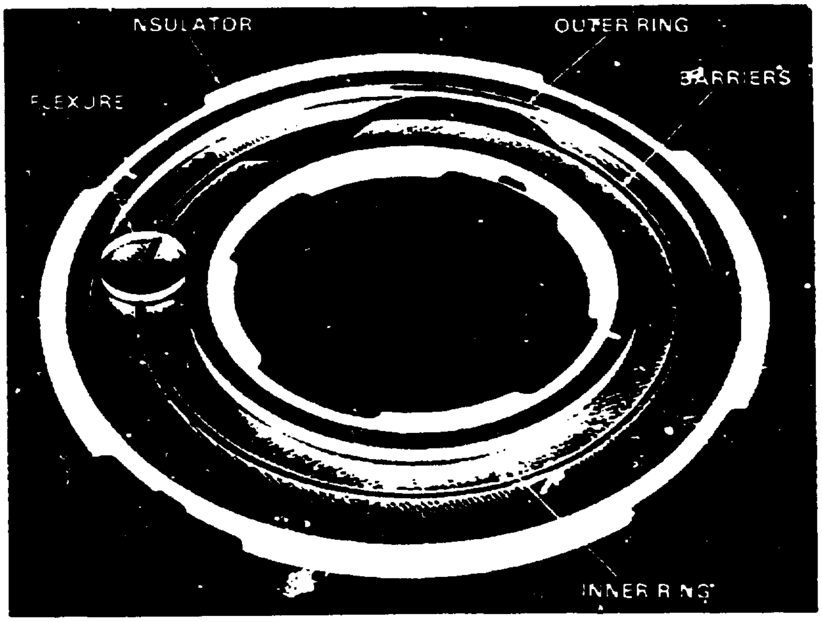

Figure 1: Single Roll-Ring Circuit

DESIGN FEATURES – CURRENT CAPACITY

When transfer currents exceed 15 amperes, the roll-ring design is modified and the number of flexures is increased to divide the total current. The flexure design parameters are also modified to accommodate a transfer current greater than 15 amperes.

Another design consideration is the fact that sliding contact is undesirable in any device that operates in hard vacuum. When more than one flexure is used, the high-power design includes idlers between adjacent flexures to minimize interface sliding. These idlers are guided by a set of rails that are mechanically attached to the inner ring assembly. This arrangement is shown schematically in Figure 2.

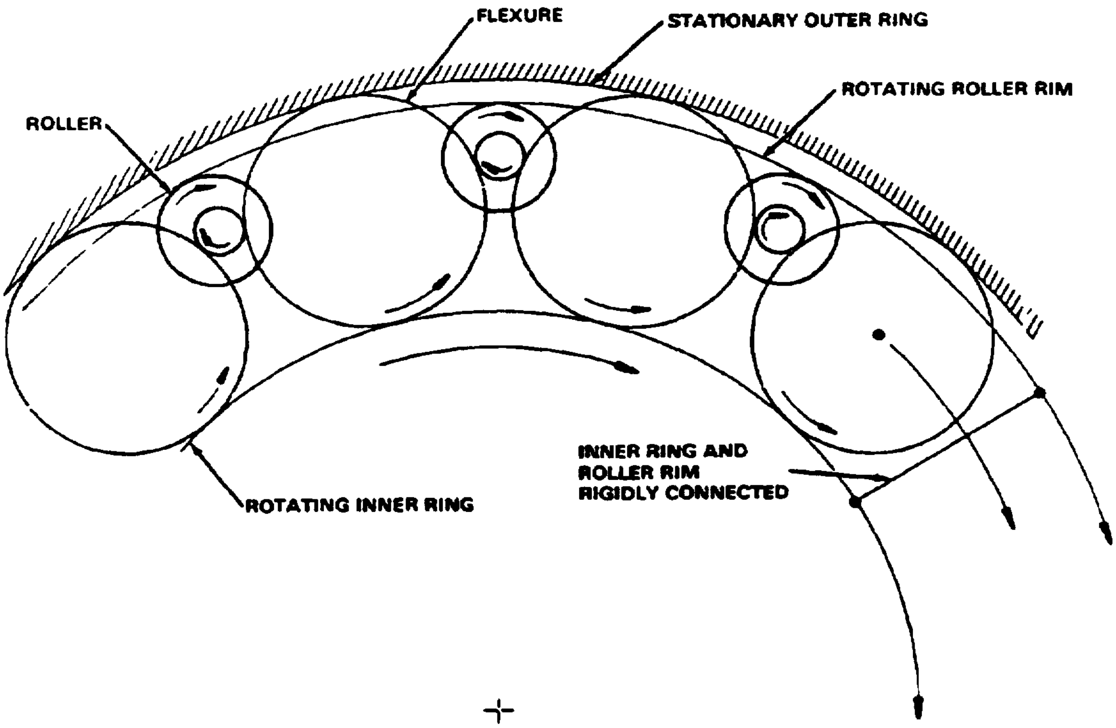

Figure 2: Multiple Flexure Idler Configuration

DESIGN FEATURES — ROLLING INTERFACES

The idlers that maintain the spacing between adjacent power flexures roll on a rim that is rigidly connected to the inner ring assembly. This nonconductive, disc-like mount acts in conjunction with the outer ring spacer/insulators to provide an effective labyrinth between adjacent ring sets. This labyrinth acts primarily to inhibit arcing and corona formation at higher voltages. It also effectively controls debris, and even though debris generated by roll-ring components is almost nonexistent, these barriers also prevent external debris from entering the circuit cavities.

In any given high-power, roll-ring design, the size of all roll-ring components is selected by simultaneous solution of the interface velocity equations of these components so that the relative velocity of the two contacting surfaces at each interface is zero. Figure 3 is a graphic representation of these various velocity vectors.

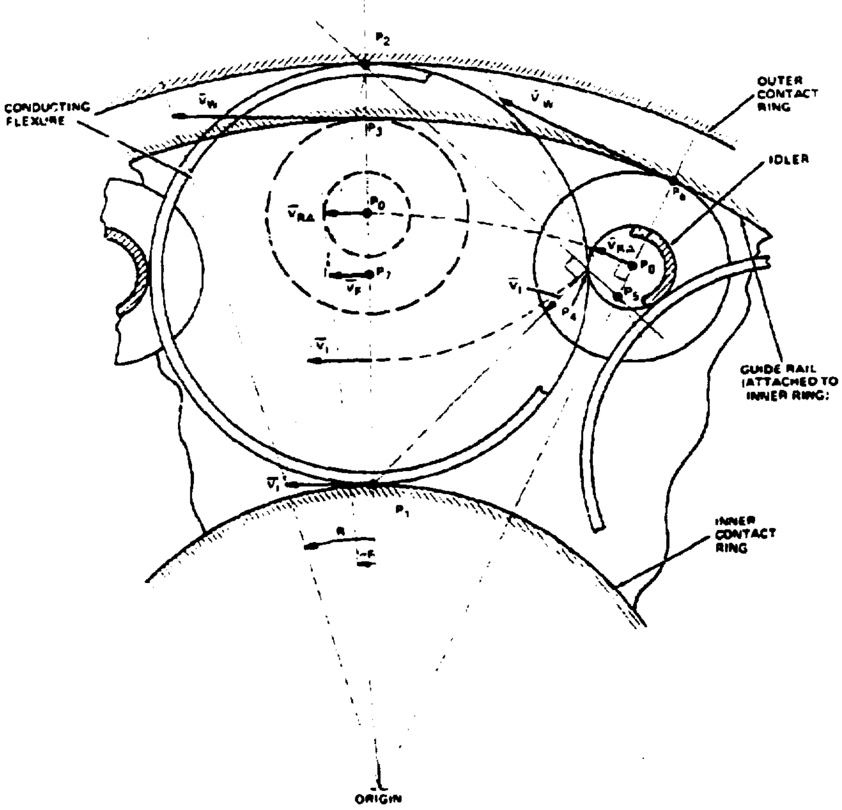

Figure 3: Velocity Vector Diagram

HIGH-CURRENT PROTOTYPES

An initial design was generated on Sperry IR&D funding for a multiflexure high-current test module that incorporated idlers to maintain the spacing between adjacent flexures. This configuration fulfills a need for high-current transfer for both oscillating and rotating applications. This design requires that a full complement of flexures exist in the annulus between the rings. Two iterations of this device have been evaluated to date. The measured contact resistance of a ring set (circuit) is less than .6 milliohm (mΩ). The unit has been tested at up to 200 amperes in 10^{-3} torr vacuum at 10 volts. The unit has been operated for >300,000 revolutions without showing measurable wear. A photograph of the original two-circuit prototype test module is shown in Figure 4. The latest version of the original prototype has demonstrated that weight-to-power ratios as low as .07 kilogram/kilowatt are achievable, even for only two-circuit configurations.

Figure 4: High-Current Test Module

PREVIOUS PERFORMANCE

The modified two-circuit prototype was tested in a 10^{-3} torr vacuum, and evaluations were made at various current levels up to 185 amperes, the limit of the power supply. The transfer efficiency, defined as the percentage of current conducted through the rotating interface without thermal loss, was derived from these tests. The mean terminal-to-terminal resistance of the prototype was measured as 6×10^{-4} ohm. This roll-ring design can be configured to accommodate high voltages, which makes it feasible to include this parameter in the potential transfer efficiency optimization. The governing equation is

$$e_T = \frac{EI - I^2R}{EI} = \frac{E - IR}{E}$$

where

E = Source Potential
I = Conducted Current
R = Effective Terminal-to-Terminal Resistance

This relationship is plotted in Figure 5 for the device resistance of 6×10^{-4} ohm.

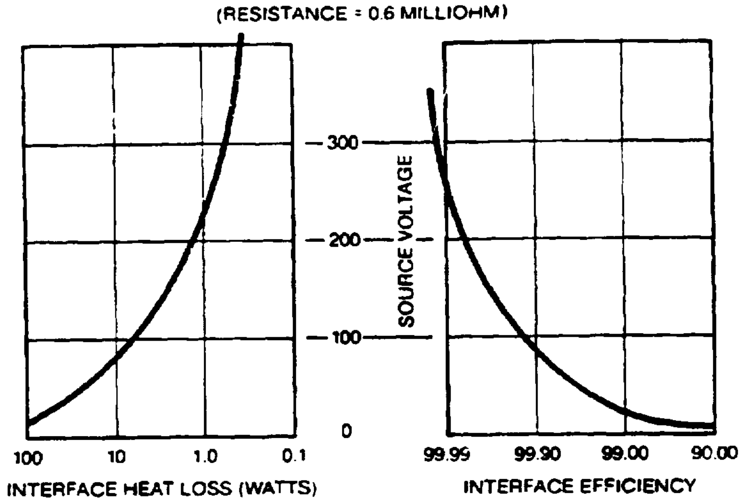

Figure 5: Electrical Transfer Characteristics at 10 kW

FUTURE EVALUATION REQUIREMENTS

The design of a "latest generation" high-power roll-ring test unit has been initiated to evaluate both high-current and high-voltage current transfer. The objective of this roll-ring power transfer assembly is to ultimately conduct up to 200 amperes of current at 500 volts dc. This represents 100 kW of power transfer per circuit.

It would be expensive and difficult to evaluate a power transfer unit under high-current and high-voltage conditions simultaneously because of the size of both the power source and the power load required. However, the unit can be satisfactorily evaluated by monitoring the performance at high voltage with reduced current, and again at high current with reduced voltage. High-voltage tests evaluate the voltage breakdown characteristics of the insulating materials as well as corona and arcing susceptibility. High-current tests evaluate the thermal properties of the unit and contact characteristics. Both test configurations evaluate the transfer efficiency of the unit. By using this approach to test a power transfer assembly, a much lower power expenditure is achieved with essentially the same results. When conducting 200 amperes at 20 volts dc, a power of only 4000 watts must be converted to thermal energy by the load. When operating at 500 volts dc and 500 milliamperes, only 250 watts must be transformed.

Figure 6 is a cross section of a representative power/signal transfer module. An evaluation module of the power transfer section of this device is now being developed under a NASA/Lewis Research Center contract to bring this technology to a more mature status.

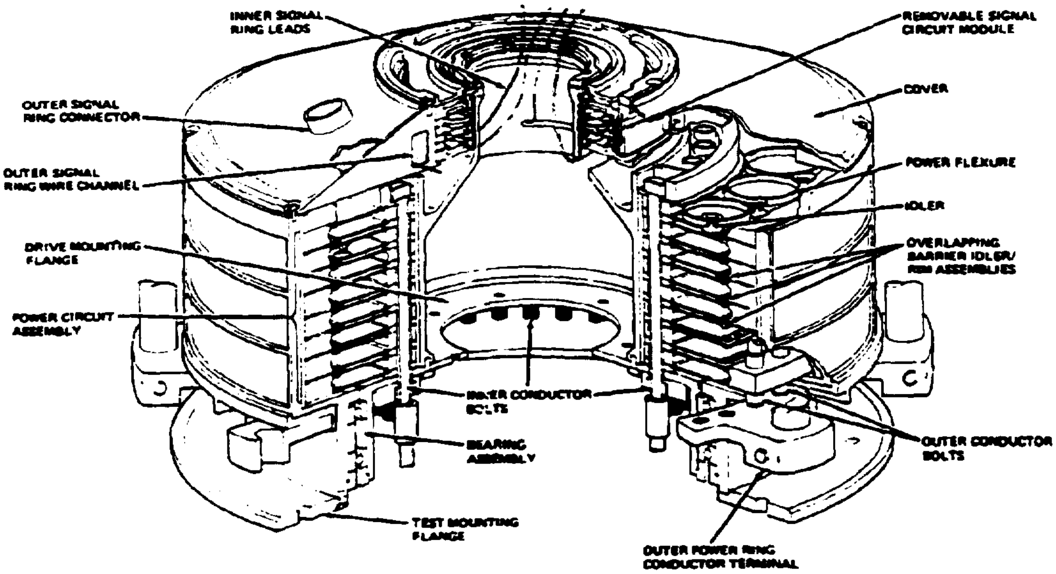

Figure 6: High-Power/Signal Test Unit

SUMMARY

- Sperry has extensively evaluated a patented roll-ring design that is uniquely suited for rotary signal/power transfer in space applications.
- Two high-power configurations of the roll ring have been developed.
- Present lab-proven hardware is available with power transfer capability of 2 kW at 200 amps.
- Higher power units with 100-kW capability are presently in design.
- Theoretical analysis has indicated that power levels of >100 kW are possible, which will keep pace with spacecraft requirements for the 1990's and beyond.