NASA Technical Memorandum 105667

Large Transient Fault Current Test of an Electrical Roll Ring

Edward J. Yenni
Rockwell International
Cleveland, Ohio

and

Arthur G. Birchenough
Lewis Research Center
Cleveland, Ohio

NASA

LARGE TRANSIENT FAULT CURRENT TEST OF AN ELECTRICAL ROLL RING

Edward J. Yenni
Rockwell International
Rocketdyne Division
Cleveland, Ohio

Arthur G. Birchenough
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

ABSTRACT

The space station uses precision rotary gimbals to provide for sun tracking of its photovoltaic arrays. Electrical power, command signals and data are transferred across the gimbals by roll rings. Roll rings have been shown to be capable of highly efficient electrical transmission and long life, through tests conducted at the NASA Lewis Research Center and Honeywell's Satellite and Space Systems Division in Phoenix, AZ [1]. Large potential fault currents, inherent to the power system's DC distribution architecture, have brought about the need to evaluate the effects of large transient fault currents on roll rings.

A test recently conducted at Lewis has subjected a roll ring to a simulated worst case space station electrical fault. The system model used to obtain the fault profile is described, along with details of the reduced order circuit that was used to simulate the fault. Test results comparing roll ring performance before and after the fault are also presented.

BACKGROUND

The space station requirement for transferring electrical power, command and data signals across rotating joints is an ideal application for roll rings due to their high efficiency and long life. Minimal coupling of disturbances on the power crossings to the signal crossings and the ability to withstand large transient fault currents are also of paramount importance to the space station application.

Although prior testing has addressed the efficiency and life aspects of roll rings, never before have transient fault currents of the magnitude discussed here been applied to a roll ring. The primary purpose of this testing was to mitigate concerns of potential damage a worst case space station fault could inflict on roll ring flexures and flexure/conducting ring interfaces.

The test described here was conducted on a four crossing unit developed by Honeywell in 1985 under a contract with NASA Lewis. Each crossing was designed to transfer a steady state 200 A at 500 volts. Prior testing of this unit included transfer efficiency, high voltage, thermal equilibrium, corona, 20 kHz performance and accelerated life test. The roll ring was not disassembled and cleaned prior to this test, due in part to the potentially destructive nature of the test.

SYSTEM MODEL

The space station solar arrays generate DC power at a nominal 160 volts and is regulated by a sequential shunt unit (SSU). The SSU feeds power to a direct current switching unit (DCSU), which controls power flow between the solar arrays and the station batteries. Battery charge and discharge units (BCDU) contain power converters for control and regulation of power into and out of the battery assemblies. Power is then fed to a main bus switching unit (MBSU) for distribution to user loads through DC-to-DC converter units (DDCU).

Precision rotary gimbals are used to position the solar arrays at the optimum angle relative to the sun. Roll rings transfer DC

power, command signals, and data across these gimbals. The gimbal located between the SSU and DCSU provides for beta angle tracking, while alpha tracking is accomplished by the gimbal between the DCSU and MBSU.

Each DCSU was assumed to contain a 4,000 µF capacitor bank to maintain source stability and acceptable primary power quality. A fault occurring close to the capacitor bank would result in a large discharge transient current. The worst case transient from the standpoint of either the alpha or the beta roll ring is a fault occurring downstream of the alpha gimbal connected to the inboard DCSU. The shorter cable lengths in this case provide less damping of the transient waveform.

A system model was developed using the Electromagnetic Transients Program (EMTP) to simulate a worst case fault scenario for the roll rings [2]. EMTP was developed primarily for electric utilities to model electrical networks, power system components, and more recently, control systems.

A one channel model of the space station electrical power system was developed to simulate steady state and transient response of the faulted system. Figure 1 is a one-line drawing of the model showing the location of the simulated fault.
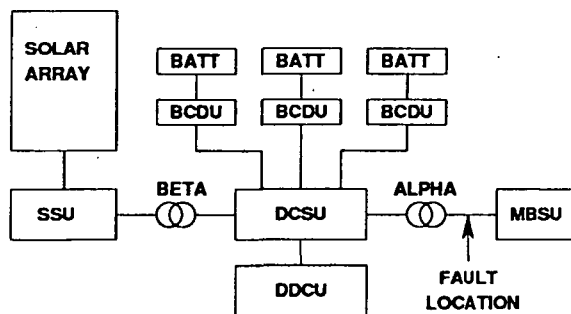

Figure 1 - Model Diagram.

The solar array is operated on the current leg of the current-voltage characteristic, below the array maximum power point. No shunting of the SSU strings to ground in response to the fault was considered. A 300 µF SSU output filter capacitor also contributes to the fault current and was included in the model.

The BCDU current limits each battery assembly to 65 A, resulting in a total battery contribution to the fault of 195 A. The BCDU output filter capacitance included in the model was 1,000 µF per unit. Although it is still uncertain whether the station batteries are to be fused, a decision was made to not include them in the model in keeping with a worst case scenario.

The DDCUs were assumed to provide total isolation from the secondary power system. The model included the DDCU input filters were modeled and assumed the converter elements to be fixed resistor loads. Although more refined models for a DDCU currently exist, this model was considered to be adequate for the purposes of this test.

The fault was assumed to be low impedance. The total fault path resistance was 9.1 mΩ, comprised of resistances associated with the interconnecting cables, DCSU switches and bus, the roll ring crossing and the capacitor equivalent series resistance. The total cable inductance included was 3.7 µH, based on a 0.13 µH per foot value for a pair of twisted 1/0 cables.

The initial state of the power system prior to the fault was full solar array insolation and battery discharge converters enabled, resulting in a 160 VDC nominal MBSU bus voltage. The roll ring was assumed to be carrying a full 130 A load current. The fault was applied and a transient current with a peak of approximately 5,200 A developed, followed by a single current reversal of 1600 A. The period of oscillation was approximately 1.1 mS. The entire transient damps out to a steady state fault current of approximately 400 A within 4 mS. Figure 2 is the EMTP output for the simulated fault.
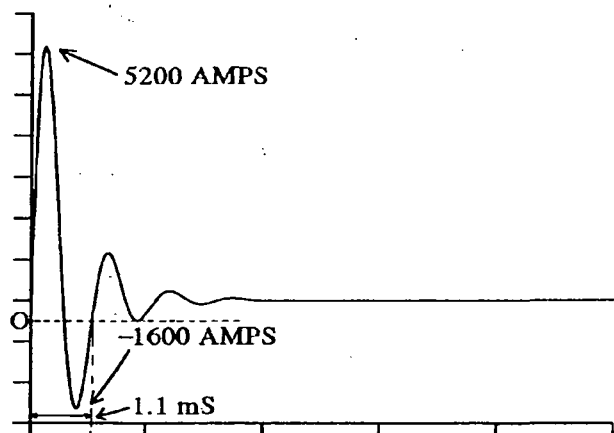

Figure 2 - Predicted Fault Current.

TEST PLAN

The four crossing unit used for the fault testing described here contains a different number of flexures than the anticipated flight design. The flight design uses fourteen flexures per crossing, while the four crossing unit uses only ten. In order to maintain approximately the same current density through each flexure for the fault test, the fault profile was scaled by 10/14. The 10/14 scaling results in a peak fault current of 3700 A.

In actual operation, the roll ring rate of rotation is extremely slow in comparison with the transient event of interest here. A fixture was fabricated to maintain the roll ring rotor and stator in alignment during the fault test, ensuring the flexure/conducting ring interfaces would be fully exposed to the fault.

The circuit shown in Figure 3 was devised to simulate the transient response of Figure 2 as closely as possible.
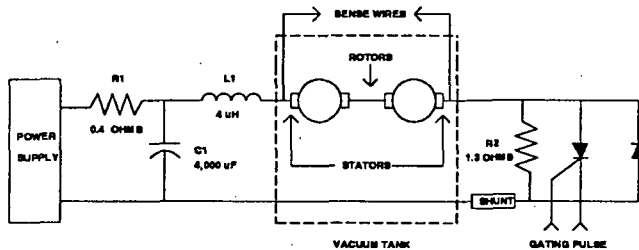

Figure 3 - Fault Test Circuit.

Resistors R1 and R2 were fabricated from 0.25 O.D., 0.014 wall, 304 stainless steel tubing. The 4,000 μF capacitor bank was assembled from multi-layer ceramic capacitor modules with extremely low equivalent series resistance and inductance. Inductor L1 consisted of several turns of closely coupled 1/0 cable.

The power supply charges the capacitor assembly, with resistors R1 and R2 establishing the initial steady state current. The SCR shorts R2 from the circuit after receiving a gating pulse, at which point the final steady state current is determined primarily by R1. The parallel diode maintains the SCR in an ON state during the current reversal. The current shunt provides a means for monitoring the waveform applied to the roll ring.

The combination of inductance, capacitance, and remaining resistance in the circuit determines the response of the transient portion of the simulated fault. The resistance determines the

damping, while frequency is primarily influenced by the inductor and capacitor values.

Adjacent roll ring crossings were connected in series by installing a jumper across their respective rotor terminals, causing the current to flow in opposite directions. The intent of this configuration was to maximize the mechanical stresses placed on the roll ring components due to repulsive forces.

Initial testing of the circuit response was performed with the roll ring disconnected and a jumper installed to avoid exposing the unit to transients until the simulator response was refined. Several trials were required before obtaining a response close to the model in peak current, frequency, and damping characteristics. Each successive test required a decrease in the circuit inductance to increase the oscillation frequency and peak current.

Although the final circuit response is not exactly as shown by the model, it is very close considering its implementation by a reduced order circuit. The component sensitivities were found to be very high and some compromises were made to closely match the desired response. The physical layout of the test circuit was done with considerable care to minimize inductance and therefore achieve the desired peak current.

TEST RESULTS

With the test circuit characteristics properly adjusted, the pre-test crossing resistance was checked for compliance with the original manufacturing specification. Static crossing resistance was a derived measurement determined by passing a known current through each crossing and measuring the resulting voltage drop. Several measurements were recorded from 1/10 to half load to verify a linear transfer characteristic.

The original design specification required the resistance to be less than one milliohm per crossing. Crossing numbers 3 and 4 were measured to be out of specification, with numbers 1 and 2 well below the one milliohm limit.

Crossings 1 and 2 were cabled to the test circuit as shown in Figure 3. The roll ring was installed on the rotor/stator alignment fixture in the vacuum tank. The jumper bypassing the roll ring was removed and several low power test firings were run to verify that the circuit performance was not altered significantly with the roll ring introduced into the circuit.

The vacuum tank was pumped down to 1.4 x 10⁻⁵ Torr and several days were permitted to allow for the assembly to outgas before proceeding with testing. At the completion of the outgassing interval, the low power circuit response was again checked for proper response.

The capacitor bank was then charged to 160 volts and the full power fault was applied. The vacuum gauges were monitored during the fault transient and no changes were observed. Figure 4 is a plot of the actual transient applied to roll ring crossings 1 and 2. The waveform had a peak current of 3860 A, a period of 970 μS and proper damping characteristics. This compared very favorably with the desired 3700 A, 1.1 mS fault waveform provided by the EMTP system model.
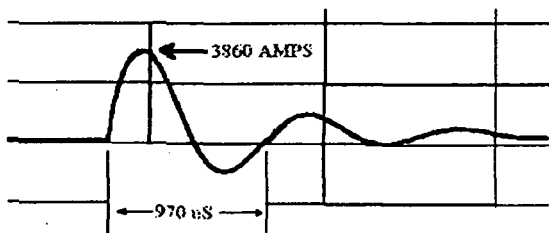

Figure 4 - Applied Fault Waveform.

The voltage drop across the series-connected crossings 1 and 2 was again measured and the derived resistance was calculated to be a 50% decrease from the pre-fault value. The vacuum tank was backfilled with air and opened. Visual inspection of the roll ring indicated that the rotor/stator alignment was maintained and no external physical damage was apparent.

The voltage drops were measured at atmospheric pressure and the values were confirmed to be the same as in vacuum. The roll ring alignment fixture was loosened and the rotor was turned 90 degrees to test for mechanical damage to the assembly. The rotor was able to be turned without difficulty.

After the rotor was moved, a check of the crossing resistance revealed an increase in the series-connected crossings from the pre-fault values by a factor of about four. Returning the rotor to the original alignment position or rocking the rotor back and forth did not appreciably affect these results within approximately +/- 10%. The test setup was reconfigured to measure crossings 3 and 4, which were not subjected to the fault. The reference ring resistances were unchanged from the original measurements.

The roll ring was partially disassembled in an attempt to further characterize the change in resistance for crossings 1 and 2. The flexure/conducting ring interfaces were inspected at the fault contact points using a 50X magnification microscope. Two of the ten flexures exhibited a slight discoloration at the contact points, however, the plating remained intact.

It was also observed that the gold alloy plating on the inner and outer conducting rings was not adhering very well to the beryllium copper alloy base metal. The loose plating was not localized to the area subjected to the fault, but was uniformly poor at the conducting ring grooves the flexures are contained in.

The voltage drop at each accessible component interface of crossing 1 was measured from stator to rotor using a calibrated current source. These values were compared with the theoretical distribution of crossing resistance to ensure there were no significant deviations [3]. The measurements showed a disproportionate increase in the outer conducting ring to flexure to inner conducting ring interfaces. Furthermore, it was more difficult to obtain consistent measurements independent of rotor position, presumably due to the loose plating.

SUMMARY

The results of the roll ring transient fault current test are generally very encouraging. No severe physical damage occurred and electrical continuity was maintained, albeit somewhat degraded. While the observation of loose plating to the conducting ring base metal cannot be explained from tests reported on here, the reasons appear to be unrelated to the fault test and was most likely a condition existing prior to testing. It is possible that a combination of prior testing, environmental and handling factors contributed to this problem.

The decreased post-fault/pre-rotation resistance, coupled with the minor discoloration observed on the two flexures, may have indicated the presence of some localized welding at the flexure-conducting ring contact points. The conducting ring plating problem most likely prohibited a uniform current distribution due to unequal flexure/conducting ring contact areas. The two flexures evidently carried the bulk of the load, yet still survived.

It is important to emphasize the four crossing roll ring that was fault tested was delivered to NASA LeRC for proof-of-concept testing and has undergone accelerated life testing. The unit has been disassembled and reassembled several times and was not inspected prior to this test due in part to the potential destructive nature of the test. Honeywell has made several improvements to

the design of roll rings since delivery of the proof-of-concept unit [3].

This test was believed to be a worst case scenario for faults the space station could possibly present to the roll ring. The program is currently investigating methods of decreasing and redistributing the total bus capacitance, both of which would result in less severe roll ring fault tolerance requirements. In addition, the plating problem probably increased the current density beyond the level intended, even considering the 10/14 scaling for the number of flexures. Although these test results do not obviate the need for additional testing, the concerns associated with roll ring fault tolerance should be somewhat reduced.

ACKNOWLEDGEMENTS

REFERENCES

[1]   Renz, D.D., "Multi-Hundred Kilowatt Roll Ring Assembly Evaluation Results," NASA Lewis Research Center, Proceedings of the 23rd IECEC, 1988.

[2]   Kacpura, T.J., 1990, "Beta Gimbal Fault Current Simulations," Sverdrup Technology, Inc

[3]   Jacobson, P.E., 1985, "Multi-Hundred Kilowatt Roll Ring Assembly Final Report," Honeywell Satellite Systems Division, NASA Report No. CR-174832.

REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE 1992	3. REPORT TYPE AND DATES COVERED Technical Memorandum

4. TITLE AND SUBTITLE

Large Transient Fault Current Test of an Electrical Roll Ring

5. FUNDING NUMBERS

WU–474–42–10

6. AUTHOR(S)

Edward J. Yenni and Arthur G. Birchenough

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E–7029

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, D.C. 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM–105667

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category 20

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The space station uses precision rotary gimbals to provide for sun tracking of its photovoltaic arrays. Electrical power, command signals and data are transferred across the gimbals by roll rings. Roll rings have been shown to be capable of highly efficient electrical transmission and long life, through tests conducted at the NASA Lewis Research Center and Honeywell's Satellite and Space Systems Division in Phoenix, AZ [1]. Large potential fault currents, inherent to the power system's DC distribution architecture, have brought about the need to evaluate the effects of large transient fault currents on roll rings. A test recently conducted at Lewis has subjected a roll ring to a simulated worst case space station electrical fault. The system model used to obtain the fault profile is described, along with details of the reduced order circuit that was used to simulate the fault. Test results comparing roll ring performance before and after the fault are also presented.

14. SUBJECT TERMS

Space station; Test bed; Utility transfer assembly; Roll ring; Slip ring

15. NUMBER OF PAGES

6

16. PRICE CODE

A02

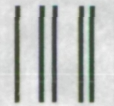| 17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

National Aeronautics and
Space Administration

Lewis Research Center
Cleveland, Ohio 44135

Official Business
Penalty for Private Use $300

FOURTH CLASS MAIL

ADDRESS CORRECTION REQUESTED

NASA