ELECTROMAGNETIC PULSE (EMP) RESPONSE OF EMI/RFI GASKET MATERIALS

Summary

Electrically conductive gaskets used for EMI shielding in electronic equipment may be permanently damaged by high currents induced on enclosure surfaces, by nuclear event. Simulated EMP current pulse testing is reported for the three major generic families of EMI gasket materials. Specific normalized values of peak pulse current capability are given for the gasket materials investigated. Transfer impedance measurements are included to relate gasket EMP damage to loss of EMI shielding effectiveness.

Introduction

Electrically conductive gaskets are widely used in protecting electronic systems from electromagnetic interference (EMI). Some also serve double-duty as environmental seals. However, if a gasketed joint is subjected to an electromagnetic pulse (EMP), such as from a nuclear event or lightning, it is possible that its EMI shielding characteristics may change. Of particular interest is the fact that gasket resistance, which is directly related to EMI shielding capability, may be degraded or even destroyed. This could result from the large currents induced in metal housings by EMP, currents that may affect both the internal structure of the gasket and its interface with the housing.

It is important for the designer who specifies conductive gaskets to know their level of EMP current capability. Equally important is predicting the changes that they may undergo, in case of EMP exposure.

To study EMP effects in EMI gasketed joints, a series of gasket materials was subjected to simulated EMP exposure in the form of single short-duration DC pulses in the 5 kA to 32 kA range, subsequently measuring any changes in gasket resistance. The test series was a two-part procedure:

1. measurement of the electrical resistance of the test gaskets, compressed between two flat metal plates before pulsing;
2. measurement of the resistance of the gaskets immediately after a current pulse or, in some cases, after a series of pulses.

The gasket materials investigated were:

- Material #1 — conductive elastomer filled with silver-coated glass;
- Material #2 — conductive elastomer filled with silver spheres;
- Material #3 — conductive elastomer filled with silver-plated copper;
- Material #4 — conductive elastomer filled with silver-plated aluminum;
- Material #5 — Monel wire mesh;
- Material #6 — tin-plated, copper-clad steel wire mesh;
- Material #7—aluminum wire mesh;
- Material #8—tin-plated beryllium-copper spiral metal strip;
- Material #9—copper-filled elastomer coating on beryl-copper spiral metal strip.

In further tests, the effects of simulated EMP pulses on EMI shielding effectiveness were studied by pre- and post-pulse transfer impedance measurements. Material #3 (Ag-Cu elastomer) was the control because it had exhibited no breakdown under pulsing in prior testing. The other materials tested had all shown significant changes in the earlier pulsing: Material #1 (Ag-glass elastomer), Material #4 (Ag-Al elastomer), and Material #9 (Cu elastomer coating on BeCu spiral). A three-part procedure was used:

1. measure the transfer impedance of each material type over a wide range of frequencies;
2. pulse the gaskets beyond their breakdown point, or to the maximum pulse available, as determined in the first series of tests;
3. retest the gaskets after pulsing over the same wide range of frequencies.

Test Equipment

The EMP simulator was a Spire SPI-PULSE 6000*, which is a coaxial transmission line pulser, DC-charged by a Van de Graaf electrostatic generator. The SPI-PULSE line impedance is about 1.5Ω, with a total capacitance of 14,000 pF. When charged to 125 kV and discharged into a short-circuited load, it can deliver a peak current up to 32 kA for a duration of 75-100 ns.

Figure 1 shows a schematic of the test chamber which is operated at about 10^{-5} mm Hg vacuum.

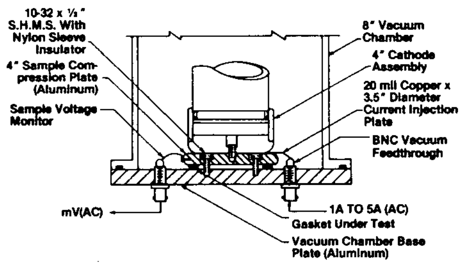

Figure 1. Pulse Test Chamber

In measurements, the stored energy is discharged into the cathode which is directly connected to the gasket compression plate. The plate and gasket form a low-resistance load, effectively a short-circuit to the ground plane. Each gasket to be pulsed was mechanically compressed to 85% (88% for the metal spiral gasket) of its original thickness by tightening the insulated screws. All of the cathode current is driven through the conductive gasket under test to ground. To measure resistance, AC currents in the range 1A to 5A were injected through the gasket. Gasket resistance was computed from the resulting voltage drop across the gasket. Each gasket was mounted in the test chamber and its resistance measured before and after pulsing.

*Some earlier testing was completed on the SPI-PULSE 5000, a similar machine capable of pulses in the 50 kA range.

Test Procedure and Results

The damage threshold current for each type of gasket material was established by pulsing at increasing currents until a significant increase in resistance occurred, or until maximum capability of the SPI-PULSE 6000 was reached.

Figures 2 through 4 show resistance vs. current for the gasket materials investigated. The graph axes are normalized to gasket length by dividing the measured current and resistance values by the linear length of the gasket in inches.

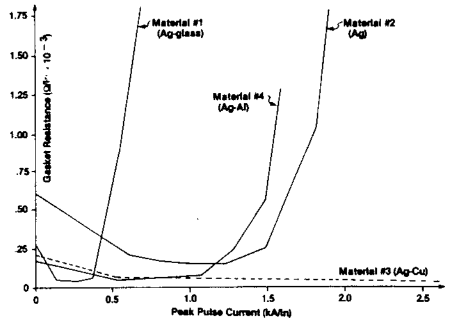

Figure 2. Resistance of Conductive Elastomer Gaskets

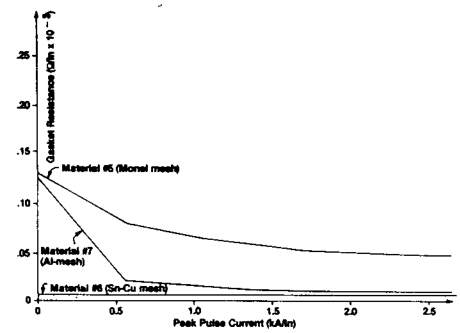

Figure 3. Resistance of Wire Mesh Gaskets

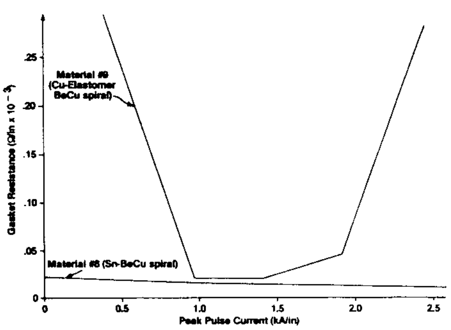

Figure 4. Resistance of Metal Spiral Gaskets

Transfer Impedance Measurements

Resistance changes are only one measure of EMI shielding effectiveness. To establish a wider base for comparing EMI shielding of the various gasket types, transfer impedance tests were carried out over the frequency range 14 kHz to 1 GHz, both before and after simulated EMP pulsing.[1]

Figure 5 is a schematic diagram of the transfer impedance fixture used for the measurements. As with the current pulsing test chamber, the gasket is compressed between two conductive plates to 85% of its original thickness (88% for the spiral metal strip). In this fixture, though, the gasket compression is controlled by air pressure rather than by insulated screws.

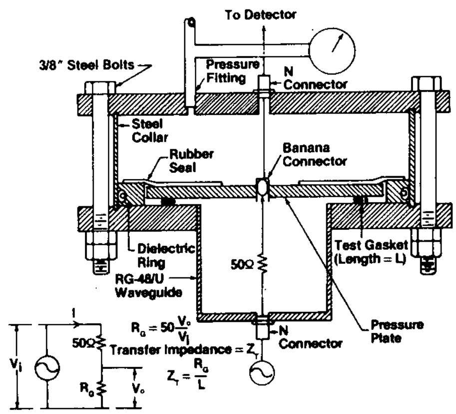

Figure 5. Transfer Impedance Test Fixture

The dimensions of the transfer impedance test fixture are such that resonances associated with circular waveguide modes are expected above approximately 700 MHz. In the measurements up to 10 GHz, therefore, the absolute accuracy of the transfer impedance data is uncertain. However, since all gaskets tested had the same physical size (5.25 inches I.D.), a comparison of transfer impedance values has some validity.

A further problem in the transfer impedance measurements is that the test gasket is free-standing so that RF leakage can occur radially through the gasket itself. It is believed that this effect becomes more pronounced at the higher frequencies and is largely responsible for the positive slope of the transfer impedance plots in Figures 6 through 9. This belief is supported by subsequent measurements made with gaskets mounted in a machined groove where it was found that the transfer impedance plots then exhibited a negative slope with frequency. Transfer impedance is derived from the measured insertion loss of the test fixture (i.e. the ability of the test gasket to short-circuit the coaxial line) and is again normalized to gasket linear length.

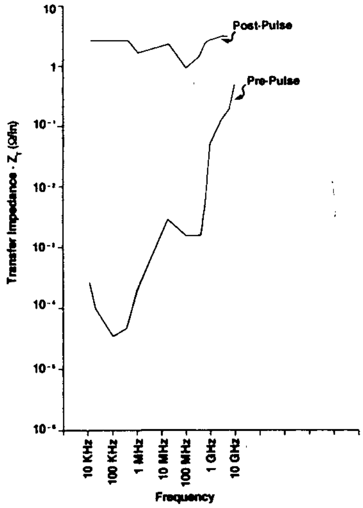

Figure 6. Transfer Impedance for Material #1 Ag-glass

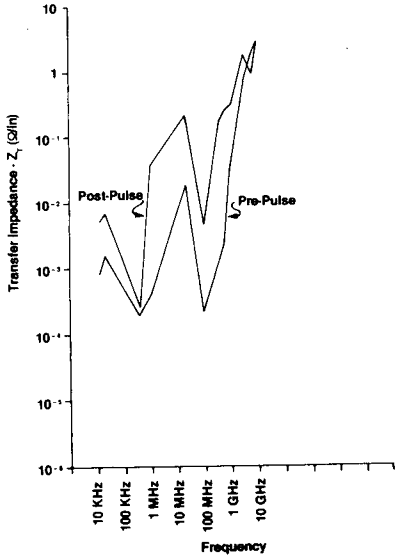

Figure 8. Transfer Impedance for Material #9 Cu-Elastomer on BeCu Spiral

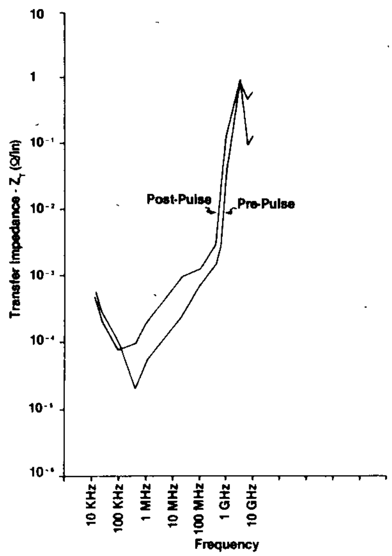

Figure 7. Transfer Impedance for Material #4 Ag-Al

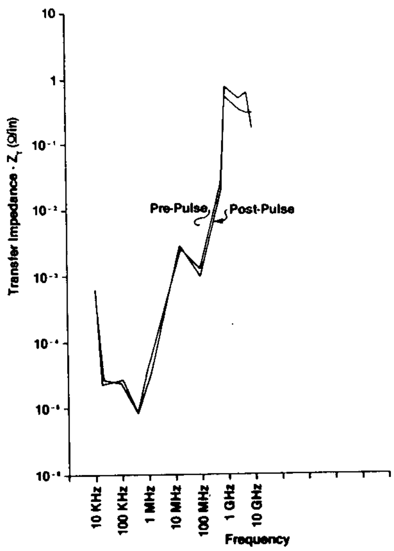

Figure 9. Transfer Impedance for Material #3 Ag-Cu

Transfer Impedance Results

Those gasket types that exhibited breakdown behavior under EMP current pulsing were tested for transfer impedance. Material #3 (Ag-Cu elastomer) was included as a control. Figures 6 through 9 show transfer impedance before and after current pulsing for the four gasket materials included in this part of the investigation.

Discussion

In most of the gasket materials tested, a pronounced "burn in" phenomenon was observed, wherein the apparent gasket resistance decreased with initial low-level current pulsing. It is believed that this effect is associated with cleanup of oxides and similar films at the gasket-to-metal surface interfaces and is not related to the gasket material itself.

In both the current pulsing and transfer impedance tests reported in this article, the gasket was free-standing between two flat metal surfaces. This represents a "worst case" situation that requires the gasket to carry all of the simulated EMP current in the first test and all of the RF current in the second test. This provides a valid, though rigorous, basis to compare the different gasket materials.

In a real-life design of an EMI gasketed joint that must survive EMP conditions, a preferred configuration choice is to locate the gasket in a grooved flange that mates to a flat surface. The gasket itself is then partially protected because a large proportion of the EMP current is carried by the metal-to-metal contact of the flange surfaces and the associated metal bolts.

The peak pulse current data given in this article is expressed in a normalized form meaningful for designers. With an estimate of the expected EMP current on the enclosure surface and knowledge of the length of the gasketed joint that must carry this current, a region can be located on the horizontal axes of Figures 2 through 4. This will then aid in the choice of an appropriate gasket material.

In the conductive elastomer family (Figure 2) it was found that Material #1 (Ag-glass) exhibited the lowest damage threshold current of all gaskets tested. The threshold was less than 0.4 kA/in. Material #4 (Ag-Al) and Material #2 (Ag spheres) both showed damage within the measurement range whereas Material #3 (Ag-Cu) was not damaged at the maximum level obtainable, which was greater than 2.7 kA/in. Current pulses beyond the damage threshold invariably resulted in a precipitous increase in gasket resistance.

GASKET TYPE			GASKET PERFORMANCE PARAMETER						
GENERIC GROUP	MATERIAL NUMBER	CONSTRUCTION	EMP DAMAGE[1] THRESHOLD CURRENT (kA/in.)	EMI PLANE[2] WAVE SHIELDING at 10 GHz (dB)	MAXIMUM CONTINUOUS OPERATING TEMP. (°C)	EMI SHIELDING UNDER VIBRATION	ENVIRONMENTAL SEALING	COMPATIBILITY[3] WITH ALUMINUM IM MARINE ENVIRONMENT	AVAILABLE SHAPES
Conductive Elastomer	1	Ag-glass	0.4	>90	+200	Severe degradation	Inherent from elastomeric properties	Compatible, with[4] proper outboard edge sealing	Wide variety of die-cut, extruded & molded forms
	4	Ag-Al	1.1		+175	Slight degradation			
	2	Ag spheres	1.2		+200	Moderate degradation			
	3	Ag-Cu	>2.7		+125	Negligible degradation			
Wire Mesh	5	Monel	>2.7	50-75	No published data	Slight degradation	None: needs additional elastomeric member.	Needs additional moisture seal member	Rectangular and circular cross section
	7	Al		50-60					
	6	Sn-Cu steel		50-80					
Metal Spiral	9	Cu-elastomer on Sn-BeCu spiral	1.4		No published data		Inherent from elastomeric properties	Needs additional moisture seal member	Circular cross section
	8	Sn-BeCu spiral	>2.7				None: needs additional elastomeric member		

Notes: 1. For free-standing gasket between flat plates.
2. From manufacturer's catalog data.
3. 6061 aluminum with chromate conversion coating.
4. Ref. MIL-STD-1250

Table 1. EMI Gasket Design Parameters

Although some minor recovery effects have been observed, the damage is permanent in the sense that once driven to a high resistance state, a given gasket material remains in that state.

The impact of this damage on EMI shielding effectiveness is clearly illustrated in the transfer impedance data. Material #1 (Ag-glass) in Figure 6 shows a drastic increase in transfer impedance of some four orders of magnitude (corresponding to a change of 80 dB) in the 1 MHz to 10 MHz range. This gasket has essentially ceased to function as an EMI shielding element. Material #4 (Ag-Al) in Figure 7 has degraded less than 20 dB and Material #3 (Ag-Cu) in Figure 9 remains unchanged.

It is believed that the failure mechanism in Material #1 (Ag-glass) relates to the point contact of glass spheres which have a very thin silver coating. There is insufficient conducting metal present to survive heavy current flow. The scanning electron microscope is currently being used in an attempt to determine the exact failure mechanism. In contrast, Material #3 (Ag-Cu) in Figure 9 is filled with silver-plated copper particles with irregular shapes. The high conducting metal content, coupled with a large number of interlocking multipoint contacts between particles, is the key to the ability of this material to withstand heavy current flow.

In the wire mesh family (Figure 3) a hierarchy of gasket resistances was found with Material #5 (Monel mesh) the worst and Material #6 (Sn-Cu mesh) the best. All of the wire mesh gaskets measured were not damaged up to the maximum current available of 2.7 kA/in.

In the metal spiral family (Figure 4) it was found that Material #8 (Sn-BeCu spiral) behaved much the same as the wire mesh types and remained undamaged to 2.7 kA/in. Material #9 is an unusual composite gasket using a copper-filled elastomer coating around a metal spiral. It exhibited the most pronounced "burn in" of all gaskets tested and thereafter behaved much the same as Material #2 (Ag elastomer). It is believed that the unusual "burn in" behavior of this gasket is associated with surface oxidation of the copper filler. After a damaging current pulse, the transfer impedance of Material #9 degraded by approximately 30 dB (Figure 8).

Conclusions

The design of a gasketed joint that will survive and continue to provide EMI shielding after EMP exposure is a complex problem that involves many more issues than the pulse current capability and transfer impedance values considered in this article. Table 1 assembles some, but not all, of the other important factors that enter into the design choice. For instance, performance under vibration is a crucial issue in most military/aerospace applications. Material #1 (Ag-glass) would be a poor choice under vibration.[2] The designer must evaluate the application against a matrix of factors and issues such as shown in Table 1. The final choice will frequently be a compromise between several conflicting issues. In most cases a conductive elastomer gasket will provide the best overall solution; in other cases a metal-type gasket may suffice. Blanks are left in Table 1 where there is not yet sufficient test data to support a statement.

This article reports the results of studies made on commercially-available EMI gasket materials with regard to their ability to survive current pulses associated with nuclear-event or lightning EMP effects. The three generic groups investigated were conductive elastomer, wire mesh, and metal spiral gasket materials. The contribution made to the art is the identification of specific normalized values of peak pulse current capabilities in the gasket materials investigated.

References

1. P.J. Madle, *Transfer Impedance and Transfer Admittance Measurements on Gasketted Panel Assemblies and Honeycomb Air-Vent Assemblies,* IEEE International EMC Symposium, Washington, D.C., 1976.
2. C.H. Kuist, *EMR Shielding of Conductive Gaskets Under Vibration,* IEEE International EMC Symposium, Seattle, Washington, 1977.

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