Degradation and Non-Linear effects in Corroded EMC Joints Exposed to High Power Microwaves (HPM)

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Abstract

Determination of shielding effectiveness is a vital part in the analysis of a systems capability to withstand High Power Microwaves (HPM). It is usually assumed that the shielding effectiveness, determined at low field levels, is valid also at HPM threat levels. This assumption might be refuted by the presence of non-linear effects. These may result in generation of new frequency components in the spectrum of the transmitted pulse. Irradiation at threat levels may also result in damage of shielding joints. Measurements have been performed on 31 corroded EMC joints. No major degradation could be detected after HPM irradiation at 3 GHz. Most of the objects showed none, or only a moderate generation, of harmonics.

1. Introduction

It is usually assumed that figures of shielding effectiveness, measured at low field levels, are valid also at HPM threat levels. The presence of non-linear effects, e.g. due to electrical discharge or metal-insulator-metal junctions caused by corrosion (the “rusty bolt effect”) may overthrow this assumption. Irradiation at threat level may also result in damage and degradation of the shielding joint. This report presents results of an experimental investigation in which both these aspects have been studied. A full report is given in [1].

2. Test Objects

Measurements were performed on 31 corroded EMC joints. These objects represent selections taken from two studies headed by the Swedish Corrosion Institute (presently SwereaKIMAB) in Stockholm.

The first study was initiated in 1994 and issued its final report in 1999 [2]. The influence of accelerated corrosion on the shielding properties of different material combinations used in joints was studied using near-field measurement techniques between 20 MHz and 2 GHz. Out of the about 40 test samples 5 were included in the present study. These represent some of the most corroded objects from that study. The objects were:
L5: Aluzink plate and lid, CuBe contact fingers. Corrosion test 3 (see below).
L20: Stainless steel plate and lid, carbon filled PTFE gasket, 3.2x1 mm (supplied by Gore). Corrosion test 4.
L31: As L5, but corrosion test 4.
L38: Clear chromated aluminum plate and lid, tin plated contact fingers. Corrosion test 4.
L40: Clear chromated aluminum plate and lid, silver filled elastomer. Corrosion test 4.
The corrosion tests were (a more thorough description is given in [2]):
Test 3: Damp heat, cyclic test according to IEC 62-2-28, 30 days, with addition of SO_2, 0.5 ppm and NO_2, 0.5 ppm.
Test 4: Damp heat, cyclic test according to IEC 62-2-28, 30 days, with addition of SO_2, 0.5 ppm and NO_2, 0.5 ppm, periodic immersion in 0.1 wt% NaCl solution, 30 days.

A drawing of the test objects is shown in Fig. 1. A photo of L38 (after corrosion testing) is shown in Figure 2.

The second SCI study started in 2000 and was reported in 2004 [3]. A summary of the report is found in [4]. It comprised 58 different combinations of gasket and frame and cover plate. The objects were exposed for one year under a hood on a terrace close to a lake, immediately north of the Stockholm city boundary, see [1,3]. A complete description of the objects and the degradation in shielding properties due to corrosion can be found in [3,4]. The geometry of the test objects was similar to that of the first study.

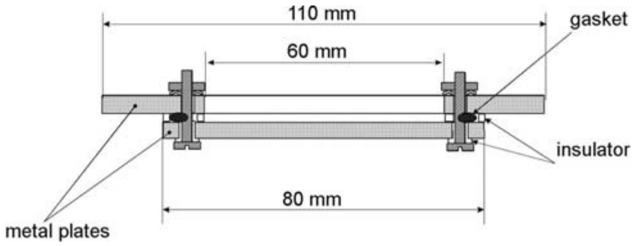

Figure 1. Geometry of the EMC joints from the first study. From [2].

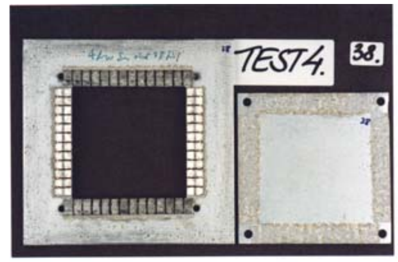

Figure 2. Tests object L38. Clear cromated aluminum, tin plated contact fingers. After exposure to test 4. [2].

3. Measurement Set-Ups

Two different kinds of measurements were performed: measurement (at low field levels) of the transmission cross section of the corroded objects, and HPM irradiation of the objects. The determination of the transmission cross section, see below, was made before and after the HPM irradiation in order to detect any degradation of the shielding properties of the objects due to effects of HPM. The HPM irradiation was carried out in order to find out if degradation would occur, and if spectral broadening occurs, the latter presumably due to nonlinear effects.

3.1 Transmission Cross Section Measurements

The shielding properties of the test objects, i.e. the apertures-under-test (AUT), were determined by measuring the transmission cross-section, σ_a, using FOI's reverberation chambers. The usefulness and benefits of the concept of σ_a compared to traditional ways of characterizing the shielding properties of apertures, together with a description of the measurement procedure, can be found in [5-8]. In the present case the absolute values of the σ_a of the test objects were achieved by calibrating the measured data for the AUT's using analytical data for a 30 mm diameter circular hole. The transmission cross section, σ_a, is defined as the power transmitted through the aperture normalized to the power density of the incident field, S_{inc} :

$$P_t = \sigma_a \cdot S_{inc} \tag{1}$$

P_t is the power transmitted through the aperture. The dimension of σ_a is given in square meters. For plane wave conditions σ_a will depend on the polarization and angle of incidence of the plane wave exciting the aperture. In a reverberation chamber, the measured σ_a corresponds to an isotropic average of plane waves arriving from "all" possible angles of incidence and polarizations from the half space irradiating the aperture. The measurements were carried out using two reverberation chambers connected by a common opening containing the AUT. The incident field was generated in one of the chambers and the transmitted power was measured in the other [3]. The measurement uncertainty was essentially due to the statistical nature of the reverberation chamber technique, i.e. not by the uncertainty of the instruments used. In the present case 10 x 10 stirrer positions were used. This gives an uncertainty of about ± 1.6 dB [5].

3.2 High Level (HPM) Testing

The set-up for HPM tests consists of a 700 kW, 3 GHz, S-band magnetron [1]. The pulse length was 1 μs and the pulse repetition frequency around 70 Hz. The field was radiated by means of a waveguide horn antenna with a gain of 15 dBi. The AUT was mounted on a 30x30 cm flange mounted on a one cubic meter large aluminum box [1]. The measured data were collected using a Tektronix TDS-6604 oscilloscope. The oscilloscope has an analogue 3 dB bandwidth of 6 GHz and a maximum sampling frequency of 20 GHz. The number of data points can be up to 200 000, which for a sampling interval of 50 ps yields a total sampling time of 10 μs. The electric field strength at the AUT was varied by moving the Al box along a rail. The electric field strength thus varied from typically 5.6 kV/m at the distance of 3000 mm, up to 100 kV/m at zero distance. The signal transmitted through the AUT was detected by a D-dot sensor (Prodyn type AD-20) located inside the aluminum box behind the AUT, 4 cm behind the plane of the flange. The uncertainty of the incident field strength depends mainly on undesired reflections around the test set-up. The uncertainty of the incident field is estimated to less than ± 1 dB.

4. Test Results

4.1 Joints Subjected to Accelerated Ageing

In order to evaluate possible damage or degradation of the shielding joints due to HPM the transmission cross-sections were measured before and after the exposure, see Figure 3 (x-axis 2 to 18 GHz; y-axis -120 to -30 dBm^2). It was hard to see any systematic changes due to the irradiation. The differences before/after for the test objects were not greater than the variation between two measurements for a solid hatch (not subjected to any high level irradiation). This conclusion holds also for object L38, which is the only object for which a distinct non-linear behavior could be detected, see below.

The HPM tests were performed at 100, 200, 500 and 1000 mm distance. Except for test object L38, where (mostly weak) non-linear effects were seen at all test distances and a pronounced effect was seen in one case, nonlinear effects were hardly noticeable. The appearance of non-linear effects were to be identified by a noticeable change in the time domain shape of the pulse and the occurrence of a peak at 6 or 9 GHz or the occurrence of low frequency content, the latter supposed to arise from envelope detection. A typical time-domain plot for the reference case, an open hatch, is shown in Figure 4. It was noted that in one case, object L38, distance 500 mm, pulse 1 out of 10, there was a marked distortion of the pulse in the time domain, see Figure 5. In frequency plots this nonlinear behavior was also established by a, compared to the reference case, pronounced peak at 6 GHz, see [1].

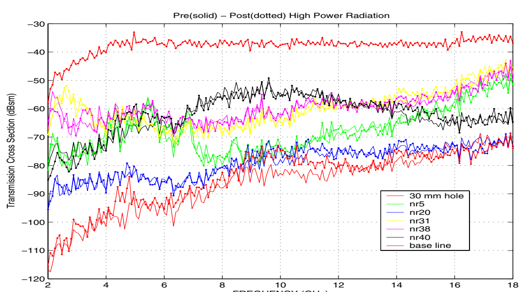

Figure 3.Transmission Cross Section before and after HPM irradiation. The upper curve, a 30 mm circular aperture, is for reference. The two lower (overlapping) curves were measured using a solid hatch. From [1].

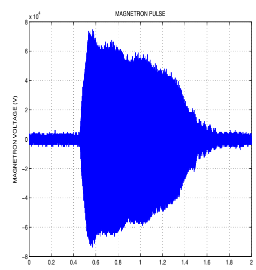

Figure 4. Reference pulse, hatch open. Distance 100 mm. E = 53 kV/m. Time-domain, 0 to 2 µs. [1].

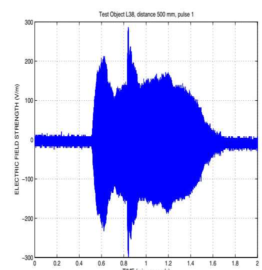

Figure 5. Test object L38. Transmitted Pulse. Distance 500 mm. E= 21 kV/m. Time Domain. [1].

4.2 Joints Subjected to Outdoor Exposure

Also in this case it was difficult to see any systematic changes in the measured transmission cross-sections after the HPM irradiation. Again, the differences before/after for the test objects are usually not greater than the variation for the solid hatch. The six objects which showed the greatest change in shielding after the outdoor exposure, see [4], show somewhat larger deviations after the HPM irradiation, although the effect is not large.

The HPM tests were performed at 200, 500 and 1000 mm distance. Only 7 out of the 26 objects showed clear, although not very pronounced peaks at 6 GHz, this for 200 mm and 500 mm distance. It shall be noticed that in most cases there were no marked distortions of the pulses in time domain.

4.3 Envelope Detection Confirmed?

Numerical FDTD simulations were carried out in order to get an opinion about the possibility to determine a (presumed) envelope detection of the pulse due to a diode-like behavior of the seam. The simulations showed that such a behavior, if existing, should be possible to detect despite the low sensitivity of the D-dot probe at low frequencies. For the test object L38 the frequency plot really showed, compared to the reference case, pronounced frequency content at low frequencies. This was also the case for some of the objects from the second study. A more careful analysis however revealed that the low frequency contents were created by an offset drift somewhere in the measurement chain. Also, there was no clear correlation found between the presence of low frequency content and non-linear effects revealed by the shape in the time-domain plot or by the presence of distinct peaks at 6 GHz.

5. Conclusions

No major degradation of the 31 corroded test objects could be detected after HPM irradiation. With one exception, the tested objects showed only rather small changes of the time domain shape of the transmitted pulse. Also, most of the objects showed no or rather small peaks at 6 GHz. This indicates only a very limited effect due non-linear behavior. Hence, it seems safe to assume that shielding effectiveness measured at low field levels is in general also valid at HPM levels and that HPM does not cause any degradation of the EMC joints.

6. Acknowledgments

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7. References

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