Using the Requirements of the MIL-STD-188-125-1 Concerning Injection of Current Pulse at Testing Resilience of Electronic Equipment to HEMP

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***Abstract* - Military standards such as MIL-STD-188-125-1 are usually applied when testing HEMP (High-Altitude Electromagnetic Pulse) resilience of industrial civil electronic equipment on military test benches. This article discusses the feasibility of adhering to requirements of section "Pulsed Current Injection (PCI) Test Procedures" of this standard and concludes that it is not practical to use it for industrial electronic equipment testing.**

***Keywords* - MIL-STD-188-125-1, HEMP, Pulse Current Injection Test Procedure, Industrial Electronic Equipment**

I. INTRODUCTION

Requirements to resilience of electronic equipment to High-Altitude Electromagnetic Pulse (HEMP) have been covered in various military and civil standards. Civil standards such as International Electrotechnical Commission (IEC) and International Telecommunication Union (ITU), Fig. 1a and military standards of US Department of Defense (MIL-STD), Fig.1b, are widely used internationally.

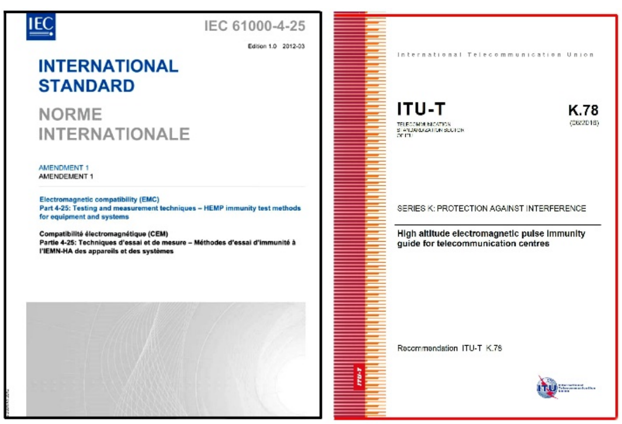

Fig. 1a. Civil standards of IEC and ITU organizations

According to basic standards applied to industrial equipment, (particularly the standards used for power industry) i.e. IEC 61000-4-25 [1] and ITU K.78 [2], the test for electronics immunity to HEMP must be divided into two parts:

- *radiated immunity test (RI)*

- *conducted immunity test (CI)*

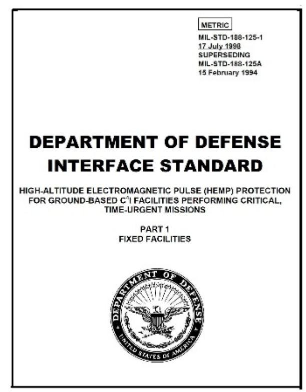

Fig. 1b. Military standard of US DoD

Normally, CI is divided into two types: *pulse voltage* applied to apparatus inputs/outputs and *pulse currents* induced into equipment circuits.

Common standard IEC 61000-4-25 [1] is based on IEC 61000-4-4 [3], which deals with electromagnetic compatibility and does not even mention testing with a pulse current. On the other hand, IEC 61000-4-25 [1] describes the current as "short circuit currents for common mode" (160A and 320A, respectively for immunity test level EC8 and EC9 [1]). According to p.8.4 of the standard IEC 61000-4-25, "the tests are required for all types of conductive lines… and shielding cables". The standard does not contain a definition for the term "*conductive lines*", and it seems that it does not discuss current injection into input circuits of electronic equipment.

ITU K.78 [2] standard also deals with control and communication cable shield tests.

Nonetheless, when testing HEMP-resilience of equipment, a reference is often made to MIL-STD-188-125-1 [4], which stipulates the necessity to test by current injection into internal circuits of electronic equipment. Is it really necessary?

II. CHALLENGES OF USING MIL-STD-188-125-1

Unlike the above-mentioned standards, MIL-STD-188-125-1 suggests a little different interpretation of the CI test. It includes a separate section called "Pulsed Current Injection

(PCI) Test Procedures" (Appendix B). The problems with this section are obvious from the very beginning, i.e. regarding the Definitions sections. The tests in this standard are divided into two sub-types: acceptance testing и verification testing:

«B.1.2 Applications. These procedures shall be used for ***acceptance testing*** *after construction of the HEMP protection subsystem and for* ***verification testing*** *of electrical POE protective treatments after the facility is completed and operational (POE – point of penetration) ».*

«Acceptance testing… to demonstrate that electrical POE protective devices, as-installed, perform in accordance with the transient suppression/ attenuation requirements of this standard»

«Verification testing… to demonstrate that mission-critical systems (MCS) are not damaged or upset by residual internal transient stresses».

It seems to be logical, but there are no further explanations to this logic, see Table 1.

TABLE 1. Definition of the Pulsed Current Injection (PCI) Test Procedures in the standard MIL-STD-188-125-1 [4]

Purpose of the acceptance test (B.4.2.1)	**Purpose of the verification test (B.4.2.2)**
a. To measure the performance of as-installed conductive POE protective devices.	a. To measure the performance of conductivePOE protective devices in operational circuit configurations.
b. To demonstrate through post-test inspection, performance checks, and response data analysis that the protective devices not be damaged or degraded by threat relatable transients.	b. To demonstrate through post-test inspection, performance checks, and response data analysis that the protective devices will not be damaged or degraded by threat-relatable transients.
c. To identify defective devices or faulty installation practices, so that repairs or replacements can be made.	c. To identify defective devices or faulty installation practices, so that repairs or replacements can be made.
-	d. To characterize the residual internal transient stresses
-	e. To demonstrate that residual internal transient stresses will not cause mission aborting damage or upsets of the MCS in their various operating states.
-	f. To provide data for HEMP hardness assessment of the facility and baseline data for the hardness maintenance/hardness surveillance program.

Clauses "a" through "c" are completely identical, while clauses "d" through "f" explain and clarification clause "c". Considering these explanations, it becomes unclear why requirements of this standard have been divided into "Acceptance test" and "Verification test". Moreover, all tests are to be conducted relative to the ground ("common mode") and no tests have been elaborated for a so called "differential mode". In other words, between terminals of the same input or output, as well as between different inputs and outputs as stipulated in all EMC standards. Why? There is no explanation of this phenomenon in the standard.

It is noteworthy that the above mentioned definitions refer to "***conductive*** *POE protective devices*", whereas the values of pulse currents are given (see B.4.5) for shortened circuits as "***short-circuit currents***":

"… pulse generator requirements are defined in terms of short-circuit current and source impedance. ***Short-circuit current is defined as current driven through ashort circuit connected to the generator output"****.*

Nevertheless,power supply circuits, as well as input and output circuits of electronic equipment, are not "conductive short-circuits" by any means and feature rather high impedance. So how should we test them?

Table B-I of this standard stipulates technical requirements for testing equipment, particularly for a high-voltage pulse generator. This device should generate a current pulse with an amplitude of up to 5,000A with the source impedance of 60 Ω. According to the standard: "source impedance is the ratio of the generator peak open-circuit voltage to the peak short circuit current", i.e.: $R_{SOURCE} = U_{OPEN}/I_{Sh.C.}$ Thus, the requirement to "open-circuit voltage" can be determined as: $U_{OPEN} = R_{SOURCE}$ x $I_{Sh.C.}$ = 60Ω x 5,000A = 300,000 V. The generator provides such parameters are really existing on the market. For example, Marx type generator, manufactured by Montena EMC company [5].

In other words, output voltage of the generator, the output terminal which is connected to a circuit with high source impedance, (such as inputs/outputs of low-voltage electronic equipment) can reach as high as hundreds of thousands of volts! Which electronic circuits could sustain this voltage? Why should this voltage be applied to these circuits as they are subject to civil standards [1, 2] restricting voltage at 8 kV (level EC8) or 16 kV (level EC9), depending on specific placement of equipment?

These simple calculations, multiple references to conductive circuits and short-circuit currents, as well as lack of tests for "differential mode",imply that the requirements of this section are not applicable for electronic equipment. They are rather suitable for testing of conductive protection devices, such as filters, which are connected into a "common mode", and grounded cable shields. I assumed this previously and thus I didnot mention pulse current tests as a recommended (see [6, 7]) method of HEMP-resilience testing of electronic equipment. However, some specialist dealing with these tests insists on adhering to requirements of this section of MIL-STD-188-125-1 when testing electronic equipment. It is globally true that HEMP simulators are usually maintained by military men or military industry representatives. They used to working with military standards and may often have no idea about existing sets of civil standards. When civil specialists test civil equipment on military test benches, they have no choice but to accept the rules established by the owners of the testing equipment. Hence, a supposed necessity of testing civil equipment based on MIL-STD-188-125-1 is also suggested in various scientific and technical papers. This is the reason why this research was necessary to challenge a common opinion.

Let us now address the necessity of using this section of MIL-STD-188-125-1 for electronic equipment protected by transient voltage suppressors, such as varistors connected parallel to input/output terminals. Parameters of varistors are known as they are published in their data sheets (e.g., see Table 2).

TABLE 2. Main parameters of some 14 mm diam. varistor types

Type/Manufacturer	Littelfuse	Epcos	Vishay	Bourns
Varistor's Type	V320LA 20CP	S14K320E2	VDRS 14T 320xyE	MOV-14D511K
Diameter, mm	14	14	14	14
Max. Operating AC Voltage, V_{RMS}	320	320	320	320
Varistor Voltage, V	558	510	510	561
Max. Absorption Energy, J	165	136	120	125
Max. Pulse Current (8/20 µs), A	6500	6000	4500	4500
Clamping Voltage, V	850	840	842	845

When necessary they can be tested separately by means of different pulse generators without any connection to the electronic equipment which they are designed to protect. The only thing that needs to be done is just to have a current pulse of a required amplitude run though this protection element and to measure the residual voltage on it.

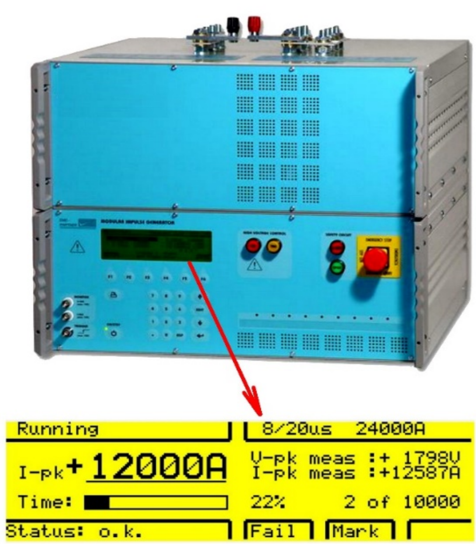

Fig. 2. Parameters of test pulse registered by internal measuring circuit of MIG0624 generator (screenshot).

Below is an example of measuring residual voltage on a 20 mm diam. varistor S20K275E3K1 type. Though its maximum rated pulse current is 12,000 A, it was subjected to a current pulse with an amplitude of about 12,500 A, obtained by means of a standard pulse (8/20 µs) generator MIG0624 (EMC-Partner), Fig. 2.

Obviously, this high pulse current amplitude results in significant residual voltage (almost 18 kV). Nevertheless, it should be taken into account that this current rating is much higher than the requirement of MIL-STD-188-125-1 (Table B-II).

Regardingthe E1 component of HEMP, the standard stipulates 5,000 A for conducting protective shields, including cable shields. For other types of equipment, (which exactly?) the standard establishes an amplitude of up to 2,500 A. Clearly, when the amplitude of current pulse is much lower than 12,000 A, residual voltage will also be lower and additional ferrite filters mountedon the penetrated cables [6]reduce it even further.

For example, Fig. 3 shows screenshots of a MIG0603OS2 pulse generator testing 14 mm and 20 mm diam. varistors by supplying a pulse current with 2,500 A amplitude. The varistors are connected to the generator's output by means of an ordinary 0.5-meter long wire harness which simulates real placement layout in a cabinet;at the same timethe residual (clamping) voltage on the varistors does not exceed 1,700 V.

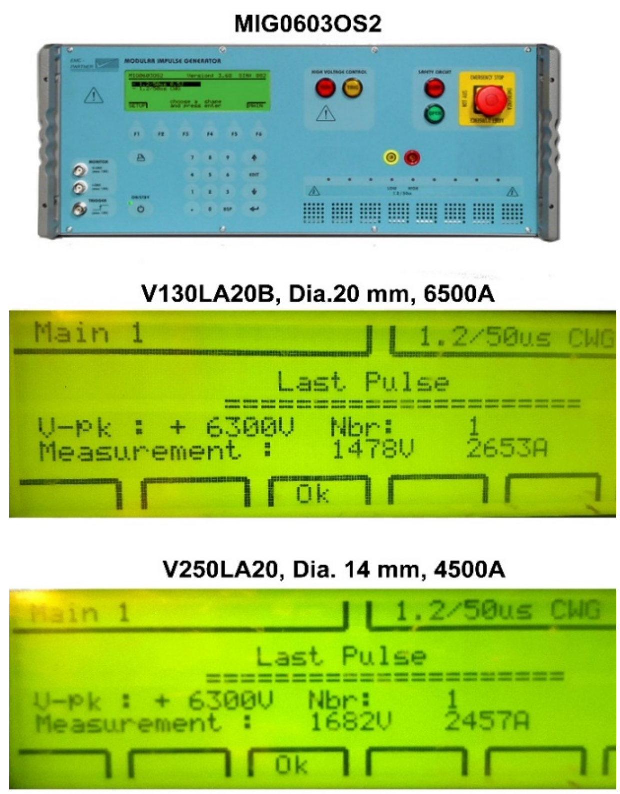

Fig. 3. Screenshots of MIG0603OS2 pulse generator when testing varistors V250LA20 (14 mm) and V130LA20B (20 mm) with maximum rated pulse current at 4,500 A and 6,500 A, respectively.

A filter with ferrite rings placed over a control cable before the varistor (Fig. 4) introduces additional pulse weakening due to circuit impedance increase. Use of this filter is recommended in [7] as an imperative technical means for protecting electronic equipment in control cabinets.

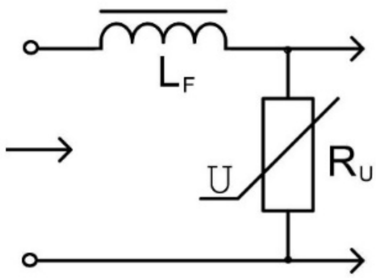

Fig. 4. Equivalent circuit for ferrite filter (L_F)and varistor (R_U) connection.

Connecting a 1-meter long wire to a generator's output results in a current pulse flowing in a wire featuring 450 A at 150 V (see screenshots in Fig. 5). However, if six ferrite rings are placed on this wire, thesame current rating will be achieved at 590 V, meaning almost 4-fold increase of impedance.

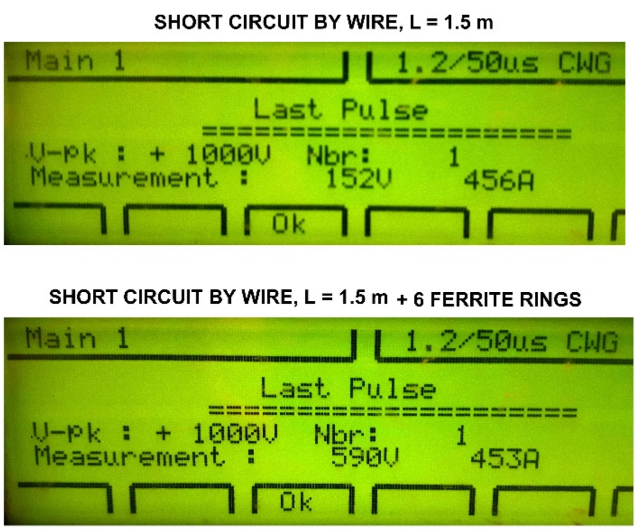

Fig. 5. Screenshots of MIG0603OS2 generator when short-circuiting its output by 1-meter long wire (top) and when placing additional six ferrite rings over this wire (bottom).

One-two kilovolt voltage applied to electronic equipment inputs (when rated pulse current flows through additional external transient voltage suppressing element placed at the input) are acceptable for industrial electronic equipment, as this meets the requirements of common standards on electromagnetic compatibility.

This means that industrial electronic equipment will be automatically resilient to current pulse flowing through input protecting elements upon HEMP impact, if it is protected from HEMP voltage pulse by adding an external transient voltage suppressing elements, such as varistors, and meets the requirements of civil standards on electromagnetic compatibility. Thus, there is no need to carry out additional tests on special testing equipment stipulated by MIL-STD-188-125-1.

III. CONCLUSIONS

Requirements of section B "Pulsed Current Injection (PCI) Test Procedures" of MIL-STD-188-125-1 are not suitable for testing civil electronic equipment by supplying test pulses to its input and output terminals. Thus, these tests should be excluded from the testing schedule of this equipment to HEMP-resilience. Industrial electronic equipment, meeting the requirements of standards on electromagnetic compatibility, will also be resilient to current pulse flowing through additionalinput-placed transient suppression protecting elements upon HEMP impact, and thus requires no additional tests to be carried out on special testing equipment stipulated by MIL-STD-188-125-1.

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