An Engineering Approach to Meeting the Requirements of MIL-STD-188-125

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INTRODUCTION

Electromagnetic pulse (EMP) protection component testing methods have been developed over a period of many years. A range of methods and protocols have evolved for a number of requirements, from large free-field simulators for systems testing (aircraft, vehicles, ships) to single component test equipment.

This testing has been based on an expected electric field pulse of 50 kV/m peak magnitude with a double exponential shape, a 10 ns rise time and 200 ns duration. Established test methodologies have been based upon this pulse and the induced currents and voltages which may be driven by it. More recently, specifications such as MIL-STD-188-125 have called for more demanding tests with durations and time histories which are dependent upon the application.

This article describes EMP protection component test methodology employed by one company, and an approach used to test the components to updated, upgraded specifications such as MIL-STD-188-125.

ESTABLISHED COMPONENT TEST METHODOLOGY

A number of tests can be performed in the laboratory or the field to check the performance of EMP protection devices. In the laboratory, tests are carried out to build confidence in a particular component or system and usually form part of the manufacturer's release procedure. In the field, on-

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site testing is performed after installation to ensure correct performance in the operational environment.

EMP pulses, by the established electric field definition, are characterized by a combination of fast rise times (nanoseconds) and modest energy contents. For test purposes it is useful to separate these two requirements and perform different tests to demonstrate speed of response and energy handling capability. By performing a two-stage test, the equipment is simplified considerably, the parameters can be varied, and some degree of overtest can be incorporated. Decreased rise time or increased energy content are possible, thereby ensuring a safety margin.

The response of a protection device, defined in terms of the let-through voltage beyond the protector, depends upon the incident rate of voltage rise: the higher the rate of rise, the higher the let-through for a given protector. It is therefore necessary to choose a rise rate which is representative of the incident field and also provides a realistic test. A 1 kV/ns rate of rise is chosen since this simulates the field rise time over a reasonable voltage range (10 kV), allowing testing within the normal range of switching voltages for typical protection components and circuits. Pulses of this type are readily derived from a system type shown schematically in Figure 1. A typical output pulse is shown in Figure 2.

Testing for energy handling capability requires that costs be balanced against a realistic test requirement. Current levels induced in cables of a representative length by an EMP pulse are several kiloamps with durations of several microseconds. Partly because of this, and partly because EMP protection and lightning protection requirements overlap to an extent, the established lightning test pulse of 8/20 microseconds (8 μs rise time, 20 μs width) is used for energy handling tests. The choice of this pulse shape ensures that a degree of overtest is included.

The use of two tests, speed of response and energy handling, has formed the basis of transient protection unit testing in the U.K. and elsewhere for a number of years. The levels and durations of current and the numbers of test pulses may vary, and may often be application driven, but testing the speed of response and the energy handling capability has become the established procedure.

NEW REQUIREMENTS

Recent EMP test specifications, such as MIL-STD-188-125, have called for the performance of more demanding tests. The requirements usually take the form of three tests: short pulse, intermediate pulse and long pulse. The magnitudes, rise times and durations of the pulses quoted in MIL-

STD-188-125 and other similar specifications represent more demanding requirements for protection devices, and the established test methodology must accordingly be changed to reflect these requirements.

The rise times associated with the short pulse are shorter than those previously required by EMP specifications, and therefore protection devices will be expected to respond faster to rising voltages. Accordingly, the test for speed of response must be carried out with a pulse of reduced rise time and increased rate of voltage change. The peak voltage must be representative of the likely operating voltages of protection devices since there is no benefit in producing a pulse of many tens of kilovolts if the protection can be expected to switch at less than a few kilovolts. Pulse sharpening of the output of the system shown in Figure 1 was found to produce a pulse with a rate of rise of approximately 5 kV/ns, a five-factor increase over the unsharpened output. This pulse was therefore adopted for speed of response testing, the proportional increase in rate of rise being approximately equal to the decrease in rise time.

Consideration of the intermediate pulses quoted in MIL-STD-188-125 shows that the charge transfer is high compared to the 8/20 microsecond pulses previously used. A pulse of 5 kA 8/20 microseconds has a coulomb content of 320 mC per shot, while the MIL-STD-188-125 intermediate pulse of 500 A with a 5 ms duration has a coulomb content of 2.5 C/shot — nearly a tenfold increase. This is clearly an issue for protection devices since it is now necessary to demonstrate increased coulomb and energy handling capability. This capability can be demonstrated with a 400-A half-sine pulse of 10 ms base width. This has the same charge transfer content and approximately the same peak current as the MIL-STD-188-125 pulse, but is much

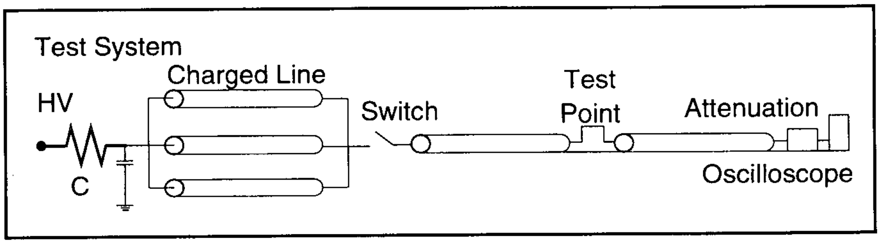

***Figure 1**. Schematic Diagram of 1 kV/ns Test Equipment.*

more readily generated.

The long pulse quoted in MIL-STD-188-125 is expected to threaten only very large systems in specific locations. Nevertheless, protection against this very long low level pulse is a considerable problem. The current levels and durations quoted are such that the charge transfers and energies involved far exceed the capabilities of existing conventional protection devices. The danger is that protection devices will be "held on" by the long current pulse after initially being switched by the earlier time components. Should this occur, then existing protection devices would be destroyed.

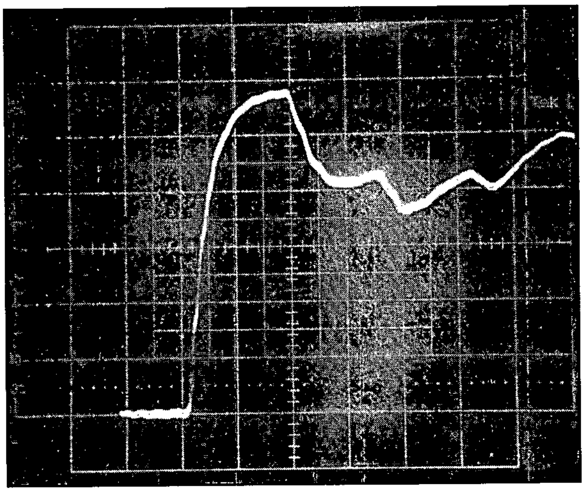

***Figure 2**. 1 kV/ns Test Pulse.*

MODIFICATION OF PROTECTION DEVICES

The advent of the new pulse requirements shifts the emphasis for protection devices toward faster-acting, higher-energy handling components. Existing devices have been developed over many years to meet established requirements for speed of response and energy handling. The changes required by recent developments represent major enhancement in protection component performance, and these enhancements cannot easily be accomplished using a single device. For many applications, a hybrid device consisting of several components will be required, with different components addressing different aspects of the required performance.

RESPONSE TIME

The response time of a component is ultimately limited by its physical size and the length of any connections made to the device. Components already exist with response times fast enough for use as protection against the new requirements (e.g., transient absorption diodes have a claimed response time of 10^{-12}s), but their performance in reality and their energy handling capability mean that their use is limited. Spark gaps combine reasonable speed of response with high-energy handling, and, therefore, improvements in their response speed would provide reasonable protection against the early-time EMP component.

Improvements in the speed of response of spark gaps can be achieved by reducing the gap spacing of the device. This requires that the gas pressure within the tube be increased, which in turn may require the tube envelope to be strengthened. These improved devices will have the necessary response speed and energy handling capability to withstand the induced current and voltages associated with the early-time pulse. In association with other components, they may provide protection against more demanding threats.

One device developed for EMP applications is a spark gap with a reduced gap spacing for improved response time. Responses of this device when tested with applied voltage rise rates of 1 kV/ns and 6 kV/ns, and let-through levels of 700 V and 1100 V respectively, are shown in Figure 3. When compared to a conventional spark gap which has let-through levels of 1000 V and 2200 V respectively, shown in Figures 4 and 5, the performance improvement of the reduced gap device is apparent.

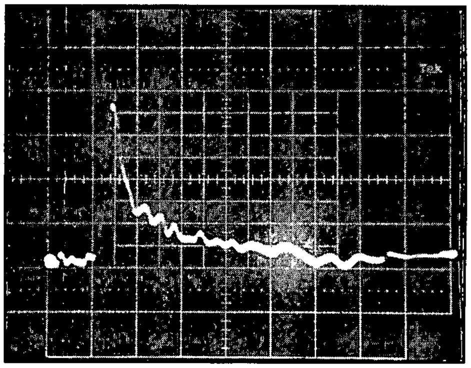

***Figure 3a**. Test at 1 kV/ns 200 V/cm 4 ns/cm, Let-through 700 V.*

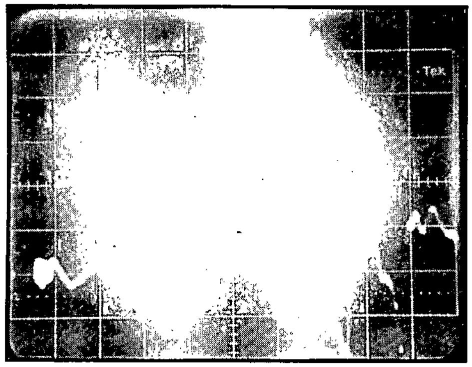

***Figure 3b**. Test at 6 kV/ns 200 V/cm 2 ns/cm, Let-through 1100 V.*

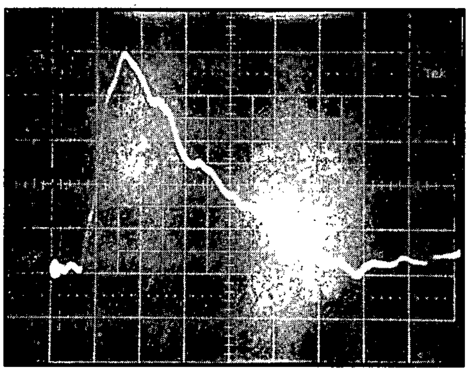

***Figure 4**. Test at 1 kV/ns 200 V/cm, 4 ns/cm, Let-through 1000 V.*

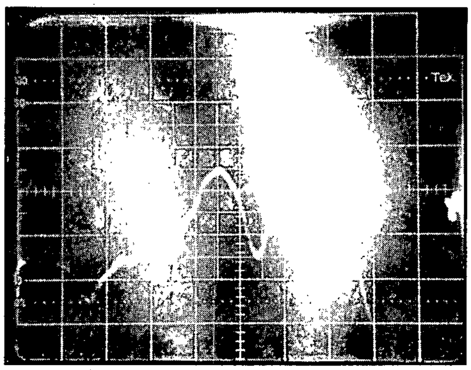

***Figure 5**. Test at 6 kV/ns 400 V/cm, 2 ns/cm, Let-through 2200 V (was 1000 V at 1 kV/ns).*

ENERGY HANDLING CAPABILITY

A typical EMP protection scheme consists of primary spark gap protection, possibly with a series varistor, followed by a secondary stage, usually an RFI filter. The primary stage is intended to divert the majority of the transient current and the secondary stage is present to reduce the voltage let-through level.

The demands of the intermediate pulse mean that the speed of response and energy handling capability of the primary protection must be improved. Improvements in the speed of response have already been discussed. Improvements in energy handling can be made by design changes to the spark gap and by matching parallel combinations of the series varistors. Matching must be accurate, or a single element will conduct the majority of the current and lead to early failure.

Careful matching of components has allowed an increase in charge transfer capability from 4 coulombs (50 shots, 5 kA, 8/20 μs) to 125 coulombs (50 shots, 400 A, 10 ms half-sine) for data line protectors, and from 16 coulombs (50 shots, 20 kA, 8/20 μs) to a minimum of 125 coulombs for power line protectors, without degradation of the let-through voltage performance.

At present, it appears that the potential threat posed by the late-time pulse will only be divertible using electromechanical devices such as circuit breakers and contactors.

CONCLUSION

The requirements of MIL-STD-188-125 stretch test capabilities to new limits. However, for the most part, it is possible to engineer solutions which are practical. Modification of protection devices to meet the threats posed by MIL-STD-188-125 is difficult but possible. Sophisticated multistage systems may be required if protection against the late-time threat is required.

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