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EOS Exposure of Magnetic Heads and Assemblies in Automated Manufacturing

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Abstract - EOS exposure to the magnetic heads in production is often overlooked in favor of ESD. As sensitivity of the heads increases for the magnetic heads, EOS exposure becomes more important and no longer can be ignored. This paper discusses specific examples of EOS exposure such as EMI-induced EOS, voltage-source EOS, transformer coupling-caused EOS and others.

1. Introduction

As damage thresholds diminish, previously neglected types of exposure for sensitive magnetic heads become important. Among them EOS – electric overstress – caused by parasitic signals which are ubiquitous in automated equipment for manufacturing sensitive components. Understanding the nature and origins of such signals, of their propagation and the ways these signals can reach and affect the most sensitive components provides valuable information for effective and intelligent yield management and for planning and executing preventive and maintenance measures to sustain acceptable yield.

2. Nature of EOS Signals in the Tools

Electric Overstress (EOS) is "the exposure of an item (an electronic component, for example) to a current or voltage beyond its maximum rating," according to a definition of the ESD Association (www.esda.org). Unlike ESD-caused signals that equalize voltage between two conductors by exchange of very limited charge, EOS-type signals have completely different properties.

a. The energy of EOS signals is not determined by the accumulated charge but rather by the practically unlimited supply
b. The time characteristics of the resulting current is continuous or periodic signal rather than an impulse or a sporadic signal.
c. EOS sources have low output impedance meaning that the resulting current may be quite significant.

Some of the signals in the tools are low-frequency signals caused by or associated with the 50/60Hz leakage, but the majority of these signals are of high frequency. Several examples of EOS sources are examined in this paper.

2.1. Voltage Source

The basic model of a voltage source is shown in Fig. 1.

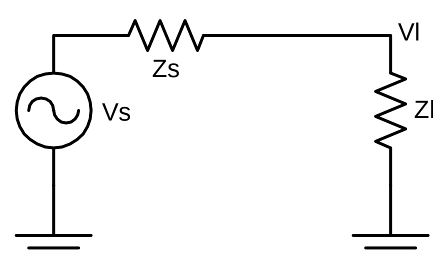

Figure 1. Basic Voltage Source

Vs and Vl are source and load voltage respectively. Zs and Zl are source and load complex impedances respectively. Voltage source can be of either AC or DC nature or a combination of both. Further in this paper we will examine some typical sources of signals found in production environment.

Real-life voltage sources are not ideal, meaning that they have finite output impedance (Zs). Zs can have very complex character and in addition, be non-linear.

There is usually a path to ground for components in a production environment, such as the part is placed on grounded surface. Impedance Zl can be, for example, slider resistance, etc., ranging for the particular example anywhere from 40 to 200 Ohms.

It should be noted that, though a significant part of load impedance Zl is in our particular case of magnetic heads resistive, the source impedance Zs may contain a significant reactive component such as inductance or capacitance.

In its simplest form the resulting voltage on the component is:

$$Vl = Vs \frac{Zl}{Zl + Zs} \quad (1)$$

Now let's examine each component of this equation.

Voltage Vs (source voltage) can be the result of several phenomena. Some of the typical sources in actual production environment are noise from switched power supplies, servo motors, solenoids, RFID (Radio Frequency ID) readers, control circuits and alike.

Source impedance Zs depends largely on how the signal gets to the ground and how it is propagated. In one particular instance, the following observation was made.

Load Impedance Zl	Voltage,RMS, mV	Current, mA
50 Ohms	96	1.92
1kOhm	155	0.155

Source impedance was calculated from this formula:

$$Zs = \frac{V_{1k} - V_{50}}{I_{50} - I_{1k}} = 33.4 \text{ Ohms} \quad (2)$$

An assumption was made that all impedances are purely resistive, which is rarely the case and is definitely not the case where this impedance has inductive component of long and/or coiled wires and mutual capacitance. As seen, the source impedance has highly non-linear character which is to large degree could be contributed to disregard of reactive properties of the impedance in the calculations. The above numbers should be viewed as a reference only.

Typical exposure to the component occurs when a supposedly grounded tool (such as a screwdriver bit, for instance) touches a component that has current path to ground (i.e. grounded). For this, there has to be a voltage difference between the tip of the tool and the ground to which the component has a direct path. It is often assumed that once a metal part is grounded, there is no voltage residing on it relative to ground. This assumption is erroneous. There are several ways the presumably grounded tool can have a voltage on it.

2.1.1. Unreliable contact with ground

This situation is very typical with rotating and/or moving tools, such as screwdriver tip, robotic arm, etc. A ball-bearing connection between the working end of the tool and the tool's grounded base is highly intermittent at best. Connection to ground in such tools is often measured in steady-state which can show reasonable connectivity. However, the tool touches the part while in motion when the contact is hardly existent. Figure 2 illustrates the mechanism of generation of voltage on a presumably grounded part of the tool. As shown, tool tip (i.e. screwdriver bit) rotates in a ball bearing that is grounded. The connection between the internal ring of the bearing with the external ring is intermittent during motion. There is a capacitive coupling between the tip of the tool and the coil of the motor that carries power line signal and associated high-frequency noise. This capacitive coupling forms a source impedance Zs. In the absence of a good contact with ground, the voltage on the tip of the tool can reach Vs and expose the component to an overvoltage.

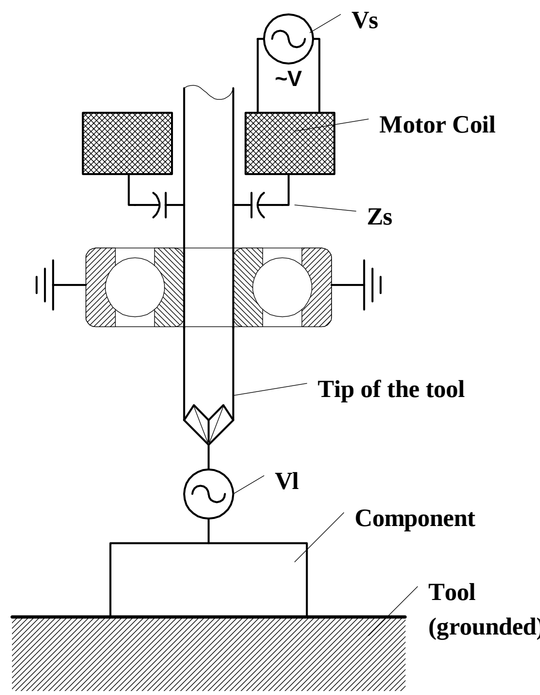

Figure 2. Generation of Voltage in a Tool via Capacitive

2.1.3. Inductance in ground path

Though the tools are intended to be grounded, all too often the ground path has one or more of the following problems:

a. An excessively long ground wire

b. A coiled ground wire that forms an inductor

c. A ground wire in a bundle with other wires carrying high-level signals

d. A ground wire which is connected to "another" ground, i.e. not to the same ground as the component in operation

Any of the above can create voltage between the tip of the tool and the part.

2.1.3,1. Long Ground Wire

While having low resistance at DC and at low frequencies, long wires have their own inductance and thus, impedance, which becomes significant at high frequencies. The formula to calculate self-inductance of a wire is:

$$L = 2l\left(\ln\frac{4 \cdot l}{d} - 1\right) \qquad (3)$$

where:

L is the inductance, nH
l is the length of wire, cm and
d is the diameter of wire, cm

For a 3m 14 AGW wire, the self-inductance would be 5.17µH. If a part of a tool is grounded via such wire and there is a leakage high-frequency current of only 100µA at 100MHz, this would cause voltage of 0.517V across this wire only due to its self-inductance. If the tool is constantly exposed to high-frequency signals, it may have significant for magnetic heads voltages. These voltages cannot simply discharge and disappear, but rather are applied constantly and are not current-limited.

2.1.3.2. Coiled Ground Wire

Often, ground wires in tools are coiled. This creates an additional inductance. Self-inductance of an air coil is:

$$L = 0.394\frac{r^2 N^2}{9r + 10d} \qquad (4)$$

where:

L is the inductance, µH
d is the thickness of coil, cm
r is the radius of coil, cm and
N is the number of turns

For a 5-turn coiled wire with a 10cm radius and a 1cm thick coil, inductance would be 9.85µH. At 100MHz, this inductance presents impedance of 6.28kOhms. A 100µA current at 100MHz would cause 0.628V voltage across such coil.

2.1.4. Inductive and Capacitive Coupling

When the wire used to ground the tool is put in a bundle with other wires, specifically wires carrying power and/or other wires that may carry strong signals, there is a possibility of noise getting on the ground wire via inductive and capacitive coupling between the wires. Depending on length and closeness of the wires, such coupling can be significant. This coupling is most efficient at higher frequencies largely due to lower impedance of capacitive coupling between the wires within the bundle at these frequencies.

All the above examples signify presence of voltages and currents in the process that are on par or above damage levels of magnetic heads.

Figures 3 shows an example of high-frequency voltage between the tip of a tool and the ground where the component is placed. Figures 4 and 5 show accordingly the test setup and an example of current from the tip of the tool to ground in GBB tool. As seen from Figure 5, the peak current through the part (182mA) exceeds all acceptable limits for today's thin-film MR heads.

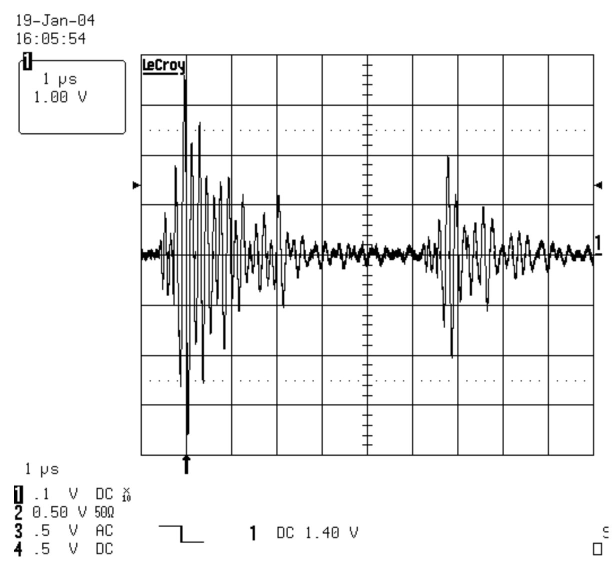

Figure 3. Voltage between the tip of a tool and ground. Peak voltage is ~3.6V

2.1.5. Excessive Ground Currents

On occasion, ground and neutral wires in power outlets are reversed by accident. While being a very serious safety hazard for employees, this also enormously increases exposure of components to EOS in many different ways. Vigilance must be employed on continuous basis to monitor and immediately correct such safety violations.

If ground and neutral wires are reversed, tool ground

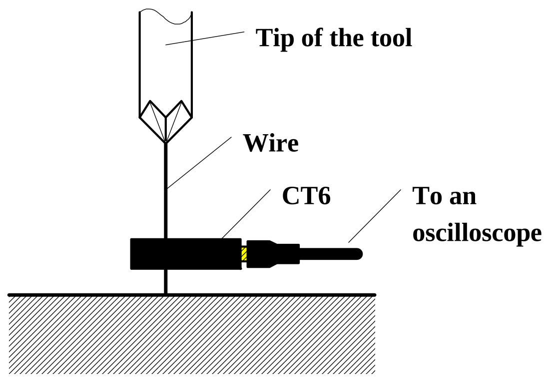

Figure 4. Current Measurement Setup in the Tool

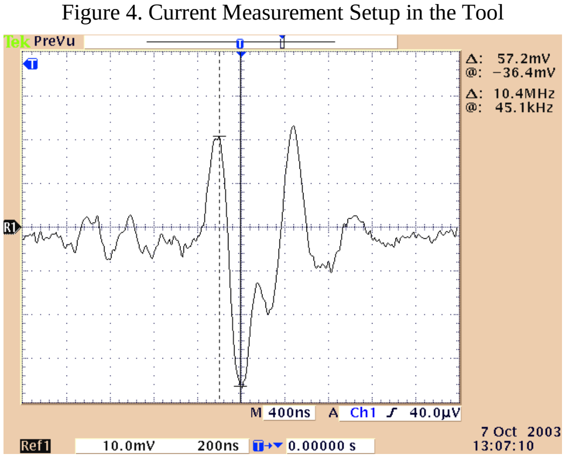

Figure 5. Current in GBB (gold ball bonding) Tool (peak current is 182mA)

is now connected to a neutral buss which can have by itself undetermined high voltage, depending on voltage drop in a long neutral wire.

Excessive current may be present in ground wire since now the return current instead of leaving the tool via neutral wire, flows via ground wire. Such currents were observed to reach 10....15A as measured with a current clamp meter.

The voltage drop due to excessive current in a ground wire alone can be calculated in one particular example as:

$$V = R \times L \times I = 0.0846 * 10 * 10 = 0.846V \qquad (5)$$

where:

R is the resistance of wire per meter (our example is 14 AWG wire)

L is the length of wire (our example is 10m)

I is the current (our example is 10m)

This problem becomes exacerbated when a separate ESD ground is used within the same tool, which may lead to a significant voltage differential within the tool and resulting excessive currents.

2.1.6 Ground Currents and Inductive Coupling

For protection of MR heads against excessive currents these heads are often shunted during manufacturing process. The shunting may pose a risk of current exposure to high frequency currents due to inductive coupling to ground currents in the tools.

Many tools have ground currents flowing through their grounded surfaces. Ground loops that are often present in the tools due to multiple points of ground connection also are significant contributors to tool malfunction which is a subject to a different discussion. While the magnitude of such currents may be significant, they may not manifest themselves with high voltage since the impedance of tool's body is low. These currents are somewhat similar to currents in the ground plane of a printed circuit boards.

Depending on the mutual inductance of a magnetic head and ground plane currents, the induced current into the head can approach level of significance.

Figure 6 shows how current in the ground plane can induce current in a shunted head. Figure 7 shows the current in the loop (Figure 8) simulating the shunted head (using 50 Ohms resistor).

The following formula indicates the voltage induced in the loop from current in ground:

$$V = M \frac{\partial I}{\partial t} \quad (6)$$

where

V is the voltage on the resistive component in the loop,

M is the inductive coupling between the loop and current path on ground

I is the current

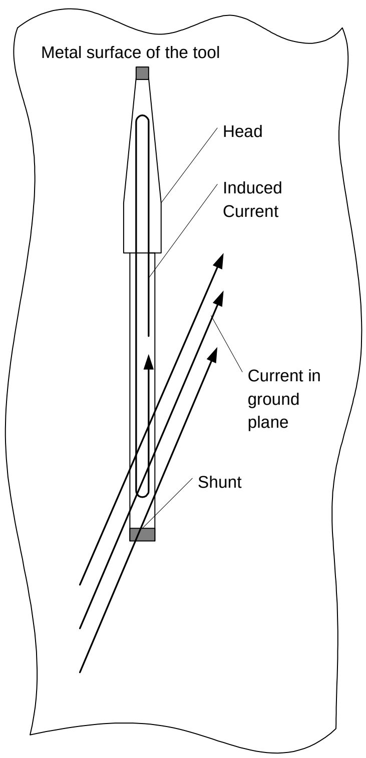

Figure 6. Inductive Coupling Between Ground Current and the Head

As seen, by equation, the voltage on the slider will be higher at higher frequency currents which are often found in operating tool.

The less the spacing between the loop and ground, the better the coupling (higher *M*) and the higher the induced voltage.

In the practical sense, if a shunted head is placed on a metal grounded surface of a tool which has current passing through it, a voltage will be induced on the slider, even if there is an insulative or dissipative layer between the slider and the ground plane such as static-dissipative tray.

EOS caused by inducing voltages and currents into the devices due to electromagnetic fields, though important, is not covered in this paper.

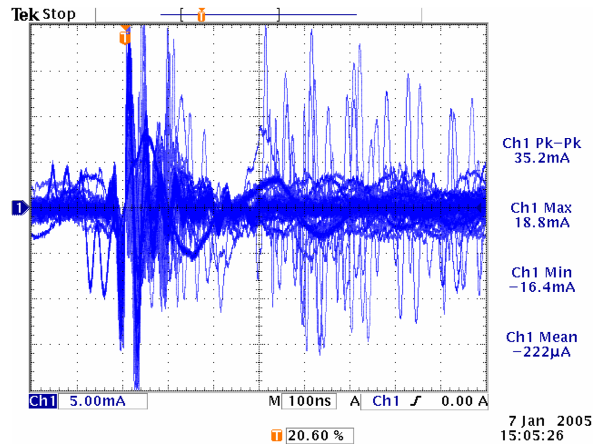

Figure 7. Current induced by transformer coupling in the tool (peak value – 35mA). Multiple signals are often present on ground as seen.

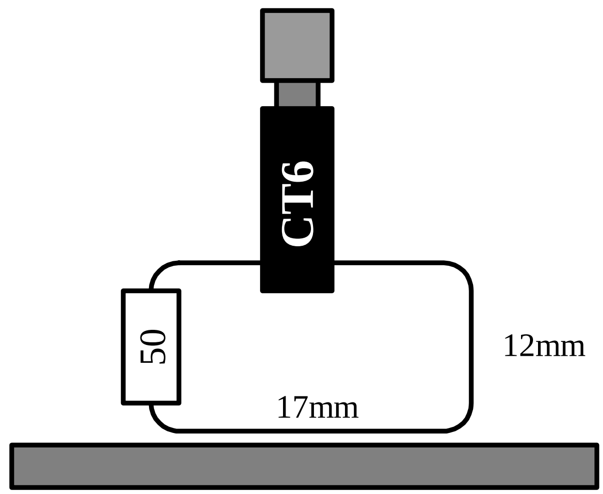

Figure 8. Configuration of Test Loop

3. Exposure vs. Damage

This paper dealt so far with exposure of magnetic heads to EOS. The logical question is how this exposure would influence damage to the heads. There are several issues to consider.

3.1. Voltage Sensitivity of the Head

Damage level of magnetic heads is very low. Depending on the process and technology, damage levels can vary, but in general they are significantly less than 1V and continue to drop. Robert Perry et.al. [2] and Baryl, et.al. [3] indicated that the damage levels for some types of heads are within 0.5V range. Keithley in its application note [4] states that voltages as low as just over 20mV applied to the GMR head can cause its damage. It would be prudent to expect these levels to continue to drop due to increased requirements for recording density.

3.2. Current Path

Though an excessive voltage may be present in a tool which comes in contact with the component, the current levels which actually pass through the head may not be sufficient to cause damage. Realistic examination of the tool and of the process combined with measurements would provide necessary information.

An important consideration should be taken into account: the highest signal levels are often present when the tool is moving due to operation of motors and solenoids. Any assessment of exposure of the components to EOS shall be done with the data taken under such circumstances.

On a cautious side, whenever there is an excessive signal present in the tool and can come in contact with the sensitive component, it would be prudent to take measures to reduce such exposure.

3.3. Long-Term Exposure

Unlike ESD exposure that lasts nanoseconds, exposure caused by EOS may last for a prolonged period of time. Some sources [5] indicate that prolonged exposure of magnetic heads to less-than-damaging levels of signal can cause head degradation. It is, therefore, recommended for magnetic head manufacturers and users to determine for themselves the damage levels of their components and subassemblies based on EOS exposure.

3.4 Latent Damage Concern

Because level of EOS exposure can approach or exceed the damage level, there is a possibility that the heads that pass the immediate test may still fail after being deployed in the field, or as early as on the next step of assembly. A study on this subject may be beneficial.

4. Quantifying EOS Exposure

Once the damage threshold of a component is known, then a tool can be "qualified" to handle it based on the amount of EOS exposure that the tool provides.

As discussed throughout the paper, most of EOS exposure has high-frequency component in it. Instrumentation and methodology to quantify EOS exposure should be able to measure such signals with the required degree of accuracy. Due to the nature of high-frequency signals in tools, it is essential that both continuous and transient signals were measured.

While measurement of high-frequency voltage between different parts of the tool can be accomplished with an oscilloscope, ground plane high-frequency current measurements have to be done with the appropriate tools and care. Commonly-used probes, such as CT1 or CT6 current probes, even when used in configurations such as one shown in Figure 9, still measure the voltage indirectly (and, accordingly, reflect low output impedance of the source).

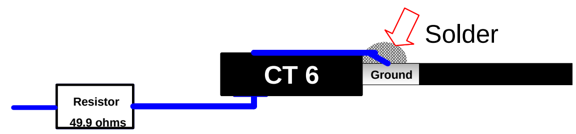

Figure 9. Measurement of possible current exposure on direct contact with CT6 probe

5. Conclusion

Magnetic heads in production can be exposed to EOS exposure of different types. Due to the ultra-sensitive nature of magnetic heads, previously-neglected signals become important. Automated assembly introduces a variety of ways in which magnetic heads can be exposed to EOS. EOS exposure is very different in nature from ESD and the damage to the magnetic heads from EOS needs to be assessed independently than from ESD.

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