Measuring and Specifying Limits on Current Transients and Understanding Their Relationship to MR Head Damage

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***Abstract*—** In recent years there has been a tremendous effort in the disk drive industry to produce devices with greater storage capacity and better performance. This push for increased density has led the industry to rely more and more exclusively on magneto-resistive (MR) or giant magneto-resistive (GMR) heads in drive design. These heads have significant advantages over the older inductive heads and have helped to increase areal densities to new heights. Unfortunately these devices have the undesirable characteristic that they are extremely sensitive to damage from current transients. Consequently manufacturers of heads and disk drives have established specifications for all aspects of handling and testing of heads. These guidelines are designed to prevent the (G)MR element from ever being subjected to a potentially damaging uncontrolled current transients.

Test equipment used by any facility that deals with (G)MR heads must necessarily be evaluated for its potential to introduce undesirable current transients. The nature of the devices used to measure current transients can and has lead to misinterpretation of test equipment safety**.** It is important to understand both how to measure current transients and whether or not these events will damage an MR element. This paper will define and discuss the nature of a true current transient, will explain the proper methods for measurement and interpretation of these events, and will discuss how they may or may not relate to damage of an MR head.

Introduction

It has been projected that by the year 2005 the HBM Failure energy for (G)MR elements will be on the order of 3 picoJoules[1]. This dramatic trend towards an increasing sensitivity of the (G)MR element to ESD damage has led manufacturers to implement strict static control and handling procedures in the production environment and stringent guidelines for test equipment manufacturers. These efforts are designed to reduce or eliminate the possibility that the MR element will be subjected to an uncontrolled current transient.

Most companies that manufacture or test (G)MR heads have established procedures designed to qualify test equipment for current transients. The results produced by this process of qualification can be misinterpreted and lead to an erroneous conclusion regarding the ESD safety of equipment.

This work is intended to provide a basic explanation of the nature of a current transient, to explain how a current transient may or may not relate to damage of an MR element, and to provide a simple method for properly evaluating a test system for transients.

Current Transient: A Definition

Apprehension exists in the disk drive industry when the expression "current transient" is used. The continuous battle to maintain a static free environment for heads has lead to an almost irrational response when this term is mentioned. However, the ability to properly observe and understand the nature of transients requires that there be some common and acceptable definition of this term.

A general definition for a current transient event, that is not specific to the disk drive industry, is "**A current transient is a non-repeating, uncontrolled, and often unpredictable, variation in current"**

Figure 1 illustrates this definition. **Figure 1** is an example of a random current transient. The wave shape is not easily predictable, has a peak value much greater than the steady state value, and occurred at no predetermined time.

A definition more appropriate for this discussion, and one that more accurately reflects the interpretation of this term from the point of view of the disk drive industry, is that "**A current transient is any *uncontrolled* change in current through an MR element**".

Figure 2 and **Figure 3** provide an example of the need for a proper understanding of the definition of a current transient. On initial examination the similarity in the general shapes of these waveforms may lead to the conclusion that both of these events are current transients which might potentially damage an MR element. Before it is possible to assess the potential for damage posed by these events, it is necessary to understand both the nature of the event as well as why current transients are a threat to MR heads.

What Kills an MR Element?

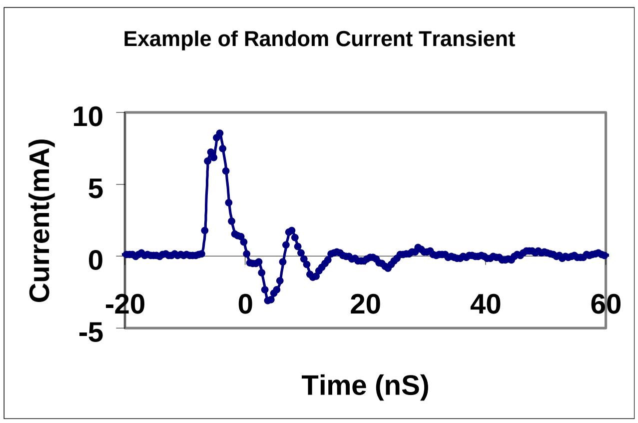

Figure 1: Random Current Transient

Why do current transients pose a threat to the MR element? The simple answer is that the physical dimensions of the MR stripe are so small that it can only tolerate a finite amount of current before sustaining damage. The GMR element is susceptible to two basic failure modes, both of which are due to I^2R heating increasing the temperature of the stripe and surrounding materials. Magnetic damage occurs when the blocking temperature of the exchange layer is exceeded. This type of damage is typically characterized by changes in the magnetic performance of the sensor with little or no change in the resistance of the stripe. The second failure mode occurs when the sensor is heated to the point of melting. In this mode the sensor is either completely open or has greater resistance than an undamaged head.

In either of these two cases the damage occurs **when the peak current through a GMR head is substantially above the normal operating current for the sensor.**[2]

Additive Noise: A Silent Threat

The end-users of test equipment will often specify limits on current transient levels. As an example, current transients are not acceptable if greater than 4mA peak to peak. **Figure 4** shows a measurement of current transients using an AC current probe. The peak to peak value of the transients is 4mA. However, because the AC probe does not pass DC values the true condition of the system is masked. **Figure 5** shows the actual configuration of the system during transient measurement. The transients were measured with respect to a 6mA bias current. Because the effects of transients are additive to any DC value which exists, the actual peak value of current seen by

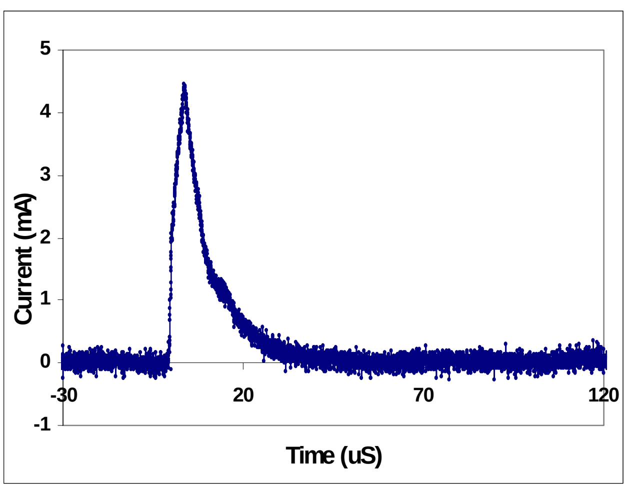

Figure 2: Sample Waveform 1

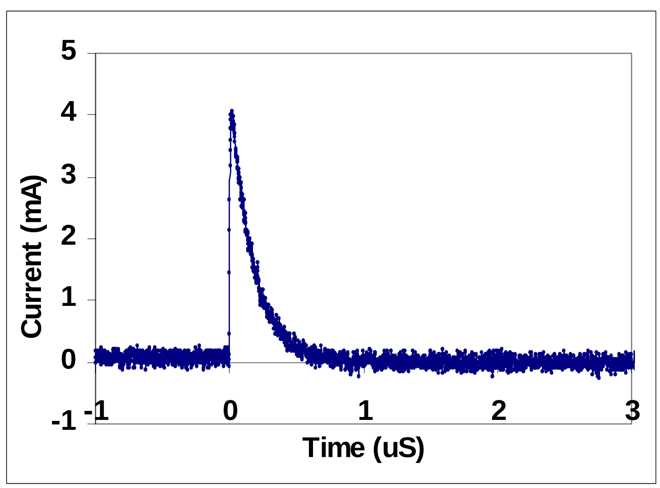

Figure 3: Sample Waveform 2

the MR element was 8mA.

The arbitrary specification of limits on the amplitude of current transients is an incomplete assessment of the actual danger that these transients represent to the MR element. A more complete specification must include references to the state of the system, descriptions of the techniques used to evaluate transients, and an indication of the absolute peak values allowed for head safety.

What does NOT kill an MR element?

As necessary as understanding what damages an MR element is the understanding of what will NOT damage an MR element.

"Any current transient or DC current level which remains <u>at or below</u> the peak operating current of the sensor will not damage an MR element."

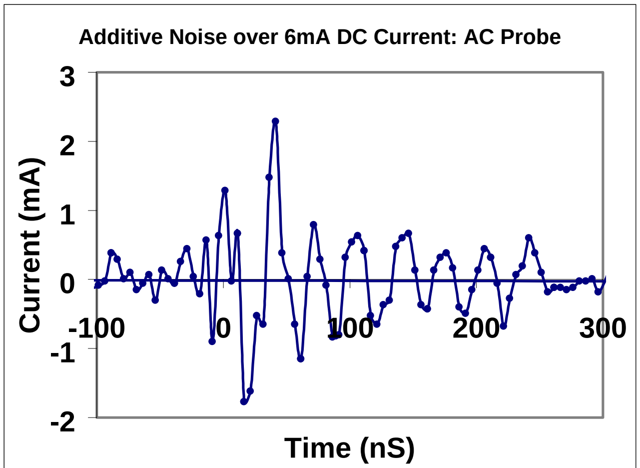

Figure 4: Additive Noise with AC Probe

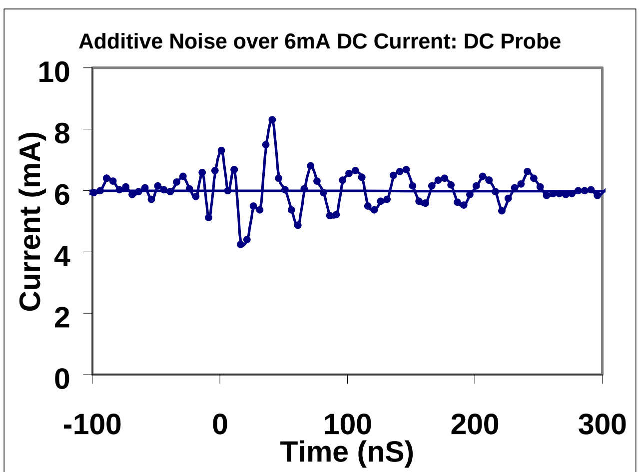

Figure 5: Additive Noise with DC Probe

This statement is true regardless of the duration or the rise time of the event. It has been shown that damage to an MR element from a current transient is a function of both peak amplitude as well as duration.[3] However, damage does not occur below the peak operating current of the element. Similarly, rise times as small as ~700pS have been used in studies with the result that there is no evidence that damage will occur if the peak current used is at or below the peak operating current of the head.[3]

With these concepts in mind the waveforms in **Figure 2** and **Figure 3** will now be defined. **Figure 2** is an example of a 'bias on' event from a preamplifier chip (Preamp A). This chip is currently used in commercially available drives. **Figure 3** is an example of a 6.5V HBM event from an ESD simulator. Most contemporary GMR head designs have an operating bias of about 5-7 mA. Because neither of these waveforms has a peak amplitude greater than 5mA, neither event will pose a threat to current GMR heads.

Bias On: The Mythical Current Transient

Test equipment designed to characterize GMR elements (either magnetically or electrically) must provide proper operating bias to the head. Because of this requirement, it is necessary for the tester to emulate the changes in bias that would normally be provided by a preamplifier chip. It is surprisingly common for these changes in bias to be misinterpreted as dangerous current transients that might pose a threat to the safety of the device under test. This misconception may be partially explained by the similarity in wave shape between a 'bias on' and an HBM event as seen through an AC current probe (refer to **Figure 2** and **Figure 3**).

The intuitive expected waveform for a 'bias on' event would be a DC to DC shift in current as shown in **Figure 6**. Less intuitive is the waveform shown in **Figure 7** which is the same 'bias on' event seen through an AC current probe. A more complete understanding of this event is possible when the results of the DC probe and the AC probe are displayed on the same graph as shown in **Figure 8**.

The response of both the AC and the DC probe is quite similar during the initial few microseconds of the transition. This is because dI/dT is above the low frequency cutoff of the AC probe. However, as the bias current asymptotically approaches its steady-state condition the rate of change of current falls below the low frequency cutoff of the AC probe and we begin to

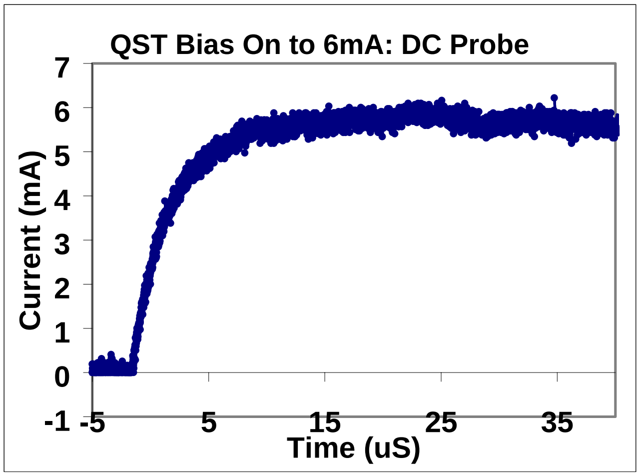

Figure 6: Intuitively Expected Waveform for Bias-On Event

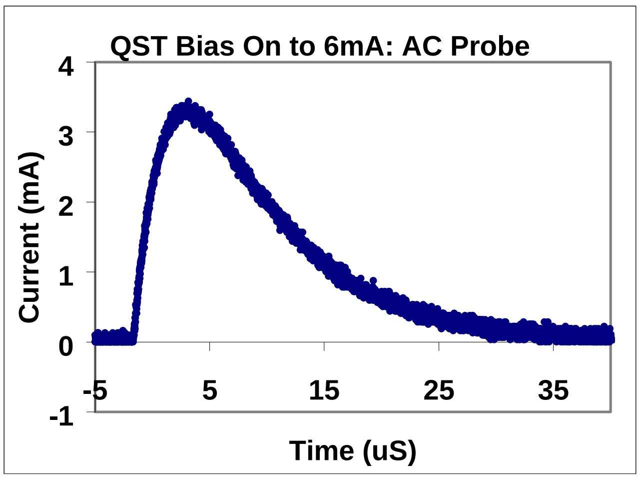

Figure 7: Bias-On Waveform from AC Probe

see roll off. When we finally achieve the desired bias current the DC probe shows the absolute DC level while the AC probe shows 0.

The peak values detected by the AC and DC current probes will match only if the slope of the transition remains within the bandwidth of each of the probes.

A useful definition to introduce is that of a current transition. **A current *transition* is a controlled change in current from one DC level to another.** Usually these events have well defined wave shapes. Examples of current transitions are the 'bias on' or 'bias off' events of preamp chips.

It is important to make the distinction between the MR specific definition of a **current *transient*** and the definition of a **current *transition***. All of the effort in industry to provide a static free environment for manufacture of MR heads, and for the qualification of MR test equipment for current transients, is to prevent the head from seeing any uncontrolled change

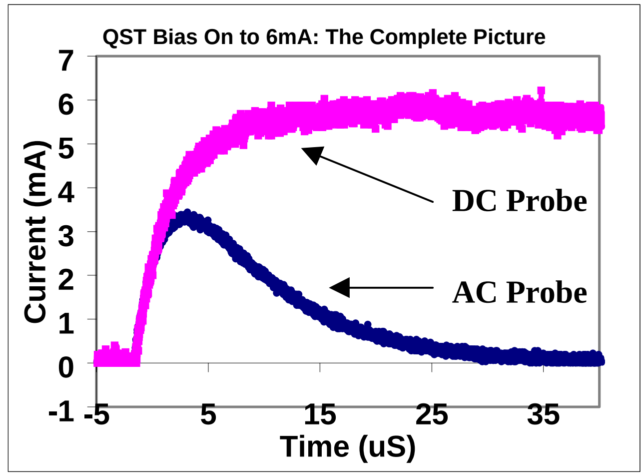

Figure 8: Bias-On The Complete Picture

in current across the sensor. For a GMR head to function properly it must be biased. This means that the GMR element must be subjected to controlled current transitions in order for the head to be tested and characterized during the manufacturing process.

To summarize:

1) **Current *transitions*** are a requirement for proper head operation
2) **Current *transients***, though undesirable, are not always a threat to the head

Some Examples of Non-Destructive Current Transitions

Some examples of non-destructive current transitions are shown in Figures 9-12. These waveforms were obtained by carefully removing the R+ and R- wires from a head stack flex connector and then attaching a resistor with an AC current probe across these points. A quasi-static tester was used to control the preamplifiers.[4] **Figure 9** and **Figure 10** are examples of a 'bias on' event for two different preamp chips (Preamp A and Preamp B). The bias was set to 6mA with a 25 ohm load resistor. The overall waveforms are quite similar with small differences in the rise time signatures. **Figure 11** and **Figure 12** show the 'bias off' event for the same two preamps under the same set of conditions. It is interesting to note that the 'bias off' event has a much faster total transition time than then 'bias on' event with effectively no low frequency roll off occurring either at the beginning or the end of the transition. This results in a reasonably accurate measurement of the DC change in current using the AC probe since there is no attenuation of the signal.

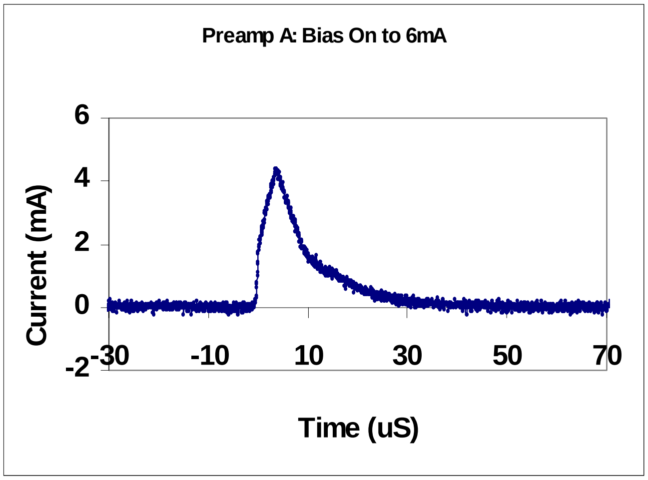

Figure 9: Preamp A Bias-On

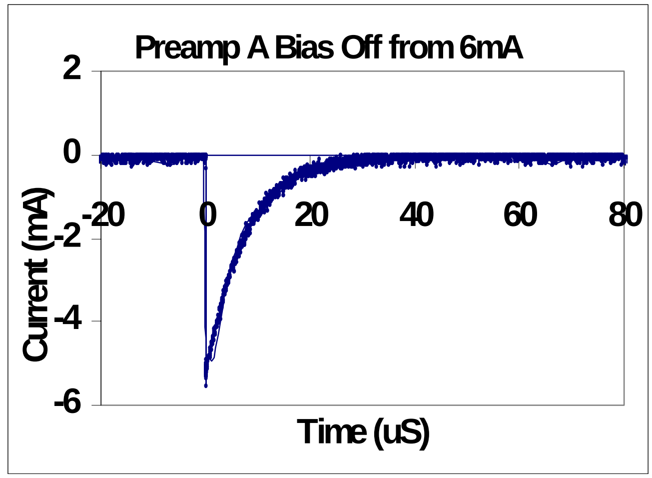

Figure 11: Preamp A Bias-Off

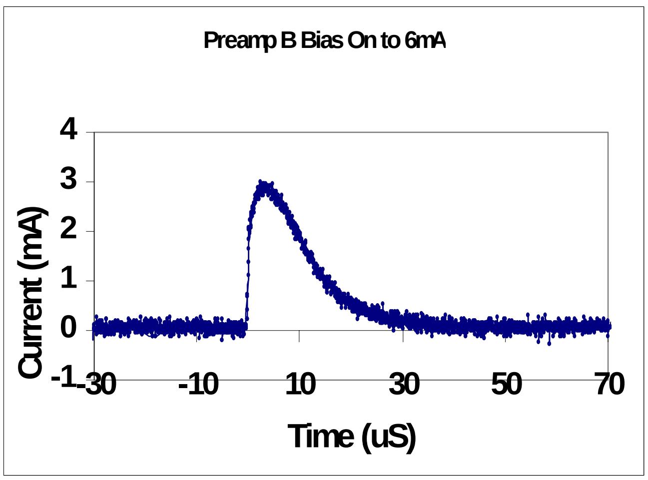

Figure 10: Preamp B Bias-On

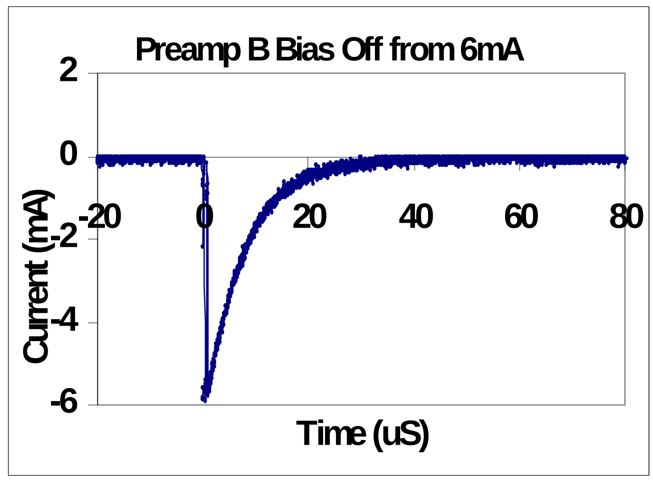

Figure 12: Preamp B Bias-Off

A feature of the 'bias off' event for Preamp B shown in **Figure 12** becomes apparent only if the first microsecond of the event is more closely examined. In **Figure 13** it is clear that an oscillation occurs during the 'bias off' event. As seen in **Figure 14** this oscillation has transitions on the order of 10ns with amplitudes of 6mA. The characteristics of these transitions are quite similar to a 6.5V HBM event.

Unfortunately, only one Preamp B headstack was available for evaluation. It is not clear whether this oscillatory behavior at 'bias-off' is the normal operating state for this chip. Though static safe techniques were used at all times when working with the head stacks, there is the possibility that the preamp chip may have been damaged or degraded before or during the measurement process. It is noted that those heads that remained connected to the preamplifier appeared to be undamaged and that reasonable quasi-static measurements were obtained on them after the transient measurement process was complete. That these heads were functioning properly is consistent with the concept that fast transitions whose amplitudes remain within bias current range will not damage the MR sensor.

Setup for Measuring Current Transients

Current transients are typically high frequency events. It is necessary to use equipment with sufficient bandwidth in order to perform an effective evaluation of a system. The suggested components are listed below.

1) Digital Oscilloscope (Recommend minimum of 1GHz bandwidth with 2Gs/s sampling rate)
2) AC Current Probe (Recommend minimum 1GHz bandwidth)

A digital scope is appropriate because it is well suited to capturing high frequency single shot events. The choice of an AC current probe versus a DC current

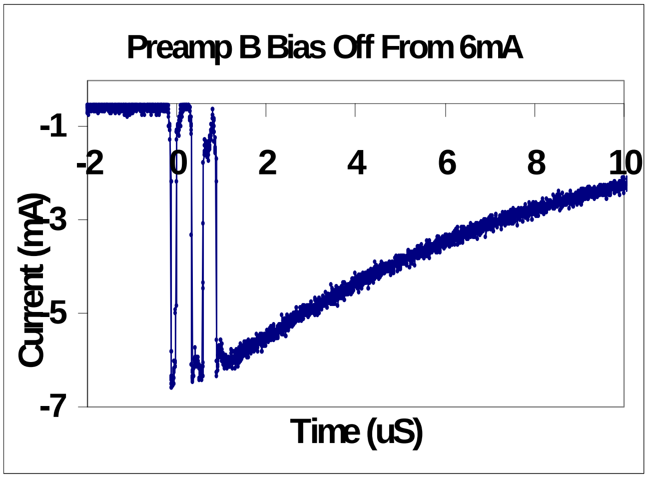

Figure 13: Zoom of Preamp B Bias-Off

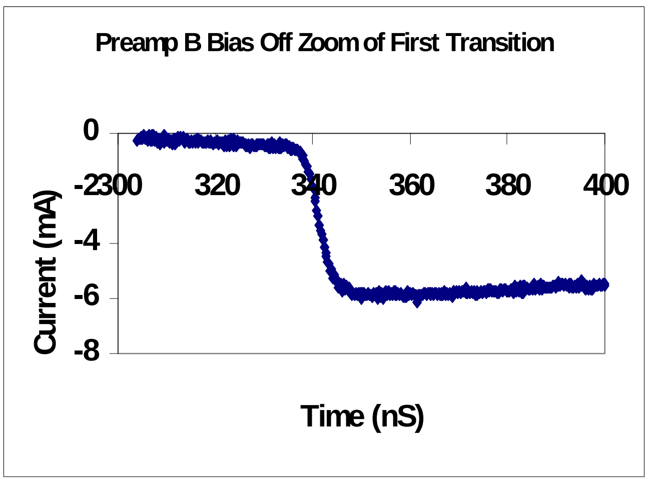

Figure 14: Preamp B Bias-Off Zoom of First Transition

probe is suggested because of the high frequency bandwidth limitations associated with DC probes.

Some examples of equipment used to measure transients are:

1) LeCroy LC574A Digital Oscilloscope:
   BW: 1 GHz
   Sampling: 4 Gs/s
2) Tektronix CT-1 AC Current Probe:
   BW: 25KHz – 1GHz
   Gain: 5mV/1mA
3) Tektronix CT-6 AC Current Probe:
   BW: 250KHz – 2GHz
   Gain: 5mV/1mA
4) Tektronix AM 503 Current Probe System
   BW: DC – 100MHz
   Tektronix DC Probe: P6302
   BW: DC – 50MHz

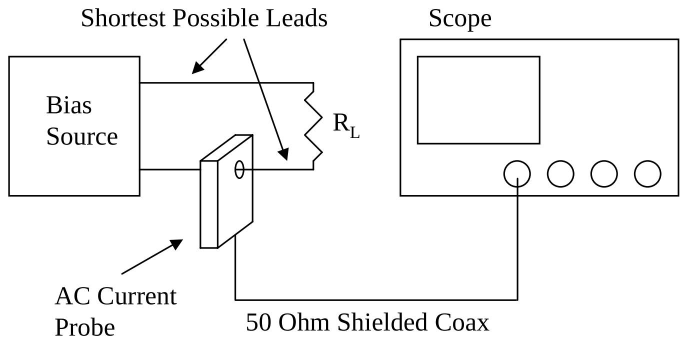

Figure 15: Basic Setup for Measuring Current Transient

Figure 15 is a representation of the configuration needed to qualify a system for current transients. This configuration is specific to systems designed to test disk drive heads. It is expected that the device under test (DUT) will be connected to a bias current source through two connections (e.g. R+ and R- of the head). It is this set of connections which is considered for transient evaluation.

When preparing the evaluation setup it is important to verify that:

1) Contacts to the system are made through the shortest possible leads to reduce susceptibility to external noise.
2) Load resistance approximates the resistance of a typical DUT.
3) Cabling connecting the current probe to the scope is shielded and of the appropriate impedance.

Understanding Current Transient Measurements

It is essential to understand how the system interacts with the DUT in order to effectively evaluate an MR test system for current transients. When placed on a tester the MR head should be in one of only two conditions: biased or not biased. To properly quantify the peak levels of any detected transients it is necessary to understand the state of the system at the time of the evaluation. If the system is being tested while the head is under bias then any transients detected are additive to the existing DC current through the MR sensor. This means that the values obtained using the AC current probe must be modified to include the DC bias level. If the sensor is grounded the AC probe measurements should accurately reflect the characteristics of any current transients detected. This assumption is only true if the transients fall within the operating bandwidth of the measurement system and are not being attenuated.

It must be clearly understood when the state of bias through the DUT is being intentionally modified. Bias-on or bias-off events will be detected using the AC probe and should be evaluated for repeatability and peak amplitude but should not be misinterpreted as current transients.

Specifying Allowable Limits

The specification of allowable limits on the amplitude of current transients must be done in the context of the level of protection required for the DUT. Current GMR head designs typically require a 5mA bias current and can sustain magnetic damage from currents as low as 9mA. Clearly a system with peak transient levels of 4mA while under bias would pose a significant threat to these heads.

Because the GMR element is most susceptible to damage from currents above peak operating levels, it is important to specify the maximum allowable peak transient limit as either an absolute DC level or as a peak current above the operating current. In either case it case it will be clear during a system evaluation whether conditions exist that will threaten a DUT.

Conclusions

The use of correct measurement techniques and the accurate interpretation of data are essential in determining the level of safety of test equipment. The sensitivity of the (G)MR element to damage by excessive current requires that both head manufacturers and test equipment makers understand how to properly control, evaluate, and measure transient events.

References

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