Laser Power Optimization Effect on Jitter and Write Width in HAMR

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In HAMR, increasing laser power widens write erase width (WEW), reducing TPI, and reduces jitter, increasing BPI. Optimum laser power, WEW, jitter, TPI, and BPI have been modeled using the assumption of a Gaussian thermal profile. Because the laser power is adjustable, if the coefficient of the jitter term that depends on thermal gradient is improved, optimum laser power is reduced. Thus, TPI increases at the expense of BPI. TPI takes advantage of the high effective field gradient, giving HAMR its TPI advantage, lowering the bit aspect ratio. On the other hand, the portion of jitter resulting from thermal noise and grain size governs BPI. These predictions are verified in a fast measurement of the jitter contributions, which sweeps write current and laser power for each head to determine three independent jitter terms that vary with: 1) grain or cluster size, 2) T50 and DCSNR, and 3) downtrack thermal gradient.

***Index Terms*— Heat Assisted Magnetic Recording (HAMR), jitter, noise, writing process, Areal Density Capability (ADC).**

I. Introduction

JITTER strongly influences areal density in HAMR. For deeper understanding, jitter has been broken down into components [1,2]. A unique feature for HAMR is the ability to adjust laser power, so that write erase width (*WEW*) and thermal gradient are adjustable. Hence HAMR has an added degree of freedom that is not available in conventional perpendicular recording.

As laser power (*LP*) increases, *WEW* becomes wider, degrading track density (*TPI*, or tracks per inch). However, thermal gradient improves, resulting in lower jitter and improved linear density (*BPI*, or bits per inch). Jitter reaches an asymptote for high *LP* at high thermal gradient, and because *BPI* gain with increasing *LP* becomes more gradual, we can calculate *LP* for maximum *ADC* ($ADC = BPI \times TPI$).

II. Approximate Model of HAMR Recording

We assume a Gaussian thermal profile for media temperature, $T - T_{amb} = (T_{peak} - T_{amb})e^{-y^2/\sigma^2}$, where T_{peak} is the peak media temperature, T_{amb} is the ambient temperature, y is the offtrack position in nm, and σ is the 1/e width of the Gaussian in nm. This Gaussian assumption is not strictly correct, but it is a useful approximation allowing analytical solutions and an intuitive understanding of the recording physics [3]. Laser Power is proportional to laser current minus the threshold laser current above which lasing occurs. WEW is the width where the criterion $T_{peak} \geq T_w$ (writing threshold temperature for the media) is met. We define a reference WEW_{TwLC} at $LP_{Tw} = 1.21 \times LP_0$, where LP_0 is the LP needed to begin writing, when $T_{peak}=T_w$. Cross-track thermal gradient CTTG is the derivative dT/dy. Then WEW and CTTG vary with laser power as

$$WEW = \frac{2\sqrt{2}}{1.23} WEW_{TwLC} \sqrt{ln\left(\frac{LP}{LP_0}\right)} \tag{1}$$

and

$$CTTG = \frac{1.23\sqrt{2}(T_W - T_{amb})}{WEW_{TwLC}} \sqrt{ln\left(\frac{LP}{LP_0}\right)} . \tag{2}$$

As *LP* increases, both *CTTG* and *DTTG* (down track thermal gradient) improve, and we assume that *CTTG* and *DTTG* are proportional—a close approximation to the actual data.

The conventional breakdown of jitter into components [1] is

$$j = \sqrt{j_{CS}^2 + j_{SFD}^2 + j_{wth}^2 + j_{rem}^2} , \tag{3}$$

where j is total jitter, j_{wth} is noise induced by thermal fluctuations at the moment of magnetization freezing, j_{rem} is amplitude noise that is detected by the reader as jitter, j_{SFD} is related to the switching field distribution, and j_{CS} is transition position error due to the finite cluster size (previously referred to as grain size noise, although exchange coupling of grains can cause cluster size to be slightly larger than the grain size). The only term that is strongly dependent on *LP* is j_{SFD}. So for the purpose of understanding *LP* dependence, we simplify (3) as

$$j^2 = j_0^2 \left(1 + \frac{\alpha}{DTTG^2}\right), \tag{4}$$

with j_0 and α being two fitting parameters, the second term being j_{SFD}^2. Jitter asymptotes to j_0 for high *LP*.

Experimentally, we know that TPI and BPI fit well as linear functions of $1/WEW_{ADC}$ (where WEW_{ADC} is *WEW* at *LP* that is optimal for maximizing *ADC*) and jitter, respectively. The data in Fig. 1 demonstrate this linearity clearly for a sample of about 15,000 heads. Equations (5) and (6) are the fit to the data.

$$TPI = 223 - 15652/WEW_{ADC} \tag{5}$$

$$BPI = 3345 - 554j \tag{6}$$

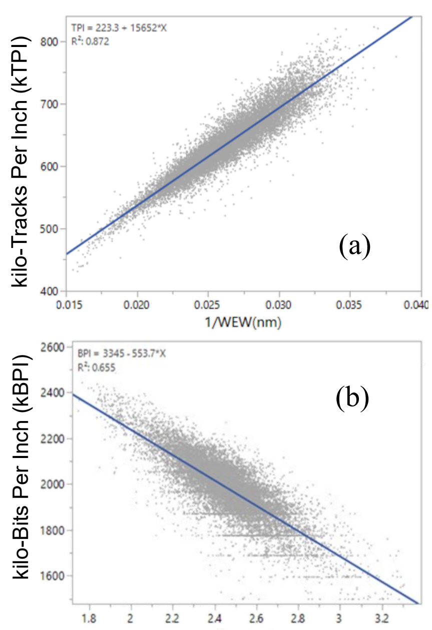

Fig. 1. (a) k*TPI* vs $1/WEW_{ADC}$, and (b) k*BPI* as a function of jitter.

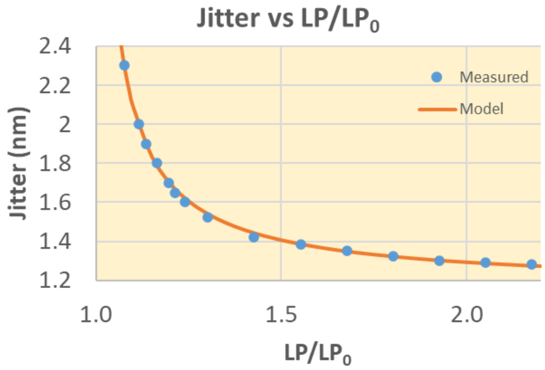

Fig. 2. Jitter vs LP/LP_0. Blue points are measured data, and the orange curve is a fit of the data to (4), with DTTG proportional to (2).

Average jitter for five heads is plotted vs LP and fit to (4) in Fig. 2. Note that jitter decreases steeply at low LP and more gradually at high LP. Thus at low LP, BPI rises sharply, but the increase is more gradual at high LP. Since TPI decreases monotonically with LP, at some laser power, the rise in BPI is more than offset by the loss of TPI. Quantitatively, there is an optimum LP to maximize ADC, and the derivative of ADC with respect to LP is zero at the maximum ADC:

$$\frac{\mathrm{d}ADC}{\mathrm{d}LP} = BPI\frac{\mathrm{d}TPI}{\mathrm{d}LP} + TPI\frac{\mathrm{d}BPI}{\mathrm{d}LP} = 0 \quad (7)$$

By substitution [(5) and (6) into (7), (1) into (5), (4) into (6), and (2) into (4) with an adjustment of $\alpha' = \alpha(DTTG/CTTG)^2$ for α into (4)], we can solve for the LP at optimum ADC, as well as for BPI and TPI.

Following this line of reasoning, we find that improvements of media SFD, σ_{Tw} (standard deviation of T_w), or thermal gradient produced by the head result in TPI gain but little change in BPI, whereas improvements in j_0 (thermal, remanent, or cluster size components) result in improved BPI but little change in TPI. In other words, the bit aspect ratio (BAR) becomes lower with improved SFD or thermal gradient, but BAR increases with improvement in other jitter components.

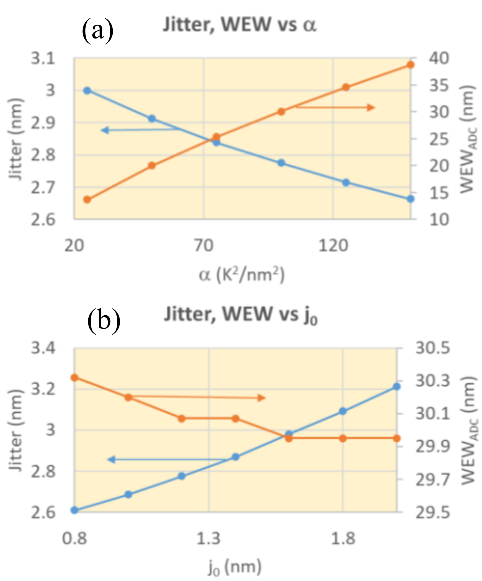

Fig. 3. Jitter (left axis) and WEW_{ADC} (right axis) vs (a) α and (b) j_0. In (b), j_{SFD} is held constant; thus $\alpha = 144/j_0^2$.

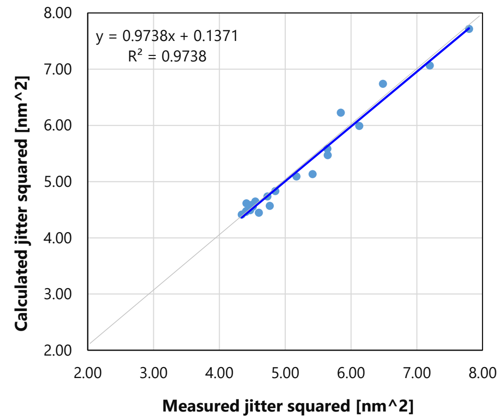

Fig. 4. Least-squares fitted j^2 from (8) vs measured j^2.

This point is illustrated in Fig. 3. Note the expanded scale of jitter in Fig. 3a and of WEW_{ADC} in Fig. 3b, corresponding to little change of these two parameters.

III. Fast Measurement of Jitter Components

We have developed a fast measurement of the breakdown of jitter into its components. Write current I_w and LP are swept (five I_w values between 25-105 mA, seven LP settings between 80% and 120% of the optimum for maximum ADC). Magnetic read width MRW, $T50$, $DTTG$, low-frequency signal-to-noise ratio $DCSNR$ (in dB) are measured at each I_w and LP, and σ_{Tw} (from THmap [3]) at each I_w. In (8), the first term is j_{CS}^2, the second term is j_{rem}^2, and the last term is j_{SFD}^2. From a least-squares fit, parameters CS, γ, and β are extracted. Fig. 4 shows an excellent fit for one head as an example.

$$j^2 = \frac{CS^3}{12MRW} + \gamma\left(\frac{T50}{10^{DCSNR/20}}\right)^2\frac{CS}{MRW} + \beta\left(\frac{\sigma_{Tw}}{DTTG}\right)^2\frac{CS}{MRW} \quad (8)$$

Two types of media were compared in Table 1. The jitter breakdown is the average for 8 heads that were measured on both Media A and Media B. Media A has superior j_{SFD}; therefore, we expect it to have higher TPI. Media B has smaller grain size and cluster size, and we expect it to have higher BPI. The independent ADC measurement confirmed these expectations.

TABLE I
Jitter Breakdown and ADC for Two Media Types

Parameter	Media A	Media B
j	1.87	1.77
j_{SFD}	1.12	1.31
j_{rem}	0.72	0.66
j_{CS}	1.31	0.98
ADC (Tb/in^2)	1.274	1.270
kTPI	609	594
kBPI	2093	2138

Jitter breakdown and ADC for two media types. Media A has superior j_{SFD} and thus higher TPI, and Media B has smaller grain size and thus higher BPI.

References

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