TWO REGION MODEL OF THE TRANSITION REGION OF PERPENDICULAR MAGNETIC RECORDING

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[Abstract] In accordance with its formation process, the transition region of perpendicular magnetic recording is considered as the combination of a reversing part and a relaxation part and a simple self-consistent model of the transition region is presented. By some reasonable simplification, analytical expressions of all the model parameters are obtained. A satisfying agreement is illustrated between the readout waveform of the new model and that of reported experiments.

INTRODUCTION

The digital magnetic recording process forms a sequence of magnetization transitions from one state to the other in the recording medium. All the performance of the recording system is finally reflected by the magnetization variation in the transition region. For a given read head and head-medium distance the read out performance is also determined by the magnetization variation around the transition region. So the modelling of the magnetization variation in the transition region is of great importance to the analysis, design and optimization of a read/write channel, especially if it can be a analytical model with reasonable accuracy. In fact, a analytical model is very useful for getting a comprehensive relation between the important parameters of a read/write channel and optimizing the read/write channel design.

Since the re-proposal of perpendicular magnetic recording technology [1], many efforts have been made to determine an analytical model for the transition region. Based on the assumption that the transition region is, in principle, free from the demagnetization field, a model of the transition region of both isolated

transitions and high density transitions has been reported [2]. Though a reasonable method for the calculation of the maximum and minimum allowable amplitude of magnetization in the transition region was presented, the authors did not give details on how to describe the magnetization variation in the whole transition region. Another important model is the dual arctangent model proposed by Koren [3]. This model gives an interesting description of the whole magnetization variation in the transition region. By some adjustment of the weight of arctangent and hyperbolic tangent functions, reasonable agreement with experimental results was reported by the proposer. However some of its assumptions, such as that the maximum demagnetization field should beat the centre of the relaxation region, are not completely reasonable and result in an un-expected minimum value of magnetization after its reverse.

Comparing the existing models of perpendicular magnetic recording with the arctangent model of longitudinal magnetic recording, it can be seen that another problem of the existing models of the transition region of perpendicular magnetic recording is that at least three parameters are not directly available for all of the models. To calculate those parameters, additional numerical calculation is required. As one of the most important purposes of modelling of the transition region is to give a brief but direct description of the relationship between transition region parameters and

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the head-medium interface parameters, such an additional numerical calculation is not the best choice.

Considering the transition region as the combination of a reversing part and a relaxation part, a new model is proposed and the method of parameter calculation is presented. In the new model, only 2 parameters are to be estimated, one for the reversing part and the other for the relaxation part. By analysis of the characteristics of the possible recording density and its relation to the reversing region length, and the characteristics of the demagnetization field in the relaxation region, a simplified method of parameter calculation is found and direct expressions for the two transition region parameters are thus obtained without any additional numerical calculation, as is the case with all other existing models. To check the reliability of the model, a comparison of the readout waveform of a single transition between the calculated waveform based on the new model and that from experiment [4] is made and the agreement is satisfying.

MODELLING

1. The Formation of Transition Region

As it is believed to be more suitable for the realization of the high density potential of perpendicular magnetic recording [5] [6], the modelling described below is focussed on the the combination of a single pole head and double layer medium.

A recorded transition region is the region through which the magnetization varies from one steady state to the other. Enlarged model studies [7] show that the magnetization in the transition region varies first from one (for example, negative) steady value to a reversed (for example, positive) maximum value and then reduces from that maximum value to the reversed steady state (for example, positive). As the reversing of magnetization happens in the area in which M varies from its steady state to the reversed maximum value, this area is defined as the reversing part or the

reversing region. After the moving away of recording head the reversed magnetization will relax down from its maximum possible value to its steady value under the action of the demagnetization field. So this area is named as the relaxation region.

2. Description of the Reversing Region

1) General Model

As the reversing region is established when the recording field switches from one direction to the other, the magnetization variation at the time the head field reduced to zero again could be described as:

$$M_{rev} = \frac{M_{max} + M_0}{\pi} \tan^{-1} \left(\frac{x}{\beta_{rev}} \right) + \left(\frac{M_{max} - M_0}{2} \right) \quad (1)$$

Here M_{max} is the maximum possible magnetization when the recording current reaches zero. By the same method used in [2] together with consideration of the imaging effect of the recording head and the underlayer, then M_{max} can be estimated as:

$$M_{max} = \frac{H_c + 2\pi M_0}{4 \tan^{-1} \left(\frac{2T}{3\delta} \right)} \quad (2)$$

Here, T is the pole width, δ is the recording layer thickness and M_0 is the value of magnetization in the steady region, that is, the region out of the transition area of magnetization. Since (a) in the steady area the demagnetization factor of the medium is 4π , (b) the $4\pi M_s$ of the medium is normally larger than its coercivity force H_c in perpendicular magnetic recording and, (c) the squareness of the medium's hysteresis loop is quite high (normally more than 0.94), the M_0 can be estimated as:

$$M_0 = \frac{H_c}{4\pi} \quad (3)$$

The parameter β_{rev} is the reversing region length parameter and the $\pi \beta_{rev}$ is the reversing region length, as illustrated in

Fig.1 Two Region Model of Transition Region of Perpendicular Recording

Fig.1. This parameter can be estimated by the self-consistent method, as described in [3]. The basic equation for the calculation is:

$$\left. \frac{dM}{dx} \right|_{x=0} = \left. \frac{dM}{dH} \right|_{M=0} \frac{d(H_h + H_d)}{dx} \Big|_{x_0} \quad (4)$$

where H_h , H_d are the head field and demagnetization field respectively, dM/dH is the slope of the hysteresis loop when $H = H_c$; x_0 is the point at which the magnetization reaches zero. Setting the zero magnetization point to be of a maximum value of dH_h/dx , the equation can be solved by numerical iteration method and the value of β_{rev} can thus be obtained.

2) Simplified Model

Experiments [4] show that a bit interval of less than one eighth of the medium thickness can be recorded. As the maximum possible recording bit length of a recording system should be not less than the reversing region length, the experimental results suggest that the reversing region length could be quite short. As an approximation, the reversing region length parameter β_{rev} can be estimated as one-fourth to one-tenth of the medium thickness, that is:

$$\beta_{rev} = (0.1 \sim 0.25) \delta \quad (5)$$

3. Modelling of the Magnetization Variation in the Relaxation Region

The most difficult but important part of the modelling of the transition region of perpendicular magnetic recording is the modelling of the relaxation region. As the relaxation process is a process of reducing the magnetization toward the steady value M_0 , such a reduction process can be described as:

$$M_{relax} = - \frac{M_{max} - M_0}{\pi} \tan^{-1} \left(\frac{x - x_1}{\beta_{relax}} \right) - \left(\frac{M_{max} - M_0}{2} \right) \quad (6)$$

where β_{relax} is the relaxation region length parameter and $\pi \beta_{relax}$ is the relaxation region length; x_1 is the offset of the relaxation region centre. As the relaxation region should be immediately after the reversing region, as illustrated in Fig.1, this offset can be defined as:

$$x_1 = \frac{\pi (\beta_{rev} + \beta_{relax})}{2} \quad (7)$$

4. Modelling of the Transition Region

Combining equations (6) and (1), a general model for the whole transition region is obtained:

$$M(x) = \underbrace{M_{rev} \frac{2}{\pi} \tan^{-1} \left(\frac{x}{\beta_{rev}} \right)}_{\text{reversing part}} - \underbrace{M_{relax} \frac{2}{\pi} \tan^{-1} \left(\frac{x - x_1}{\beta_{relax}} \right)}_{\text{relaxation part}} \quad (8)$$

where, M_{rev} is the amplitude of the variation part of magnetization in the reversing region and M_{relax} is that of the relaxation region:

$$M_{rev} = \frac{M_{max} - M_0}{\pi} \quad (9)$$

$$M_{relax} = \frac{M_{max} - M_0}{\pi} \quad (10)$$

The β_{relax} can be calculated under the condition that the maximum demagnetization field should not be larger than H_c . For a

double layer medium with a recording layer thickness of $0.1 \mu\text{m}$, main pole width of

Fig.2 Magnetization Variation
Calculated from the Two Region Model

$0.4 \mu\text{m}$, coercivity of 980 Oe, saturated magnetization of 410 emu/cc, the calculated β_{rev} , β_{relax} are 0.010, 0.040 respectively. The modelled magnetization variation of the above parameters is illustrated in Fig.2. The corresponding demagnetization field (H_d) variation is illustrated in Fig.3. The H_d components from both the reversing part and the relaxation part of the model are also illustrated in the figure by a dashed line and broken line respectively.

Fig.3 H_d variation in Transition Region

5. Comparison with Other Models

Though there is some similarity in the form of the expression with Koren's dual arctangent model [3], the difference between our model and Koren's model is great.

First, in our model, the starting point of the relaxation region is immediately after the end of the reversing region (as in Fig.1) whilst for Koren's model, the starting point is determined by (a) calculation of the offset of the relaxation region centre from the reversing region centre and (b) the relaxation region length. As those calculations are based only on the assumption that H_a will reach its maximum value at the centre of the relaxation region and should not be larger than H_c , the start point of the relaxation region would therefore normally not be immediately after the end of relaxation region. It is possible to get a starting point into the reversing region or out of the reversing region in Koren's model and this is not physically realistic. In fact, it is just for this reason that a minimum value could appear in the relaxation region which is not practical.

A second difference is in the calculation of the parameters. In Koren's model, the calculation of the two relaxation region parameters (the relaxation region length and the centre of relaxation region) is based on an assumption that the point corresponding to the maximum value of H_a is exactly at the centre of the relaxation region. However the author did not give any explanation as to the reason for that assumption. In fact, it is difficult to see that this assumption is correct. In our model the only parameter for the relaxation region is the β_{relax} and its value is calculated according to the obvious condition that the maximum field should not be larger than H_c after relaxation. It is believed that our consideration is more reasonable. This has also been proved by the good agreement of the modelled readout waveform with experimental results as described in the following.

The third difference is that though

Koren's model is named a dual arctangent model, to get a reasonable agreement with experimental results, another hyperbolic part should be introduced and a reasonable weight should be given to the arctangent part and the hyperbolic part. But for our model, no other additional part is needed and a good agreement with experimental results can still be obtained.

So far, it is impossible for all of the perpendicular magnetic recording models to get a direct formula for the transition region length. But with some reasonable simplification, a direct formula for the relaxation region length can be obtained by the present model, as described later.

6 Comparison with Experimental Results

Fig.4 is a comparison of the readout waveform of a single transition between that obtained experimentally [4] and that calculated based on our model. A satisfying agreement between experiment and calculation is obtained and illustrated. The small difference at the peak area of waveform comes from the limit of the Karlquist equation at the case $y/T \ll 1$, since this equation was used as an approximation for the sensitivity function of the read head.

Fig.4 Readout Waveform Comparison

RELAXATION REGION LENGTH CALCULATION

For the model described in (6) and with the consideration of the imaging effect of

the underlayer, the demagnetization field at point (x,y) can be expressed as:

$$H_d(x, y) = -4 [M_{rev} f(x, y, \beta_{rev}, \delta) - M_{relax} f(x-x_1, y, \beta_{relax}, \delta)] \quad (11)$$

$$\text{where, } f(x, y, \beta, \delta) = \tan^{-1} \left(\frac{x}{\beta + 3\delta/2 + y} \right) + \tan^{-1} \left(\frac{x}{\beta + \delta/2 - y} \right)$$

Fig.5 gives the H_d variation when β_{relax} equals $0.06 \mu m$. From this figure

Fig.5 H_d variation ($\beta_{relax} = 0.06 \mu m$)

and Fig.3 ($\beta_{relax} = 0.04 \mu m$), it can be seen that with the increase of β_{relax} , the maximum field increases and the point corresponding to the maximum demagnetization field ($x(H_{d_max})$) increases also. It can be seen also from these 2 figures that though for most cases the $H_d(max)$ does not happen at the centre of the relaxation region, the value of the demagnetization field at the centre of the relaxation region is not far from the maximum value of H_d .

The demagnetization field at the bottom of the medium (that is, $y = -\delta/2$) can be expressed as:

$$H_d(x) = -8 \left[M_{rev} \tan^{-1} \left(\frac{x}{\beta_{rev} + \delta} \right) - M_{relax} \tan^{-1} \left(\frac{x - x_1}{\beta_{relax} + \delta} \right) \right] \quad (12)$$

Assuming that the H_d at the centre of the relaxation region is kH_c ($k = 0.90 \sim 1.00$) and considering that the maximum value of H_d should not be larger than H_c , then,

$$k H_c = -8 M_{rev} \tan^{-1} \left(\frac{x_1}{\beta_{rev} + \delta} \right) \quad (13)$$

Combining (7) and (13), a analytical relation of the relaxation region length parameter β_{relax} to the medium parameters is obtained:

$$\beta_{relax} = \frac{2}{\pi} (\beta_{rev} + \delta) \tan \left(\frac{k H_c}{4 (M_0 + M_{max})} \right) + \beta_{rev} \quad (14)$$

CONCLUSION

1. A new two region model for the transition region of perpendicular magnetic recording is proposed. Compared with other models, the model is simpler, more physically realistic and gives good agreement with experimental results.

2. Only one parameter needs to be calculated for the modelling of the relaxation region of the two region model, whilst for all other models at least two parameters need to be estimated. This gives a better prospect of achieving a analytical direct relationship between the relaxation region length and the head-medium parameters.

3. As the H_d at the centre of the relaxation region is close to the maximum value of H_d , the H_d at the centre could be assumed as $k H_c$ ($k = 0.90 \sim 1.00$). Together with the consideration that the maximum value of H_d should not be larger than H_c , a direct analytical formula for the relaxation region length parameter β_{relax} is obtained.

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