DYNAMIC MAGNETIC HYSTERESIS BEHAVİOR OF BLUME-CAPEL MODEL UNDER THE PRESENCE OF AN OSCILLATING MAGNETIC FIELD: THE PATH PROBABILITY METHOD APPROACH

[1]MEHMET ERTAŞ, [2]MUSTAFA KESKIN

Department of Physics, Erciyes University, 38039 Kayseri, Turkey
Email: mehmetertas@erciyes.edu.tr, keskin@erciyes.edu.tr

Abstract- Recently, Ertaş and Keskin [Physica A 411, 42-52 (2014)] presented a study of the dynamic phase transition (DPT) temperatures and the dynamic phase diagrams in the Blume-Capel model under an oscillating external magnetic field by using the path probability method. They calculated the dynamic phase diagrams in three different planes and found that the dynamic phase diagrams contain the paramagnetic (P), ferromagnetic (F) and the F + P mixed phases and exhibit the dynamic tricritical and reentrant behaviors as well as a double critical end point and triple point depending on interaction parameters. In this paper, we study dynamic magnetic hysteresis behavior of Blume-Capel model under the presence of an oscillating magnetic field by using the path probability method approach. We also investigate the effect of the temperatures and rate constants on dynamic hysteresis behaviors and found that results are in a good, quantitatively, agreement with some theoretical and experimental results.

Keywords: The Blume-Capel model; Dynamic magnetic hysteresis; Dynamic phase transition; Path probability method.

I. INTRODUCTION

This paper is an extension of the previously recent published work [1] (and referred to as paper I as following). In paper I, we calculated the dynamic phase transition (DPT) temperatures and presented the dynamic phase diagrams in the Blume-Capel (BC) model in an oscillating external magnetic field by using the path probability method that contains two rate constants and that are very important for the investigation of the dynamic behaviors of systems.

The dynamic phase diagrams contain the paramagnetic (P), ferromagnetic (F) and the F+P mixed phases and display the dynamic tricritical and reentrant behaviors as well as a double critical end point and triple point that strongly dependent on interaction parameters. We also investigate influences of the two rate constants and found that the rate constants effect on the topological behavior of dynamic phase diagrams very much. In this paper, we study the behavior of dynamic magnetic hysteresis loops of the BC model under the presence of an oscillating magnetic field within the path probability method (PPM). We also investigate the effect of the temperatures and the rate constants on dynamic hysteresis behavior.

It is worthwhile mentioning that the study of ferromagnetic hysteresis represents the important and open field of current interest due to its wide technological applications as well as academic research [2, 3]. On the other hand, dynamic magnetic hysteresis (DMH) has been the subject of a great deal of interest both theoretically and experimentally, because the DMH has important technological implications such as for high frequency devices applications. A phenomenon known as dynamic magnetic hysteresis is following [4-6]. If the external magnetic field oscillates, the magnetization will also oscillate with necessary modifications in its form, and lag behind applied field of frequency.

This delay in the dynamic response gives rise to a nonvanishing area of magnetization-field loop. This phenomenon has been called as the DMH. Theoretically, DMH has been mostly investigated by using Ising models, especially spin-1/2 Ising model (see [1, 4, 7-11] and references therein) as well as some other models (see [12-16] and references therein). Many experimental works have also been devoted to the MDH (see [17-20] and references therein).

The rest of this paper is organized as follows. In the next section, we briefly describe the model and derivation of the set of dynamic by using the PPM in a presence of a time-varying magnetic field. In Sec. 3 we present the numerical results with discussion and a brief conclusion.

II. MODEL AND DYNAMIC EQUATIONS

Since the detailed description of the BC model and derivation of the dynamic equations are given within the PPM in paper I extensively, we shall only give a brief summary in this paper. The Hamiltonian of the BC model, which is the spin-1 Ising model with bilinear (J) and a single-ion potential or crystal-field interaction (D), is given by

$$H = -J\sum_{\langle ij\rangle} S_i S_j - D\sum_i S_i^2 - H(t)\sum_i S_i, \qquad (1)$$

where the S_i takes the values ± 1 or 0 at each site i of a lattice and the summation index < ij > indicates a summation over all pairs of nearest neighbor sites. J is the bilinear exchange interaction and D is the crystal-field interaction parameters. H(t) is an oscillating magnetic field that is given by $H(t)=H_0\cos(wt)$ and H_o and $w=2\pi\nu$ are the amplitude and the angular frequency of the oscillating field, respectively.

The BC model is a three-state, namely X_1, X_2 and X_3 that are the average fractions of spins with values +1, 0 and −1, respectively that obey the normalization relation ($\sum_{i=1}^{3} X_i = 1$) and following two-order parameters system. (i) The average magnetization m=< S >, which is the excess of one orientation over the other orientation. (ii) The quadrupole moment q which is the average squared magnetization q=< S^2 >. m and q can be expressed in terms of the state or internal variables as

$$m \equiv \langle S\rangle = X_1 - X_3 \text{ and } q \equiv \langle S^2\rangle = X_1 + X_3. \quad (2)$$

X_i (i=1, 2, 3) can be written in terms of m and q by using Eq. (2) with the normalization relation

$$X_1 = \frac{1}{2}(m+q),\ X_2 = (1-q) \text{ and } X_3 = \frac{1}{2}(q-m). \quad (3)$$

We use the PPM to obtain the set of dynamic equations or equations of motion. In PPM, the rate of change of the state or point variables is written as [21]

$$\frac{dX_i}{dt} = \sum_{i\neq j}\left(X_{ji} - X_{ij}\right), \quad (4)$$

where X_{ij} is the path probability function (PPF) for the system to go from state i to j and in the thermal equilibrium, the detailed balancing holds, i. e. $X_{ij} = X_{ji}$. Kikuchi introduced two different options and called recipe I and II for the X_{ij} [21]. We used the recipe II and defined as

$$X_{ij} = k_{ij} Z^{-1} X_i \exp\left(-\frac{\beta}{2}\left(\frac{\partial E}{\partial X_j}\right)\right). \quad (5)$$

Eqs. (4) satisfies the necessary requirements of the detailed balancing and $\beta = k_B T$. k_{ij} are the rate constants with $k_{ij} = k_{ji}$. Two rate constants in the model are following. (i) $k_{12} = k_{23} = k_1$ that is the insertion or removal of particles associated with the translation of particles through the lattices which corresponds to D. (ii) $k_{13} = k_2$ is associated with the reorientation of a molecule at a fixed site that corresponds to J and H. We assume only single jumps are allowed; hence that double processes, the simultaneous insertion, removal or rotation of two particles do not occur. Z is the partition function and defined as

$$Z = \sum_{i=1}^{3} e_i,\ e_i = \exp\left(-\frac{\beta}{2}\left(\frac{\partial E}{\partial X_i}\right)\right), \quad (6)$$

E is the internal energy that is obtained by solving Eq. (1) using the expression of m and q in terms of the internal variables

$$E = -J\left(X_1 - X_3\right)^2 + D\left(X_1 + X_2\right) - H(t)\left(X_1 - X_3\right), \quad (7)$$

Thus, we used recipe II and obtained the following set of coupled dynamic equations by using Eqs. (2) - (7), and found

$$\Omega\frac{dm}{d\xi} = \frac{-\left[2k\cosh(a) + \frac{k_1}{k}\exp\left(-\frac{d}{T}\right)\right]m + 2\frac{k_1}{k}(k-1)\sinh(a)\,q + 2\frac{k_1}{k}\sinh(a)}{2\cosh(a) + \exp\left(-\frac{d}{T}\right)}, \quad (8a)$$

$$\Omega\frac{dq}{d\xi} = \frac{-\frac{k_1}{k}\left[2\cosh(a) + \exp\left(-\frac{d}{T}\right)\right]q + 2\frac{k_1}{k}\cosh(a)}{2\cosh(a) + \exp\left(-\frac{d}{T}\right)}, \quad (8b)$$

where a = 1/T (m + h cos ξ) m = < S >, q = < Q >, $k=k_2/k_1$, $\Omega = w/k$, $\xi = wt$, $d=D/2J$, $h=H_0/2J$ and $T=(\beta J)^{-1}$. T, h, d, and Ω are dimensionless. Solution and discussion of Eq. (8) were extensively given in paper I.

In order to study the DMH behavior, one should define the dynamic hysteresis loop area and it is defined as

$$A = -\oint m(t)\,dh = -h_0 w \oint m(t)\cos(wt)\,dt, \quad (9)$$

Solution and discussion of Eq. (9) will be given in the next section.

III. NUMERICAL RESULTS AND CONCLUSION

We solved Eq. (9) by combining the numerical methods of Adams-Moulton-predictor-corrector with the Romberg integration for a given set of system parameters and presented in Figs. 1 and 2.

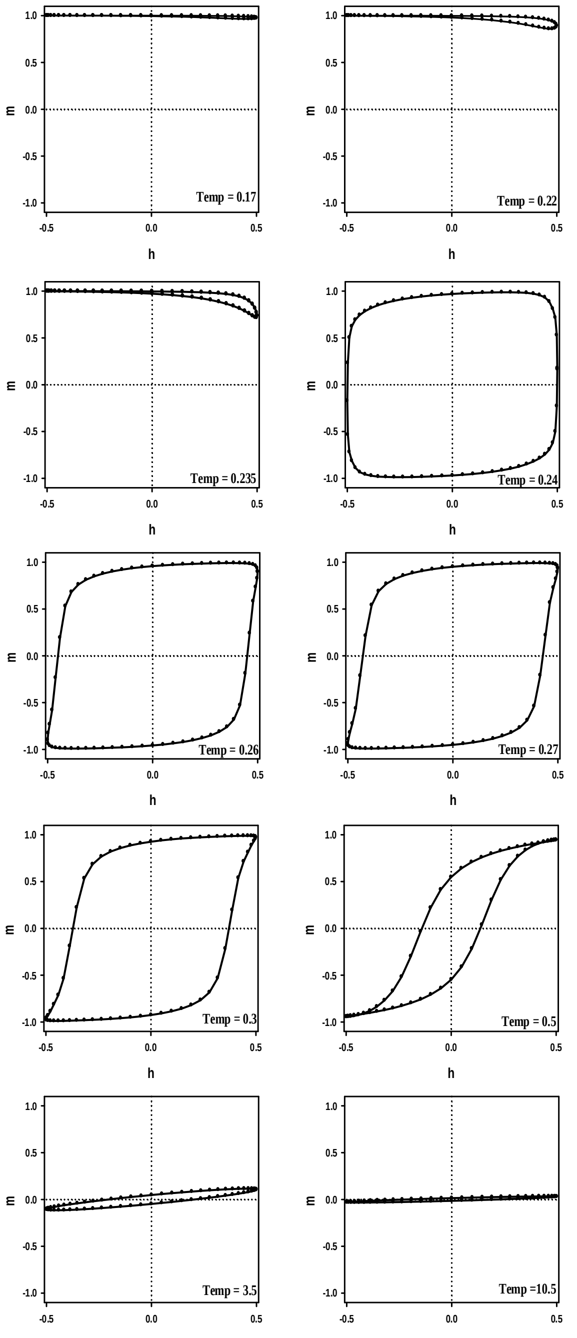

Fig. 1. The behavior of the dynamic hysteresis loops as a function of h for w=0.06π, k=1, k_1=1, J=1, D=0.25, and Temp= 0.17, 0.22, 0.235, 0.24, 0.26, 0.27, 0.3, 0.5, 3.5, 10,5.

Fig. 1 illustrates dynamic magnetic hysteresis loops for w=0,06π, k=1, k_1=1, J=1, D=0.25 at T=0.17, 0.22, 0.235, 0.24, 0. 26, 0.27, 0.3, 0.5, 3.5 and 10. From this figure, one can see that the dynamic magnetic hysteresis loop areas increase as the temperature increases and at a certain temperature loop areas decrease with increasing the temperature that is in a good, quantitatively, agreement with some theoretical [10, 11, 22] results. Experimentally, it was reported that for the high value of temperature dynamic magnetic loop area is small, but for the low value of temperature is large [23]; hence our results are also consistent with the experimental work.

Fig. 2 shows the influence of rate constants on the behavior of dynamic magnetic hysteresis loops for w=0,06π, k_1=1, J=1, D=0.25, T=0.5 and k= 0.1, 1.0, 2.0, 3.0, 5.0, 8.0.

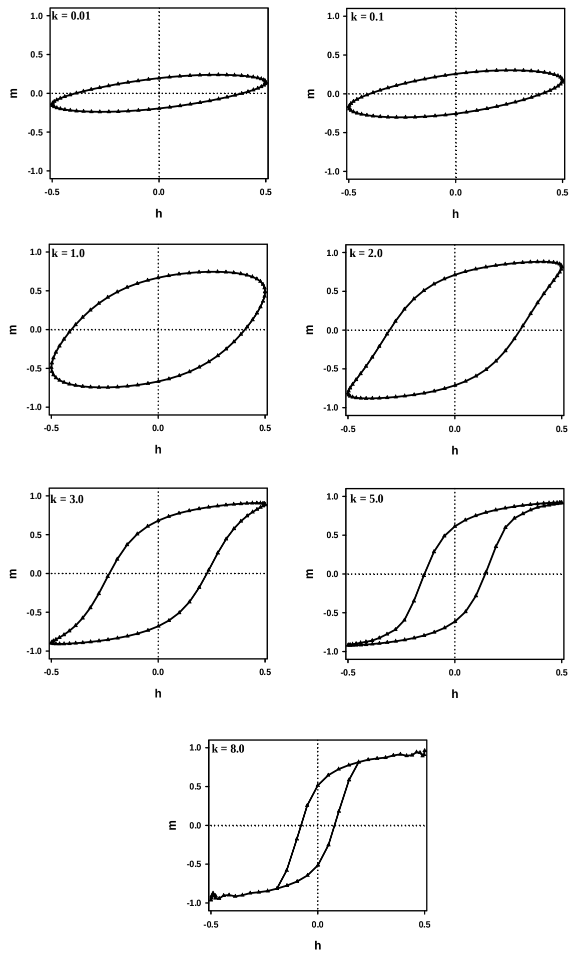

Fig. 2. Same as Fig. 1, but w=0,06π, k1=1, J=1, D=0.25, T=0.5, and k= 0.1, 1.0, 2.0, 3.0, 5.0, 8.0.

Fig. 2 illustrates that dynamic hysteresis loop areas increase with increasing the rate constants and a certain rate constant loop areas become smaller in which is in a good agreement with the experimental result [24]. We should also mention that the wheel speed in Ref. 24 corresponds to the rate constant in the present work. Moreover, larger hysteresis loop areas correspond to the hard magnet that are obtained for the bigger rate constant in which is also in a good, quantitatively, agreement with the experimental works that hardness values of alloys increase with the increasing the values of the solidification rates (see [25-27] and references therein).

In conclusion, our results are in a good, quantitatively, agreement with some theoretical and experimental results. More details of our results will be appeared in the future communication due to the page limitation here.

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