Equatorial nonequilibrium states in magnetization dynamics in ferromagnets : Generalization of Suhl's spin－wave instabilities

C. Kosaka *, K .Nakamura*,S. Murugesh #, and M.Lakshmanan #

* Department of Applied Physics, Osaka City University, Osaka 558-8585,Japan

Department of Physics ,Bharathidasan University ,Tiruchirappalli 620024, India

横振動磁場下における強磁性体の新しい非平衡状態を考察する。P−modeと呼ばれる回転座標系での新しい固定点を求め、一様な摂動に対する不安定性とスピン波に対する不安定性(Suhlの理論の拡張)の2種類の解析を行う。基礎方程式としては、強磁性体における磁化M(r ,t)の非平衡状態に散逸項を取り入れて記述したLandau−Lifshitz−Gilbert(LLG)方程式を採用する。

In ferromagnets, the strong exchange interaction between neighboring spins prevents spins from radically falling down from the direction of applied static field. Here, ferromagnetic resonances just imply the spin-wave instability of saturation magnetization directed towards north pole, i.e, parallel to longitudinal (a vertical) magnetic field.

Recent progress in nanotechnology has made it possible to fabricate nano-scale ferromagnets where an assembly of spins can fall toward the equatorial plane in the presence of oscillating transverse field.

We shall investigate nonlinear dynamics of magnetization **M**(r,t) of nano-scale ferromagnets that obeys Landau－Lifshitz－Gilbert(LLG) equation. Besides static－vertical and oscillating－transverse fields, the demagnetization field coming from the spatial inhomogeneity of the magnetization vector plays an essential role. We shall first treat the homogeneous magnetization and determine novel fixed points－P-mode－that are located far from north pole. Then we proceed to analyze their stability against both homogeneous perturbations and spin－wave excitations.

In ferromagnets the magnetization vector **M(r,t)** obeys the following Landau－Lifshitz－Gilbert(LLG) equation :

$$\partial_t \vec{M} = -\vec{M} \times \vec{H}_{eff} + \alpha \vec{M} \times \partial_t \vec{M} \qquad (1)$$

where, α denotes a damping parameter. On the r.h.s of Eq.(1), the 1st term represents a torque, and the 2nd term describes a phenomenological dissipation. The effective field H_{eff} stands for:

$$\vec{H}_{eff} = \vec{h}_a + \vec{h}_M + \vec{h}_{AN} + \vec{h}_{EX} \qquad (2)$$

In Eq.(2), the 1st term $\vec{\mathbf{h}}_a$ is an external field (oscillating transverse field + static vertical field), the 2nd term $\vec{\mathbf{h}}_M$ stands for a long-range demagnetization field, the 3rd term $\vec{\mathbf{h}}_{AN}$ represents an anisotropy and the 4th term $\vec{\mathbf{h}}_{EX}$ is a short－range exchange field. The most important field is the demagnetization field $\vec{\mathbf{h}}_M$, which comes from a spatial variation of the magnetization. The functional form differs seriously between the uniform P-mode and spin waves: $\mathbf{H}_m^0 = -N_{\perp}\mathbf{m}_{\perp}^0 - N_z\mathbf{m}_{\parallel}^0$ for the P-mode and $\boldsymbol{H}_m = -\nabla\phi$, $\nabla^2\phi = -4\pi\nabla\vec{\boldsymbol{M}}$ for spin waves.

Figure 1 shows the phase portrait for the choice for which the only fixed points are along the equator using equation (1), assuming spatial homogeneity of $\hat{\psi}$, for choice that are possible. $\hat{\psi}$ is the complex stereographic variable $(\hat{\psi}(\mathrm{r},t) = m_x + im_y/1 + m_z)$.

Fig.1

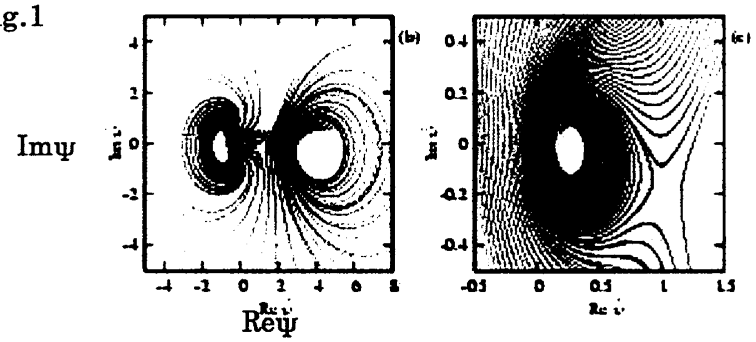
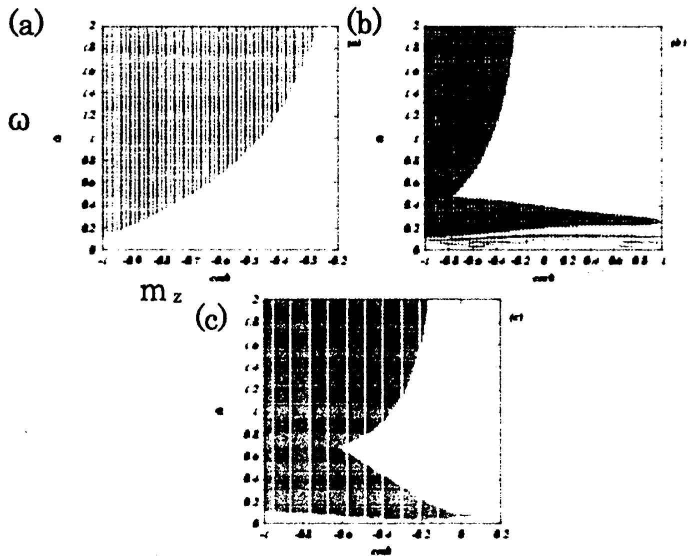


Figure 2 shows unstable regions in the (m_z,ω) space as shaded regions for different values of the angle θ_k : (a) $\sin\theta_k = 0$, (b) $\sin\theta_k = 0.6$ and (c) $\sin\theta_k = 1.0$. Note that θ_k defines the angle between the anisotoropy axis and the plane of the ferromagnetic film.

Fig.2



From the linear stability analysis, we notice resonance occurs at the frequenciesωk =ω /2, ω.The arbitrariness of the axis of anisotropy is crucial in determining the resonance frequencies. The resonances are absent when the wave vector associated with the spin wave lies in the x-y plane, the plane of the ferromagnetic film. Details are given in Reference.

Reference

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