CHAOS IN POLISHED AND ROUGHENED YIG SPHERES

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Abstract. – We have studied quasi-periodic and chaotic auto-oscillations in the ferromagnetic resonance of polished and roughened YIG spheres between 2.0 and 3.6 GHz. Regions of quasi-periodicity, steady chaos, transient chaos and intermittency were maped out. The average times for transient chaos follow a scaling law in microwave power. Roughened samples show a greater variety of responses. Changes were also noted in the Fourier spectrum of chaos. The information dimension of the chaos in both types of sample was 3.3 ± 0.2.

Introduction

Recently we have reported non-linear effects in the saturated ferromagnetic resonance of highly polished, undoped YIG spheres, including the temporal dependence of chaotic transient [1], the nature of transitions between quasiperiodic states [2], and an analysis of stable chaos and intermittency. In this paper we extend these observations to roughened spheres and find dramatic changes in the non-linear response.

We have chosen to operate our experiment at ferromagnetic resonance in perpendicular pumping with microwave frequencies selected to excite the *first* order Suhl instability [3] generating spin waves at half the excitation frequency with a wave vector $k \approx 0$. In this regime it is possible to excite a large number of spin wave modes at modest microwave intensities [3].

When two or more spin wave modes are excited, their interaction produces a slowly varying signal (kiloHertz). These auto oscillations are what we measure.

Experiment

Our 20 mil diameter YIG samples were placed between orthogonal excitation and pick-up loops and nonresonately excited between 2.0 and 3.6 GHz. A dc magnetic field was applied orthogonal to both coils and tuned to ferromagnetic resonance. The synthesized microwave input power was stepped or ramped and the signal transmitted *via* the resonant YIG sample was detected, amplified, digitized and sent to a VAX computer for later analysis.

We studied several 20 Mil diameter highly polished, undoped, single crystal YIG spheres. As the microwave power is increased above the Suhl instability, collective spin-wave interactions produce a series of quasi-periodic auto-oscillations in the transmitted signal. As the microwave power is further increased the auto-oscillations become chaotic. The polished samples exhibited chaotic transients for excitation frequencies in the band 2.0 to 2.8 GHz. Transients were produced either by suddenly stepping up the microwave power [1] ($\geq$ 3 dB) or as an intermediate state that appearing in the irreversible transition between distinct quasi-periodic states [2]. In both cases the average time the chaotic transient persisted followed a scaling theory first proposed by Gebogi, Ott and Yorke [4-6] with slight modifications to account for the presence of multiple quasi-periodic attractors [1]. The information dimension of the transient chaotic state was found to be 3.3 ± 0.2 in both cases. A schematic representation of the nature of the kiloHertz modulations for the smooth sphere is seen in figure 1 where the abscissa is the microwave power in dB relative to the Suhl instability (0 dB). A small region of intermittency was also seen between 2 and 2.3 GHz. In this region ran-

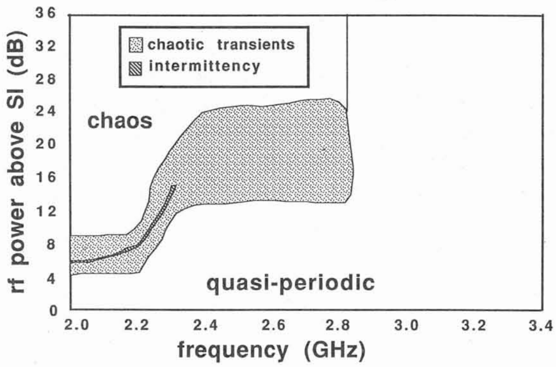

Fig. 1. – Sketch of the behavior of auto oscillations in 20 mil diameter polished YIG spheres at different locations in parameter space.

dom switching occurs between large and small chaotic waveforms with no change in drive parameters. The observed features were insensitive to external noise and reflect the internal collective dynamics of the sample.

Neither chaotic transients nor intermittency were seen above 2.9 GHz. Successive quasi-periodic oscillations reversibly melded into each other without intervening episodes of chaos. Only a few phenomena appear for the polished sphere, and most of these are visible over a wide range of power and are stable with respect to the experimentally controlled parameters.

We roughened the surface of one of our samples to study the effect of increasing the number of interacting low k spin waves [7]. The 20 mil YIG sphere was milled with 20 micron abrasive, causing the ferromagnetic resonance line width to increase from 0.16 gauss to 0.70 gauss. The size of the pits on the sphere was substantially smaller than 20 microns.

Roughening the surface of the YIG sphere complicated the response as is seen in figure 2. Chaotic transients were still present, but over a much smaller range. Intermittency is common in the rough sphere. We saw intermittency both between quasiperiodic oscillations and chaos and between two types of chaos, both with approximately the same dimension (3.3 ± 0.2) but different amplitudes. We also observed transient episodes of intermittency, in which two types of chaos alternated for some time, after which the intermittency suddenly disappeared and a quasiperiodic auto oscillation took its place. The boundary between transient and non-transient regimes moved up in frequency, from 2.8 GHz (polished) to 3.0 GHz (roughened).

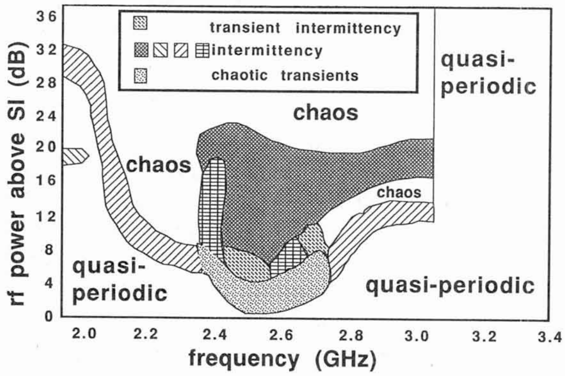

Fig. 2. – Sketch of auto oscillation behavior seen in different regions of parameter space for a roughened YIG sphere.

Figure 3 shows typical Fourier amplitude spectra of chaos in polished (3a), and roughened (3b) samples. In the polished YIG sphere, the power spectrum of chaos goes approximately as $1/f$. The Fourier spectrum of chaos in the rough sphere has broad peak between 2 and 10 KHz.

Conclusions

YIG spheres were driven at ferromagnetic resonance in the frequency range 2.0 to 3.4 GHz where low k spin waves are generated *via* the first order Suhl instability. Above the Suhl instability quasi-periodic and chaotic auto-oscillations appear in the resonance. Transient chaos and intermittency were encountered. In polished samples the auto-oscillations displayed a transient and a non-transient region with a narrow band of intermittency. The types of behavior seen in a roughened sample were much more complex with regions of transient chaos, intermittency between quasi-periodic and chaotic state and between distinct chaotic states, and a region of transient intermittency. In the polished sample the Fourier spectrum of chaos varied as $1/f$ whereas in the roughened sample a broad peak appeared between 2 and 10 kHz. The information dimension of the chaos is both types of sample was 3.3 ± 0.2.

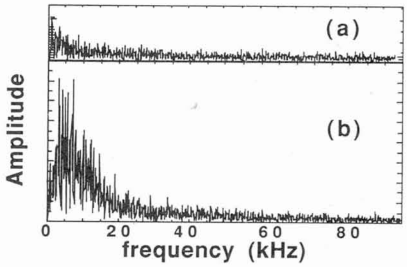

Fig. 3. – Fourier amplitude spectra of chaos in polished (3a) and roughened (3b) YIG spheres.

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