Electronics Research Laboratory
University of California
Berkeley, California
Internal Technical Memorandum M-81

INSTABILITIES IN THE MAGNETIZATION VECTOR IN YIG AT HIGH MICROWAVE POWER LEVELS

by

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*The research reported herein was supported by the Joint Services Electronics Porgram (Air Force Office of Scientific Research, Army Research Office, Office of Naval Research) under Grants 139-63 and 139-64.

July 8, 1964

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ABSTRACT

At microwave power levels above that necessary for spin wave growth in Y I G coherent relaxation oscillations are observed for three distinct values of H_{dc}. The location of one of the regions and its change with power level agrees closely with the location of a foldover region for M_z calculated by Suhl. Information is obtained on the relationship between the longitudinal relaxation time and the relaxation time of the oscillations by using spheres with different linewidths also by obtaining results at 300° K and at 77° K. The amplitude of the oscillations is also compared to the value of $M_o - M_z$ which is present just before the oscillations take place. The information obtained strongly indicates a foldover process is involved in the three regions.

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INTRODUCTION

In ferromagnetic resonant experiments the power absorbed by a sample from the microwave field is proportional to χ'' the complex or out of phase part of the susceptibility. At low microwave power levels χ'' has a resonant form of lorentzian shape as a function of H_{dc} at constant frequency and is independent of the microwave power level. As the microwave power is increased to relatively large values a critical value is reached where magnetic waves (spin waves) are parametrically excited by the uniform mode.[1] To first order the effect of the spin wave excitation is to add additional loss to the uniform mode which causes the shape of x'' to become broader and in addition at x-band frequencies there is an absorption of power at dc field below H_r.

At power levels just above the critical level (h_c) in Yttrium Iron Garnet (YIG) this broadening of the main line and appearance of the subsidiary absorption are just the effects that are observed on the complex part of the susceptibility. As the microwave power is increased further there is an additional effect which takes the

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form of relaxation-like oscillations observed as an amplitude modulation of the power reflected from a cavity containing a sample of Yttrium Iron Garnet.

An experimental investigation of the corresponding z component of magnetization by means of a small pickup coil located in the cavity[2] near the sample has revealed information sufficient to indicate that the effect is due to a foldover response similar in nature to that reported by Weiss[3] for disks and Masters[4] for the low frequency oscillations which occur because of the temperature dependence of the anisotropic constant.

EXPERIMENTAL

The following results were obtained on three single crystal YIG spheres which have diameters of 0.01", 0.02", and 0.04" and low power linewidths of 1.0, 2.2 and 1.0 o.e. respectively.

The samples were inserted into a microwave cavity made from a section of an x-band waveguide one guide wavelength long at 9400 megacycles. The cavity was finely tunable over a 200 mc range by means of a tuning screw on a gear arrangement. The sample was located in the cavity 0.07" from the back wall of the cavity opposite the coupling iris. The samples were mounted loosely in the end of a quartz tube for insertion through a hole in the cavity side wall into the cavity.

The pickup coil consisted of a couple of turns of fine wire made into a coil with a diameter of 0.125" and located perpendicular to H_{dc} and parallel to the microwave field. Located in this way the coil had only a small effect on the cavity fields. The signal from the coil led to a high gain low input impedance (25 ohm) amplifier and then to an oscilloscope. The entire ensemble along with a gear arrangement for rotating the sample could be inserted into a 1.4" diameter dewar for low temperature measurements.

The dc magnetic field was monitored by a Bell incremental gauss meter which could measure field differences to the order of 0.3 gauss.

The microwave power was obtained from an L. F. E. ultra-stable microwave oscillator followed by a traveling wave tube amplifier which gives an available power of greater than 10 watts from 8,500 to 10,000 megacycles. In order to eliminate and observe temperature effects the microwave power was pulsed using two diode modulators and a pulse generator. The microwave power could then be amplitude modulated with any pulse length (0.1 microseconds to continuous) and repetition rate desired. The on-off ratio obtained was 40 db and the rise and decay time of the amplitude of the microwave power was 10 n.s.

RESULTS

With the YIG sphere stable-coherent relaxation oscillations, whose envelope was constant over the microwave pulse length, were observed to occur at three distinct ranges of the dc field (H_{dc}) for perpendicular pumping; (1) at H_{dc} for subsidiary absorption and at power levels larger than 2 db above h_c where h_c is critical level for subsidiary absorption to take place; (2) at $H_r \pm 2$ o.e. and at a power level 13 db ± 2 db above h_c for the main line decline due to spin wave growth; (3) at dc field which lies below H_r by an amount which depends on the microwave power level. In case three, the oscillations first occur at 10 db above h_c for the main line decline and about 10 o.e. below H_r. Fig. 1 shows χ'' vs H_{dc} (not to scale) for both low and high microwave power levels and the location of the three regions for the occurance of coherent relaxation oscillations in the YIG spheres.

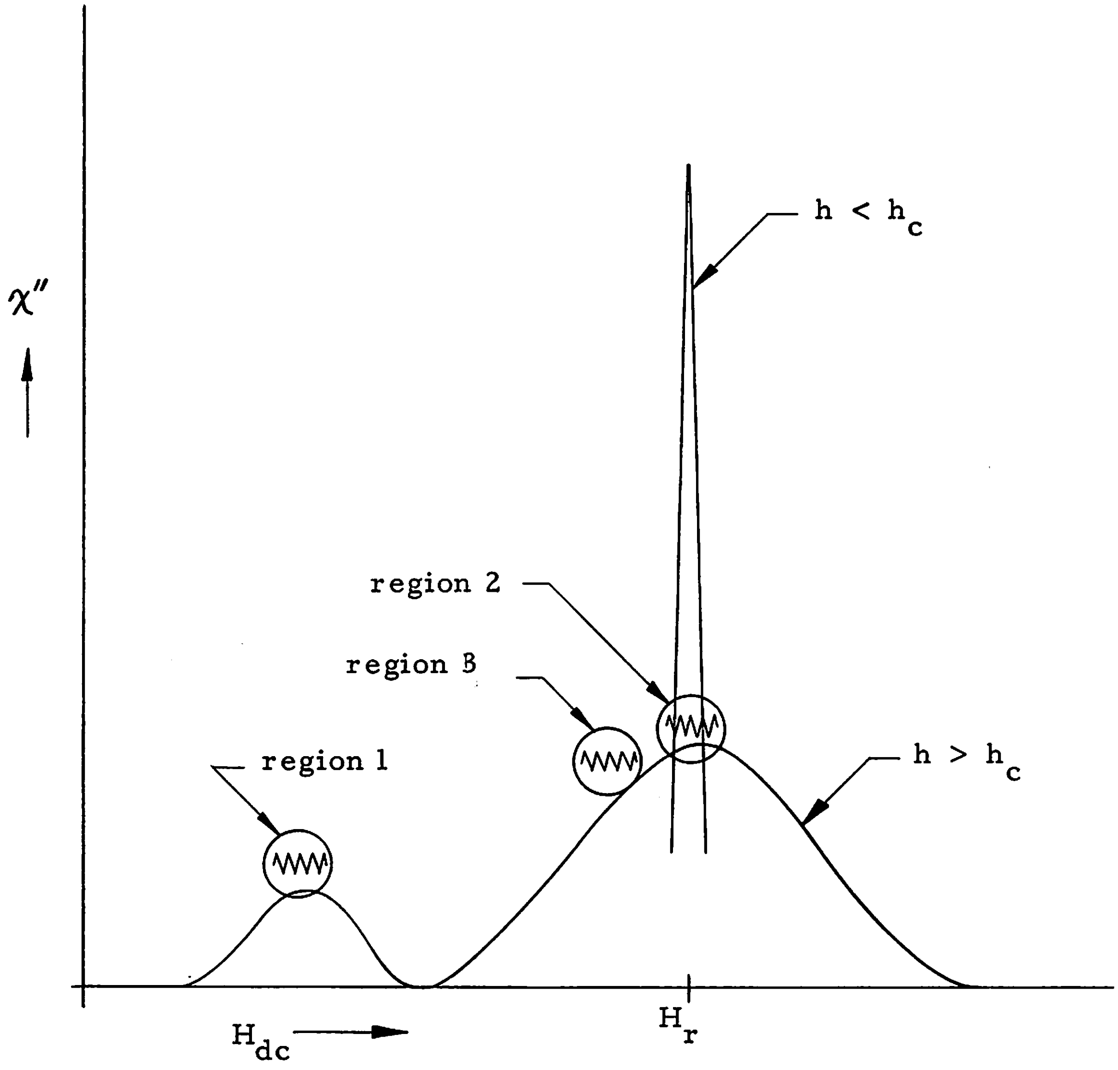

Fig. 1. Typical ferromagnetic resonance curve at low and high power levels in a ferrite indicating broadening out of the main resonant line and appearance of the subsidiary absorption line and the relative location of the three regions of coherent relaxation oscillations.

The coil located in the cavity can be used to measure the relaxation time for M_z, the relaxation time of the oscillations, the amplitude of the oscillations and the amplitude of $M_o - M_z$ just before the oscillations take place.

The relaxation time for the return of M to a position along H_{dc} when the microwave power is turned off is measured for the 0.02" sphere at the subsidiary absorption and main line at power levels just below that necessary for the oscillation to occur. At the subsidiary absorption the only appreciable contribution is from the spin waves with $K \longrightarrow 0$, whereas at the main line the spin waves and uniform mode have comparable amplitudes. These relaxation times for M_z are then compared with the relaxation times for the oscillations at the subsidiary absorption and at the main line. For the 0.01" sphere, the oscillations are observed at the main line only because of its smaller size and correspondingly smaller signal. The relaxation time of the oscillations for the 0.04" sphere could only be obtained at the subsidiary absorption because of its large size and limiting effect on the cavity field at the main line.

Returning to the 0.02" sphere the relaxation times $T_{Kl}(K \longrightarrow 0)$ and T_1 were measured as 200 n.s. and 60 n.s. respectively. The measured relaxation time for the oscillations at the subsidiary absorption and at the main line were 200 n.s. and 70 n.s. respectively. In the case of 0.01" sphere (which had a linewidth of about half the 0.02" sphere) the oscillations at the main line had a relaxation time of 135 nanoseconds and the oscillations for the 0.04" sphere (which also had a linewidth of about half that of the 0.02" sphere) had a relaxation time of 400 nanoseconds at the subsidiary absorption. In addition the temperature of the 0.02" diameter sphere was lowered to 77^{o} where the line width is somewhat larger than at room temperature and the relaxation time for the oscillations underwent a corresponding decrease. The same results as indicated above were also obtained on a 0.02" sphere which was rigidly mounted on both a quartz rod and a lucite rod instead of being loosely mounted.

The above results indicate that the repetition rate of the relaxation oscillation is closely related to the longitudinal relaxation time and in this case is relatively independent of the sample size, lending weight to a foldover process where the cavity electric and magnetic field buildup time is much faster than any of the above times.

The amplitude of the oscillations in M_z can be measured and compared to the value of $M_o - M_z$ just before the oscillations take place. This was done for the three cases with the 0.02" sphere. As the microwave power is increased above h_c in case 1 the value of $M_o - M_z$ increases up to the point where the relaxation oscillations occur and at this time the ratio of the transverse component of the spin wave to that of the uniform mode $(M_{KT}/M_{oT} = 60)$ is reached. This value agrees quite well with a calculation of the spin wave amplitude from theory.[5] At this point the oscillations take place and have an amplitude equal to almost the entire value of $M_o - M_{Kz}$ which was present just before the oscillations were inititiated. This information that the oscillations involve such a large amount of $M_o - M_z$ rather than being a small perturbation on $M_o - M_z$ adds considerable weight to a foldover type phenomenon.

The same relationship between the oscillations and amplitude of $M_o - M_z$ was obtained for cases 2 and 3. In addition, in case 3 results indicate even more strongly that a foldover process is involved. If a microwave power level larger than 10 db above h_c is present and the H_{dc} field is lowered from H_r slowly the value of $M_o - M_z$ changes very slightly as you move down from H_{dc} until suddenly relaxation oscillations are observed, and as H_{dc} is reduced further the oscillations stop in a couple of oersteds and the value of $M_o - M_z$ is now only about 1/3 of what it was previously. (In some instances

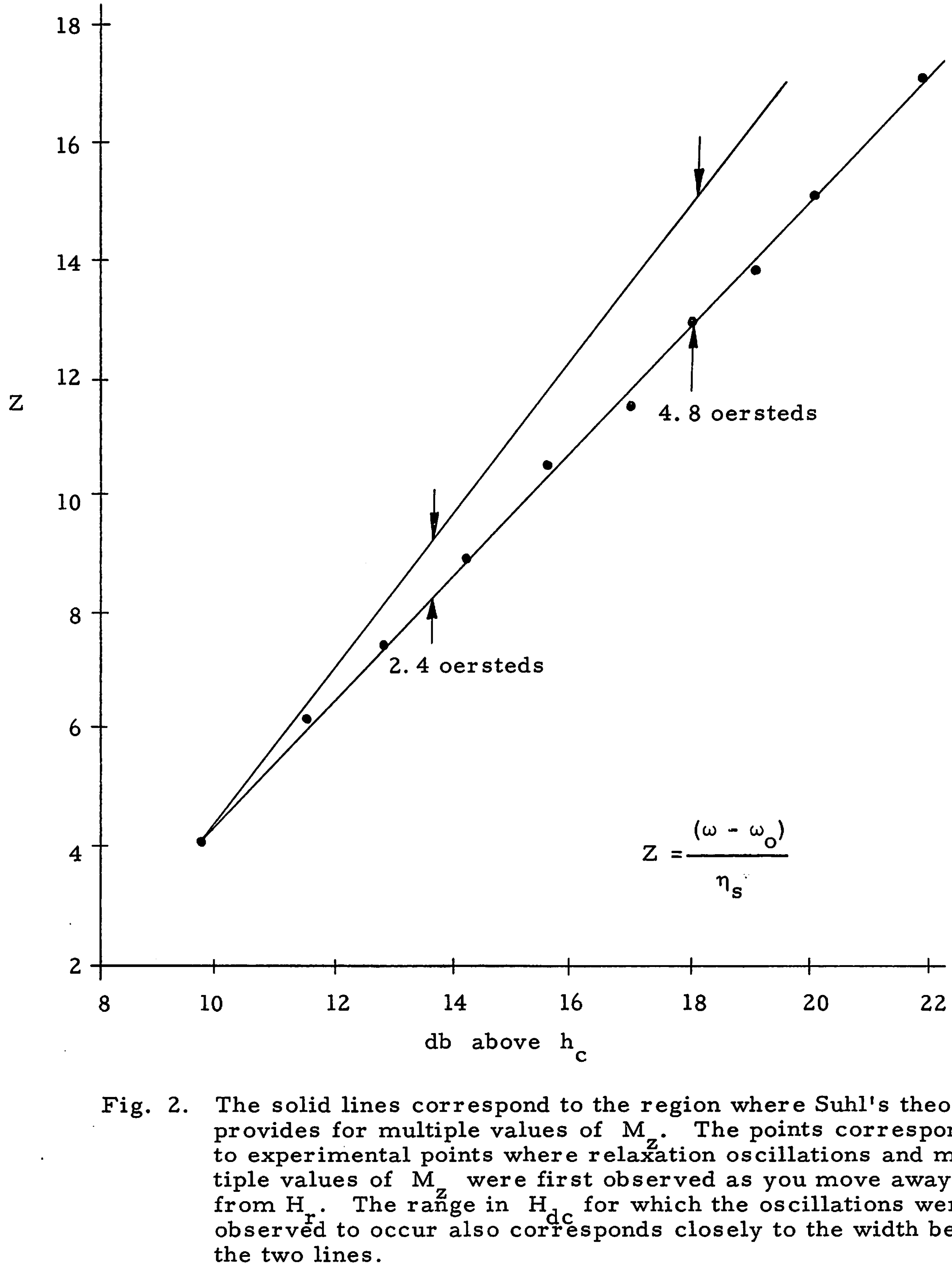

Fig. 2. The solid lines correspond to the region where Suhl's theory provides for multiple values of M_z. The points correspond to experimental points where relaxation oscillations and multiple values of M_z were first observed as you move away from H_r. The range in H_{dc} for which the oscillations were observed to occur also corresponds closely to the width bethe two lines.

three separate values of $M_o - M_z$ were observed in a range of only a couple of o.e.) Suhl[6] has analyzed the response of the uniform mode taking into account the effect of the excited spin waves on the uniform mode and shows that this leads to a foldover response for the uniform mode. Suhl's curve is shown in Fig. 2 which indicates the region of multivalueness. The points on this figure are the experimental points (for the 0.02" sphere) which give the values of H_{dc} at which the oscillations first take place and a jump in $M_o - M_z$ is first observed as you move away from H_r for different cavity field strengths. The first point occurs at 10 db above h_c and is matched to the theoretical curve by adjusting η_s the rest of the points were obtained using this value of $\eta_s = 2.4\ \gamma_e$ which is more than twice as large as the value of $\eta_o = 1.1\ \gamma_e$ given by a low power measurement of the linewidth.

CONCLUSION

The evidence for a foldover process being responsible for the observed relaxation oscillations at a dc field slightly below H_r (case 3) is very strong in view of all the evidence, especially the correspondence between the region calculated by Suhl for multiple values of $M_o - M_z$ to occur and the observed experimental points. The oscillations themselves are the result of an interaction between the cavity fields and the multiple values of M_z. A mathematical theory for the oscillations is not available at this time but physically it is quite plausible and the process proceeds as follows: On the upper portion of the multivalued part of the absorption curve the large value of χ'' decreases the cavity Q and reduces the cavity field to a level below that necessary for a foldover response to occur. The absorption then decreases and the cavity field builds up again to a value larger than that necessary for a foldover region to exist. The stage is then set for the process to repeat itself.

In cases 1 and 2 because of the large amplitude of the oscillations and similarity to the oscillations that occur under conditions 3 it is suspected that they also are a result of a foldover process. A theoretical explanation for the source of the foldover process is not available but a possible explanation is given below. In Ref. 3, it is suggested that the foldover process in a disk sample originates in the power dependence of the resonant term in the denominator of the expression for the amplitude of the uniform mode. This effect enters because of the dependence of the resonant frequency on the z component of magnetization M_z through the demagnetizing term when the experiment is performed on a disk. In our case we are using spheres and this effect is not present. In Ref. 4, the explanation for the source of the foldover process is again a power dependent, resonant denominator where the resonant frequency depends on K_1 the anisotropic constant, which depends on temperature and in turn on χ'' or the power absorbed by the sample. In our case a low duty cycle was used and also no change was observed by varying the duty cycle which ruled out this cause. In the results reported here it is observed that the relaxation oscillations are observed only after the spin waves have attained large amplitudes. The spin wave frequency ω_K depends on M_z even in a sphere. To complete the picture an expression for the amplitude of a spin wave at constant microwave frequency as ω_K changes with M_z is needed. As this expression is unavailable at this time we can only postulate that the expression will have a resonant form with terms in the denominator of the form $(\omega/2 - \omega_K)$ and $(\omega - \omega_K)$ for cases 1 and 2 respectively. With this power dependent denominator for the amplitude of the spin waves a foldover process can take place at sufficient spin wave amplitude and relaxation oscillations will occur in an interaction with the cavity microwave fields.

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