Elementary excitation spectrum of a moving domain wall in a ferromagnet

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The spectrum of flexural standing waves of a uniformly propagating domain wall in an yttrium iron garnet has been studied experimentally. An increase in the velocity of the domain wall was found to decrease the phase velocity of flexural waves. The flexural modes were found to be suppressed at sufficiently high velocities of the domain wall.

In the theory of magnetism, the interaction of various types of excitations has been analyzed for a long time because of the need for a systematic description of the relaxation processes in a uniformly magnetized crystal.[1] Such processes have fairly recently begun to be analyzed in the description of the dynamics and relaxation of magnetization in crystals containing domain walls and Bloch lines.[2,3] The possibility

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of experimentally studying these phenomena in a single domain wall was pointed out after the recent observation of a resonant excitation of flexural standing waves in a domain wall in single crystals of yttrium iron garnet[4] with a record-low damping constant. In the present letter, we report the first results of an experimental study of the interaction of translational and flexural vibration modes of a domain wall in an yttrium iron garment, in which it was possible to determine, in particular, the dispersion of magnons in a moving domain wall.

A rectangular sample $20\times0.3\times0.04$ mm in size contained a single domain wall oriented parallel to the long side. This wall separated the domains with the magnetization vectors $\vec{M}$ in the (112) plane of the wafer. A uniform static magnetic field H_x perpendicular to this plane stabilized the initial "magnetized" state of the wall (i.e., the state without Bloch lines). The static equilibrium state of this wall in the sample was determined by the internal gradient field, whose strength is characterized by the measured restoring force $\kappa = 4.4\times10^3$ g/cm$^2\cdot$s^2. Therefore, to displace the wall at a constant velocity, we used a field $\vec{H}_z \| \vec{M}$ which increased linearly with time and which canceled the indicated gradient field. The flexural vibration modes of the wall were

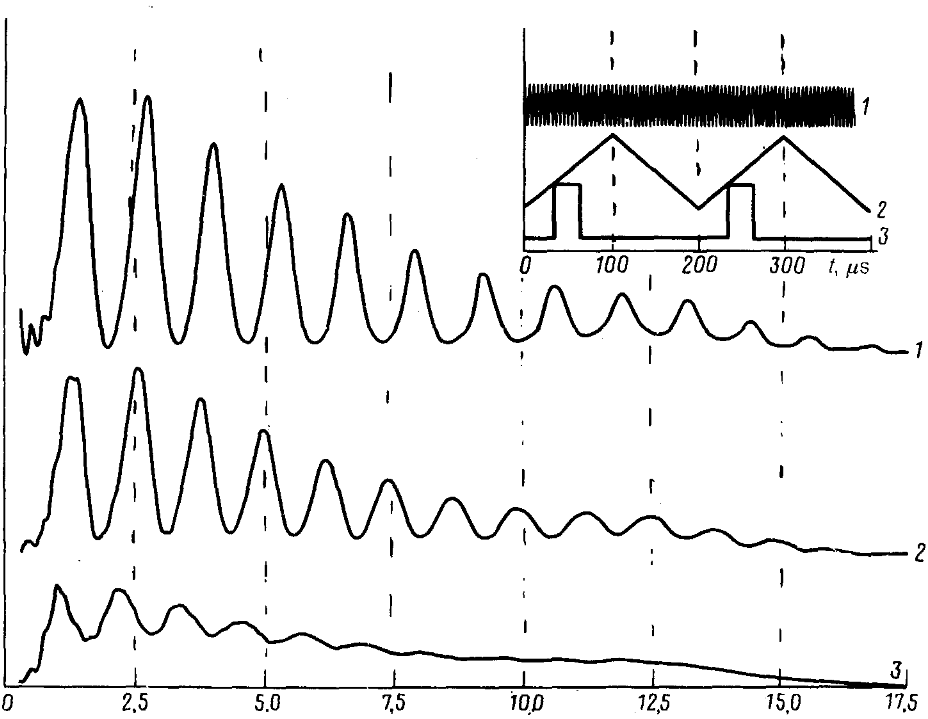

FIG. 1. Vibration amplitude of the wall versus the frequency of the field, $h_z = 19$ mOe, measured at various amplitudes of the field H_z (wall velocities, respectively): 1—$H_z = 0$ Oe (0 m/s); 2—0.05 Oe (0.6 m/s); 3—0.12 Oe (1.6 m/s); $H_z = 28$ Oe. The curves taken from the computer memory are projected along the vertical on the TV screen. The inset shows (1) the time-dependent sweeps of the sinusoidal field h_z, (2) of the sawtooth field H_z, and (3) of the 30-μs square pulses, during which the amplitude of the rf oscillations of the wall was measured.

excited by a uniform rf field $\vec{h}_z \| \vec{M}$, whose amplitude was held constant during the frequency sweep. The vibration of the wall was measured inductively using a compensating pickup coil which was wound directly on the sample. The signal from this coil was sent to a specially designed electronic breaker and then to a CK4-59 spectrum analyzer which operated in the mode that measured the amplitude and frequency characteristics. Consequently, the amplitude of the rf oscillation of the wall was measured selectively only during the generation of short pulses in a certain phase of a low-frequency sawtooth field H_z (see the inset in Fig. 1). The frequency sweep of the spectrum analyzer and additional signal storage and averaging were controlled by a computer. To completely eliminate the signal component due to an incomplete compensation of the coil, we measured the spectra of the sample in the presence of a domain wall and without it and then subtracted the latter from the former. The use of this method allows us to record extremely small displacements of the wall (smaller by a factor of several tens than those obtained by magneto-optic measurements[4,5]) and very large displacements where the wall approached the edge of the sample.

Figure 1 is a plot of the amplitude of the rf oscillation of the wall as a function of the frequency of the field h_z, measured for several values of the amplitude H_z of the sawtooth field. The set of nearly equidistant resonance peaks which was observed is attributable to the excitation of the flexural standing waves of the wall in the depth of the sample.[4] With an increase in H_z, two effects can clearly be seen. First, the resonance frequencies are shifted, causing the slope of the curve of the frequency of the peak versus its number, $\nu_r(N)$, to decrease (Fig. 2). More exact measurements have

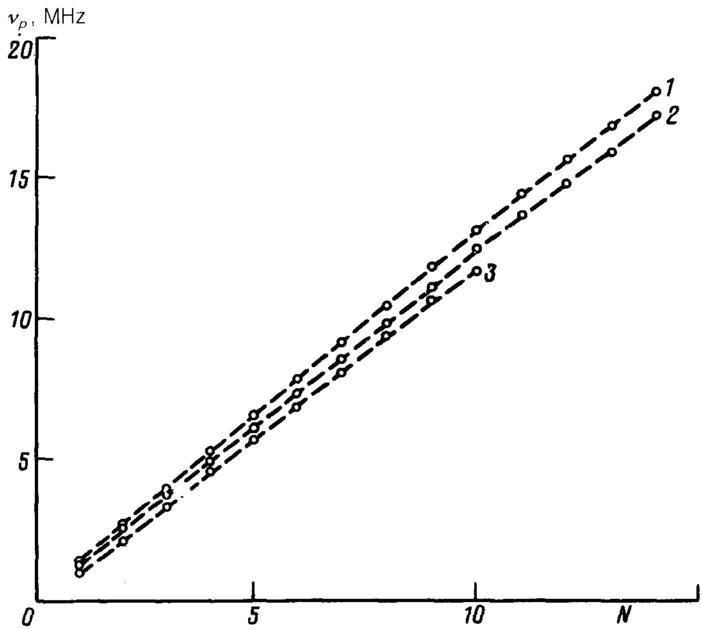

FIG. 2. The resonance frequency of the peak ν_r versus its number N, obtained from the analysis of curves 1–*3* in Fig. 1.

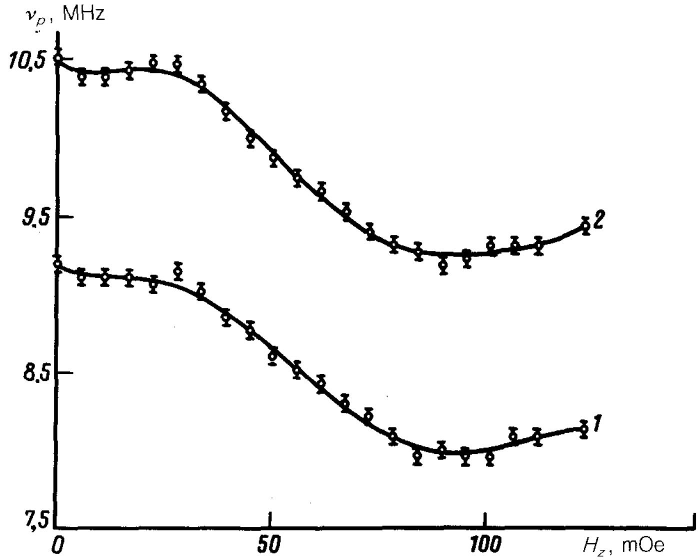

FIG. 3. Frequency of the peak, with (1) $N = 7$ and (2) $N = 8$, versus H_z at $H_z = 28$ Oe $h_z = 19$ mOe.

shown that ν_r decreases nonlinearly in a monotonic manner with increasing H_z (Fig. 3). Secondly, the peaks are suppressed at fairly large H_z (curve *3* in Fig. 1), where the strongest suppression is that of the rf peaks, i.e., the long-wave modes.

Since the curve of $\nu_r(N)$ characterizes the dispersion of the flexural modes, the data which we obtained show that their phase velocity decreases. This effect is apparently attributable to the fact that a steady motion causes a small angle to form between the magnetization in the wall and its plane, which is proportional to the bias field. This field therefore affects the magnon spectrum in a similar way a field H_y normal to the plane of the wall affects it. Such a field leads, as was established in Ref. 5, to a quadratic decrease of the phase velocity $[1 - (MH_y/2K)^2]$, where K is the anisotropy constant. The excitation spectrum of the wall of an easy-axis ferromagnet, which moves at a low velocity $V \ll V_w = \gamma 2\pi M\Delta$, where γ is the gyromagnetic ratio, $\Delta = (A/K)^{1/2}$ is the width of the wall, and A is the exchange constant) was calculated in Ref. 6, and a relation for the phase velocity $[1 - (V/V_w)^2]^{1/2}$ was derived there. This result is in qualitative agreement with the arguments advanced above and with our experimental results (see Fig. 3) if we take into account that the wall velocity V is proportional to H_z.

In the case of preferential suppression of the long-wavelength excitations, two factors must be taken into account. First, an increase in the wall velocity increases the dissipation due to the many-magnon processes in which a spatial dispersion can occur.[2] Secondly, at high values of V the number of dynamic small-scale irregularities of the wall structure (various types of short- and long-lived nonlinear excitations) increase in the wall. Interaction of the flexural waves with such irregularities can also cause the damping dispersion that has been observed. Unfortunately, such processes thus far have not been studied theoretically, to the best of our knowledge, even in very simple idealized models.

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