Space-time focusing of a magnetostatic wave packet in a nonstationary medium

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The compression of a packet of magnetostatic waves propagating in a nonstationary dispersive medium (a ferromagnetic film) has been observed experimentally. This compression occurs as a result of the dependence of the group velocity of waves on the magnetizing field strength.

In the present letter we report the experimental observation of space-time focusing of a magnetostatic wave packet which propagates in a ferrite film ($Y_3Fe_5O_{12}$) placed in a time-varying magnetic field $\mathbf{H}(t) = \mathbf{H}_0 + \mathbf{h}(t)$. To receive and excite the magnetostatic waves, we used two microstrip converters which were deposited on the

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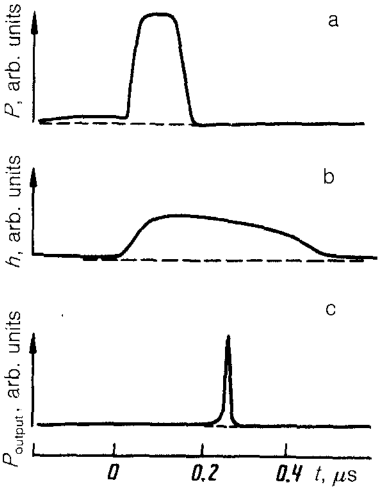

FIG. 1. Oscilloscope traces of the exciting microwave pulse (a), the magnetic field pulse (b), and the contracted microwave pulse (c) under focusing conditions. $H_0 = 2270$ Oe, $h(t) < 50$ Oe.

film surface. The static magnetizing field H_0 was oriented parallel to the converters in the plane of the film. The time variation of the field was produced by pulsing the current transmitted through the metallic strip which was placed on the free surface of the substrate and which was oriented parallel to the direction of propagation of the waves. The magnetostatic waves were excited by quasimonochromatic microwave pulses of frequency $\omega_0/2\pi = 8.7$ GHz, length 0.1–0.3 μs, and power $P \lesssim 1$ mW which assured a linear propagation of waves. In the experiment we determined the delay time and the shape of the delayed microwave pulses at the receiving converter.

As a result of changing the magnetizing field strength in the range of excitation of the magnetostatic waves with a frequency ω_0 $\{\omega_0/\gamma - 2\pi M \leqslant H_0 \leqslant [(\omega_0/\gamma)^2 + (2\pi M)^2]^{1/2} - 2\pi M$, where γ is the gyromagnetic ratio, and M is the saturation magnetization$\}$, the delay changed from 0.4 to 0.01 μs. Under steady-state conditions, $\mathbf{h}(t) = 0$, we saw a dispersive spreading of the magnetostatic wave packet. If the field strength increased in a pulsed manner during the excitation of the waves, the delayed pulses were found to be contracted at a certain value of H_0 (see Fig. 1). The minimum detected pulse length in this case was ~ 12 ns and the contraction coefficient was ~ 20. In the case of a pulsed decrease of the field strength, the broadening of the delayed pulses was greater than their dispersive spreading.

The effect which we observed is attributable to the dependence of the group velocity of the magnetostatic waves on the magnetic field strength. The group velocity $v = \partial\omega/\partial k$ and the wave number k of the wave change over time as a result of excitation of the magnetostatic waves by a monochromatic signal of frequency ω_0 in a time-varying magnetic field. In accordance with the dispersion equation, the initial values of v_0 and k_0 are determined by $H(\tau)$ at the time τ of the excitation. As the wave continues to propagate, the wave number is conserved because of the homogeneity of the medium and remains equal to its initial value, $k = k_0(\tau)$, while the group velocity continues to change because of the change in the wave frequency $\omega(t)$ in a time-varying field.[1] At the time t the excited wave has passed the specified distance y if the following conditions hold[1]:

$$y = \int_{\tau}^{t} v_{k_0}(t')\,dt', \quad \omega_{k_0}(\tau) = \omega_0 . \tag{1}$$

For a surface magnetostatic wave[2] and a linear variation of the field strength $H(\tau) = H_0 + \alpha\tau$ the dependence of the time t on the time τ the wave becomes excited is given by

$$\omega(t) = \omega(\tau)\cosh\left\{\frac{y}{b}\,\frac{\alpha\gamma}{\omega^2(\tau)-\omega_0^2}\right\} + \omega_0 \sinh\left\{\frac{y}{b}\,\frac{\alpha\gamma}{\omega^2(\tau)-\omega_0^2}\right\}, \tag{2}$$

where $\omega(t) = \gamma H(t) + \omega_m/2$, $\omega(\tau) = \gamma H(\tau) + \omega_m/2$, $\omega_m = \gamma 4\pi M$, and b is the film thickness.

Figure 2 shows the $t(\tau)$ curves, calculated from relation (2), for the case in which $H(\tau)$ increases (curve 1) and the case in which it decreases (curve 2) in the field of the magnetostatic waves. In the calculations we used the parameter values corresponding to the experimental conditions: $b = 10\,\mu$m, $y = 0.4$ cm, $4\pi M = 1750$ G, and $\alpha \cong 5\times10^8$ Oe/s. We see that if the field is increasing, there can be a partial contraction ($\tau > \tau_f$), time-dependent focusing ($\tau \cong \tau_f$), or envelope inversion ($\tau < \tau_f$) of the magnetostatic wave packet at a distance y, depending on the time τ the excitation occurs. A reduction of the field can only increase the duration of the wave packet.

Figure 3 qualitatively illustrates the space-time evolution of the envelope of the

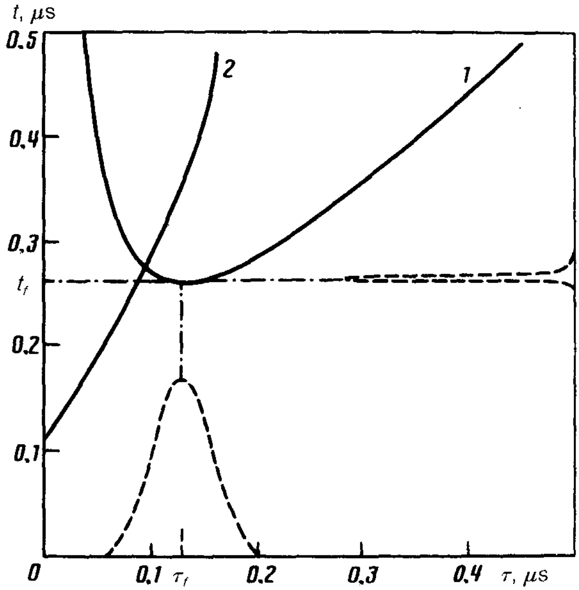

FIG. 2. The time t it takes the magnetostatic waves to propagate a distance y versus the time τ at which they become excited as a result of increasing the magnetic field (1) and as a result of decreasing it (2).

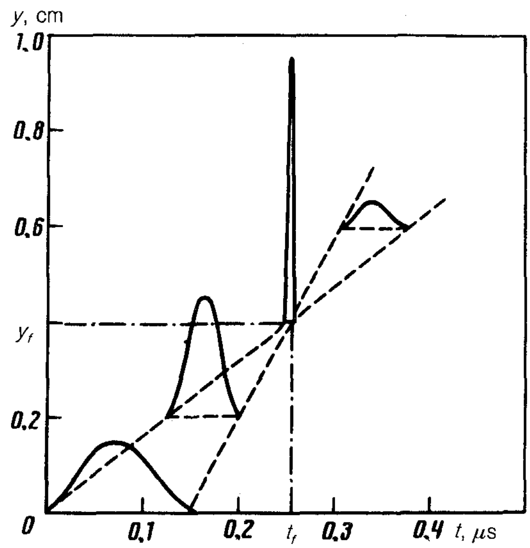

FIG. 3. Evolution of the envelope of the magnetostatic wave packet in the case of propagation under focusing conditions.

magnetostatic wave packet excited at the time τ_f. The minimum duration and the spatial dimension of the packet in the focusing region $\{t_f, y_f\}$ depend on the parameters of the ferrite film, the length of the exciting pulse and the field variation rate. As the experiment has shown, at the focal point the amplitude of the magnetostatic wave packet, which depends on the wave attenuation, may be more than an order of magnitude greater than the amplitude of the packet with the same delay time under steady-state conditions.

We have also observed a space-time focusing in the case of a packet of bulk magnetostatic waves propagating in a ferrite film parallel to the direction of H_0 upon a pulsed reduction of the magnetic field strength, consistent with the theory.

The experimental results presented here show that magnetostatic waves can be used in the study of various wave processes which, according to the theory,[3,4] can occur in unsteady media.

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