Mutual influence of the kinetic and parametric methods of exciting spin waves

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The paper reports an experimental investigation of the thresholds for spin-wave excitation under the action on an yttrium iron garnet sample of two pumps, one of which is powerful enough to excite a secondary (kinetic) instability of the spin waves. A diagram of the spin-wave instabilities occurring in various parts of the spectrum, depending on the powers of the pumps, is constructed and explained.

INTRODUCTION

Spin waves can, starting from some pump-power value $P = P_{\text{th}}$, be excited in a threshold manner in ferrite single crystals located in constant and superhigh-frequency magnetic fields.[1] This spin-wave instability, which is parametric, is, in the simplest case, a process of decay of the pump oscillation (under conditions of parallel pumping, in which the constant-magnetic-field vector $\mathbf{H}_0$ is parallel to the variable-magnetic-field vector $\mathbf{h}$), or of the homogeneous oscillation of the magnetization (under conditions of perpendicular pumping, in which $\mathbf{h} \perp \mathbf{H}_0$), into two spin waves with frequencies equal to half the pump frequency ω_p and wave vectors, $\mathbf{k}_p$ and $-\mathbf{k}_p$, that are oppositely directed to each other. Beyond the parametric-excitation threshold (i.e., for $P > P_{\text{th}}$) the integral number n_p of parametrically excited spin waves (PSW) significantly exceeds the corresponding thermodynamic-equilibrium value, and increases steadily with increasing P: for $P \gg P_{\text{th}}$, $n_p \sim P$ (Ref. 2). Finally, at some value $n_p = n_p$ kin corresponding to a pump power $P = P_{\text{kin}} > P_{\text{th}}$ the PSW's themselves can bring about a secondary spin-wave instability.[3] A study, carried out on single-crystal samples of yttrium iron garnet (YIG), has shown that this instability, which is called the kinetic instability of spin waves,[3] arises from a four-magnon process involving the fusion of two PSW ($\omega_{\mathbf{k}p'} = \omega_{\mathbf{k}p''} = \omega_p/2$; $\mathbf{k}_p' = \mathbf{k}_p'' = \mathbf{k}_p$) and the production of a secondary low-frequency ($\omega_{\mathbf{k}} < \omega_p/2$) and a secondary high-frequency $\omega_{\mathbf{k}p' + \mathbf{k}p'' - \mathbf{k}} > \omega_p/2$) spin wave:

$$\omega_{\mathbf{k}_p'}+\omega_{\mathbf{k}_p''}=\omega_{\mathbf{k}}+\omega_{\mathbf{k}_p'+\mathbf{k}_p''-\mathbf{k}}=\omega_p. \qquad (1)$$

As shown in Ref. 3, the processes (1) make a negative contribution to the damping of the spin waves:

$$\Gamma_{\mathbf{k}}=\gamma_{\mathbf{k}}-\gamma_N=\gamma_{\mathbf{k}}-2\pi\int|T_{\mathbf{k}\mathbf{k}_1\mathbf{k}_p'\mathbf{k}_p''}|^2 n_{\mathbf{k}_p'} n_{\mathbf{k}_p''}\delta(\omega_{\mathbf{k}}+\omega_{\mathbf{k}_1}-\omega_p)\,\delta(\mathbf{k}+\mathbf{k}_1-\mathbf{k}_p'-\mathbf{k}_p'')\,d\mathbf{k}_1\,d\mathbf{k}_p'\,d\mathbf{k}_p''. \qquad (2)$$

Here $\Gamma_{\mathbf{k}}$ is the total damping constant for the spin waves with wave vector $\mathbf{k}$, $\gamma_{\mathbf{k}}$ is the intrinsic damping constant for these waves in the absence of PSW; $n_{k_p'}$ and $n_{k_p''}$ are the occupation numbers for the PSW with wave vectors $\mathbf{k}_p'$ and $\mathbf{k}_p''$; and $T_{\mathbf{k}\mathbf{k}_1\mathbf{k}_p'\mathbf{k}_p''}$ is the matrix element of the four-magnon interaction. It can be seen from (2) that the four-magnon process (1) decreases the spin-wave damping constant by an amount γ_N proportional to the square of the integral PSW number n_p. Since γ_N depends weakly on the wave vector $\mathbf{k}$ of the spin waves,[3] the smallest damping constant will, in the presence of PSW, be possessed by the waves having the smallest intrinsic damping constant $\gamma_{\mathbf{k}} = \gamma_{\min}$. In the case of a pump power equal to the kinetic instability threshold power, i.e., for $P = P_{\text{kin}}$, these waves have their decrement totally canceled out ($\Gamma_{\mathbf{k}} = 0$), and at $P > P_{\text{kin}}$ they begin to exponentially intensify in time. It has been experimentally demonstrated[3] that the kinetic instability results in the excitation of waves with a wave vector $\mathbf{k}_0$ and a polar angle $\theta_{\mathbf{k}_0}$ that are nearly equal to zero, i.e., that lie close to the minimum frequency $\omega_{\min}$ in the spin-wave spectrum. Because of the smallness of the wave vector $\mathbf{k}_0$ of the excited waves, the onset of the kinetic instability is found to be followed by the emission of appreciable electromagnetic radiation from the sample at the frequency $\omega_{\mathbf{k}_0} \approx \omega_{\min}$ of these waves and at the doubled frequency $2\omega_{\mathbf{k}_0}$ (Ref. 3).

The purpose of the present investigation was to carry out an experimental study of spin-wave damping in a ferrite in the presence of PSW. According to (2), in this case there should occur a decrease in the damping constant for those spin waves for which the relation (1) is valid. At least for the waves with frequencies close to the bottom of the spectrum, i.e., for the waves with $\omega_{\mathbf{k}} \approx \omega_{\min}$, this decrease should be substantial, since the situation in which $\gamma_N \approx \gamma_{\mathbf{k}}$ is easily realized for them in experiment.[3]

EXPERIMENT

To investigate spin-wave damping in the presence of PSW we applied to a ferrite sample, besides the first (parallel) pump with frequency ω_{p1}, which produced PSW_1 and then waves at the bottom of the spectrum, a second (perpendicular) pump, whose frequency ω_{p2} was each time chosen so as to satisfy at all the varying—in the course of the experiment—values of the external constant magnetic field H_0 the requirement that the principal resonance coincide with the secondary one.[1] Here and below, for convenience, we label all the quantities pertaining to the first pump by the index 1 and the quantities pertaining to the second pump by the index 2.

Figure 1 shows a graphical representation of the disposition of the pump frequencies relative to the spin-wave spectrum. For the requirement that the principal resonance coincide with the secondary resonance to be satisfied, the frequency ω_{p2} of the second pump should be equal to the ferromagnetic-resonance frequency (for a spherical sample $\omega_{p2} = gH_0$, where g is the gyromagnetic ratio for the elec-

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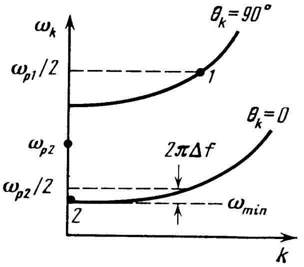

FIG. 1. Disposition of the pump frequencies relative to the spin-wave spectrum: 1) location in the PSW_1 spectrum; 2) location of the spin waves excited as a result of the kinetic instability: $\omega_{p2}/2$ is the frequency of the PSW_2 and ω_{p2} is the frequency of the uniform magnetization oscillation (i.e., of the ferromagnetic resonance) and of the second pump.

tron spin) and the frequency $\omega_{p2}/2$ of the spin waves (PSW_2) parametrically excited by this pump should lie within the spin-wave spectrum: $\omega_{p2}/2 - \omega_{\min} = 2\pi\Delta f > 0$. It is precisely this situation that is qualitatively depicted in Fig. 1. At values of the power P_2 of the second pump higher than some threshold value $P_{2\,\mathrm{th}}$ there occurs in the sample parametric excitation of spin waves PSW_2 at the frequency $\omega_{p2}/2$. The quantity $P_{2\,\mathrm{th}}$ is directly proportional to the damping constant $\Gamma_{\mathbf{k}}$. Thus, we can, by measuring the threshold power for excitation of the spin-wave instability of the second pump in the presence of the first, obtain information about the PSW_1-induced change in the damping constant for the spin waves with frequency $\omega_{p2}/2$.

With the aid of the two-pump method used in the present investigations, and based on the phenomenon of reciprocal influence of the kinetic and parametric methods of excitation of spin waves, we can study, besides the above-described effect of the first pump on $P_{2\mathrm{th}}$, the influence of the second pump on the kinetic-instability threshold $P_{1\,\mathrm{kin}}$ for the spin waves. It is quite probable in this case that the second pump will, as a result of regeneration, reduce the damping constant for the waves with frequency $\omega_{p2}/2$ to such a level that it becomes smaller than $\gamma_{\min}$, and, in the case when (2) is valid, it is precisely these waves that should be excited as a result of the kinetic instability.

Figure 2 shows a block diagram of the experimental setup. A pulse of the first pump from a magnetron is fed through a number of wave-guide elements to the measuring unit with the ferrite. The duration of the first-pump pulses ranged from 40 to 100 msec; the repetition frequency, from 5 to 50 Hz; $\omega_{p1} = 2\pi \times 9.37$ GHz. The measuring unit was a cavity resonator with an oscillation mode H_{011} of frequency equal to the first pump's frequency, prepared from a piece of standard three-centimeter waveguide. The sample was placed (see Fig. 2) near the end wall of the resonator, and was encircled by a pickup loop connected to a coaxial cable. This cable was used to lead out from the sample the electromagnetic radiation emitted at the frequencies $\omega_{\mathbf{k}_0}$ and $2\omega_{\mathbf{k}_0}$, as well as to feed to the sample in synchronism with the first pump a second pump at a frequency of $\omega_{p2} = 3.2$–3.4 GHz. The specific values of the second pump's frequency ω_{p2} and the constant magnetic field $H_0 = \omega_{p2}/g$ were determined on the basis of the required value of Δf, the difference, introduced above, between the PSW_2 frequency $\omega_{p2}/2$ and the bottom $\omega_{\min}$ of the spin-wave spectrum. The value of $\omega_{\min}$ was determined experimentally from the minimum frequency of the radiation emitted from the ferrite under conditions of kinetic instability of the spin waves.[3,4]

The duration and repetition frequency of the pulses of the klystron oscillator coincided with the duration and repetition frequency of the pulses from the magnetron. To reduce the distortions in the configuration of the fields of the cavity resonator to a minimum and ensure the perpendicularity of $\mathbf{H}_0$ and $\mathbf{h}_2$ at the location of the ferrite, we set the pickup loop such that its plane was parallel to $\mathbf{h}_1$ and $\mathbf{H}_0$. The conditions for perpendicular pumping of the spin-wave instability were then secured at the frequency ω_{p2}. To increase the concentration of the microwave field at the frequency ω_{p1}, we used, besides the cavity resonator, an open dielectric resonator, in which the ferrite was placed.

We investigated spherical YIG samples of diameter ranging from 1.5 to 2.5 mm. The constant magnetic field was oriented along the axis of easy magnetization of the crystal. The measurements were performed at room temperature.

The values of the threshold powers $P_{1\,\mathrm{th}}$ and $P_{2\,\mathrm{th}}$ were respectively fixed upon the appearance of a chip[2] on the first- and second-pump pulses reflected from the measuring unit. The quantity $P_{1\,\mathrm{kin}}$ was fixed upon the appearance of a second chip on the reflected first-pump pulse and the emergence of electromagnetic radiation from the ferrite.[3]

Figure 3 shows the experimental dependence of the threshold power $P_{2\,\mathrm{th}}$ of the second pump on the power P_1 of the first pump for the smallest, experimentally discernible quantity $\Delta f \lesssim 10$ MHz and $\Delta f = (15 \pm 5)$ MHz. It can be

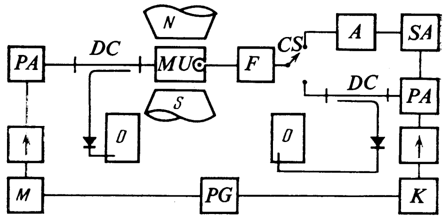

FIG. 2. Block diagram of the experimental setup: M is a magnetron oscillator; PA, a precision attenuator; DC, a directional coupler; MU, the measuring unit with the ferrite; PG, a trigger pulse generator; O, oscillograph; F, filter; CS, coaxial switch; A, amplifier; SA, spectrum analyzer; and K, klystron oscillator.

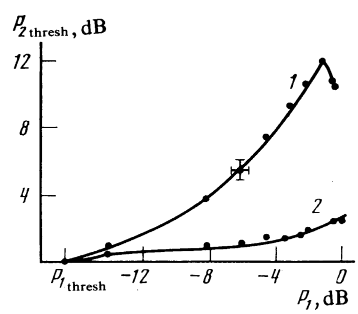

FIG. 3. Dependence of the second pump's threshold $P_{2\,\mathrm{thresh}}$ on the first pump's power P_1: 1) $\Delta f \lesssim 10$ MHz; 2) $\Delta f = 15 \pm 5$ MHz (see Fig. 1). 0 dB on the vertical axis corresponds to the quantity $P_{2\,\mathrm{thresh}}$ in the absence of the first pump ($P_1 = 0$); 0 dB on the horizontal axis corresponds to the kinetic-instability threshold $P_{1\,\mathrm{kin}}$ in the absence of the second pump. The sample was a spherical YIG single crystal of 2 mm diam.

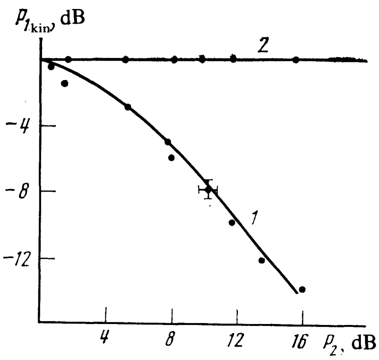

FIG. 4. Dependence of the kinetic-instability threshold $P_{1\,\mathrm{kin}}$ on the power P_2 of the second pump: 1) $\Delta f = 15 \pm 5$ MHz; 2) $\Delta f = 100 \pm 5$ MHz (see Fig. 1). 0 dB on the vertical axis corresponds to the quantity $P_{1\,\mathrm{kin}}$ in the absence of the second pump ($P_2 = 0$); 0 dB on the horizontal axis corresponds to the threshold $P_{2\,\mathrm{thresh}}$ for parametric excitation of the second pump. The sample was a spherical single crystal of 2 mm diam.

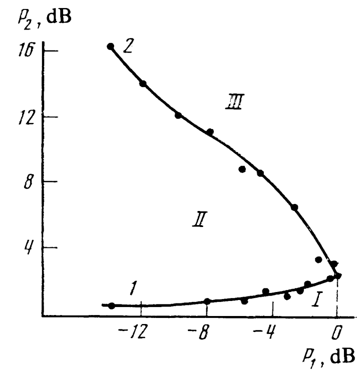

FIG. 5. Stability diagram for the spin waves in the case when $\Delta f = 15 \pm 5$ MHz. In the region I spin waves with frequency $\omega_{p1}/2$ are excited; in the region II, spin waves with frequencies $\omega_{p1}/2$ and $\omega_{p2}/2$; in the region III, spin waves with frequencies $\omega_{p1}/2$, $\omega_{p2}/2$, and $\omega_{\mathbf{k}_0} \approx \omega_{\min}$.

seen that, in the presence of the first pump, the PSW$_2$-excitation threshold is, when $P_1 > P_{1\,\mathrm{th}}$, always higher than the threshold in its absence, i.e., contrary to (2), in the presence of PSW$_1$, the damping of the PSW$_2$ not only does not decline, but intensifies. In this case the influence of the PSW$_1$ on $P_{2\,\mathrm{th}}$ decreases with increasing Δf. The experiment showed that this influence becomes noticeable only when $\Delta f \lesssim 100$ MHz, i.e., when the frequency of the PSW$_2$ is not further than ~ 100 MHz from the bottom of the spin-wave spectrum.

Figure 4 shows the results of the experimental investigation of the dependence of the kinetic-instability threshold $P_{1\,\mathrm{kin}}$ on the second pump's power P_2. A dependence is observed only in the region $P_2 \gtrsim P_{2\,\mathrm{th}}$, i.e., after the excitation of PSW$_2$ in the ferrite. Furthermore, as in the case of the influence of P_1 on $P_{2\,\mathrm{th}}$ (Fig. 3), the reciprocal influence of the two pumps shows up only when the frequency of the PSW$_2$ is sufficiently close to the bottom of the spin-wave spectrum. As can be seen from Fig. 4, $P_{1\,\mathrm{kin}}$ does not depend on P_2 when $\Delta f \approx 100$ MHz. At the highest power that was available in the experiment, $P_2 = 25$ mW ($P_2 = 10^2 P_{2\,\mathrm{th}}$), P_2 had an effect on $P_{1\,\mathrm{kin}}$ only when $\Delta f \lesssim 30$ MHz. The greatest decrease, equal to ~ 15 dB, in the kinetic-instability threshold was achieved when $\Delta f \lesssim 10$ MHz. In this case the power of the second pump exceeded the PSW$_2$-excitation threshold $P_{2\,\mathrm{th}}$ by ~ 16 dB.

With the aid of the experimental data shown in Figs. 3 and 4 we can construct a stability diagram for the spin waves for the case when the two pumps act together. Figure 5 shows this diagram for $\Delta f = 15 \pm 5$ MHz. Only PSW$_1$ are excited in the region under the curve 1; PSW$_1$ and PSW$_2$ are excited in the region between the curves 1 and 2; and in the region above the curve 2 there occurs, besides the excitation of PSW$_1$ and PSW$_2$, kinetic instability of the spin waves in the vicinity of the bottom of the spin-wave spectrum. The curves 1 and 2 in Fig. 5 were constructed with the aid of the experimental curves 2 in Fig. 3 and 1 in Fig. 4.

Investigation of the electromagnetic radiation emitted from the ferrite under kinetic-instability conditions showed that its frequency and spectral composition were, to within the limits of the experimental error (± 5 MHz), not affected by the presence of the second pump, i.e., as a result of the kinetic instability, there were always excited secondary spin waves with frequency $\omega_{\mathbf{k}_0}$ close to the frequency $\omega_{\min}$ of the bottom of the spin-wave spectrum.

DISCUSSION OF THE RESULTS

As we can see, the experimental results obtained by us (e.g., the increase, and not decrease, of $P_{2\,\mathrm{th}}$ with increasing P_1) do not fit into the theoretical scheme based only on the four-magnon mechanism of fusion of two PSW$_1$ (1) and the resulting relation (2), according to which the influence of the PSW$_1$ leads only to a decrease in the damping of the spin waves. It is therefore necessary to consider the whole four-magnon Hamiltonian describing the interaction between the waves near the bottom of the spectrum and the parametric waves. On account of the conservation laws, there are allowed, besides the processes (1), only the processes involving the scattering of the waves with frequency $\omega_{\mathbf{k}} \approx \omega_{\min}$ lying near the bottom of the spectrum by the PSW$_1$:

$$\omega_{\mathbf{k}_{p1}'} + \omega_{\mathbf{k}} = \omega_{\mathbf{k}_{p1}''} + \omega_{\mathbf{k}_{p1}' + \mathbf{k} - \mathbf{k}_{p1}''}, \tag{3}$$

where, as in (1), $\omega_{\mathbf{k}p_1'} = \omega_{\mathbf{k}p_1''} = \omega_{pi}/2$, $\mathbf{k}_{p1}' = \mathbf{k}_{pi}''$.

Here we carry out a qualitative analysis of the contribution of the elastic scattering of the spin waves with frequency lying near the bottom of the spectrum by the PSW$_1$ to the kinetic instability and to the process of parametric excitation of the PSW$_2$. In the presence of the processes (3), the kinetic equation for the wave number $n_{\mathbf{k}}$ assumes the form

$$\partial n_{\mathbf{k}}/\partial t = (\gamma_N - \gamma_{\mathbf{k}}) n_{\mathbf{k}} - J_{\mathbf{k}},$$

where $J_{\mathbf{k}}$ is the collision term due to the elastic processes:

$$J_{\mathbf{k}} = 2\pi \int | T_{\mathbf{k}\mathbf{k}_{p1}'\mathbf{k}_1\mathbf{k}_{p1}''} |^2 (n_{\mathbf{k}_{p1}'} n_{\mathbf{k}_{p1}''} + \mathrm{Re}\, \sigma_{\mathbf{k}_{p1}'} \sigma_{\mathbf{k}_{p1}''}) \times \delta(\mathbf{k} + \mathbf{k}_{p1}' - \mathbf{k} - \mathbf{k}_{p1}'')\, \delta(\omega_{\mathbf{k}} - \omega_{\mathbf{k}_1}) (n_{\mathbf{k}} - n_{\mathbf{k}_1})\, d\mathbf{k}_1\, d\mathbf{k}_{p1}'\, d\mathbf{k}_{p1}'', \tag{4}$$

$\sigma_{\mathbf{k}}$ being the anomalous correlator for the parametric waves.[2]

Let us point out that, owing to the last factor in the integrand in (4), the effectiveness of the elastic-scattering process depends essentially on the nature of the distribution of the waves over the resonance surface. Accordingly, the thresholds for kinetic and parametric wave excitation are affected differently by the elastic scattering. Indeed, as shown in Ref. 5, in the case of kinetic excitation of spin waves in the absence of a second pump, the processes (3) lead to a situation in which the secondary waves are excited all over a constant-frequency surface, and the excitation threshold is determined by the value of the damping constant averaged over this surface:

$$\gamma_N=\langle\gamma_{\mathbf{k}_0}\rangle=\frac{1}{\Delta\Omega}\int\gamma_{\mathbf{k}_0}(\Omega)\,d\Omega,$$

where Ω is a solid angle in $\mathbf{k}$ space and $\Delta\Omega$ is the angle region occupied by the surface $\omega_{\mathbf{k}}=\omega_{\mathbf{k}_0}$. This form of the threshold condition leads to quite important consequences. If we take into account the fact that the damping of the spin waves intensifies as the wave vector increases, then the averaged damping constant $\langle\partial_{\mathbf{k}_0}\rangle$, together with the kinetic-instability threshold, will decrease as Δf decreases, i.e., as the constant-frequency surface on which the spin waves are excited approaches the lower limit $\omega_{\min}$ of the spin-wave spectrum. Together with the minimum of the damping constant for the spin waves close to the bottom of the spin-wave spectrum,[3] this guarantees a deep kinetic-instability threshold minimum at the frequency $\omega_{\mathbf{k}_0}\approx\omega_{\min}$. Actually, owing to the nonlinear mechanism underlying the limitation,[5] there will, of course, occur in the spectrum of the excited waves, as in the spectrum of the electromagnetic radiation emitted from the ferrite, frequencies different from $\omega_{\mathbf{k}_0}$. According to Ref. 3, the spectral width of the excited waves is ~ 15 MHz.

The elastic scattering has an entirely different effect on the parametric PSW_2-excitation process. As can be seen from (4), $J_{\mathbf{k}}$ can be represented in the form of a sum of an integral arrival term and a term proportional to $n_{\mathbf{k}}$: $\gamma_p n_{\mathbf{k}}$, where γ_p is thus a positive correction to the damping due to the scattering of the PSW_2 by the PSW_1. For a first-pump power $P_1\ll P_{1\,\mathrm{kin}}$, γ_N, $\gamma_p\ll\gamma_{\mathbf{k}}$, and the second pump excites a narrow—with respect to the polar angles $\theta_{\mathbf{k}}$—wave packet on the resonance surface $\omega_{\mathbf{k}}=\omega_{p2}/2$. For such a packet, the departure term $\gamma_p n_{\mathbf{k}}$ in $J_{\mathbf{k}}$ is much greater than the arrival term. In this case

$$\Gamma_{\mathbf{k}}\approx\gamma_{\mathbf{k}}-\gamma_N+\gamma_p=\gamma_{\mathbf{k}}\left(1-\frac{\gamma_{\mathbf{k}0}}{\gamma_{\mathbf{k}}}\frac{P_1^2}{P_{1\,\mathrm{kin}}^2}+\frac{\gamma_{\mathbf{k}_0}}{\varepsilon\gamma_{\mathbf{k}}}\frac{P_1^2}{P_{1\,\mathrm{kin}}^2}\right),\qquad(5)$$

where $\varepsilon=\gamma_N/\gamma_p$. For yttrium iron garnet at room temperature, we can, by using (4) and Ref. 3, show that

$$\varepsilon^{-1}\approx2\cdot10^3\frac{2\pi\Delta f}{\omega_M}\ln\frac{\omega_M}{2\pi\Delta f},$$

where $\omega_M=4\pi gM_0$, M_0 being the saturation magnetization of the ferrite. Thus, $\gamma_p>\gamma_N$ even when $\Delta f>0.2$ MHz, which explains the increase, observed in our experiment, of the threshold $P_{2\,\mathrm{th}}$ with increasing P_1. Since γ_p is due to a process in which two PSW_1 participate, as can be seen from (4), $\gamma_p\sim n_{p1}^2\sim P_1^2$, which is demonstrated within the limits of the experimental error by the initial sections of the curves 1 and 2 in Fig. 3.

As P_1 is increased further, the growth of γ_p leads to the increase of the angular width of the excited PSW_2 packet. Because of this, the arrival term in $J_{\mathbf{k}}$, which was neglected in (5), increases with increasing P_1 faster than the departure term, which leads to a greater and greater reduction in the positive contribution of the elastic scattering to $\Gamma_{\mathbf{k}}$. As a result, $P_{2\,\mathrm{th}}$ may, beginning at some value of the power P_1, decrease with increasing P_1, which occurs in the case of the curve 1 in Fig. 3 when $P_1>-1$ dB.

Thus, it is now clear in what sense we can say that the presence of PSW_1 leads to a decline in the damping of the waves with frequencies lying close to the bottom of the spectrum (the occurrence of such a decrease is indicated by the very fact that kinetic instability is possible). Because of the presence of elastic scattering, the damping constant for the packet of waves excited in a small part of the constant-frequency surface increases as the number of PSW_1 increases. On the other hand, the damping constant for the packet covering the entire resonance surface decreases with increasing n_{p1}.

Let us now proceed to discuss the dependence $P_{1\,\mathrm{kin}}=f(P_2)$, depicted in Fig. 4, of the kinetic-instability threshold on the power of the second pump.

If the instability regions for the waves with frequencies $\omega_{\mathbf{k}_0}$ and $\omega_{p2}/2$ are separate regions in $\mathbf{k}$ space, then the spin-wave excitation processes in them occur independently,[6] which was observed in the experiment when $\Delta f\gtrsim 30$ MHz. In this case the threshold for kinetic instability of the waves at the frequency $\omega_{\mathbf{k}_0}$ did not depend on the power of the second pump.

As the instability regions approach each other (i.e., as Δf decreases), the pumps begin to influence each other. And what is more, the second pump can exert its influence on the excitation of spin waves with frequency $\omega_{\mathbf{k}_0}$ in two ways. The first one is the direct decay of the uniform magnetization oscillation of frequency ω_{p2} into two spin waves with frequency $\omega_{p2}/2\approx\omega_{\mathbf{k}_0}$. It is clear that, for this to be the case, the frequency $\omega_{p2}/2$ should fall within the spectrum of the spin waves excited under the conditions of kinetic instability, which corresponds to the case in which $\Delta f\lesssim 15$ MHz. The second way is effected through the action, resulting from the processes (1), of the PSW_2 on the spin waves with frequency $\omega_{\mathbf{k}_0}$, which, as a result, will be under the influence of two spin-wave pumps: the PSW_1 and PSW_2.

Thus, for $\Delta f\lesssim 15$ MHz, the spin waves with frequency $\omega_{\mathbf{k}_0}\approx\omega_{\min}$ are actually under the influence of three pumps: the PSW_1, the PSW_2, and the uniform magnetization oscillation of frequency ω_{p2}. In this case a decrease in one pump can be canceled out by an increase in the two others, a possibility which is shown by the curve 1 in Fig. 4.

It was experimentally established that the second pump has no effect on the kinetic-instability threshold in the case when $\Delta f\gtrsim 30$ MHz. Such a value of Δf is probably fixed by the laws of conservation of energy and momentum during the excitation of the kinetic instability under the action of the PSW_1 and PSW_2. But it is not possible to estimate it theoretically at this time, since to do this we must solve the nonlinear problem of spin-wave distribution in the vicinity of the bottom of the spectrum over the natural frequencies and wave vectors, which is beyond the scope of the present paper.

CONCLUSIONS

We have studied the action on a YIG sample of two pumps with frequencies ω_{p1} and ω_{p2} such that $\omega_{p1}/2$ is far from the frequency $\omega_{\min}$ of the bottom of the spin-wave spectrum, while $\omega_{p2}/2$ is close to it and, furthermore, the power P_1 of the first pump is sufficient for the excitation of the kinetic instability of the spin waves. It turned out here that, as a result of the kinetic instability in the presence of the additional pump, or in the absence of it, there are always excited spin waves with frequencies close to the frequency $\omega_{\min}$ of the bottom of the spin-wave spectrum. The threshold for their excitation can be decreased with the aid of a second pump. The greatest decrease in the threshold attained in the experiment was ~ 15 dB.

The parametric-instability threshold for the spin waves excited at the frequency $\omega_{p2}/2$ increases with increasing P_1 because of the scattering of these waves by the waves excited by the first pump.

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