Investigation of the stationary state of parametrically excited spin waves in antiferromagnetic $MnCO_3$

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The stationary state of parametrically excited spin waves (PSW) in the easy-plane antiferromagnet $MnCO_3$ is studied at $T = 1.62$°K and at a pumping frequency $\omega_p/2\pi = 36$ GHz. Transient processes in the PSW system were observed following rapid (relative to the magnon lifetime) variation of the phase, frequency, or intensity of the microwave pumping. The stationary phase of the PSW and its dependence on the microwave field amplitude h are determined from the response of the spin system to variation of the pumping phase. Collective PSW oscillations with a frequency $\Omega \sim 1$ MHz were observed in the same experiments. The results are in agreement with predictions of the nonlinear stationary theory [11] and indicate that in the stationary state the PSW system is a coherent system of standing spin waves with a certain phase shift relative to the pumping phase. Rapid variation of the pumping frequency $\Delta\omega_p$ produces oscillations (of frequency $\Delta\omega_p$) in the energy absorbed by the sample. The lifetime of PSW is estimated on the basis of the damping of the oscillations and is found to be $\tau_M \approx 0.5$ μsec.

1. INTRODUCTION

Parametric excitation of electron spin waves in antiferromagnets with easy plane anisotropy, such as $MnCO_3$, has been the subject of a number of studies[1-7]. Detailed studies were made of the conditions for the excitation and kinetics of the process. It was shown[5-7], that in $MnCO_3$ and $CsMnF_3$, at temperatures 1.2–2.1°K and pump frequencies $\omega_p/2\pi = 36$ GHz, the parametric excitation of low-frequency (quasiferromagnetic) branch of the spectrum has a "hard" character. Excitation of the parametric spin waves (PSW) occurs if the microwave field amplitude h on the sample exceeds a certain critical value h_{c1} ($h > h_{c1}$). After a certain time τ_1, when the PSW density reaches a definite value exceeding the thermal background by two or three orders of magnitude, a cascade-like growth of the number of spin waves takes place, apparently due to saturation of one of the relaxation mechanisms. After a time of ~ 10 μsec, the PSW system goes over to a stationary state characterized by the critical field $h_{c2} < h_{c1}$ (the parametric excitation of the spin waves stops at $h < h_{c2}$). From h_{c2} we can calculate the PSW relaxation frequency $\Delta\nu_2$.[8] For $MnCO_3$ samples with linear dimensions on the order of 1 mm at T = 1.2–2.1°K, the minimum value of $\Delta\nu_2$ is ≈ 0.15 MHZ[6], corresponding to a magnon lifetime $\tau_M \approx 1$ μsec.

The purpose of the present work was to study the stationary state of PSW in $MnCO_3$. Inthe stationary state, the PSW system is at equilibrium with the pump field incident on the sample. The rapid variation of the pump parameters (phase, frequency, amplitude) in comparison with τ_M leads to a perturbation of the PSW system, in which a certain transient process is observed, and the system again becomes stationary after a time $\approx \tau_M$. From the response of the PSW system to the change of the pump parameters, we can assess the properties of the stationary state.

2. PROCEDURE

We used a setup basically analogous to that described earlier[4, 6, 7]. Besides operating in the sweep regime, the klystron oscillator produced long pulses of duration ≥ 1 msec and repetition frequencies 50 Hz, and the klystron frequency could be varied within the generation band at any desired instant of the long pulse, by an amount 0.1–10 μsec, via additional modulation of the reflector voltage. The measurements were performed at the frequency $\omega_p/2\pi = 35\ 490$ MHz.

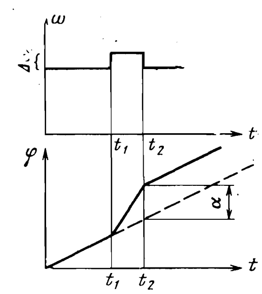

FIG. 1. Phase-rotation method ($\varphi = \int_0^t \omega\, dt, \alpha = \Delta\omega\, (t_2 - t_1)$)

The microwave-pump phase was switched by changing the klystron frequency $\Delta\omega_p$ for a time $\delta = t_2 - t_1 \approx 0.1$ μsec (Fig. 1). The phase shift was then

$$\alpha = \int_{t_1}^{t_2} \Delta\omega_p\, dt. \quad (1)$$

The width of the klystron generation band was ~ 50 MHz, so that by using a pulse of 0.1 μsec duration we could rotate the radiation phase through $\sim 5 \times 2\pi$ rad. The rapid change of power was produced with a germanium modulator operating at helium temperature and employing the low-temperature breakdown effect[9]. The shortest time of variation of the microwave-field phase in the resonator was 0.1–0.15 μsec, and the time of frequency and phase switching was 0.05 μsec.

To apply a microwave signal to the sample, namely magnetic field exceeding h_{c1}, the $MnCO_3$ crystal, measuring 1 × 1 × 1 mm, was fastened at an antinode of the magnetic field of the H_{012} mode of a cylindrical resonator with $Q \approx 1500$, so that the parallel-pumping conditions[8] were satisfied during the course of the experiment, namely, the external magnetic field and the microwave pumping magnetic field were parallel and were in the basal plane of the sample.

The signal passing through the resonator was received by a crystal detector and displayed on an oscilloscope screen. The excitation of the PSW was registered by means of the absorption of the power by the sample, which led to a decrease in the microwave signal passing through the resonator. Owing to the above-described hardness phenomenon, this signal has at $h > h_{c1}$ the form of a pulse with a steep drop, as shown in Fig. 2a (see also Fig. 1 of[6]). We shall designate as Secs. 1 and 2 those ahead and past the drop. The

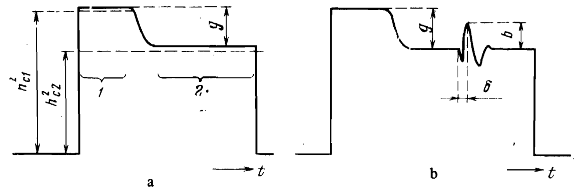

FIG. 2. Waveform of microwave-power pulse passing through the resonator when PSW are excited in the sample and the spin system is perturbed in the stationary state.

difference between the detector-voltage signals before and after excitation of the PSW is a measure of the power absorbed in the sample. For the stationary state, this is the value marked g in Fig. 2a. Assume now that after reaching the stationary regime we perturb the PSW system for a time δ. As a result, the power absorption at the instant of the termination of the action changes. This will be revealed by the deviation of the detector signal from the stationary value. We designate this deviation by b (Fig. 2b), it is precisely this quantity which is convenient to measure in the experiment. The measure of the absorbed power is the segment g–b. A decrease or increase in the absorbed power corresponds to positive or negative b.

The excess h/h_{c2} above threshold was measured by a procedure analogous to that described in[6, 7], the only difference being that instead of a long microwave pulse with a smooth decrease of the power (Fig. 2 of[6]), the klystron frequency was swept with a slow passage (~10 msec) through the resonance curve of the resonator. A photograph of the sweep oscillogram is shown in Fig. 3. The detector signal at the instant when the PSW excitation is "turned off" corresponds to the threshold field h_{c2}.

3. RESPONSE OF PSW SYSTEM TO RAPID CHANGES OF THE PUMP PHASE

A. Results

It turned out in the experiment that the PSW system reacts to rapid switching of the phase of the microwave pump. By varying the phase at some instant of time prior to the precipice, it is possible to lengthen the time τ_1 of the abrupt break. If we change the phase after the drop, then, at the instant after the switching, the microwave power absorbed by the system of spins can be larger or smaller (depending on the change of the phase α) than in the stationary state; moreover, at certain values of α the system of spins radiates and gives up energy to the resonator. Then, after a time ~1 μsec, the system returns to the stationary state.

Figure 4 shows photographs of oscillograms of the transient processes of different values of the change of the pump phase, while Fig. 5 shows the general form of the microwave power pulse passing through the resonator with the sample, when the spin system radiates as a result of phase switching.

The small frequency change $\Delta\omega_p \lesssim 10$ MHz, and also the deviation of the shape of the additional voltage pulse V applied to the reflector from rectangular (the pump front was comparable with its duration) cause the phase shift as determined from (1) to be subject to a large error. We therefore use the following method of determining α. We worked at the center of the klystron oscil-

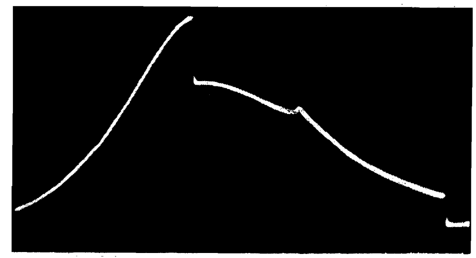

FIG. 3. Resonator resonance curve when parametric spin waves are excited in the sample (illustrating the procedure used to determine h_{c2}).

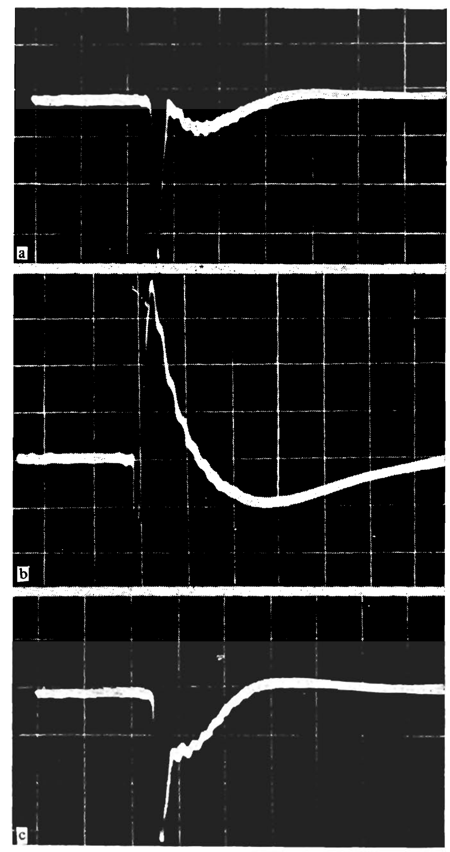

FIG. 4. Oscillograms of transients in a PSW system after a change of the pump phase; sweep 0.5 μsec/div.

lation band, where the relation $\Delta\omega \propto V$ is satisfied with good accuracy. The waveform of the pulse did not change with its amplitude, since the waveform is determined by the slopes of the fronts, so that the phase shift α was proportional to the pulse amplitude:

$$\alpha \propto \int_{t_1}^{t_2} V(t)\,dt \propto V.$$

In the experiment we plotted the function b(V), which turned out to be periodic in V and consequently also in α. It is clear from general considerations that the period of the function $b(\alpha)$ is either equal to 2π, or is smaller than 2π by an integer factor. To ascertain this circumstance, we have compared the reaction of the PSW and of a high-Q resonator (Q = 50 000) to the change of the klystron radiation phase. To this end, a directional coupler was used to divert part of the microwave power to the resonator. The electromagnetic-oscillation damping time in such a resonator was 0.4 μsec, so that

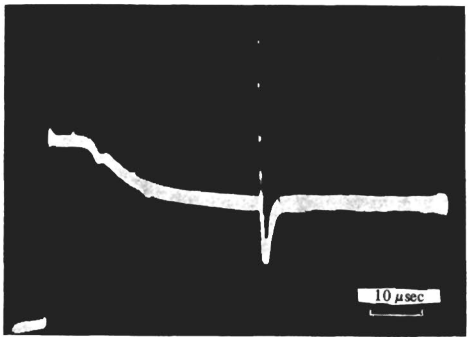

FIG. 5. Overall view of microwave power pulse passing through resonator. The PSW system radiates at the start of the transient process after passing through the phase shifter.

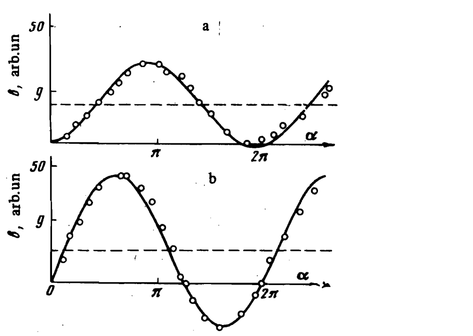

FIG. 6. Results of experiments on switching of the pump phase: a–h/h_{c2} = 1.08, b–h/h_{c2} = 2.25; T = 1.62° K, H = 2.55 kOe.

the damped oscillation with the "old" phase interfered effectively with the growing oscillation of the "new" phase. Owing to the interference, the field in the resonator after the phase switching depends on α. The period of this dependence is obviously 2π. It turned out that the reaction of the PSW and of the resonator had the same period. On the basis of the results we assigned a value $\alpha = 2\pi$ to the period of the experimentally obtained plot of b(V), and by the same token calibrated the "phase shifter."

In the described experiments, the klystron was tuned to the resonator frequency when the PSW were excited in the sample, and a stationary state was established. The influence of the shift of the natural frequency of the resonator, due to the change in the beyond-threshold susceptibility of the sample, was small, since the largest shift of the natural frequency of the resonator due to the excitation of the PSW was 2 MHz (at $h/h_{c2} = 3$), and the half-width of the resonance curve was 20 MHz. It was verified experimentally that detuning of the resonator relative to the klystron radiation by 2 MHz does not affect the $b(\alpha)$ dependence.

At T = 1.62°K, we obtained several $b(\alpha)$ plots for different excesses over threshold. Figure 6 shows the obtained plots of $b(\alpha)$ for two excesses over threshold. The solid lines are sinusoids that coincide in amplitude and in period with the experimental data. In our experiments, during the time of the phase shifting, the klystron frequency increase, i.e., the radiation at the instant t_2 (Fig. 1) was leading the initial radiation in phase. The maxima and minima of the $b(\alpha)$ curves (Fig. 6) then shifted monotonically towards smaller α with increasing h/h_{c2}.

B. Discussion

We first show that the results of our measurements make it possible to determine the phase of the excited spin waves. The dependence of this phase on the pump amplitude plays an important role when it comes to comparison with the existing theories of parametric excitation. According to the existing concepts, parametric buildup causes excitation of an aggregate of standing spin waves with wave vector **k**, such that the resonance condition $\omega_k = \omega_p/2$ is satisfied. Here ω_k is the frequency determined from the wave dispersion law, **k** assumes in the experiments values in the interval 0–6 × 10^5 cm^{-1} [7]. The temporal phase κ of each of the standing waves from this assembly turns out to be perfectly defined, κ is reckoned relative to the oscillation cos $\omega_k t$, and the pump field depends on the time like 2 $\omega_k t$.

A standing spin wave S_0 can be represented as a sum of two traveling waves with opposite **k**,S_k and S_{-k}, which in turn are sums of elementary excitations of a magnetic crystal–magnons:

$$S_0 \infty \cos(\mathbf{kr}+\beta)\cos(\omega_k t+\varkappa),$$

$$S_\mathbf{k} \infty \cos(\omega_k t+\varphi_k-\mathbf{kr}), \quad S_{-\mathbf{k}} \infty \cos(\omega_k t+\varphi_{-k}+\mathbf{kr}).$$

It follows from this representation that $2\kappa = \psi_k$, where $\psi_k = \varphi_k + \varphi_{-k}$ is the sum of the time phases of the waves traveling in opposite directions. The power absorbed by the standing waves from the pump is[10]

$$W_k = N_k h V_k \sin\psi_k,$$

where N_k is the average number of magnons constituting the aggregate of the standing waves (in[11], N_k is called the "pair" amplitude), h is the amplitude of the pump field, and V_k is the parameter of the coupling with the pump. The most favorable phase for energy absorption corresponds to $\psi_k = \pi/2$.

We shall next follow the terminology of Zakharov, L'vov, and Starobinets[10–13], i.e., we shall find as a "pair of waves" the assembly of standing waves with definite value of **k**. The quantity ψ_k will be called the phase of the "pair" or the phase of the PSW.

We turn now to the experimental situation. Assume that at the instant of phase switching the PSW system consists of "pairs" for which $\psi_k = \psi_{st}$. If the phase of the microwave pump increases by α after a time that is short in comparison with τ_M, then after switching the phase we have for the PSW system $\psi_k = \psi_{st} - \alpha$. Recognizing that for the absorbed power we have

$$W \infty \sin\psi_k, \quad W \infty g-b, \quad b(\psi_k=\psi_{st})=0,$$

we obtain at the instant t_2 Fig. 1):

$$b(\alpha)=g[1-\sin(\psi_{cr}-\alpha)/\sin\psi_{st}]. \tag{2}$$

The first maximum of the function b(a) occurs at $\alpha = \pi/2 + \psi_{st}$. From the $b(\alpha)$ curves we can determine the value of ψ_{st}. We note that the most favorable for the energy absorption is the phase $\psi_{st} = \pi/2$.

Such a reduction of the experimental data shown in Fig. 6 shows that the PSW has a phase whose deviation from $\pi/2$ is larger the larger the intensity of the microwave field on the sample. This fact is closely connected with the mechanism of limitation of the amplitude of the spin waves in parametric excitation. As the PSW phase turns away from $\pi/2$ the value of sin ψ decreases, and this leads to a decrease in the coupling with the external pump, and in final analysis to a limitation of the PSW amplitude, i.e., one of the mechanisms of the limitation of PSW amplitude is phase rotation of the system of spins relative to the pump. This amplitude-limitation mechanism was predicted theoretically[10, 11] on the basis of an analysis of the interaction of the PSW with one another.

The observed dependence of ψ_{st} on the pump field plays an important role in the check on the validity of the existing theories of parametric excitation[10-13, 14]. In their recent papers, Zakharov, L'vov and Starobinets have reached the conclusion that at a sufficiently small excess over the threshold there is realized a "regime" in the form of one monochromatic wave pair, "i.e.,, the distribution of the PSW in k-space constitutes two points, symmetrical about to zero, on the equal-energy surface $\omega_k = \omega_p/2$. For this case, the equations that determine the amplitude and phase of the pair ([11], Eq. (6b)) can be written in the form

$$\frac{1}{2}\frac{dN_k}{dt} = N_k[-\gamma + hV_k \sin\psi_k], \tag{3a}$$

$$\frac{1}{2}\frac{d\psi_k}{dt} = \omega_k + 2TN_k - \frac{\omega_p}{2} + hV_k \cos\psi_k + SN. \tag{3b}$$

Here γ is the damping of the waves $(1/\tau_M = 2\gamma)$, ω_k is the PSW frequency, and S and T are the coefficients of the Hamiltonian of the interaction of the spin waves ($2TN_k$ is the nonlinear frequency shift).

In the stationary state we have

$$\omega_k + 2TN_k - \omega_p/2 = 0, \tag{4}$$

$$\sin\psi_{st} = \gamma/hV_k = h_c/h, \tag{5a}$$

$$N_{st} = \gamma[(h/h_c)^2 - 1]^{1/2}/|S|. \tag{5b}$$

Figure 7 shows the results of experiments on the determination of ψ_{st}, in the coordinates $\sin\psi_{st}$ and h_{c2}/h. Within the limits of experimental error, the points fall off on the bisector of the coordinate angle, as follows from (5a). This is evidence that the theory of[10-13] describes correctly the essential features of the excitation of the PSW.

4. COLLECTIVE OSCILLATIONS

We now turn to consider the transient process through which the PSW system goes over into a stationary state after switching the phase. When the phase is switched to an angle $\alpha \sim 30°$–$40°$, the absorbed power returns gradually to its stationary value. This change, however, is not monotonic, One can see that power oscillations with a period ≈ 1 μsec, which become more frequent with increasing excess over threshold (see the photograph of the oscillogram in Fig. 8[1)]). Within the framework of the aforementioned theory[11], these oscillations must be attributed to oscillations relative to stationary values of the number and phase of the PSW.

It was shown in particular[12] that in stable state that

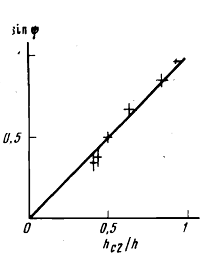

FIG. 7. Results of experiments on the determination of ψ_{st} : T = 1.62° K, H = 2.55 kOe.

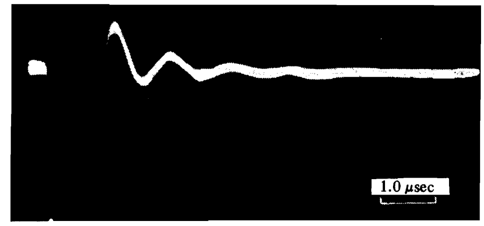

FIG. 8. Oscillogram of collective oscillations.

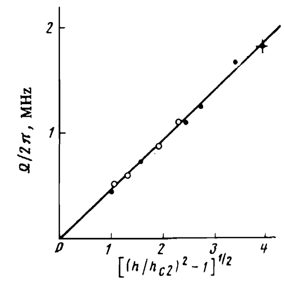

FIG. 9. Results of observation of collective oscillations: T = 1.62° K, H = 0.73 KOe.

exists at $S(2T + S) > 0$, the PSW system can execute harmonic oscillations with frequency

$$\Omega = 2\gamma\left[\frac{2T+S}{S}\left[\left(\frac{h}{h_{c2}}\right)^2 - 1\right]\right]^{1/2}. \tag{6}$$

The damping of the oscillations will take place with the characteristic time $1/\gamma$. These oscillations will be called[12] "collective oscillations."

Using a magnetron microwave-power source, we obtained the experimental values of $\Omega(h/h_{c2})$ for values of h/h_{c2} from 1.1 to 4. The results of the measurements at T = 1.62°K and H = 0.73 kOe, are shown in Fig. 9. We see that the experimental points fall, in good agreement with the theory, on a straight line plotted in the coordinates Ω and $[(h/h_{c2})^2 - 1]^{1/2}$. From the reduction of the experimental data we obtain the value

$$\frac{2\gamma}{2\pi}\left(\frac{2T+S}{S}\right)^{1/2} = \Delta\nu\left(\frac{2T+S}{S}\right)^{1/2} = 0.5 \pm 0.05 \text{ MHz}$$

which agrees in order of magnitude with the value $\Delta\nu_0 = 0.35$ MHz obtained from data on the damping of beats (see Sec. 6 below).

5. RESPONSE OF PSW SYSTEM TO INTERRUPTION OF THE MICROWAVE PUMP POWER

To estimate the lifetime of the PSW, experiments were performed on interruption of the power. The very phenomenon of the damping of the PSW has an interesting peculiarity, in that the change of the pair amplitude is accompanied also by a change in its phase ψ. This change (which follows also from the theory[11]) can be observed in the following qualitative experiment. As a result of turning off the microwave pump power for a time $\delta \approx 0.4$ μsec, the energy absorbed by the PSW system changes the instant when the power is turned on. The corresponding change in the detector signal is $b_0 > 0$.

It turned out, however, that this change can be partly offset by simultaneously switching the phase of the pump. To this end, the klystron radiation phase was rotated, by the method indicated above, through an angle α^*, during the time that the power was switched off with the aid of a germanium modulator that partitioned off the waveguide channel. If the pump phase is switched through an angle α^*, on the other hand, without simultaneously modulating the power, then the resultant change in the absorbed power is again approximately equal to b_0. Thus, the separate use of each of the actions, namely modulation of the power and switching of the phase, leads to a larger deviation of the absorbed power from the stationary value then their joint use. In other words, the change of the pump phase by α^* in the stationary state decreases absorption of the PSW. To the contrary, a similar change of the phase in a system in which the spin waves have been partly damped because the pump had been turned off, leads to an increase of the absorption. This indicates that in the course of the damping ψ_k deviates from ψ_{st} and approaches $\pi/2$.

With increasing pause duration δ, the value of b increases monotonically from zero to g (b = g at $\delta \approx 2$ μsec). The depth of power modulation in our experiments was 90%, so that during the pause we had $h/h_{c2} \approx 0.3$–0.5.

6. RESPONSE OF PSW SYSTEM TO SWITCHING OF THE PUMP FREQUENCY

A. Results

In the case of fast switching (within ≈ 0.05 μsec) of the pump microwave frequency, at constant power, the experiments yield two types of transients, depending on the change $\Delta f = \Delta\omega_p/2\pi$ of the klystron frequency.

1. $\Delta f \lesssim 1$ MHz. After switching, an increase or decrease takes place in the absorbed power. The sign of b is reversed together with the change of the sign of Δf. After a time ≈ 1 μsec, the absorbed power assumes a stationary value. Figure 10 shows an oscillogram of a microwave power pulse passing through the resonator, with the klystron frequency change occurring within 6 μsec. The sensitivity of the spin system to the frequency shift is extremely high–a shift $\Delta f \approx 10$ kHz (a value close to the short-time stability of the generator) can be sensed by the spin system. The time to assume the stationary value decreases with increasing h/h_{c2}.

2. At $1/\Delta f \approx 1$ μsec, the transient of the first type goes over smoothly with increasing Δf into absorbed-power beats at a frequency Δf about the zero position (b = g, see Fig. 2), which are damped exponentially. The beat damping time depends on the temperature and on the external magnetic field, and does not depend, within the limits of our accuracy, on the microwave power fed to the resonator. Fig. 11 shows (with a sweep of 5 μsec/div), the overall picture of the power pulse passing through the resonator. After the sharp drop, at the instant marked +, the frequency was switched over. The oscillogram of the vicinity of this instant, with rapid sweep (0.5 μsec/div), is shown in Fig. 12. Beats appear

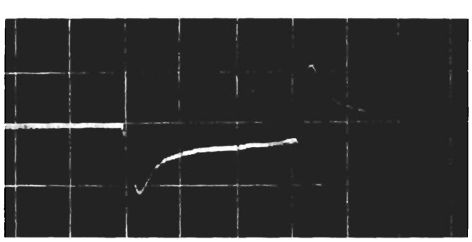

FIG. 10. Oscillogram of the response of the PSW to a shift of the pump frequency; f = 0.5 MHz, sweep 2 μsec/div.

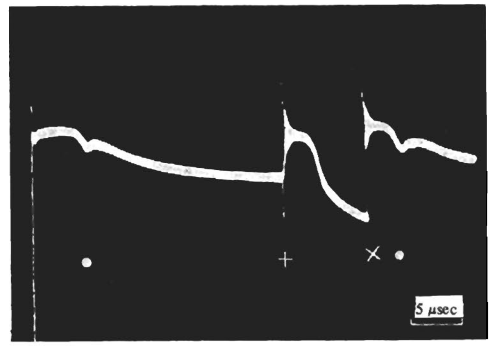

FIG. 11. Overall view of the microwave power pulse passing through the resonator. After the PSW assumed a stationary state at constant power fed to the resonator, the pump frequency was shifted by $\Delta f = 8$ MHz.

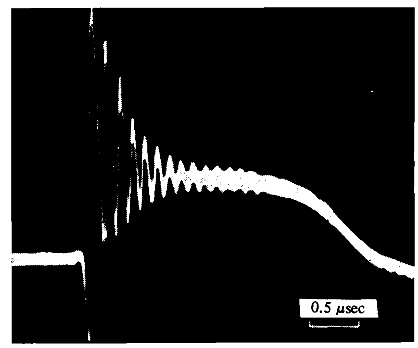

FIG. 12. Oscillogram of the response of PSW to a shift $\Delta f = 8$ MHz of the pump frequency.

and are damped. We see that the beats occur near the zero level of the absorbed power. This is followed by another sharp drop and establishment of the stationary state. At the instant noted by the lying cross in Fig. 11, the frequency was switched in the reverse direction, beats and sharp drops are again observed. The disparity between the stationary values of the power at the instants to the left of the plus sign and to the left of the lying cross is due to the slight inequality of the power generated by the klystron at these instants, owing to transition to another section of the generation band when the frequency is switched.

We noted another feature of the approach of the PSW system to the stationary state. At an excess above threshold $h/h_{c2} \sim 2$ and when working not with the natural frequency of the resonator (which is necessary in order to have the same microwave field intensity in the resonator at different frequencies), another nonmonotonic component of the decrease of the microwave power is observed during the time of the drop and takes the form of "tick". (These instants are marked in Fig. 11 by white points.) The instant of its appearance depends on the excess over threshold and on the tuning of the resonator. When h_{c2} is exceeded by more than three times, the smooth exponential shape of the beat envelope becomes distorted. To study the lifetime of the standing waves, the beats were photographed at $\Delta f = 5$ MHz and at different values of the magnetic field and of the temperature. We observed beats with frequency up to 15 MHz. When the frequency shift was large, owing to the selective action of the resonator, it was impossible to reach the power necessary to excite the PSW.

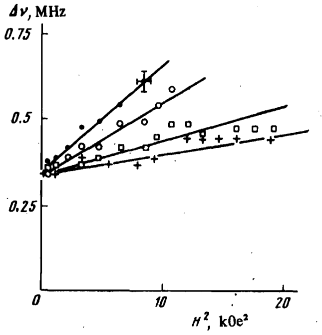

FIG. 13. Results of the reduction of the beat oscillograms: ●–T = 1.94 K, ○–T = 1.84 K, □–T = 1.69 K, +–T = 1.63 K.

B. Discussion

The response of PSW to shifts in the pump frequency is described by expression (3): when the stationary condition (4) is violated, the phase ψ_k begins to change, and this leads to a change in the absorbed power. A computer was used to solve the system (3) numerically for several excesses above threshold h/h_{c2} and for several values of Δf, neglecting the term $2T(N_k - N_{st})$. It turned out that for $\Delta f = 5$ MHz and $h/h_{c2} \leq 1.5$ the function $N_k(t)$ after the shift is close to an exponential with a damping time $\tau_M = 1/2\gamma$, while ψ_k is close to a linear function of the time, with $d\psi_k/dt \approx 2\pi\Delta f$. Thus, the absorbed power is $W \propto N_k \sin \psi_k$ and is made up of damped oscillations with frequency Δf, the envelope of which is an exponential function of the time with characteristic time τ_M. The absorption of the power by the wave with a new value ω_k should be small, since, as seen from the oscillogram of Fig. 11, the buildup of the new wave begins (owing to the hardness effect) only after a certain time following the damping of the beats. Thus, the beat damping time is the lifetime of the PSW.

After reducing the photograph of the oscillograms, we obtain the values of the lifetime for different H and T. These data are plotted in Fig. 13 in coordinates $\Delta\nu = 1/2\pi\tau_M$ and H^2 (just as in[6], where $\Delta\nu$ was obtained from measurements of h_{c1} and h_{c2}). Within the limits of the accuracy of our experiment, the points fit the straight lines $\Delta\nu = \Delta\nu_0 + \beta H^2$. The smallest observable relaxation ($\Delta\nu_0 = 0.35$ MHz corresponds to a lifetime $\tau_M = 1/2\pi\Delta\nu_0 = 0.45$ sec. The constant β depends on the temperature.

The value of the relaxation as $H \to 0$, determined for the given crystal by measuring h_{c2} using the procedure described in[6], is $\Delta\nu_2 = 0.05$ MHz; this is approximately one-seventh the value determined from the damping of the beats. This difference may be due to the presence of inhomogeneities in the sample. As shown by Zakharov and L'vov[13], this results in a damping, as determined from the threshold field, of the order $(\Delta\nu\Delta\nu_{imp})^{1/2}$, where $\Delta\nu$ is the natural damping of the magnons and $\Delta\nu_{imp}$ is the damping due to the scattering by the inhomogeneities, whereas the magnon damping in the absence of the pump is equal to the sum $\Delta\nu + \Delta\nu_{imp}$. It should be noted that the use of Eqs. (3) to reduce the results of (3) is not quite legitimate in the presence of impurities, since the features of scattering by inhomogeneities were not taken into account in the derivation of (3).

Thus, we have observed in our study the response of a PSW system to a change in the pump phase. We have determined the dependence of the sum of the phases of the traveling waves of a parametric pair in the stationary state on the pump field intensity. This dependence is in good correspondence with the predictions of the theory[11] and offers evidence that the essential mechanism for limiting the PSW amplitude in $MnCO_3$ is the rotation of the phase ψ of the pair relative to the pump phase. Rotation of the PSW phase during the damping process was observed experimentally.

In experiments with switching of the pump phase, we observed oscillations of the absorbed power with a period ~ 1 μsec), which depends on the excess above threshold. The presence of such oscillations also agrees with theory[11].

From the observation of the damping of the beats when switching the pump frequency, we obtained the dependence of the PSW relaxation $\Delta\nu$ on the magnetic field for several values of the temperature in the interval 1.65–2.0°K. The smallest obtained value was $\Delta\nu = 0.35$ MHz, corresponding to a lifetime $\tau_M = 0.45$ μsec.

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1) Figure 4 shows oscillograms of the transients at a slight excess above threshold, when the period of oscillations is close to the damping time.

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