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Transient processes in fast excitation of a coherent population trapping resonance

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It is for the first time established that dynamic excitation of coherent population trapping (CPT) resonances in Rb vapour at modulation frequencies of the frequency difference of a bichromatic pumping field ranging from tens of Hz and higher produces intensity oscillations in the radiation passed through the Rb vapour cell, which alter the resonance shape considerably. The presence and anharmonicity of these oscillations have been experimentally measured and validated theoretically. We also discuss the effect of alteration of the CPT resonance shape on stability of atomic clocks when the resonance is excited relatively quickly.

In order to generate a CPT resonance in a three-level Λ-system, the difference between the frequencies of a bichromatic pumping field is modulated. Higher modulation frequencies lead to improvement of the signal-to-noise ratio and to better stability of atomic clocks relying on this resonance. However, as it was demonstrated in [1], raising the modulation frequency also leads to a significant modification of the CPT resonance parameters.

The present work for the first time establishes that this modification of the CPT resonance parameters results from alteration of the resonance shape, in its turn caused by relaxation processes playing increasingly significant role in CPT resonance formation as the modulation frequency rises. It was discovered that excitation of a CPT resonance on the Λ−transition of D1 line in ^{87}Rb (Fg=1,2→Fe=2) at frequencies of several tens of Hz and higher generates relaxation oscillations of the radiation intensity, which give rise to a significant transformation of the resonance shape. We have measured this behaviour experimentally and validated our results theoretically using the modelling technique presented in [2].

In Fig. 1b, we present a theoretical dependence of the intensity of radiation passed through the Rb vapour cell upon time at the modulation frequency of 100 Hz (the central part of the CPT resonance is highlighted in red). It is obvious that CPT resonance excitation in this case features a considerable decaying oscillatory process that leads to a major modification of the resonance shape. Similar oscillations were observed earlier in step-wise CPT excitation [3]. Our modelling results of the process of step-wise excitation of a CPT resonance are shown in Fig. 1e. Our experiments and calculations have shown that the difference in relaxation of CPT excitation between step-wise and harmonic excitation consists in that harmonic excitation leads to anharmonic intensity oscillations of radiation passed through the vapour cell (Fig. 1a), whereas step-wise excitation produces regular harmonic oscillations (Fig. 1d). Experimental proof of anharmonic oscillations caused by harmonic CPT excitation is presented in Fig. 2 (the experimental set-up is described in [1]). The inset of Fig. 2 shows the measured dependence of the oscillation period upon time, which is in qualitative correlation with the calculated dependence of Fig. 1a.

Fig. 3 contains the calculated evolution of the CPT resonance shape at various modulation frequencies. Significant increase in oscillation amplitude at progressively higher modulation frequencies is readily visible.

The present work gives a detailed description of the obtained experimental and theoretical results, discusses the need to take into account these results when designing atomic clocks based on CPT resonances and transient CPT [3].

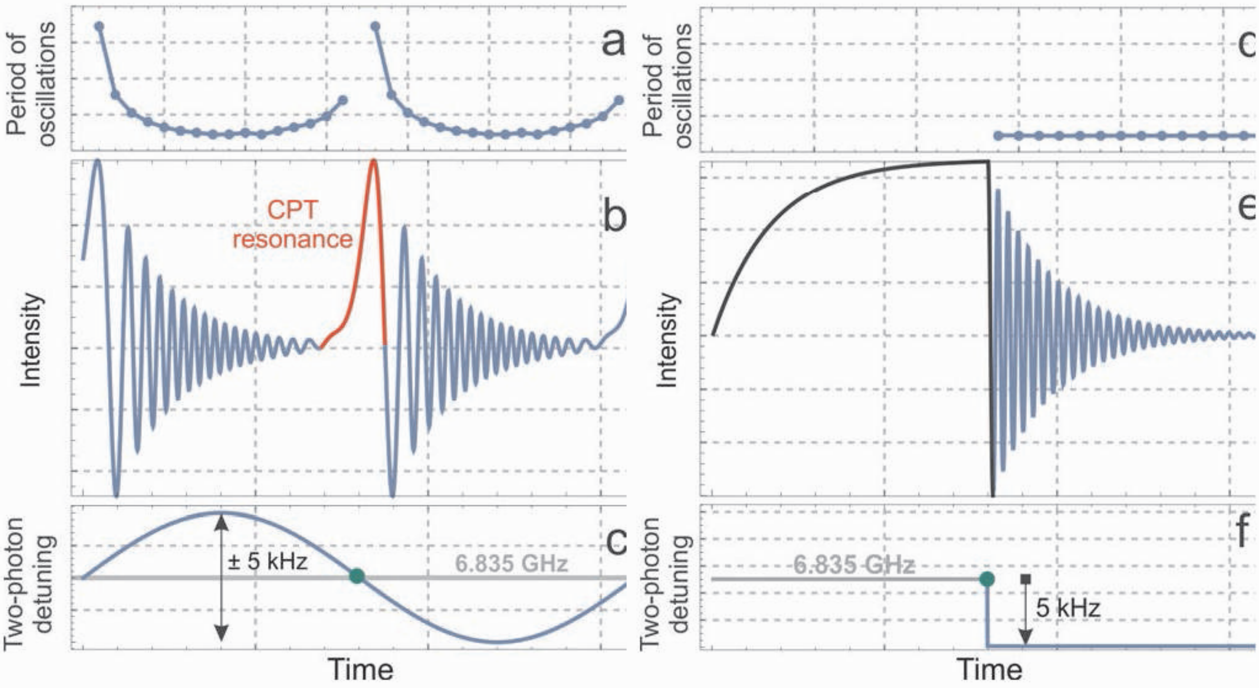

Fig. 1: Theoretical temporal traces of harmonic (a, b, c) and step-wise (d, e, f) CPT excitation.

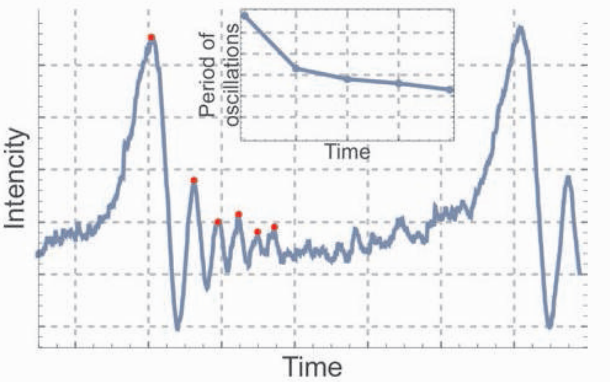

Fig. 2: Experimental dependence of the intensity of radiation passed through a Rb vapour cell upon time at the modulation frequency of 100 Hz.

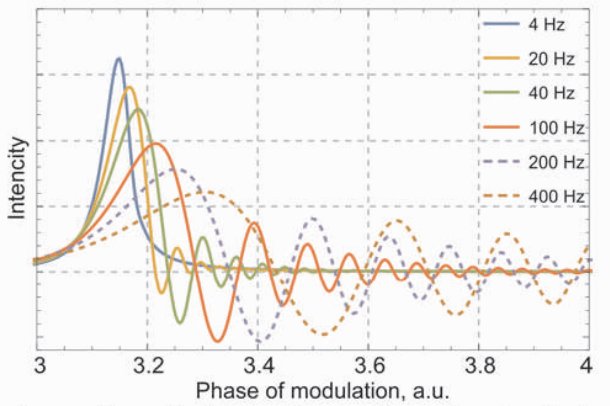

Fig. 3: Theoretical dependence of intensity of radiation passed through a Rb vapour cell upon the modulation phase at different modulation frequencies.

Acknowledgments

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