OBSERVATION OF SUB-POISSON FIELD IN A GAS LASER WITH FEEDBACK

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Generation of sub-Poisson fields (SF) is a timely problem in view of the prospect of using them in exact measurements and in fundamental research [1-4]. Some of the first observations of SF were made with semiconductor [5] and gas [6-7] lasers in photoreceiver—pump feedback (FB) loops. The operation of a gas laser with FB [6-7] is analyzed here using for the numbers of photons and photoelectrons the balance equations substantiated in [8]. Although no method of extracting radiation from such a FB loop has been found, investigation of FB lasers is important, since it permits a study of methods of active control of laser-emission statistics.

The schematic Fig. 1 illustrates the main details of the experiment. We investigated an He–Ne laser ($\lambda = 0.63 \, \text{µm}$) consisting of an active element (AE) and mirrors $M_1$ and $M_2$. The laser operated in the single-frequency regime. The excess of gain over loss was regulated by slightly misadjusting the cavity, and also by using a spectroscopic slit placed in the cavity. The laser emission was recorded with a photodiode (PD) whose signal was fed first to a preamplifier 1 and then to a selective amplifier 2. The overall gain was $k_1(v)$. The FB signal was fed next to the power supply of the active element to control the laser pumping by modulating the discharge current. This process is described by a transfer coefficient $k_2(v)$. The signal from the preamplifier was fed also to a spectrum analyzer, effecting thereby selective FB. The selective FB is not of fundamental importance and is needed only for frequency detuning from the technical fluctuations [9].

The photocurrent-fluctuation level is given by

$$m^2_{\nu} = G(\nu)/\nu^2,$$

where $G(\nu)$ is the spectral density of the PD-current fluctuations, and $i_0$ is the dc component of the PD current. Preliminary investigations similar to those described in [11] have shown that the value of $m^2_{\nu}$ in the investigated laser in the range $\nu = 2-1000 \, \text{kHz}$ was determined by the natural intensity fluctuations (NIF) and by the shot noise (SN).

Following application of the FB and selection of the gain and phase of the FB network, a decrease was observed in the value of $m^2_{\nu}$ determined from the PD current. This decrease was observed when the FB system frequency was tuned in the range 2-10 kHz. The frequency constraint is not essential and is caused at low frequencies by technical fluctuations and at high ones by the inertia of the photoreceiver. Figures 2 and 3, corresponding to different pass bands of the FB system, illustrate the characteristic $m^2_{\nu}$ variation observed when the FB is turned on. Curves 1 show the PD current fluctuation level with the FB circuit disconnected, as determined by the NIF and the SN. The SN level is shown by curves 2. To determine the SN level, the PD was illuminated by an incandescent lamp whose radiation intensity was adjusted to make the PD current produced by lamp illumination equal to that produced by laser illumination. The points on curves 4 show the PD-current fluctuation level observed with the FB loop connected. It is seen that in this case the PD current fluctuation level at the center of the FB circuit pass band becomes lower than the SN level.

Since the PD quantum yield $\eta$ is less than unity, part of the photon flux, equal to $1 - \eta$, was not recorded. The quantity $m^2_{\nu}$ therefore does not yield full information on the statistics of the photon flux incident on the PD. To find the statistics of the entire photon flux we assume that the PD quantum yield is unity and introduce a mirror $M_3$ (imaginary) with a transmission coefficient $\eta$ and a second (also imaginary) photodiode PD' with a quantum yield likewise equal to unity (see Fig. 1). The statistics of the total photocurrent of photodiodes PD and PD' is then determined by the statistics of the total photon flux present in the FB loop.

We assume hereafter that the laser operates far above threshold, so that its intensity fluctuations are described by linear equations [10]. This permits linear balance equations to be used also to analyze the photon- and photoelectron-number fluctuations

$$\dot{n}(t) = r(t) - Cn(t) - f_1(t) - f_2(t);$$

*Presented at the International Workshop on Squeezed and Correlated States, Moscow, December 3-7, 1990.
Fig. 1. Experimental setup.

Fig. 2. PD current-fluctuation spectra [6]: 1 - laser without FB; 2 - SN level; 3 - calculated from Eq. (10); 4 - calculated from Eq. (15). Curves 3 and 4 merge above the SN level.

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i(t) = eC_1 \eta n(t) + eF_{11} \xi(t),
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i'(t) = eC_1 (1 - \eta) n(t) + eF_{12} \xi(t),
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