STUDYING THE STABILITY OF WAVELENGTHS RADIATED BY A GAS LASER

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The development of a continuously operating, highly stable He-Ne laser is described in article [1], which also mentions the structure of its generator and cites the frequency composition of its radiation. Since the described laser is intended for metrological work, the stability of its frequency and wavelength are of particular interest.

No method as yet exists for measuring directly a laser frequency. Therefore, in cases when its absolute value is required, the radiated wavelengths are measured for the purpose. However, the precision in measuring wavelengths is limited, and for relative instability evaluations it is more convenient to use relative frequency measurements.

**Stability of the Radiated Frequency (Wavelength) of a Laser.** Let us examine the factors which affect the stability of a laser frequency characteristic and determine its value.

The length of the laser resonator in question [1] amounts to 500 mm. It is then possible to generate up to five modes within the range of the Ne amplification curve Doppler spread. By selecting the operating conditions it is possible to excite one of the modes which is nearest to the maximum of the amplification curve. In such a case a stable generation of a single mode is possible in the range of

\[ \Delta \lambda = \frac{\lambda_1}{2n_l} = 3.7 \times 10^{-4} \text{ nm}, \]

where \( n_l \) is the resonator's optical length, \( \lambda_1 \) is the laser radiation wavelength.

The corresponding instability range of a single-mode generator under normal operating conditions is

\[ \frac{\Delta \lambda_1}{\lambda_1} = \pm 6 \times 10^{-7}. \]

However, it will be shown below that in fact the stability of a laser can be better.

The stability of a laser radiation frequency (wavelength) in a general case can be represented [2] by the expression

\[ \frac{\Delta \lambda}{\lambda} = \frac{\Delta \nu}{\nu} = \frac{\Delta d}{d} + \frac{\Delta n}{n} + \frac{\Delta \mu}{\mu}, \]

where \( \mu \) is the refractive index of the amplifying medium, \( d \) is the resonator length, \( n \) is the refractive index over the Brewster "mirror-window" section.

The optical resonator has the largest effect on frequency stability. Its natural wavelength \( \lambda_t \) depends to a great extent on geometrical dimensions [3];

\[ \frac{\Delta \lambda_t}{\lambda_t} \approx \tau \frac{\Delta d}{d}. \]

where \( \tau \) is the measurement time.

Investigations have shown that changes in the resonator length are mainly due to temperature variations. Therefore, (2) can be represented as

\[ \frac{\Delta \lambda_t}{\lambda_t} \approx \nu \alpha \frac{dT}{dt}, \]

where $\alpha$ is the linear expansion coefficient of the resonator, $dT/dt$ is the temperature gradient.

Under normal laboratory conditions in a stable state we find that

$$\frac{\Delta \lambda_r}{\lambda_r} \approx \pm 1.6 \cdot 10^{-6}. $$

The value thus obtained virtually characterizes the instability of a laser wavelength due to variations of the resonator's geometrical dimensions.

The laser radiation wavelength instability due to changes in the refractive index depends on the temperature, pressure and humidity of air in the resonator [3]:

$$\frac{\Delta \lambda_{n_T}}{\lambda_r} = q \beta_T \left(\frac{dT}{dt}\right) \approx \pm 0.7 \cdot 10^{-8},$$

$$\frac{\Delta \lambda_{n_P}}{\lambda_r} = q \beta_P \left(\frac{dP}{dt}\right) \approx \pm 6.8 \cdot 10^{-10},$$

(4)

$$\frac{\Delta \lambda_{n_h}}{\lambda_r} = q \beta_h \left(\frac{dh}{dt}\right) \approx \pm 5.0 \cdot 10^{-10},$$

where $q$ is the relative size of the Brewster "mirror-window" air gap; $\beta_T$, $\beta_P$, and $\beta_h$ are respectively the air temperature, pressure, and humidity variation factors in the resonator under normal laboratory conditions.

It will be seen that in the worst case the laser radiation wavelength instability does not exceed $\pm 10^{-8} \lambda_r$.

The refractive index is also affected by changes in the position angle of the Brewster windows (due to variations in the volume of glass). Calculations have shown that for the laser structure under consideration the instability of its radiation wavelength due to this parameter does not exceed $\pm 10^{-8}$.

Let us note that the laser design provides for a reduction of the external media effects on the refractive index (a careful isolation of the air gap between the mirror and the Brewster output window, covering the exit pupil with an objective, a protective partition behind the output glass window, mounting of all the generator components inside the quartz tube).

The nature of the amplifying medium refractive index effect on the stability of the radiation wavelength has not been sufficiently studied, and the corresponding wavelength instability is estimated at $\sim 10^{-8}$ [4]. Variations in the pressure of the He-Ne mixture over a wide range have not produced changes in the radiation wavelength exceeding the resolution of a 150 mm long Fabry-Perot reference standard which was used in our measurements. This leads to the assumption that the instability of the radiation wavelength due to the refractive index of the amplifying medium could hardly exceed $1 \cdot 10^{-8}$.

In summing up the instability of the radiation wavelength (1) for the most unfavorable case we obtain a value not exceeding $1 \cdot 10^{-7}$ for 10 min. By adding up all the above wavelength instabilities, we obtain a maximum total instability of $\Delta \lambda_r/\lambda \approx 10^{-7}$. Thus, the laser in question can operate in the TEM$_{00}$ mode for 20-30 min, changing subsequently to the next basic mode.