Researches of certain characteristics of spectrum analyser of optical range based on acoustooptic tunable filter

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ABSTRACT / KEYWORDS

We study the dependencies of basic characteristics of optical ranging spectrum analyzer (SA), based on acoustooptic tunable filter (AOTF) from the form and parameters of control signal and the influence of register on the basic characteristics of such analyzer.

Spectral analyzer, spectrum spread function, acoustooptic, control signal, tunable filter.

INTRODUCTION

Spectral analyzers based on AOTF [Ref.1] have some advantages as against classical SA of optical range (grating, prism). These advantages are the fast variation possibility of basic characteristics of SA, the convenience of spectrometric information reading-out by variation of electrical control signal form and parameters.

It is the electric variation of SA parameters that saves from necessity of complex mechanical units application. Due to mentioned advantages SA based on AOTF they are used widely to solve many problems. Today the various aspects of theory and practice are studied but whole series of important theoretical aspects is not investigated including basic metrological characteristics.

The complex spectrum spread function $K(\cdot)$; the analyzing frequency range $(\omega_0 - \Delta\omega, \omega_0 + \Delta\omega)$; time duration T_a; tunable time of control signal needed to measuring of optical spectrum in the analyzing frequency range T_s; the resolution of SA optical part and electric part (the register) are the basic metrological characteristics of optical ranging SA based on AOTF.

The time duration is the time of optical signal spectrum measuring by optical part of SA that is determined by the following parameters of optical system: focal dimension of lens, dimension of aperture and the frequency of monochromatic optical radiation.

The specific character of optical radiation spectral measures by SA based on AOTF conditions the introduction of two temporal characteristics in comparison with other spectral analyzers.

These characteristics are studied with two forms of control signals: linear frequency modulating (LFM) and step frequency modulating (SFM), in addition there are the standard assumptions of linear regime acoustooptic interaction analyzing.

OPTICAL FIELD IN OUTPUT PLANE OF SA WITH LFM CONTROL SIGNAL

The optical field onto output plane of SA with LFM control signal is described by the expression [Refs.2,3]:

$$\dot{f}_4(x_2, \lambda, \lambda') = \int_{-L}^{L} e^{i[x^2\gamma_0 - 2xx_2\gamma_1]} dx +$$

$$+ \alpha e^{-i\left[\Omega t + \frac{Mt^2}{2}\right]} \int_{-L}^{L} e^{i\left[x\left\{\frac{Mt}{V} - 2x_2\gamma_1 + \frac{\Omega}{V}\right\} + x^2\left\{\gamma_0 - \frac{M}{2V^2}\right\}\right]} dx \quad , (1)$$

Where *2L* is aperture dimensional of the acoustooptic modulator, x_2 is cartesian coordinate of the point photo detector onto output plane, α is constant, ω' is circular frequency of optical radiation, Ω is initial circular frequency of electrical control signal, M is variation velocity of control signal instantaneous frequency, V is the velocity of acoustic waves propagation in the material of acoustooptic modulator, t is running time, $\gamma_1 = k/2F$, k is wave number of optical radiation, $\gamma_0 = \gamma_1 - \gamma_1^2/\gamma_2$, $\gamma_2 = k/2(F \pm \Delta F)$, ΔF is the shift of SA output plane relatively focal plane of optical system.

In Eq. (1) the first component describes the zero diffraction order; the second summand is complex spectrum spread function of SA.

The expression of complex spectrum spread function is considered in two cases: the output plane coincides with focal plane of optical system and this one has parallel shift ΔF. It the latest case the square phase term does not influence if $\Delta F = -MF^2(kV^2)^{-1}$ and the squared complex spectrum spread function module is given by:

$$K(x_2, \omega, \omega') = L^2 Sinc^2\left(\left[\frac{Mt}{V} - 2x_2\frac{\pi\omega}{Fc} + \frac{\Omega}{V}\right]\frac{L}{2}\right). \quad (2)$$

The normed function graph (2) has the following form for the initial data: $2L = 50мм$, $M = 2.28 \cdot 10^{13}\ рад/c^2$, $V = 3.63 \cdot 10^3\ м/c$, $F = 50мм$, $\Omega = 314 \cdot 10^6\ рад/c$

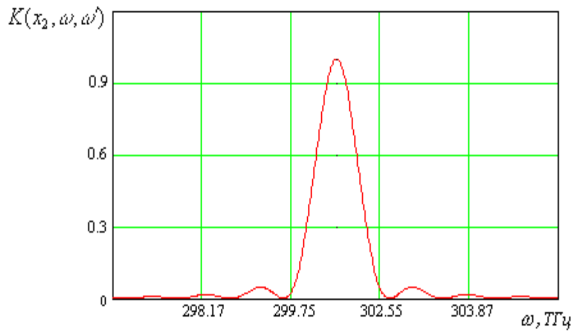

Fig. 1

From Eq. (2) it follows that the variation velocity increasing of control signal M instantaneous frequency leads to the decreasing of spectrum spread function width and increasing analyzing velocity of frequency range. The resolution of SA does not change and increasing the analyzing velocity of frequency range is limited by the overlay of zero diffraction order on the first one. The fig.2 shows the level of the zero diffraction order in the coordinate of the first diffraction order.

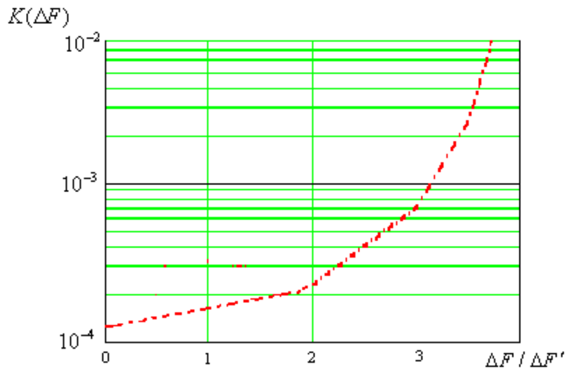

Fig. 2

In the figure 2 the graphic is calculated for case: $x_2 = 0.872\,мм$, $\alpha = 10^{-3}$, $\Delta a' = 0{,}436\,KK$ - the drift of the device regarding lens focus in the output plane with frequency deviation in the aperture of acoustooptic modulator $\Delta V = 50\,T\,s\,L$

When the output plane coincides with the focal plane of the optical system, it is only possible to decrease the influence of phase square component by decreasing of value M.

Spectrum spread function diagram was represented at the fig. 3 for the case $x_2 = 0.872\,мм$, $\alpha = 10^{-3}$, $\Delta V = 50\,T\,s\,L$, $M = 2.28 \cdot 10^{13}\ рад/c^2$

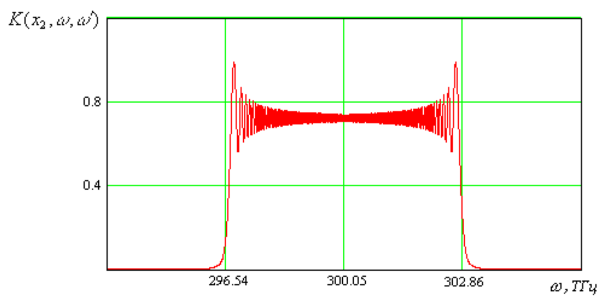

Fig.3

When $M \to 0$, the spectrum spread function (fig.3) approaches to the form shown in fig.1. In this case analyzing time is essentially increased.

THE OPTICAL FIELD ONTO OUTPUT PLANE OF SA WITH SFM CONTROL SIGNAL

The law of instantaneous frequency variation is shown in fig.4 with SFM control signal.

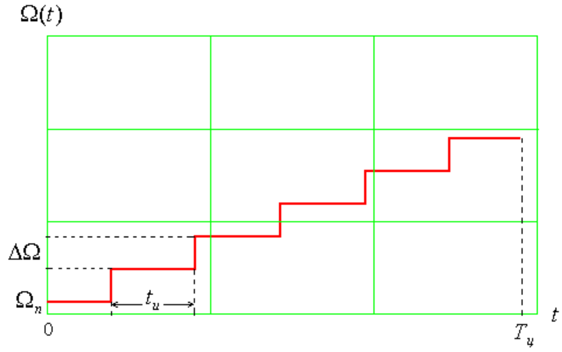

Fig.4

The following designations are used at the fig. 4:
t_u is elementary impulse duration of SFM electrical control signal, when its instantaneous frequency is constant; $\Delta\Omega$ is the difference of the circular frequencies in the enjoining impulses of SFM control signal; Ω_n is the circular frequency of the first impulse of control signal; $T_ц$ is time needed for spectrum measuring in the total range of analyses frequencies.

The expression of optical field was obtained onto output plane of SA in the papers [Refs. 2, 3]. The investigation of SA operation is considered for one value of frequency with SFM control signal, and at the condition $t_u \Delta\omega / 2\pi >>> 1$. The operation of SA is similarly to the action of diffraction SA in the time duration t_u where grating is replaced by acoustooptic modulator [Ref. 4].

In this case we have the diffraction of monochromatic optical radiation on the harmonic acoustic wave. Optical field distribution is given by the following expression in the output plane [Ref. 5].

$$K(x_2, \omega, \omega') = B \cdot Sinc^2\left(\left[\frac{\Omega}{V} - \frac{x_2 \omega'}{c \cdot F}\right] L\right). \quad (3)$$

There is the electrical signal in the SA output of ideal electrical unit including square point photo detector and temporal integrator. This signal is proportional to the power spectrum value of optical radiation of according frequency and photo detector coordinate onto output plane:

$$G(\omega) = \int_{-\frac{t_u}{2}}^{\frac{t_u}{2}} dt \int_{\omega_0-\Delta\omega}^{\omega_0+\Delta\omega} Sinc[(\omega-\omega')T_a] S(\omega') \exp(-i\omega' t) d\omega' \times \quad (4)$$

$$\times \int_{\omega_0-\Delta\omega}^{\omega_0+\Delta\omega} Sinc[(\omega-\omega'')T_a] S^*(\omega'') \exp(i\omega'' t) d\omega''$$

where $\partial_M = pa_2 / мc$ is time analyzing duration of optical signal for this optical system $\partial_M << u_u$, $S(\omega)$ is complex spectrum of input optical radiation, $G(\omega)$ is the power frequency distribution onto SA output plane. The expression (4) is formed as [Ref. 6]:

$$x\ (\omega) = \int_{\omega_0-\Delta\omega}^{\omega_0+\Delta\omega} \left| LЋc\ [(\omega - \omega')\partial_V] \right|^2 \left| L(\omega') \right|^2 t\ \omega' . \quad (5)$$

The kernel of integral operator (5) is represented by series according to sampling theorem, in the form:

$$LЋc^2[(\omega-\omega')\partial_V] = LЋc[(\omega-\omega')u_u] + \\ + \sum_{c=\infty, c\neq 0}^{\infty} S(c\Delta\Omega) LЋc[((\omega - c\Delta\Omega)-\omega')u_u]' \quad (6)$$

and by substituting it in Eq. (5) we obtain:

$$x\ (\omega) = \int_{\omega_0-\Delta\omega}^{\omega_0+\Delta\omega} LЋc\ [(\omega - \omega')u_u] \left| L(\omega') \right|^2 t\ \omega' + \\ + \int_{\omega_0-\Delta\omega}^{\omega_0+\Delta\omega} i\ (\omega, \omega') \left| L(\omega') \right|^2 t\ \omega' \quad . \ (7)$$

When $\Delta\omega$ is very large the kernel of the first summand becomes reproducing in expression (7), that the first integral determines power spectrum of optical signal with duration t_u, the second summand is the measuring error of power spectrum or bias of estimation.
It is follows from Eq. (6) that this bias of estimation can be quite essentially because it is determines by infinite number of summands whereas the first integral consists of the alone summand.
Fig.5 shows the expansion in series (6) according to sampling theorem.

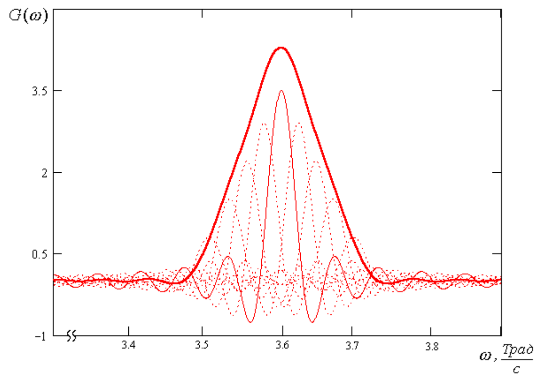

Fig. 5

In the fig.5 the continuous heavy line shows the power spectrum spread function (square module of complex spectrum spread function) of “the real SA in the ideal performance ”, the continuous thin line shows the reproducing kernel which provides undistorted measurement of optical radiation power spectrum during the time u_u, another lines (dashed) contribute in bias of estimation of power spectrum which can be very large.

CONCLUSION

The basic results of made researches conclude in the following. It is establishes physical limitation of the increasing of analyzing velocity of analyzed frequency range with LFM control signal caused by influence of the first diffraction order. It is shown that the estimation of power spectrum of optical radiation is shifted even in the case if SA consists of ideal elements. Where this shift can be quite essentially.

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