UDC 621.378.525: 535.8 (045)

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A NEW PATTERN OF DEVELOPMENT OF THE DOPPLER EFFECT IN A COHERENT GEOMETRY OF THE MULTI-WAVE SENSING AND RECEIVING LASER RADIATION

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Abstract—*New patterns of display of transversal of Doppler effect in nonrelativistic case at the multi-wave concerted sounding and reception of electromagnetic emission, sent to the quadratic detector is proposed.*

Index Terms—Multi-wave Doppler laser locator; quadratic detector; electromagnetic emission.

I. Introduction

Our researches allowed to set new patterns of display of transversal of Doppler effect in nonrelativistic case at the multi-wave concerted sounding and reception of EM emission, sent to the quadratic detector (QD). On this basis we are develop the methods of multi-wave Doppler laser locator (MDLL). The distinctive feature of the offered methods of MDLL is independence of frequency of Doppler signal on the output of QD from a wave-length the emission accepted EM.

II. Main Result

Let a moving object (for example, microparticles) the size of which compare with a wave-length EM emissions move at a speed of $\overline{V}$ through the sounding area (SA).

In a differential method MDLL (Fig. 1) a sounding area is formed with a help of "*n*"-numbers of pair of coherent beams on lengths of waves $\lambda_1,\lambda_2 \ldots \lambda_n$ with the change of frequency of one of beams of pair on a wave-length λ_i on the fixed size Ω_M which intersect in SA under the concerted angles γ_1, $\gamma_2 \ldots$ λ_n thus n-numbers lie in one plane (for example, in horizontal plane – *OXZ*) and bisectrices of angles γ_i (i = 1, 2, 3, …, n) all pair of beams coincide in space. The emission dissipated on the moving particle of EM going in a large angular aperture and heads for a quadratic detector.

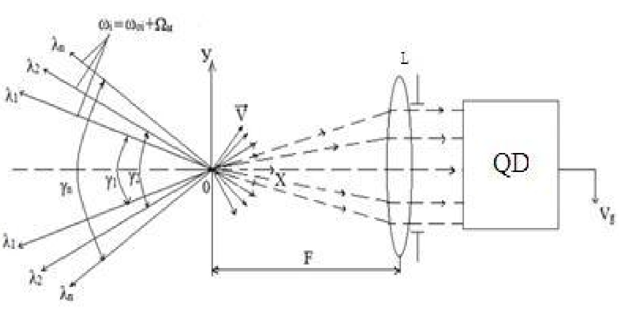

Fig. 1. Differential method MDLL

Expressions, allowing to expect the parameters of differential method of MDLL at which frequency of doppler signal on the output of QD does not depend on a wave-length EM emissions and receive-directions

$$\gamma_i = 2\arcsin\left(\frac{\lambda_i}{\lambda_1}\sin\frac{\gamma_1}{2}\right),$$

where $i = 2, 3, \ldots, n$.

This frequency is determined only the projection of vector of speed on the difference wave vector of soundings pair of beams (for example, ichnography *Vx* if bisectrices of angles of all γ_i coincide with the axis of *OZ*). The doppler signal on the output of QD is superposition of *n*-number signals of one frequency, each of which is formed at a reception EM emission on length of wave λ_i

$$U_g = \sum_{i=1}^{n} U_{mg} \cos\left(\Omega_M + \omega_{gi} t\right) - \Phi\lambda_i - \Phi_{gi};$$

$$\omega_{g1} = \omega_{g2} = \ldots = \frac{4\pi}{\lambda_1}\sin\frac{Y_1}{\lambda_1}V_x;$$

$$\Phi_{\lambda_1} = \Phi_{\lambda_2} = \ldots = \Phi_{\lambda_n},$$

where $\Phi_{\lambda 1}$ is component of phase of doppler signal, determined arrival of particle time in the area of measuring, formed crossing of beams on a wave-length λ_i ; Φ_{gi} is component of phase of signal, determined the effects of dispersion ($\Phi_{gi} = 0$, or $\Phi_{gi} = 180°$ at the use of forming technologies phase the attended doppler signals [5]).

In an inversion-differential method MDLL a sounding area is formed one narrowly directed sounding bunch (axis *OZ*) which consist of superposition of *n* is number of beams on lengths of waves λ_i which have flat wave fronts of EM emissions. Emission dissipated on a moving particle for every wave-length λ_i going in two receive-directions from angles between them equal β_i (for example, in *OXZ*) and after spatial overlay of their wave vectors in an interferometer (IF) further goes on QD (Fig. 2).

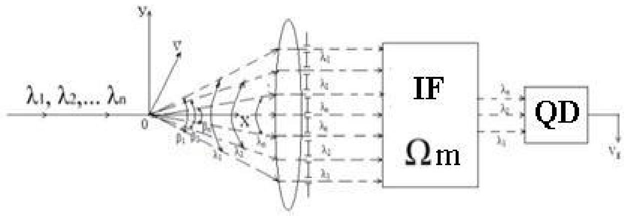

Fig. 2. After spatial overlay of wave vectors in an interferometer (IF) further goes on QD

Bisectors of the angles β_i lie in the plane *OXZ* and coincide with each other (for example, axis *OZ*). Expressions allow calculation of parameters inversely differential method MDLL, in which the frequency of the doppler signal at the output of the QD does not depend on the wavelength and direction sounding, as determined solely by the projection of the velocity vector on the wave vector difference of the two scattered beams at the appropriate wavelength λ_i

$$\beta_i = 2\arcsin\left(\frac{\lambda_i}{\lambda_1}\sin\frac{\beta_i}{2}\right);$$

$$\omega_{gi} = \omega_{g2} = \ldots = \omega_{gn} = \frac{4\pi}{\lambda_1}\sin\frac{\beta_i}{2}V_x.$$

In MDLL method that implements four-wave mixing mode overlapping electromagnetic EM emission sensitive layer on the surface of the QD, sounding area is formed by two intersecting beams under angle γ each of which is a superposition of n-number of beams of EM emission at wavelengths λ_i=(i=1,2…n) Moreover, one of these beams passed a delay line therefore SA crosses pair of beams at a wavelength of mutually no coherent. Overlayed pairs of beams at each wavelength λ_i collected in two symmetrical directions angled β_i (for example, in the plane *OXZ*). Bisectrices of these angles β_i each pair of beams at wavelengths λ_1, λ_2, …, λ_n coincide (for example with the axis *OZ*). Further, all the pairs of beams for each wavelength λ_i spatially combined in interferometer and sent to the surface of the QD. Thus one of each pair of beams at a wavelength for QD before mixing takes place also delay line. The delay time is selected from the conditions for ensuring the coherent overlay mode. As a result, the QD is formed at the output the useful Doppler signal, while the HF crosstalk is suppressed. Expressions allow calculation of geometry parameters agreed MDLL sounding and reception at which the doppler signal has a frequency independent of the wavelength of EM emission.

$$\beta_i = 2\arcsin\left[\frac{\lambda_i}{\lambda_1}\sin\frac{\beta_i}{2} + \left(\frac{\lambda_1-\lambda_i}{\lambda_1}\right)\sin\frac{\gamma}{2}\right];$$

$$\omega_{g1} = \omega_{g2} = \ldots = \omega_{gn} = \frac{8\pi}{\lambda_1}\left[\cos\left(\frac{\gamma+\beta_i}{4}\right)\sin\left(\frac{\gamma+\beta_i}{4}\right)\right]V_x.$$

For example, consider this method for optical range EM emission wavelengths using an argon laser which emit at three different wavelengths.

Multiwavelength laser doppler anemometer (MLDA) includes (Fig. 3): multiwave laser 1, which emits a beam 2 at three wavelengths λ_1, λ_2 and λ_3 (for example, argon laser), multiwave beam splitter 3 which divides the beam 2 into two beams 4 and 5 of equal intensity at each of wavelengths of emission λ_1, λ_2 and λ_3 frequency shifter 6 a high-frequency generator 7, mirror 8, a delay line 9, aperture diaphragm 10 with eight circular holes, focusing lens 11, measurement area 12, where two beams 4 and 5 intersect at the focus of the lens 11 under the angle γ scattered beams 13, 14,15,16,17 and 18, selective mirror 19 for the wavelength λ_3 selective mirror 20 for the wavelength λ_2 selective mirror 21 for the wavelength λ_1 delay lines 22, 23 and 24, multiwave composite mixer 25 for the wavelengths λ_1, λ_2 and λ_3 diaphragm 26 with six holes line of six interference filters 27 for the wavelengths λ_1, λ_2 and λ_3 photodetector 28, meter of doppler frequency 29, block of the formation of two parallel beams 34, which comprises optical elements and devices 3,6 and 8; an optical time delay device 35 which comprises: 9, 19, 20, 21, 22, 23, 24, 30 and 31; sensor 36 which comprises: 10 and 11; receiving block 37 which comprises: 25, 26, 27 and 28.

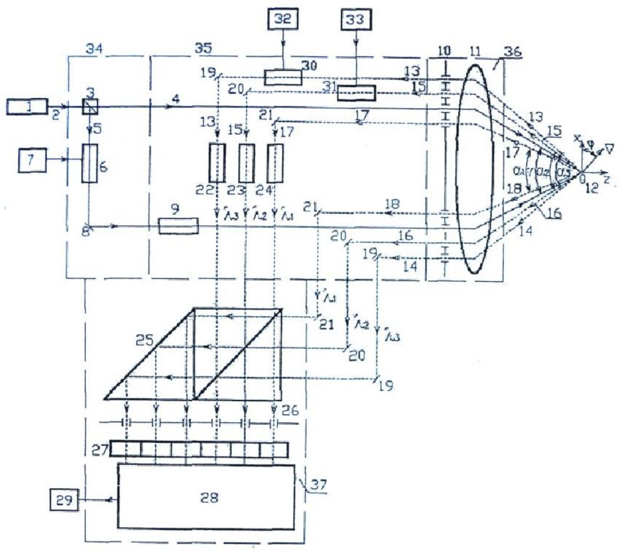

Fig. 3.Multiwavelength laser doppler anemometer (MLDA)

Multiwavelength laser doppler anemometer works as follows. Laser 1 emit a beam 2 on three powerful lengths of waves λ_1, λ_2 and λ_3 which divided a beam splitter 3 on two beams of equal intensity 4 and 5. That is why power of beam 4: $P_4=P_{\lambda1}+P_{\lambda2}+P_{\lambda3}$ equals power of beam 5: $P_5=P_{\lambda1}+P_{\lambda2}+P_{\lambda3}$, where $P_{\lambda i}$ is power of emission on wavelength (i = 1, 2, 3). After passing of frequency moving device beam 6 displaced on fixed size frequency Ω_M and then reflected from a mirror 8 and spreads like beam 4 parallel and symmetric in relation to the optical axis of chart of *OZ*. Beams 4 and 5 have the consistent states of polarization. For example these beams are apeak polarized. Beams 4 and 5 after passing through two openings of diaphragm 10 focus an object 11 in the area of measuring 12 in which they intersect under an angle γ (Fig. 3). However, as beam 5 after passing through the delay line 9 delayed time relative to the beam 4 on a value $\tau_3>\tau_{ki}$ (τ_{ki} - the maximum time coherence of the emission corresponding to the wavelength of λ_i, an interference picture is not formed in the area of measuring. At passing through the area of measuring 12 (for example, current of air) the emission dissipated on microparticless is in directions 13 and 14, 15 and 16, 17 and 18 which are symmetrical about the axis *OZ*, going a lens 11 within the limits of the small round openings of aperture diaphragm 10 which is located in the focal plane of the lens 11.

Scattered beams 13 and 15 after passing the relevant photoregulation 30 and 31 and reflections from selective mirrors 19 and 20 on the wavelengths λ_1, λ_2 passing delay lines 22 and 23 and sent to the first output of compound mixer 25. On the same input of the mixer is directed beam 17 after reflection from selective mirrors 21 at the wavelength of λ_2 and going through the delay line 24. Scattered beams 14, 16 and 18, after passing the relevant lines delays 22, 23 and 25, are going for the second entrance of mixer 25 (on Fig. 1 on the way beams 14, 16 and 18 shows mirrors 19, 20 and 21 setting of which in the chart of MLDA does not have an of principle value).

Time delay beams 13- $\tau_{\lambda1}$; 15- $\tau_{\lambda1}$; 17- $\tau_{\lambda1}$ created with the help delay lines 22, 23 and 24, choose that at the optical mixing of pair of beams : 13-14; 15-16; 17-18, for these pair there is the module of degree of temporal coherent $\left|\gamma_{\lambda_1}(\tau_3)\right|=1$.

On the output of mixer 25 six beams are formed and proper wavelengths: λ_1, λ_2, λ_3, λ_1, λ_2 and λ_3 which pass through six openings of diaphragm 26 and line from six interference color filters accordingly on wavelengths λ_1, λ_2, λ_3, λ_1, λ_2 and λ_3 and further sent on a photocathode of photodetector 28. On the output of photodetector 28 three useful high-quality signals are formed and correspond the optical mixing of the dissipated beams on wavelengths. λ_1, λ_2, λ_3 on doppler frequency

$$\omega_{gi}=\Omega_M+\frac{8\pi}{\lambda_i}\left(\cos\left(\frac{\lambda+\alpha_i}{4}\right)\sin\left(\frac{\lambda+\alpha_i}{4}\right)\right)V_x,$$

where α_i is the angle between the scattered beams (i = 1, 2, 3) on wavelength λ_1; V_x is the horizontal projection of the velocity vector $\bar{\mathbf{V}}$.

These three signals coincide on frequency ω_{g1} = = ω_{g2} = … = ω_{gn} and added. If the geometry of the probing and scattered beams is the following relation

$$\alpha_i=2\arcsin\left[\frac{\lambda_i}{\lambda_1}\sin\frac{\alpha_1}{2}+\left(\frac{\lambda_1-\lambda_i}{\lambda_1}\right)\sin\frac{\gamma}{2}\right],$$

where: $\lambda_1>\lambda_2>\lambda_3$ and i = 2, 3.

Three useful signal on one frequency ω_g , specific parameters of the optical scheme of MLDA may have different phase. Therefore for increasing power total useful signal on frequency ω_g, it is necessary to provide the phase concordance of these three signals also [4].

Equiphase condition of these three signals is ensured with the photoregulator 30 and 31. On the output of photodetector 2 also can be formed high-frequency signals-interference, accordingly 5 signals-interference for each of wavelengths λ_1, λ_2, λ_3.

However, for a scheme of MLDA (Fig. 3) these 15 signal-interference automatically suppressed because of these signals module complete the degree of temporal coherence equal zero.

SUMMARY

Developed previously unknown regularity of the independence of the Doppler frequency signal when the multi-wave EM matched sensing and receiving scattered radiation from a moving object for the following geometries sensing and reception, namely, that:

– upon irradiation of a moving object pairs coherent electromagnetic beams at wavelengths λ_1, λ_2, …, λ_n , intersecting corresponding under the terminated corners γ_1, γ_2, …, γ_n , the value which is the equation:

$$\gamma_i=2\arcsin\left(\frac{\lambda_i}{\lambda_1}\sin\frac{\gamma_1}{2}\right),$$

where i = 2, 3, …, n, occurs equality differential wave vectors of the two sensing EM beams at each i-th wavelength and their spatial coincidence with the same directionality;

– upon irradiation of a moving object in one by the probing beam at wavelengths λ_1, λ_2, …, λ_n and reception of the scattered electromagnetic radiation in two directions at angles $\alpha_1, \alpha_2, \ldots, \alpha_n$, accordingly, for each of the wavelengths, the values of which are consistent with each other equate:

$$\alpha_i = 2\arcsin\left(\frac{\lambda_i}{\lambda_1}\sin\frac{\alpha_1}{2}\right),$$

where $i = 2, 3, \ldots, n$, occurs equality differential wave vectors of the two scattered beams at each i th wavelength and their spatial coincidence with the same directionality;

– upon irradiation of a moving object pairs by coherent beams at wavelengths $\lambda_1, \lambda_2, \ldots, \lambda_n$, intersecting corresponding under the terminated corners $\gamma_1, \gamma_2, \ldots, \gamma_n$ and reception of the scattered radiation at wavelengths $\lambda_1, \lambda_2, \ldots, \lambda_n$ in two directions at an angle β when the terminated value of the angle sensing γ_i and receive β, determined from the equation:

$$\gamma_i = 2\arcsin\left[\left(\frac{\lambda_i}{\lambda_1}\right)\sin\frac{\gamma_1}{2} + \left(\frac{\lambda_1-\lambda_i}{\lambda_1}\right)\sin\frac{\beta}{2}\right],$$

where $i = 2, 3, \ldots, n$, occurs equality difference between two spatially coincident vectors $\overline{K_{1l}}\ \overline{K_{sl}}$ for each of the wavelengths of EM radiation, where $\overline{K_{1l}}$ – differential wave vector of the two sensing beams at a wavelength λ_i spatially coincident and overlay in direction with the vector $\overline{K_{1j}}$ at a wavelength λ_j; vector $\overline{K_{sl}}$ – differential wave vector of the two scattered beams at a wavelength of λ_i, spatially coincident and overlay in direction with the vector $\overline{K_{sj}}$ at a wavelength λ_j;

– upon irradiation of a moving object pairs of coherent beams at wavelengths $\lambda_1, \lambda_2, \ldots, \lambda_n$, intersecting at terminated angles $\gamma_1, \gamma_2, \ldots, \gamma_n$ and receiving scattered radiation at wavelengths $\lambda_1, \lambda_2, \ldots, \lambda_n$ in two directions at an angle β when the matched value of the angle sensing γ_i and receive β, determined from the equation:

$$\gamma_i = 2\arcsin\left[\left(\frac{\lambda_i}{\lambda_1}\right)\sin\frac{\gamma_1}{2} + \left(\frac{\lambda_1-\lambda_i}{\lambda_1}\right)\sin\frac{\beta}{2}\right],$$

occurs equality of the sum mentioned above, a two-dimensional combined vectors $\overline{\mathbf{K}_{1l}} + \overline{\mathbf{K}_{sl}}$ for each of the wavelengths of EM radiation;

– upon irradiation of a moving object in two sensing beams at wavelengths $\lambda_1, \lambda_2, \ldots, \lambda_n$, intersecting at an angle γ and receiving scattered electromagnetic radiation in two directions at angles $\beta_1, \beta_2, \ldots, \beta_n$, accordingly, for each of the wavelengths, at a terminated angle sensing γ and angles of reception β_i, determined from the equation:

$$\beta_i = 2\arcsin\left[\left(\frac{\lambda_i}{\lambda_1}\right)\sin\frac{\beta_1}{2} + \left(\frac{\lambda_1-\lambda_i}{\lambda_1}\right)\sin\frac{\gamma}{2}\right],$$

where $i = 2, 3, \ldots, n$, occurs equality difference between two spatially coincident vectors $\overline{K_{1l}} - \overline{K_{sl}}$ for each of the wavelengths of EM radiation, where $\overline{K_{1l}}$ – differential wave vector of the two sensing beams at a wavelength λ_i, which intersect at an angle γ for each wavelength, spatially coincident and coincident in direction with the vector $\overline{K_{1j}}$ at a wavelength λ_j; $\overline{K_{sl}}$ – differential wave vector of the two scattered beams at a wavelength λ_i, spatially coincident and overlay in direction with the vector $\overline{K_{sj}}$ at a wavelength λ_j;

– upon irradiation of a moving object in two probing beams at wavelengths $\lambda_1, \lambda_2, \ldots, \lambda_n$, intersecting at an angle γ and receiving scattered electromagnetic radiation in two directions at angles $\beta_1, \beta_2, \ldots, \beta_n$, accordingly, for each of the wavelengths, at a consistent angle sensing γ and angles of reception β_i, determined from the equation:

$$\beta_i = 2\arcsin\left[\left(\frac{\lambda_i}{\lambda_1}\right)\sin\frac{\beta_1}{2} + \left(\frac{\lambda_1-\lambda_i}{\lambda_1}\right)\sin\frac{\gamma}{2}\right],$$

occurs equality of the sum of the above two spatially coincident vectors $\overline{K_{1l}} + \overline{K_{sl}}$ for each of the wavelengths of EM radiation.

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Received 18 October 2014.

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В. М. Землянський, М. О. Гусєв. Нова закономірність прояву допплерівського ефекту при когерентному багатохвильовому узгодженому зондуванні та прийомі лазерного випромінювання

Запропоновані нові закономірності виявлення допплерівського ефекту при багатохвильовому узгодженому зондуванні і прийомі електромагнітного випромінювання на квадратичному детекторі.

Ключові слова: багатохвильовий допплерівський лазерний локатор; квадратичний детектор; електромагнітне випромінювання.

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В. М. Землянский, М. О. Гусев. Новая закономерность проявления допплеровского эффекта при когерентном многоволновом зондировании и приеме лазерного излучения

Предложены новые закономерности выявления доплеровского эффекта при многоволновом согласованном зондировании и приёме электромагнитного излучения на квадратическом детекторе.

Ключевые слова: многоволновой доплеровский лазерный локатор; квадратичный детектор; электромагнитное излучение.

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