THE REFERANCE RANGE FINDER BASED ON THE FEMTOSECOND LASER FOR THE LENGTH MEASUREMENT IN THE RAGE UP TO 60 M. DESIGN AND APPLIOCATION.

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The paper presents the purposes and objectives, the description of the operating principal and construction, results of metrological research, the details of the practical relevance of the research work on the range finder construction based on the femtosecond laser for the length reproduction in the rage up to 60 m

Research and development of the distant measuring systems using the femtosecond lasers are carried out in different laboratories of the world. This is due to the fact that the femtosecond oscillators of an optical frequency comb was discovered in 1999. They have measuring properties when a repetition frequency of the femtosecond pulses by a phase depends on a phase of a frequency standard.

One of the first works of Japanize specialists from NRLM (Tokyo) described the measurements of 240-m distance with the accuracy of 50 μm in an optical tunnel using a stabilized femtosecond laser.

In 2004, Jun Ye from NIST in his theoretical paper offered the high length accuracy scheme in the range from some meters to 10^6 m in the Space with an accuracy of an interference fringe using a femtosecond laser [2].

In the paper of Japanese scientists on the distant measurement using a long wavelength heterodyne interferometer [3] as a source of femtosecond laser radiation a stabilized optical comb is used.

They have proven that the absolute distant measurement is possible by scanning the band and frequency shifts.

The femtosecond technologies for distant measurements are described in this paper. The purpose is to develop and study the reference range finder based on the femtosecond laser that is the base of the prototype stationary complexes for metrological assurance of measuring means of the length in the range up to 60 m. This primary measuring mean provides an independent realization and storing of a linear unit.

To achieve this goal the following tasks were solved:

1. The experimental confirmation for the application of the range finder based on the femtosecond laser pulse repetition of a frequency of 61 MHz and the metrical arm of 60 m for the reproduction of a meter as a length unit.
2. Development and validation of the structural and optical scheme of the range finder using mirror optics.
3. Development of the mirror telescopic system of the compact size.
4. Eliminating false remirror of a splitting cube.
5. Estimation of the systematic errors of the range finder based on the femtosecond laser.
6. Updating the method and scheme of the interference maximum registration of the coincidence of femtosecond pulses with a period of 250 cm, determined by frequency pulse repetition of a laser of about 61 MHz and that allowed to reach a high resolution:
   a) selection and justification of the type registration using spectral and temporal characteristics of the interference pattern;
   b) formulation and justification of the technical order to the developer of the radioelectronic equipment.
7. Conducting metrological research for determination of the reproducibility of a length unit using the reference-measuring complex of the length in the range up to 60 m.

<u>The description of the operating principle, construction and ongoing research.</u>

The paper presents the research and development results of the range finder based on the femtosecond laser stabilized by frequency pulse repetition from the rubidium frequency standard that is traceable to the State standard of time and frequency of GET 1-2012 using the direct comparison method for ensuring the traceability of the length unit to the State standard of time and frequency of GET 1-2012.

For reproducing the length unite in the range finder on the basis of the femtosecond laser the method based on the peak coincidence registration of the femtosecond pulses was applied. This method allows to generate a measuring scale unite equal to about 2.5 m. determined by the pulse frequency repetition of a laser equal to about 61 MHz. The pulse frequency repetition and hence the wavelength (a unit of a measuring scale) is in a radio band and it is measured with a standard method. When having the system of phase control of the frequency from the frequency of the external rubidium standard the traceability to the time and frequency standard for the measurements of the frequency pulse repetition and measuring scaling unit is provided.

The Michelson non equal-sized interferometer is the heart of the setting that realizes this method. One of the arms of interferometers is a basic and short one and the other is long and metrical.

The **Table 1** shows the scheme of the circuit set for the realization of the distance meter based on the femtosecond laser. The reflector no 4 moves along the measuring line by changing the path difference of waves between the arms of the interferometer and the acquisition equipment no 5 and detects the interference signals.

The internal phase modulation set no 3 allows periodically with a frequency of about 3 Hz to change the path difference of waves of the interferometer that is required to register the femtosecond pulse coincidence in the visual and digital signal processing.

The radiation source is a femtosecond laser no 1 on the wave length of 0.780 µm with the stabilization system of the frequency pulse repetition of 61 MHz. To obtain the high stability of the frequency pulse repetition the phase lock method on frequency from the external rubidium frequency standard that provides the traceability of the length unit from the State standard of time and frequency (GET 1-2012) using direct comparison method.

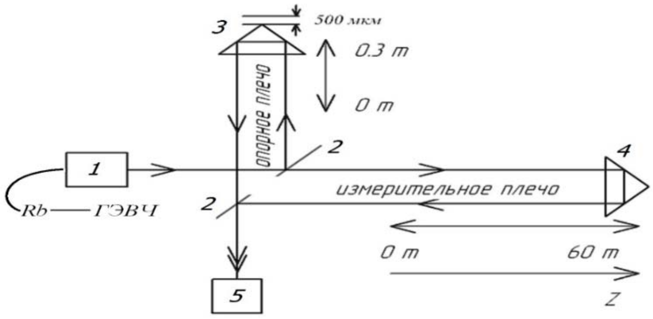

Table 1 – the principal scheme of the laser range finder:
stabilized femtosecond laser; 2 – splitting cubes; 3 – the set of the internal phase modulation (the amplitude ± 500 um) and hollow corner reflector; 4 – the hollow corner reflector; 5 – the equipment for reception of the laser radiation)

The laser beam no 1 passes through the mirror optical system and hits the mirror-lens collimating system and further the collimating laser beam through the pointing mirror hits the laser beam divider no 2.

Passing the splitting cube no 2 the beam is divided into two parts: the reference length of about 0.3 m (the corner reflector with internal phase modulation set no 3) and the signal one that propagates along the measuring line till the corner reflector no 4. Then it returns to the other beam-splitting cube no 2 and after reflection with the reference beam they hit the receiving part no 5 on which the interference signal is observed.

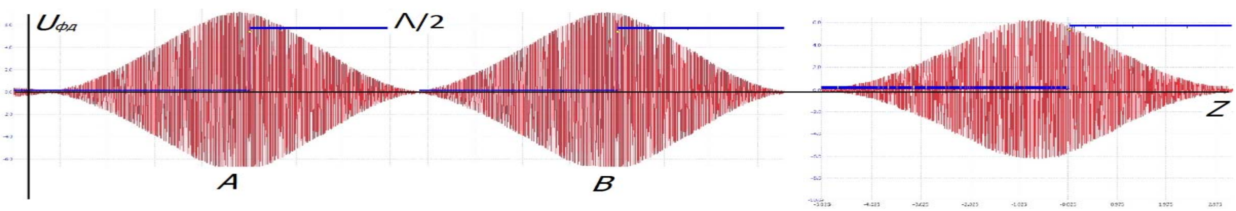

Table 2. The signal of the femtosecond pulse interference by moving the reflector-measuring arm.

The **Table 2** shows the interference signal of two combined in space laser beams based on the distance Z along the measuring line.

This is a result of operation of the internal phase modulation and the coincidence of the femtosecond pulses from the reference and measuring arm. The signal in points A, B … (A, B are fixed points) becomes of a maximum level at the coincidence of the femtosecond pulses. The distances between nearly points A, B … are of the same length and equal to:

$$|AB| = \frac{c}{2nF} = |BC| = |CD| = \ldots \quad (1)$$

where c – the electromagnetic constant,

n – the refractive index of a medium,

F – the repetition rate of the femtosecond pulses.

The parameter n is calculated according to the metrological parameters (temperature, pressure, humidity) and carbon dioxide using the Edlen`s formula with error of about $1*10^{-8}$.

The dependence no 1 is the basis for the above mentioned type of the range finder. Points A, B … on the axis Z, where the interference signal has the maximum value, are the fixed points. The representation of these points allows the scientist to develop the reference range finder for measuring the displacement of the physically limited of the long coherence length of the laser radiation and multiply to the unit of the measuring scale:

$$\frac{\Lambda}{2} = \frac{c}{2\,n\,F} \cong 250 \quad см$$

For receiving a signal carrying information about the magnitude and the direction of "tuning" of the position of a corner reflector from the nearest reference point, it is necessary to introduce a phase modulation of the interfering beams, for example, the reference arm of the interferometer.

This is achieved by bringing in an oscillatory motion with a frequency of about 3 Hz and with an amplitude of about 0.5 mm of the corner reflector of the reference arm by means of a precision mechanical system. By the application of this original method, the fixed-point setting is caring out at low modulation frequencies, which is incomparably simpler to implement than to use the known methods of recording of the phase difference of the beat signals of the reference and measuring beams equal to multimode frequency of the laser and form several hundred MHz.

On the installation that implements the above described method the experimental studies of stability of the "reference" node, sensitivity to length changes of the path difference of the waves of the interferometer of 2 m and 60 m, series of measurements of the length reproduction (Table 1) and a comparison of the uncertainty of the reproduced interval lengths with similar complexes of other countries (**Table 2**) were carried out.

Table 1. The results of measurements of the length reproduction

Node i	Time	Frequency pulse repetition, Hz	The average temperature in a distance, ºC	Pressure, Pa	Humidity, %	Calculated reference distance, Li^{culcul}, m	Amendment of reproduction of the reference distance ΔLi, mkm	Reproduction of length Li^{culcul}, m	Random error of reproduction $Si^{calcul,}$ mkm
1	2	3	4	5	6	7	8	9	10
0	14-20	61898868.084	20.75	100145	41.5	0	-0.1		0.58
1	14-51	61898868.084	20.75	100145	41.5	2.420.9742	-0.7	2.420.9735	0.91
10	15-08	61898889.540	20.65	100135	41.5	24.209.7324	0.3	24.209.7327	0.91
20	15-24	61898889.540	20.60	100130	41.5	48.419.4632	0.4	48.419.4636	1.09
25	15-40	61898889.540	20.55	100110	41.5	60.524.3294	1.7	60.524.3311	1.02

Table 2. The comparison of the uncertainty units of the reproduced interval length with the same complex of RTB

№	Country	Type of measuring means	Range	Item	Uncertainty	Item	Confidence limit
1	FSUE VNIIFTRI Russia	Laser interferometer	0…60	m	Q[1, 0.8L]. L in m	µm	95%
2	RTB, German	50 m Measuring line of the Laser interferometer	0…50	m	Q[13.4, 0.72L]. L in m	µm	95%
3	RTB, German	50 m Measuring line of the Laser interferometer	50…100	m	Q[41, 0.72 (L-50)]. L in m	µm	95%

Conclusions:

- The proposed pilot scheme of the distant meter based on the femtosecond laser confirmed the possibility of its application for reproducing the meter - unit of length;
- the proposed pilot scheme of the distant meter based on the femtosecond laser allows to achieve the error of the length reproduction of 60m not more than 10 µm, which corresponds to the level of similar complexes in other countries.

The range finder based on the femtosecond laser has become a basic element in the composition of the pilot length measuring complex in the rage up to 60 m. After the approval of the distance meter as the State primary special reference standard of the length, it will become the basic reference standard for ensuring the uniformity of measurements of measuring means of the long and extra-long length.

References:

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