LASER SYSTEM FOR REMOTE SENSING MONITORING OF AIR POLLUTION AND QUALITY CONTROL OF THE ATMOSPHERE

by

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Monitoring of the atmosphere and determination of the types and amounts of pollutants is becoming more important issue in complex and global monitoring of the environment. On the geocomponent and geocomplex level problem of monitoring the environment is attracting the attention of the scientific experts of different profiles (chemists, physicists, geographers, biologists, meteorologists), both in the national and international projects. Because of the general characteristics of the Earth's atmosphere (dynamically balanced instability) and the potential contribution to climate change solutions air-pollution monitoring has become particularly important field of environmental research. Control of aerosol distribution over Europe is enabled by EARLINET systems (European aerosol lidar NETwork). This paper is analyzing the first step in the study of air-pollution, which is consisted of the realization of a functional model of LIDAR remote sensing devices for the large particle pollutants.

Key words: *laser sensing, air pollution, environment, atmosphere*

Introduction

Need for continuous measurements of atmospheric aerosols is the result of their influence on many aspects of life, on the eco-systems in case of significant mass transport; on the chemistry of the atmosphere, as surface for chemical reactions, which lead to the reduction of the ozone layer; on the radiation balance and temperature distribution in the atmosphere. Along with greenhouse gases, aerosols play an important role in climate change. It is particularly significant their role in domain of health care – studies show that particles smaller than 10 μm, more precisely 2.5 μm, have an easy access into the respiratory organs and therefore can cause serious health problems. Their deposition in the oceans can lead to an algal bloom. Eruption of the volcano under the Eyjafjallajokull glacier (April 2010) has confirmed the great potential of aerosols' impact (including those of natural origin) on all spheres of life on Earth [1, 2].

Atmospheric aerosols play an important role in biogeochemical cycle of elements such as carbon, nitrogen and sulphur. Aerosols' lifespan and therefore their transport in the atmo-

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sphere (in different physical-geographical conditions, at different latitudes and altitudes, and on the basis of the general circulation of the atmosphere), depending on whether they are in the gas or corpuscular phase [3].

Atmospheric aerosols have an important role in the field of atmospheric discharges, in control of optical properties of the atmosphere, in maintaining radiation's equilibrium, in heat balance of the Earth-atmosphere system, in the overall process and (co)evolution of the ecosphere [1]. Their great impact on the elements (precipitation, insolation), and on climate in general, has been proven. In fact, atmospheric aerosols were condensation nuclei for the formation of cloud drops. Serbia is the most often exposed to impact of aerosols originating from North Africa or the Sahara's ergs (so-called "dirty rain and snow"). Geographical, meteorological, and other investigations have proved that the development of cyclones in the Mediterranean is a prerequisite for the transportation of aerosols from the Sahara to the South East and Central Europe, so as to Serbia.

Degree of aerosols' harmfulness depends of many characteristics: composition, origin, size and shape of particles, method of creation (dispersion or condensation). The period of its inhibition in the air also affects its hazard degree. For particles smaller than 10 μm retention period in the atmosphere is very long; thereby the perimeter of transport is being increased, so as possibility of their interactions and potential effects on natural and anthropogenic systems. Particles larger than 100 μm have relatively short emission time, because they are quickly being deposited, due to gravity, near the place of creation, and particles with diameter 10-100 μm have the characteristics of both above mentioned.

Positive correlation between the exploitation of fossil fuels and anthropogenic impacts on the state of the atmosphere is significant. By its spatial presence, trend of consumption growth and synergetic impact on the atmosphere and the environment in general, fuel oil has gained a special place during the 20th century. During last century, energy consumption has increased 300 times. Despite the significant modernization of the process of exploitation and transportation of crude-oil from exploitation fields to refineries, as well as its processing, fuel oil and its products are ubiquitous environmental pollutants. That is why the study of the petroleum pollutants' types' destiny in recent years has evolved into a separate scientific discipline. Surface waters, soil, and recent sediments are the most exposed to its pollution and due to strong interactions with air masses, atmosphere is also exposed to it to a large extent.

The coal combustion in thermal power plants leads to substantially greater solid particles emission to the atmosphere than in cases of liquid or gas fossil fuel combustion. According to the EU Directive 2001/80/EC of the European Parliament and of the Council on the limitation of emissions of certain pollutants into the air from large combustion plants [4], the dust emission limit value is 50 mg/m^3 for existing plants, while for the new ones that will be constructed and put into operation in the near future this limit is even more strict 30 mg/m^3. The standard equipment at the current large coal-fired thermal power plants, which should provide this emission quality, is an electrostatic precipitator. The precipitator collects particles most easily when the particle size is coarse. Smaller particles (in the range of 1 μm or smaller) are difficult to collect because the fundamental field-charging mechanism is overwhelmed by diffusion charging due to random collisions with free ions. Hence, a considerable amount of small particles – aerosols might be emitted to the atmosphere from the coal-fired large combustion plants. Hence, the measurement of the aerosols content in the atmosphere in the vicinity of thermal power plants is very important to diagnose and ensure the environmental protection. This especially holds for Serbia, where more than 50% of primary energy is provided by the domestic lignite [5].

This paper presents an original method for the measuring of aerosols content in the atmosphere based on the laser remote sensing of air pollution. Laser remote sensing was conducted at the Institute of Physics in Belgrade 25 years ago, when the first domestic LIDAR device has been developed. Its capabilities were modest, but it and experience of research centres around the world were the basis for implementation of a new LIDAR device LID-2. The subject of this work will be its ability in the remote detection of air pollution, so as the monitoring and control of atmospheric conditions [6] – the activity that is very important in the energy sector regarding the aerosols emission from the fossil fuel-fired furnaces and the corresponding environmental protection.

Use of laser system for remote detection of air pollution

Method of laser remote sensing of pollution of the atmosphere (LIDAR) is one of many, and it is based on emitting a laser beam (in the direction of expected pollutants' zone), collecting and analyzing reflected light. Backward beam can be reflected, abstracted or a consequence of induced emissions. Theoretical and experimental procedures have been developed in order to determine the type and quantity of pollutants, while the method of differential absorption has special advantages. Remote sensing of pollution has advantages over methods of direct measurement because it is sufficiently sensitive and applicable to larger distances [7].

Use of lasers in remote detection of air pollution is based on the analyzing beam, which is after passing through the atmosphere returning to the receiver. For the work it is needed at least two wavelengths, one of which corresponds to the expected maximum absorption of pollutants (resonant), and the other is outside the area (non-resonant – reference). Both laser emissions have approximately equal return loss under the influence of the standard radiation content of the atmosphere, so that weak resonant return emission (more weakened compared to the reference) indicates the presence of certain pollutants. The weakening of the return signal may be due to scattering. Backward radiation can be provided in several ways: by setting retro-reflector, topographic reflection (wood, chimney, construction building, positive topographic structure, *etc*.) or by reflection of radiation on the scattering aerosols (*e. g.* dust particles). Directing the laser beam is simple and allows scanning and 3-D mapping of space. Electronic detection systems and computational data processing allows determining the type and concentration of pollutants and their space distribution.

The basic applications of LIDAR are:

- determining the vertical distribution and boundary of mixing layer of the atmosphere, which is important for establishing the major routes of transport of pollutants,
- predictions based on measurements and application of the model, which leads to the development of a successful system for warning,
- identifying the sources of aerosols,
- assessment of the impact of specific episodes (Saharan sand, urban photochemical smog, products of volcanic eruptions, forest fires), and
- determination of the relevant concentrations of aerosols in the atmosphere and their impact on the optical properties of the atmosphere.

There are number of techniques used for examination of aerosols: a significant number are based on measurement of spectral phenomena such as light scattering, absorption, fluorescence, and chemiluminescence. The other methods include chromatographic separation (GC-gas chromatography and HPLC – high performance liquid chromatography) combined with different detection techniques (UV-VIS-IR absorption, FID, MS, ECD), mass spectrometry, various electrochemical methods and so-called wet chemical analytical methods. Method of sampling has a primary role because it is used for determination the spatial and temporal resolution measurements.

Methods for remote monitoring and following-up of aerosol are from the group of spectrometry methods, and they are based on analysis of the light structure, which is the result of interaction between electromagnetic radiation and the appropriate media. Among them, LIDAR holds an important position. This technique is basically the contactless and generally has a good time and spatial resolution. Earlier indications are known and also important for the determination of the concept of LIDAR system, which is being developed at the Institute of Physics in Belgrade, in accordance with available technical, technological, and financial capabilities.

Method of pollution detection, as already stated, consists of the fact that a laser beam is send in the observed area, and then detects and analyzes the reflected beam. The process of passing radiation through the atmosphere is defined by the formula:

$$I_{(x)} = I_o \exp(-\alpha x) \tag{1}$$

where $I_{(x)}$ is the intensity of return signal, I_o – the baseline signal intensity, and α – the coefficient of extinction.

The coefficient of extinction ($\alpha = \alpha_{abs} + \alpha_{Mie} + \alpha_{Ray} + \ldots$) is linked to the absorption and scattering, and depends on the wavelength of laser radiation and present particles in the atmosphere. Strong absorption is related to CO_2 and water vapours, and there is a series of lines that are characteristic of other gases. By measuring and analyzing the response, pollutant that is controlled can be recognized. As for the scattering, there is a deviation from the original direction of radiation propagation, and the tracking is done at a certain angle [8].

If the quasi-parallel, monochromatic, coherent, and linearly polarized radiation (laser beam) emitted into the atmosphere, there is a different process happening: the elastic (Rayleigh and Mie molecular with aerosols) and perfectly inelastic (molecular Raman) scattering, refraction and/or absorption diffraction. The probability of an event of this process is defined by sections that are functions of incident intensity and wavelength of radiation, a process of interaction and properties of atmospheric broadcaster. This method is one of the so-called active methods because there is an interaction with the media, using an artificial source of light. By the analysis of scattered radiation at several wavelengths, the information on the extinction coefficient of radiation scattered backwards (aerosols and clouds), atmospheric concentrations (ozone, water vapours) and atmospheric parameters (temperature, wind speed) can be obtained with a relatively large time (several tens of minutes or hours) and spatial resolution (several tens and hundreds of meters).

Rayleigh, Mie, and Raman scattering are non-selective interactions, while the absorption is selective process as it depends on the absorption cross section at laser wavelength. Resonant processes (Rayleigh or Raman) are also selective, which means that the wavelength of the laser radiation coincides with the specific electronic transitions of molecules. In addition to extinction and back scattering coefficients for describing the type of interaction it is additionally used dimensionless parameter for size χ, which is defined as the ratio of particles volume (molecule, aerosol) to the wavelength of light $\lambda : \chi = 2\pi r/\lambda$.

According to the value χ, scattering radiation can be: Rayleigh $\chi \ll 1$, Mie $\chi \sim 1$, and geometric $\chi \gg 1$.

The main elastic and inelastic processes with molecules and aerosols, on which the application of LIDAR is based are:

- elastic scattering on the molecules N_2, O_2 ($\lambda_D = \lambda_L$), *i. e*. Rayleigh diffusion ($\lambda_L \gg$ d, where *d* is the diameter of molecule),
- elastic scattering on aerosols ($\lambda_D = \lambda_L$), *i. e*. Mie scattering ($\lambda_L \sim d$, where *d* is diameter of aerosol),
- inelastic scattering on molecules of N_2, O_2, and H_2O (λ_D, λ_R), *i. e*. Raman scattering ($\lambda_L \gg d$; where *d* is the dimension of molecules),
- gas or aerosol absorption (if the radiation on λ_L is absorbed by atmospheric molecules or components of aerosols), and
- scattering in the clouds ($\lambda_D = \lambda_L$, with $\lambda_L \ll d$, where *d* is the geometric dimensions of water droplets or ice crystals).

Completed LIDAR LID-2 system monitors the interaction of laser radiation to the content of the atmosphere on the basis of Mie scattering.

Mie scattering includes elastic collisions between photons and aerosols, which result in emission of photons of the same energy as one that caused them. It dominates in ranges in which the particles of the same measurement range as the wavelength of an incidence laser beam. If the particles' sizes, on which scattering is done, is less than the wavelengths of incident radiation, as in the case of scattering of atoms, Rayleigh scattering will predominate. It is process in which during collision, electron rises on higher energy vibration level and returns to the ground state with emission of photons of the same energy that was absorbed. As a result of both processes, the energy of emitted photons is not changing, and the wavelengths of scattered and incident radiation are same. In contrast to these processes, Raman scattering results by transfer of the electron to higher energy state (as in Rayleigh's scattering), but the electron does not return to ground state. Electrons can gain the energy, and in this case emitted photon has a smaller amount than amount of absorbed energy (Stokes case), or to lose energy and in this case delivers to emitted photon (anti-Stokes case). The amount of lost or obtained energy by photon depends on the energy gap between electrons' states and therefore it is characteristic for the scattering centre, which makes this method selective. By measuring shifts in the wavelengths of scattered radiation, one can precisely determine the type of scattering centres.

Characteristics of realized system

The basic architecture of LIDAR device consists of four subsystems (fig. 1): transmitting (1), receiving (2), system for manage and process data (3), and supporting structure (4).

Transmitter emits short laser impulses in the atmosphere. The interaction of laser beam with atmospheric constituents is based on the fundamental principles of propagation of electromagnetic waves through various media. The atmosphere contains numerous constituents, whose diameters are in a wide range of sizes, ranging from size of atoms and molecules ($d \sim 10^{-3}$-10^{-4} μm), aerosols ($d \sim 10^{-2}$-5 μm), to water vapours drop and ice crystal ($d \sim$ 1-15 μm and bigger).

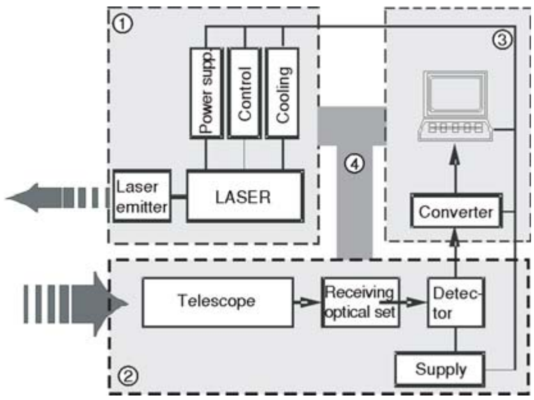

Figure 1. Concept of laser system for remote sensing of aerosols

Mixture of these different components has resulted in appearance of a series of complex interactions of laser beams with atmospheric content. Telescope accepts a small portion of the return beam, and the receiver performs spectral separation and analogue-digital conversion for signal preparation for archiving and analysis.

By preliminary determination of the backward scattering coefficient and extinction coefficient, based on the fundamental physical settings, starting value of the laser beam energy of 100 mJ is set. This is in line with comparable LIDAR systems that are already working in the EARLINET [9, 10]. In order to measure the backward scattering coefficient (Mie scattering) in aerosols and the total coefficient of extinction, it is necessary to use the laser emission at two wavelengths. In this case, Nd^{3+}:YAG laser radiations' wavelength of fundamental harmonic is 1064 nm and 2nd harmonic wavelength is 532 nm. For the 1064 nm wavelength backward scattering coefficient has value of $\beta = 3 \cdot 10^{-5}$ 1/sr, and the total extinction coefficient value of $\alpha = 6.8 \cdot 10^{16}$ 1/m. To calculate and design detection system, it is necessary to switch the energy of the emitted radiation in the number of transmitted photons, which is, for the energy of 100 mJ given $n_{ph} = 5.36 \cdot 10^{16}$. Total number of photons of scattered laser radiation (n_{ph}), which enter at the detector system for Nd^{3+}:YAG laser with radiation energy of 100 mJ, is variable with distance (z) and is showed in tab. 1.

Table 1. Total number of photons of scattered radiation in the function of distance

z [m]	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
n_{ph}	80386	20093	8929	5022	3213	2230	1640	1254	986	804

Light transmitter is Nd^{3+}:YAG laser type LS 2131, constructed by Lotis TII company from Minsk, Belarus. Laser beam is Q-switch. Pulse energy is 100 mJ at 1064 nm and 50 mJ at 532 nm. Repetition rate is 1-20 Hz, and its duration is 10-15 ns. Transmitter – emitting optical block is renewed and complemented with several types of beam expander, designed and implemented specifically for this purpose [11].

Collection of reflected/scattered light is performed with telescope and receiving optics. Primary telescope's mirror is parabolic, with clear aperture of 203 mm, approximate radius of 1500 mm and 750 mm focal length. Final results were made by calculations and tests with the telescope type Cassegrain and classical Newton telescope. In fact, the device has been realized through several phases. In the first part of the experiment, individual blocks with optical wavelength of 1064 nm (fig. 2) and 532 nm (fig. 3) were used.

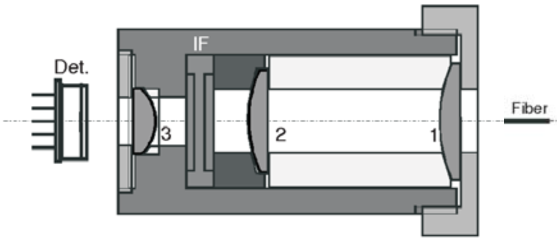

Figure 2. Receiver optics for 1064 nm

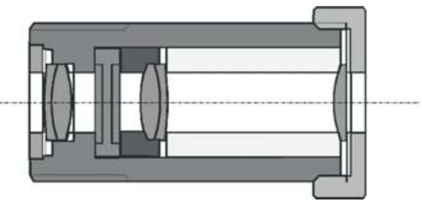

Figure 3. Receiver optics for 532 nm

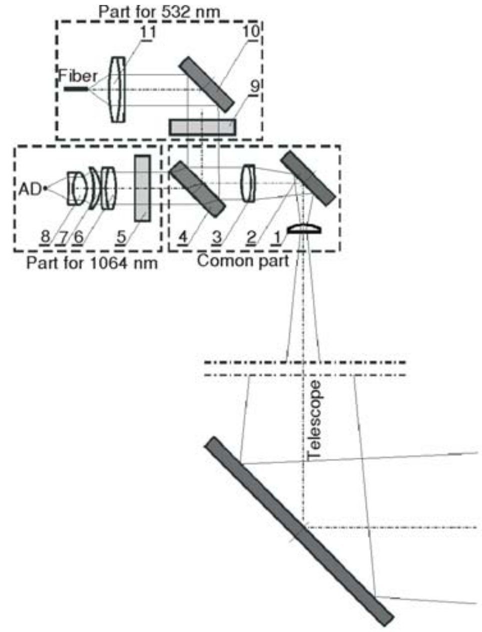

Figure 4. Optical scheme of the receiving block to 532 nm and 1064 nm

By respecting all principles of projection systems, calculations and experiments, a new technical solution for receiving optical block is realized, unique for both wavelength 1064 nm and 532 nm (figs. 4 and 5).

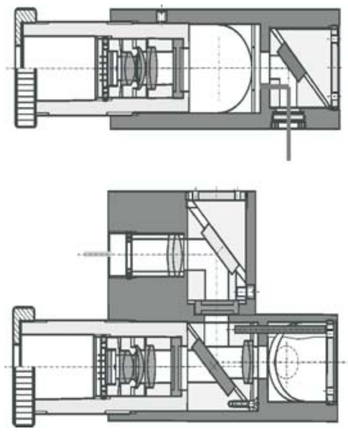

Figure 5. The appearance of a unique design receiving optical blocks

There is a unique optical block in focal plane of telescope's parabolic mirror, and its collective lens (1). After it, there are various optical components, which form a complex optical system and has task to bring concentrated laser radiation from objective lens to two detector systems. Role of the collector lens is to back scatter laser radiation introduce into the optical block. Suitable structural solution ensures that optical block's plane and the plane telescope axis are parallel. This is achieved by using of beam deflector (2), and because received laser radiation should be parallel, behind beam deflector the collimator lens is put – achromatic doublet (3). Harmonic separator (4) has a role to transmit the laser radiation of wavelength 1064 nm, and to reflect the laser radiation wavelength 532 nm. Collective lens, beam deflector, collimator lens, and harmonic separator are a common part of the whole optical receiving block.

On the part of optical block for wavelength of 1064 nm, laser radiation leads to interference filter for 1064 nm (5). It is necessary to take into consideration filter's bandwidth, because of the level of radiation transmitted through the filter. After passing through the filter, radiation is led to the focusing objective lens, which consists of two double (6 and 8) and the meniscus lens (7). In the focus lens photodetector's radiation wavelength is 1064 nm – silicon avalanche photodiode (APD).

On the part of the optical block for wavelength of 532 nm, laser radiation leads to narrow interference filter for 532 nm (9), and then using beam deflector (10) to the objective lens (11) by which radiation is being focused on multimode optical fiber core diameter of 1.5 mm and numerical aperture NA = 0.37. The other end of fibre (output) is connected to photomultiplier.

It is obvious that receiving optical block for receiving scatter laser radiation consists of two independent parts, for two wavelengths of 1064 nm and 532 nm. Therefore, design of optical systems is made independently for two wavelengths through a review of the dominant energy features: vignetting diagram, spot diagram, and geometric encircled energy.

Specific of this solution is mirror rotating (input bean deflector) for 90°, which is achieved by:
– the optical axis of both receiving parts – of the 1064 nm and 532 nm lie in the same plane,
– that axes of both receiving parts are parallel to the axis of the telescope, and
– that axes of both receiving parts are approximately equal distanced from the axis of the telescope.

Structure of the optical block is unique for all optical components, providing the necessary system's rigidity in case of capture of different observation's directions by azimuth and elevation. Parts of the system are made in segments, so necessary optical components can be installed easily. Possible errors (acceptable to available production technology) are without influence on the optical characteristics of receiving system. Complete receiving optical system allows the reception of a return signal which is strong enough to all working distances covered by LIDAR. Built-in optical components are made according to special requirements regarding the type of substrate material, radius, size and clear aperture. Specification of components is precalculated with using specialized software packages and simulation on the computer.

Signal detection and acquisition have demanded some hardware support, mostly from standard components. Experimental and later work in the system's optimization required use of different detectors types that cover diverse parts of the spectrum. All detectors were characterized by great sensitivity and high speed response, because the return signal radiation is small. Three different detectors are being used: silicon PIN photodiode, photomultiplier tube (PMT) and avalanche photodiode diode (APD). PIN diodes are characterized by great sensitivity and speed of response, and photomultiplier tube by high quantum efficiency, while APD offers a combination of high sensitivity, speed response, and high quantum efficiency.

During the testing and setting the parameters of whole system, it is necessary to (among others) made frequent interventions photo-detector block. That considers its separation from the subsystem for the reception of back scattered radiation, which damages the photo-detector's set-up position in relation to focus of receiving optical system. After performed intervention, block is being returned, and it is necessary to re-adjust its position (setting photo-detector in focus of receiving optics). In order to facilitate manipulation during adjustment and intervention in settings of photo-detector block, a concept that involves use of fiber-optic cable is introduced, in which the signal is from the focus of telescope is transmitted to block photo-detector which is separate from the telescope. Due to the high permeability of 532 and 1064 nm fiber-optic cable BFL37-1500 (Thor Labs) is being used. Its features are: quartz core diameter 1.5 mm, polymer coating 1.55 mm, insulating sheath 2.0 mm. Numerical aperture is 0.37, the spectral range of 0.4-2.2 mm, with a minimum of weakening in the range of 500-1100 nm. With the optical cable, corresponding adapter was used and all of which provides the opportunity to relocate photomultiplier of telescope tube.

For detection of signal on the second accordion, amplifier of discrete elements is designed, whose main characteristic is to eliminate the negative deviation, which is not correct for further signal processing (digitization and software processing).

Part for processing of information consists of a computer digitizer (A/D card NI-5124 of manufacturer National Instruments) and program that allows collection and preprocessing of data. Electrical signal from detector is processed and introduced into the digitizer. Created program allows exploitation, the preparatory processing f signal and its storage in computer's memory. Primary prepared data are ready to be submitted to software package for complete data processing and their interpretation in the physical and environmental sense.

Acquisition is carried out in two stages; first – working parameters are being set up and register and then data is being collected. Environmental parameters are constants related to the external environment (speed of light, minimum and maximum distance from which come transmitting radiation which is being detected – lower and upper limit of detection). Parameters related to the digitizer were divided into three groups: vertical, horizontal, and trigger. Vertical parameters are specified by range and offset signals and coupling. Horizontal parameters are sampling drift, number of samples. Trigger parameters are trigger source, threshold, slope, trigger coupling, delay, and other.

The entire acquisition is based on repetition of individual acquisitions, *i. e.* data collection after each impulse. Remote sensing process begins by emitting laser pulse into the atmosphere. During the transmittance, pulse start trigger, this determines starting point of individual acquisition. Delay, which is defined as trigger parameter, is more precisely defining the moment when collecting of data begins. By defining of length of every single acquisition, completion of a single collection is determined, which is related to furthest distance from which round radiation is coming (upper limit of detection). Upon completion of data collection at a particular acquisition, data is prepared in vector and store in folder on hard disk. Individual acquisitions are repeated in predetermined number of times, depending on the amount of data that we want to collect.

Maximum distance from which backscatter radiation is collected is 5000 m. After emission, feedback signal lasting 33 μs is being collected, and AD conversion and registration on hard drive lasts 49 ms. Number of samples processed for sampling rate of 33 μs is determined by the digitizers of 200 M sample/s and makes 6600 (12-bit) samples or 7900 bit (9900 kB). While registering at hard-disk by speed of 475 Mbit/s, time required to enrol these 6600 samples was 167 μs. Together with time of collection, total elapsed time of emitting to registries of samples is about 200 μs. By increasing of total time needed for photo-detection sampling, from 30 to 100 μs, new range which can collect radiation from distance of 15 km is obtained.

The supporting structure brings together all sections of the operational unit. It is important to provide a constant relative concernment – the position of emitted signal and return on the one hand and on the other, easily routing device according to potential polluters.

There are two basic position of the laser to the telescope: the telescope and laser axes are parallel, but between them there is a transverse distance and telescope and laser axes coincide. The first position is used when it is necessary to avoid dazzle (saturation) detector with feedback dispersed radiation. The second position is used when it is possible to place an obstacle in telescope's sight, which prevents dazzle. In contrast to the second position, the first laser beam position is not included in the cone area of the telescope visible immediately after leaving the laser, but only at a certain distance. This distance can be changed by adjusting of an angle and cross-axis distance between telescope and function of overlapping can be derived.

Axis of the telescope and lasers are not coaxial but, that are parallel. Parallel axis is adjusting with fine adjustment screws on the holder. By using a periscope tracking system adjustion is easier, and therefore has been set camera which allows easy guidance of reference point through monitors.

Experiments and conclusions

To ensure full efficiency of LID-2 in order to determine the existence and location of air pollution, it is needed to manage its set-up and calibration for proper determination of a valid return signal and its separation from the noise. Therefore, a series of experiments were conducted with receiving of return signals from known objects on the known distance [12].

Check of the photo-detection block's effectiveness, was performed in a test series of sending a laser beam to the object at a distance 350 m and acceptance and detection of backward scattered laser radiation.

For the first test, distance of 500 m was chosen (reflected signal is not too weak) and adjustment of laser's position to the telescope was made. Starting time of a single collection is about 3 μs (2×500 m/$3 \cdot 10^8$ m/s)) – after emitting laser pulses. Time elapsed between emitting of impulses (activation of triggers) and the time of commencement of data collection is defined by the trigger delay. By estimation of maximum distance of 5 km from which an open emission comes (it is assumed that for greater distances scattered signal of return radiation is too weak), end time of signal collecting is 33 μs after broadcast of laser pulses. Therefore, the total time of an individual photo-detection signal is about 30 μs. For the highest frequency of broadcasting laser pulses of 20 Hz time elapsed between two pulses is 50 ms. From here, the available time for translating optical signals from analogue to digital electronic form is about 49 ms.

Based on the received signal it is clarified that beginning of signal's increase correspondents to the of beam's entering cone's visibility; for the time of 0.75 μs equivalent range is about 90 m. Maximum signal corresponds to the entry of entire beam in the cones' visibility; for period of 1.2 μs equivalent distance is 157.5 m (fig. 6). Local extremes in the diagram correspond to changes in scattering along the laser beams (fig. 7).

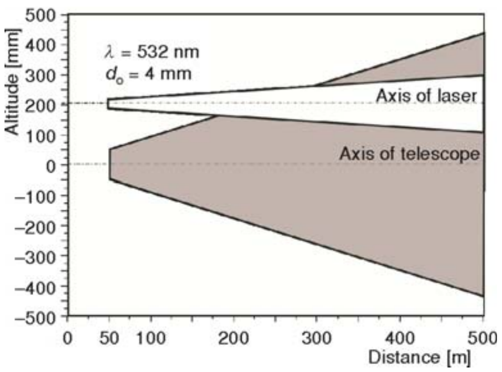

Figure 6. Visibility field of lasers and telescopes for distance 500 m

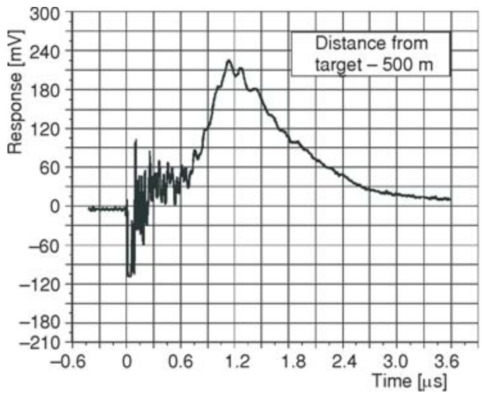

Figure 7. Signal from target – 500 m

Next test series were carried out with an object at a distance of about 1050 m along with optical path without barrier. Reflection surface dimensions of 1000×2000 mm are set to be approximately perpendicular to the incidence laser beam. By multiple test with emitting and receiving signals in relation to known object optimization and calibration of a certain noise level of 10 mV were derived (all above that is actual signal). Differences in response volume were insignificant in each experiment, and therefore diagrams show the actual gain value.

Full confirmation of the accuracy of measuring and test efficiency of the device, was received by emitting signals in the atmosphere and acceptance of the return radiation. From a number of separate experiments, typical one was distinguishes (fig. 8). Measurement was carried out by a laser beam aimed at the sky. The weather was cloudy, with a low and thick clouds, with no fog and rainfall and air temperature about 8 °C. Detected signal in the area between 28 μs and 31.5 μs indicates the occurrence of three chambers and the three smaller maximum. This area corresponds to feedback signals from the clouds which range from 4 to 4.5 km [13].

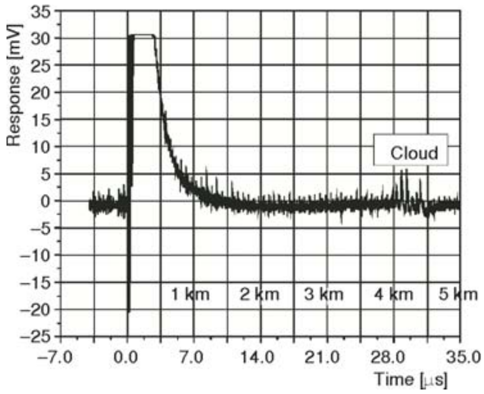

Figure 8. Return signal detected by a LIDAR (LID-2) of the cloud

Gathered results are in complete agreement with the results of other researchers, although there are considerable technical and technological differences. As a result, expectations for involvement in international project are real. It is expected to provide all necessary conditions for the realization of a mobile LIDAR system, such that operator on the field can monitor changes and recording the types and amounts of pollution.

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