LABORATORY REPORT OPTICAL RADIATION MEASUREMENT
PROJECT: FALCON 4G / SEC TECHNOLOGIES, s.r.o.

TESTER:	Thomas Collath	**DATE:**	June 12, 2019
OBJECT:	FALCON 4G		
CLIENT:	SEC Technologies, s.r.o. Družstevná 5 SK – 031 01 Liptovský Mikuláš		
SCOPE OF TESTING:	Determination of the laser class based on the radiation parameters in accordance with standard EN 60825-1:2014, IEC 60825-1: 2014.		

1 Parameters of the laser system

The determination of the laser class is based on the basis of the following laser parameters:

data necessary for a "theoretical" classification:
- Wavelength :

Both lasers used in Falcon 4G are tuneable TEA CO2 lasers; that means the generated wavelength can be between 9.2 and 10.7 microns;

- Pulse duration, pulse frequency, and pulse energy.

Pulse duration :
Pulse of all TEA CO2 lasers consists of :
- Short and intense spike, which originates as a result of "gain switching"; in our case it lasts approx. 100 ns (FWHM);
- Nitrogen "tail", duration of the "tail" depends on amount of N2 in the used laser mixture; in our case the "tail" lasts approx. 1 microsecond;

Pulse frequency :
Our lasers are able to operate with pulse-repetition-rate up to 2 pps continually;
Pulse energy :
The total pulse energy of our lasers at the strongest CO2 line (10P20) is approx. 50 mJ (the first short spike contains 25 mJ, the "tail" contains the remaining 25 mJ);

- Beam shape (TEM-mode), beam diameter (according to which determination: 1/e2 or 4σ), beam divergence.

Our laser beam is nearly a Gausian one;
Beam diameter is approx. 32 mm (1/e2);
Beam divergence is approx. 1 mRad

- All operation modes.

TEA CO2 laser is a pulsed laser (unable to operate in a CW mode)
Maybe important information: Our LIDAR is intended for Stand-off detection of various gaseous stuffs in air. However, before starting the detection, FALCON 4G measures range to the terrain feature, at which it is aimed. If some obstacle is in front of our system (and obstacles range is under e.g.100 m), the range of the terrain feature cannot be estimated (optical receiver of our LIDAR is saturated) and, after transmitting 2 pulses, operation of lasers is stopped.

Principle of operation	Active - Differential Absorption LIDAR using CO2 lasers
CO2 isotopes useable in System's lasers	12C16O2 and 13C16O2
Spectral range	9.2 – 10.7 (9.6 -11.3) * µm
Number of useable laser lines	> 60 (125) * CO2 lines
Number of lasers in System	2 tunable pulsed CO2 lasers
Energy of laser pulse (on 10P20 laser line using 12CO2)	50 mJ
Pulse repetition rate of lasers	< 4 pulses per second

The laser parameters as stated by SEC Technologie

2 Determination of the limit value

In accordance with standard EN 60825-1:2014 table 3 contains the limit value of laser class 1 for laser radiation between 4000 nm to 10^6 nm:

	Emission duration t (s)		
	10^{-9} – 10^{-7}	**10^{-7} – 10**	**10 – 30 000**
Limit value	100 J m^{-2}	5600 $t^{0,25}$ J m^{-2}	1000 W m^{-2}

(where **t** is the pulse duration)

The following methods must be used to determine the class of laser device with repeated pulsed or modulated emission.

For all wavelengths the requirements 1) and 2) have to be examined. Concerning wavelengths from 400 nm to 1400 nm the requirements 3) also need to be examined, by a comparison with the thermal limit values. Therefore requirements 3) do not have to be taken into consideration for the laser system discussed here.

The class is determined by applying the most restrictive criteria from 1) and 2) and, where applicable also 3).

1) Radiation by each individual pulse of a pulse sequence must not exceed the AR for a single pulse. In order to determine the accessible radiation of a prolonged source, the pulse duration is used to determine α_{max} and the reception angle γ_{th} .

2) The average power for a pulse sequence with the emission duration T mustn't exceed the power in accordance with the AR for a single pulse with the duration T (AR_T). To determine the accessible radiation of a prolonged source, the radiation duration T is used to determine α_{max} and the reception angle γ_{th}. In the case of irregular pulse patterns (including varying energy of the pulse), T varies between T_i and the time base. In the case of regular pulse patterns, it is sufficient to average over the time base (T equals the time base).

3) The energy per pulse must not exceed the AR for a single pulse, multiplied by the correction factor C_5.

$$AR_{single\ pulse,\ sequence} = AR_{single\ pulse} * C_5$$

Where:

$AR_{single\ pulse,\ sequence}$ of the AR for a single pulse in the pulse sequence

$AR_{single\ pulse}$ of the AR for a single pulse

3 Measurement conditions

Two measurement conditions have been specified in order to determine the accessible radiation Condition 1 applies to wavelengths, for which looking into collimated beams with telescopic optics can increase the risks. Condition 3 applies to the naked eye.

For the wavelength of the examined laser radiation from 9.2 µm to 10.7 µm optical instruments are usually not transparent. An observation in accordance with condition 1 is therefore not necessary.

For the considered wavelength range the following is applicable:

Measuring	Orifice plate (mm)		
	$t \leq 0.35$ s	$0.35\ s < t < 10$ s	$t \geq 10$ s
0 mm	1	$1.5\ t^{3/8}$	3.5

Distances and time-related orifice plates for measuring condition 3
in accordance with standard EN 60825-1:2014, table 10.

4 Calculation of the laser output power

In accordance with condition 3, the power of the laser has to be determined with a orifice plate 1 mm in diameter for the laser pulses and with 3.5 mm in diameter for the CW mode.

In the case of a Gaussian beam the energy trapped by an orifice plate can be calculated by:

$$E(r) = E_0 \left[1 - e^{-2\left(\frac{r}{r_G}\right)^2}\right]$$

with: E_0 = total laser power

r_g = gaussian beam radius relative to $1/e^2$ = 16 mm

In order to determine the pulse energy, it is assumed that only **one laser module can be active at the same time**.

The pulse energy of the laser is 100 ns and 1 µs:

$$E_{100ns} = 25\ mJ$$

$$E_{1\ \mu s} = 50\ mJ$$

Through the corresponding orifice plate (1 mm and 3.5 mm) the pulse energy will be detected by:

$$E_{1;100ns} = E_{100ns} * 1{,}951E - 3 = 48{,}8\ \mu J$$

$$E_{1;1\mu s} = E_{1\mu s} * 1{,}951E - 3 = 97{,}6\ \mu J$$

$$E_{3,5} = E_{1\mu s} * 23{,}64E - 3 = 1{,}18\ mJ$$

Taking into account the surface of the orifice plate, the irradiance is:

$$B_{1;100ns} = \frac{E_{1;100ns}}{A_1} = 62{,}1\ \frac{J}{m^2}$$

$$B_{1;1\mu s} = \frac{E_{1;1\mu s}}{A_1} = 124\ \frac{J}{m^2}$$

$$B_{3,5} = \frac{E_{3,5}}{A_{3,5}} = 123\ \frac{J}{m^2}$$

with: A_1 = 785E-9 m^2

$A_{3.5}$ = 9,62E-6 m^2

In order to determine the average power a maximum frequency of 2 is assumed.

An average power at a frequency of 2 Hz and with overlaid beam paths of both laser modules:

$$E_{e;3,5} = B_{3,5} * 2\,Hz = 246\,\frac{W}{m^2}$$

An average power at a frequency of 2 Hz and with a perfect overlay of the two beams paths of both laser modules:

$$E_{2e;3,5} = 2 * B_{3,5} * 2\,Hz = 491\,\frac{W}{m^2}$$

For further evaluation the critical case with a perfect overlay of the two beam paths is used.

5 Evaluation

A comparison of the limit values of the laser class 1 with den calculated beam parameters shows the following result:

Limit values		Laser radiation	Δ
100 ns	100 J m^{-2}	62.1 J m^{-2}	62%
1 µs	177 J m^{-2}	124 J m^{-2}	70 %
cw (> 10 s)	1000 W m^{-2}	491 W m^{-2}	49%

From the carried out calculations we see that the laser radiation emitted by the laser system FALCON 4G achieves only 70% of the laser class limit value. A system with these beam parameters could be classified into laser class 1.

Darmstadt, 12th of June 2019

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