Factory test certificate of Pharos

Model of Pharos	**PH1-06-1500-02-42**
Serial number of Pharos	**L191325**
Serial number of Oscillator	OSC-191378
Serial number of Regenerative Amplifier	RA-191064
Serial number of Stretcher-Compressor	SC-191267
Serial number of Timing Electronics Module	TEM-1431
Serial number of RA HV supply	HV-3913
Serial number of PP HV supply	HV-3937
Serial number of RA Pockels cell driver	PC-K4567
Serial number of PP Pockels cell driver	PC-K4707
Serial number of Netbook	PF1NRGA9
Model of Power Supply	PS01-5A
Serial number of Power Supply	PS-1422
Model of Chiller	P307-22304
Serial number of Chiller	120549
Model of automated harmonics module	PHM01-2H-4H
Serial number of automated harmonics module	G-19383
Serial number of Faraday Isolator	FI-033

Tested by:

Name: T. Vilkys Date: 2020-01-29

Place: Vilnius, Lithuania

Approved by:

Name: V. Kilas Date: 2020-01-29

Light Conversion, UAB, Keramiku str. 2B, LT-10233 Vilnius, Lithuania
Phone +370 5 2491830; E-mail: lasers@lightcon.com

Contents

1. Output beam measurements

Item	Specified value	Measured value	Figure
Beam quality M^2	M^2<1.3 at 6 W, 200 kHz	M^2_X=1.06 M^2_Y=1.09	Fig. 1
	M^2<1.3 at 3 W, 2 kHz	M^2_X=1.07 M^2_Y=1.10	Fig. 2
	M^2<1.3 at 6 W, 4 kHz	M^2_X=1.09 M^2_Y=1.11	Fig. 3
Waist width	Not specified ($FW1e^{-2}$) at 6 W, 200 kHz	d_x = 4.91 mm d_y = 4.93 mm	Fig. 1
	Not specified ($FW1e^{-2}$) at 3 W, 2 kHz	d_x = 4.62 mm d_y = 4.65 mm	Fig. 2
	Not specified ($FW1e^{-2}$) at 6 W, 4 kHz	d_x = 4.64 mm d_y = 4.70 mm	Fig. 3
Waist location*	±5000 mm at 6 W, 200 kHz	loc_x = -1631 mm loc_y = -2465 mm	Fig. 1
	Not specified at 3 W, 2 kHz	loc_x = -43 mm loc_y = -965 mm	Fig. 2
	±5000 mm at 6 W, 4 kHz	loc_x = 1945 mm loc_y = 830 mm	Fig. 3
Astigmatism	<0.20 at 6 W, 200 kHz	0.05	Fig. 1
	<0.20 at 3 W, 2 kHz	0.06	Fig. 2
	<0.20 at 6 W, 4 kHz	0.07	Fig. 3
Beam ellipticity	d_{minor}/d_{major}>0.80 at 6 W, 200 kHz	d_{minor}/d_{major}>0.94	Fig. 4
	d_{minor}/d_{major}>0.80 at 3 W, 2 kHz	d_{minor}/d_{major}>0.96	Fig. 5
	d_{minor}/d_{major}>0.80 at 6 W, 4 kHz	d_{minor}/d_{major}>0.96	Fig. 6

* Waist location is relative to the laser face panel. Positive value means that waist location is in front of the laser face panel and negative when behind the laser face panel

Fig. 1 M^2 measurement at 6 W, 200 kHz

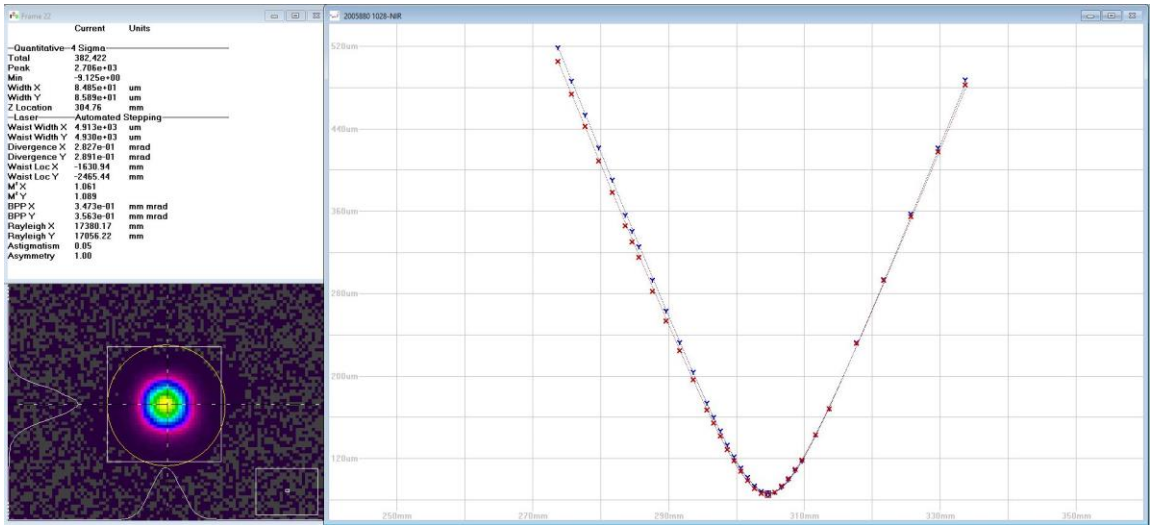


Fig. 2 M^2 measurement at 3 W, 2 kHz

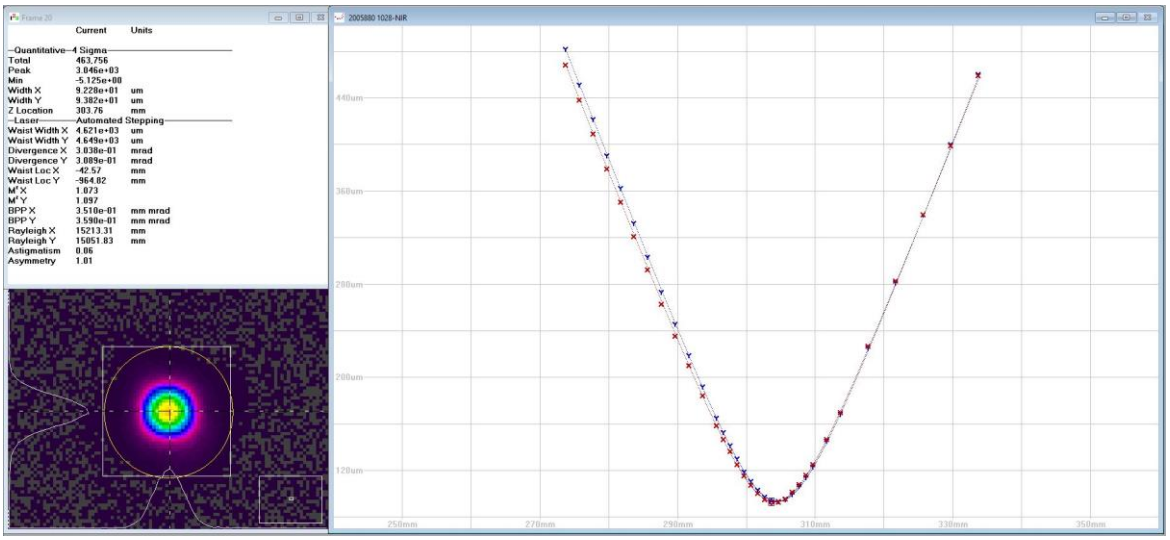


Fig. 3 M^2 measurement at 6 W, 4 kHz

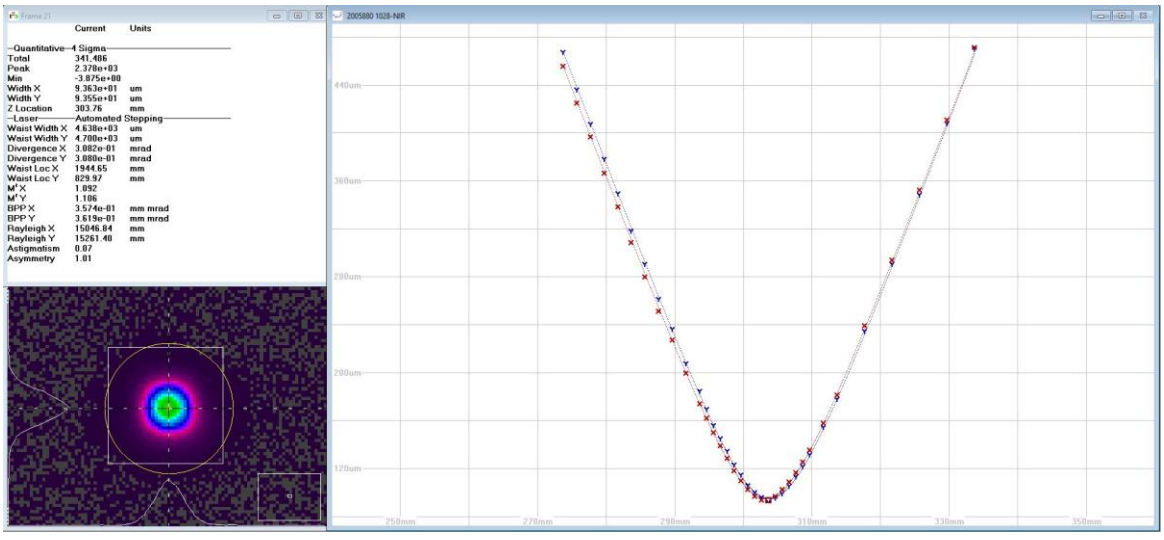


Fig. 4 Beam profile measurement at 6 W, 200 kHz

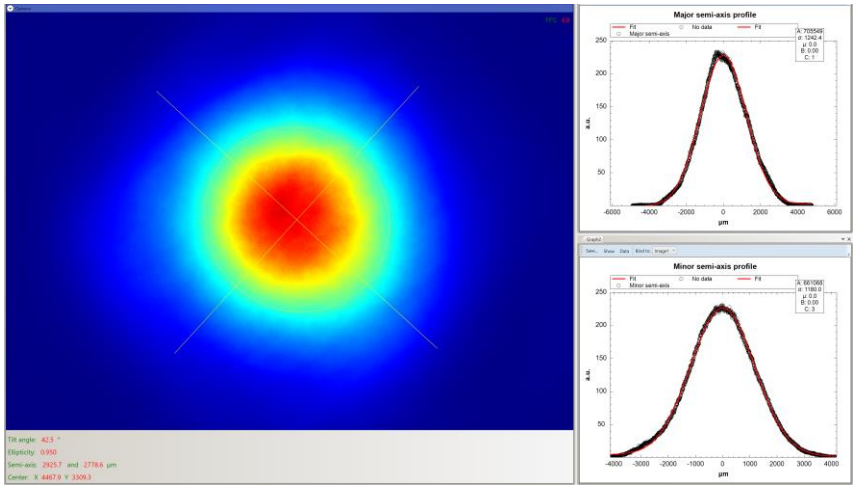


Fig. 5 Beam profile measurement at 3 W, 2 kHz

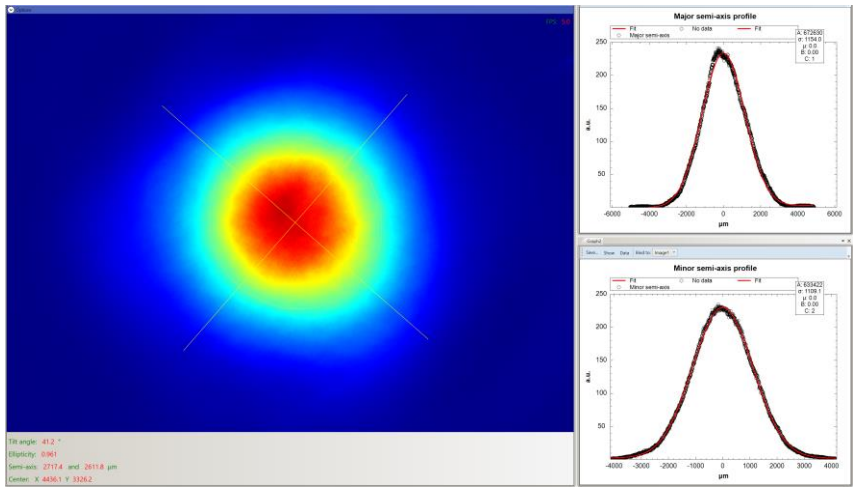
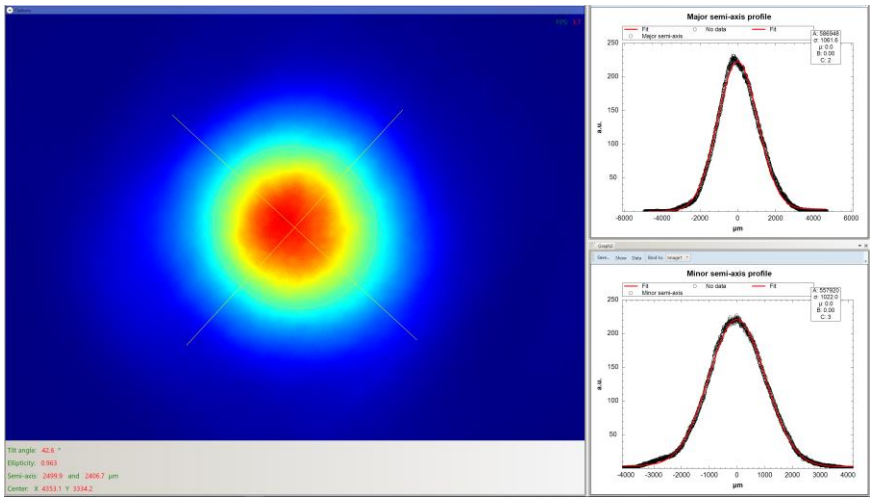


Fig. 6 Beam profile measurement at 6 W, 4 kHz



2. Output pulse measurement

Repetition rate, kHz	Pump current, A	Output power, W	Pulse energy, µJ	Pulse duration, fs	RA On Delay / Cavity Dumping Time, ns	Compressor position, (No. of a step)
1	28.80	1.52	1515	2277	21.5/257.4	0
2	29.60	3.02	1512	2218	21.5/257.2	0
4	32.50	6.05	1513	2286	21.5/257.0	0
10	32.00	6.02	602	2490	21.5/257.0	0
50	31.00	6.04	121	2668	21.5/257.0	0
200	29.70	6.05	30	2737	21.5/256.5	0

Fig. 7 Output power and pulse energy vs pump current

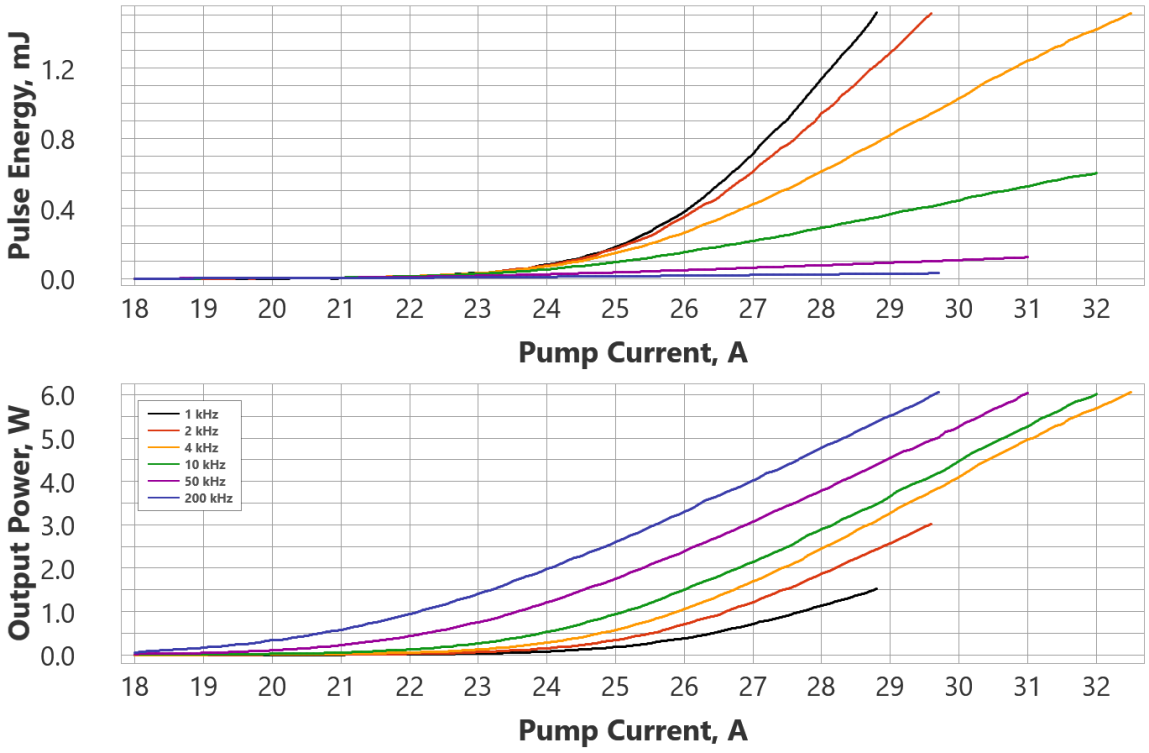


Fig. 8 Output spectrum of oscillator (18.1 nm FWHM centered at 1033 nm) measured at operating current (16.4 A, middle of ML range)

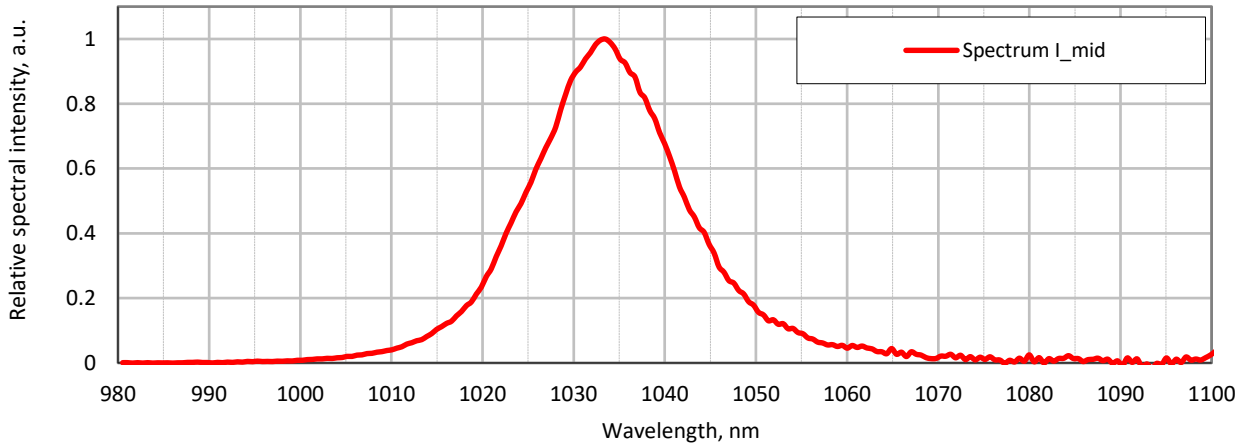


Fig. 9 Pulse spectrum and autocorrelation function at 1 kHz, 1.5 W

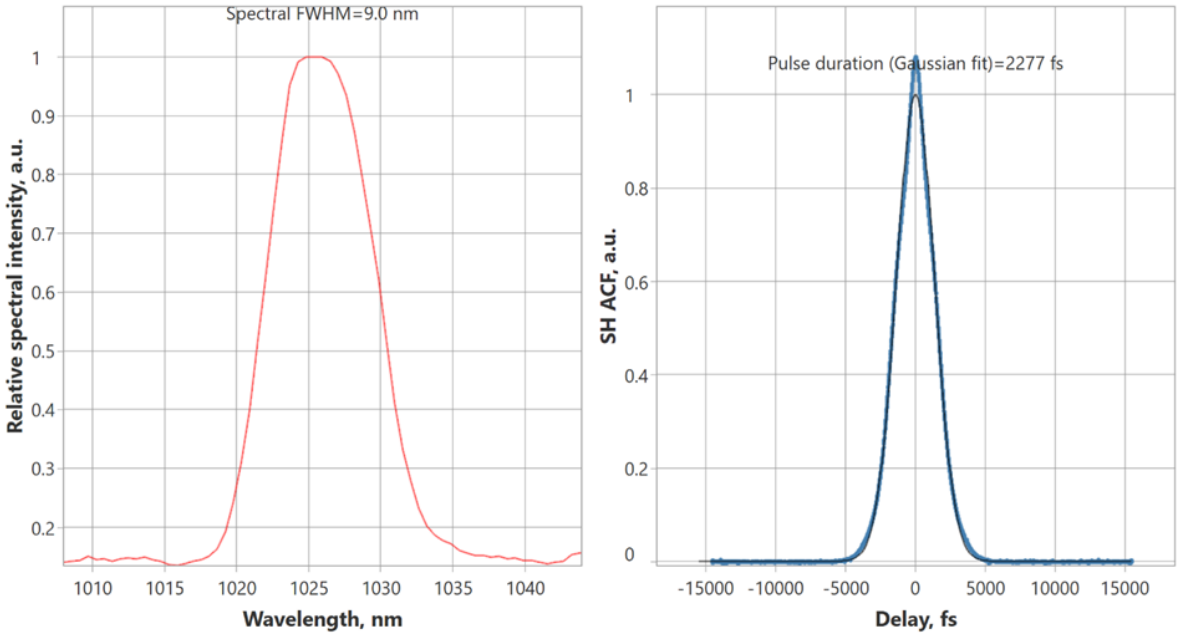


Fig. 10 Pulse spectrum and autocorrelation function at 2 kHz, 3.0 W

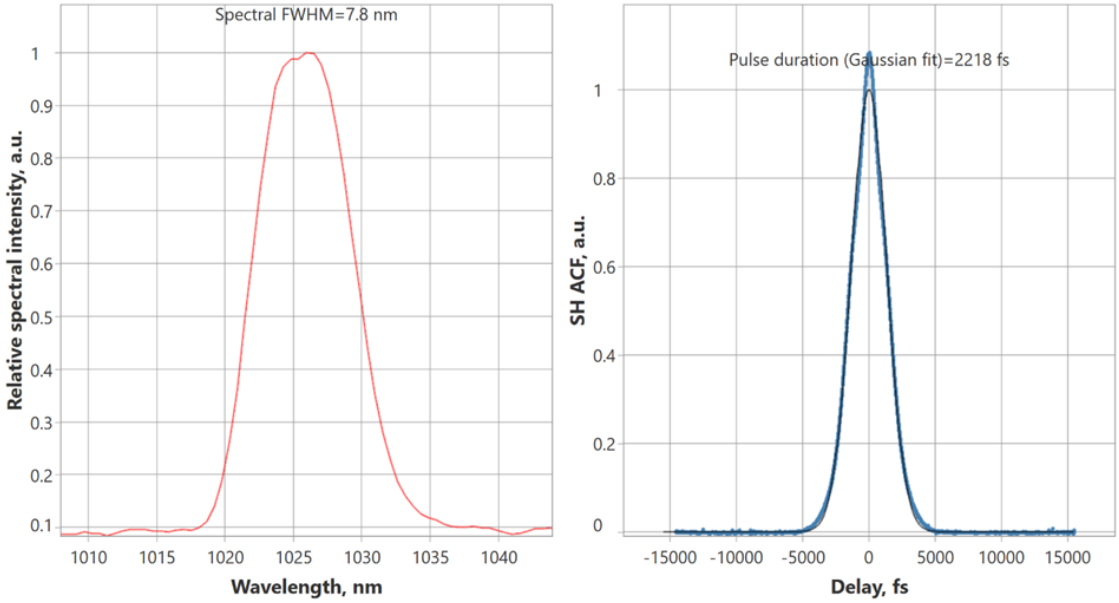


Fig. 11 Pulse spectrum and autocorrelation function at 4 kHz, 6.0 W

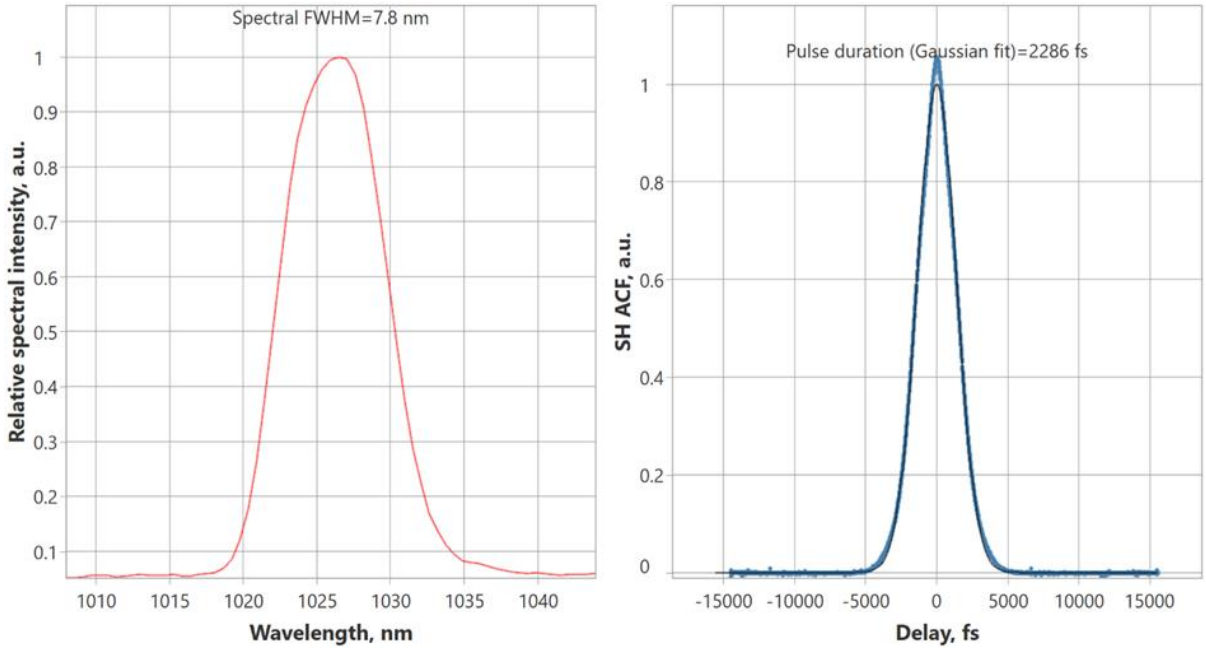


Fig. 12 Pulse spectrum and autocorrelation function at 10 kHz, 6.0 W

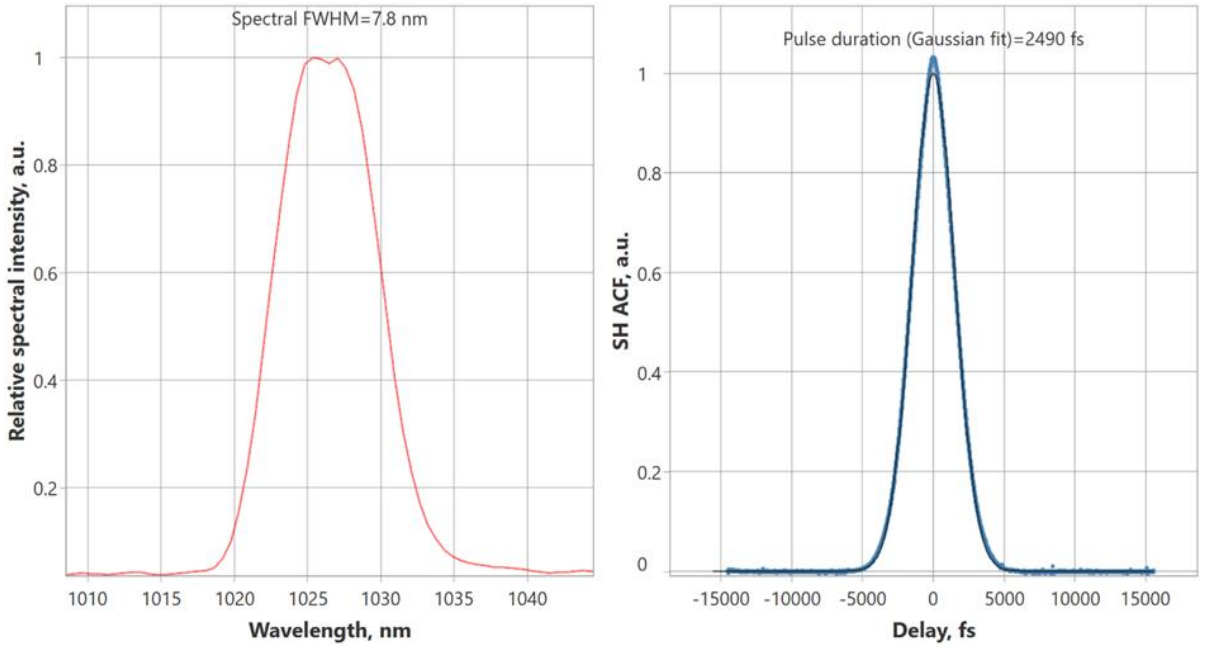


Fig. 13 Pulse spectrum and autocorrelation function at 50 kHz, 6.0 W

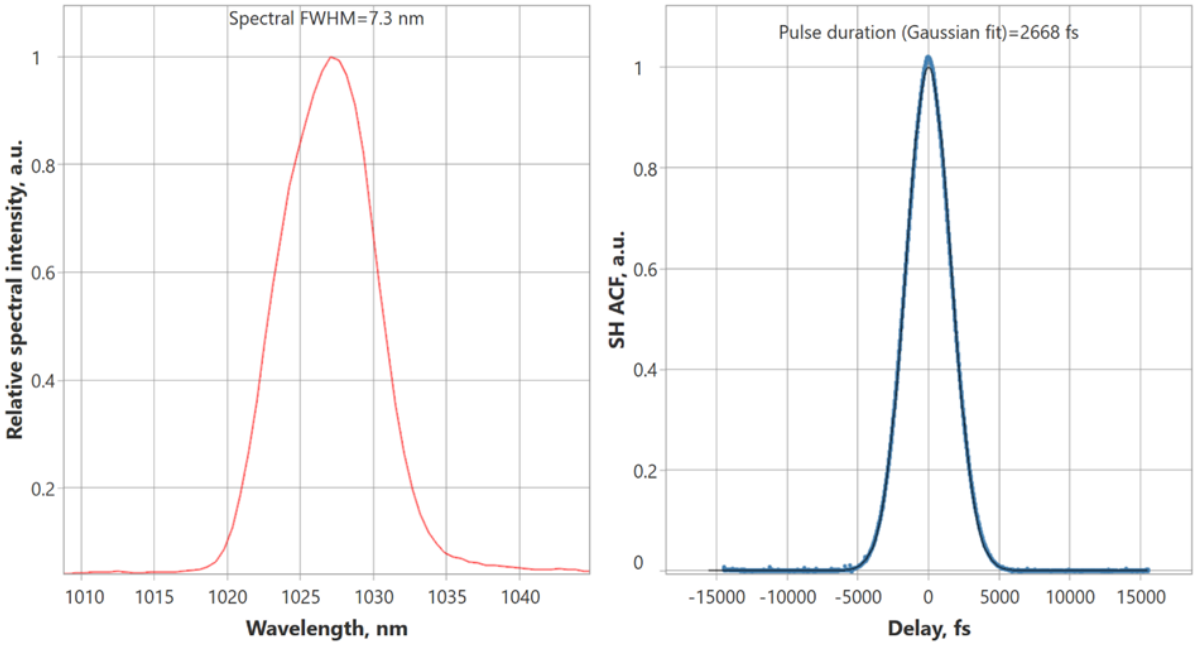
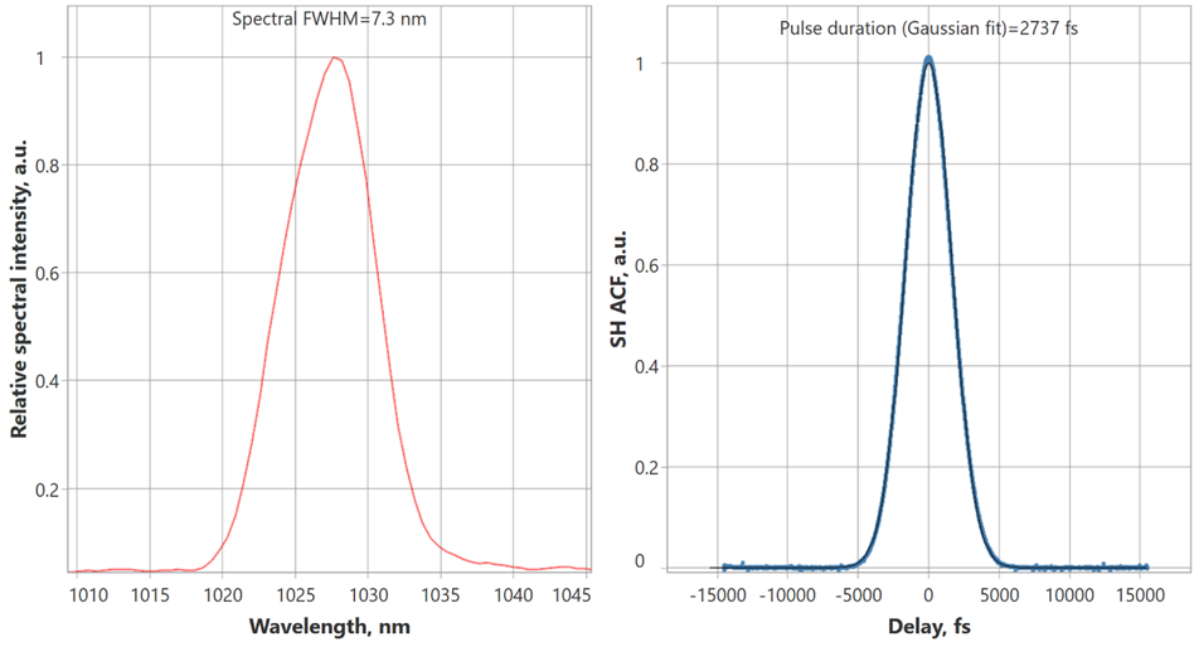


Fig. 14 Pulse spectrum and autocorrelation function at 200 kHz, 6.0 W



2.1. Pulse duration vs compressor motor position at 6 W, 200 kHz

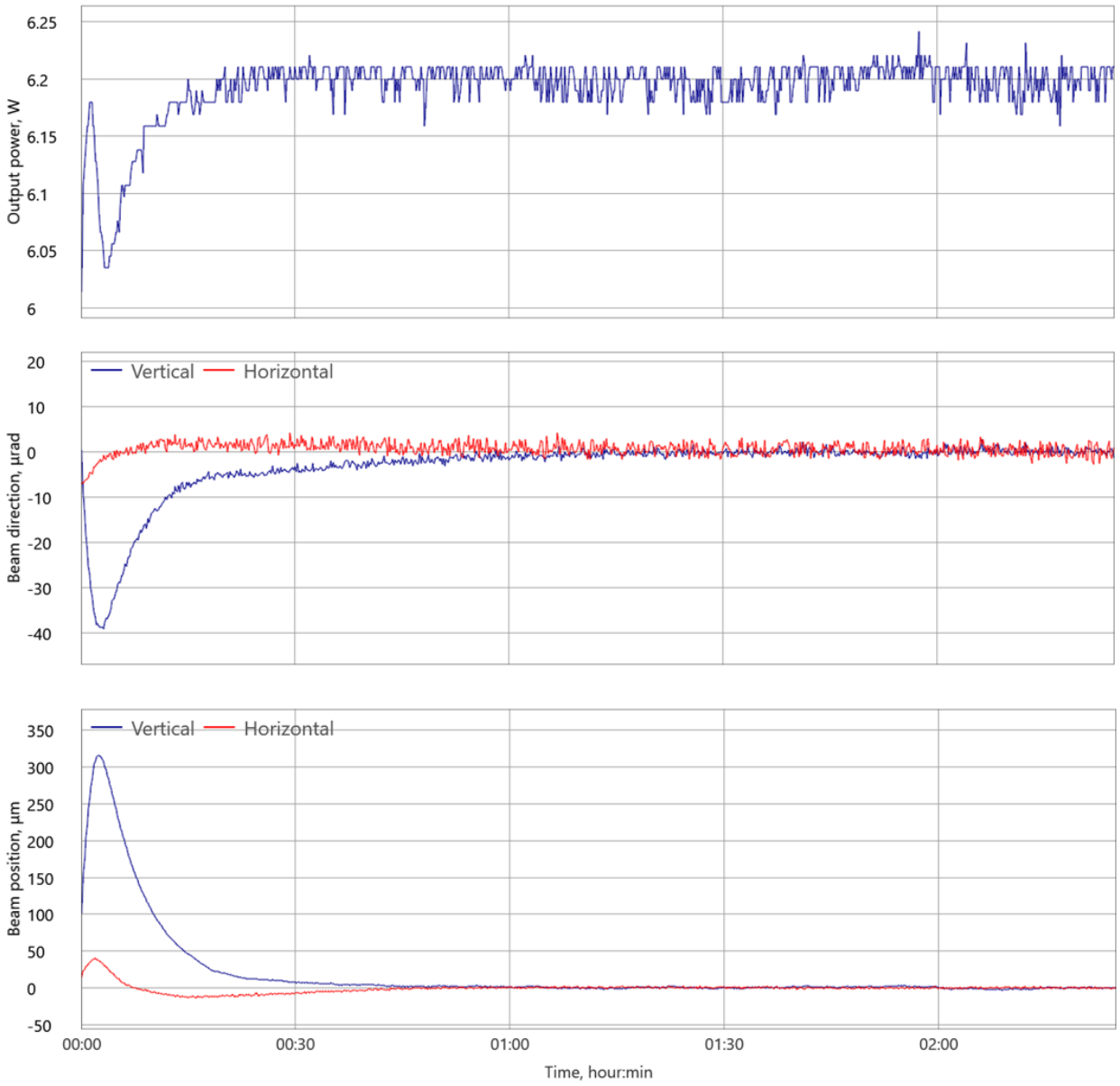
Pulse duration, fs	Position of motor, in steps
min duration (2737)	0
3000	6200
4000	16900
5000	32800
6000	48700
8000	80500*
10000	112300*
12000	144100*
14000	175900*
16000	207700*
18000	239500*
20000	271300*
22000	303100*

- Positive chirp with increasing motor position number (*extrapolated value)

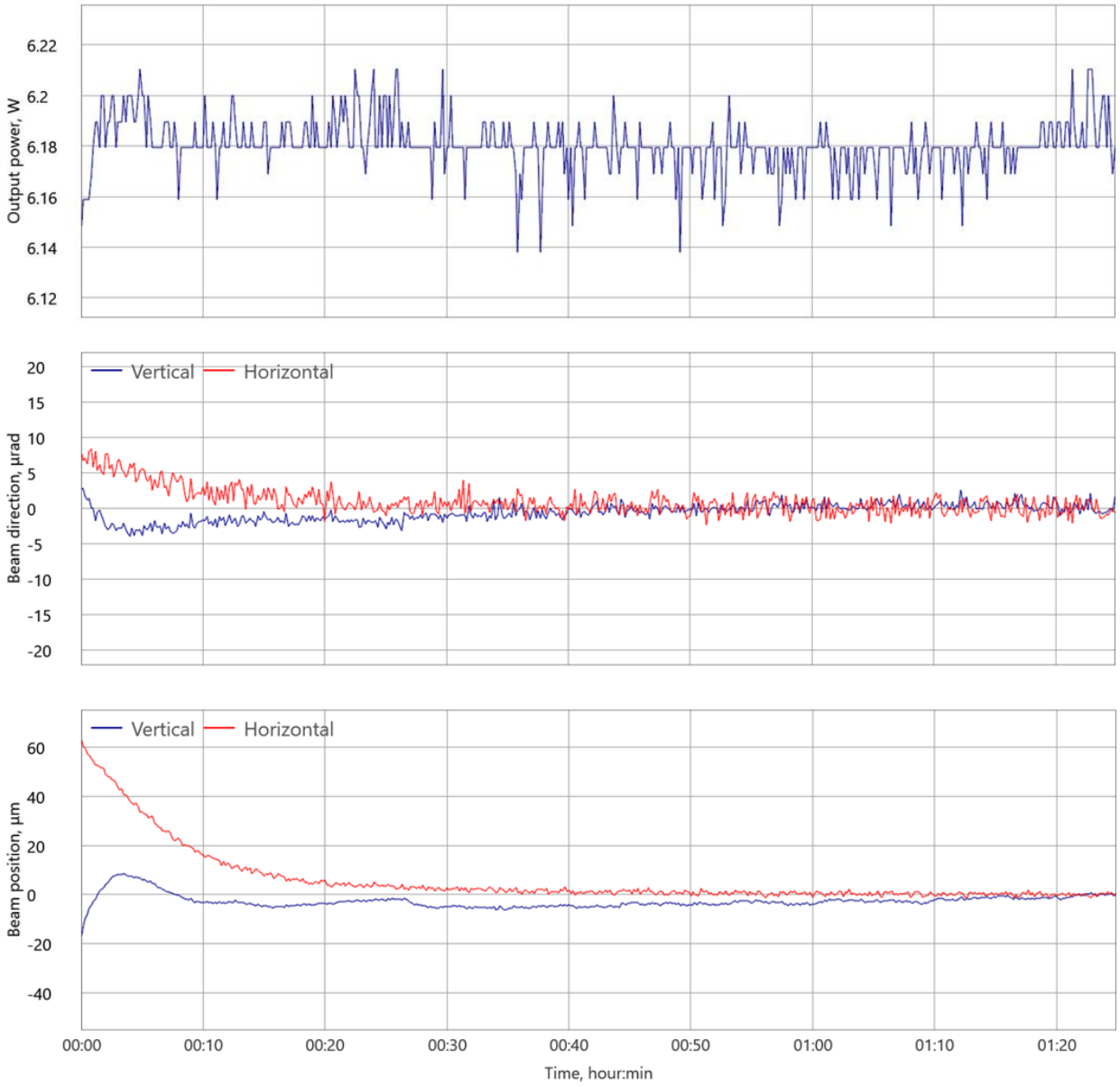
Item	Specified value	Measured value
Polarization	Horizontal >500:1 at 6 W, 200 kHz	Horizontal >2000 :1
Pulse energy stability over 1 minute with power lock On	RMS<0.5% at 6 W, 200 kHz at 3 W, 2 kHz at 6 W, 4 kHz	 <0.18%, 1.8/1040 mV <0.19%, 1.9/1040 mV <0.15%, 1.5/1040 mV
Pulse energy stability over 24 hours with power lock On	RMS<0.5% at 6 W, 200 kHz	 <0.25%, calculated value
Amplitude of a first pulse after PP ON	En1/En(N)=0.97	En1/En(N)=0.99
Pulse contrast ratio at 6 W, 200 kHz	Pre-pulse/Pulse <1:1000 Post-pulse/Pulse <1:200	<1:1000, <3 mV/3000 mV <1:1000, <3 mV/3000 mV
Leakage output power from external pulse picker	<0.5% at 6 W, 200 kHz	<0.1%, <6 mW at 6 W
Influence of PP on internal power meter of RA	<0.5% at 6 W, 200 kHz	<0.1%, <30/32320 counts

3. Output beam pointing and output power stability check

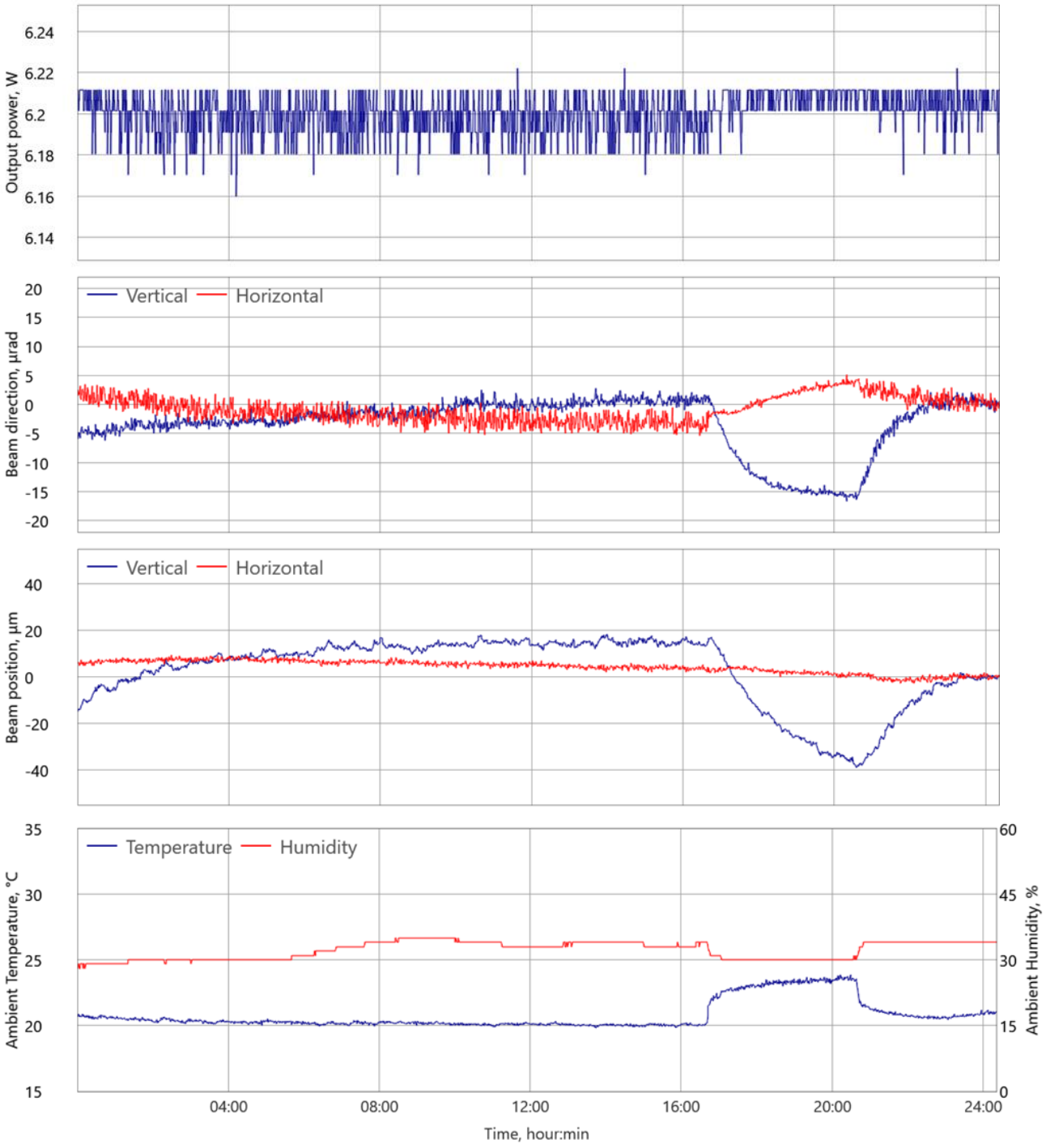
3.1. Cold Start



3.2. Hot Start


Output power, W
6.22
6.2
6.18
6.16
6.14
6.12
Beam direction, µrad
Vertical
Horizontal
20
15
10
5
0
-5
-10
-15
-20
Beam position, µm
Vertical
Horizontal
60
40
20
0
-20
-40
00:00
00:10
00:20
00:30
00:40
00:50
01:00
01:10
01:20
Time, hour:min

3.3. Long Term Stability



Cold start	Hot start	Long term
1. Initial conditions: Output power of the RA is 6 W, 200 kHz, OSC power-locked at operating current (in the middle of ML range) 2. Stop OSC and RA LDDs 3. Set chiller water temperature to 21 °C 4. Wait for 1 hour 5. Set chiller water temperature to 23 °C 6. Start OSC and RA LDDs 7. Start ML 8. Enable OSC power-locking 9. Start the RA, open PP 10. Measure output power, beam direction and beam position for more than 2 hours	1. Initial conditions: Output power of the RA is 6 W, 200 kHz, OSC power-locked at operating current (in the middle of ML range) 2. Stop the RA 3. Wait for 2 hours 4. Start the RA, open PP 5. Measure output power, beam direction and beam position for more than 1 hour	Conditions: Output power is 6 W, 200 kHz, OSC power-lock On, RA power-lock On

	Item	Typical value	Measured value	Page
Cold Start	Output power recovery time	<1 hour to 98% at 6 W, 200 kHz	<10 min	11
	Output beam direction recovery time	<1 hour to 95% at 6 W, 200 kHz	<10 min	
	Output beam position recovery time	<1 hour to 95% at 6 W, 200 kHz	<10 min	
Hot Start	Output power recovery time	<20 min to 98% at 6 W, 200 kHz	<5 min	12
	Output beam direction recovery time	<20 min to 95% at 6 W, 200 kHz	<5 min	
	Output beam position recovery time	<20 min to 95% at 6 W, 200 kHz	<5 min	
Long Term	Output power stability	RMS<0.5 % over 24 h at 6 W, 200 kHz	<0.16%	13
	Output beam direction stability	<20 µrad/°C at 6 W, 200 kHz	<5 µrad/°C	
	Output beam position stability	<50 µm/°C at 6 W, 200 kHz	<14 µm/°C	

4. Parameters of oscillator output

Item	Measured value	Figure
Beam diameter	d_{major} = 1.24 mm d_{minor} = 1.16 mm	Fig. 15
Beam ellipticity	d_{minor}/d_{major}>0.93	Fig. 15
Pulse duration	74.8 fs (Gaussian fit)	Fig. 16
Simultaneous oscillator output	>0.56 W	-
Oscillator repetition rate*	64.9081 MHz	-

*Oscillator repetition rate is measured by internal laser timing electronics. It counts no of oscillator optical clock periods which fits into 1ms. 1ms is defined by 100MHz 25ppm internal quartz oscillator (error +/- 1 oscillator period).

Fig. 15 Oscillator beam profile measurement

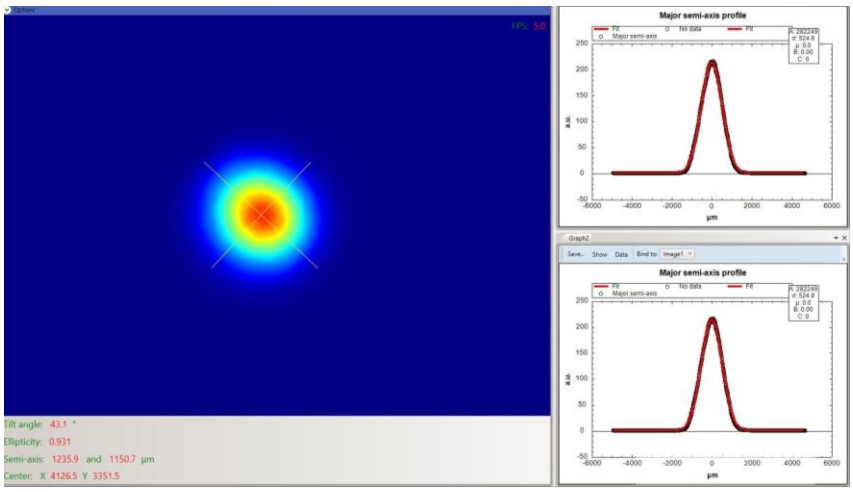
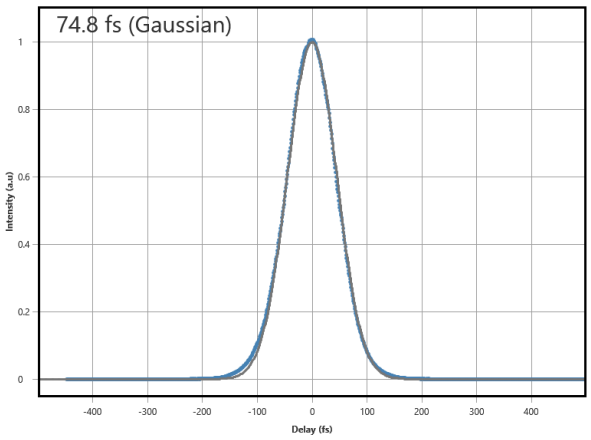


Fig. 16 Autocorrelation function



5. Control and safety functions

	Item	Checked
1.	Oscillator Power-Lock function	OK
2.	OSC sync voltage	2950 mV
3.	OSC sync failure threshold	400
4.	CW detector detects CW component	OK
5.	RA Power-Lock function	OK
6.	Calibration of RA internal power meter	OK
7.	RA level too high error	343 (1650 μJ)
8.	Narrow bandwidth detector functions	OK
9.	Narrow bandwidth signal	3780
10.	Narrow bandwidth failure threshold	1000
11.	PP offset, ns	-7
12.	Safety shutter functions	OK
13.	Interlock functions	OK
14.	Laser settings and functions controllable from PC	OK
15.	Laser diagnostics available through a PC	OK
16.	Laser control through DB15	OK
17.	Analog PP HV control	OK
18.	All critical failures enabled	OK
19.	CAN statistics	OK
20.	Maximum output power is limited at 7 W	OK
21.	Osc. bar operating hours (On/Off times)	679 (57)
22.	RA bar operating hours (On/Off times)	681 (38)
23.	Pharos configuration file check	OK
24.	Chiller water temperature	22.9 °C
25.	Chiller water flow	2.8 L/min
26.	Chiller parameters	OK

6. Overall inspections

Mechanical components fixing inspected	☐ OK
Cables (type, length) inspected	☐ OK
Tubing (type, length) inspected	☐ OK
Stickers inspected	☐ OK
User‘s manual	☐ OK
Additional components included	☐ OK
Packing list complete	☐ OK
Photo of the product	☐ OK
Configuration file name:	PharosL191325_2020-01-29.log

7. Vibration and thermal pre-shipment tests

Vibration Test (Vibro-test): the whole laser head is vibrated for 5 minutes at 50 Hz with max. acceleration of ~ 3±0.3 g.
Thermal Treatment (TT): Chiller temperature is cyclically varied between 15 and 35 ºC within 1 hrs intervals

	Parameter	Before tests	After tests	Pre-shipment test
	Date	2019-12-05	2019-12-06	2020-01-23
RA performance	Bar Pump Current	30.3 A	30.3 A	30.8 A
	Pulse Repetition Rate	200 kHz	200 kHz	200 kHz
	RA On delay/Cavity Dumping Time	21.5/256.5 ns	21.5/256.5 ns	21.5/256.5 ns
	Output Power with open seed (external power meter)	6.33 W	6.27 W	6.31 W
	Output Power with open seed (internal power meter at calibration factor =1)	36110 counts	35864 counts	36299 counts
	Output Power with closed seed (external power meter)	3.39 W (400 ns)	3.36 W (400 ns)	3.39 W (400 ns)
	Output Power with closed seed (internal power meter at calibration factor =1)	18624 counts	18468 counts	18741 counts
	Pre-pulse/Output Pulse Ratio (PP offset -40ns)	<1:1000	<1:1000	<1:1000
	Post-pulse/Output Pulse Ratio	<1:1000	<1:1000	<1:1000
	PP Leakage, Output Power (RA ON, PP OFF)/ Output Power (RA ON, PP ON)	<0.1 % <4 mW at 6.33 W	<0.1 % <3 mW at 6.27 W	<0.1 % <1 mW at 6.31 W
	RA Voltage and Current	2200 V, 12.4 mA	2200 V, 12.4 mA	2200 V, 12.5 mA
	PP Voltage and Current	2219 V, 12.4 mA	2220 V, 12.4 mA	2220 V, 12.5 mA
	RA Bar Temperature	25.5/25.7 °C	25.4/25.6 °C	25.4/25.6 °C
	RA Humidity	31.7 %	21.9 %	22.7 %
	RA Temperature	24.6 °C	24.5 °C	24.6 °C
Oscillator performance	Osc Mode-locking (ML) Range	17.0–16.0=1.0 A	17.1–16.0=1.1 A	17.1–16.0=1.1 A
	Relative ML range	1.0/16.0=0.063	1.1/16.0=0.069	1.1/16.0=0.069
	ML Starting Range	17.5–16.0=1.5 A	17.5–16.0=1.5 A	17.5–16.0=1.5 A
	FI Performance (Osc current; power locked at operating current (RA On/Off))	16.42/16.42 A	16.43/16.44 A	16.43/16.42 A
	Osc. Output (CW) at: The lowest ML Current Operating Current The highest ML Current	 13 mW (16.0 A) 144 mW (16.5 A) 704 mW (17.0 A)	 34 mW (16.0 A) 137 mW (16.5 A) 698 mW (17.1 A)	 14 mW (16.0 A) 174 mW (16.5 A) 841 mW (17.1 A)
	Osc. Output (ML) at: The lowest ML Current Operating Current The highest ML Current	 1195 mW (16.0 A) 1279 mW (16.5 A) 1335 mW (17.0 A)	 1220 mW (16.0 A) 1300 mW (16.5 A) 1356 mW (17.1 A)	 1192 mW (16.0 A) 1275 mW (16.5 A) 1333 mW (17.1 A)
	Osc Bar Temperature	24.9 °C	24.9 °C	24.9 °C
	Osc Humidity	34.8 %	23.0 %	27.6 %
	Osc Temperature	23.3 °C	23.2 °C	23.2 °C
	Ambient Humidity	30.1 %	21.4 %	26.2 %
	Ambient Temperature	23.7 °C	23.6 °C	23.8 °C
	Compressor motor position at optimal pulse compression	0	0	0

8. Testing equipment for laser

1. Output beam measurement

Equipment	Model	Serial number
M^2 meter	Spiricon M2-200S-FW	2005880
CCD	Point Grey GS3-U3-28S5M-C	17550235

2. Output pulse parameters

Equipment	Model	Serial number
Power meter	Ophir Juno	902022
Power meter head	30A-BB-18	646042
Oscilloscope	Tektronix TDS 3064B	B040102
Photodiode	THORLAB DET 10A/M	
Spectrometer	AvanSpec-2048-USB2	1803050U1
Autocorrelator	GECO, Light Conversion	A13105

3. Output beam pointing and power stability

Equipment	Model	Serial number
Power meter	Ophir Juno	902022
Power meter head	30A-BB-18	646042
Module for beam pointing measurement	LC construction	30

4. Vibration and thermal pre-shipment tests

Equipment	Model	Serial number
Power meter	Ophir Juno	902022
Power meter head	30A-BB-18	646042
Oscilloscope	Tektronix TDS 3064B	B040102
Photodiode	THORLAB DET 10A/M	

9. Automated fourth harmonic module

Automated fourth harmonic module was optimized at:

- Rep. rate =1 kHz; P_{laser}=1.5 W*; $\tau_{cavity\ dumping}$= 257.4 ns; $\tau_{RA\ On\ Delay}$= 21.5 ns;
- Compressor position at 34500 steps (pulse duration 4 ps);
- Output energy: >140 µJ @ 257 nm.

Fig. 17 Harmonics module output power **

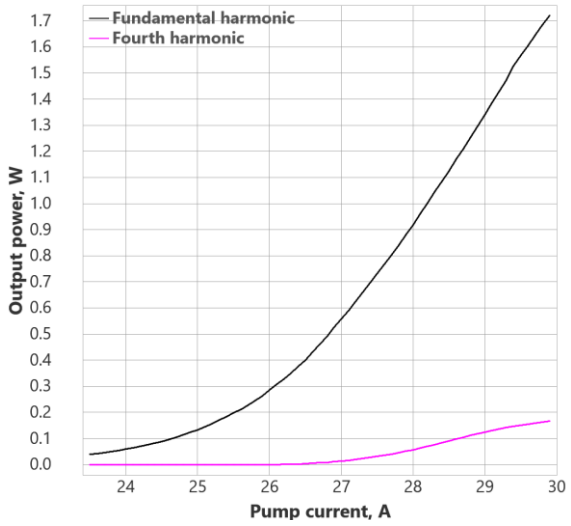
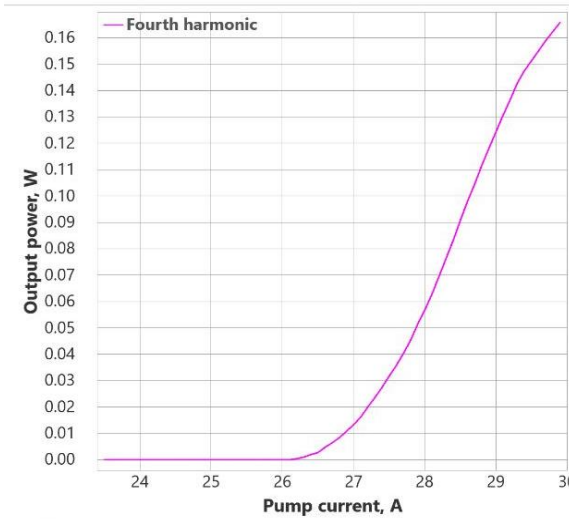


Fig. 18 Harmonics module output power ** (only 4H)



**Internal power meter*

***Angles of 2H and 4H crystals are optimised for best performance at 257 nm*

9.1. Beam parameters of fourth harmonics output

Fig. 19 Beam profile of fourth harmonic at P_{4TH} = 140 µJ

$d_{major@fwhm}$ = 2.37 mm, $d_{minor@fwhm}$ = 2.12 mm (at 30 cm distance)

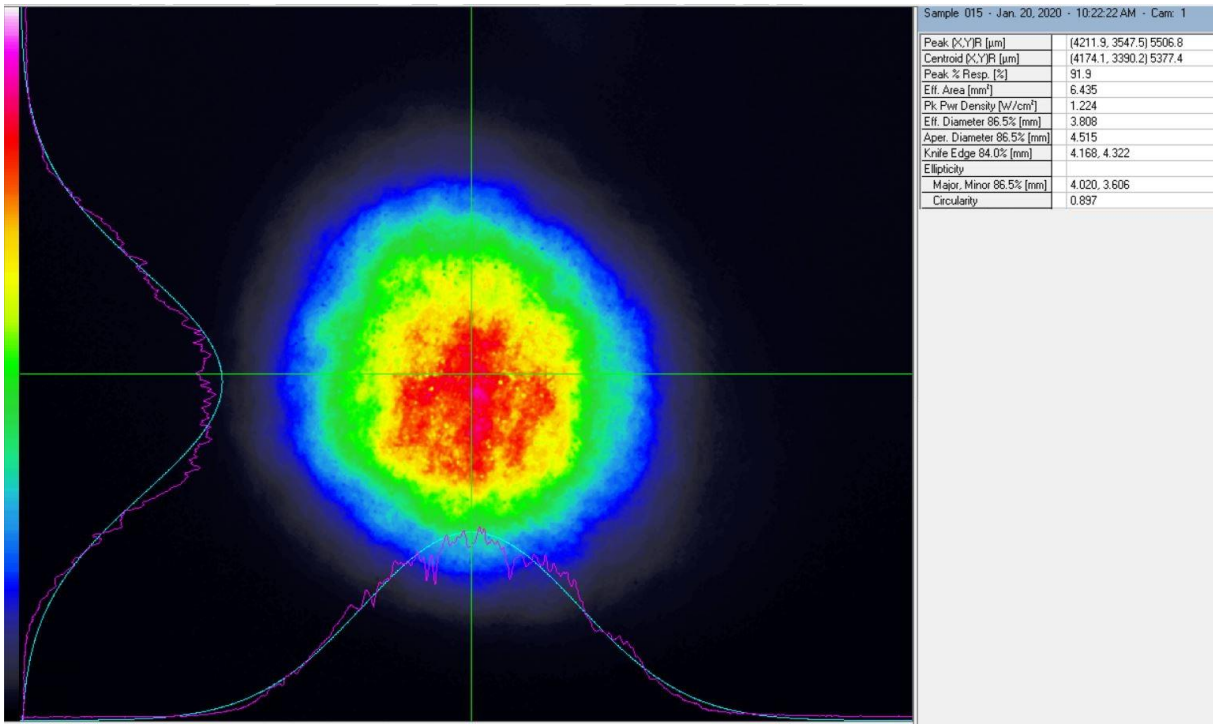
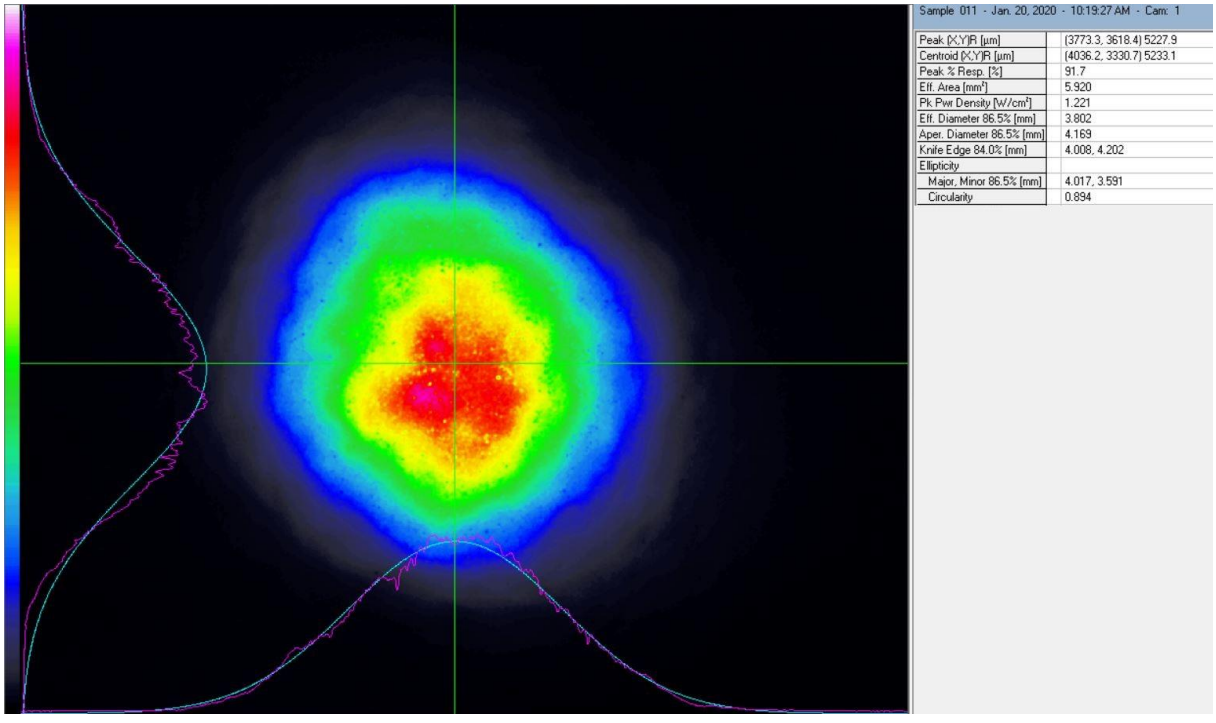


Fig. 20 Beam profile of fourth harmonic at P_{4TH} = 140 µJ

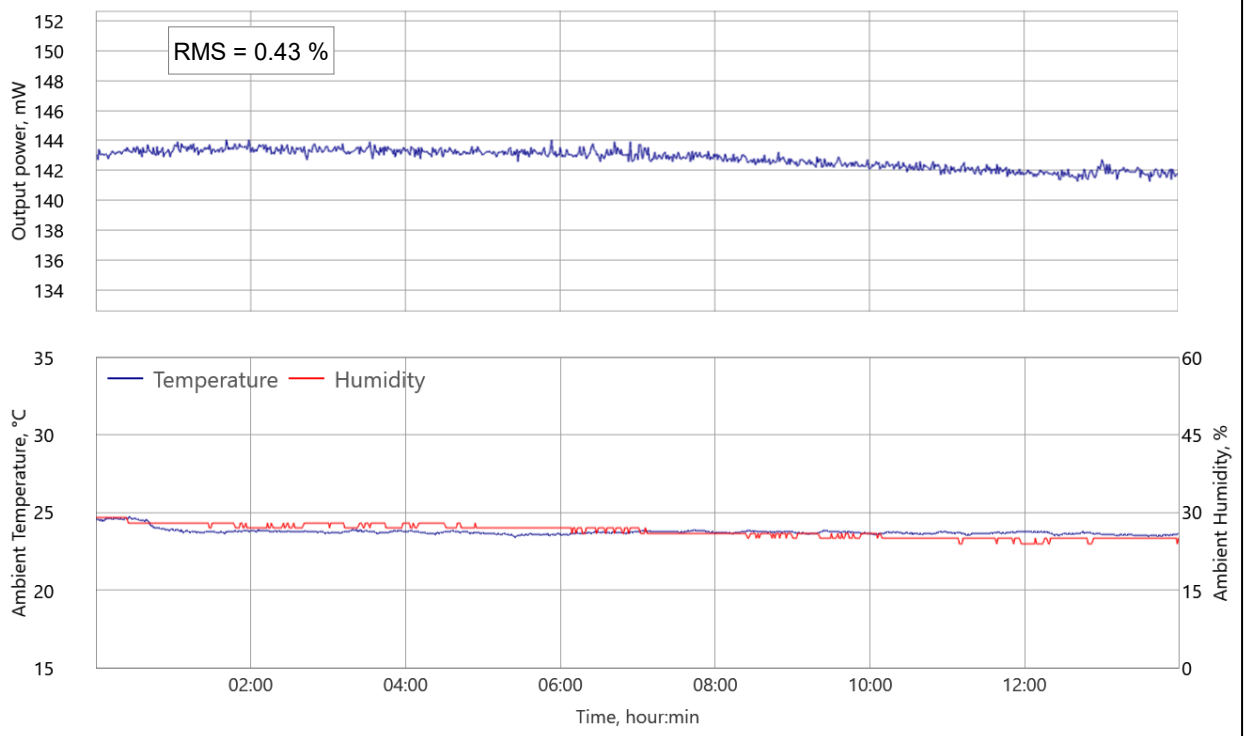
$d_{major@fwhm}$ = 2.37 mm, $d_{minor@fwhm}$ = 2.11 mm (at 200 cm distance)



9.2. Stability of fourth harmonic output power

The output power of harmonic was measured with Ophir power meter.

Fig. 21 Long term observation of fourth harmonic output power at P_{laser}=1.5 W, f_{rep}=1 kHz



10. Testing equipment for harmonic module

1. Output beam measurement

Equipment	Model	Serial number
M^2 meter	Spiricon M2-200S-FW	2005886
CCD	LaserCam -HR-UV	5479H16R

2. Output pulse parameters

Equipment	Model	Serial number
Power meter	Ophir Nova 2	902022
Power meter head	30A-BB-18	646042

3. Output power stability

Equipment	Model	Serial number
Power meter	Ophir Nova 2	902022
Power meter head	30A-BB-18	646042