

# **Third-order cross-correlator**

MODEL Rincon 800-5

## **INSTRUCTION MANUAL**

**Version 2.3**

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Please take time to read and understand this Manual and familiarize yourself with the information that we have compiled for you before you use the product. This Manual should stay with the product to provide you and all future users and owners of the product with important operating, safety and other information.

## GENERAL SAFETY INSTRUCTIONS

In order to ensure the safe operation and optimal performance of the product, please follow these warnings and cautions in addition to the other information contained elsewhere in this document.

**WARNING:** Make sure this instrument is properly grounded through the protective conductor of the AC power cable. Any interruption of the protective grounding conductor from the protective earth terminal can result in personal injury.

**CAUTION:** Before supplying the power to the instrument, make sure that the correct voltage of the AC power source is used. Failure to use the correct voltage could cause damage to the instrument.

**WARNING:** If this instrument is used in a manner not specified in this document, the protection provided by the instrument may be impaired. This product must be used only in normal condition.

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## 1. ACCESSORIES

1. Opto-mechanical assembly -	1 unit
2. Electrical control unit	1 unit
3. Connection cables	
3.1) Cable DB9M (signal black cable)	1 unit
3.2) Cable DB9F	2 units
3.3) AC power cable 110/220 V	1 unit
3.4) USB cable	1 unit
4. Table clamp	4 units

## 2. INTRODUCTION

### 2.1. General information

Third-order cross-correlator RINCON-800 is a device developed for measuring and determining pulse pedestal, pre- and post-pulses and amplified spontaneous emission in a high dynamic range. It is based on third-order cross-correlation technique and provides information about the cross-correlation function of pulse intensity in  $fs$  scale.

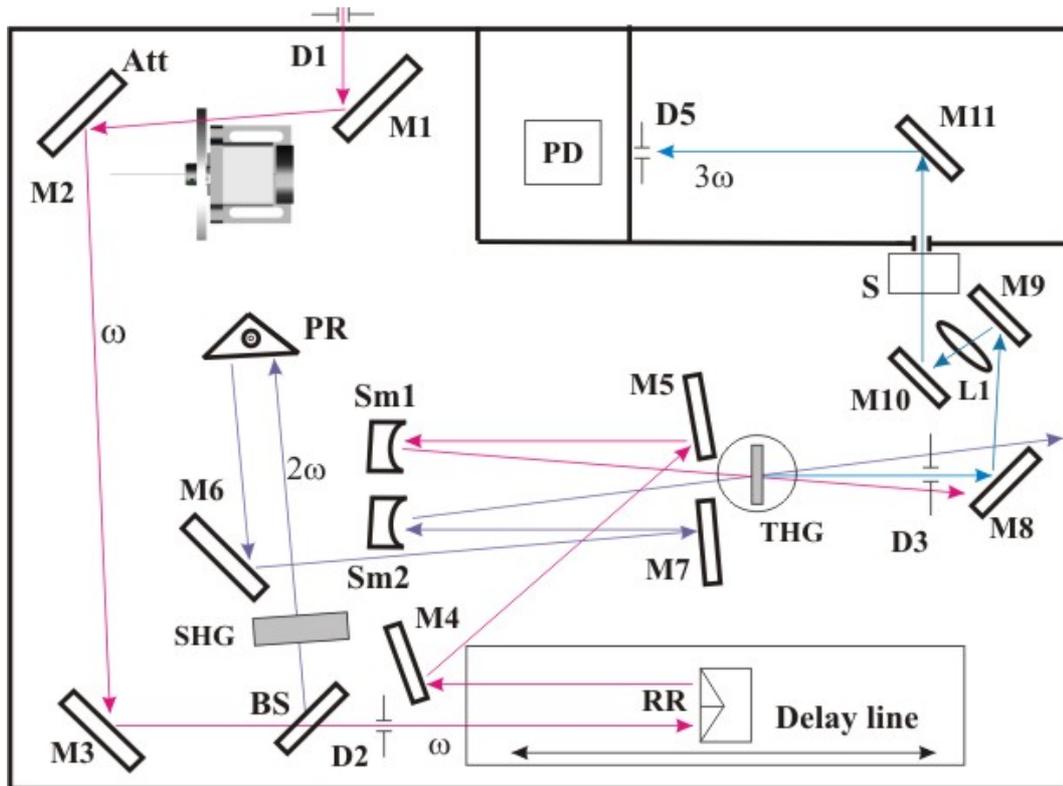


Fig.1. Optical arrangement of RINCON.

The basic optical arrangement of the correlator is depicted on Fig.1. An incoming pulse ( $\lambda=780-820$  nm) splits on two beams in ratio 1:9. The most intensive part reflecting from the beamsplitter BS generates second harmonic (SH) signal ( $\lambda=390-410$  nm) within the BBO crystal (SHG). An adjustable optical delay (RR) is placed into fundamental pulse arm. Polarization rotator (PR) that converts horizontal polarization of the fundamental beam to vertical one is inserted into SH pulse arm. Then two beams (fundamental and SH) are focused onto BBO crystal

for the sum frequency generation (SFG type I). Then TH signal is imaged on photodetector by lens L1 and separated from fundamental and SH ones by slit D3 and two dichroic mirrors S. Dielectric mirrors M8, M9, M10, M11 that have very low transmittance for fundamental and SH beams gives an additional selection. Then TH beam after is incident on photodetector PD that is connected with the control unit. The attenuator optic wheel (Att) is used for attenuation of input fundamental beam.

Detection of TH signal as a function of optical delay between the interacting fields yields the cross-correlation function. High gain and low noise of electronic detector unit and attenuation of fundamental pulse energy provide high dynamic range in TH signal measurement.



Fig.2. RINCON800-5

## 2.2. Key components

Optomechanical unit consists of the further components:

- 1) Crystal BBO, I type,  $\theta=29.2^\circ$ ,  $d=0.2$  mm.
- 2) Crystal BBO, I type,  $\theta=44.3^\circ$ ,  $d=0.18$  mm.
- 3) BS – beam splitter (1:9).
- 4) M6, M7 - dielectric mirrors for SH radiation ( $\lambda=400$  nm).
- 5) PR – geometrical polarization rotator, consisted of three dielectric mirrors for SH ( $\lambda=380-420$  nm).
- 6) M1, M2, M3 – gold mirrors.
- 7) SM1, SM2 – Al and Au spherical mirrors for fundamental and SH beams mixing, focus  $f=250$  mm.
- 8) RR – retroreflector, consisted of three Au mirrors.
- 9) L1 – lens (ARC 220-300 nm,  $f=120$  mm) for TH imaging.
- 10) M4, M5 - gold mirrors.
- 11) M8, M9, M10, M11 – dielectric mirror for UV radiation ( $\lambda=267$  nm).
- 12) D1, D2, D3, D5 – apertures.
- 13) Att – attenuator for fundamental radiation based on diffraction grating.
- 14) S – UV separators.

### 2.3. Theoretical background

We consider an interaction between the femtosecond pulse at  $\lambda=800$  nm with duration  $\tau=50$  fs with the SH pulse ( $\lambda=400$  nm), generated in BBO crystal. Interaction of these pulses in nonlinear crystal leads to sum frequency (specifically, third harmonic) generation at wavelength  $\lambda=267$  nm. SH intensity as function of time delay between fundamental and SH pulses is third-order cross-correlation function.

$$\mathbf{I}_{3\omega}(\tau) = \int_{-\infty}^{+\infty} \mathbf{I}_{\omega}(t+\tau) \mathbf{I}_{2\omega}^2(t) dt. \quad (1)$$

Generally, when dealing with the ultra-short laser pulse sources the effects of group velocity mismatch (GVM) and group velocity dispersion (GVD) have to be taken into account. In this case the effective mismatch:

$$\Delta k_{eff} = \Delta k + \Delta g_{31} \omega' + \Delta g_{12} \omega'' \quad (2)$$

consists of phase mismatch ( $\Delta k = |k_3 - (k_1 + k_2)|$ ) and GVM ( $\Delta g_{31} = 1/v_{g3} - 1/v_{g1}$  и  $\Delta g_{12} = 1/v_{g1} - 1/v_{g2}$ ), where index 1 corresponds to fundamental pulse, indices 2 and 3 correspond to SH and TH harmonics, respectively.

Let us assume the  $\tau_1, \tau_2, \tau_3$  as durations of fundamental, SH and TH pulses, respectively and a  $\tau_{cc}$  as a cross-correlation function width. Because the phase mismatch at  $\tau_1=50$  fs is much less than GV mismatch we can neglect it ( $\Delta k \approx 0$ ). Now we consider two cases.

1) In the case of complete group velocity matching ( $\Delta g_{31} = 0, \Delta g_{12} = 0$ ) the cross-correlation function width:

$$\tau_{cc} = (\tau_1^p + \tau_2^p)^{1/p}, \quad (3)$$

where  $p=2$  and  $1.65$  for Gaussian pulse and  $sech^2$  pulse, respectively.

If the  $\tau_1/\tau_2 > 6$  the function  $\mathbf{I}_{2\omega}(t)$  can be substituted to function  $\delta(t)$ . In this case the cross-correlation function retrieves the fundamental pulse profile  $\mathbf{I}_{\omega}(\tau)$ :

$$\mathbf{I}_{3\omega}(\tau) \approx \mathbf{I}_{\omega}(\tau). \quad (4)$$

2) If the  $\Delta g_{12}L \neq 0$ , this is serious impact on the cross-correlation function width  $\tau_{cc}$ . At the large group delay mismatch ( $\Delta g_{31}L > \tau_1$ ) the cross-correlation function width tends to a limit:

$$\lim_{\Delta g_{12}L / \tau_1 \rightarrow \infty} \tau_{cc} = \Delta g_{12}L \quad (5)$$

where the L is a nonlinear crystal length. At a small group delay mismatch or a long pulse width  $\tau_1$  the cross-correlation function width tends to a limit:

$$\lim_{\tau_1 / \tau_2 \rightarrow \infty} \tau_{cc} = \tau_1. \quad (6)$$

## 2.4. Artifacts in cross-correlation measurements

There are some artifacts in contrast scanning that look like pre- and post-pulses. They originate from multiple reflections from optics inside the cross-correlator. The common cross-correlation trace obtained with RINCON800 is depicted on [Fig.3](#). We have found **3** peaks – at -27.43 ps (on level approximately  $4.5 \times 10^{-7}$ ), at +27.43 ps (on level  $\sim 4 \times 10^{-4}$ ) and at +54.7 ps (on level  $\sim 5-6 \times 10^{-7}$ ) are identified with double and quadruple reflections of fundamental beam in attenuator filter wheel. **Besides of that** there may be two peaks (at -2 ps and at +1.8 ps) on level less than  $1 \times 10^{-5}$  that are attributed to the double reflection of SH beam in SH crystal (d~0.2mm) and double reflection of fundamental beam in TH crystal (d~0.18mm). You should take them into account in your measurement.

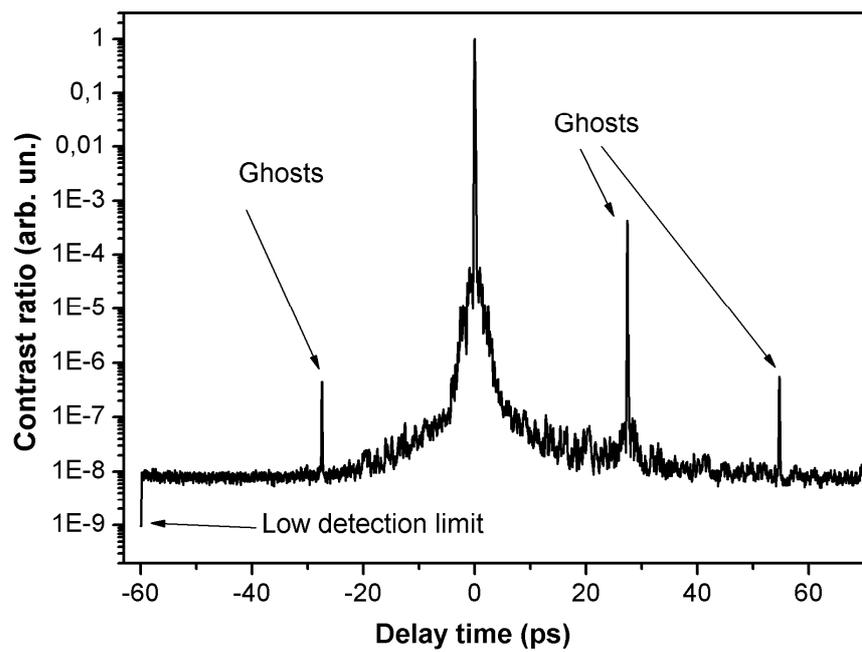


Fig.3. Cross-correlation traces (artifacts).

### 3. SPECIFICATIONS

- Input wavelength - 780 - 820 nm
- Pulse width -  $> 20$  fs
- Input pulse repetition rate -  $< 3$  kHz
- Dynamic range -  $> 10^9$
- Temporal range - 990 ps
- Input energy (at 40-50 fs input pulse duration) -  $\leq 150$   $\mu$ J
- Beam diameter (full) -  $< 8$  mm
- Input polarization - Linear- horizontal
- Resolution - 70 fs
- Electric power - 110/220 V AC, 50/60 Hz  $\pm 10\%$
- Dimensions -
  - optical unit 657mm x 345mm x 210mm
  - control unit 255mm x 200mm x 80mm

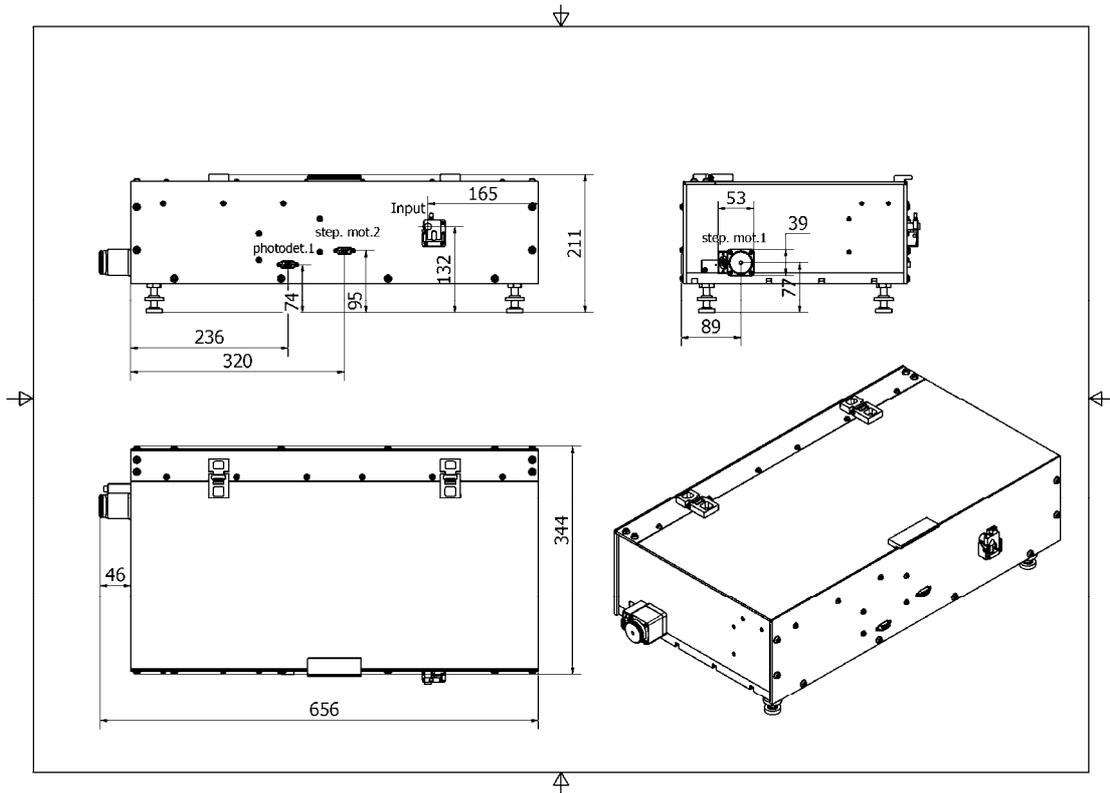
## 4. INSTALLATION AND ALIGNMENT OF RINCON

RINCON was packed with great care and all containers were inspected prior to shipment: the correlator left Del Mar Photonics in good condition. Upon receipt of your laser, immediately inspect the outside of the shipping containers. If there is any major damage, such as holes in the box or cracked wooden frame members, insist on that a representative of the carrier should be present when you unpack the contents.

Carefully inspect generator box as you unpack it. If you notice any damage, such as dents, scratches or broken knobs immediately notify the carrier and your Del Mar Photonics Sales representative.

Open the cover of the box head and remove the bags that cover the elements of RINCON. **Just cut elastic bands that fasten the bags and pull the bags!** Otherwise you can misalign the device and even damage optical elements. After that remove the residue from the elastic bands.

**Especially take care of attenuator because it can be very easy damaged!**



**Fig.4.** Outline drawing of RINCON800-5.

RINCON consists of opto-mechanical box, control unit and connection cables. Box has two outlets for stepping motors of delay line and filter wheel (st.mot.1 and st.mot.2, respectively) and one outlet for photodetector (Photodet.1) (Fig.4).

- 1) Install control unit near the main box.
- 2) Connect control unit and optical box via three connection cables. Connector with “Step.mot.1” mark should be connected to connector “Step.mot.1” on the side of the opto-mechanical box and connector “Step.mot.2” must be connected to “Step.mot.2” connector on another side of the box.
- 3) Black DB9M cable connects two outlets “Photodet.1” on opto-mechanical box and control unit.
- 4) Connect the control unit and computer via USB cable applied.
- 5) Apply a positive synchronous signal with amplitude of 4-15 V and duration not shorter than 0.5  $\mu$ s in the BNS outlet “Trigger” of control unit. The repetition rate must be the same as repetition rate of laser source. Before

starting a work you need to adjust the synchronous signal with laser pulse using the oscilloscope and avalanche diode. **The leading edge of synchro-signal must be in advanced before the leading edge of laser pulse on 150-200 ns.**

- 6) Install optical unit of RINCON on the optical table horizontally approximately at the same height as the pump beam. Use low screws to adjust a level. The level of input beam outlet is  $135 \pm 5$  mm (Fig.4).
- 7) Before you get started you need to set the input radiation power. You should have a possibility to change the input power gradually. We recommend you to start with input radiation energy  **$80 \mu\text{J}$** .
- 8) Direct the beam through the apertures D1 and D2 (see. Fig.1). Flip the diaphragm D1 to “down” state. Insert a visualization IR card after the D2 (Fig.5). Let the beam pass through the D2 so that a dark dot (from a beam diffraction on D1) must be on the center of the beam spot after D2. Flip the diaphragm D2 to “down” state.



Fig.5. Diaphragm D2.

- 9) Turn on control unit and set the attenuator optic filter wheel in position №2 (See **6. Measurement procedure**).
- 10) Insert the piece of white paper before the separator S.
- 11) The delay line must be in “0” position (far edge of carriage should point on the mark “0”).
- 12) If the TH doesn't appear change turn optic filter wheel to the position № 1.
- 13) Try to detect TH signal by eye moving the delay line with RR handle (**turn off the control unit before**) in clockwise and anti-clockwise directions approximately on  $\pm 5$  mm. *If you still have a problem with TH signal detection contact us for further help instructions.*
- 14) Check that the TH beam reflects from the mirrors M9 and M10 freely.
- 15) Be sure that the TH spot is not cut off on the aperture D3. Shift the D3 if it necessary ([Fig.6](#)). At the same time check that the SH signal doesn't propagate through the D3 at all.
- 16) Open the small black box and check that TH beam passes through the separator S freely, reflects from a mirror M11 and then check that it is incident on the center of the aperture D5. Adjust the M11 if it is necessary.
- 17) Now the box is installed and you can go to signal measurement with the knowledge of software description.

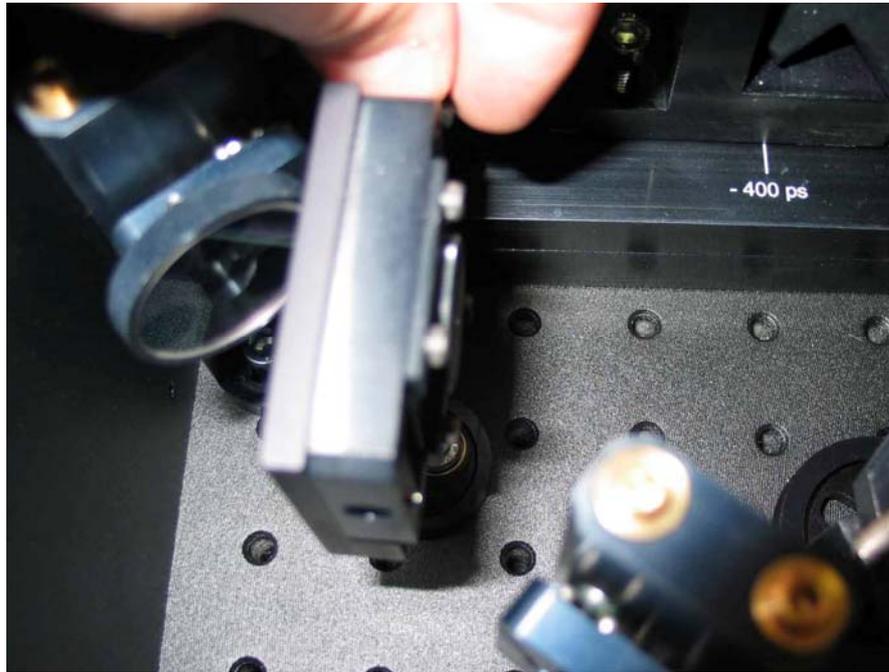


Fig.6. D3 aperture.

## 5. WORKING WITH SOFTWARE AND HARDWARE

### 5.1. Software installation

Device software consists of Contrastmeter software and drivers. Electronic control unit connects with the computer via USB 1.1 interface.

1) There are two parts of software on the CD: drivers and main program. Copy directory *\Drivers\* to your directory on a hard disk.

2) Connect the control unit with your computer via a USB cable. Turn on the control unit.

3) When the computer indicates that it finds a *New Hardware*, point path to a directory with drivers and follow the installation instructions.

4) Launch *Setupe.exe* (main software) and follow installation instructions.

If the software is installed successfully, it will find the hardware automatically.

## 5.2. Settings

Main menu contains all functional potentialities of the hardware. It contains four sub-menus (Fig.8).

The sub-menu “File” can be used for saving and opening project files and for exporting and printing the data.

Sub-menu “Device” contains commands calling settings dialog frames including: 1) settings and 2) adjustment.

All commands in sub-menus are duplicated on “Control panels”.

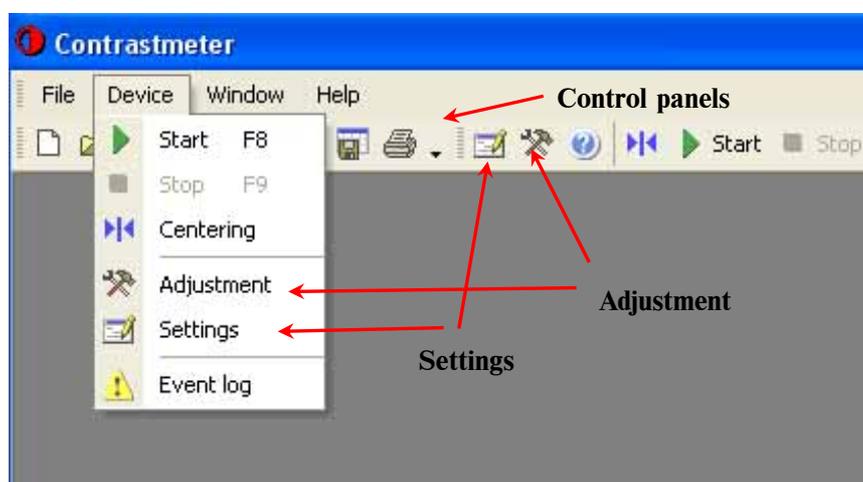


Fig.7. Main software frame.

Before getting started you need to specify hardware preferences that given in “Settings” (see Fig.8).

*Length* is a total range of delay line given in the motor steps. It equals to a total number of the motor steps from initial limit switch to final limit switch. It is obtained from calibration (see 6. “**Measurement procedure**”).

*Zero position* is a number of motor steps from initial switch to position where the maximum of signal is achieved.

*Step motor period*, ms, is a time between driving pulses applied to stepping motor in delay line. **Strongly recommended value is 4 ms.**

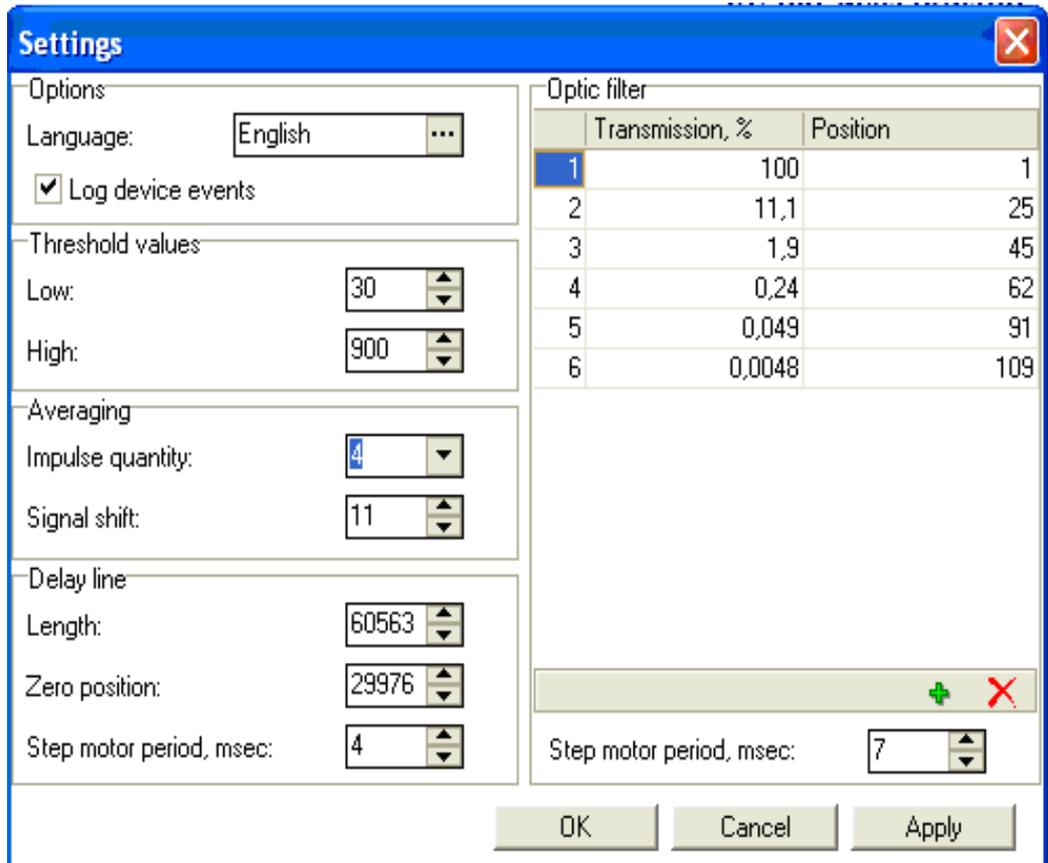


Fig.8. Settings.

*Transmission of attenuator optical filter, (%)* are attenuator transmittance values for each position in the set. Each position is given in steps from initial limit switch.

You need to make calibration each time when you go test another system or the wavelength of you system changes. See **Appendix A** for calibration procedure description. First time you might use values from Fig.8.

*Step motor period of optic filter, ms,* is a time between driving pulses applied to stepping motor in filter wheel. **Strongly recommended value is 7 ms.**

*Low threshold and high threshold* are the values that limit real signal. Recommended values are **30** and **900**, respectively.

*Averaging impulse quantity.* The number of measurements made on each step of delay line. It is determined by the repetition rate of your laser system and the scale of laser fluctuations.

*Signal shift* is a positive shift of delivered signal. It is property of electronics and it is should be maintained as **11**.

*Log device events*, allows the log read in file.

*English (Russian)* you can choose appropriate language.

### 5.3. Adjustment

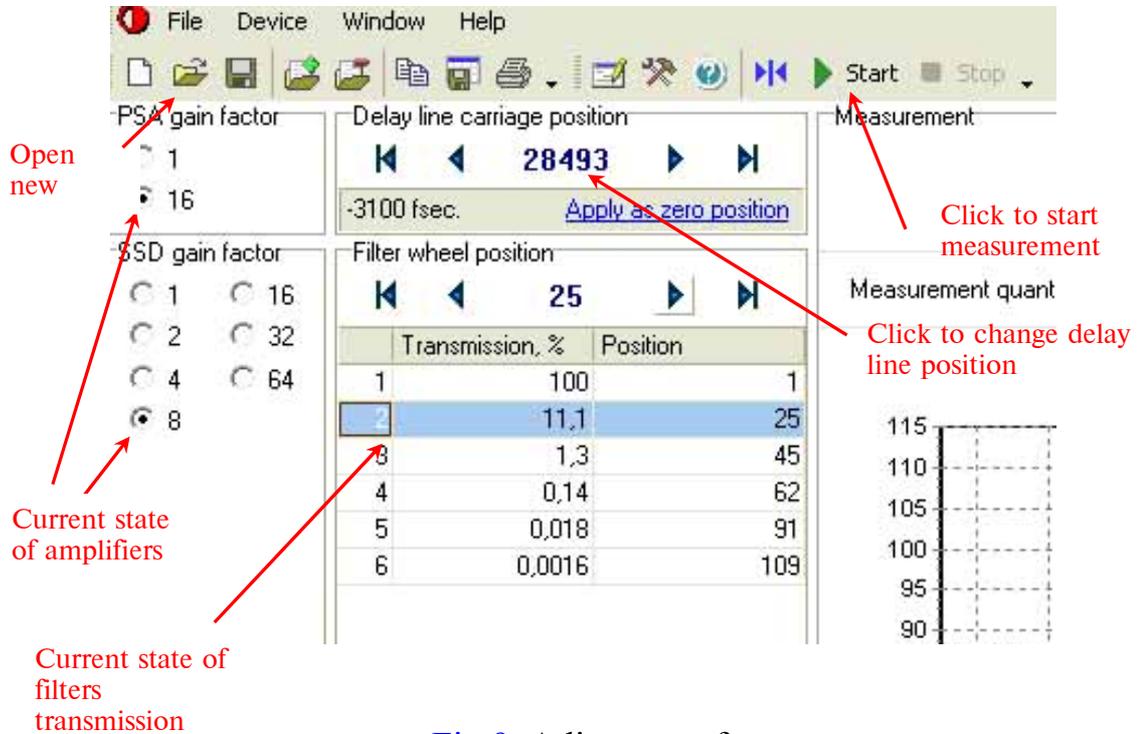
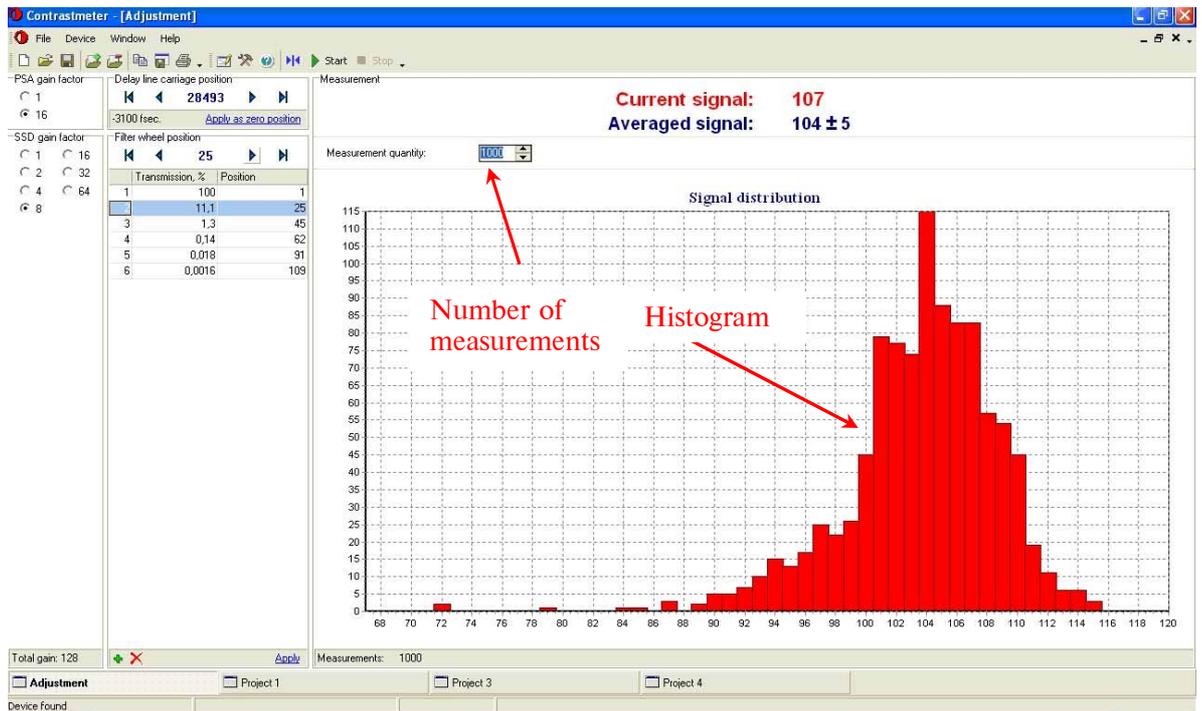


Fig.9. Adjustment frame.

This mode should be used for alignment. Its panel contains further options:

Signal level is delivered from the output of analog-digital converter (ADC) in the range from 11 to 1000 units. There are two amplifiers -- photosensor array (PSA) amplifier and storage-selection device (SSD) amplifier – and attenuator wheel with 6 (or more) positions of attenuation. PSA gain has two discrete values (1 and 16); SSD gain has 7 discrete values (1, 2, 4, 8, 16, 32, 64). So total gain varies from 1 to 1024. You can change PSA and SSD gain manually. Also the optic filter position could be changed manually by double click on the filter position stroke.

You can measure signal at any delay line position. Click on the central bar at the carriage position panel (see Fig.9) and set the number of delay line steps or value in *fs* where you want to move delay line. The button  moves delay line on one step and the buttons  and  move the carriage to initial or final limit switch, respectively.

Button “Start” start measuring the signal level. You can see at the screen histogram of signal (dependence of measurements number on signal level). Button “Stop” stops the measurement.

#### 5.4. Scanning

Scanning mode is a main mode of the software (Fig.10). In this regime dependence of the contrast ratio on the delay time between fundamental and second harmonic pulses is obtained. To start measuring open a new project. *Initial shift*, *Final shift* (delay) are set in *fs*. *Step* is set in units of motor steps. Motor step is equal to 16.6667 *fs* and is fixed (Fig.11). Press button “Start” to make a contrast measure. Software will start the scan. It will automatically change the amplifiers gain or attenuator wheel transmittance when the signal goes beyond thresholds. Contrast ratio is shown in dB. During the measurement, step by step, the signal is normalizing on the local maximal value of signal. Generally speaking, each local maximum will be normalized on 1 unit.

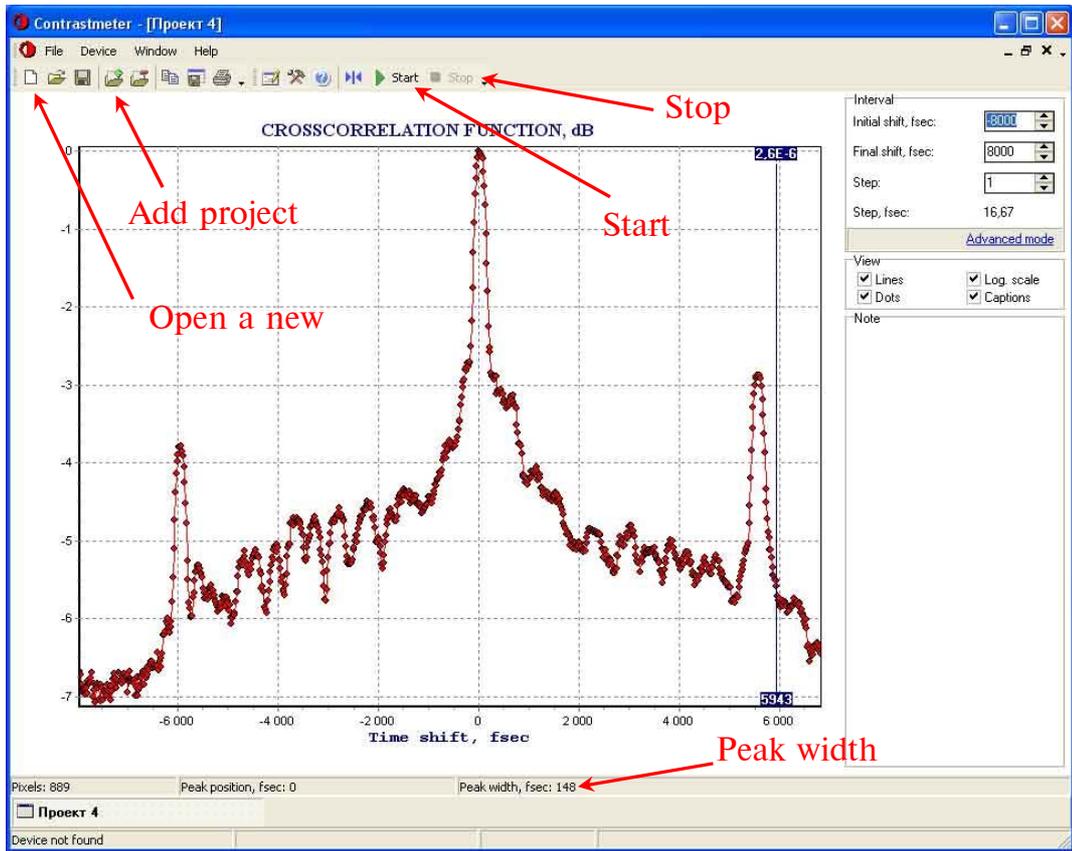


Fig.10. Scanning mode.

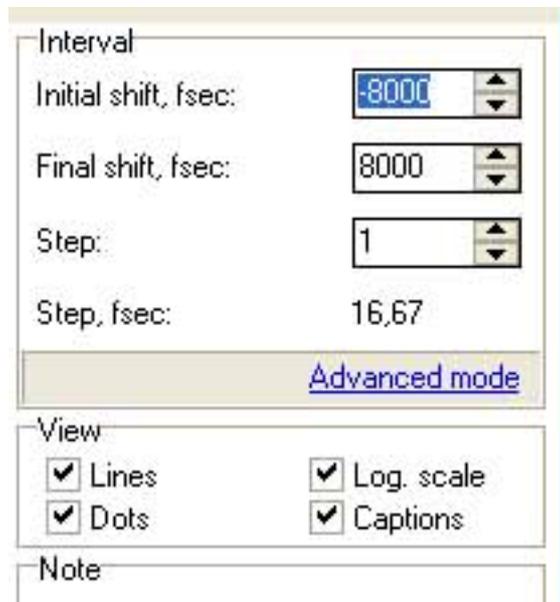


Fig.11. Simple sequence of delay shifts.

Interval		
Shift, fsec	Step	Step, fsec
-4015	1	16,67
2981	4	66,67
31581	1	16,67
34623		

[Standard mode](#)

View

Lines       Log. scale  
 Dots       Captions

Note

Fig.12. Advanced mode of delay shifts.

*Advanced delay line sequence* is switched when you click “Advanced mode”.

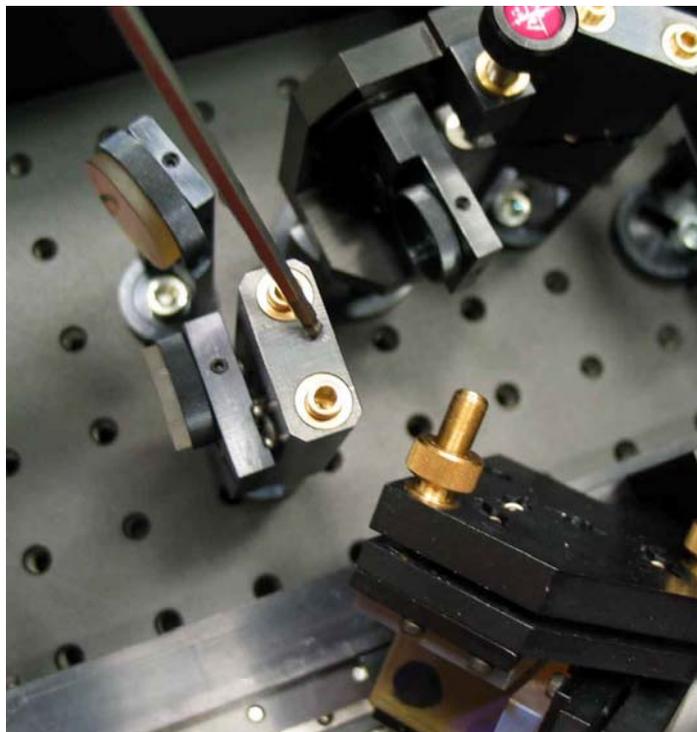
The values for advanced delay line sequence consist of initial delay time and group of simple delay line sequences that are defined by their own delay step and final delay time (Fig.12). Initial delay time for  $i$  sequence is a final delay time for  $i-1$  sequence. Delay line sequences must be specified in ascending order. To add or delete sequence you should click on green or red cross, respectively.

Advanced mode can be useful for detailing some regions in intensity-delay time distribution when the measurement takes a long time.

## 6. MEASUREMENT PROCEDURE

Before starting measurements you need to optimize TH energy.

- 1) If you detect TH signal by eye launch the “Contrastmeter.exe” and try to maximize TH signal with software.
- 2) Set parameters in “Settings”. In needs calibrate the filter wheel (**Appendix A**). **At the beginning you can use default optical filter calibration** (see [Fig.8](#))
- 3) Switch to “Adjustment” mode. Set filter wheel in the last position №6 (minimal transmittance) and set total gain factor as 4 or 8.
- 4) Measure the signal. If it is lower than low threshold increase the gain factor. If it is higher than upper threshold decrease the gain.
- 5) Set the averaging number **4-8** if you have 10 Hz repetition rate laser source and **16-32** if you have 1kHz laser.
- 6) Adjust vertical and horizontal screws of mirror M7 to achieve the maximum of the TH intensity (see [Fig.13](#)). **Do it very carefully!** Look at the current signal in “Adjustment” mode frame.



[Fig.13](#). M7 mirror.

- 7) Adjust the screw of the THC mount to achieve the maximum of the TH intensity (see Fig.14).

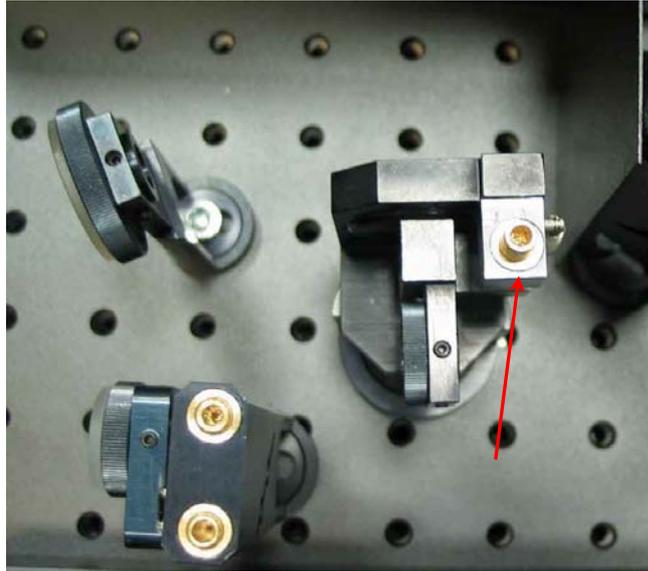


Fig.14. TH crystal.

- 8) Move delay line on one or two steps back or forward to get the maximal TH signal.
- 9) Adjust vertical angle of SH crystal to get the maximum of TH signal (see Fig.15).

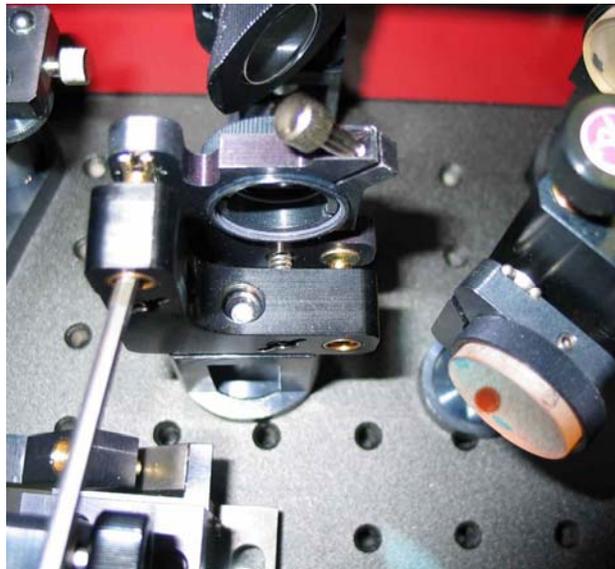


Fig.15. SH crystal.

- 10) Repeat steps 5), 6) and 7) until the maximum of TH is achieved.
- 11) Increase gradually the input energy of fundamental pulse until the signal achieve approximately 300 units (at filter wheel position № 6 and total gain

factor - 2). **Don't increase the energy higher than 150  $\mu$ J (at full beam diameter of 8 mm)!**

- 12) Click on "Apply as zero position" in the delay line frame.
- 13) You don't need to make a delay line calibration because it was already done in Del Mar Photonics.
- 14) Now you can switch to the contrast measurements.
- 15) Open a new project. Set appropriate *Initial shift*, *Final shift* and *Step* or a sequence of delay line shifts (See **5.4. Scanning**)
- 16) Press the button ("Start"). Process can be stopped if you press the right button "Stop". To continue the measurement press ("Start") again.
- 17) If the measurement finish save the file and/or export a data to *.dat* file.
- 18) Software remembers the delay line position when you turned off the control unit. So when you turns it on next time the software will show you delay line position in which you left it.

## Appendix A

### Calibration of attenuator wheel.

- 1) Shift delay line stage from “Zero position” approximately on -3000 fs.
- 2) Switch to “Adjustment mode”. Set PSA gain factor as **16**, SSD gain factor as **8** and switch the filter wheel on the **1st** filter position. The **1st** attenuator position is always 100 %.
- 3) Measure the signal. The signal value must be approximately 300-600 units. If the signal is higher than high threshold, shift the delay line carriage away from “Zero position”. If the signal is lower than low threshold shift the delay line carriage closer to “Zero position”.
- 4) Measure the signal again. Remember its value.
- 5) Switch the filter wheel on the **2nd** position (for instance, unknown xx% of transmittance). Then raise the SSD gain factor to **16** or **32** (if it is necessary) so that the signal value will be in the range from 200 to 600 units.

Transmittance of 2nd filter can be calculated according to equation:

$$XX(\%) = \frac{S_2 G_1^{SSD} G_1^{PSA}}{S_1 G_2^{SSD} G_2^{PSA}} 100\%,$$

where  $S_1$  – the signal at the 1<sup>st</sup> filter,  $S_2$  – the signal at the 2<sup>nd</sup> filter,  $G_1^{SSD}$   $G_1^{PSA}$  - SSD and PSA gain factor, respectively, at the 1<sup>st</sup> filter,  $G_2^{SSD}$  and  $G_2^{PSA}$  - SSD and PSA gain factor, respectively, at the 2<sup>nd</sup> filter. The 3<sup>rd</sup> filter will be calibrated respecting to the transmittance of the 2<sup>nd</sup> filter and so on.

- 6) Calibrate the other filters in the same way.
- 7) Set the attenuator transmittance values in “Settings”. **Don’t modify the values of filter wheel position!**

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