Laser Measurement System

Laser Scale LS10

Installation and Operation Manual

Lasertex
LASER METROLOGY FROM POLAND

Rev. B.2

1. Contents

2. Device characteristics

Laser Scaler LS10 laser is a device for measuring displacement with high accuracy and resolution. The measurement is performed on the basis of a laser interferometer. The heart of the device is the frequency-stabilized, two-mode helium-neon laser working on the laser line length of 633nm. The device operates in the homodyne interferometer configuration (see Annex).

The device can be used either for single or for dual channel measurements. Dual channel measurements require an additional optical receiver, optical path elements and compensation unit.

The main elements of the Laser Scale are: the Laser Head, the Environmental Compensation Unit and elements of the optical path with the Optical Receiver.

The Environmental Compensation Unit is a device for increasing accuracy and/or resolution of position encoders like laser, glass or magnetic scales. Also the accuracy of a machine where the position encoder is mounted can be increased.

The device modifies the signal from the position encoder in real time in dependence on the thermal expansion of the encoder, the machine and the workpiece.

The output of the device i.e. the measured shift, can be read either over ***USB*** interface, through ***OUTPUT*** connector (A-quad-B signal format) or through ***AUX*** connector.

The device works in two modes. The first mode is used for compensation of non-laser position encoders. For operation the temperatures of the scale, the workpiece and the machine structure are taken for compensation.

The second mode is used for compensation of the laser scales. In this mode the device compensates automatically changes in the laser wavelength caused by changes in the environmental conditions and the base expansion due to the base temperature changes. The environmental parameters can be also programmed into the device over the USB interface. The environmental parameters set as default are:

- air temperature: 20 degrees Celsius
- air pressure: 1013.2 hPa
- air humidity: 50 %
- base temperature: 20 degrees Celsius

2.1. Components of the device

The complete delivery of the Laser Scale LS10 device consists of:

- 1 x Laser Head LH-02
- 1 x Environmental Compensation Unit ECU-02,
- 1 x 12VDC power supply,
- 1 x scale temperature sensor,
- 1 x workpiece temperature sensor,
- 1 x structure temperature sensor,
- 1 x air temperature sensor,
- 1 x Optical Receiver OR-1,
- 1 x USB cable,
- 1 x linear interferometer IL1 ,
- 1 x linear reflector RL1,
- 2 x magnetic mounts.

2.2. Safety considerations

The Laser Scale LS10 is a Safety Class I product designed and tested in accordance with international safety standards. It is also a Class II Laser product conforming to international laser safety regulations. The instrument and the manual should be inspected and reviewed for safety markings and instructions before operation.

2.3. Warnings

Although the Laser Scale LS10 is design to be used in harsh environment, the following conditions must be met:

- The laser head must not be put near strong magnetic fields.
- The head must not be thrown or dropped.
- Keep the optical components clean and avoid scratching them.
- When the optics is dusted, clean it with pure alcohol.
- Do not use the system beyond its work conditions.

3. Device operation – laser measurements

Depending on the purchased configuration (LS10-1 or LS10-2) either single or dual channel measurements can be performed. Below there are shown standard optical configurations for both versions. Depending on the need another versions can be used, e.g. a flat mirror configuration or a version with a more complex beam delivery part.

3.1. Standard single channel configuration

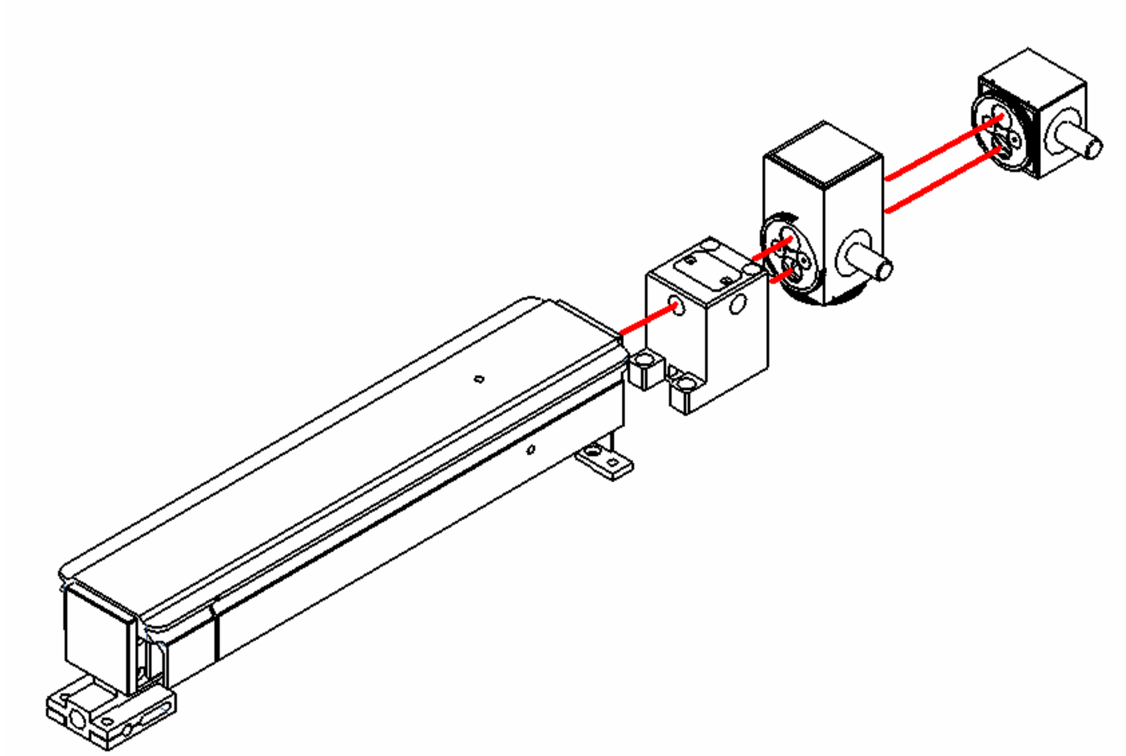


Fig. 3.1. *Standard single channel configuration of the LS10*

In the single channel operation as shown, in the figure 3.1, the Laser Scale requires in the optical path three elements: Optical Receiver OR-1 , Linear Interferometer IL1 and Linear Reflector RL1. In order to make measurements not along the Laser Head additional beam benders (e.g. high quality mirrors) have to be used.

3.2. Standard dual channel configuration

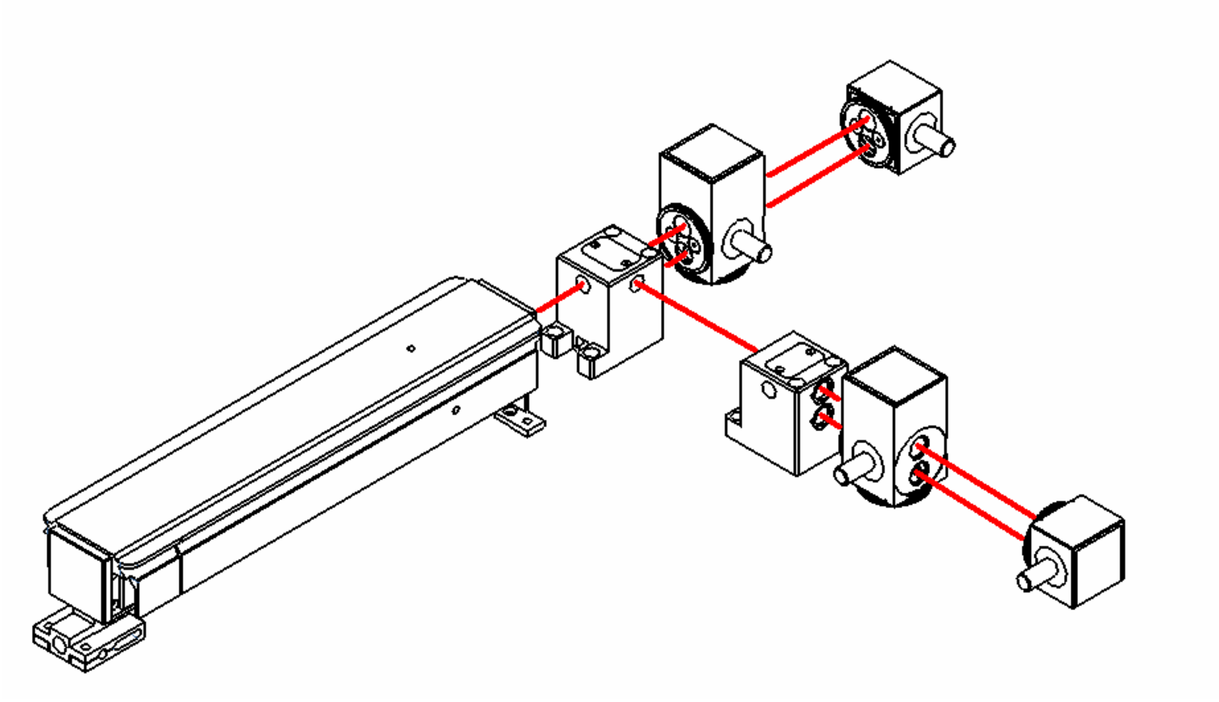


Fig. 3.2. *Standard single channel configuration of the LS10*

In the dual channel operation as shown in the figure 3.2 the Laser Scale requires in the optical path the same elements like in the single channel operation but doubled for the second channel. In order to make measurements not along the Laser Head beam benders included in the delivery or some other high quality optical elements can be used.

3.3. Optical elements in the optical path

The Laser Scale LS10 measures displacement between linear interferometer IL1 and reflector RL1. It is not important whether the moving element is the interferometer or the reflector or both. It is important though that the direction of movement of both elements is along the laser beam. In the path of the laser beam, in addition to the interferometer and reflector, there is placed an optical receiver (Detector in the Fig. 3.3). The detector (optical receiver) converts the electrical signal intensity of the returning beam into the electrical signal.

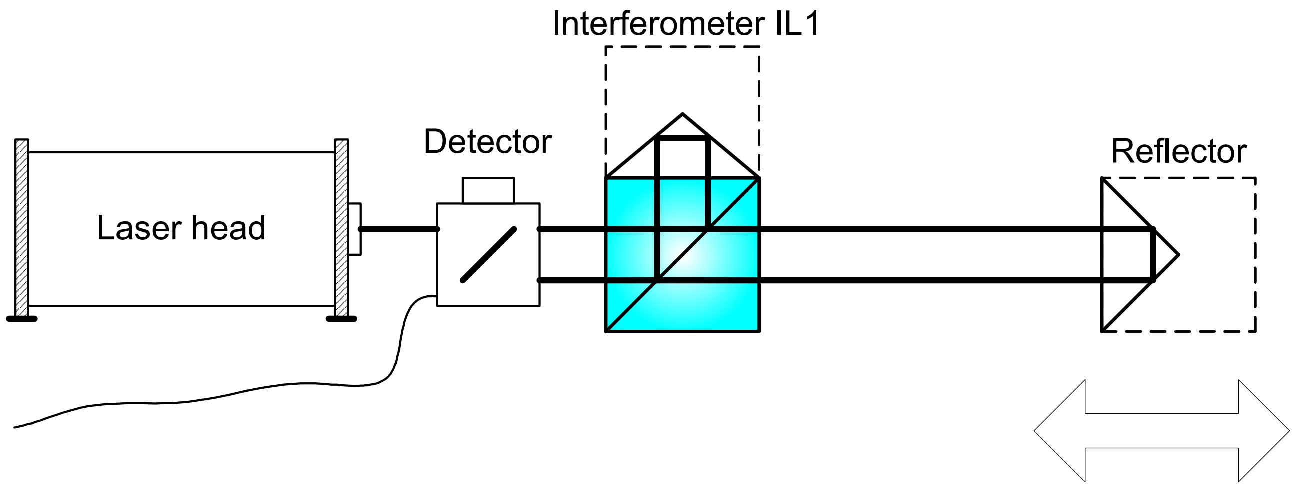


Fig. 3.3. *The way of setting the optical elements in the optical path*

When setting the optical elements it should be taken into consideration that, while the reflector and the detector can be placed anywhere in the measuring path, the interferometer IL1 should be placed in a location that, in one of the extreme positions, is as close to RL1 as possible. In this way the dead path error is minimized (see Annex).

3.4. Preparing for operation

Start-up procedure:

1. Place the Laser Head LH-02 on the measured bench,
2. Connect the laser head connector to the socket LASER on the front panel of the supply box. IMPORTANT!!! Make sure that that the connector sits well in the socket. Screw the connector to the socket!
3. Connect the optical receiver OR-1 to the DETECTOR socket

a. For dual channel devices second ECU-01 or ECU-02 unit has to be used

4. Connect USB cable (if necessary)
5. Connect OUTPUT cable (if necessary)
6. Connect temperature sensor(s) to TEMP socket(s)
7. Insert power plug to PWR socket

3.4. The procedure for adjusting the optical path

For proper operation of the device, the optical path has to be properly adjusted. This means that the laser beam must be parallel to the trajectory of movement of the reflector (or interferometer).

Fig. 3.4. *Reflector RL1 and interferometer IL1 with diaphragms set into work position.*

In order to facilitate proper beam path adjustment on the interferometer IL1, the reflector RL1 and the receiver OR-1 there are placed diaphragms (see fig. 3.4). During optical path setting the diaphragms should be adjusted so that the beam falls on the white place with a tiny hole (alignment position). At the end of adjustment procedure the diaphragms should be moved to the so-called working position (beams can not "lick" diaphragms).

In order to properly set the optical path, please follow these steps:

1) Place the laser head in position. Connect the detector and the computer. Wait for the stabilization of the laser (the green LED (READY) on the front panel should be on).
2) Insert the optical receiver in the optical path so that it is positioned in line with the laser head. The laser beam should fall on the upper opening of the detector. During the laser heating the beam passing through the optical detector may periodically dim.

3) Insert into the path an optical interferometer IL1. Set the diaphragm into adjustment position. Adjust the position of the interferometer, so that its face is parallel to the front of the laser head. When the interferometer is properly set than through an opening in the bottom diaphragm a part of the beam will be returning to the detector (the second part is reflected by the reflector - Figure 3.3).

4) Insert into the beginning of the optical path the reflector RL1 (as close to the IL1 as possible). Set diaphragm into adjustment position. Adjust the reflector so that the returned beam falls on the hole in the bottom diaphragm of the interferometer (should fall on the beam returned by the interferometer).

5) Move the reflector to the end of the measuring path. If the position of the reflected beam falling on the interferometer diaphragm does not change, this means that the track is properly adjusted. If, however, the beam position changes, so some correction of the position of the laser head have to be made.

6) When the path is properly aligned move the diaphragms in their working position, taking care not to change the position of the elements of the path.

4. Device operation – compensation unit

The Environmental Compensation Unit is a device that automatically compensates the changes of the temperature of a machine and modifies the encoder signal between the position sensor and machine control. Depending on the chosen configuration ECU-01 reads up to three temperature sensors and/ or one pressure sensor. ECU-02 unit, as prepared for operation with the laser head, controls up to four temperatures and the air pressure.

The input signal can be of three different types:

1) analog signal from an optical receiver OR-1 produced by Lasertex (Laser Line mode)
2) analog signal from an encoder in 1Vpp format (Analog Input mode)
3) digital signal from an encoder in RS-422 format (Digital Input mode)

The resolution of the input signal is chosen be the user.

The device outputs both analog (1Vpp standard) and digital (RS-422) signals. The resolution of the input signal is chosen be the user.

The ECU-01 and ECU-02 are stand-alone devices. After configuration through an USB port the devices are ready to be placed to their work position.

The operation and control of the device can be performed through the USB interface.

4.1. Thermal expansion effects

The main function of the Environmental Compensation Unit ECU-01/02 is CNC machines accuracy increase by reduction of thermal expansion effects. Those effects originate in three main places:

- thermal expandability of the position encoder (scale)
- thermal expandability of the machine
- thermal expandability of the workpiece.

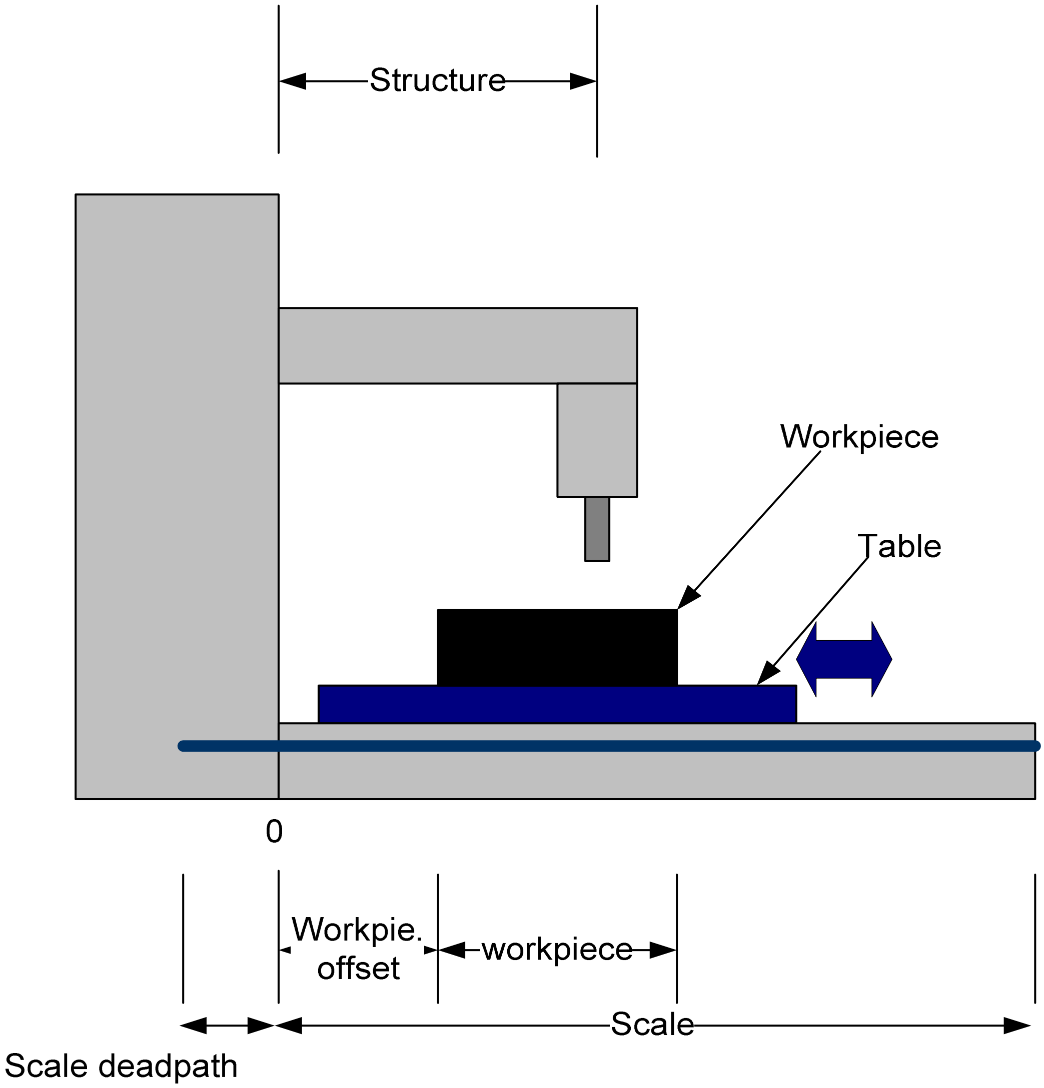


Fig. 4.1. *Illustration of the compensation mechanism of the ECU-01/02 used in a CNC machine*

In the figure 4.1 there was shown a schematic of an exemplary machine with the thermal sensitive elements presented. The example shows compensation of a single axis. If more axes are to be compensated, then more ECU-01/02 units have to be used: one ECU-01/02 for one compensated position encoder.

The position encoder (marked as **Scale**) is the part that is connected to the CNC control. It can be of different construction – magnetic, glass, laser, etc. Its expansion is corrected with positive sign in order to force the CNC control to leave the table in the same position despite the thermal expansion of the scale.

The important parameters in the Scale length compensation are:

- scale thermal expandability factor in [ppm] or [μm/(m*K)] units; for glass scales it can have very low value
- scale deadpath – the length of the non-used scale part (see figure 3.1) or the distance between the beginning of the scale and the Zero mark

The **Structure** expandability influences the position of the workpiece or of the worktool, depending on the configuration of the CNC machine. This change in the structure dimensions is taken with the negative sign to have the same effect as in the correction of the Scale, i.e. that the machine despite thermal effects stays in the same position.

The important parameters of the Structure length compensation are:

- structure thermal expandability factor in [ppm] or [μm/(m*K)] units; usually
- structure length – the length of the structure that's expandability is compensated (see figure 4.1)

The **Workpiece** can change its dimensions during the work procedure quite significantly. Therefore it is important to use the workpiece temperature sensor to measure and compensate the workpiece temperature alterations. Because the workpiece is usually smaller then the position encoder of the machine thus the workpiece offset parameter is introduced. This parameter shows the beginning of the workpiece in the position encoder reference frame. The second parameter of the workpiece is its thermal expansion coefficient. The influence if the workpiece expansion is corrected with the negative sign.

4.2. ECU-01/02 in the control loop of a machine

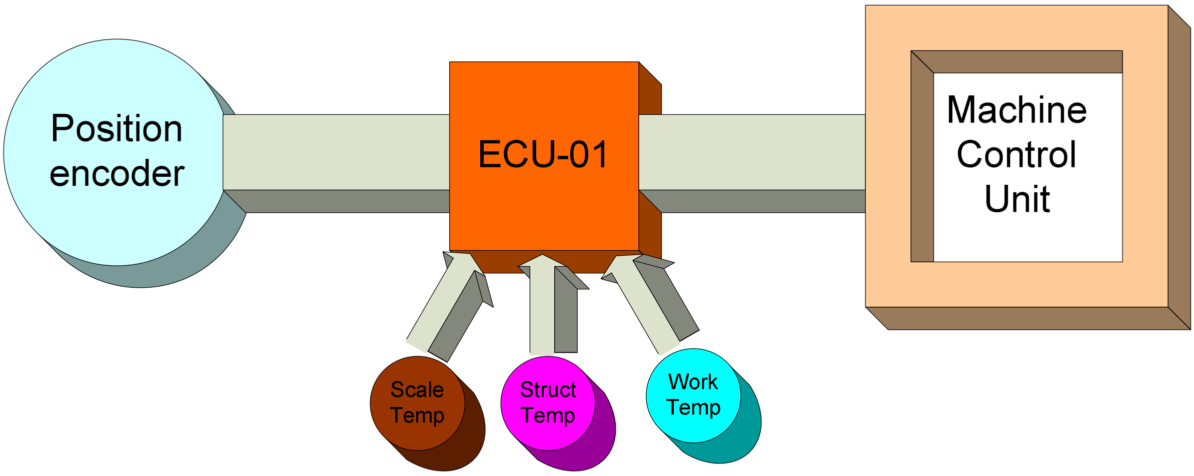


Fig. 4.2. *Position of the ECU-01 in the control loop of the machine*

In CNC machines the machine control unit usually obtains information about the real position of the driven physical object from a position encoder. The ECU-01/02 modifies signal from the position encoder in the real-time depending on the detected temperatures.

> The ECU-01/02 should be placed between the Position Encoder and the Machine Control Unit as shown in the figure 4.2.

The temperature sensors can be used but do not have to, depending on the desired functionality of the device. As it shown in the next paragraphs it is possible to use the ECU-01/02 also or only for translation of the signal from position encoder between different standards.

In the figure 4.3 there is schematically shown how the compensation in the ECU-01/02 is working. From the Optical Receiver or a Position Encoder there is received an A-quad-B signal with a certain period. The Digital Signal Processor DSP inside the ECU-01 unit gathers the environmental data and modifies the data on both outputs. The combination of the fast DSP and programmable logic chip (FPGA) allows ***real time*** compensation of the effects in the output signal.

4.3. Connections

It is possible to connect to the ECU-01 three types of input signals: analog, digital and analog from an optical receiver OR-1. Depending on the input signal type there are possible two schemes of device connections.

The connection scheme for analog and digital input signals from a non-laser position encoders is shown in the figure 4.3. In this case the differential signal from the position encoder is connected to the inputs. The differential output signal can be used either in digital or in analog format as they are always generated in parallel. The differential, quadrature output is denoted in the figure 4.3 as “A quad B”.

The output signal is already compensated in dependence on the three temperature sensors and the parameters chosen during device configuration. The “Struct Temp” is an abbreviation from Structure Temperature Sensor, “Scale Temp” from Scale Temperature Sensor and “Work Temp” from Workpiece Temperature Sensor.

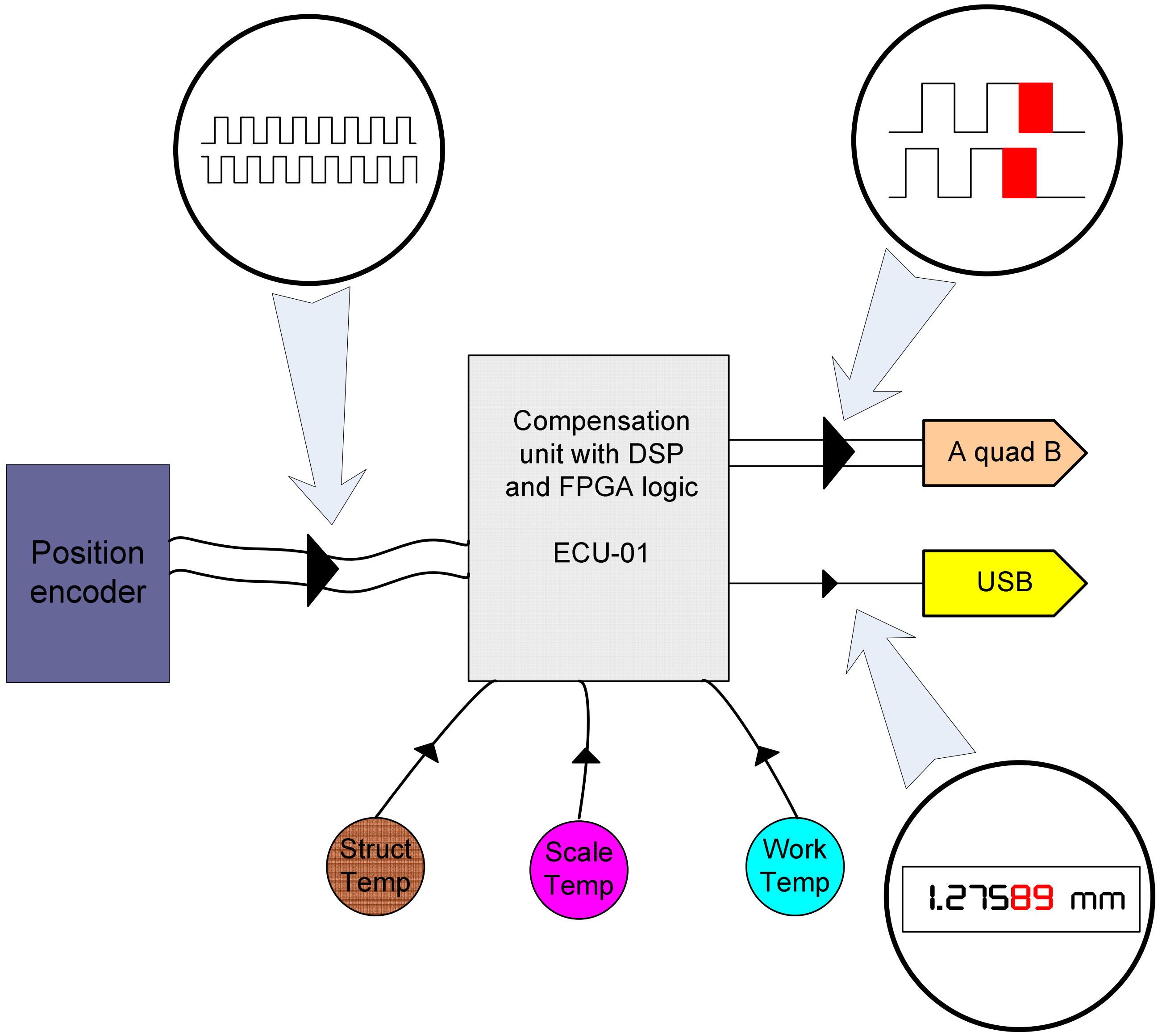


Fig. 4.3. *Compensation of the environment in the Analog and Digital Input mode*

The configuration and monitoring of the device is done through an USB interface. The software for device monitoring and configuration is described in the following paragraphs.

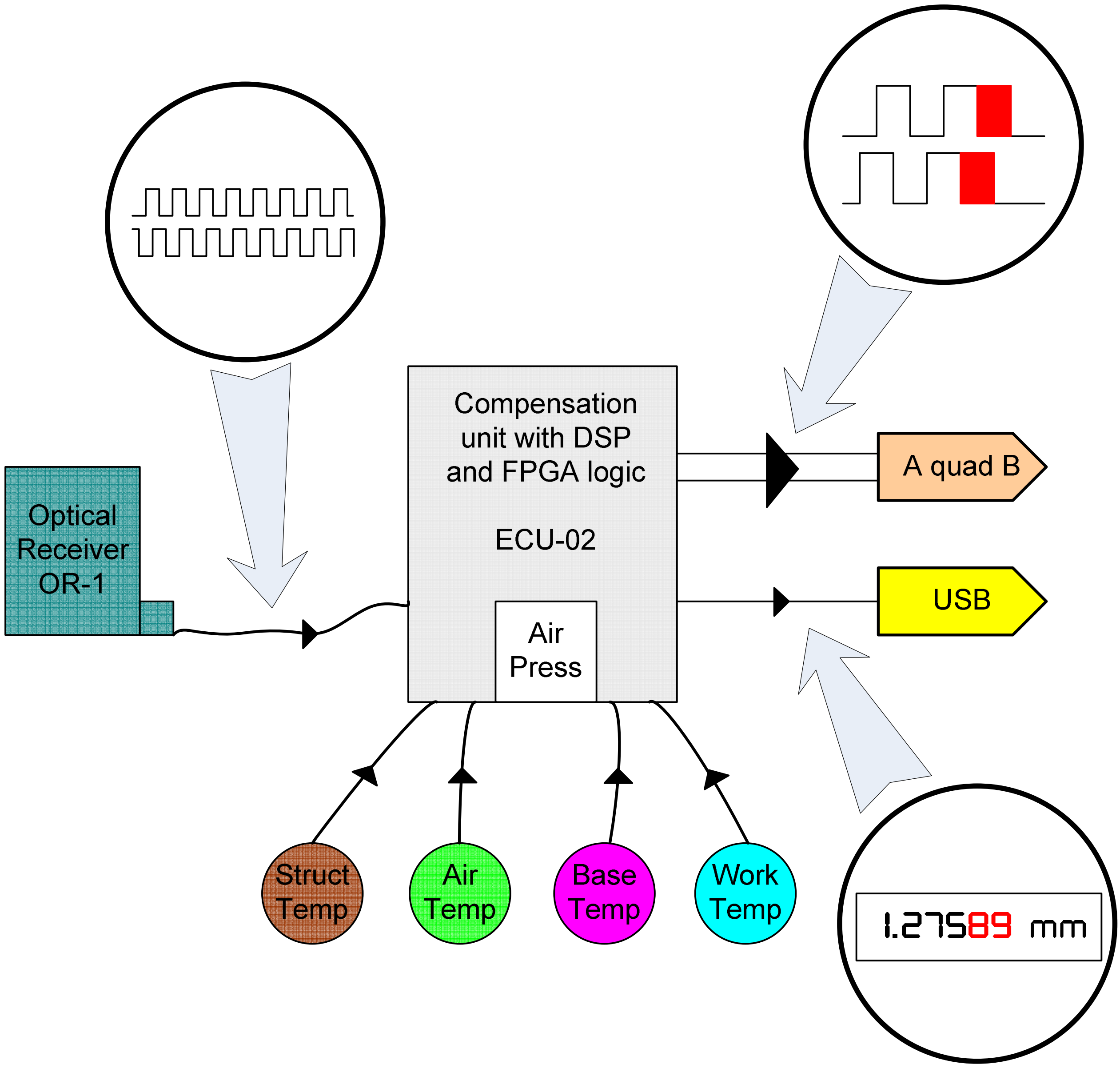


Fig. 4.4. *Compensation of the environment in the Laser Line Input mode*

The connection scheme for analog and from a laser position encoders (e.g. LS10) or from a optical receiver OR-1 is shown in the figure 4.4. In this case the differential signal from the optical receiver is connected to the inputs of the ECU-01/02. The differential output signal can be used either in digital or in analog form like in the configuration shown in the figure 4.3. The differential, quadrature output is also denoted as “A quad B”.

The main difference between configuration shown in the figures 4.3 and 4.4 is the number of environmental sensors used. Because of the necessity of laser wavelength compensation depending on the air parameters there are necessary two additional sensors: air pressure sensor and air temperature sensor. Air pressure sensor is included inside the compensation unit in both versions (i.e. ECU-01 and ECU-02). The air temperature sensor is included in the standard delivery only for the ECU-02 unit.

4.4. Device panels

The ECU-01/02 has two panels with connectors. The front panel is shown in the figure 4.5. The back panel for version ECU-01 is presented in the figure 4.8a, while for version ECU-02 in the figure 4.8b.

On the side of the unit there are two threaded M4 holes separated of 100mm for mechanical mounting of the device. The length of the used screws cannot be longer than 30mm.

4.4.1. Front panel

Fig. 4.5. *Front panel of the ECU-01 and the ECU-02 units*

4.4.1.1. Status diodes

On the front panel of the ECU-01/02 device there are available four connectors and two diodes.

The diodes inform about the device state:

- when the red **PWR** diode is on, the device is properly supplied and the main subsystems are working
- when the green **READY** diode is on the data on the outputs are valid.

During device startup the **READY** diode may be blinking. That is normal behavior of the device meaning the duration of the startup procedure.

4.4.1.2. DETECTOR connector

The **DETECTOR** connector is the main input of the device. The functionality of each pin is shown in the Table 4.1. To the connector there can connected either optical receiver OR-1 or another Position Encoder (PE).

Pin number	**Function**	**Remarks**
1	VEE	-5V/100mA negative supply output
2	/A	analog input, differential to A (pin 10)
3	/B	analog input, differential to B (pin 11)
4	/Zd	digital input, differential to Zd (pin 12)
5	/Bd	digital input, differential to Bd (pin 13)
6	/Ad	digital input, differential to Ad (pin 14)
7	Sig	Signal level input – do not use
8	VCC	+5V/100mA positive supply output
9	GND	Ground pin
10	A	analog input, differential to /A (pin 2)
11	B	analog input, differential to /B (pin 3)
12	Zd	digital input, differential to /Zd (pin 4)
13	Bd	digital input, differential to /Bd (pin 5)
14	Ad	digital input, differential to /Ad (pin 6)
15	NC	Not connected

Tab. 4.1. *DETECTOR input connector pinout*

If the output signals of the PE are of 1Vpp analog type then the encoder should be connected to pins 10-2 and 11-3. If the outputs from the encoder are digital TTL (or RS-422) type then the input pairs 14-6, 13-5 and 12-4 should be used. Pins 1,8 and 9 can be used when necessary as a power supply. Pins 7 and 15 should not be connected – they are usable only with the OR-1 receiver.

4.4.1.3. USB connector

The **USB** connector is used for monitoring and control of the device operation from the level of an external computer. The software application for this purpose is described in the following chapter. The ECU-01/02 is an autonomous device, thus it is not necessary to connect it to a computer during normal operation – all chosen configuration parameters are stored in the non-volatile memory inside the ECU-01/02 and are remembered after power cycle.

4.4.1.4. AUX connector

The **AUX** connector is the connector with different, auxiliary signals usable for proper interfacing of the ECU-01 with a machine control unit. The functionality of this connector depends on the wish of the end user. The meaning of the AUX connector pins is shown in the table 4.2.

Pin number	**Function**	**Remarks**
1	VCC12	+12V/200mA positive supply output
2	SIG2	Digital input/output. Functionality defined by the user. Output signal amplitude defined by VCC_IN
3	SIG4	Digital input/output. Functionality defined by the user. Output signal amplitude defined by VCC_IN
4	SIG6	Digital input/output. Functionality defined by the user. Output signal amplitude defined by VCC_IN
6	VCC	+5V/100mA positive supply output

7	SIG1	Digital input/output. Functionality defined by the user. Output signal amplitude defined by VCC_IN
8	SIG3	Digital input/output. Functionality defined by the user. Output signal amplitude defined by VCC_IN
9	SIG4	Digital input/output. Functionality defined by the user. Output signal amplitude defined by VCC_IN
5,10	NC	Not connected
11	VCC_IN	Positive supply input for output buffers (+24VDC max)
12,13,14,15	GND	Ground pin

Tab. 4.2. *Pinout of the AUX connector*

On this connector there are available:

- differential, digital output signals in RS-422 standard, i.e. A and B paths

- Data Ready output signal for information about the device state; The meaning of this signal and READY led on the front panel is the same

- Differential input signal for the main counter clearing – Z and /Z signals

- Signal for intra device synchronization; Proper operation requires presence of the ECU-02 in the device chain

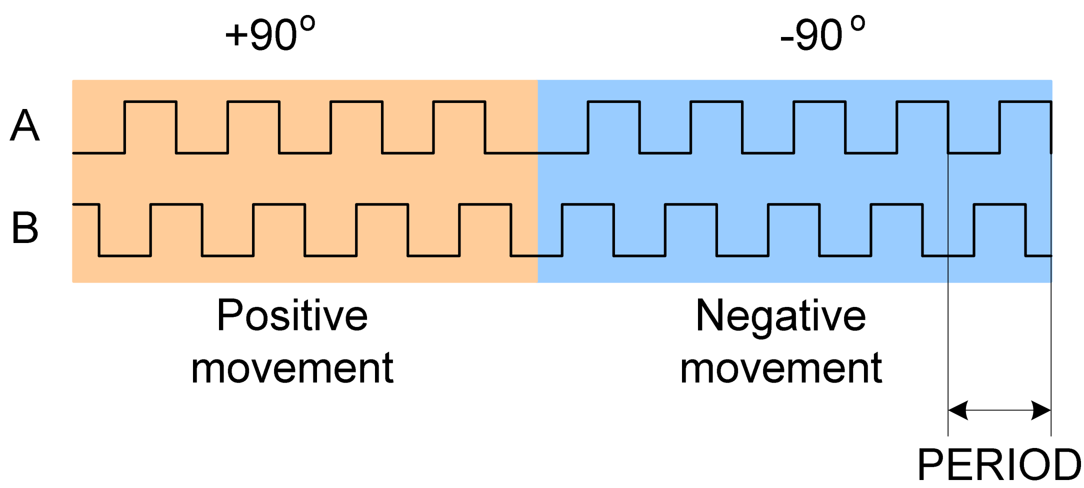


Fig. 4.6. Digital *OUTPUT signals*

The digital output signals are of A-quad-B nature, which means that the movement direction is coded in the phase difference between signals, while the movement itself depends on the number of signal transitions. The exemplary shape of the output signal is shown in the figure 4.6.

3.4.1.5. Power connector

The device works according to the rule: always on. There is no power switch, thus the only method to switch the device off is the disconnect the power supply plug from the power connector. The appropriate power supply is included in the standard delivery. The power requirements of the device can be found in the Technical Data chapter.

3.4.2. Back panel

Fig. 4.8a. *Back panel of the ECU-01 unit*

Fig. 4.8b. *Back panel of the ECU-02 unit*

3.4.2.1. TEMP connectors

On the back panel of the compensation unit there are present three 4-pin circular sockets in the ECU-01 version and four such sockets in the ECU-02 version. Those sockets are to be used for connection of temperature sensors of all necessary kinds (see figure 4.9): Scale, Base, Structure and Workpiece. Sensor type is coded inside the sensors, thus it is not important which sensor is inserted into which socket.

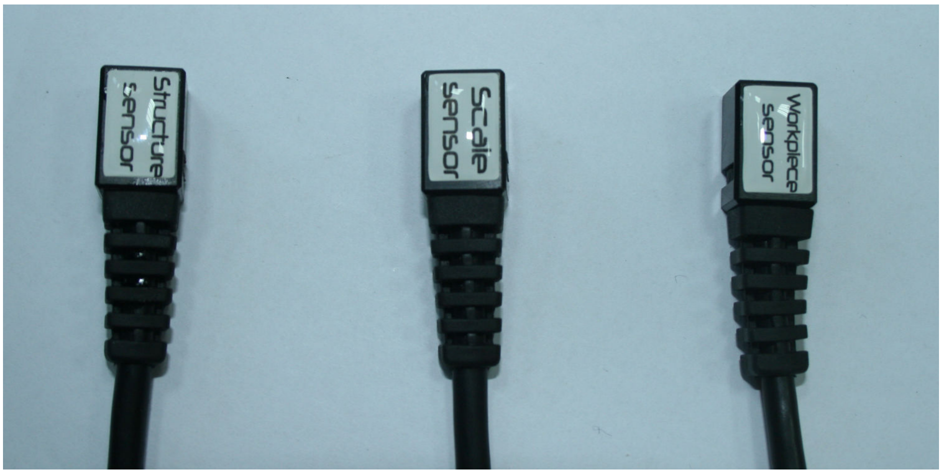


Fig. 4.9. *Temperature sensors of the ECU-01*

3.4.2.2. OUTPUT connectors

Analog signals are available in the differential 1Vpp format. The analog signals are also shifted in phase by +/- 90 degrees (sinA/ cosB format). The period of the analog signals is changed together with the period of the digital outputs. The period of analog signals is 10 times larger than the period of digital signals.

The OUTPUT connector (DB9) pinout is shown in the table 4.3.

Pin number	**Function**
1	GND
2	sinA- (analog)

3	sinA+ (analog)
4	sinB- (analog)
5	sinB+ (analog)
6	Aout+ (digital)
7	Aout- (digital)
8	Bout+ (digital)
9	Bout- (digital)

Tab. 4.3. *Pinout of the OUTPUT connector*

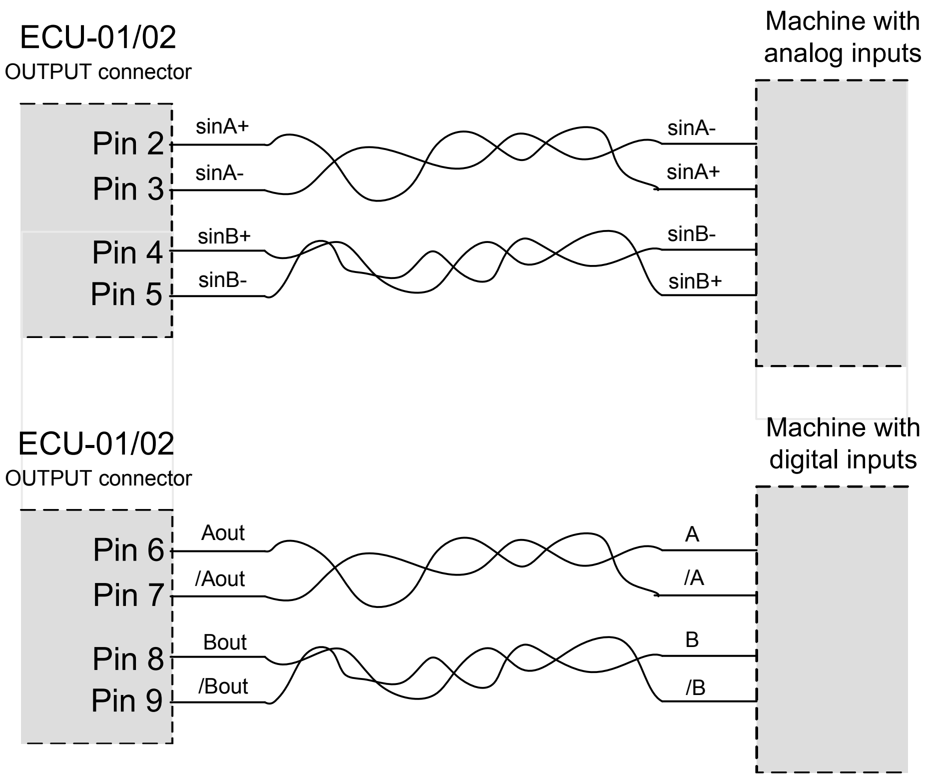


Fig. 4.10. *OUTPUT signals connection diagram*

In the figure 4.10 there is shown the connection diagram of the OUTPUT connector. Exemplary connection of digital and analog signals are shown.

5. Device configuration and control

Environmental Compensation Unit ECU-01/02 has been designed in such a way that the device works independently on other devices. An external computer with an USB interface is only necessary for configuration and control of the device. The delivered program – LS10.exe – can be used to monitor the behavior of up to six compensation units at the same time.

The program should be installed from the CD attached in the delivery.

5.1. Software installation

To start the measurements using the "LS10" software, this program should be installed on a hard disk of a PC computer. The hardware requirements are:

Windows XP/Vista/7 system,

CR-ROM

Pentium processor, 1 GHz or better

SVGA graphic card making possible working with resolution 800x600

USB 2.0

The software is located on the CD that comes with the measurement system. Once inserted into the computer, view the contents of the CD and find a file named LS10_install, and then run it. The installation process of the application and the necessary drivers should start automatically.

Fig. 5.1. *Icon of the setup application.*

Fig.5.2. *Welcome window.*

After running the setup file, in following windows the program asks about the necessary parameters to correctly install the software. To let ECU-01/02 to work correctly, the following components must be installed:

- LS10 application
- directory FTDI Driver for USB
- Documents folder with the manual and other documents (depending on system version)

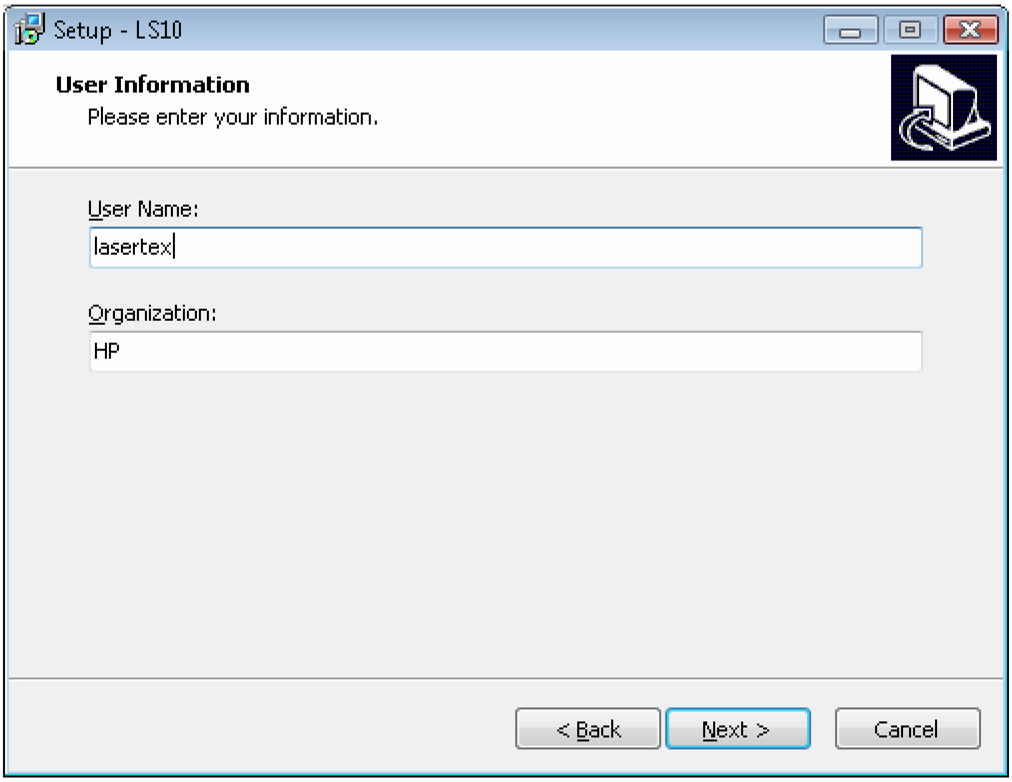


Fig.5.3. *User Information window*

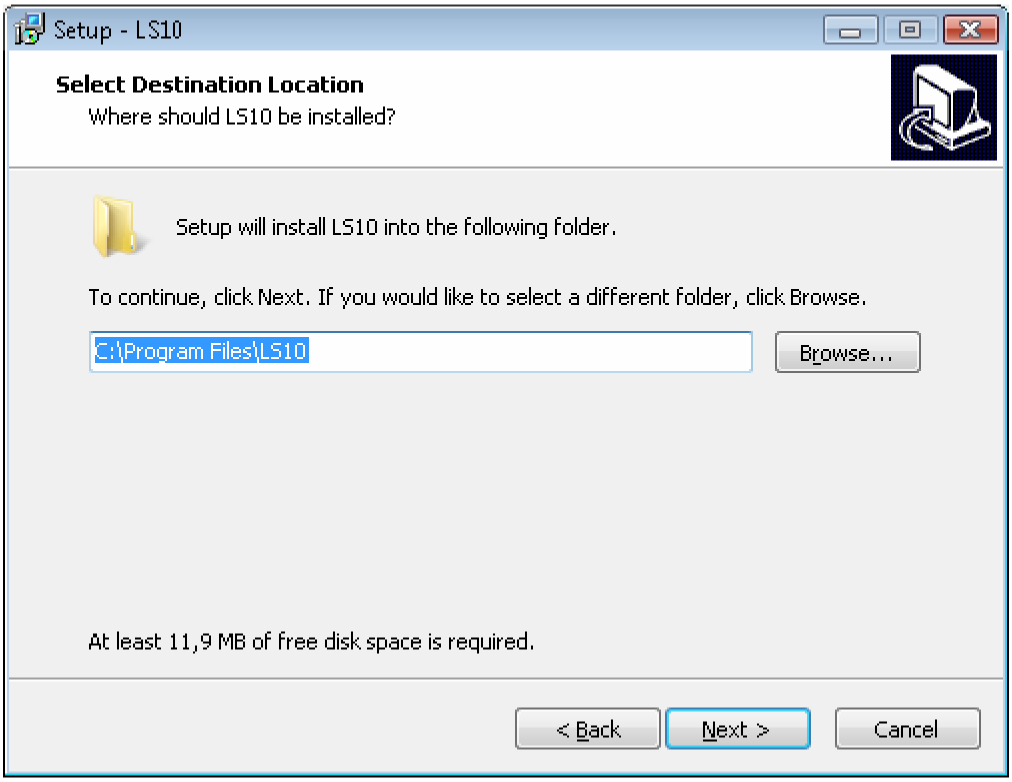


Fig.5.4. *Program destination folder window.*

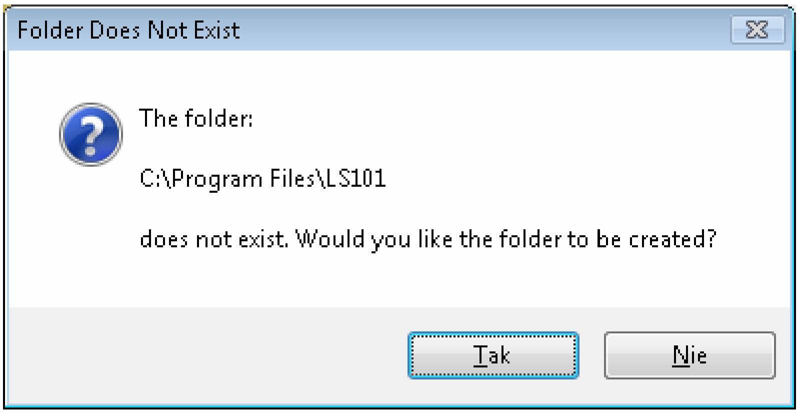


Fig.5.5. *Window appearing when the folder name does not exsist in the system.*

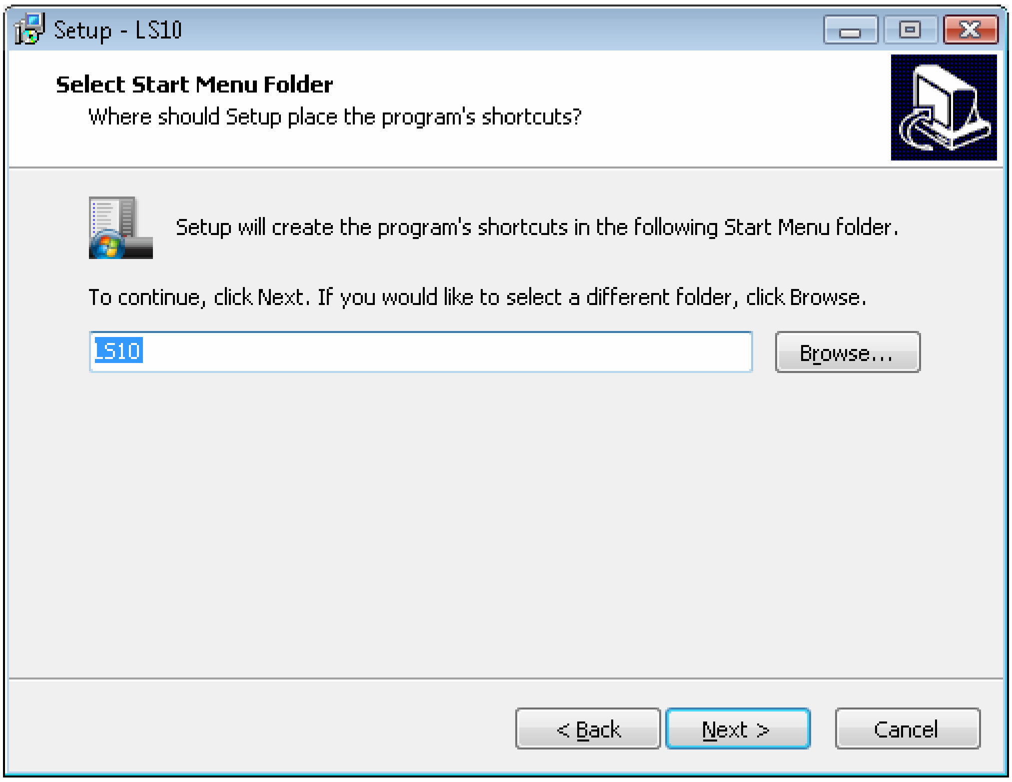


Fig.5.6. *Start Menu name choice window*

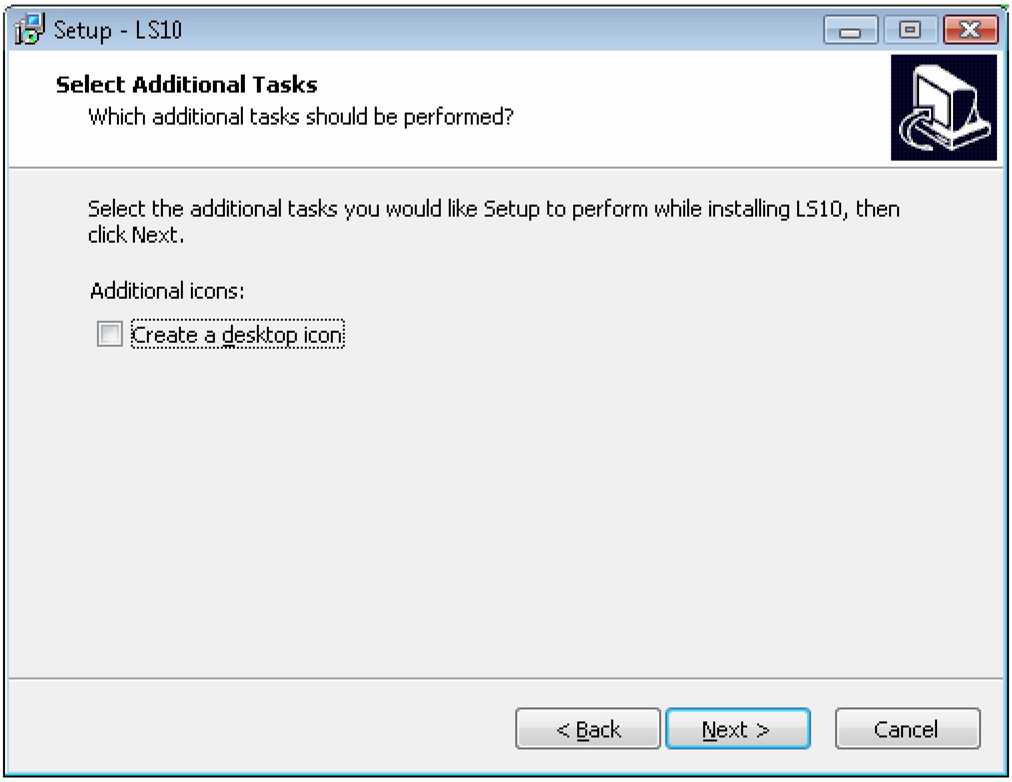


Fig.5.7. *Desktop icon setup window*

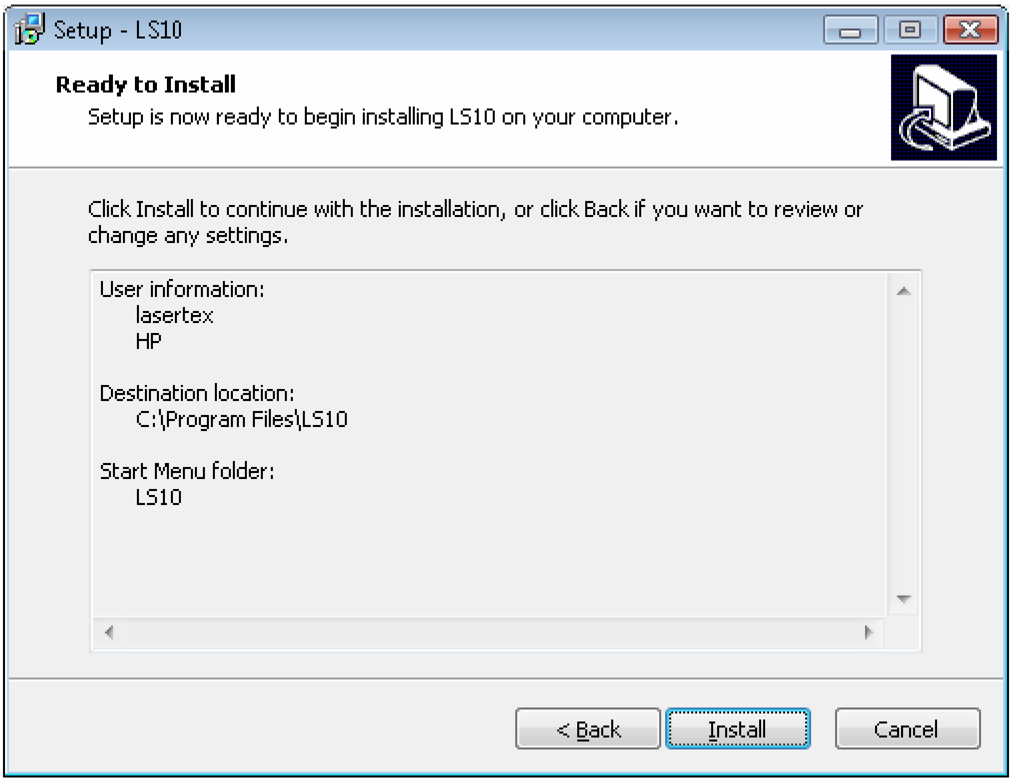


Fig.5.8. *Window with installation information*

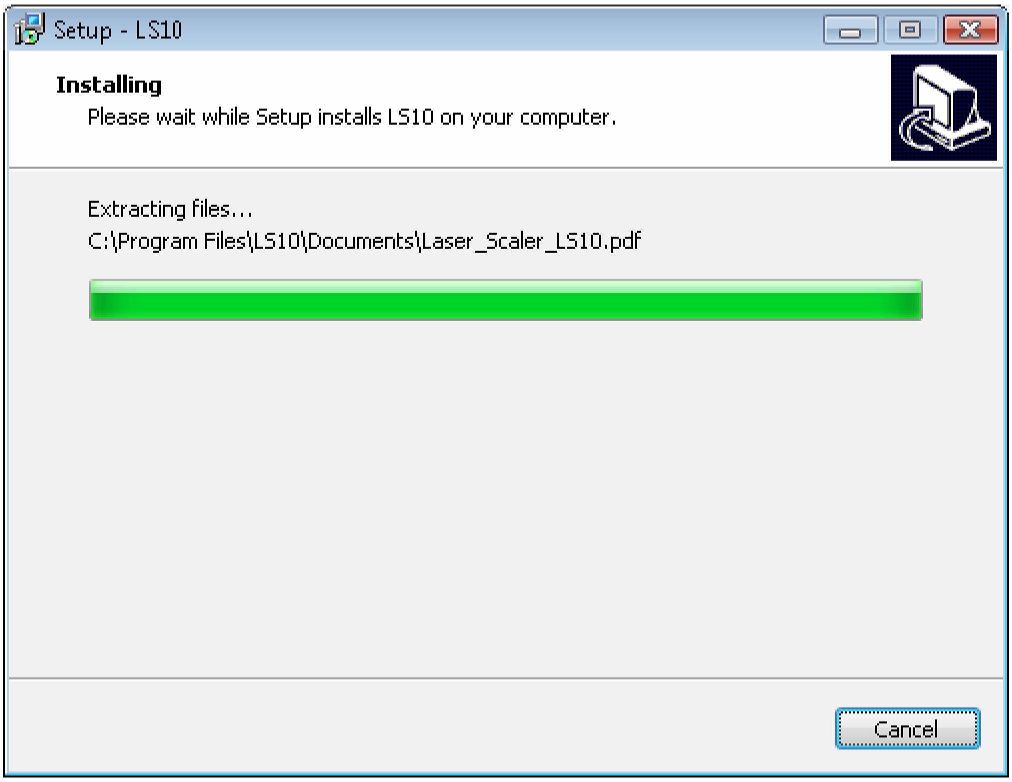


Fig.5.9. *Installation window during data copy operation*

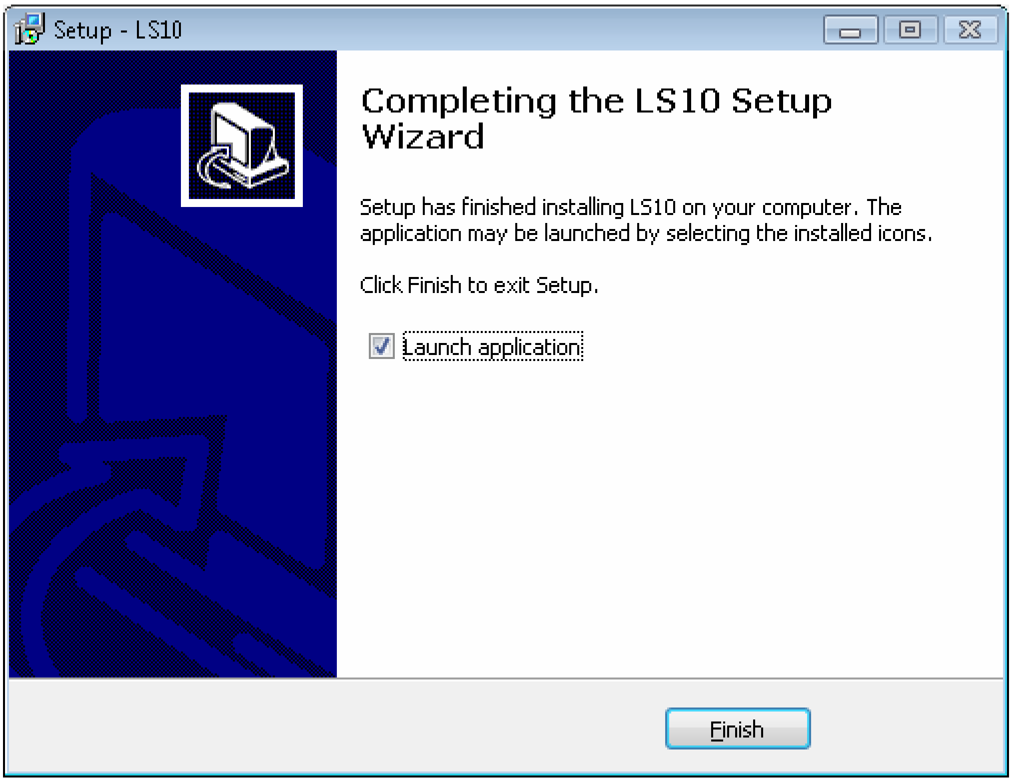


Fig.5.10. *Installation summary window*

In most cases, the installation is semi-automatic requiring only confirmation by the Enter key.

After installation of the first time on the computer, the application should not be run right away. First the drivers should be allowed to find the laser measurement system. To this end, the system must be connected by a USB cable to your PC, then wait until the system finds the device and Windows matches for the drivers.

To run the application, see the Windows Start Menu Programs tab, and then find the folder LS10 (assuming that the installation settings were not changed) and run LS10. Running applications can also be made from the desktop, if this option was chosen during installation.

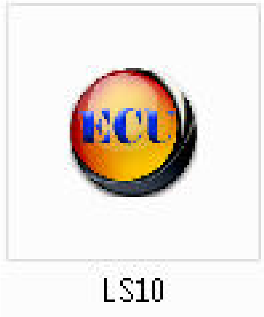


Fig.5.11. *Icon of LS10 application.*

In order to uninstall the LS10 application please choose *Uninstall LS10* from Menu Start.

5.2. Device monitoring and control

5.2.1. Connecting and disconnecting

After software start the window with two pages (Display, Configuration) can be seen, as shown in the figure 5.12. In the bottom part of the window there are three buttons:

- Connect – press for automatic connection with all devices connected to the PC via USB ports (up to six devices). After successful connection with at least one device the name of the button changes to Disconnect with such a function
- Exit – press for closing the software window
- Excel link – press to make a link to an Excel.exe spreadsheet; Microsoft Excel software has to be installed on the computer

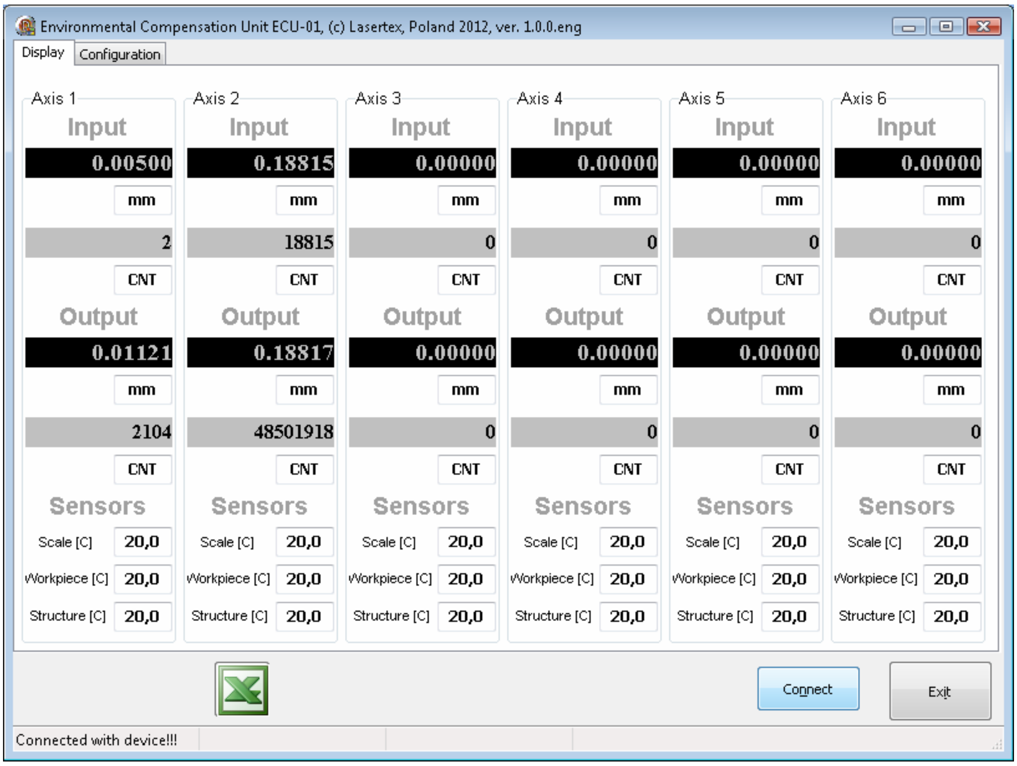


Fig. 5.12. *Display screen of the ECU-01 software without connection to any ECU-01/02 device*

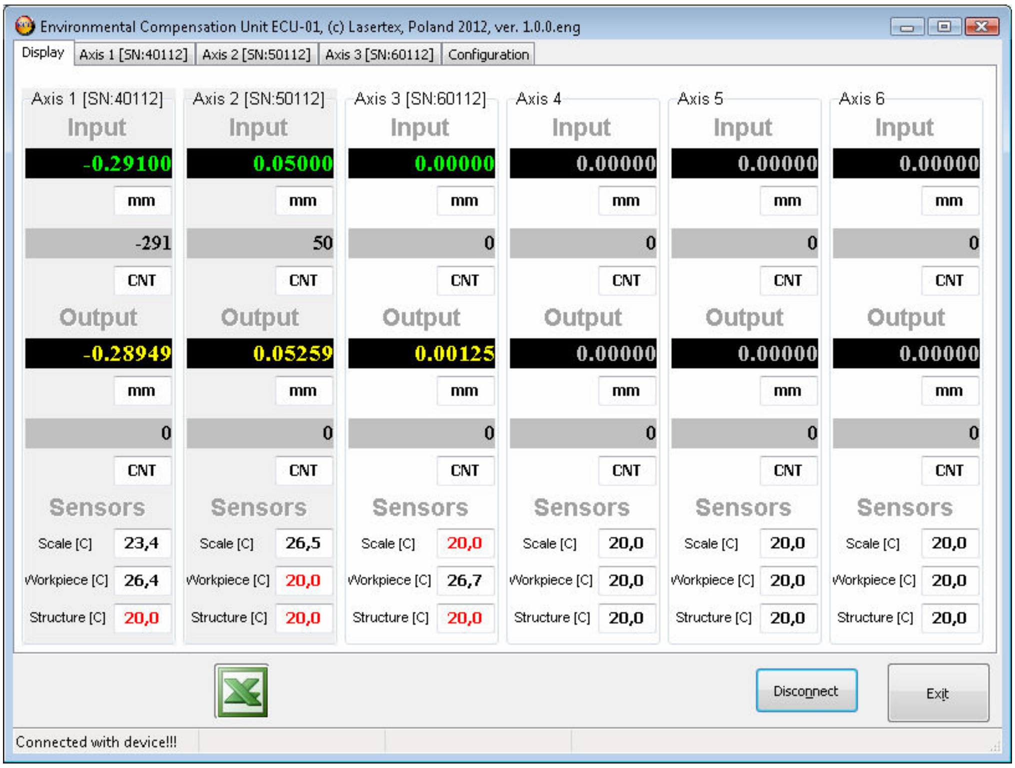


Fig. 5.13. *Display screen of the LS10 software after connection to three ECU-01/02 devices*

If there are ECU-01/02 devices connected to the PC then pressing the Connect button causes modification of the number of pages in the main window. For each device found there appears an additional page. The name of the page is the combination of the *Axis 1* to *Axis 6* text with a serial number of the connected device (i.e. Axis 1 [SN: 40112]).

Also the appearance of the *Display* page changes: respectively to the number of recognized devices a proper number of panels become active with the names of the panels modified with serial numbers.

5.2.2. ECU-01 monitoring

Each channel can be monitored either on the *Display* page or on the dedicated *Axis* page (see next paragraph). The first method gives a complex view of all connected ECU-01/02 channels at the same time. For each channel there are three different types of information visible on the *Display* screen: input information, output information and sensor information (see figure 5.13).

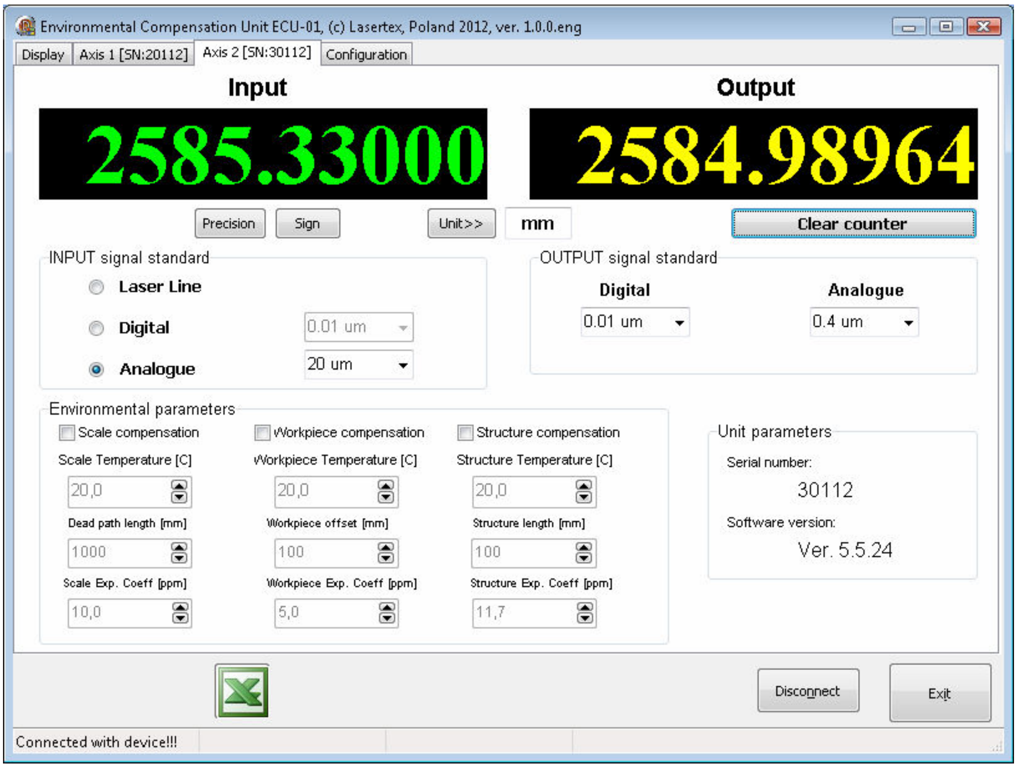


Fig. 5.14. *Axis page*

In the *Input* section there are shown two displays. The larger one shows the current position of the connected position encoder while the smaller shows the number of input signal transitions.

Also in the *Output* section two counters can be found. The larger one shows the compensated input signal. The smaller shows the number of output pulses.

The difference between the main *Input* and *Output* counters indicates how much the original position encoder value is compensated.

In the third part of the panel there are displayed temperature sensors: Scale, Workpiece and Structure. In the number shown is red then it means that there is a sensor error or no sensor is currently connected.

5.2.3. Modification of ECU-01/02 parameters

The *Axis* page allows not only for monitoring of each channel input and output signals and temperatures but also for modification of some parameters of the device.

The page is split into five main subsections:

- an input/output displays part
- an input signal standard part
- an output signal standard part
- an environmental parameters part
- a unit parameters part

> All changed parameters are automatically stored into ECU-01/02 eeprom. No further user action is necessary.
>
> After connecting to the device the program reads the actual state of the device automatically.

5.2.3.1. Displays section

In the displays section there are two main displays. The left, green one shows the uncompensated value of position encoder. The right, yellow one shows the compensated value that is generated on the device outputs.

Below the two displays there are additional buttons for the configuration of the displayed values format – Precision, Sign and Unit>>, and the button for manual counter zeroing.

Precision, Sign and Unit>> button have no influence on the physical operation of the ECU-01/02.

5.2.3.2. Input signal section

The device allows three types of the input signal: analog from OR-1, digital RS-422 and analog 1Vpp. The first option should be used only when using a laser encoder LS10 configuration. This requirement is because the ECU-02 unit searches for a connection with a stabilized laser head LH-02 and will not work without it.

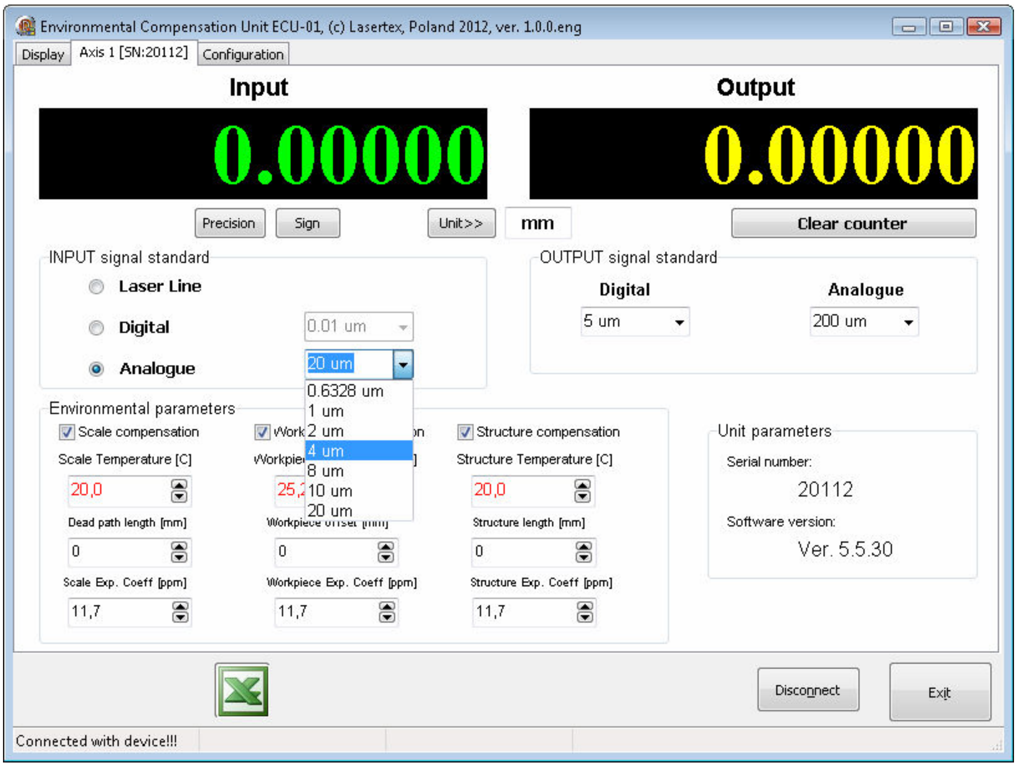


Fig. 5.15. *Modification of input signal standard*

If the compensated position encoder output is a digital signal then the *Digital* checkbutton should be pressed. From the pulldown list a proper input signal resolution should be checked. The digital input resolution is defined as shown in the figure 5.16. The amplitude of the input signal is limited to +/-5V.

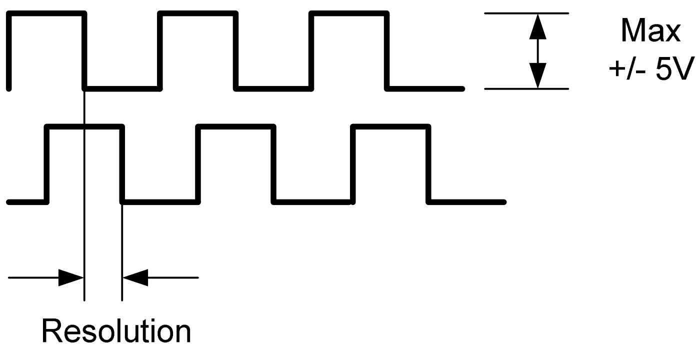


Fig. 5.16. *Digital resolution definition*

The digital input signal resolution can be defined from a wide number of predefined values. Because there is a limit of the input signal frequency (10MHz) than for each resolution there is an input speed limitation. The speed limit values for the digital input choice are shown in the table 5.1.

Digital input resolution	**Input Speed limit**
0.01 um	0.4 m/s
0.02 um	0.8 m/s
0.05 um	2 m/s
0.1 um	4 m/s
0.2 um	8 m/s
0.5 um	20 m/s
1 um	40 m/s
2 um	80 m/s
5 um	200 m/s

Tab. 5.1. *Digital input signal speed limit vs input resolution*

In case of choosing the analog input the analog pulldown list becomes active. The resolution of the analog signal is defined differently from the digital one – not as a single signal transition but as a full signal period (see figure 5.17). The amplitude of the input signal is limited to +/-5V.

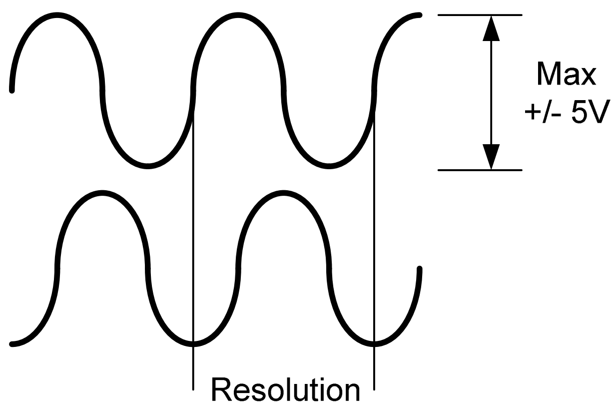


Fig. 5.17. *Analog resolution definition*

The analog input signal resolution can be defined from a wide number of predefined values. The first value on the list (0.6328 μm) is the same to choosing Laser Line option. Because there is a limit of the input signal frequency (10MHz) than for each resolution there is an input speed limitation. The speed limit values for the analog input choice are shown in the table 5.2.

Digital input resolution	**Input Speed limit**
1 um	10 m/s
2 um	20 m/s
4 um	40 m/s
8 um	80 m/s
10 um	100 m/s
20 um	200 m/s

Tab. 5.2. *Analog input signal speed limit vs input resolution*

5.2.3.3. Output signal section

In the output signal section the resolution of the signal generated by the ECU-01/02 unit can be chosen. The device generates both signals at the same time. The resolutions of the signals are defined like for the inputs and as it is shown in the figures 5.16 and 5.17. The resolutions of the output signals are fixed with the formula:

Output analog resolution = 40 x Output digital resolution

The output signal frequency is limited to 2.4 MHz in the analog path and 24 MHz in the digital path. This limitation causes the limitation of the output translation speed limit as shown in the table 5.3.

Digital output resolution	Analog output resolution	Output Speed limit
0.0025 um	0.1 um	0.24 m/s
0.005 um	0.2 um	0.48 m/s
0.01 um	0.4 um	0.96 m/s
0.02 um	0.8 um	1.92 m/s
0.05 um	2 um	4.8 m/s
0.1 um	4 um	9.6 m/s
0.2 um	8 um	19.2 m/s
0.5 um	20 um	48 m/s
1 um	40 um	96 m/s
2 um	80 um	192 m/s
5 um	200 um	>200 m/s
10 um	400 um	>200 m/s
20 um	800 um	>200 m/s

Tab. 5.3. *Digital and analog output signal speed limit vs output resolution*

5.2.4. Spreadsheet connection

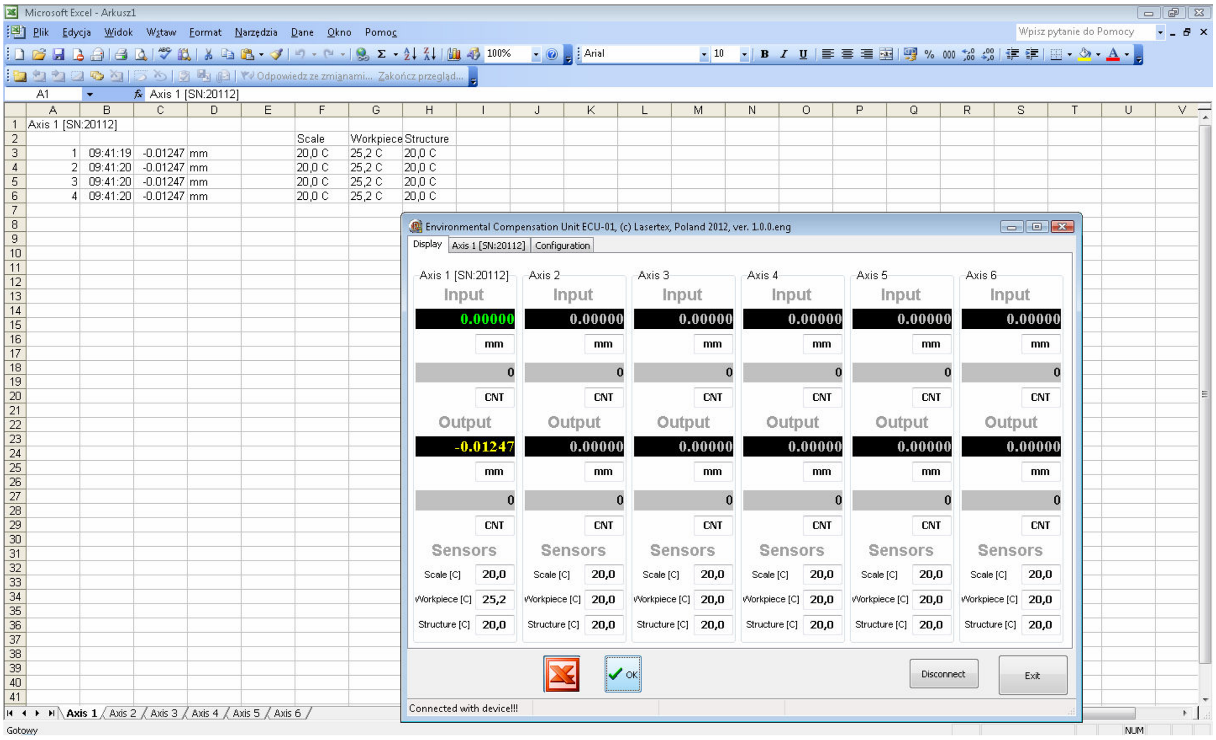


Fig. 5.16. *Spreadsheet connection*

It is possible to register data displayed in the Display tab directly to a Microsoft Excel spreadsheet. For this purpose an Excel button in the bottom part of Display tab is available (see figure 5.16).

For the proper operation of this option on the computer the Excel program must be installed. If this condition is fulfilled then pressing the button open an Excel spreadsheet in the background and sets up a link between LS10 and Excel software. If the link was successfully set then an OK button appears in the LS10 software (Figure 5.16).

By clicking the OK button the data from the Display tab are transferred to the background Excel spreadsheet.

5.2.3. Configuration

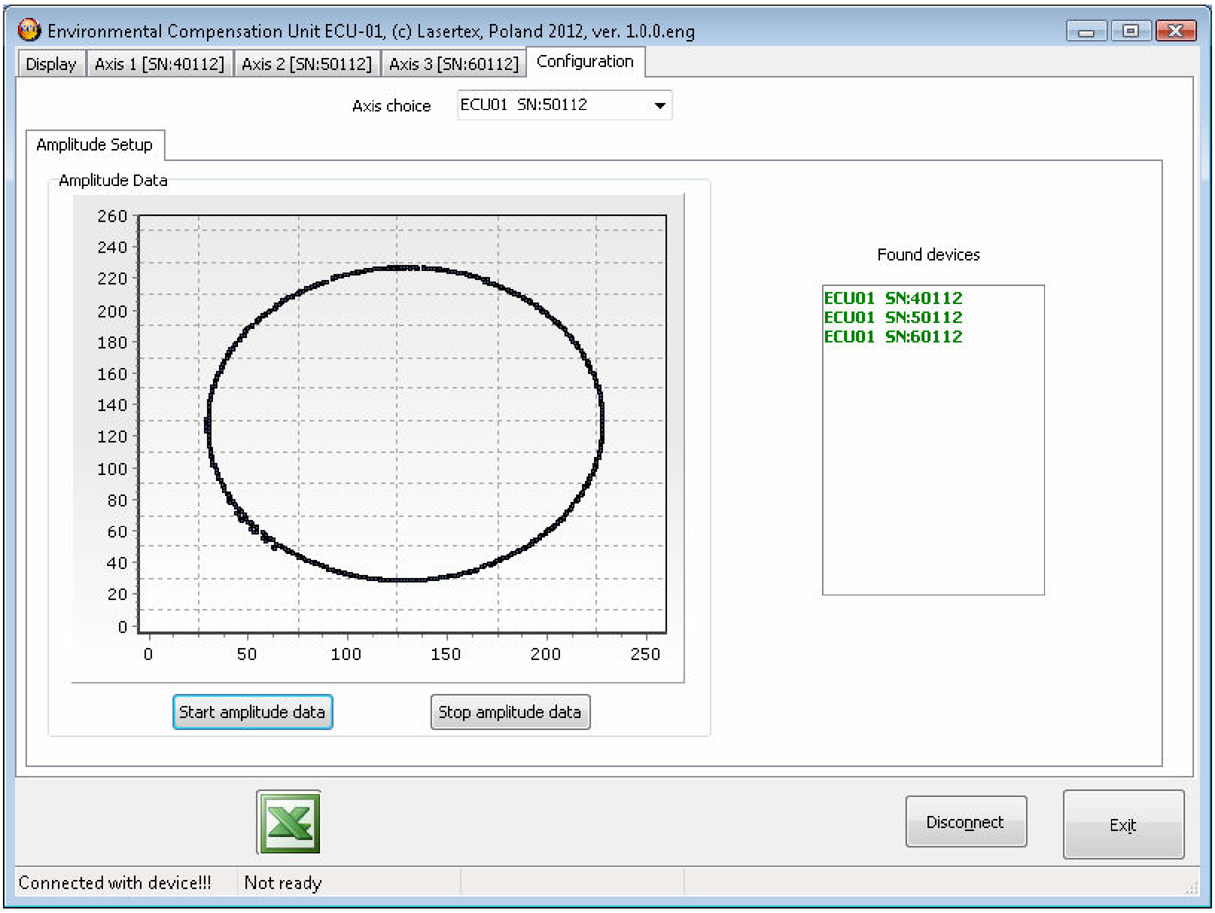


Fig. 5.17. *Monitoring input signal quality*

The options available in the Configuration tab allow full control over the operation of the device. For the normal user only the Amplitude Setup tab is available.

The Amplitude Data chart allows control of optical beam path alignment through the monitoring of the strength of interference signal. Because the LS10 works in the homodyne configuration, thus the control signal is a Lissajou figure, i.e. an ellipse.

An ellipse or a circle would be visible on the chart only if optical elements are being moved or if they are vibrating with amplitude exceeding 320nm.

By pressing the *Start amplitude data* button an ellipse (or a circle) should appear on the chart. The size of the circle would depend on the quality of optical path alignment. The firmware inside the power supply box is adapting the size of the circle with advanced algorithms. In some situations the circle may become a square.

After finishing the beam control process the user MUST press the *Stop amplitude data* button. Otherwise the other part of the LS10 software may not function properly!

6. Technical data

6.1. Work conditions

Ambient temperature range	10 – 35 °C
Allowable temperature change during the measurements, to assure the accuracy of measurement	± 2 °C
Permissible humidity	10 – 90 %
Power	10VDC-26VDC/200mA
Power Consumption	4 W (operation-ECU-01) 30 W (operation – ECU-02 with LH-02)
Any computer with USB connector and an installed FTDI driver.	

6.2. Laser head (ECU-02 version)

Laser Type	Two-mode 633nm HeNe laser with stabilized frequency

Heating time	approx 10 min
Wavelength (vacuum)	632,990539 nm (Channel A)
	632,992040 nm (Channel B)
The accuracy of the wavelength (in vacuum)	± 0,02 ppm, calibration by comparison with iodine stabilised HeNe laser
Short-term frequency stability	± 0,002 ppm (1 hour)
Long-term frequency stability	± 0,02 ppm
Output power of laser radiation	900 μW
Diameter of the laser beam	8 mm
The distance between the beams	12,7 mm
Laser head dimensions	30x45x245 mm
Net weight	1500 g
Safety class	Class 2 laser device according to PN-91/T-06700
Power	12V/4 A

6.3. Input signal

Input signal format	1) Two digital differential signals shifted in phase +/- 90 degrees (AquadB format) 2) Two analog, differential signals in phase +/- 90 degrees (sinA/ cosB format) 3) Differential analog signal from optical receiver OR-1
PERIOD values in Digital Input mode	User programmable: - 0.01 μm - 0.02 μm - 0.05 μm

	- 0.1 μm - 0.2 μm - 0.5 μm - 1 μm - 2 μm - 5 μm
PERIOD values in Analog Input mode	User programmable: - 0.6328 μm (Laser Line) - 1 μm - 2 μm - 4 μm - 8 μm - 10 μm - 20 μm
Maximum input frequency of the analog signal input (DETECTOR connector)	5 MHz
Maximum input frequency of the digital signal input (DETECTOR connector)	10 MHz

6.4. Output signal

Output signal format	4) Two digital differential signals shifted in phase +/- 90 degrees (AquadB format) 5) Two analog, differential signals in phase +/- 90 degrees (sinA/ cosB format)
PERIOD values (A-analog, D-digital)	User programmable: - 0.1 μm (A)/ 0.0025 μm (D) - 0.2 μm (A)/ 0.005 μm (D)

	- 0.4 μm (A)/ 0.01 μm (D)
	- 0.8 μm (A)/ 0.02 μm (D)
	- 2 μm (A)/ 0.05 μm (D)
	- 4 μm (A)/ 0.1 μm (D)
	- 8 μm (A)/ 0.2 μm (D)
	- 20 μm (A)/ 0.5 μm (D)
	- 40 μm (A)/ 1 μm (D)
	- 80 μm (A)/ 2 μm (D)
	- 200 μm (A)/ 5 μm (D)
	- 400 μm (A)/ 10 μm (D)
	- 800 μm (A)/ 20 μm (D)
Maximum output frequency of the analog signal outputs (OUTPUT connector)	2.4 MHz
Maximum output frequency of the digital signal outputs (AUX connector)	24 MHz
Output supply range:	
- digital outputs (A, /A, B, /B)	Differential RS-422 format (0 – 5 V)
- analog outputs (sinA+, sinA-, cosB+, cosB-)	1 Vpp
OUTPUT connector type	HIROSE HR10A-10P-10P

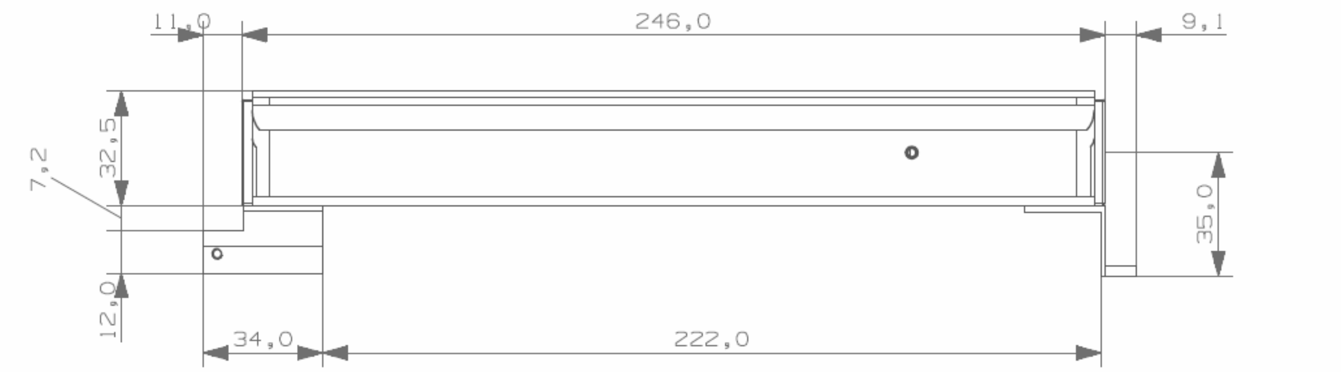
6.5. Environment influence

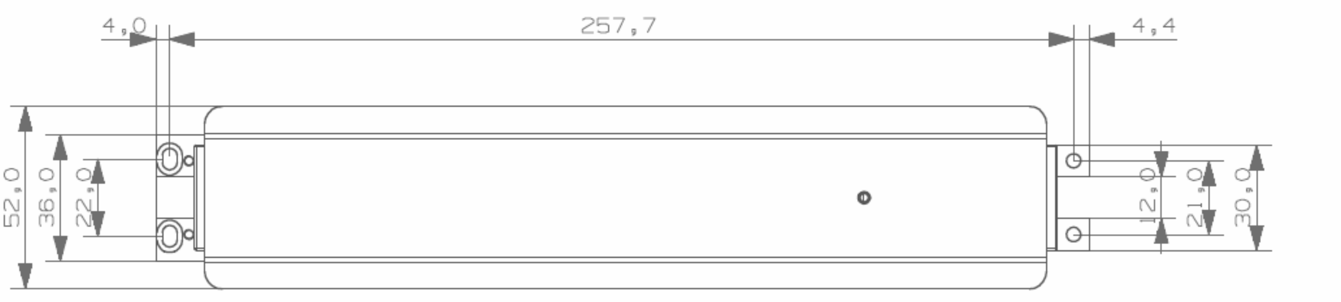
Compensation of air refraction index changes (laser wavelength changes, ECU-02 version)	Fully automatic with air pressure and air temperature measurement
Compensation of base expansion	Fully automatic with base temperature measurements
Compensation of position encoder expansion	Fully automatic with position encoder temperature measurements

Compensation of workpiece expansion	Fully automatic with workpiece temperature measurements
Compensation of structure expansion	Fully automatic with structure temperature measurements
Pressure sensor accuracy	1 hPa in 940 – 1040 hPa pressure range
Temperature sensors accuracy	0.15 C in 0 – 50 deg temperature range

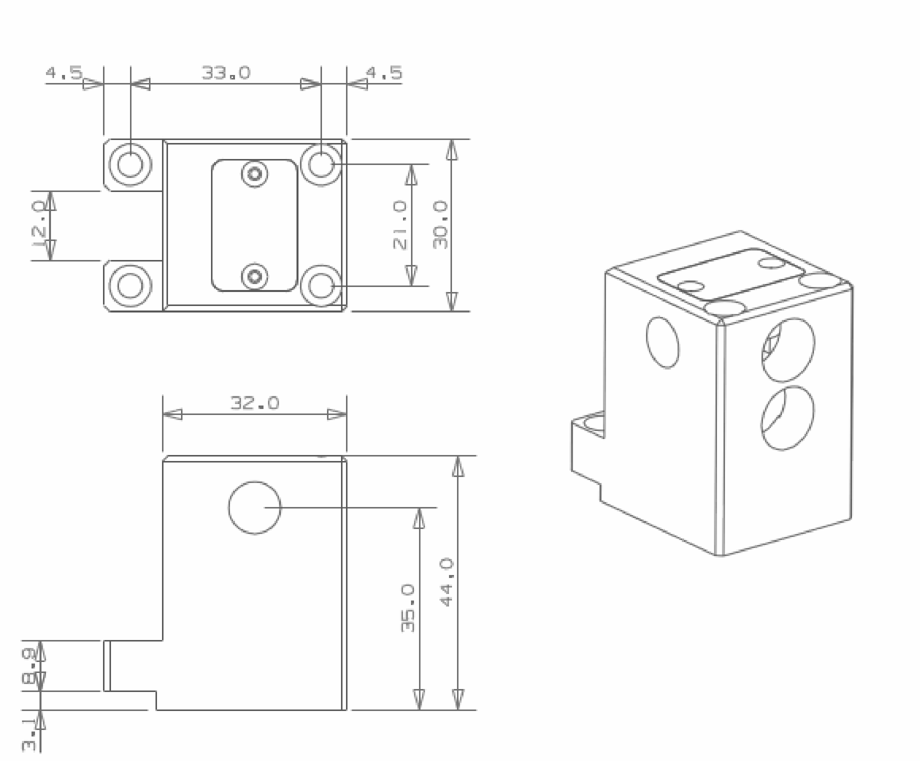
6.6. Mechanical Drawings

6.6.1. Laser Head LH-02

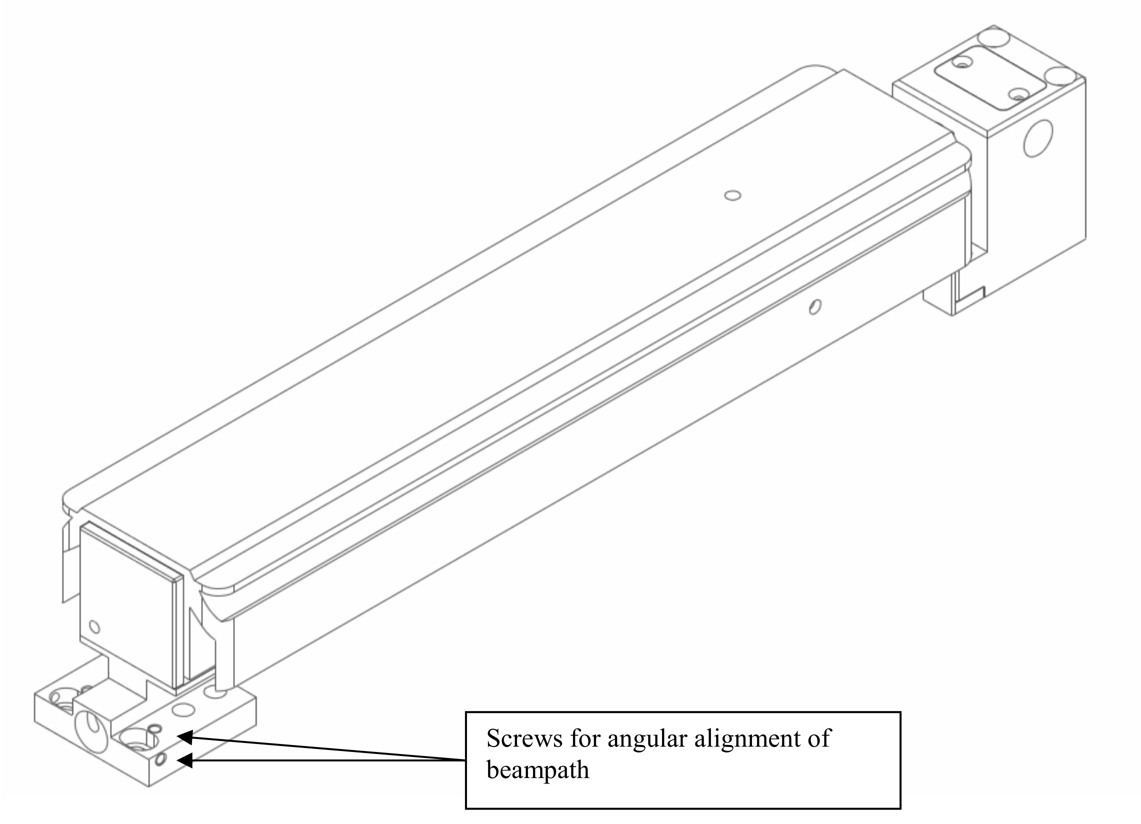




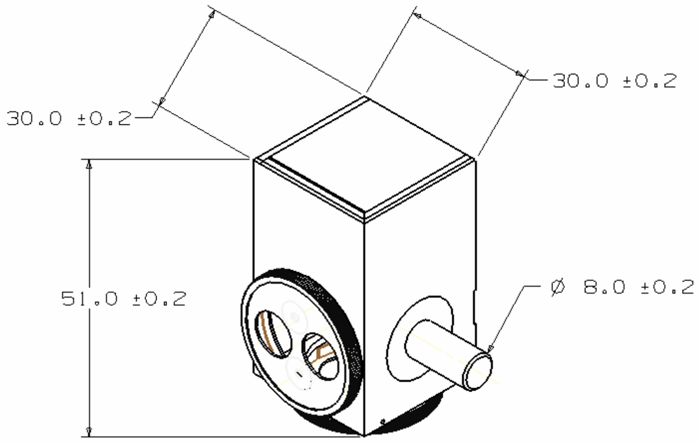
6.6.2. Optical Receiver



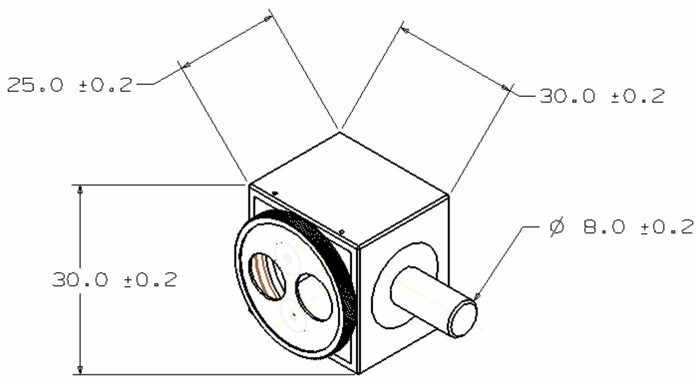
6.6.3. Mounting of laser head and optical receiver



6.6.3. Linear Interferometer IL1



6.6.4. Linear Reflector RL1



7. Annex – Priciples of Laser Interferometry

A.1. The Rules of Laser Displacement Measurements

Displacement measurements with the use of laser allow obtaining the accuracy of 1 ppm or better. The tool that allows such high accuracies is the interferometer, first built by A.A. Michelson in 1881. Its simplified schematic is shown in the Fig. A.1.

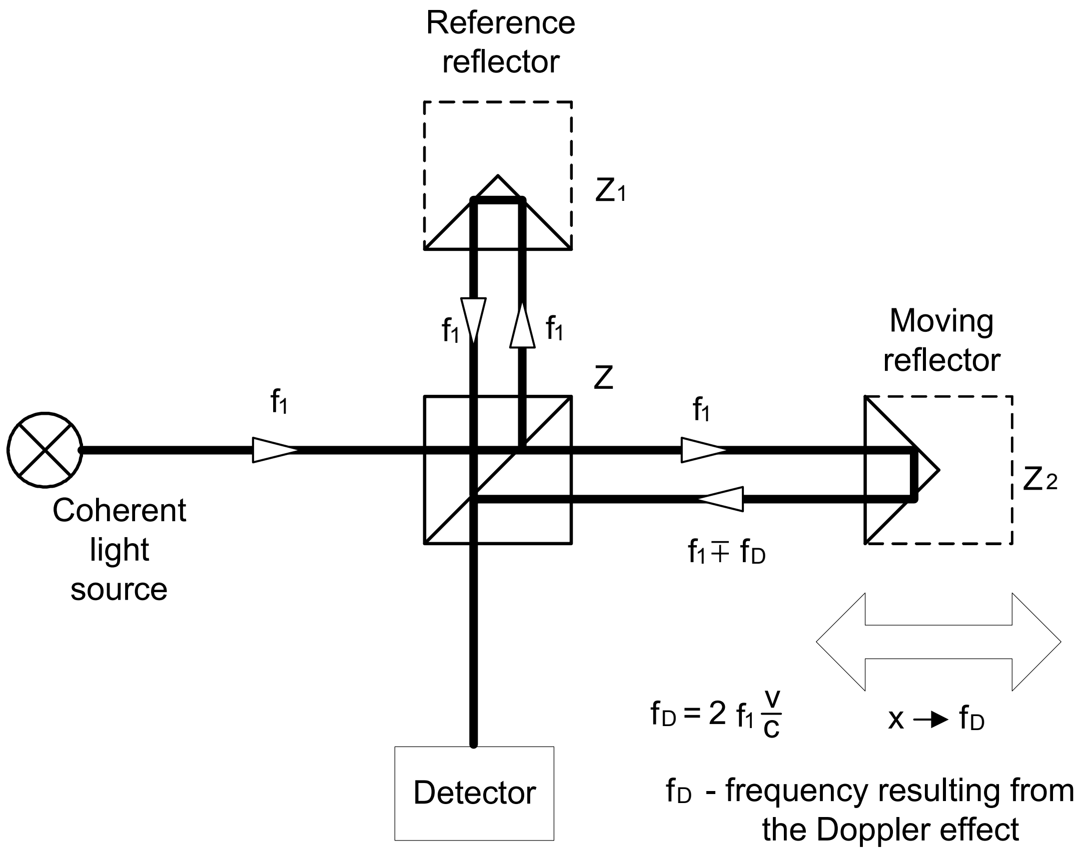


Fig. A.1. *The Michelson interferometer.*

Coherent light beam fall on a self-transparent mirror. This mirror splits the light on two beams. The first goes to the reference arm and reflects from the reflector Z_1; the second goes to the measurement arm and reflects form the reflector Z_2. The reflected beams meet again on the detector. Because these beams come from the same, coherent, source, they will interfere. When the moving reflector is being displaced, the frequency of the reflected beam in the measurement arm changes. The detector counts the frequency difference between reflected beams f_D (see Fig. A.1). The measured value of displacement is obtained according to

$$L = f_D * \frac{\lambda}{2} = N * \frac{\lambda}{2} \qquad (1)$$

Where: N – number of pulses,

λ - light wavelength.

A.2. The Construction of Real Interferometers

The main disadvantage of Michelson interferometer results from the fact that the detector does not determine, whether f_D is negative or positive, thus from the measurements one obtain the displacement of the moving reflector without the sign. Currently there are widely used two methods that allow to get also the direction of the movement. Depending on the number of light frequencies (wavelengths) used in the interferometer, the first is called homodyne (one frequency) and the second heterodyne (two frequencies) method.

In the homodyne method, shown in the Figure A.2, as a coherent source of light is used linearly polarized laser. If it is two-mode laser (i.e. it generates two wavelengths) than one mode must be cut off with the use of a properly set polarizer. The polarising splitter splits the light beam from the laser on two beams polarized vertically (90^o) and horizontally (0^o). The former is directed to the measurement arm and the latter to the reference one. The frequency of the beam in the measurement arm changes with the movement of the moving reflector. The polarization of the reflected beams is changed to circular with the use of a λ/4 waveplate. Setting polarizers to angels 0° and 45° two signals shifted in phase are obtained. The phase shift is +90° when the measurement arm moves to and -90° when it moves from the laser.

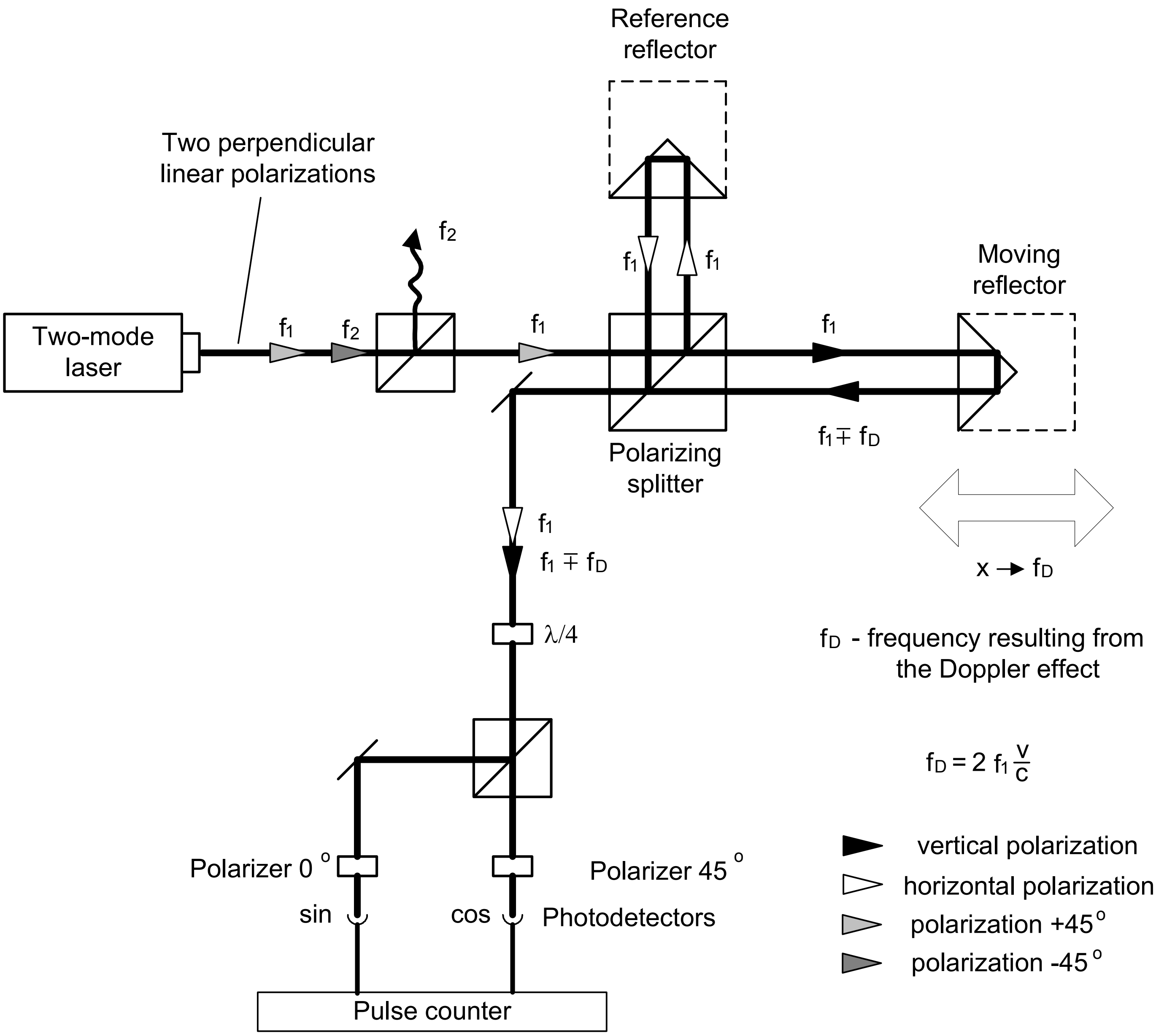


Fig. A.2. *The block diagram of an interferometer working according to the homodyne method.*

In the heterodyne method, shown in the Figure A.3, two laser frequencies are used. Therefore a two-frequency laser is needed, e.g. a Zeeman laser. A two-mode laser is not suitable for heterodyne method interferometer, because the difference between f_1 and f_2 is usually too high for an electronic counter. The output beam of a Zeeman laser consists of two circularly polarized „subbeams”, one polarized leftward and the second rightward. A λ/4 waveplate changes circular polarization to linear. The main difference between two described methods is that in the heterodyne one the beam frequency in reference arm differs from the beam frequency in the measuring arm. A detection path is also different – the measurement is done by subtracting differential frequencies of reference and measuring arms.

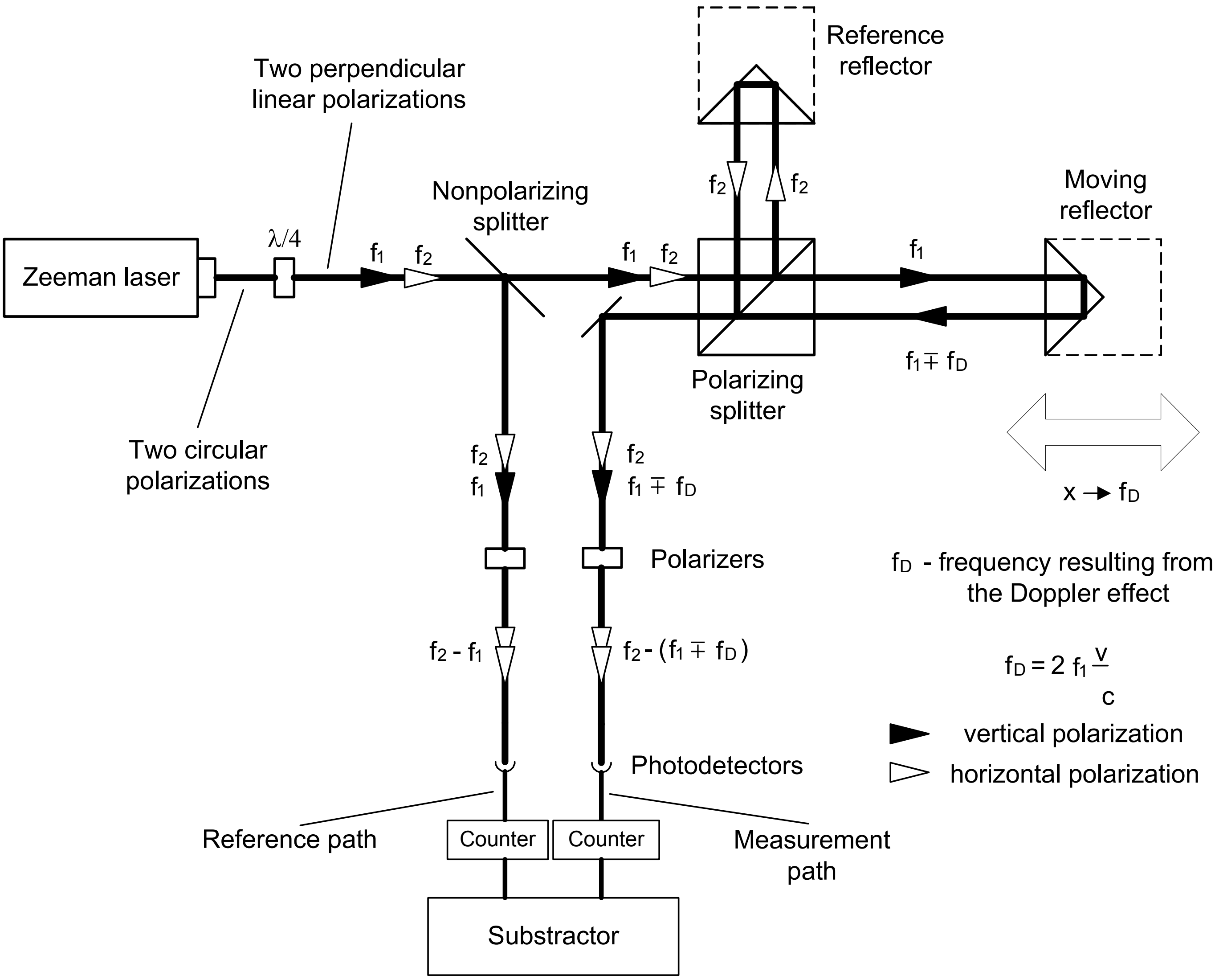


Fig. A.3. *The block diagram of an interferometer, working according to the heterodyne method.*

The heterodyne method gives correct results only when f_D does not exceed the difference between the laser frequencies, i.e.: $f_2 - f_1$. In reality, that difference, resulting from the Zeeman effect, is about 1MHz. This limits the maximum available velocity of measuring arm, in one direction, to 0.3 m/s. The next disadvantage of the heterodyne method is, that two frequencies must be used for measurements, while in the homodyne method the second may be used for measuring e.g. a second axis.

A.2.1. The Influence of the Outside Conditions on the Measurement Accuracy

According to equation (1) an interferometer's unit of measure in length measurement is laser's wavelength. From definition

$$\lambda = \frac{v}{f} \qquad (2)$$

a wavelength depends on laser's frequency f and the speed of light v in the measuring path. If the measurement is done in vacuum, than $v = c = 3*10^8$ m/s. The speed of light in a medium other than vacuum (e.g. air, water) is lower and is described as

$$v = \frac{c}{n} \qquad (3)$$

Where: n – a refraction coefficient.

Normally the refraction coefficient n is a complex variable or even a tensor, but for less accurate calculations it is simplified to a constant. The air coefficient depends mostly on the pressure P, temperature T and humidity H. The dependence n(T,P,H), for the air was empirically determined by Edlen and is described as

$$n_{T,P,H} - 1 = 2{,}8775 * 10^{-7} * P \frac{1 + 10^{-6} * P * (0{,}613 - 0{,}00997 * T)}{1 + 0{,}003661 * T} + \Delta n \qquad (4)$$

$$\Delta n = -3{,}033 * 10^{-9} * H * e^{0{,}057627 * T} \qquad (5)$$

From the above equations one may obtain the refraction coefficient dependences on T, P and H in usual conditions (T=293K, P=1000hPa, H=50%):

$$\frac{\partial n}{\partial T} = -0{,}93 * 10^{-6} \left[\frac{1}{K} \right]$$

$$\frac{\partial n}{\partial P} = +0{,}27 * 10^{-6} \left[\frac{1}{hPa} \right]$$

$$\frac{\partial n}{\partial H} = -0{,}96 * 10^{-8} \left[\frac{1}{\%} \right]$$

It is worth to notice that the most critical parameter is the temperature, because its change influences the coefficient n more than changes in the pressure and much more than changes in the humidity.

A.3. Errors Caused by the Environment

The most impotent source of errors in machine geometry measurements is the temperature (or more exactly, the change of the temperature) of the measured machine. For example, if the machine's base is made of steel, than the base's length increases 11.7μm when its temperature changes 1K. It shows how important it is for very precise measurements to measure the temperature of the controlled part of the machine and to use it in readout corrections. This is not a simple task for a few reasons, but the most important one is that, than when the machine operates, there are temperature gradients on it. That means that more than one temperature sensor is needed and that the more sensors are used the better accuracy can be achieved. Moreover the shape of the measured part of the machine may "absorb" a part of the expansion of the material or the part may be built of materials of different expandability.

As was mentioned in the previous chapter, the temperature influences the accuracy also as it changes the refraction coefficient of the medium the measurements are made in (usually it is air, but may be e.g. water). The Edlen equation was presented, showing how the refraction coefficient of the air changes with the change of the air temperature, pressure and humidity. The errors caused by the change of the wavelength are less important than the mentioned above, but they cannot be abandoned. Roughly, a 1ppm error (i.e. 1μm/m) is caused by: the air temperature change of o 1K, the air pressure change of 4hPa and the air humidity change of 30%.

A.4. The Dead Path Error

A dead path error is an error associated with the change in environmental parameters during a measurement. This error occurs when some part of the light path (a dead path) is not included in the temperature (both air and base), pressure and humidity compensation.

The dead path of the light path is a distance between the optical interferometer and the base (or the null point) of the measuring position (L¬1 in the Figure A.4). Let the position of the interferometer and the retroreflector do not change. When there is a change in the air temperature, pressure or humidity, than the wavelength changes on the whole path length ($L_1 + L_2$). The path length changes also when the temperature of the base changes. But the correction system will use the correct wavelength only on the length L_2 and will correct only this length. The correction will not be made on a dead path L_1. In this way, the laser system will "move" the base point.

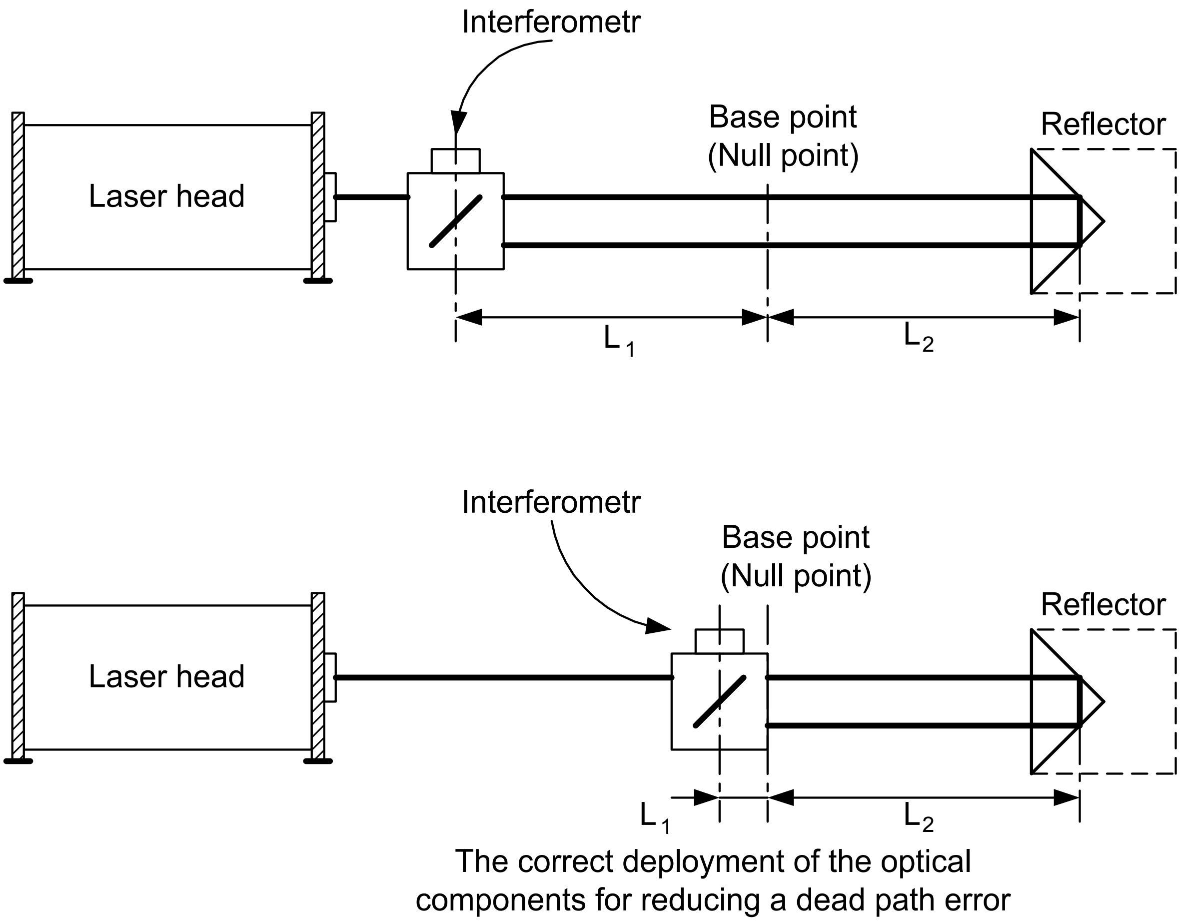


Fig. A.4. *An illustration of a dead path error..*

The dead path error is the more severe the greater is the distance between the interferometer and the base point. This error is especially important in laser interferometers where the interferometer is build-up in a common casing with a laser head, because it is than very difficult to reduce a dead path.

A.5. A Cosine Error

If the laser beam is not parallel to a measured axis of a machine (i.e. the optical path is not properly adjusted) than a difference between the real distance and the measured distance occurs. This error of unadjustment is known as a cosine error, because its magnitude depends on the angle between the laser beam and the axis of the machine (Fig. A.5).

If, as a reflector a flat mirror is used, than the beam must be perpendicular to it. If the machine changes its position form point A to point B, than the beam stays perpendicular to the mirror, but moves on its surface. The distance measured by the laser interferometer L_{LMS}, will be smaller, than the real distance L_M, according to

$$L_{LMS} = L_M * \cos\Theta \quad (6)$$

The above equation is valid also when as a reflector a corn cube is used.

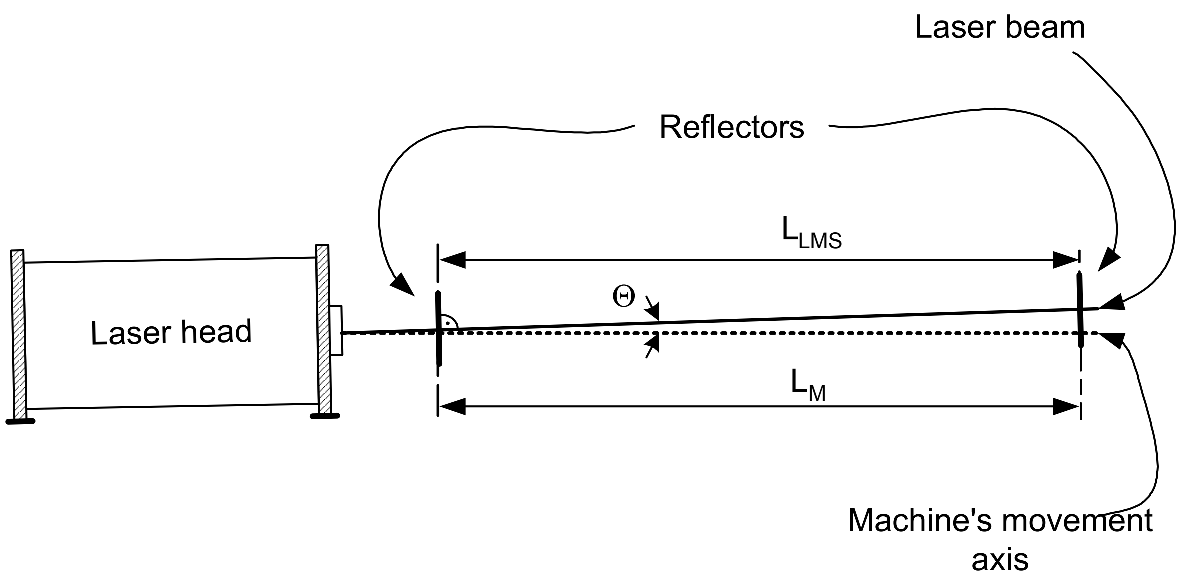


Fig. A.5. *The beam unadjustment as a cause of a cosine error.*

The only method of eliminating the cosine error is a proper laser beam adjustment done before a measurement.

A.6. The Abbe Error

The Abbe error occurs when, during measurements, the measured part does not move perfectly straight and there appear angular movements, which cause sloping of the retroreflector. The sloping of the reflector is the greater the longer is the distance between the axis of the measurement and the axis of movement.

This distance is called An Abbe offset. Only the movements in the axis of the measurement are important (see Fig. A.6). An Abbe error may be avoided only when there are no angular movements of the retroreflector in the axis of the measurements.

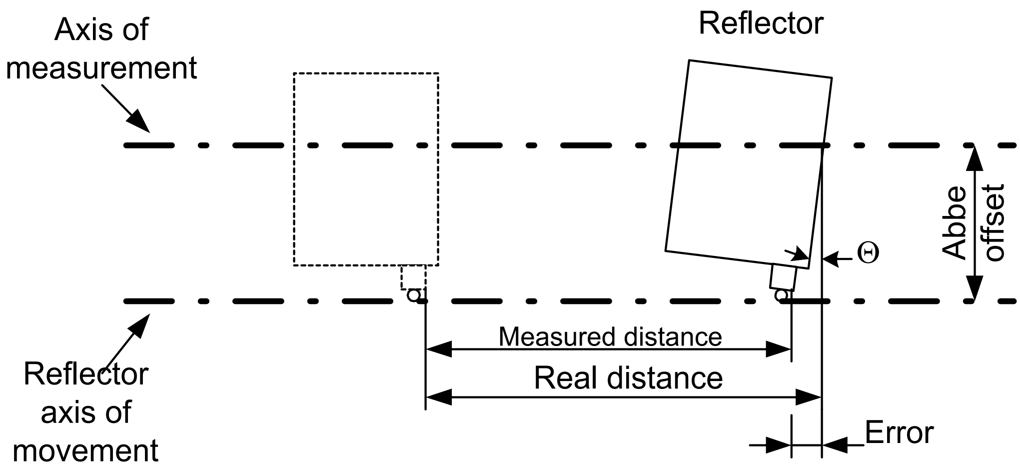


Fig. A.6. *An illustration of an Abbe error.*

A.7. The Laser Stability Error

As was already mentioned, in laser measurements the laser wavelength instability changes directly the readout from the interferometer, e.g. a relative instability of the laser in the range of 1ppm (10^{-6}), causes an error of 1μm on every 1m of a measured distance. Therefore the laser instability error is important mainly in measurements in vacuum (where a refraction coefficient is constant) and when a low stability laser is user (e.g. a semiconductor laser). The stability of usually used in laser measurement systems, HeNe gas lasers is 0.01 ppm, so the stability error may be neglected.

A.8. Other Errors

In some conditions, a noticeable error may be caused by the electronic part of the interferometer. As the electronics is used mainly for counting, the errors may be associated either with miscounting (some pulses are not counted) or with miscalculating (the calculations are made with finite precision).

A.9. Summary of the Laser Measurement System Errors

In order to show which of the errors influence the accuracy of a laser measurement system the most, an exemplary calculation of errors on a 1m long steel machine is shown in the Figures A.7 and A.8. Different scales of the charts should be taken into account.

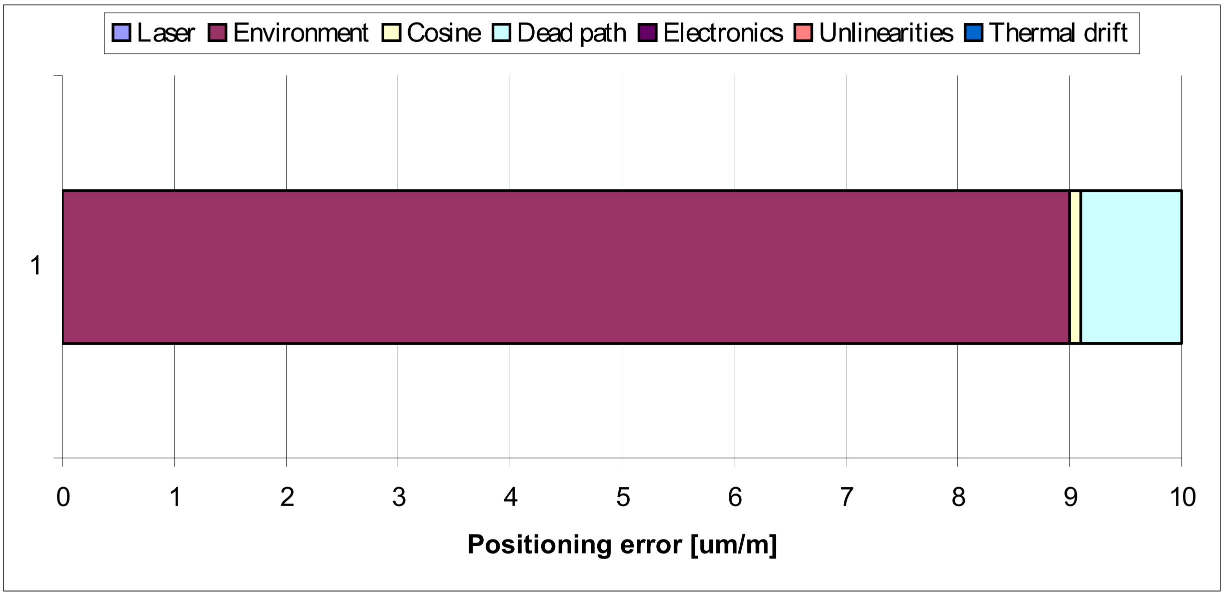


Fig. A.7. *A calculation of errors for a laser measurement system without the compensation of the environment.*

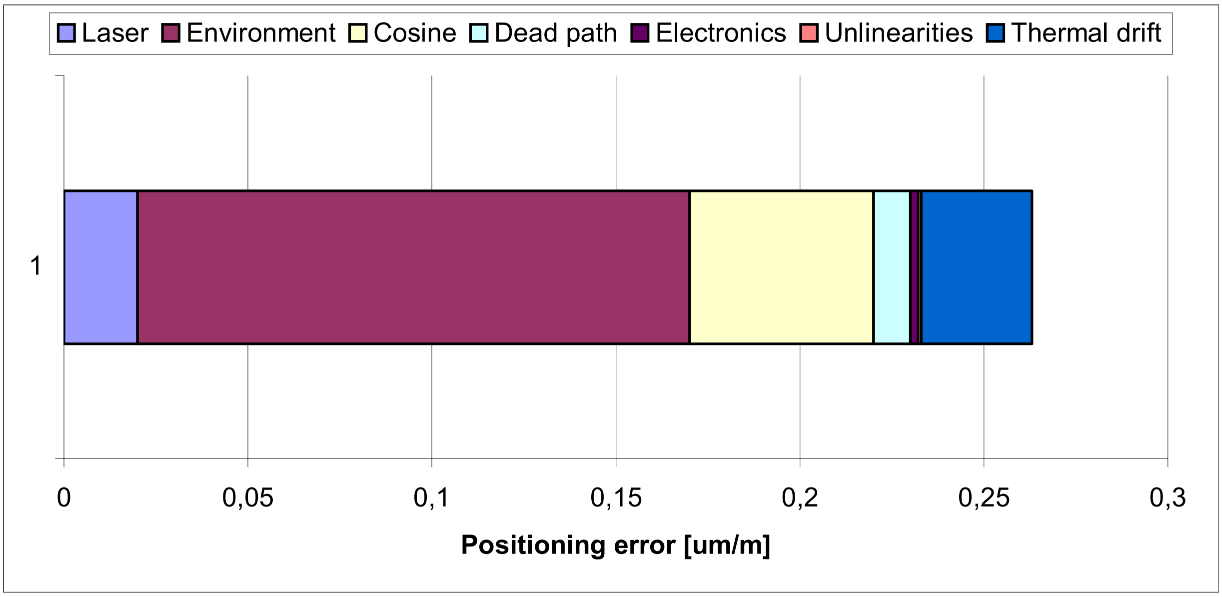


Fig. A.8. *A calculation of errors for a laser measurement system with the compensation of the environment.*