µLine F1

PRECISION – LASER - INTERFEROMETER

MANUAL

Status Pro
maschinenmesstechnik

http://www.statuspro.com

Status Pro Maschinenmesstechnik GmbH,

Mausegatt 19, D-44866 Bochum, Germany

☎: +49(0)23 27/98 81-0, 📠: +49(0)23 27/98 81-81

🌍: http://www.statuspro.com

Laser Interferometer µLine F1

User manual

Bochum 2011

1

INTRODUCTION

Laser measurement system ***µLine F1*** is a two frequency laser interferometer intended to be used mainly in machine geometry measurements. Its small size and low weight simplify transportation and make the instrument especially useful for service applications. Software version for Windows 9x/NT/2k/XP and automation of many measurement processes make the interferometer easy to use. Software, compliant with ISO/DIS 230 and PN–93 M55580, enable making rapports and diagrams. It is possible to choose statistical results processing according to norms: ISO 230-2 (European), VDI/DGQ 3441 (German), NMTBA (USA), BSI BS 4656 Part 16 (British) and PN-93 M55580 (Polish).

Very good technical parameters of the interferometer allow using it also in scientific laboratories, for precision positioning, for scaling optical and magnetic liners, etc.

Safety considerations

The Laser Interferometer ***µLine F1*** 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.

Warnings

Although the laser measurement system ***µLine F1*** was 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 should not be unscrewed from its base and if it is, it **may not** be put on a heat sink (e.g. thick metal plate).
- 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.

2

PRINCIPLES OF OPERATION

The rules of laser displacement measurements

Displacement measurements with the use of a laser interferometer allow obtaining the accuracy of a displacement measurements of 0.4 ppm in air and 0.02 ppm in vacuum. The interferometer was first built by A.A. Michelson in 1881. The simplified schematic of the interferometer is shown on fig. 2.1.

Coherent light beam falls on a semi-transparent mirror. This mirror splits the light into 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. 2.1). The measured value of the displacement is calculated according to

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

Where: N – number of pulses,

λ - light wavelength.

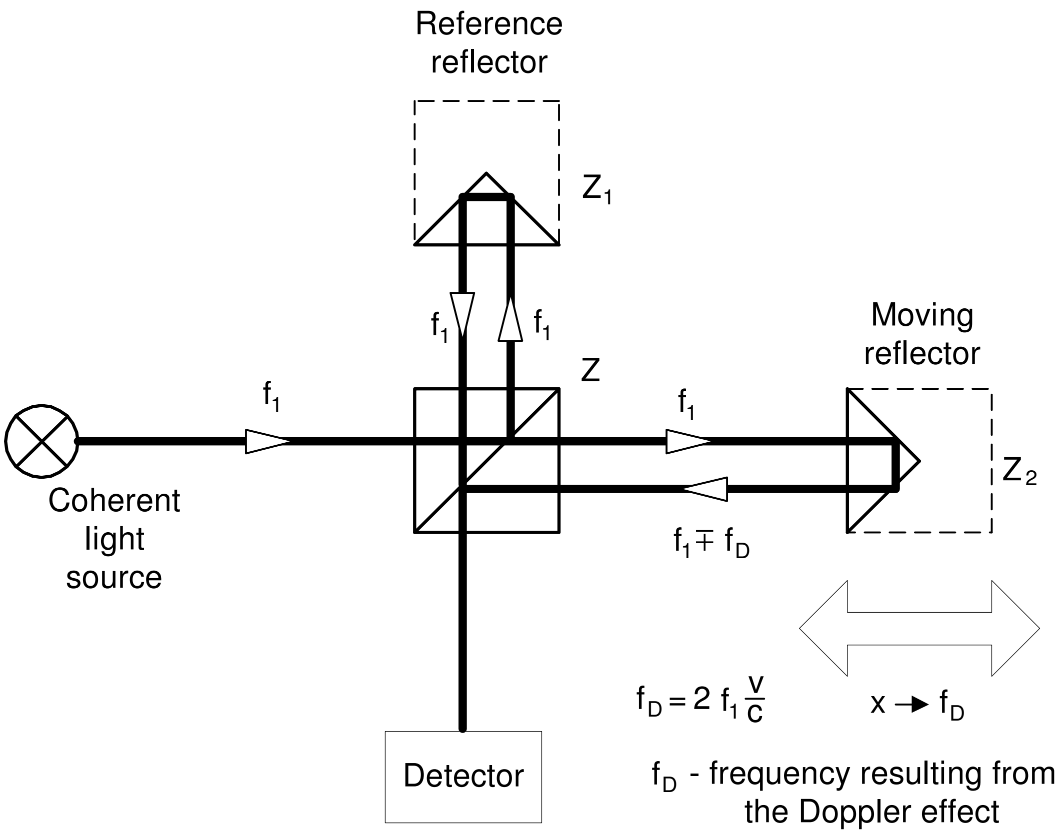


FIG.2.1. THE MICHELSON INTERFEROMETER.

The construction of real interferometers

The main disadvantage of Michelson interferometer results from the fact that the detector cannot determine, whether f_D is negative or positive thus, from the measurements the displacement of the moving reflector without the sign is obtained. Currently there are widely used two methods that allow getting 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 on figure 2.2, as a coherent source of light a linearly polarized laser is used. 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 into two beams polarized vertically (90°) and horizontally (0°). 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. After 0° and 45° polarizers, 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.

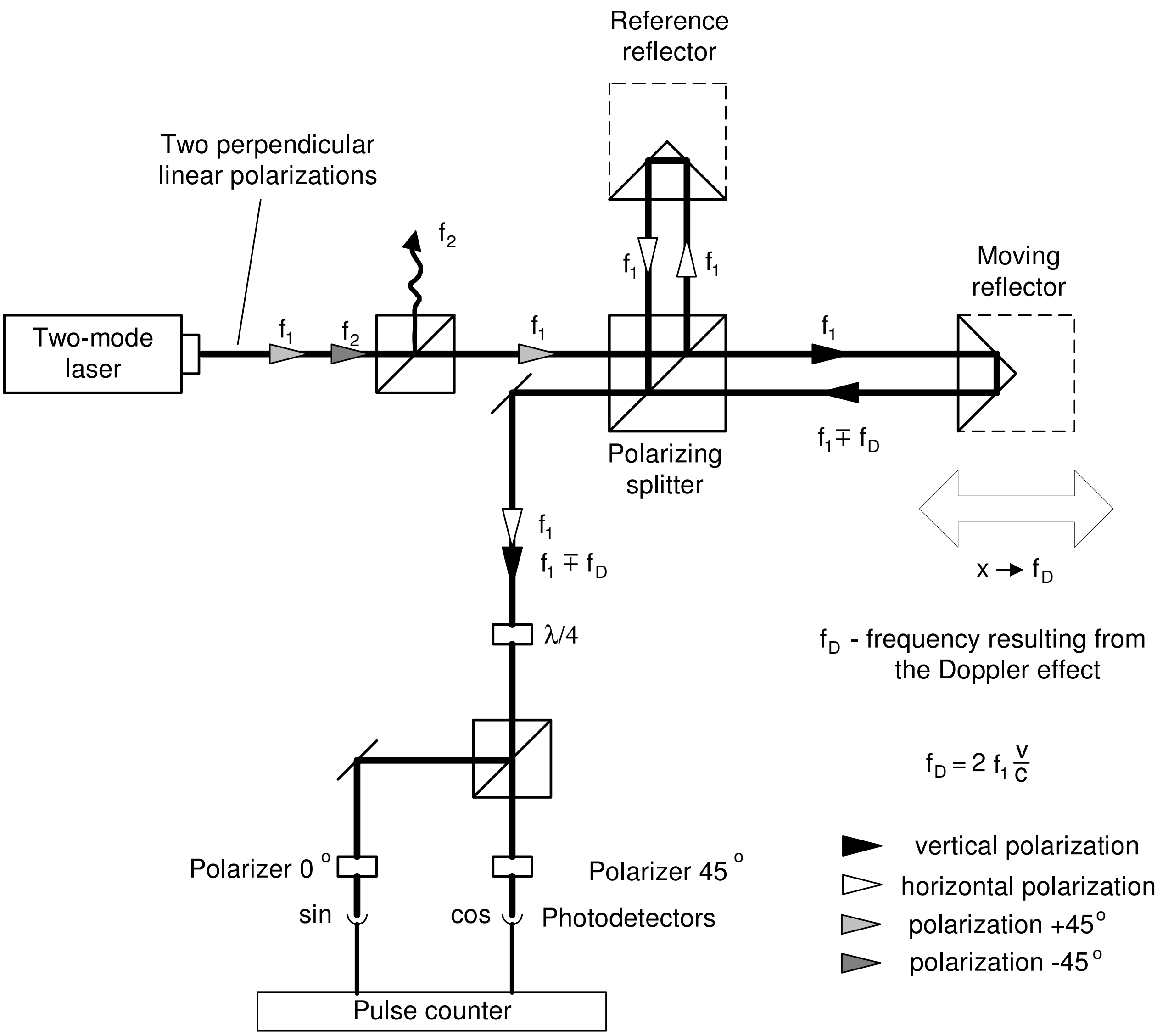


FIG.2.2. THE BLOCK DIAGRAM OF AN INTERFEROMETER WORKING ACCORDING TO THE HOMODYNE METHOD

In the heterodyne method, shown on figure 2.3, 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 the 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 beams, 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 – subtracting differential frequencies of reference and measuring arms does the measurement.

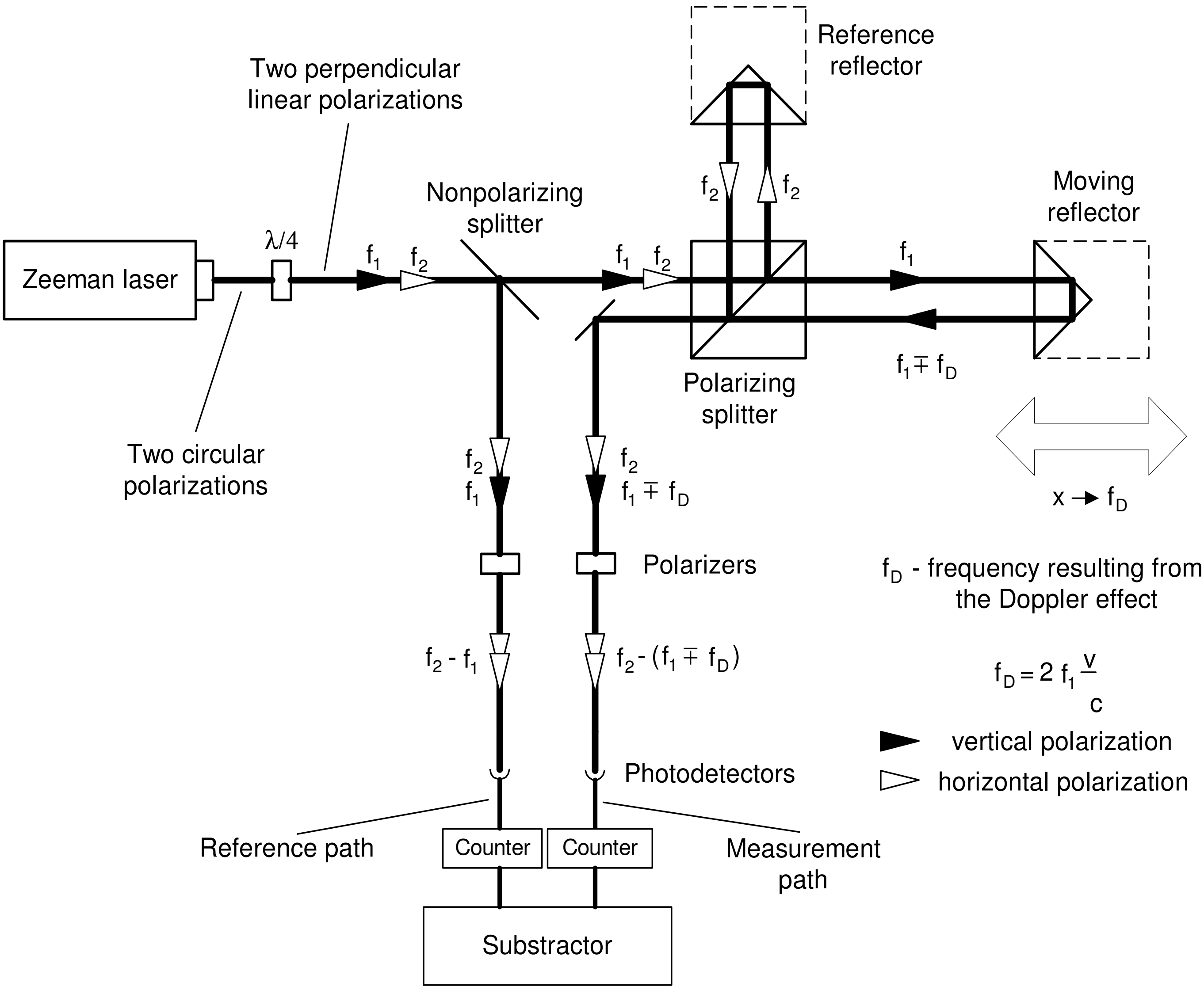


FIG.2.3. THE BLOCK DIAGRAM OF AN INTERFEROMETER, WORKING ACCORDING TO THE HETERODYNE METHOD

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.

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

$$\lambda = \frac{v}{f} \tag{2}$$

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 $\nu = c = 3*10^8$ m/s. The speed of light in a medium other than vacuum (e.g. air, water) is lower and is described as

$$v = \frac{c}{n} \tag{3}$$

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 Edien 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.

The accuracy of laser interferometers

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.

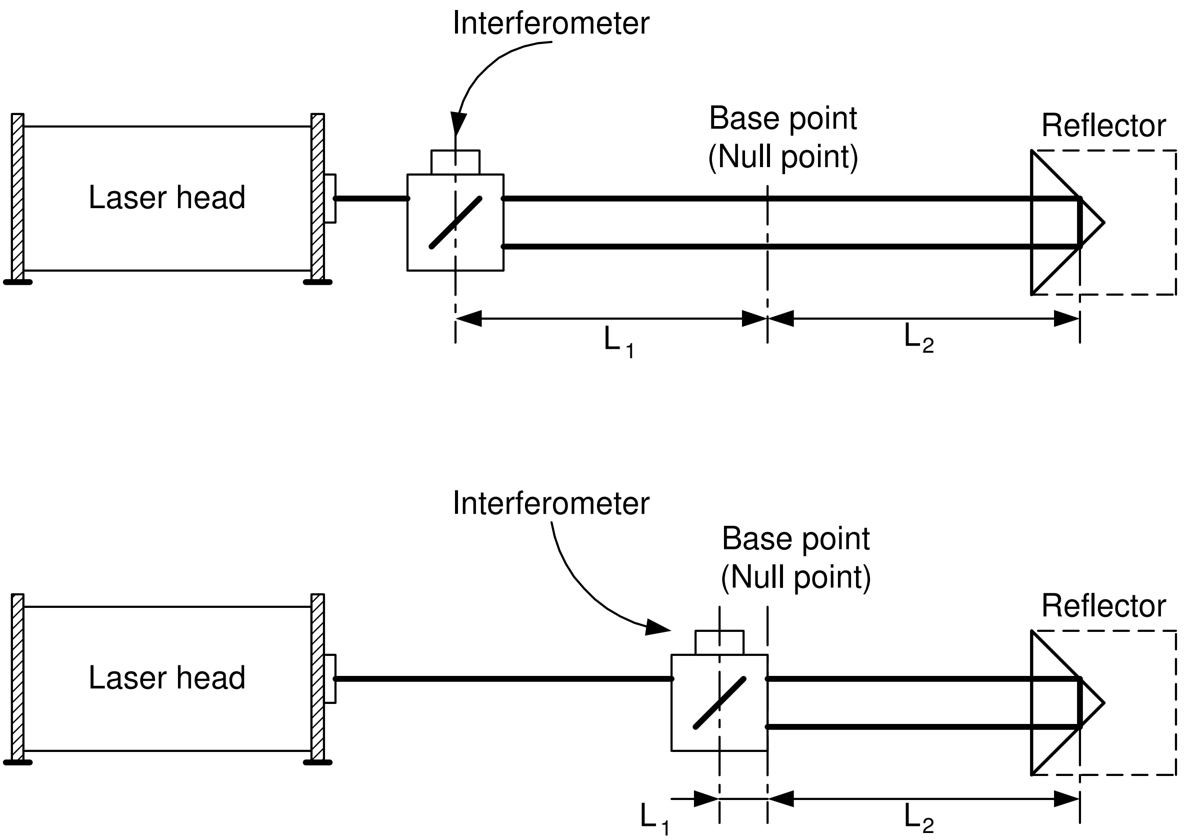
As was mentioned in the previous chapter, the temperature influences the accuracy also as it changes the refraction coefficient of the medium the measurements are made in (usually it is air, but may be e.g. water). An Edien equation was presented, showing how the refraction coefficient of the air changes 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 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 on figure 2.4). Let the position of the interferometer and the retro-reflector 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 L2 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.

A 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.



The correct deployment of the optical components for reducing a dead path error

FIG.2.4. AN ILLUSTRATION OF A DEAD PATH ERROR

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 un-alignment is known as a cosine error, because its magnitude depends on the angle between the laser beam and the axis of the machine (fig. 2.5).

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

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

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

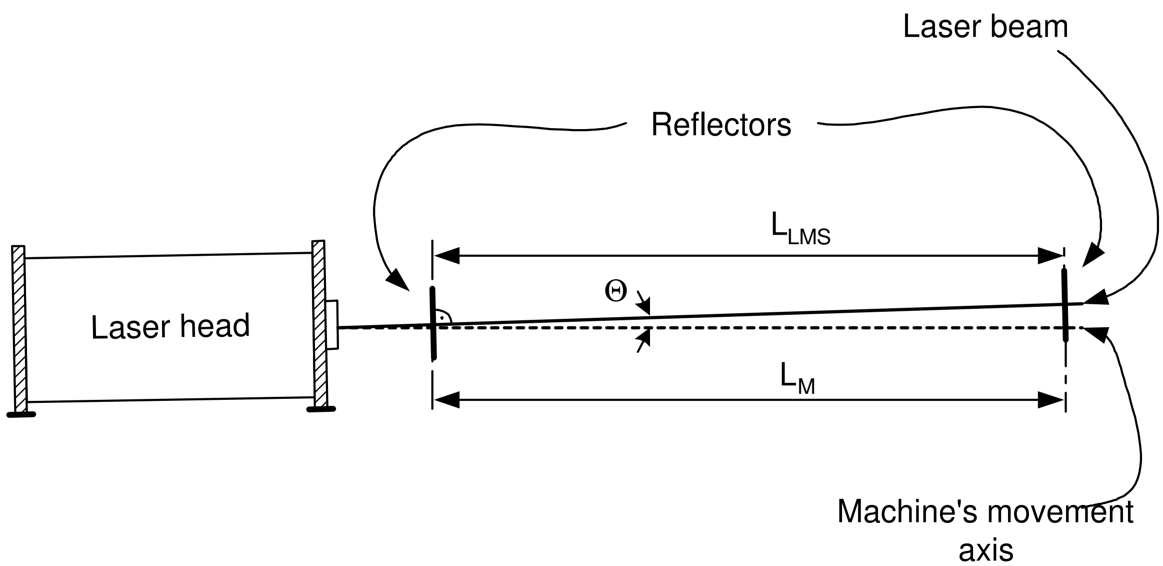


FIG.2.5. THE BEAM UNALIGNMENT AS A CAUSE OF A COSINE ERROR

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

An Abbe error

An Abbe error occurs when, during measurements, the measured part does not move perfectly straight and there appear angular movements, which cause sloping of the retro-reflector. 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. 2.6). An Abbe error may be avoided only when there are no angular movements of the retro-reflector in the axis of the measurements.

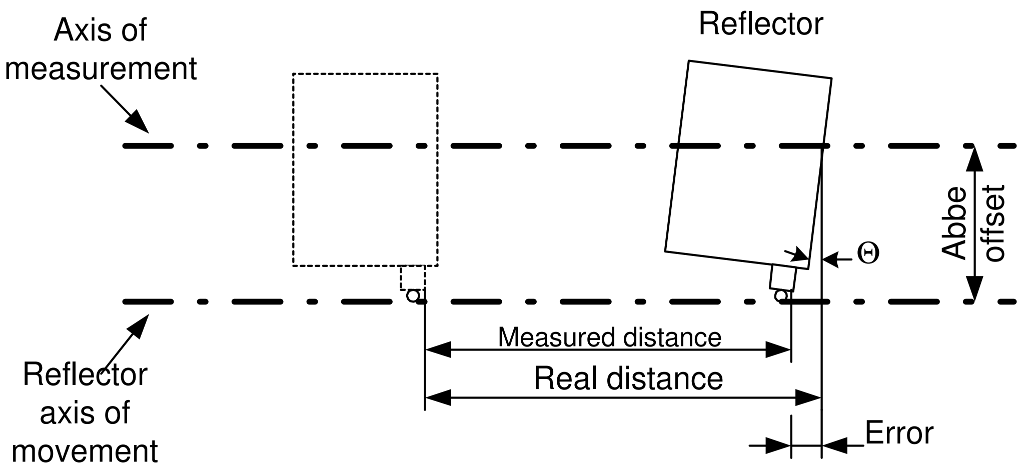


FIG.2.6. AN ILLUSTRATION OF AN ABBE ERROR

A 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 used (e.g. a semiconductor laser). The stability of usually used in laser measurement systems, HeNe gas lasers is 0.02 ppm, so the stability error may be neglected.

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 summary of 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 on figures 2.7 and 2.8. Different scales of the charts should be taken into account.

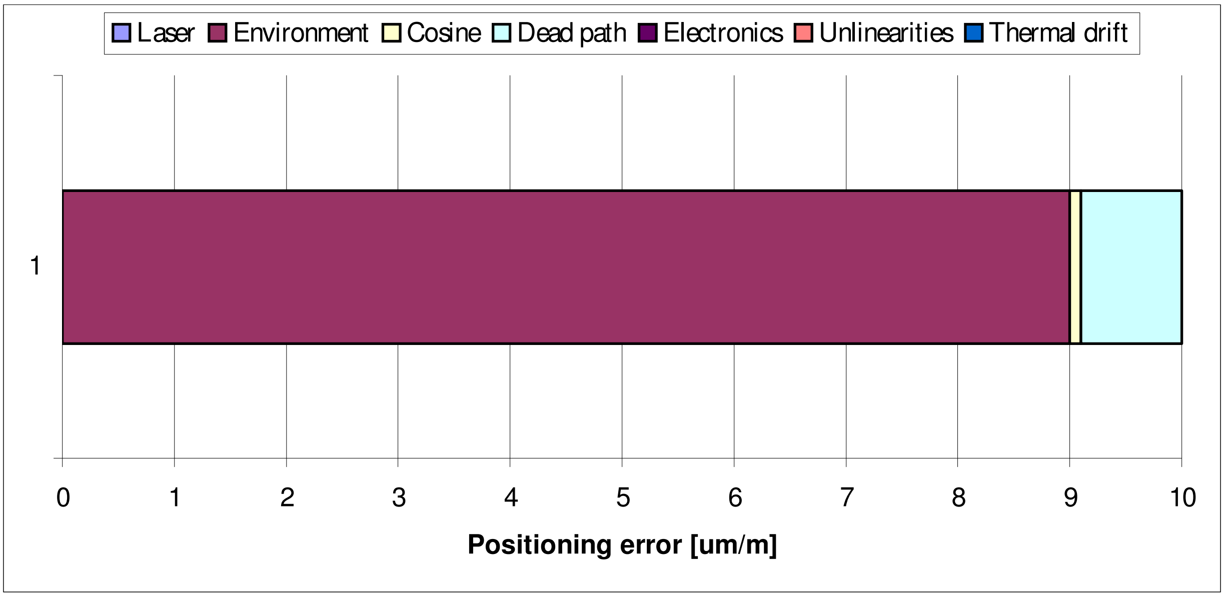


FIG.2.7. A CALCULATION OF ERRORS FOR A LASER MEASUREMENT SYSTEM **WITHOUT THE COMPENSATION** OF THE ENVIRONMENT

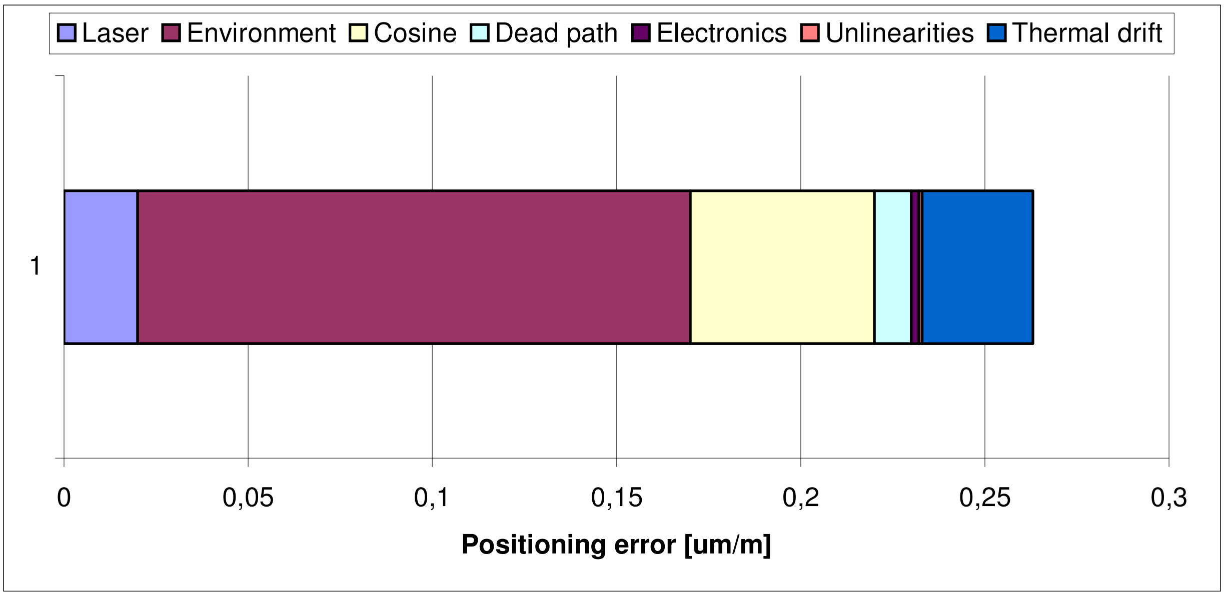


FIG.2.8. A CALCULATION OF ERRORS FOR A LASER MEASUREMENT SYSTEM **WITH THE COMPENSATION** OF THE ENVIRONMENT

3

PREPARATIONS

To start the measurements using the Laser Interferometer ***µLine F1***, software *"LSP 30 -3D"* should be installed on HD of a PC computer. The hardware requirements are:

- Windows 9x/NT/2k/XP system,
- CR-ROM
- Pentium processor, 600 MHz or better
- SVGA graphic card making possible working with resolution 800x600.

Software installation

To install the LSP program on the PC computer put the CD disc " µLine F1 " into the CD-ROM. The program will be installed automatically. If the installation does not start automatically, explore the CD and double click on setup.exe icon.

The Laser Interferometer system elements

The number of elements the system consists depends on desired types of measurements. To the standard set (for linear measurements) belong:

1. 1 x Laser head – *Laser Interferometer*
2. 1 x Power supply - *Laser Interferometer Power Supply*
3. 1 x Tripod stand
4. 1 x Environmental Compensation Unit - (ECU) **SM1**
5. 1 x Laser head to power supply cable
6. 2 x Magnetic holder **UM1**
7. 1 x Linear interferometer **IL1**
8. 1 x Linear retro-reflector **RL1**
9. 3 x Basis temperature sensor **T1, T2, T3**
10. 1 x USB cable
11. 1 x Manual Strobe cable

See fig. 3.1b on the next page for pictures of the elements of the standard set and fig.3.1a present the suitcase for transportation and storing of the interferometer system.

.

Additional elements for angular measurements are:

1. 1 x Angular interferometer **IK1**
2. 1 x Angular retro-reflector **RK1**
3. 2 x Beam directing mirror **ZK1**
4. 1 x Rotary table **SO1**

FIG.3.1a. THE SUITCASE FOR TRANSPORTATION AND STORING OF THE INTERFEROMETER SYSTEM

FIG.3.1b. THE ELEMENTS OF THE STANDARD SET

Preparing the interferometer to work

The Laser Interferometer ***µLine F1*** is supplied from autonomous power supply –„*Laser Interferometer Power Supply”(***2***)*. Communication with a PC computer is performed by USB interface. Before starting the measurements place the laser head –*"Laser Interferometer"(***1***)* on the *Tripod stand* (**3**) and connect it with the LSP power supply. Connect with the green cable (**5**) the laser head with the *"Laser Interferometer Power Supply"*. Connect the USB cable *(***10***)* to male socket on the front panel of the Power Supply. The second end of the cable plug into the USB socket of the computer. Connect the air temperature and humidity sensors *(***4**) - (THS – Temperature and Humidity Sensors) to the 6-pin socket marked THS on the front panel of the Power Supply Unit. Temperature sensors T1, T2, T3 (**9**) connect to 4-pin sockets placed on the front panel. To 6-pin socket marked STROBE should be connected a source of strobe signal (**11**). Strobe signal may be produced by a pulse switcher (5 m cable with a pulse switcher is in standard set) or by any other devices. Strobe input is used to control the moment of measurement either by hand or automatically during dynamic positioning. The linear interferometer (**7**) and linear reflector (**8)** should be mounted in magnetic bases (**6**).

FIG.3.2. ELECTRIC CONNECTIONS OF THE µLINE F1

Switching the system on

After connecting all necessary cables to the Power Supply unit, switch on the device according to the following instructions:

1) Switch on the power switch in the Laser Interferometer Power Supply,

2) Start LSP30 – 3D program on a computer.

When the main menu appears at the computer monitor (fig.3.3) choose option **Display** (fig.3.6)

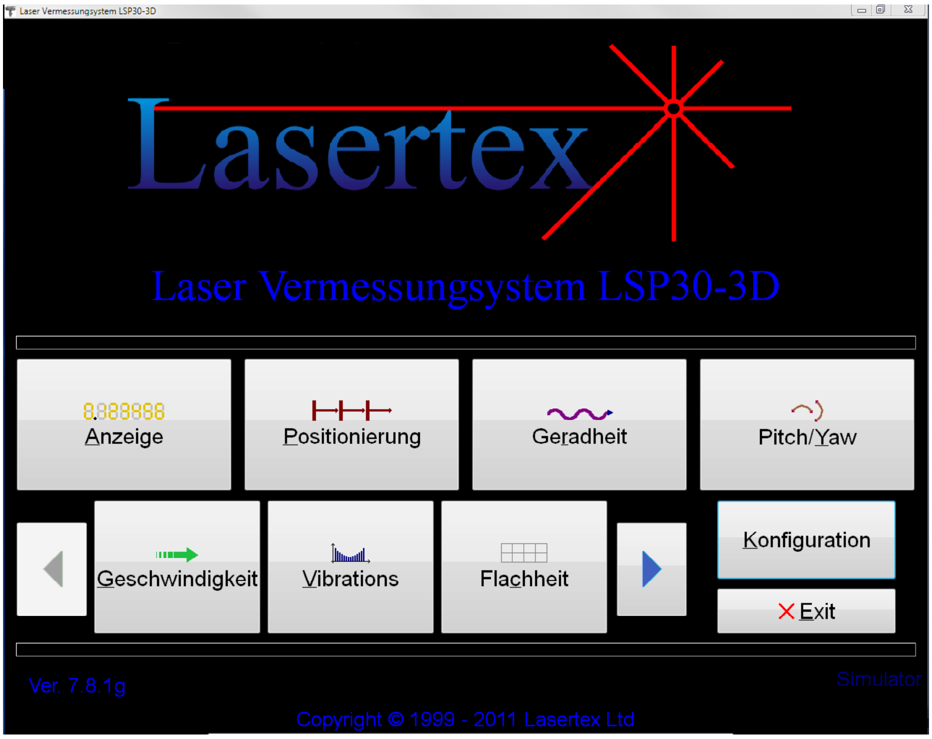


FIG.3.3. MAIN MENU

If the program is started before the Power Supply is turned on or the Power Supply is not connected properly to the computer, on the monitor an error window with *"No connection or Power Supply Off"* line will appear (fig. 3.4). To get rid of this error quit the program, check the connection and/or the supply of the Interferometer (the POWER diode should be on).

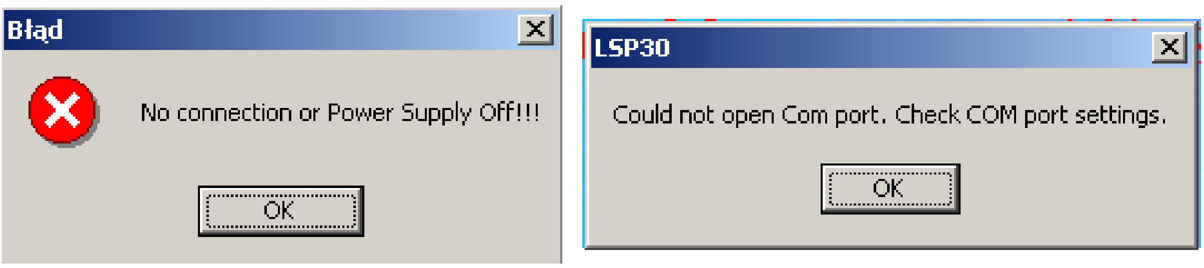


FIG.3.4. ERRORS THAT MAY OCCUR DURING SOFTWARE LOADING

If the interferometer is not connected to the computer an error window with *"Could not open COM port. Check COM port settings"* line will appear. Please check the connection between the computer and the power supply.

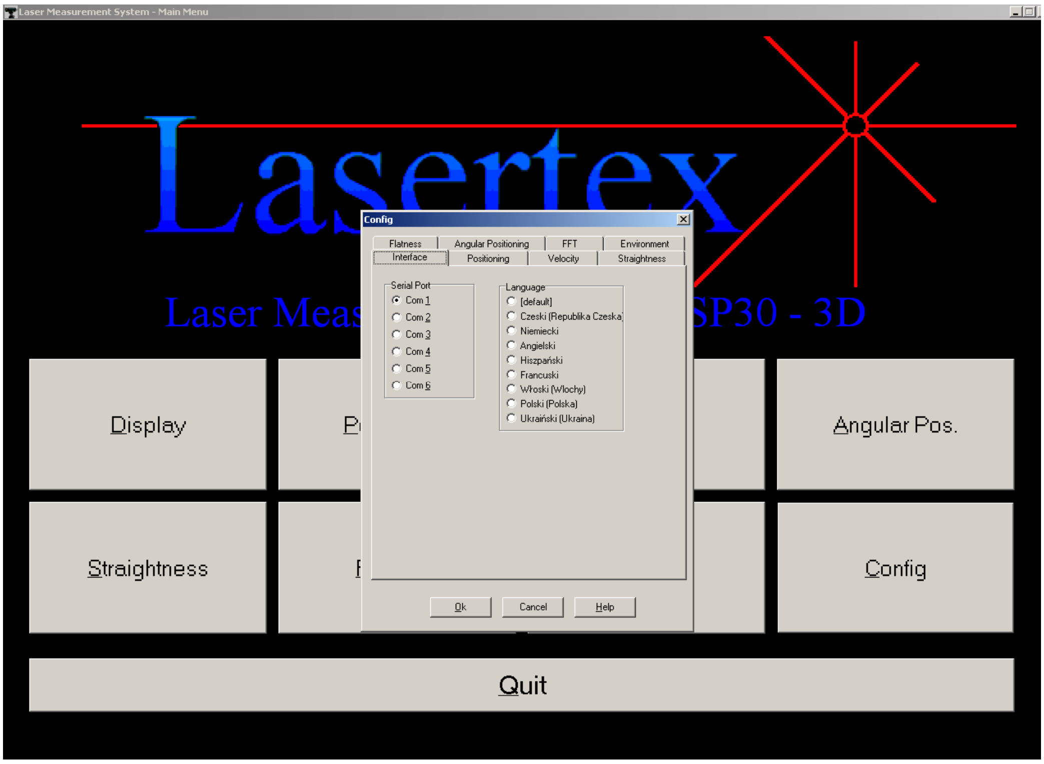


FIG. 3.5. OPTION CONFIG

In the option **Config** (Fig. 3.5) the user can change the language of the program (after installation it opens in the language of the installed Windows system). In other panels of mentioned window the user can configure many parameters of all types of measurements feasible with the system. These panel can be also reached from other parts of the program.

Getting basic information from the system.

After proper software loading choose option **Display**. The laser system will be heated up. If the output beam of the laser is properly redirected to the laser head (e.g. with the use of the retroreflector RL1) the **Beam Strength** – the green indicator on the screen – will appear and disappear. The speed of changes will become smaller due to the increase in the temperature of the laser system cover. During the heating up time the measuring system is ready for the alignment of the optical arrangement of the laser path (see chapter 4).

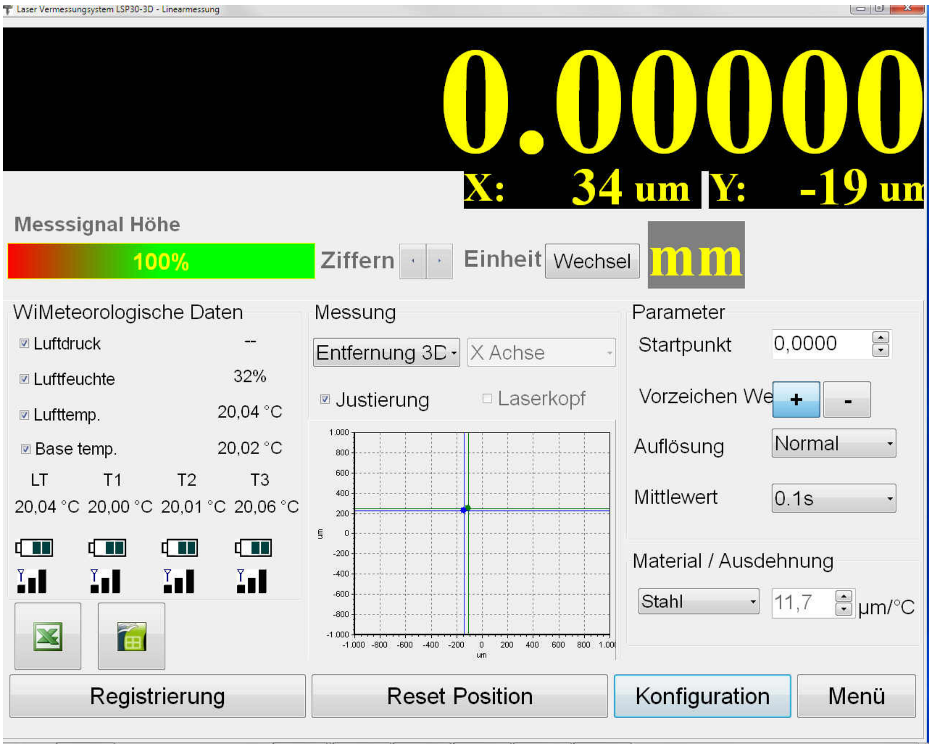


FIG.3.6. OPTION DISPLAY

On the Display screen there are four panels:

- Panel containing the digital result of the measurement, the measuring signal level indicator and the buttons for changing the number of displayed **Digits** and for changing **Units**. Quantity of significant digits on display may be changed with the use of buttons ↑ ↓, pressing button with an inscription **Change** changes measurement unit on the display. In the upper left corner there is an icon making link to Microsoft Excel (if installed). Running this link allows to register measurement in Excel cells by each STROBE button press.

- Panel **Environment** where measured data obtained from the Environmental Compensation Unit - (ECU) are shown. On the screen there are shown: temperature, pressure and humidity of the atmosphere (*Humidity*, *Pressure* and *Air Temp*.) and temperatures measured by three base temperature sensors (*Average temp*., *T1*, *T2* and *T3*). Average temperature of the base measured by three sensors is also presented.

- Panel **Measurement** contains basic information about conducted measurement. With the left button the type of measurement can be changed. The right is used for choosing measuring axis. At every change of measuring option (i.e. distance, speed, angle, straightness) and/or change of measuring axis (i.e. X, Y, Z) a drawing suggesting the arrangement of the optical elements appears on the screen. Clicking with left mouse key in the area of the drawing invokes help on a theme of the optical arrangement alignment. Panel **Measurement** also contains an option **Adjustment.** This option is very helpful in optical path *alignment process* (see chapter 4).

- Panel **Parameters**, contains a few options. Option **Sign** allows choosing whether enlarging distances between the retro-reflector and the interferometer gives positive (default "+") or negative result on the display. In the option **Material** one can choose the material from which a basis of a machine is made of. The value of the thermal expandability coefficient of the basis is used for calculations of the real shift value (i.e. measured value referred to the temperature of 20°C). Option **User** makes it possible to enter any value of the thermal expandability coefficient. In the panel **Resolution** one can change between high (10nm) and low (100nm) system resolution. In higher resolution accepted movement velocity is strictly limited (see Technical data chapter for details). In the panel **Environment** the data from Environmental Compensation

Unit - (ECU) may be controlled. From console of the computer one can switch off the data coming from Environmental Compensation Unit - (ECU) and insert the parameters of the atmosphere by hand.

When measurements are executed with automatic compensation of the atmosphere parameters and the compensation of the basis temperatures one should:

- place the air temperature and humidity sensors THS on the machine in the vicinity of the laser beam.
- place the sensors of the basis temperature along the measured axis on the machine basis

Measurement executed without automatic compensation are referred to normal conditions: temperature 20 °C, pressure 1016 hPa, humidity 50 %.

4

BEAM ALIGNMENT

The alignment of the optical path is the most **difficult** and **laborious** part of the whole measurement process. Be very **careful** reading this chapter!

The LSP-3D provide unique functions: **Alignment** and **Laser Head** which are very useful tools for the laser beam alignment. Beam alignment is a process in which the user, with the use of certain mechanical arrangements, makes the direction of the laser beam **parallel** to the direction of the movement in a measured axis. If the beam is not correctly aligned an effect like the one shown on Fig.4.1 may happen, i.e. the position of the beam returning on the detector in the laser head from the moving retroreflector may vary with the position of the retroreflector resulting in a cosine error (see chapter 2) and/or misalignment of the optical path (no *Beam Strength*).

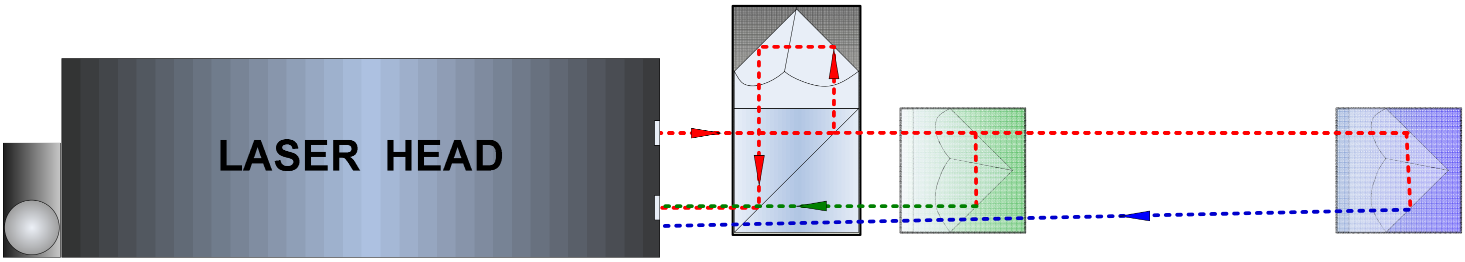


FIG.4.1. ILLUSTRATION OF BEAM ALIGNMENT

The alignment of the optical set up should be conducted in option **Display**. It can be done during laser head heating. Final check should be made when the system is ready to work.

The Laser Head should be firmly attached to the tripod. The tripod should not touch a machine as it may cause vibration of the laser head and the optical path. Turn special attention, not to move the legs of the tripod during the measurements, because it will cause shift of elements of the optical path and the necessity of repetition of the alignment process.

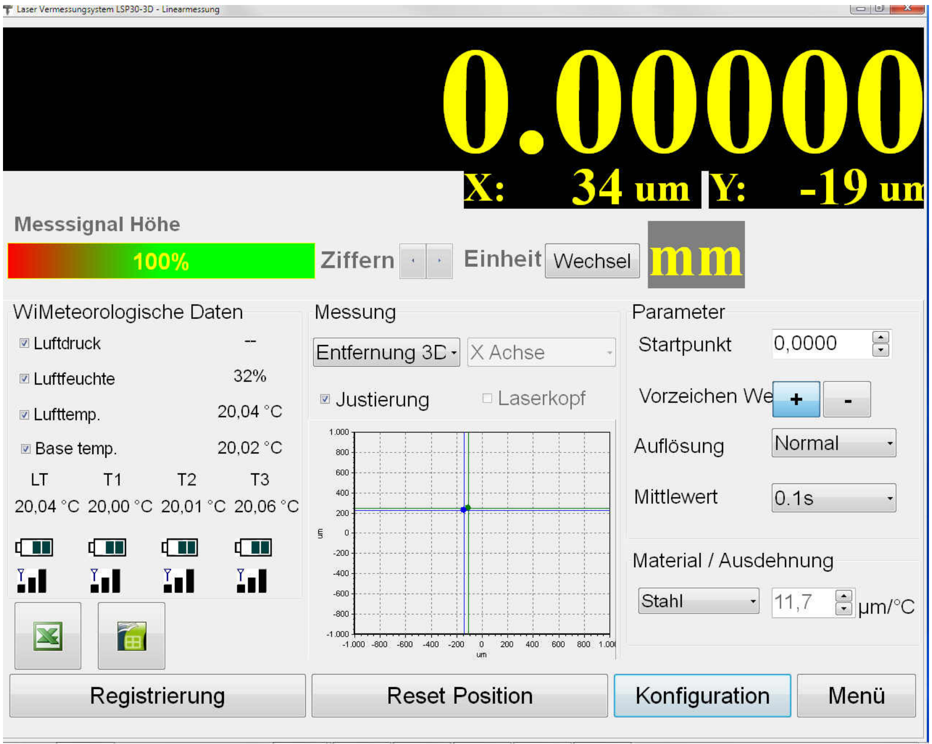


FIG. 4.1 ILLUSTRATION OF THE FUNCTION LASER HEAD

The arrangement of the tripod helps to adjust the optical path. Inspection of the level of arrangement can be made using level fastened on the tripod. The angular position of the laser head is set using the function **Laser Head**. The tripod must be levelled, and after that with the function **Laser Head** the position of laser head must be set according the angle of measuring path. In the most application the laser head is levelled. In special cases, when the measuring path is sloped to the level, the angle of slope must be set. The angle of rotation of laser head must be set to zero degree (90 degree in some configuration). The diaphragm of the laser beam on the front panel of the laser head helps in the process of alignment. The diaphragm can be placed in three positions:

- Right extreme position (fig. 4.1a) –" **Alignment**" – the laser beam goes out through opening in the diaphragm about 2 mm diameter,
- Central (fig. 4.1b) –" **Measurement**" from the laser head goes out beam about 8 mm diameter,
- Left (fig. 4.1c) - extreme position, in which the exit of the beam from the laser head is completely closed.

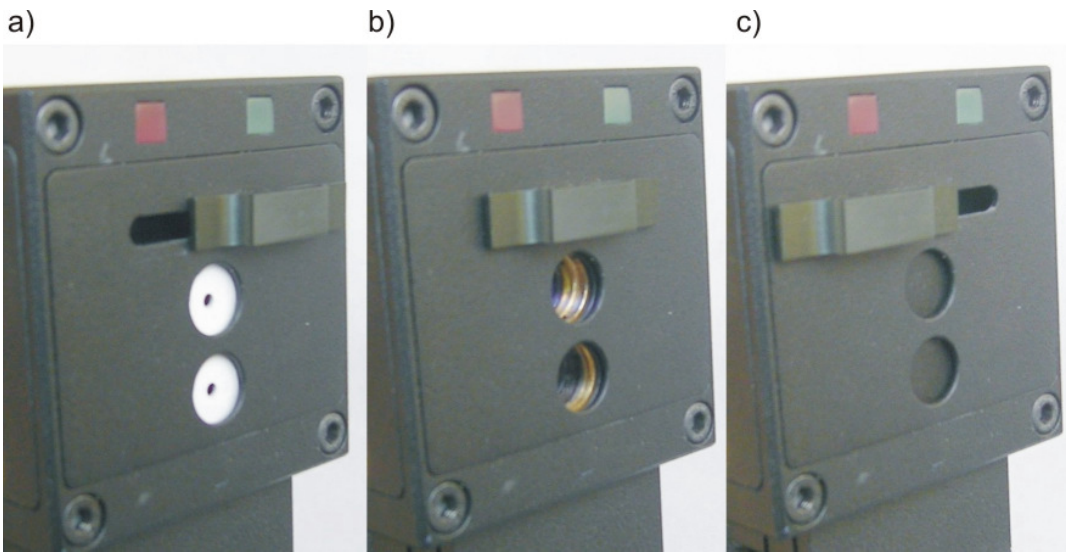


FIG.4.1. DIAPHRAGM POSITIONS. A) RIGHT, B) CENTRAL, C) LEFT

During transportation or when system is not used, correct position of diaphragm is left extreme position. In this position optics is safe from getting dirty, covering with dust and accidental damage during transportation.

Beam alignment process

1. In the option **Display** in the PC program choose type of measurement, which will be done and axis along of which measurements will be carried. On the screen will appear a drawing showing recommended arrangement of measuring elements at the chosen type of measurement (Fig. 3.6).

2 Linear interferometer IL1 and linear retro-reflector RL1 should be mounted on magnetic holders UM1, UM2. Regulating elements (see Fig. 4.2a, b, c) of the laser head should be placed in central positions, to assure maximum range of regulation.

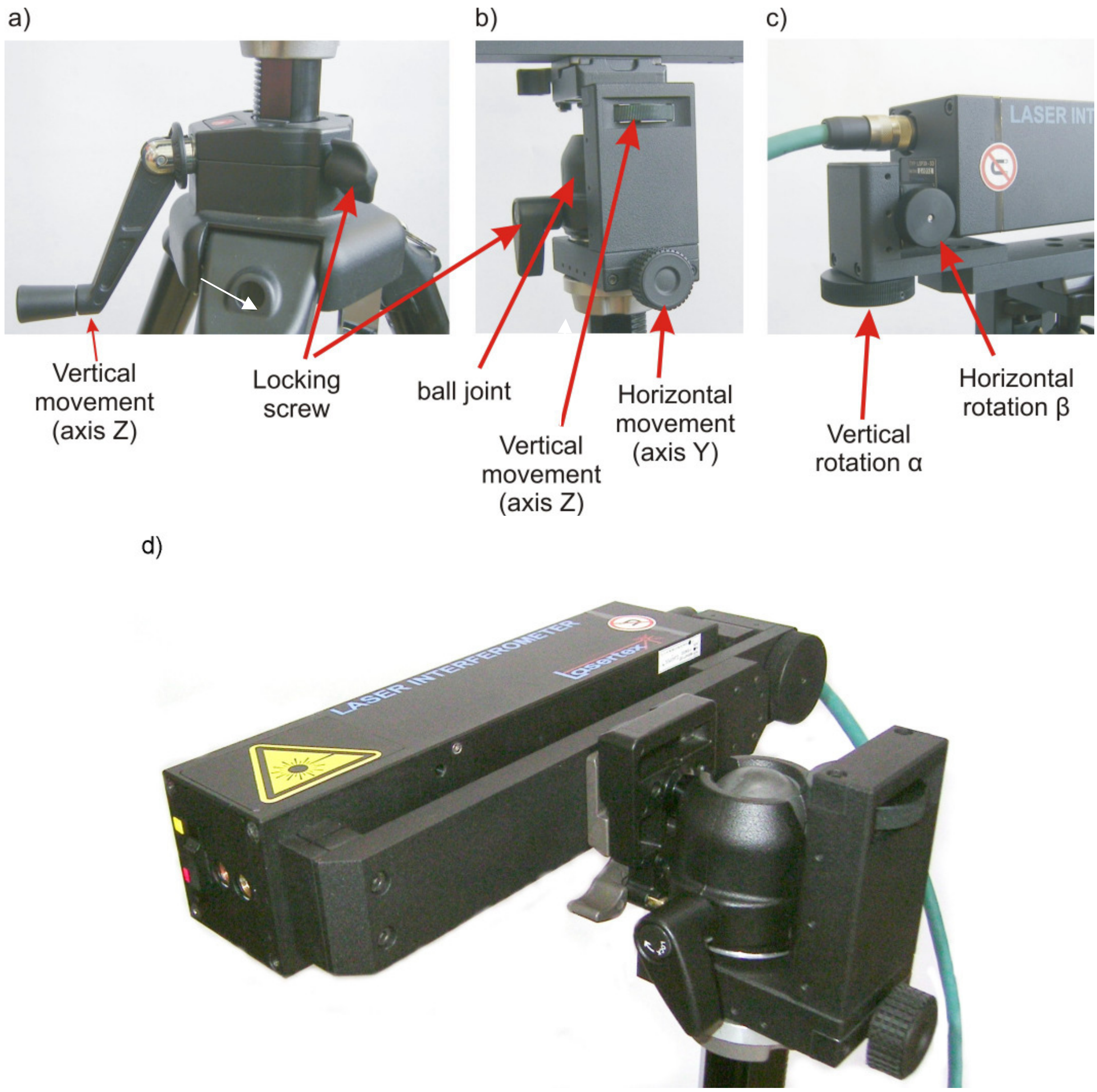


FIG.4.2. THE LASER HEAD ALIGNMENT ELEMENTS

3. Choose which from the optical elements will be moved (retro-reflector RL1 or interferometer IL1) and attach both with magnetic holders: one to a moving element of the machine, second to an element in relation to which displacement will be measured (for example: the retro-reflector may be fasten to a moving element, and the interferometer to a motionless table). Remember, *that relative linear displacement between the retro-reflector and the interferometer is measured*.

Attention! It is inadmissible to place one of optical elements (i.e. RL1 or IL1) outside the machine on an additional stand – the system measures then also displacements of the machine in relation to the stand!!!).

4. The moving element of investigated axis should be moved as close as possible to the position of the laser head and the tripod.

5. Place the interferometer optics **IL1** and the retro-reflector **RL1** on the axis of movement. If the axis of movement is horizontal check the level indicators (Fig. 4.3) on the laser head and the interferometer. In both cases the blob should be inside the inner circle.

Attach the retro-reflector **RL1** to the interferometer **IL1** (there is a special socket for this purpose in **IL1**) – see fig.4.3.

FIG.4.3. START POSITION OF ALIGNMENT

6. Move the moving element of the machine together with the attached optical element to the opposite, extreme position. Diaphragms on **IL1** and **RL1** and of laser head place in position – "Alignment" (Fig. 4.4a).

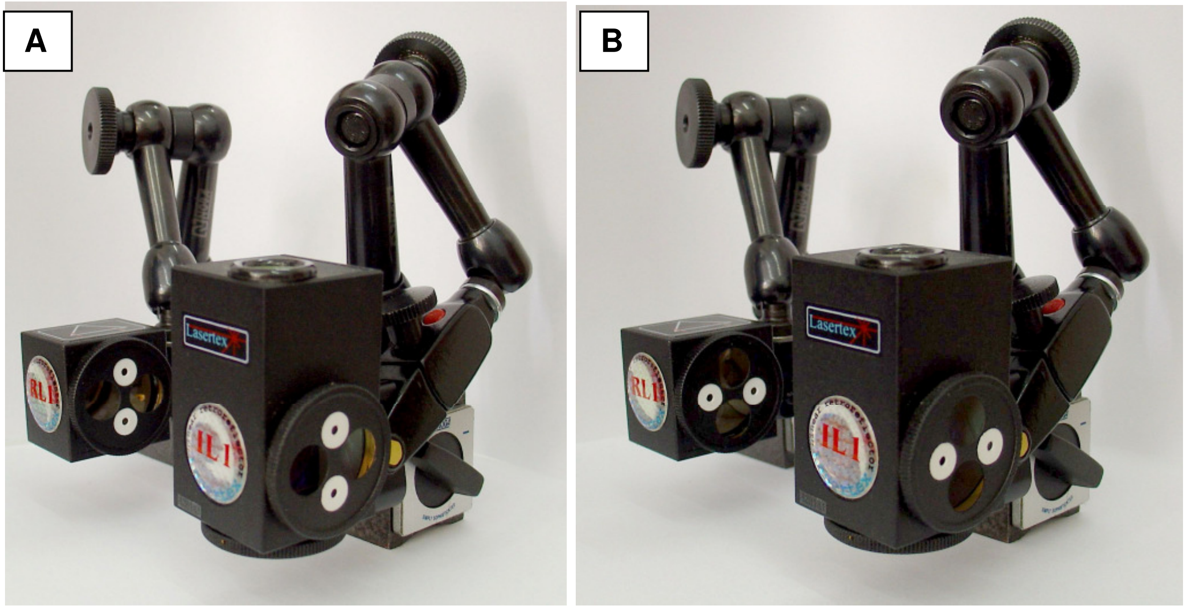


FIG.4.4. ALIGNMENT POSITION (A) AND WORK POSITION (B)

7. Regulate the tripod height and level of the laser head by means of a sphere joint. The laser beam has to fall on the upper hole of the interferometer diaphragm and after passing by the hole must be found within diaphragm area of the retro-reflector. The laser head should be placed horizontally (for horizontal axes) – control it on the level indicator.

8. Using regulating elements of the laser head (Fig. 4.2) find a position in which laser beam passes through both upper holes in the diaphragms placed on the interferometer and the retro-reflector. The spot position on the diaphragm of the interferometer (the interferometer is placed closer to the laser head) – should be regulated with X stage and up-down translation stage Z and up-down translation of the tripod. The spot position on the retro-reflector diaphragm (the retro-reflector is far from laser interferometer) – should be regulated with "α" angle alignment in vertical and "β" angle alignment in horizontal line.

9. Switch the diaphragms on **RL1** in a position "Work".

10. Using the regulating elements of the laser head adjust the position of laser beams on the diaphragm of laser head. Two return beams should exactly cover each other on the entrance hole on the front panel of the laser head during

the whole movement range. If this is necessary gently correct the position of the **IL1**. Shift the diaphragm on the laser head to the position "Work". The level of the measuring signal (the green indicator on the screen of the computer) should have value not less than 80 % during translocation of the moving element along the whole path.

11. For precision alignment, when the straightness measurement will be carried on, use electronic alignment. Switch screen of the *Display* to Adjustment mode. Move the machine to the position where the optical elements are closest to themselves. Then, using horizontal and vertical alignment screws set two crosses, blue and green, to the centre of the screen. Blue cross corresponds to the reference beam while the green one to the measuring beam see Fig 4.5. Now move the machine to the position where the distance between the optical elements is the highest. Check if the crosses are still in the same place when they were in the former position.

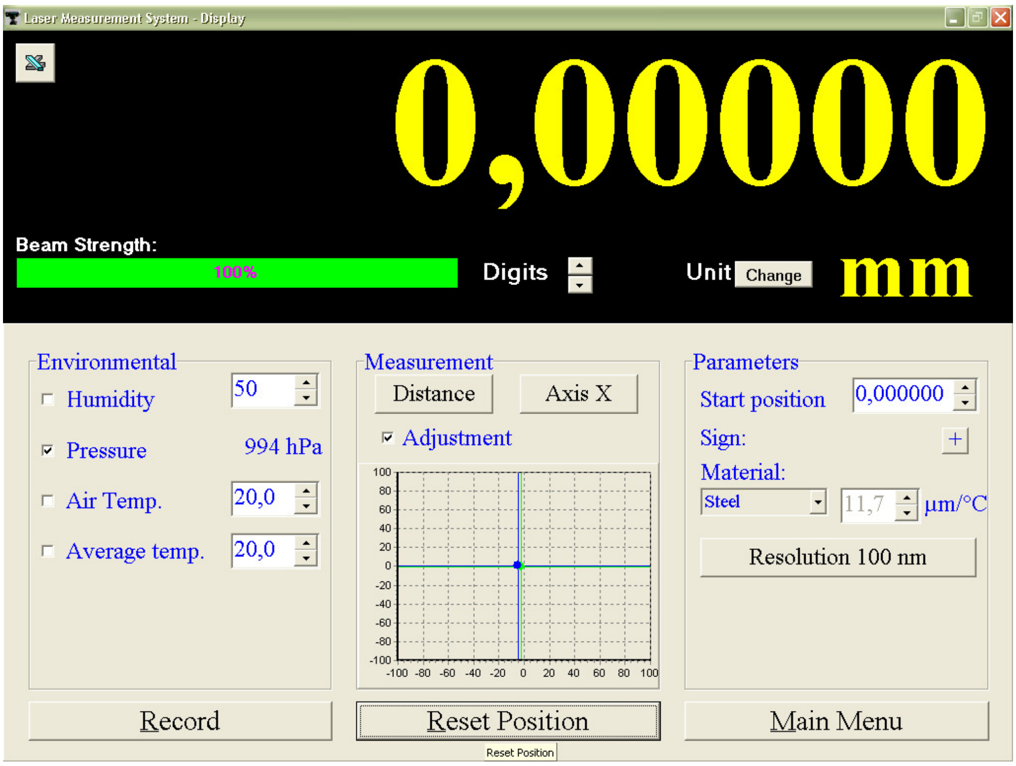


FIG.4.5. CORRECT ALIGNMENT OF OPTICAL PATH

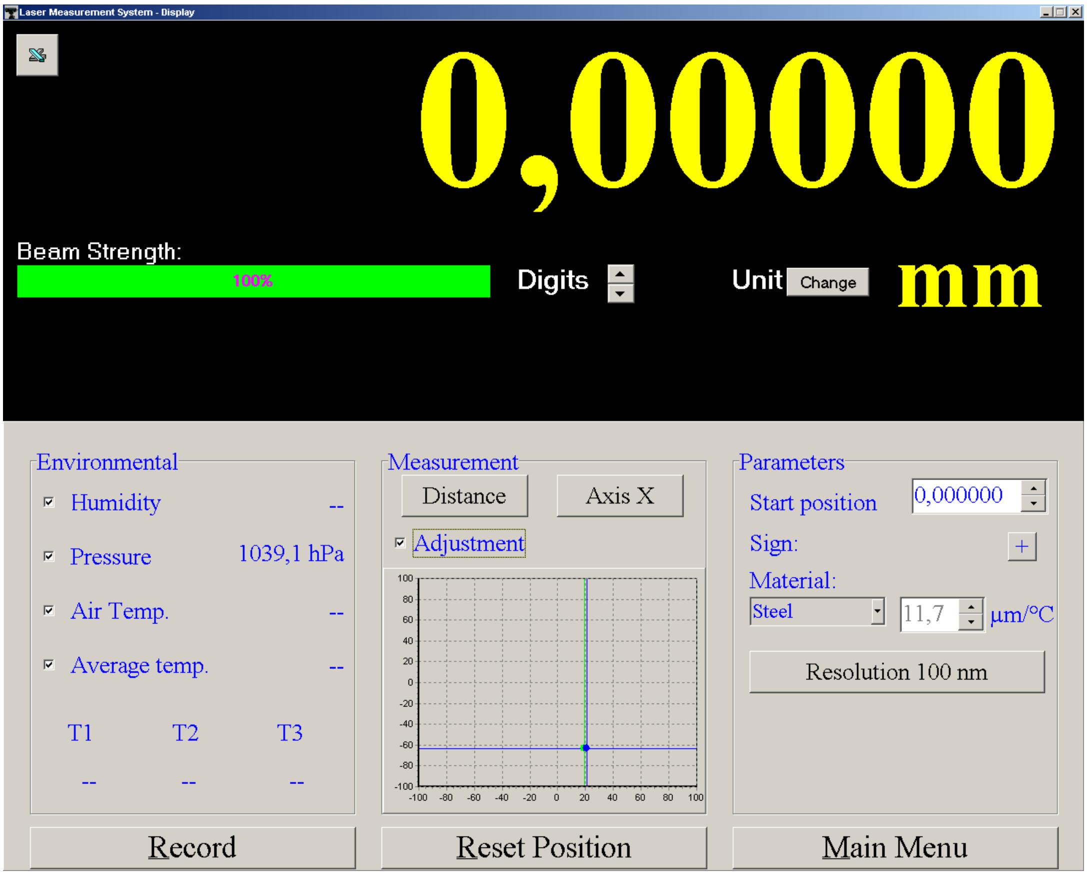


FIG.4.5. INCORRECT ALIGNMENT OF OPTICAL PATH

If they are not, correct the position of the laser with screws responsible for angular movement.

12. Reset displayed position using “Reset” button on the display. System is ready to work.

Attention! Remember, that the position when the interferometer touches the retro-reflector can serve only to adjust. Be sure that during measurements in extreme nearest measuring position the retro-reflector does not touch the interferometer, because it can be a source of measuring errors.

5

LINEAR MEASUREMENTS

Measurement set

Linear measurements are the most often used measuring option. Using this option it is possible to measure:

- Linear displacement;
- Velocity of moving element;
- Linear positioning;
- Vibrations (see Chapter 8);
- Straightness (see Chapter 9).

Measurements may be executed in three mutually perpendicular measuring axes X, Y, Z. Change of a measured axis will demand realignment of the optical path.

Required measuring set: a computer, a laser head with a power supply, a tripod, two magnetic holders **UM1** (or two **UM2**), an Environmental Compensation Unit (ECU) - **SM1**, basis temperature sensors **T1**, **T2**, **T3**, a linear interferometer **IL1**, a linear retro-reflector **RL1** and, optionally, remote control Strobe.

.

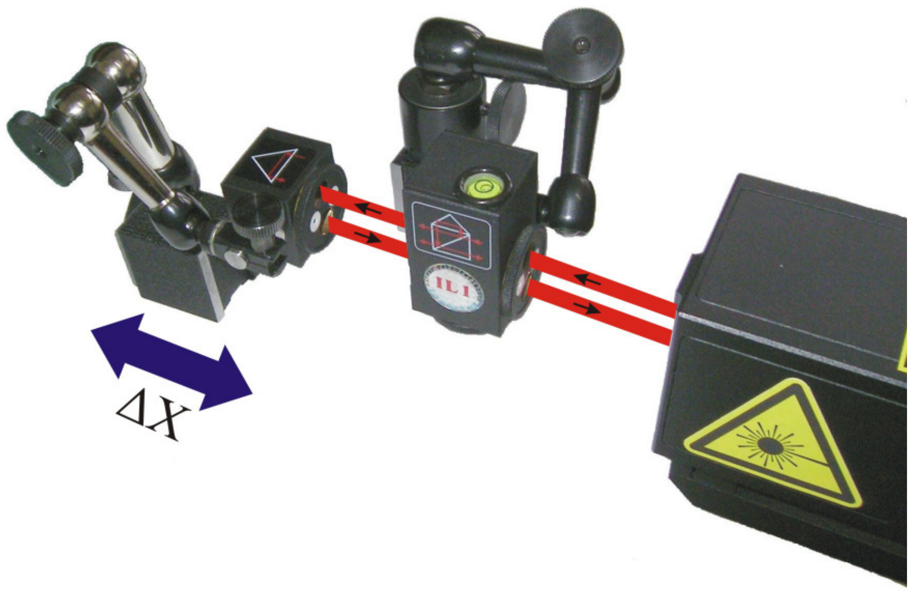


FIG.5.1 SET UP FOR LINEAR MEASUREMENTS IN X AXIS

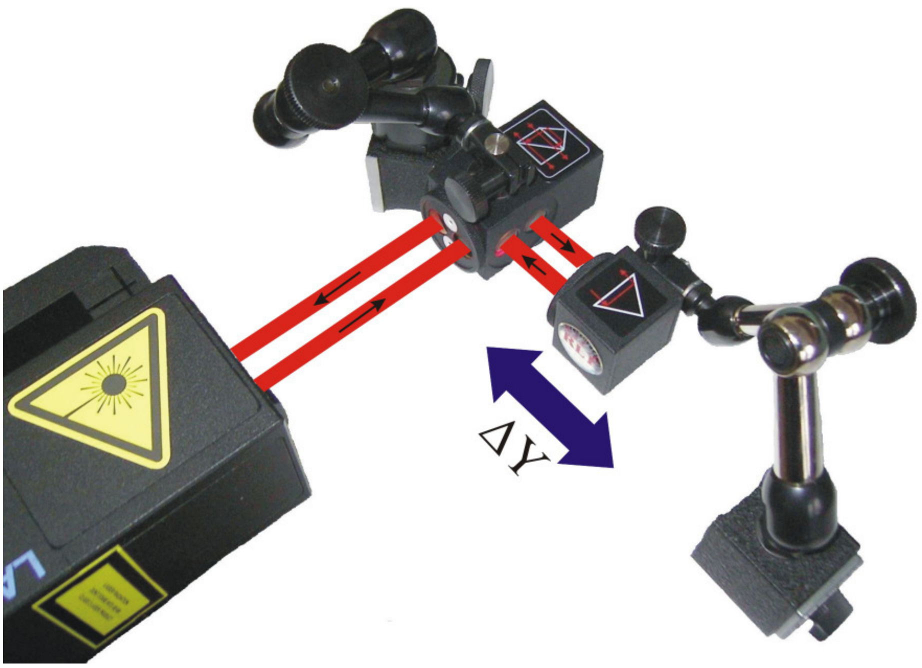


FIG.5.2. SET UP FOR LINEAR MEASUREMENTS IN Y AXIS

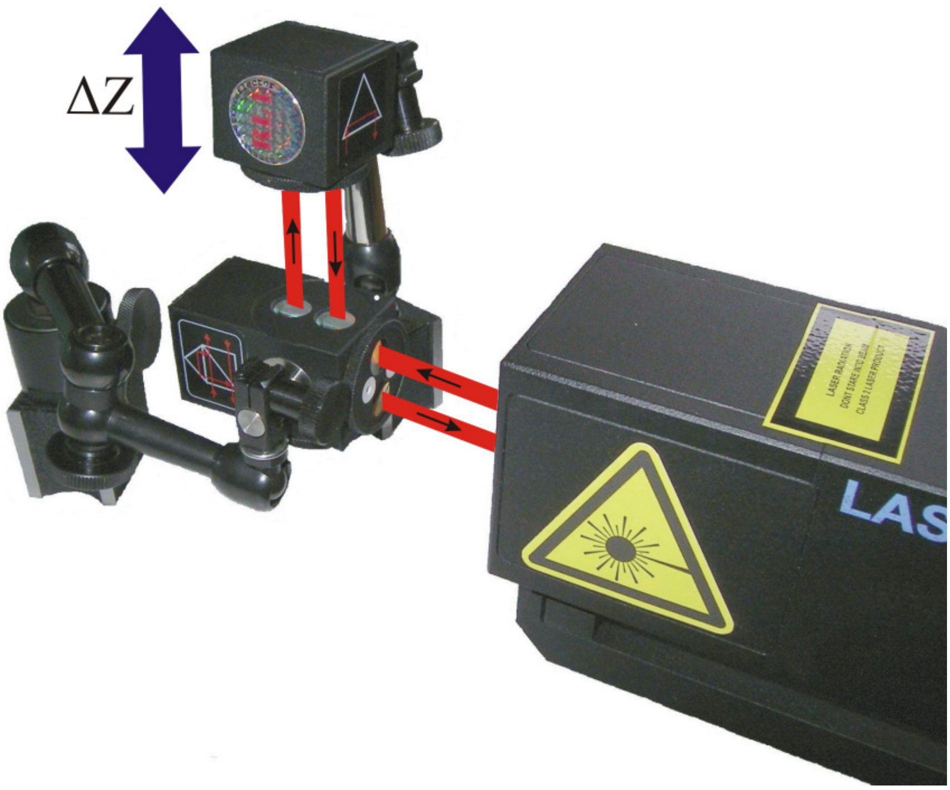


FIG.5.3. SET UP FOR LINEAR MEASUREMENTS IN Z AXIS

Linear displacement measurement

When one wants to prepare the measurement system for the measurement of a linear displacement, electric connections and alignment of the optical path (see chapter 4) must be carried out. When the laser system is ready to work – green LED light on the forehead of the laser head will be on. Next, it is necessary to check optical path, i.e. whether the measuring signal value shown in the **Display** option as *Beam Strength* is at least 80% on the entire axis. The measurements now can start. A measuring unit (mm, µm), a number of significant positions on a display, a measured axis, a sign ("+" or "-") and base's material can be chosen. After resetting, the display system is ready for measurements. When the retro-reflector is moved, on the screen the displacement in relation to the starting point is displayed (it is also possible to move the interferometer in relation to the standing retro-reflector).

Linear displacement velocity measurement

The arrangement of the optical path and the laser head should be the same as in the paragraph above. The measurement of the linear displacement velocity is executed in option **Display**. The type of measurement should be changed to **Velocity** and a unit should be chosen (**m/min, m/s**). After resetting the result on the display, system is ready for the velocity of displacement measurement. During translocation of the retro-reflector the value of velocity is presented on the screen.

Velocity graph

The arrangement of the optical path and the laser head should be the same as in the paragraph above. Velocity graph can be activated in the **Main Menu** by choosing the option **Velocity**. The screen will look like shown on the Fig. 5.4. When the measurements are to be started the button **Start** should be pressed and the object, which displacement velocity we investigate, should be moved. To finish the velocity measurements the button **Stop** should be pressed. On the screen the velocity graph will appear. By clicking on a part of the graph and moving the mouse rightwards the graph can be zoomed. By clicking on a part of the graph and moving mouse leftwards the zoom is cancelled. The graph can be printed or saved to a file. This can be done by choosing from the upper menu **File**, and then suitable a option (i.e. Save, Save as, Print).

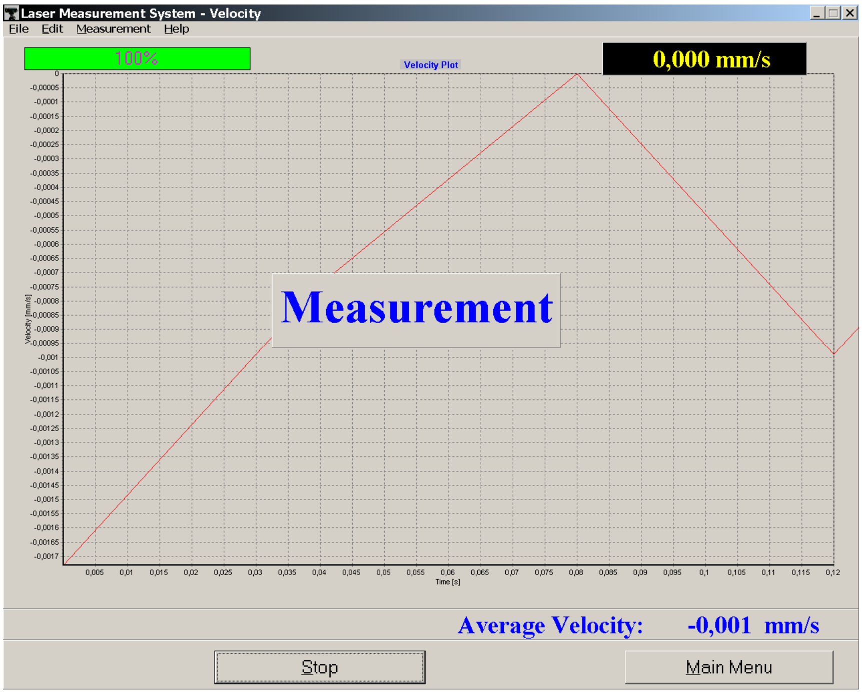


FIG.5.4. VELOCITY GRAPH WINDOW

An example graph of changes of the linear displacement velocity of a machine table in one axis is presented on fig. 5.5.

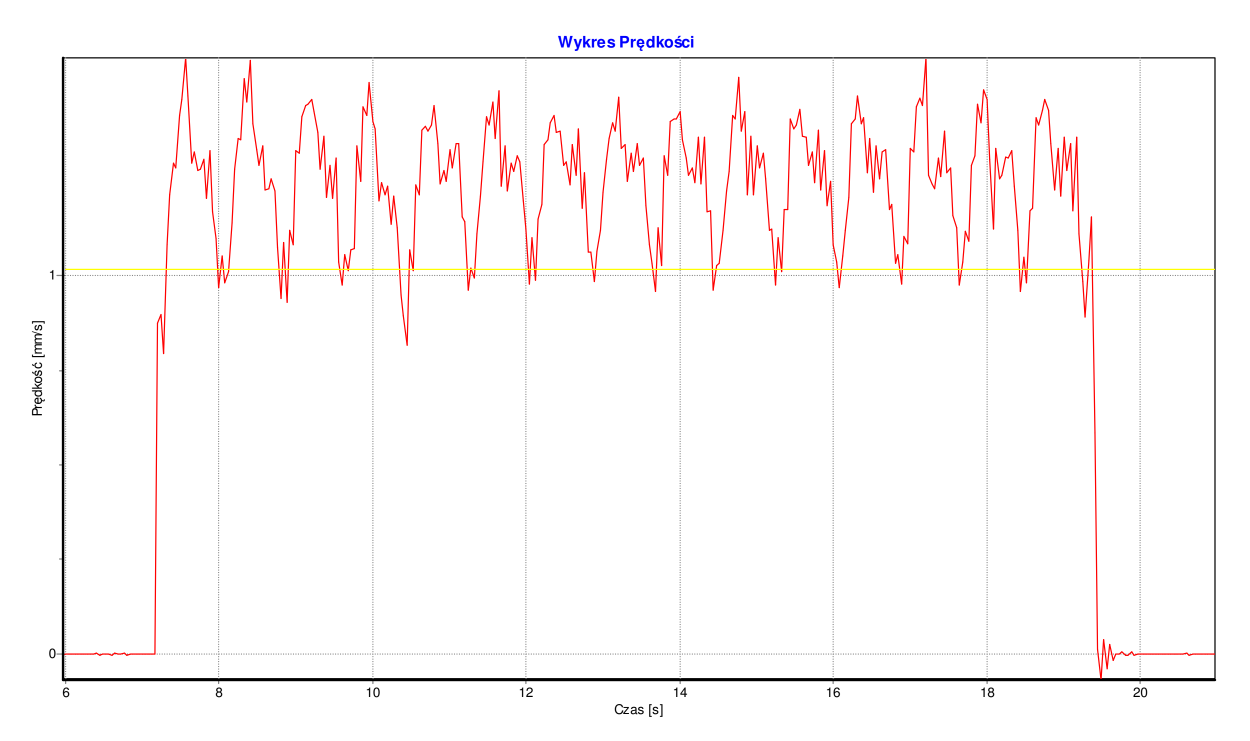


FIG.5.5. EXAMPLE GRAPH OF CHANGES OF LINEAR DISPLACEMENT VELOCITY

Program also calculates an average velocity from a visible range on the graph. It is also possible to preset minimum and maximum values for measured axis. Clicking left mouse button on selected axis or clicking right mouse button within the area of the graph appears a menu, from which a proper axis can be chosen. On the screen a window with options **Velocity scale** and **Time scale** will appear. Scaling can be set as automatic or set to maximum or minimum values.

Program makes it possible to saving the velocity graph and then load it for example to a Word editor. To save graph to the file we should click with the right mouse key within the area of the graph. From the popup menu that will appear the **Copy to clipboard** option should be chosen.

The choice of the speed unit is also possible: from menu **Edit** we should choose option **Config**, where the velocity unit can be set.

Linear positioning measurement

The linear positioning measurement is the most advanced option of linear measurements. It is the most common form of laser measurements performed on machines. The system measures linear positioning accuracy, repeatability and backlash by comparing the position to which the machine moves (i.e. the position displayed on the machine's readout) with the true position measured by the interferometer. In order to start measurements the option **Main Menu** should be activated and the **Positioning** button should be pressed. On the screen will appear a window **Linear positioning** as presented on the fig. 5.6

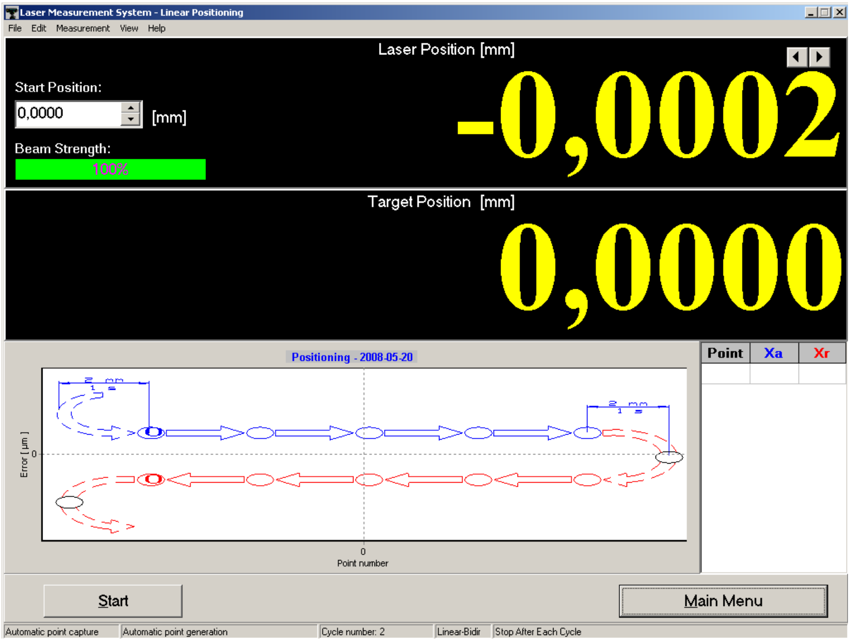


FIG.5.6 LINEAR POSITIONING WINDOW

The upper menu of this window consists of options: File, Edit, Measurement, View, Help. In the option File there can be found instructions for reading measured data from a file, saving the data to a file and printout of measurements results.

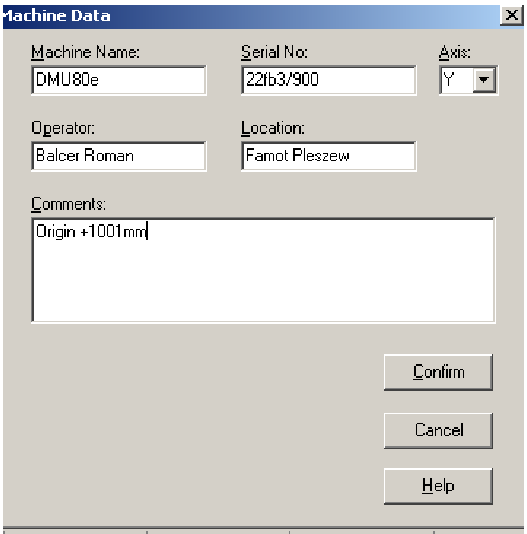


FIG.5.7 MACHINE DATAWINDOW

Option **Edit** allows to enter data of the measured machine (Fig 5.7), preview of measurement results in every cycle of positioning and edition of positioning points (when option **Target Points from List** from menu **Measurement** is active).

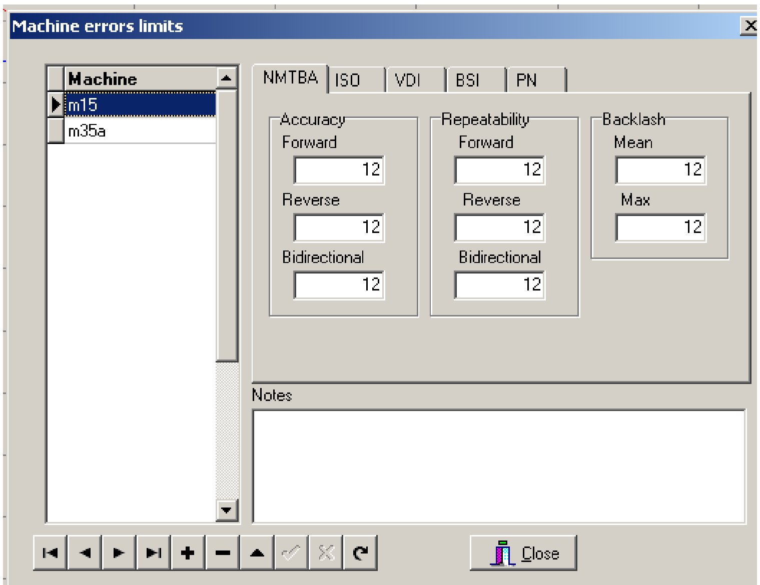


FIG.5.8 MACHINE ERROR LIMITS WINDOW

In the **Edit** option the user can also setup allowable error limits of the machine for different norms (option **Machine error** limits - Fig. 5.8). The results of the whole linear positioning measurements are compared with this limits (see Fig. 5.10). This option is especially useful when there are checked many machines of the same type and the same requirements on their accuracy.

In the panel **Positioning** of the **Config** window the user can set up important options of the linear positioning measurements (Fig. 5.9). There are three available ways of checking machin's positioning: Linear, Pilgrim1 and Pilgrim 2 (buttons in *Measurement method* panel). The directions of the expected movement of the machine are shown on the pictograms. Usually the *Linear* method is used.

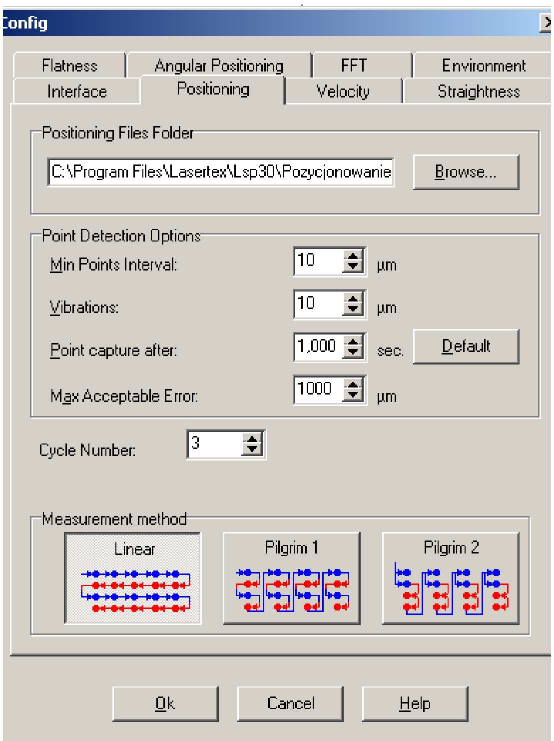


FIG.5.9 LINEAR POSITIONING CONFIG WINDOW

In the *Cycle number* the user can set how many complete measurements cycles are to be performed. The more cycles is chosen the better results will be achieved.

Max Acceptable Error is an option where the user can set the maximal acceptable error level above which the software will communicate to the user about a machine error.

Options *Point capture after* and *Vibrations* are valid only when an automatic point capture is chosen. By changing these options the user can decide after how much time a trial of automatic point capture should be made by the program and what is the acceptable level of vibration (level of vibration depends mainly on the measured machine).

Min Points Interval describes minimal distance between positioning points.

Option **Measurement** includes the options connected with the process of measurement:

Start – beginning of measurements

Stop – break of measurements

Automatic Point List Generation – this option is marked when the positioning points are calculated automatically by the program and not chosen by the user (see below)

Target Points From List – after choosing this option on the screen appears a window for edition measuring points in which we write or count distance value for positioning points. If this option is not active then the positioning points are marked automatically in first measuring cycle and the option **Automatic Points List Generation** is marked.

Stop After Cycle – if this option is active program breaks the measurement after realization of a measuring cycle; if it is not active the configured number of cycles is executed.

Manual Capture – choosing this option causes that for measuring points the measured displacement value is registered by the program after pressing a button **Manual Capture** or a pulse switcher Strobe. If this option is not active than points are captured automatically (program detects the moment of machine stop).

Target Position Correction – setting this option gives possibility to change an earlier defined distance value of a measuring point during the measurement process. Before point capture appears a window in which can be written new distance value whereupon marked are only places after comma what causes that it is not necessary to write all distances.

Option **View** serves to switching on or off a panel **Target Position, Error Table** and to switching on drawing on the graph of measuring points from all cycles (active cycle is drawn using solid line but remaining cycles are illustrated using only points).

If system is ready to work, then on the screen appear two digital displays and gauge of measuring signal level (Fig. 5.6). On the upper display the measured value is shown. On the bottom display the value of the target position, read from data points table or appointed automatically, is shown. Under the displays on the left side there is shown a graph on which the results of measurements are shown. On the right side an **Error Table** can be found. Under the graph two buttons can be found: **Start** - beginning of the measurement and the button **Main Menu** - allowing to re-enter the Main menu.

In the bottom parts of the window a status bar can be found, on which there is presented a configuration of the positioning measurements. In the first field the information about the method of measuring points capture is placed (manual, automatic). In second field information whether measuring points originate from list or are marked automatically is shown. The next field informs about number of cycles in series (number of cycles executed one after one, if not active is the option **Stop After Cycle**).

To execute the linear positioning measurement, the program has to know the target position in which it has to make measurement and where it has to calculate deviation from an expected value. The positioning points can be automatically defined in the first measuring cycle on a condition that distances between points are marked with an accuracy of 1.000mm. The positioning points can be also written or calculated after marking an option **Target Points From List**. After activating this option the positioning points can be defined in any accuracy.

Measurement can be done in an **Automatic** option or in a **Manual Capture** option. In the automatic version the system itself recognizes the moment of stop, the value of target point, the direction of movement and the series number.

For correct operation of the automatic option below rules should be followed:

1) The time of machine stand still duration in a positioning point must be no less then 1 second – default value (this can be changed in the **Config**->*Max Accaptable Error*),

2) Vibrations of the target should be less then 10 µm - default value (this can be changed in the **Config**->*Vibrations*),

3) After every pass the target should be moved at least 2 mm away from the last positioning point, stopped until capture and, after it, **returned to the last positioning point** - this procedure is necessary for correct backslash error measurements.

If vibrations are too large and system does not capture points – then the option **Manual Capture** should be switched on in the menu **Measurement**. After choosing the **Manual Capture** option on the bottom of the screen appears an additional button **Manual Capture**. Capture of the measuring point takes place by pressing this button or pressing the button on the impulse switcher.

Examination of linear positioning of machine consists of at least 2 measuring cycles. In every cycle the measured machine will move the retro-reflector for programmed distance fore (Avers) and back (Revers). After each shift the machine should stop for a time at least one second. The measured distance by the laser system is saved in the table of results. After at least three series of measuring cycles, statistical calculations can be executed and the report from examination is prepared. In order to get the final report press a button **Report**. Using buttons **Remove** and **Add** it is possible to change the measuring cycle in which accidental error is suspected. The screen of the computer after pressing the button **Report** is presented on fig. 5.10

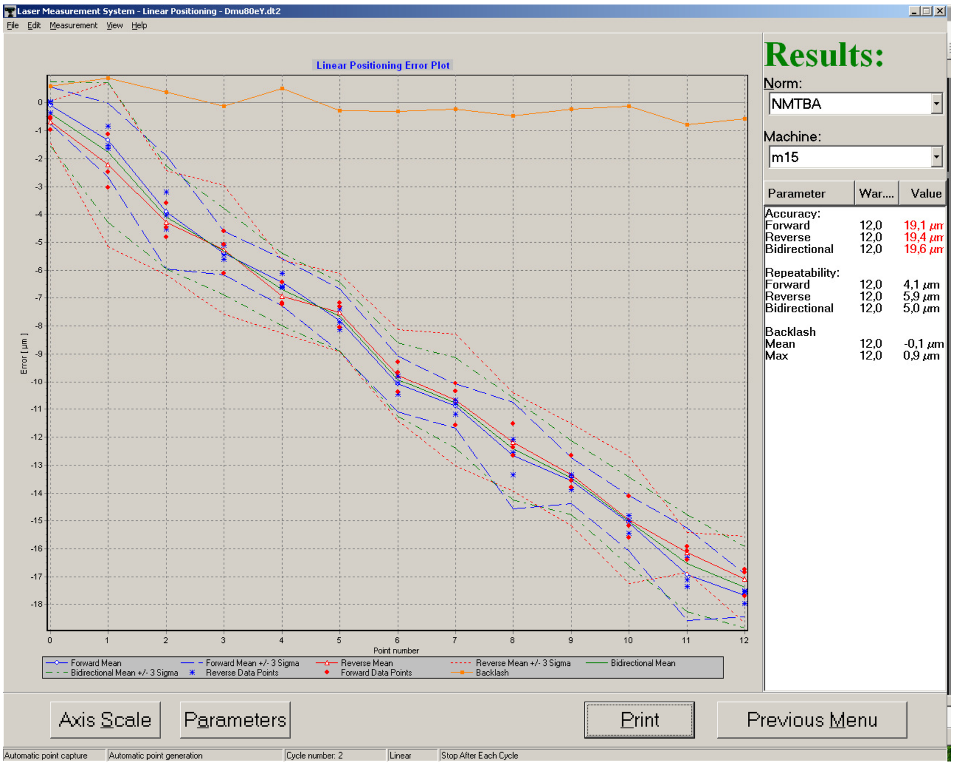


FIG.5.10. LINEAR POSITIONING RESULTS

The positioning parameters are presented on the graph. In the right side panel **Results** is found, on which the results of statistical calculations, the norm according to which calculations were executed and the limit values for the certain machine are presented. If the error value exceeds set limit for the machine this error is displayed in red. The norm can be chosen from a list. After choosing a new norm the results are recalculated.

Under the graph there are: buttons used for change of the axis scale **Axis Scale** (automatic scaling or assignment, minimum and maximum values), choosing of parameters shown on the graph **Parameters**, report, printout **Print** and return to looking through the measuring **cycles Previous Menu**.

Example of linear positioning report of CNC machine in axis is presented on fig. 5.11

POSITIONING RAPPORT

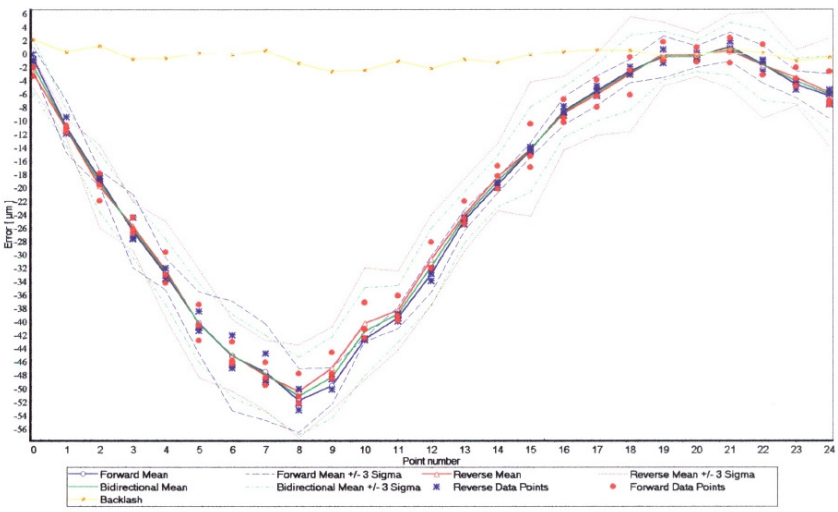
Machine: BFK130 Serial No: AxisX

File Name: BFK130X1.dt2

Acquisition date:01-11-08 15:41:14 Current date: 02-11-06 15:08:15

Measurement System: LSP-30 Compact LASERTEX

Results		Measurement Conditions	
Norm: NMTBA		Air Temperature :	23,3 °C
Accuracy:		Material Temperature :	19,4 °C
Forward	59,8 µm	Humidity :	36 %
Reverse	63,5 µm	Pressure :	980 hPa
Bidirectional	61,5 µm		
Repeatability:			
Forward	16,4 µm		
Reverse	20,1 µm		
Bidirectional	13,2 µm		
Backlash			
Mean	-0,4 µm		
Max	2,6 µm		



Comments:

Location: a **Operator:** sambor **Signature:**

FIG.5.11 LINEAR POSITIONING REPORT

Recording mode

The long term changes of the length of machine axes under changes of temperature condition may give the information about thermal properties of the machine. This kind of measurements called "Recording mode" may be chosen by pressing RECORD button on the **Display** screen. This switches the system into the mode of the data recorder. The time interval of the records could be programmed from the computer by setting a required value.

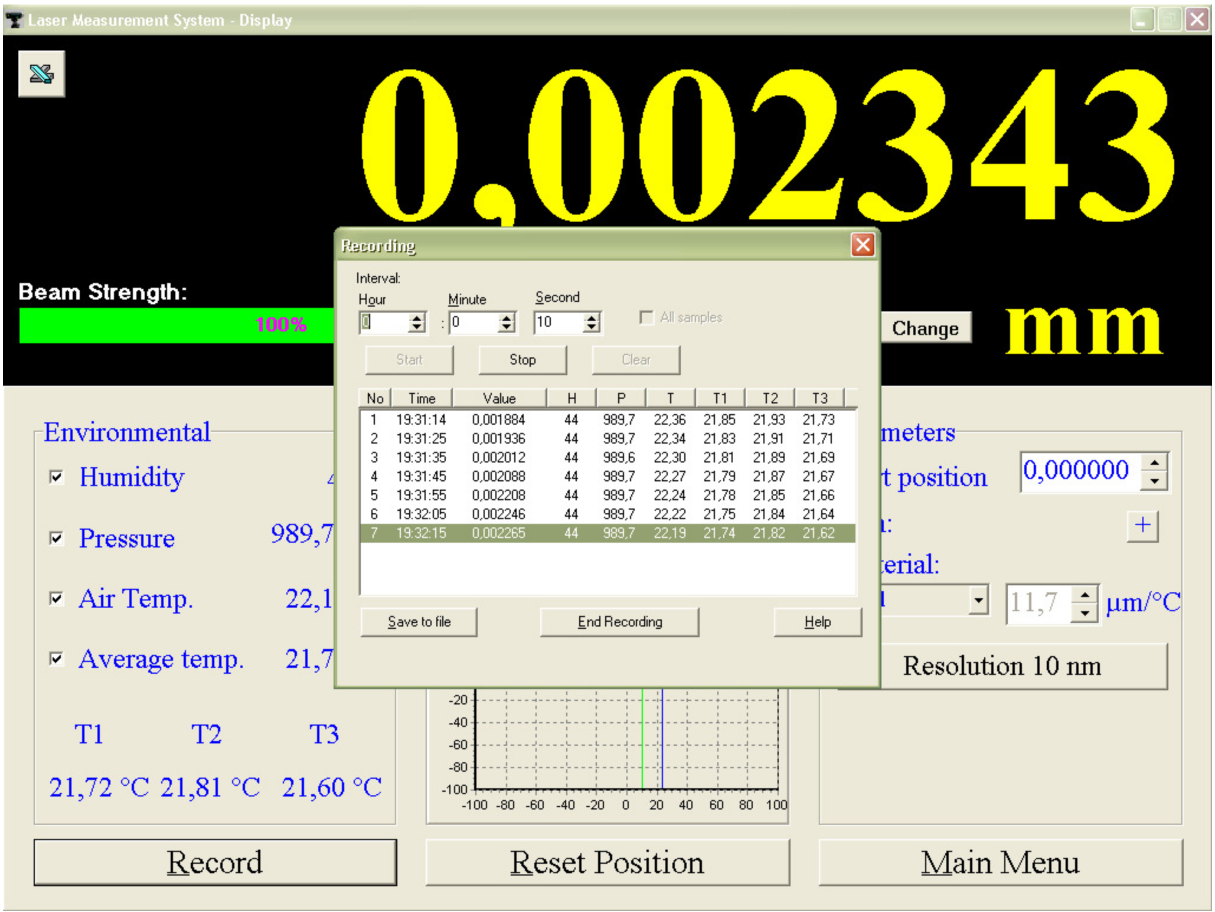


FIG.5.12 RECORDING DATA MODE

Pressing "End Recording" finishes the data recording. The results can be saved with the choice of "Save to file". In fig. 5.12 the example of Data Record is presented.

Flat mirror measurements - option

The flat mirror measurements permits the measurements of displacement, velocity, positioning and vibrations of a flat surface. The surface should have mirror quality (surface flatness λ/8) and the reflection coefficient not less 50%. The aluminium, gold or dielectric mirror mounted to the moving part is suggested. There are two possible configuration: double pass setup Fig. 5.13 a and single pass setup 5.13.b. The resolution of double pass setup is two time bigger then one pass. The setup consist from the laser head, the flat mirror interferometer **FMI** and the flat mirror. One have to chose the single/double pass option on the screen in display mode to have correct result of measurement.

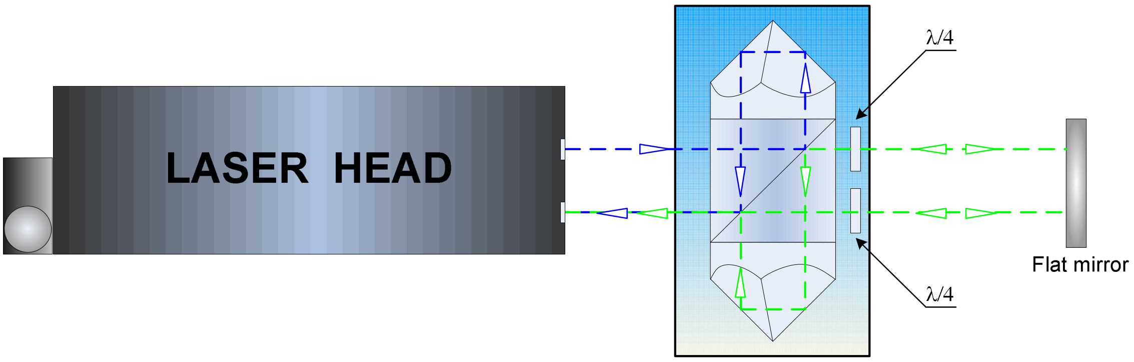


FIG. 5.13 a DOUBLE PASS FLAT MIRROR INTERFREOMETER

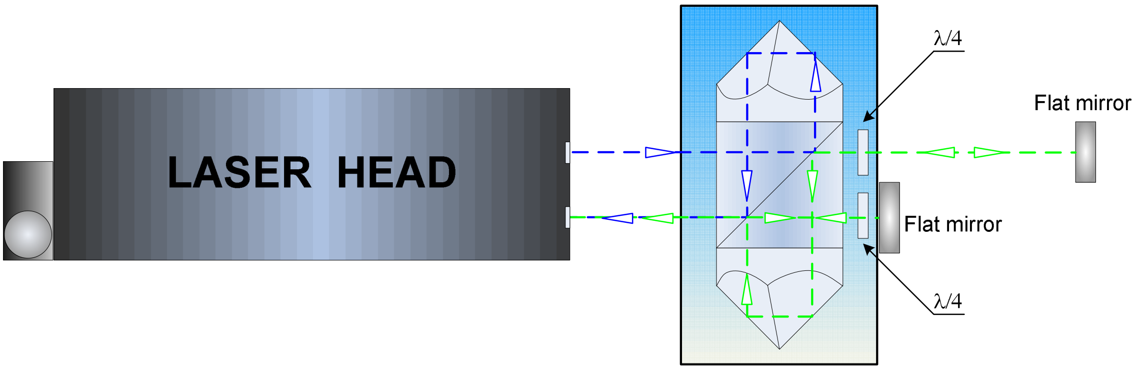


FIG. 5.13 b SINGLE PASS FLAT MIRROR INTERFREOMETER

6

ANGULAR MEASUREMENTS

Measuring set for angular measurements

The angular measurements performed by the laser interferometer system are used for straightness, surface flatness and angular positioning of rotary tables. Straightness measurements can be done in three mutually perpendicular axes X, Y, Z.

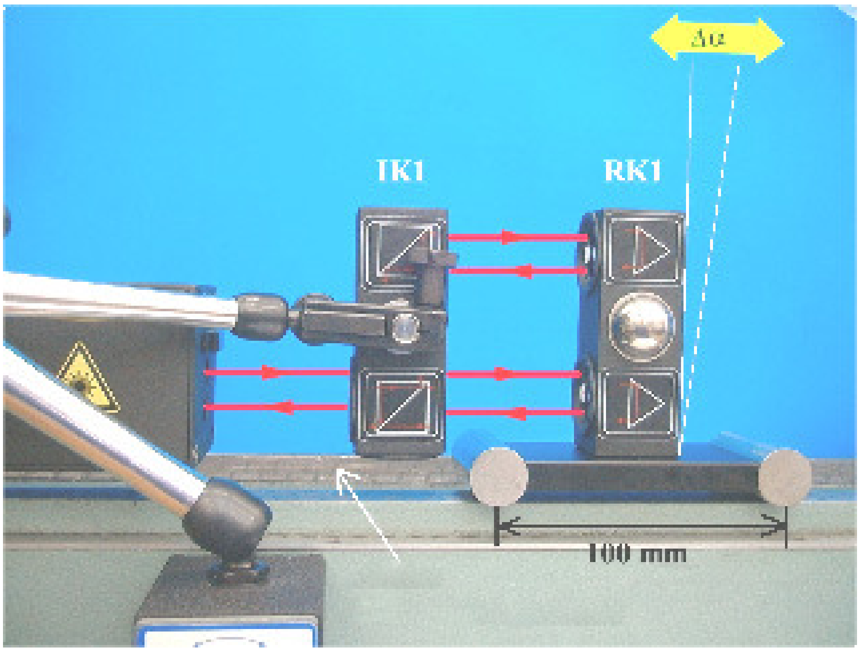


FIG.6.1. SETUP FOR ANGULAR MEASUREMENTS IN HORISONTAL X-AXIS

Change of measuring axis will demand displacements of angular optics (figures 6.1, 6.2 and 6.3).

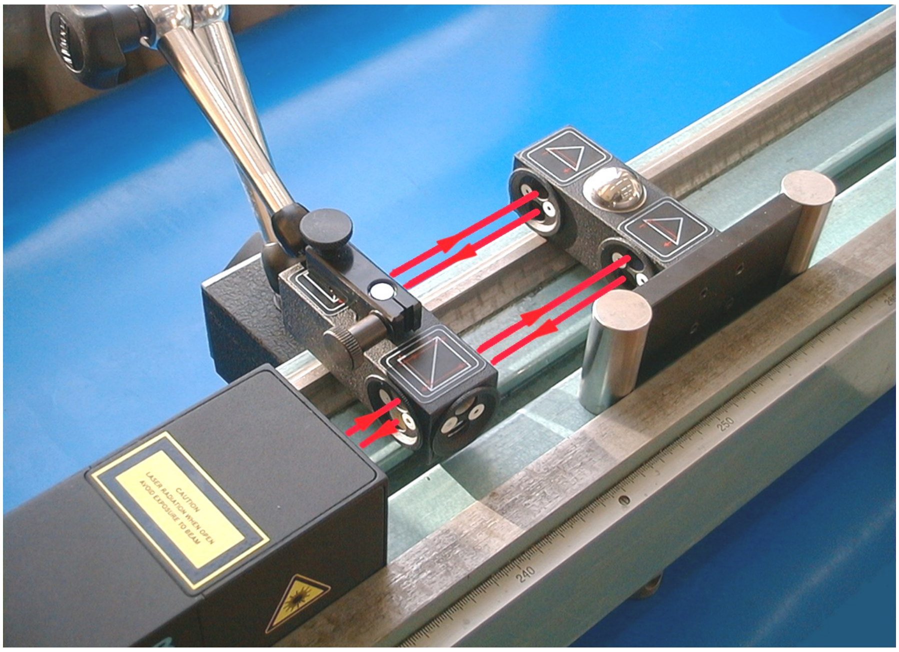


FIG.6.2. SETUP FOR ANGULAR MEASUREMENTS IN VERTICAL X-AXIS

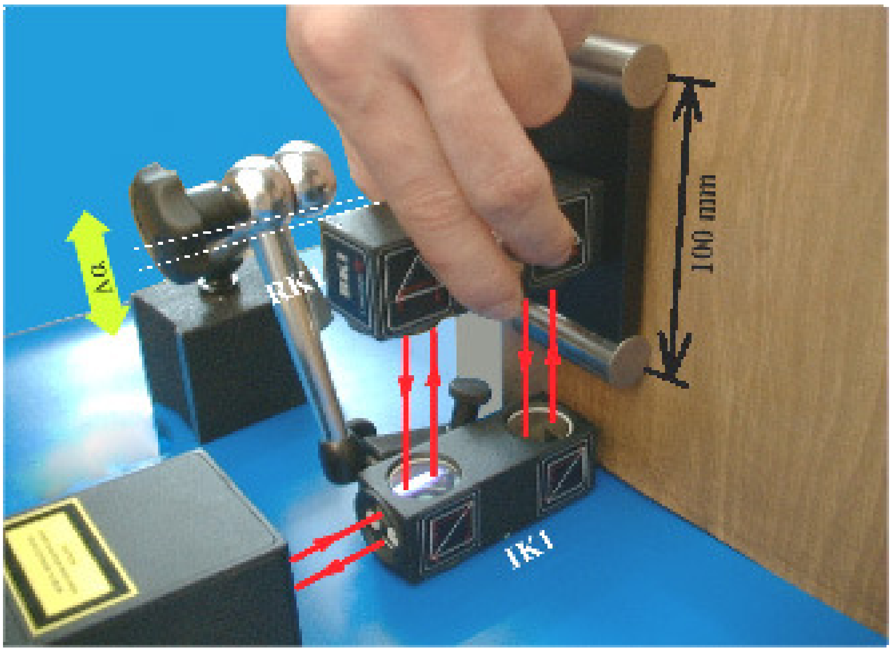


FIG.6.3. SETUP FOR ANGULAR MEASUREMENTS IN Z-AXIS

Required measuring set: a computer, a laser head with an interferometer power supply, a stand Tripod, two magnetic holders **UM**1 (or **UM**2), a

Environmental Compensation Unit - (ECU) **SM1**, sensors of basis **temperature T1, T2, T3**, an angular interferometer **IK1**, angular retro-reflector **RK1** mounted on **P100** mm base, remote control Strobe (option).

Auxiliary equipment used in the angular measurements is: two mirrors ZK1 mounted on supports, serving to reflect the laser beam - necessary to measurements of the surface flatness; a rotary table **SO1** controlled by step motor - used to angular positioning measurements.

Measurement of angle deviations

Preparations to measurements are similar to those described in the previous chapter. The measurements are executed in **Display** mode. The type of measurements should be set to **Angle** and a suitable measured axis should be chosen (fig. 6.4). It is accepted that when the retro-reflector is bent towards the laser head direction, measured value is positive. It is possible to change the sign in the panel **Parameters – Change of sign**.

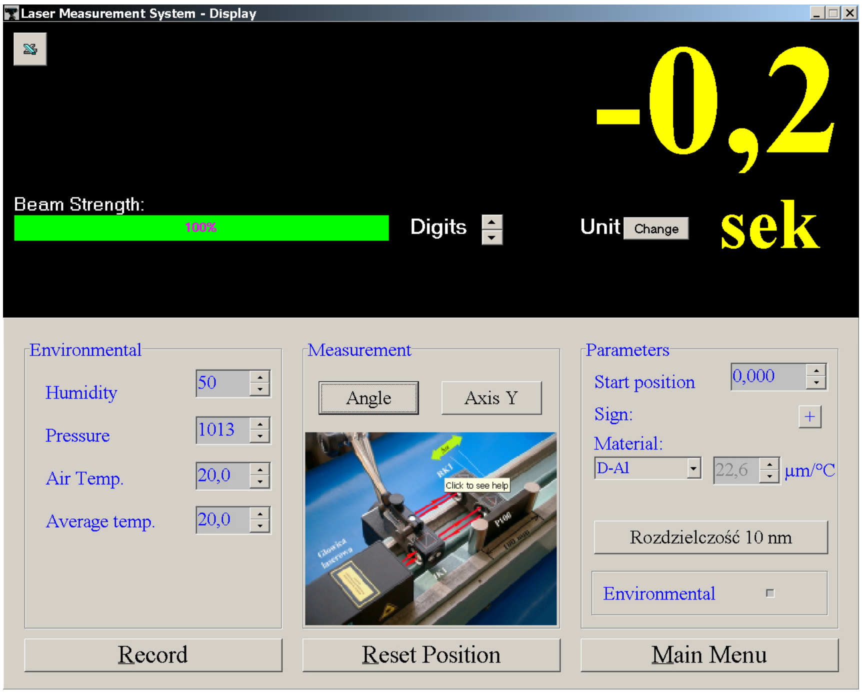


FIG.6.4. ANGLE DEVIATIONS MEASUREMENT SETUP

After **Reset Position** the system is ready to measurements. If the retro-reflector is moved to a new point and on the screen the value of the angle deviation in relation to the first point is shown. It is also possible to measure change of the angle deviation in the same point if the inclination of retro-reflector changes.

Straightness measurements

The straightness measurements are driven along a straight line to which side surface of the angular retro-reflector base is tangent. In order to get the correct measurement the straight ruler, along which retro-reflector base will be pushed, should be fasten on a measured axis. In every moment of the measurement side surface of the retro-reflector base should be tangent to the ruler (see fig. 6.5).

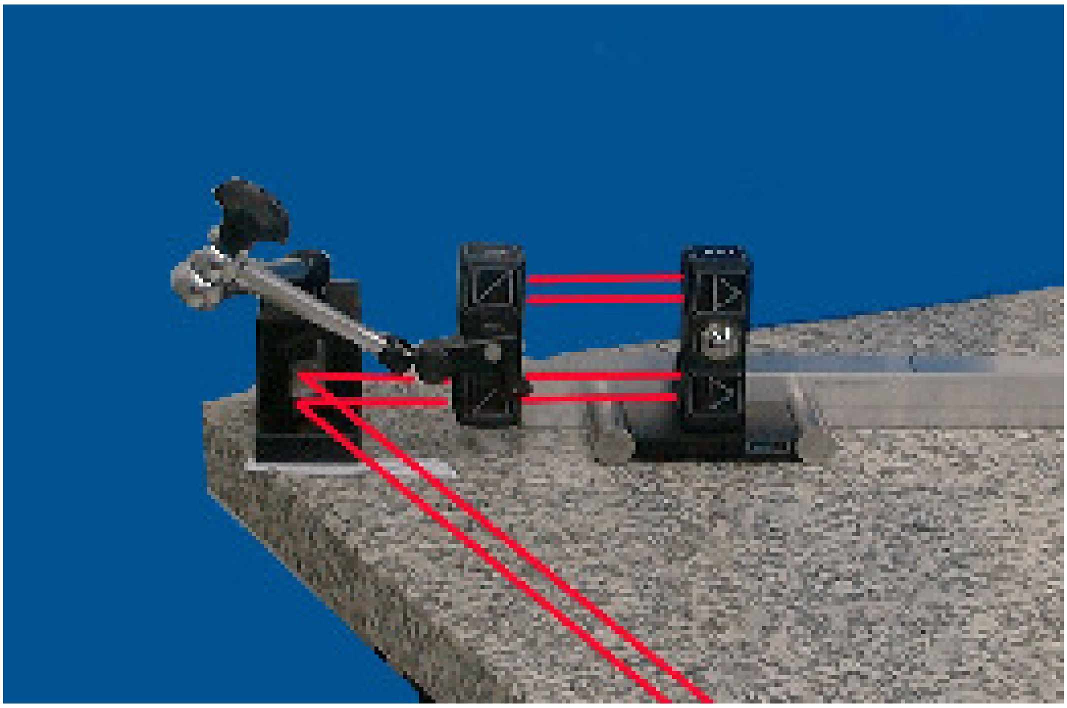


FIG.6.5. AN EXAMPLE OF OPTICAL COMPONENTS SETUP IN STRAIGHTNESS MEASUREMENT

Required measuring set: a PC computer, a laser head with a laser interferometer power supply, a stand Tripod, two magnetic holders **UM1** (or **UM2**), a Environmental Compensation Unit - (ECU) **SM1**, sensors of basis temperature **T1**, **T2**, **T3**, an angular interferometer **IK1**, an angular retro-reflector **RK1** on a support base **P100** mm, a remote control Strobe.

The Straightness measurement is based on pushing angular retro-reflector about an interval 100 mm and measuring its angle deviation. Before beginning to the measurement, measuring points should be marked every 100 mm distance on the leading ruler or on the examined surface. It is recommended using ruler with scale. The straightness measurement is performed in the option **Straightness**, chosen from Menu Main (fig. 6.6).

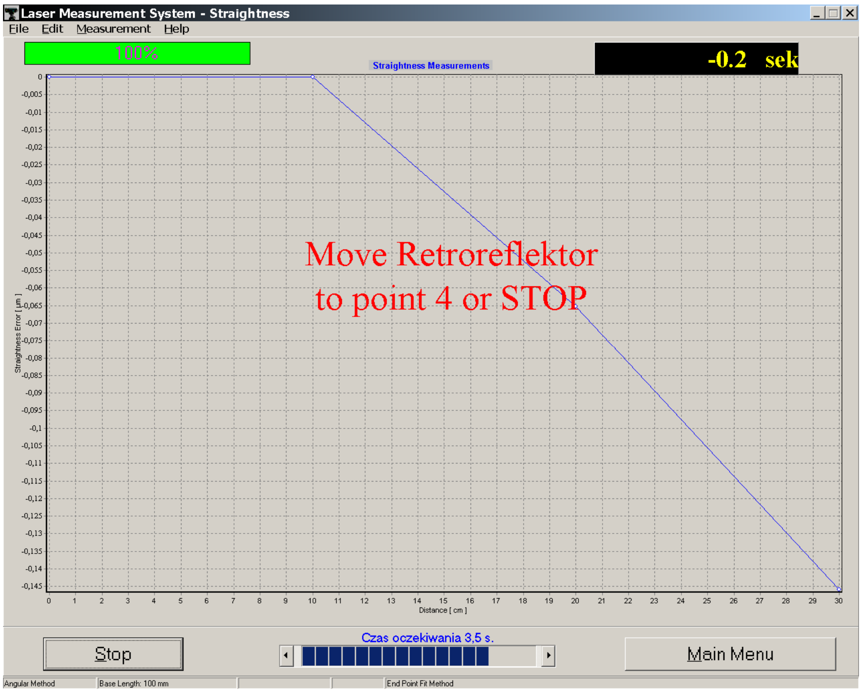


FIG.6.6. STREIGHTNESS MEASUREMENT WINDOW

The measurement can be done in an automatic mode (standard arrangement) or in a manual mode with manual capturing of measuring points.

In the automatic mode capturing of the measuring points takes place when a temporary time interval runs out. The time between capturing the measuring points is used to move the retro-reflector about a distance of 100 mm. The time interval should be used in dependence from practices of a person leading the measurements. It is suggested to set the time on 10 s and to decrease it if needed. An arrangement of the time interval may be done by pressing ← , → keys on the computer screen . The retro-reflector base P100 should be placed at the beginning of the examined axis close to the interferometer. After the **Start** button is pressed one should wait on capturing the first measuring point. Then one should to move the retro-reflector base of about 100 mm and to wait on the next point capture. Announcements shown on the computer screen make the measurement easy. After capturing the last measuring point press Stop.

If from some reasons will not be possible to move the retro-reflector base before the capture moment, the measurement should be repeated from the beginning point and possibly the measuring interval should be enlarged.

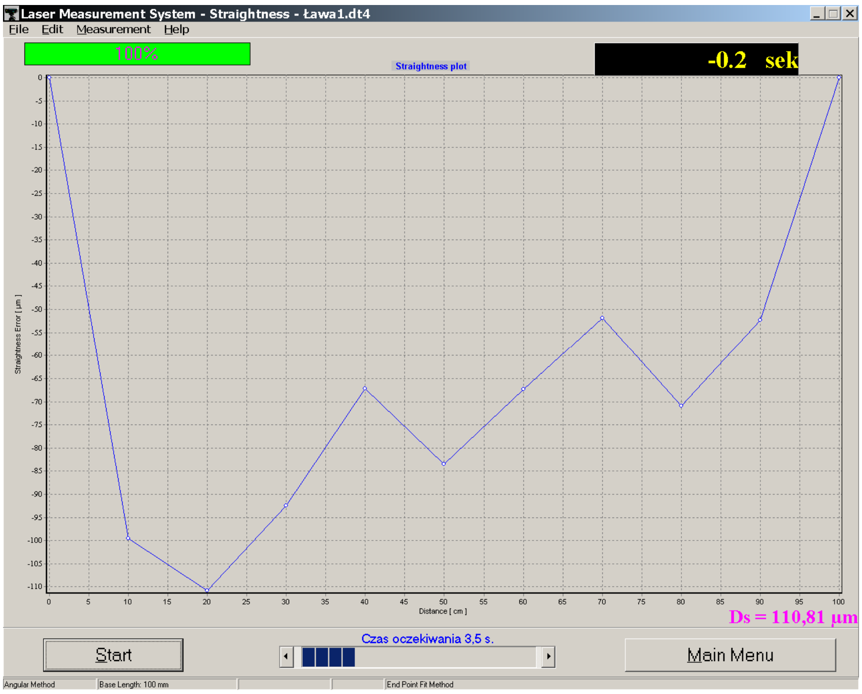


FIG.6.6. A RESULT OF STREIGHTNESS MEASUREMENT

To make the measurement in the manual capture of the measuring points, the **Measurement automatic** in panel **Measurement** should be switched off.

The measurement begins by pressing **Start**. The Capture of the measuring points can be done from the computer keyboard or by pressing the remote Strobe button. Each time after the movement of the retro-reflector base of about 100 mm, measuring point should be captured. After capturing the last point **Stop** should be pressed.

The results of the measurements may be saved to a file or printed in dependence on the options chosen in the menu **File**.

7

FLATNESS MEASUREMENTS

Preparations

The flatness measurement is done on the basis of straightness measurements of eight axes. From obtained data a flatness map is drown (fig.7.1.).

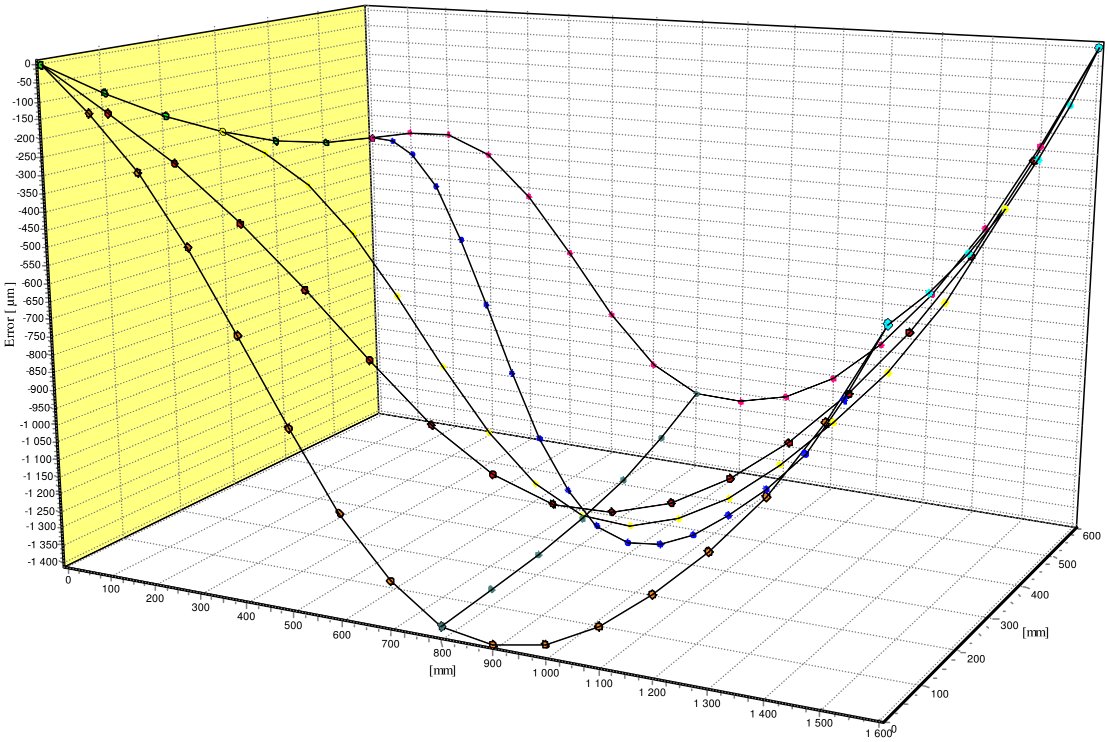


FIG.7.1. AN EXEMPLARY SURFACE FLATNESS MAP

Required measuring set consists of: a PC computer, a laser head with a power supply, a **Tripod** stand, two magnetic bases (**UM1** and/or **UM2**), a Environmental Compensation Unit - (ECU) **SM1**, basis sensors (**T1**, **T2**, **T3**), an angle interferometer **IK1**, an angle retro-reflector **RK1** on a base **P100** and two beam directing mirrors **ZK1**.

The element set for the flatness measurements is shown on fig. 7.2.

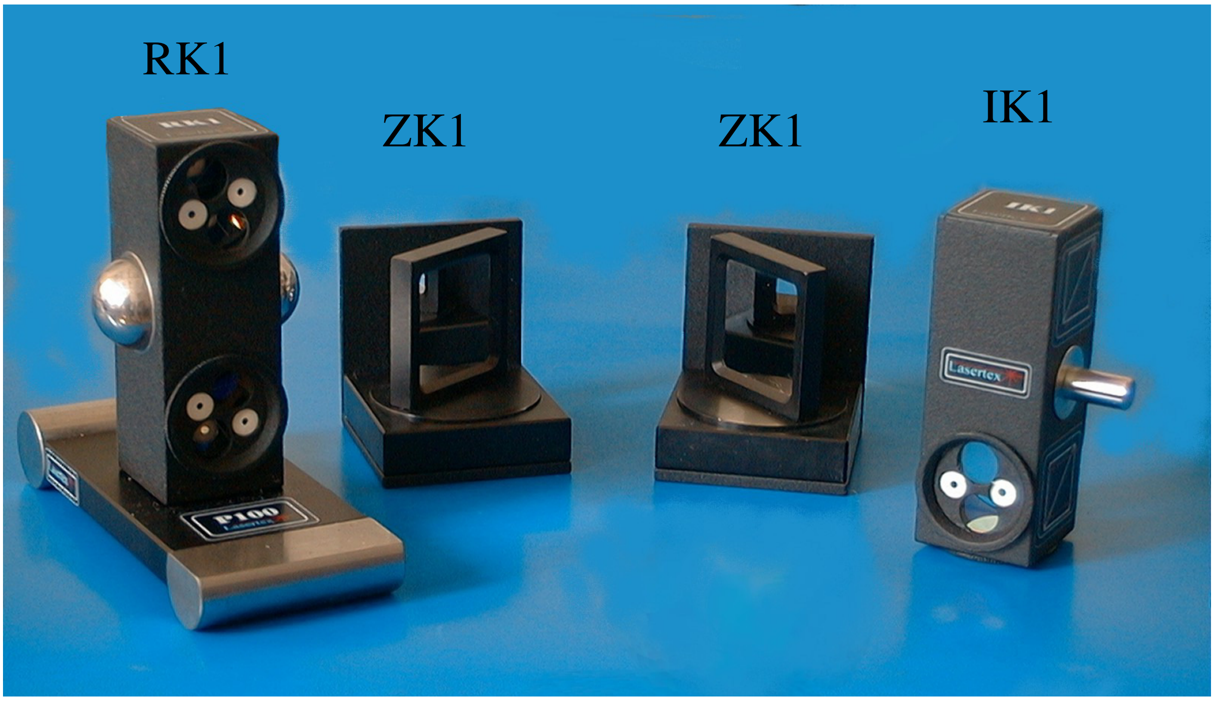


FIG.7.2. THE ELEMENT SET FOR THE FLATNESS MEASUREMENTS (**IK1, RK1** ON **P100** BASE AND **ZK1**)

Alignment of optics for the flatness measurements

The measurement of flatness consists of the measurements of deviations from straightness made along 8 axes. The measurement axes are set (in panel–Measurement->New Axis) on a measured surface as shown on figure 7.3. On this figure are shown also: directions of measurements in the axes and margins that must be kept during measurements.

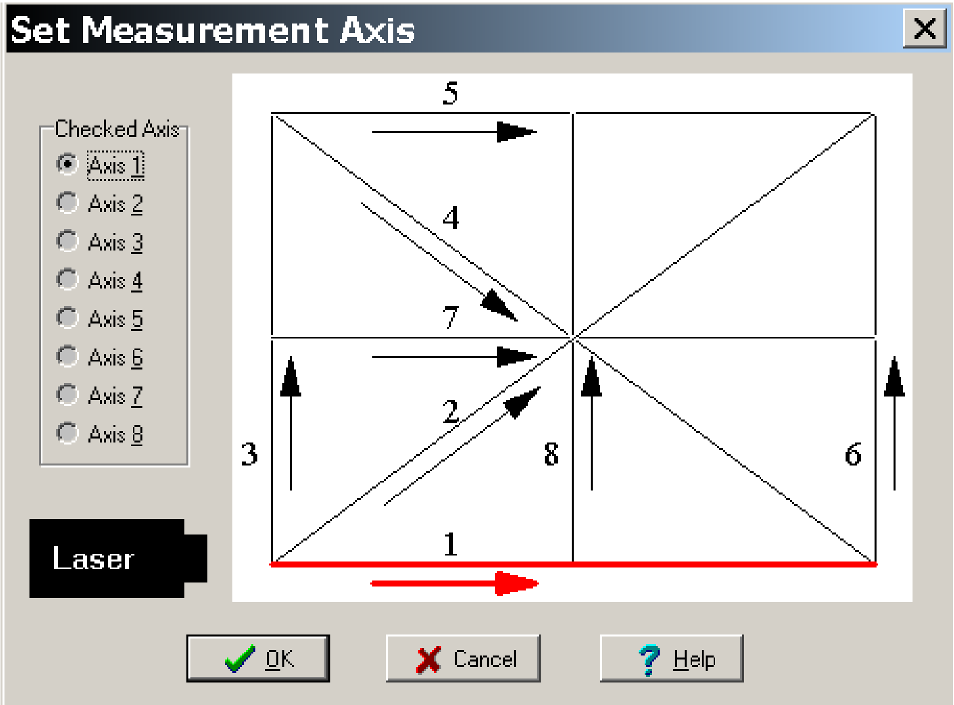


FIG.7.3. THE MEASUREMENT AXES

The measurements of deviations from straightness are made with angular optics as described in Chapter 6, *Straightness measurements*. Depending on the measurement axis, a different set of optical components is used and the alignment of the optical path is done in slightly different way. All flatness measurements are done with one laser head position, shown on Figure 7.3.

The flatness measurements are performed in the option **Flatness.** chosen from the **Main Menu**. After setting proper base length (standard is 100mm) and machine data (Edit->Machine Data and Edit->Base Length), the *Measurement* button should be pressed. Than a measured axis should be chosen (fig. 7.3) and than the optical path should be adjusted (see below). After the straightness of a chosen axis is measured a next axis should be chosen – Measurement->New Axis (fig. 7.4) When all the axes are measured, Flatness Plot button should be pressed. The received flatness plot (fig. 7.1) may be saved, printed or exported to a text file (File->Save, File->Print or File->Export).

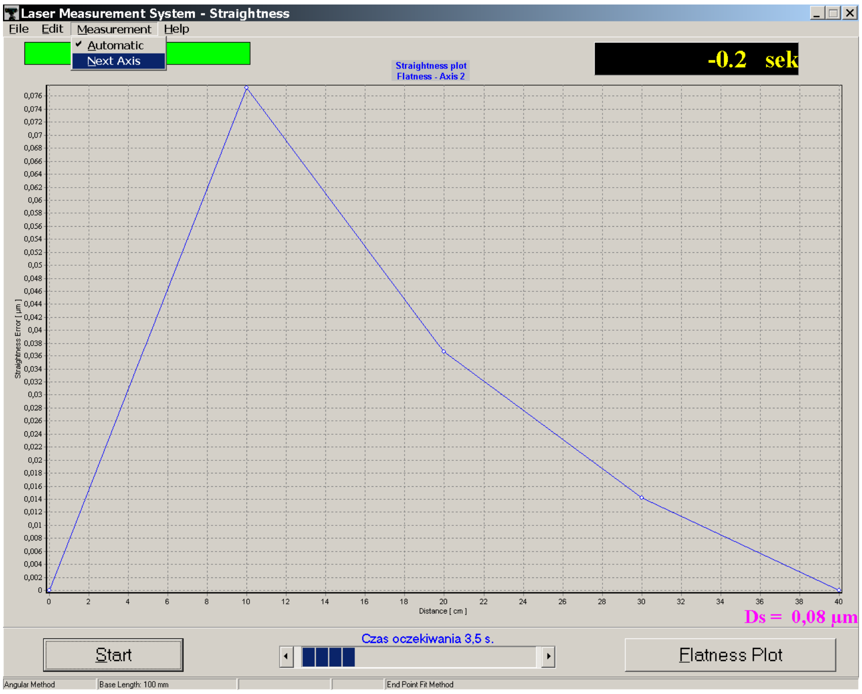


FIG.7.4. CHANGING AXIS IN FLATNESS MEASUREMENT

Optical path alignment in the axis "1".

The straightness measurement in the axis "1" is done with the optical components and in the way described in Chapter 6, *Straightness measurements*.

Optical path alignment in the axes: "3", "6", "8".

During flatness measurements in the axes "3", "6" and "8" an additional beam directing mirror **ZK1** is used. The way of using it is shown on Figure 7.5.

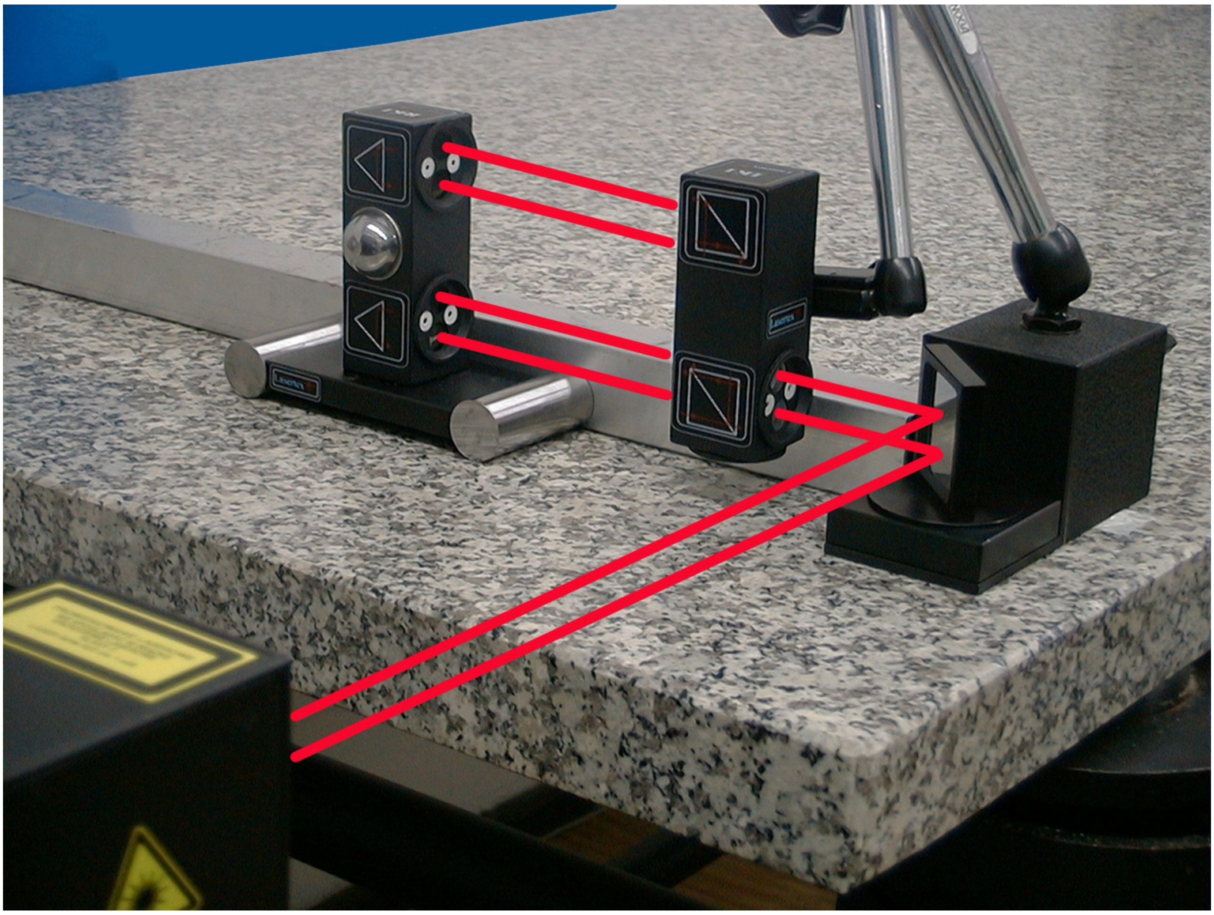


FIG.7.5. THE SET OF THE OPTICAL COMPONENTS USED IN STRAIGHTNESS MEASUREMENTS IN THE AXES: “3”, “6:” AND “8”

1. The diaphragm on the laser head set to the *Alignment* position,
2. The beam directing mirror **ZK1** set 45^{o} to the laser beam coming out from the head,
3. Place the angle interferometer **IK1** in the measured axis,
4. Set the diaphragm on the angle interferometer to the *Alignment* position,
5. Change the position of the head so that the beam falls in the middle of upper interferometer’s diaphragm,
6. Set the diaphragm on the angle retro-reflector to the *Alignment* position

7. Moving the retro-reflector along the axis, change the position of the head so that the beam passing through the interferometer falls also in the middle of the retro-reflector's diaphragm,
8. After changing the positions of the diaphragms on the interferometer and on the retro-reflector to *Working* positions, check if the return beam falls in the middle of measuring opening in the head. Do the check moving the retro-reflector along the axis. Corrections, if needed, can be made both changing the head or the interferometer position,
9. Set the diaphragm on the laser head to *Working* position and check if the level indicator on the display shows around 100%,
10. Now the straightness measurements, as described in Chapter 6, can be made.

Optical path alignment in the axes: "5" and "7"

During flatness measurements in the axes "5" and "7" two beam directing mirrors **ZK1** are used. The way of using them is shown on Figure 7.6.

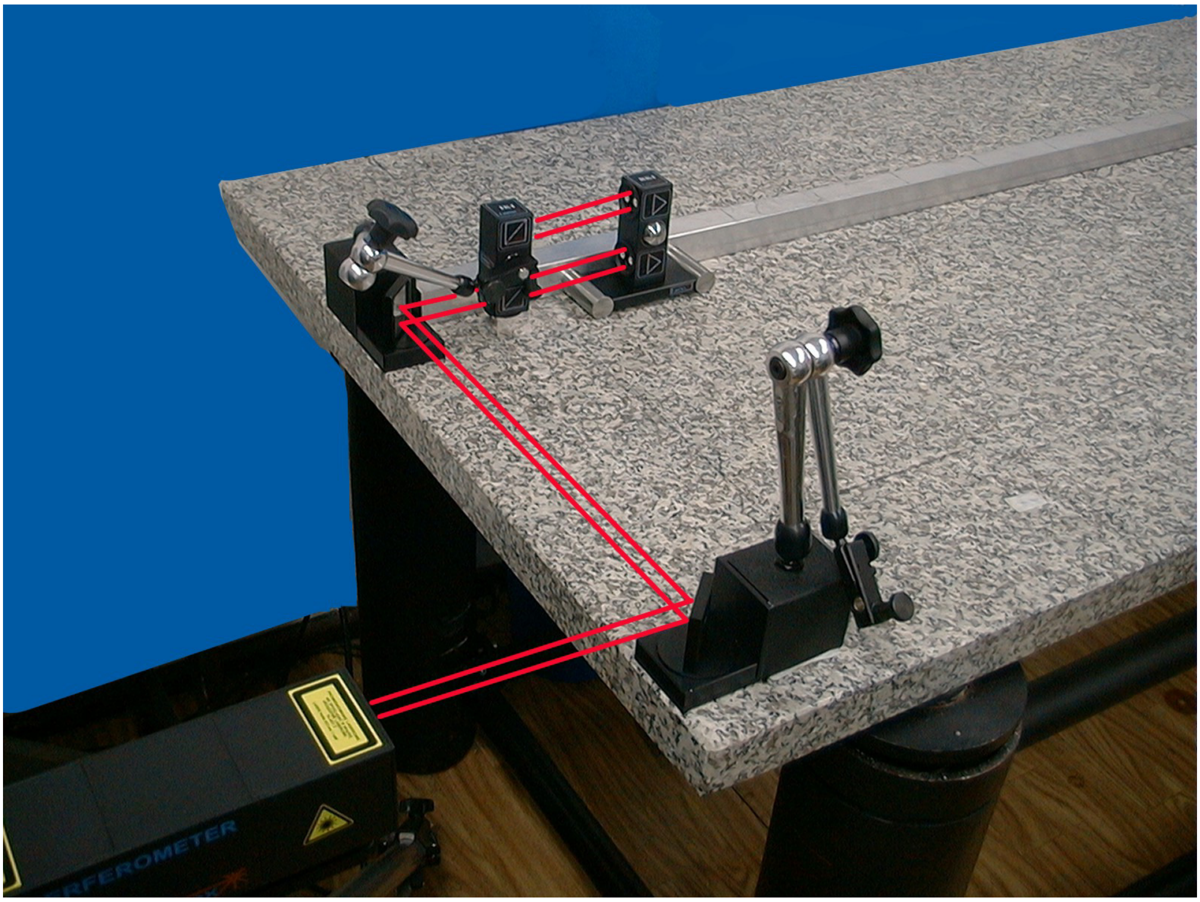


FIG.7.6. THE SET OF THE OPTICAL COMPONENTS USED IN STRAIGHTNESS MEASUREMENTS IN THE AXES: “5” AND “7”

1. The diaphragm on the laser head set to the *Alignment* position,
2. The first beam-directing mirror **ZK1** set 45° to the laser beam coming out from the head. The position of the laser head should be regulated in a way that the beam reflected from the first mirror runs parallel to the axis “3” and falls on the second beam-directing mirror. The second mirror is set 45° to the first one,
3. Changing the position and the angle of the second mirror direct the reflected beam along the axes “5” or “7” in a way the beam is parallel to the axis,

4. Place the angle interferometer in magnetic holder of the second mirror and set it in the optical path,
5. Set the diaphragm on the angle interferometer to the *Alignment* position,
6. Change the position of the head so that the beam falls in the middle of upper interferometer's diaphragm,
7. Set the diaphragm on the angle retro-reflector to the *Alignment* position,
8. Moving the retro-reflector along the axis, change the position of the head so that the beam passing through the interferometer falls also in the middle of the retro-reflector's diaphragm,
9. After changing the positions of the diaphragms on the interferometer and on the retro-reflector to *Working* positions, check if the return beam falls in the middle of measuring opening in the head. Do the check moving the retro-reflector along the axis. Corrections, if needed, can be made both changing the head or the interferometer position,
10. Set the diaphragm on the laser head to *Working* position and check if the level indicator on the display shows around 100%,
11. Now the straightness measurements, as described in Chapter 6, can be made.

Optical path alignment in the axes: "2" and "4"

Similar to previously described, during flatness measurements in the axes "2" and "4" two beam directing mirrors **ZK1** are used. The difference is that the angle of the second mirror usually differs from 45^{o}. The way of using them is shown on Figure 7.7.

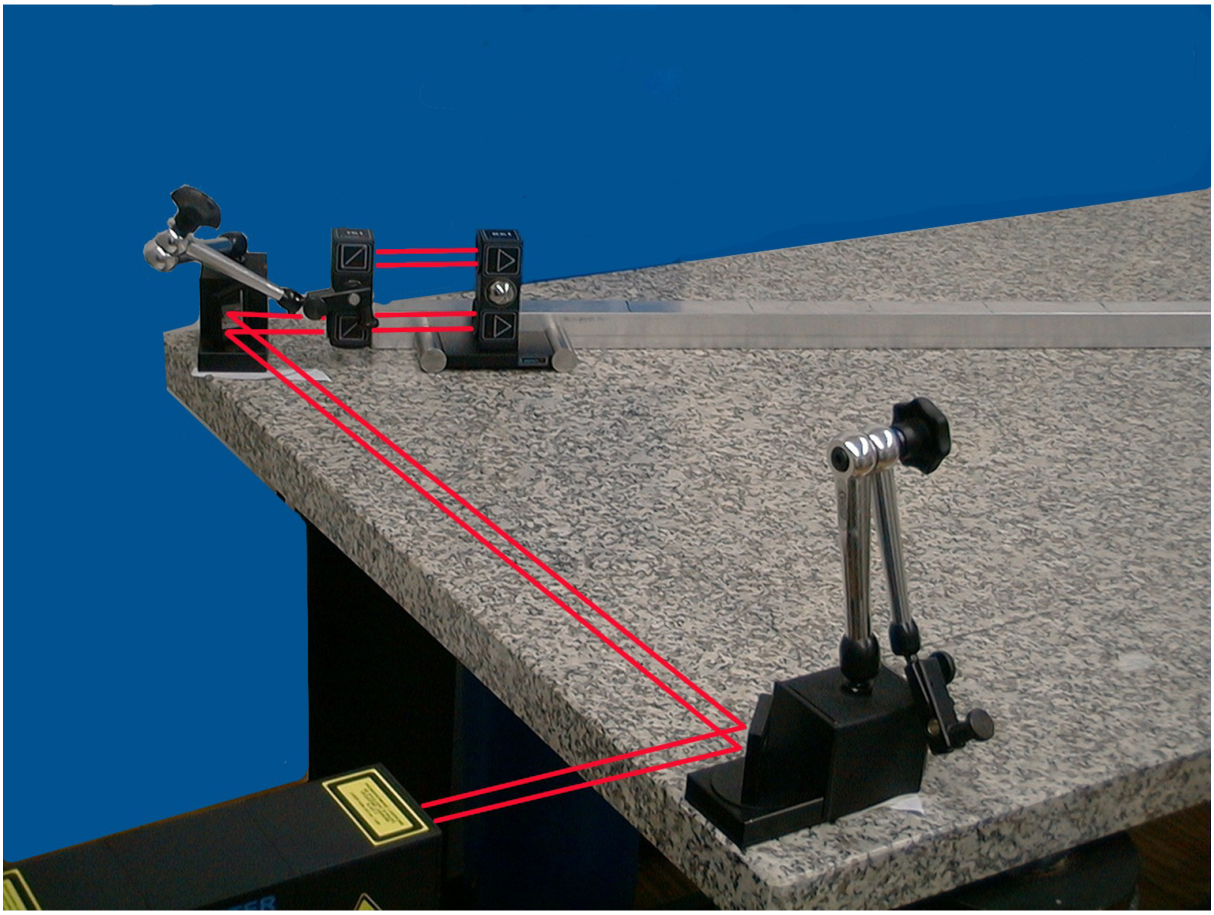


FIG.7.7. THE SET OF THE OPTICAL COMPONENTS USED IN STRAIGHTNESS MEASUREMENTS IN THE AXES: “2” AND “4”

1. The diaphragm on the laser head set to the *Alignment* position,
2. The first beam-directing mirror **ZK1** set 45^{o} to the laser beam coming out from the head. The position of the laser head should be regulated in a way that the beam reflected from the first mirror runs parallel to the axis “3” and falls on the second beam-directing mirror. The second mirror is set in the necessary angular to the first one,
3. Changing the position and the angle of the second mirror direct the reflected beam along the axis “4” in a way the beam is parallel to the axis,
4. Place the angle interferometer in magnetic holder of the second mirror and set it in the optical path,

5. Set the diaphragm on the angle interferometer to the *Alignment* position,
6. Change the position of the head so that the beam falls in the middle of upper interferometer's diaphragm,
7. Set the diaphragm on the angle retro-reflector to the *Alignment* position,
8. Moving the retro-reflector along the axis, change the position of the head so that the beam passing through the interferometer falls also in the middle of the retro-reflector's diaphragm,
9. After changing the positions of the diaphragms on the interferometer and on the retro-reflector to *Working* positions, check if the return beam falls in the middle of measuring opening in the head. Do the check moving the retro-reflector along the axis. Corrections, if needed, can be made both changing the head or the interferometer position,
10. Set the diaphragm on the laser head to *Working* position and check if the level indicator on the display shows around 100%,
11. Now the straightness measurements, as described in Chapter 6, can be made.

In the case of the measurements in the axis "2", the path alignment procedure is the same as described above. The only difference is that the second mirror, as not needed, is not used.

8

STRAIGHTNESS MEASUREMENTS – 3D

Straightness/squareness measurement highlight any bending component or overall misalignment in the guideways of a machine. This could be a result of a wear in the guideways, an accident or poor machine foundations. The straightness/squareness errors are a direct effect of a machine geometry and their elimination increases machining accuracy. The quick assessment of the machine geometry is one of the most important action required when the machine is mounted on the foundation.

The geometry measurements are one of the most time consuming measurements. There are three methods of straightness measurement: with angular optics, with Wollastone prism and with 3D method patented by Lasertex. The commonly used Wollastone prism optics is expensive and very difficult to adjust although it gives the most accurate results. Operation of the system with the Wollastone prism optics requires highly skilled personnel. The method with the angular optics was presented in the section ANGULAR MEASUREMENT (see Chapter 6).

The optics for the Wollastone prism and the angular method are supplied optionally. The method of straightness measurement does not require any additional optics – the standard linear set is used.

For squareness measurement one additional optical element is necessary – the optical square etalon (supplied optionally).

The straightness of the movement is measured by measuring the position of the reference beam and the position of the measuring beam returning to the laser head. 3D measurements offer unique possibility of measurements of straightness in two dimension in one measurement. This significantly shortens the measurement time.

One could measure the straightness in **Straightness** option chosen from the main menu. For 3D measurements one have to choose the 3D method of measurement from the "Measurement" menu or from the **Config** menu (on the main screen). The straightness measurement software procedure are the same like for straightness measurements described in "ANGULAR MEASUREMENT" section. In Fig. 8.1 the print screen made during the measuring process is presented. The automatic option of the measurement was chosen. In the left black rectangle one can see the position of the retro-reflector in mm, while in the upper and lower black rectangle the horizontal and vertical shift in micrometers.

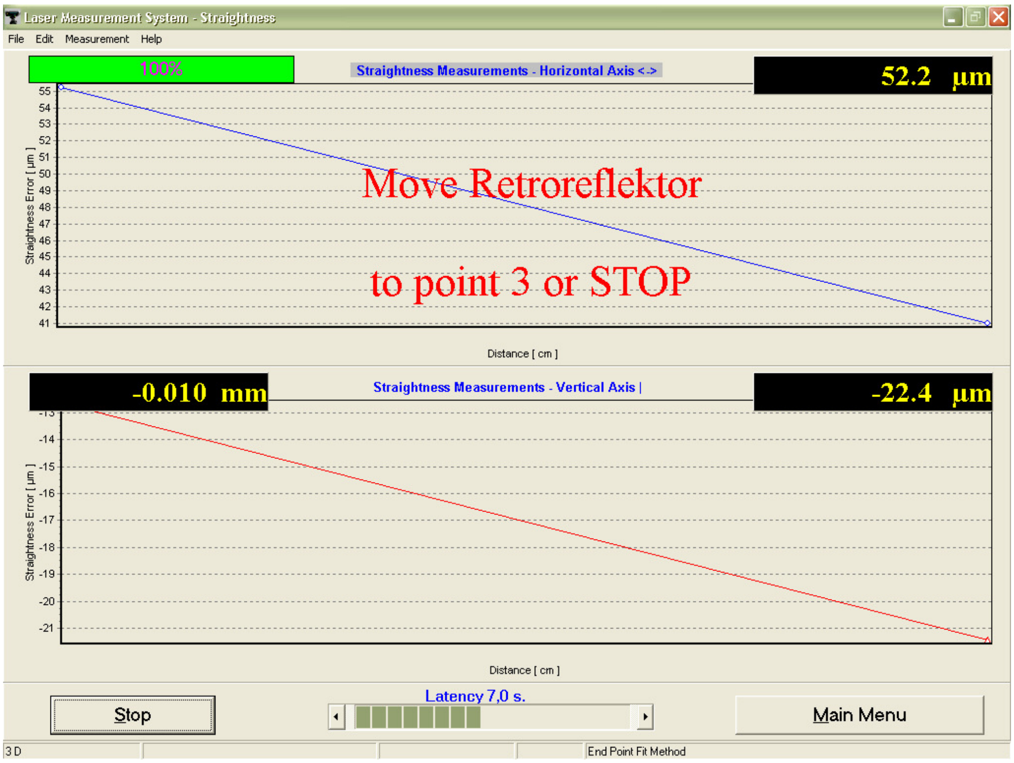


FIG. 8.1. THE PRINT SCREEN OF STRAIGHTNESS MEASUREMENT

The result of the measurements are presented in Fig.8.2. The upper trace shows the straightness for the horizontal axis and the lower one the straightness of the vertical axis. The parameter D_s represent the straightness error. End point fit method was chosen for plotting the result and for calculating of the straightness error.

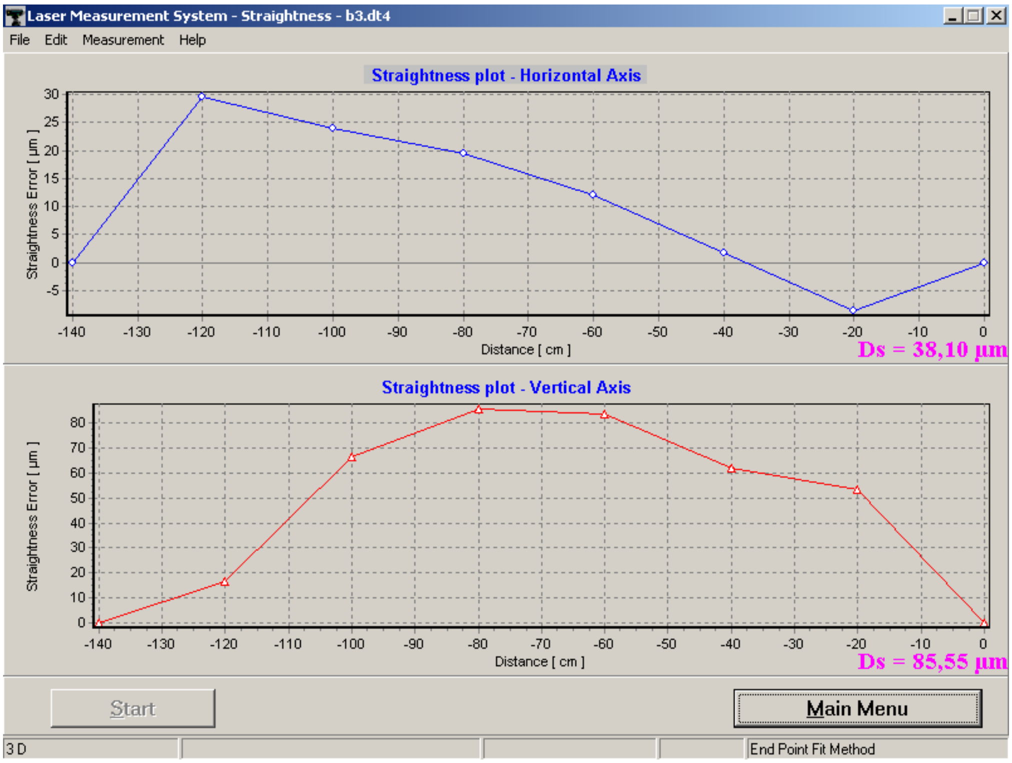


FIG. 8.2 THE RESULTS OF STRAIGHTNESS MEASUREMENTS

The accuracy of the straightness measurements depends on the precision of the alignment of the measured axis. It is recommended that the position of the crosses during alignment (as seen on the **Display** screen) procedure to be set to the center of the screen (zero position).Vibrations of the base where the tripod is placed and air density fluctuations are the source of noise that lower accuracy of the measurement. When required accuracy of straightness measurement for tested machine is not satisfactory one have to proceed to measurements with the use of angular optics or with the Wollastone prism.

Squareness measurements

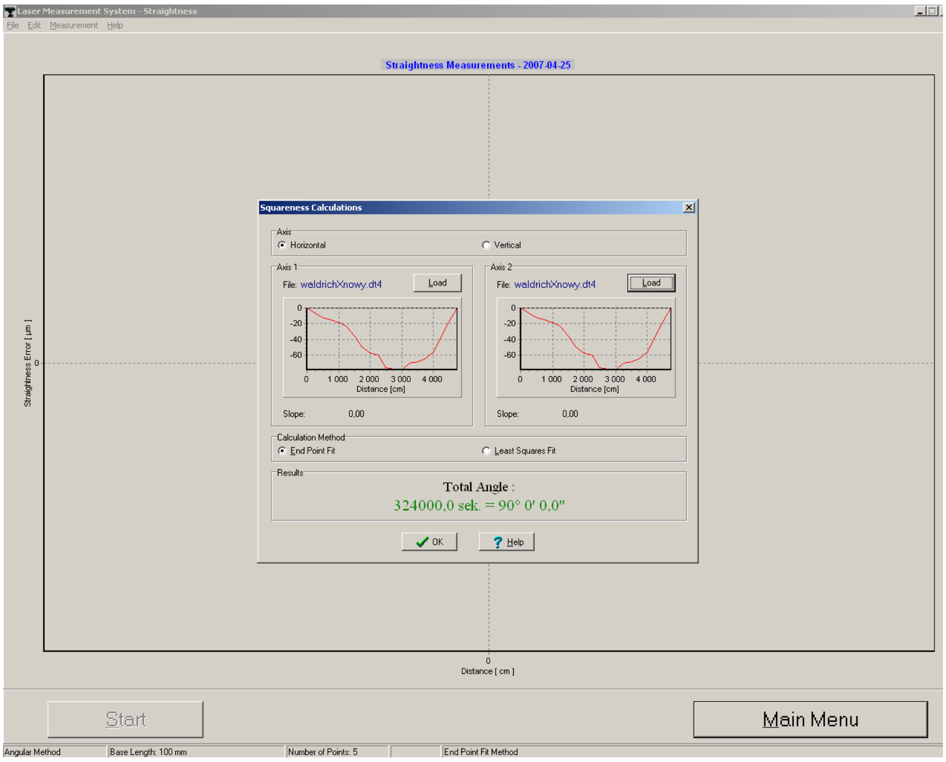


FIG.8.3. SQUARENESS MEASUREMENT RESULTS

Procedure of measuring the squareness of the machine's axes:

a. Set up the laser head at a certain position;

b. Measure the straightness of the movement in the first axis according the previous described procedure. Straightness can be measured with the Wollastone or the 3D method.

c. Store obtained results.

d. Measure the straightness of the movement in the second axis according the previous described procedure. Use the optical square etalon. ***Do not move the laser head!!!*** Any shift of the laser head position requires restarting the procedure from point 1).

e. Store obtained results.

f. Choose **Edit->Squareness** option. The window like the one shown on the Fig. 8.3.

g. Load stored results and choose the squareness of which axes is of interest (i.e. Horizontal or Vertical).

h. Calculated angle is shown in the bottom part of the window.

9

VIBRATION MEASUREMENTS

The laser measurement system µLine F1 is capable of detecting machine vibrations in the frequency range from 0 to 500 Hz. For these measurements an element set for linear measurements is used i.e.: a PC computer, a laser head with a power supply, a stand Tripod, magnetic holders (one **UM1** and one **UM2**), a linear interferometer **IL1**, and a linear retro-reflector **RL1**.The Environmental Compensation Unit - (ECU) and the temperature sensors do not have to be used. The optical path should be adjusted as shown in Chapter 4.

To obtain correct results, a point of attaching the retro-reflector to the corpse of a measured machine must be carefully chosen. If the point is chosen improperly than, instead of a sought frequency *f,* a multiple frequencies *n*f* appear (where n=1,2,...) on the FFT chart. For that reason the retro-reflector **must not** be in theses measurements used with the magnetic holder **UM1**. It must be also remembered that the system measures the vibration only in the axis of the optical path. Any vibrations in perpendicular axes do not influence the measurement (see fig.8.1). An example of a properly attached retro-reflector is shown on fig. 8.2.

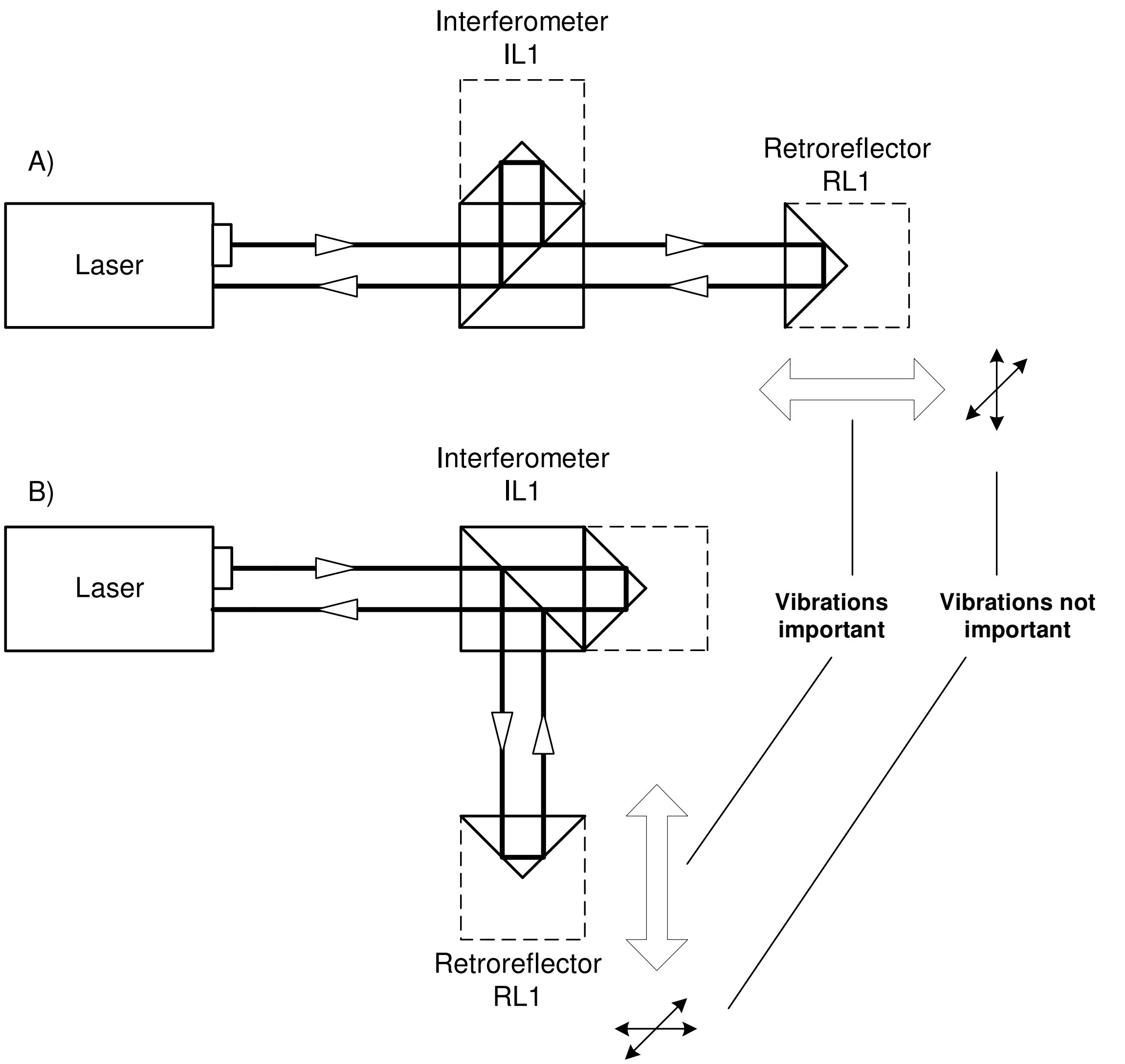


FIG.8.1. VIBRATION MEASUREMENT IN DIFFERENT AXES

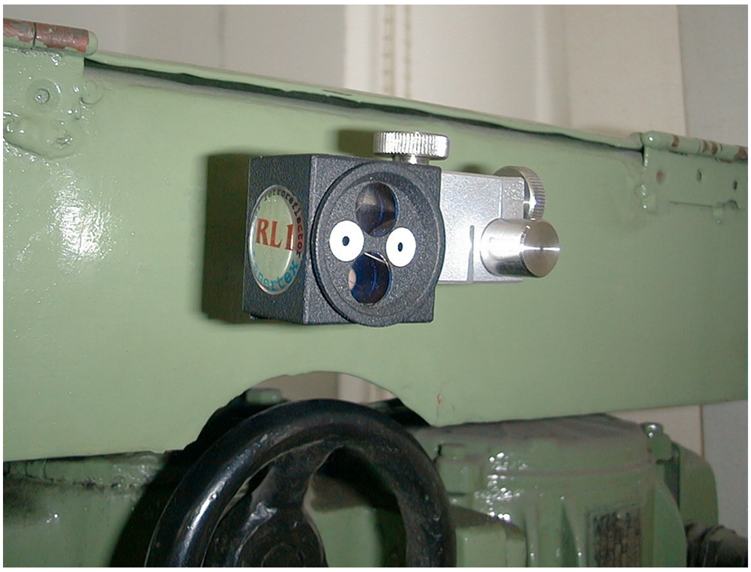


FIG.8.2. EXAMPLE OF PROPERLY ATTACHED RETRO-REFLECTOR

Measurements

After adjusting the optical path and choosing **FFT** option from **Main Menu** a window, as shown on fig.8.3 appears. The most important parts of this window are: time diagram, frequency diagram and radio buttons (on the right side). Before measurements a machine data may be set (Edit->Machine Data). The measurement starts after pressing the Measurement button. Then appears the Measurement Window (see fig.8.3) that shows two progress bars – the upper (blue) one shows the progress in measurement; the lower (green) one shows progress in sending data to the computer. The measurement is in progress when the upper bar is in the range of 0-100% (it lasts approx. 12s)!

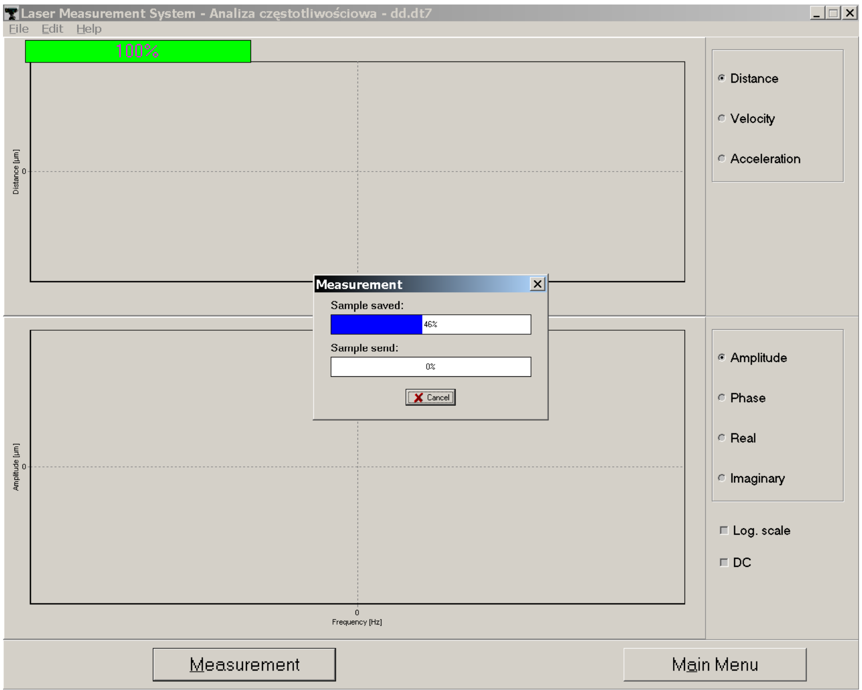


FIG.8.3. VIBRATION MEASUREMENT WINDOW

When both the measurement and the transmission are done, the measurement results are presented on the time diagram and its FFT analysis on the frequency diagram (fig.8.4). The results can be saved, printed or exported (menu File). With the use of radio buttons the type of input data may be chosen, i.e. whether amplitude of Distance, Velocity or Acceleration is important. In the frequency diagram not only the amplitude of vibration frequencies may be displayed, but also their phase, real and imaginary part of the vibration. The check radio buttons in the bottom right of the window allow to change the vertical scale of the frequency diagram to logarithmic and to eliminate a DC offset.

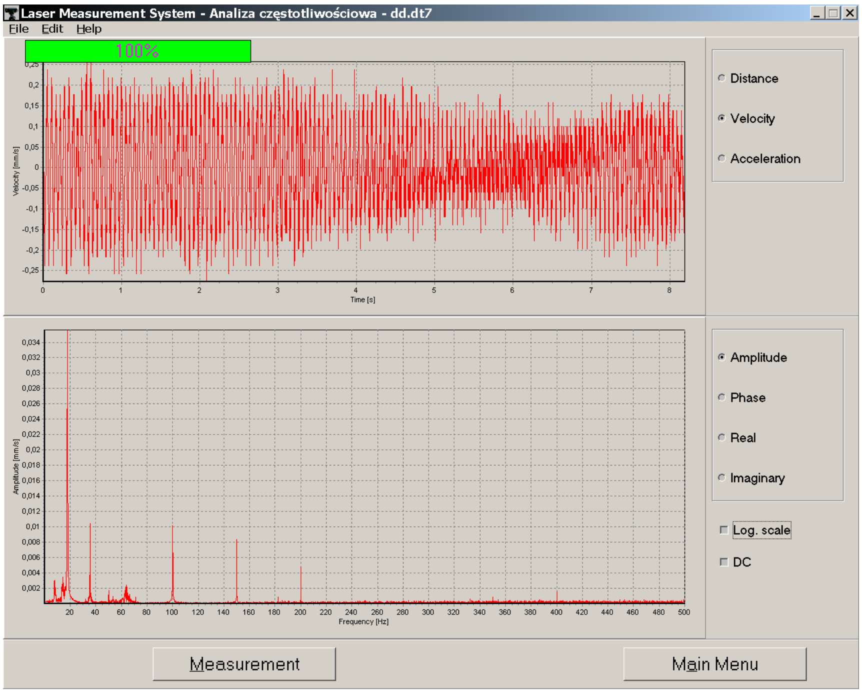


FIG.8.4. EXAMPLARY VIBRATION MEASUREMENT RESULTS

What may be confusing in obtained results are different amplitudes of frequencies on the frequency diagram after changing from Distance to Velocity and to Acceleration, fig. 8.5. It happens so, accordingly to the theory, from which results:

$E_{An} \sim f_n * E_{Vn}$

$E_{Dn} \sim f_n * E_{An}$

Where:

E_{Dn} – amplitude of n-th frequency when Distance is chosen;

E_{Vn} – amplitude of n-th frequency when Velocity is chosen;

E_{An} – amplitude of n-th frequency when Acceleration is chosen.

f_n – n-th frequency.

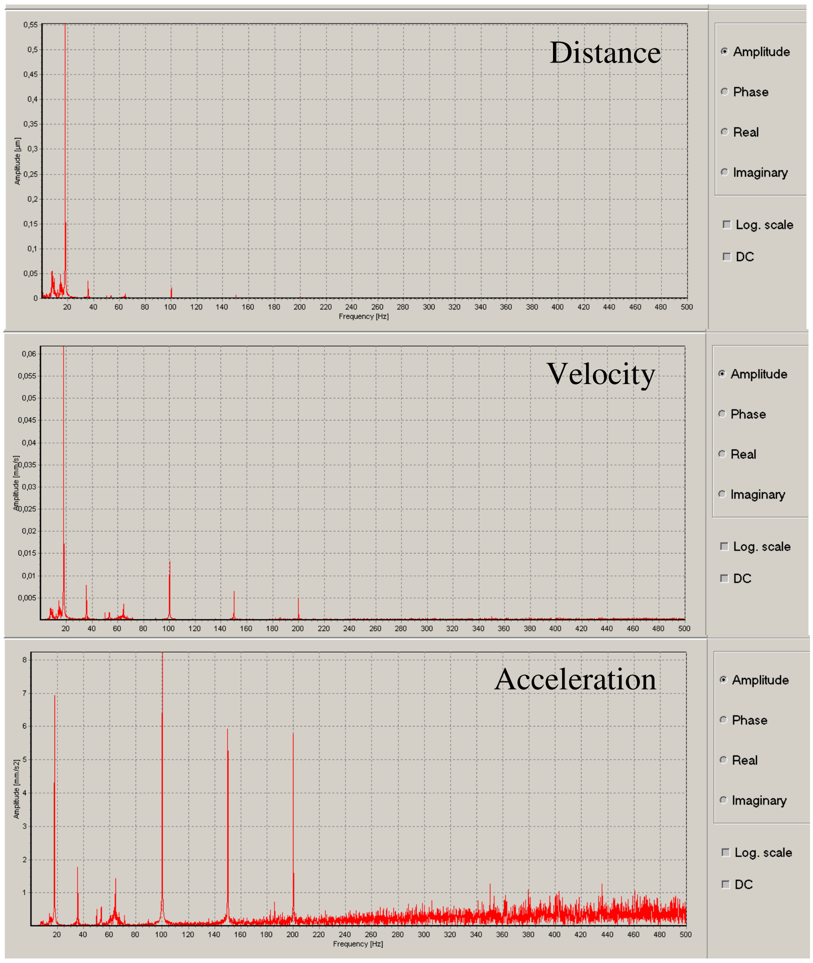


FIG.8.5. DIFFERENT FREQUENCIES' AMPLITUDES IN DEPENDANCE ON

10

TECHNICAL DATA

System specifications

Measurement	Range	Resolution	Accuracy
Distance	0 – 30 m	0,01 µm (0,001 µm)	1,5 µm/m
Velocity	0 – 0,3 m/s (0,1 m/s)*	0.25 µm/s	0,1 %
Angular	0 – 3600 arcsec	0,04 arcsec	± 0,2 %
Straightness measurement (with angular optics)	0 – 12 m	0,02 µm (for 100 mm base)	± 1 %
Flatness	0 – 12 m Vertical range ±2 mm	0,02 µm (for 100 mm base)	± 0,5 %
Straightness measurement (with wollastone prism)	0 – 3 m	0.5 µm	± 1 %±(0.5±0.15L^2) µm
Straightness measurement 3D	0-5 m	0,1 µm	(5± 1 x L) µm L in meter
Squareness	± 1000 arcsec	0,4arcsec	± 1 % ± (1,5 arcsec)
Rotary measurements	± 5 °	0,04 arcsec	± 0,2 %

L = axis length in meters

* - for resolution 1 nm.

Laser head

Laser type	Zeeman HeNe laser with frequency stabilization
Heating time	Approx. 20 min
Wavelength (vacuum)	632,991354 nm
Wavelength accuracy	± 0,02 ppm
Short time stability	± 0,002 ppm (1 hour)
Output power	400 µW
Beam diameter	8 mm
Distance between out- and ingoing beam	12,7 mm
Laser head dimensions	60x60x245 mm
Net weight	1500 g
Safety class	Class 2 Laser product according to PN-91/T-06700

System work conditions

Temperature range	10 – 35 °C
Humidity range	10 – 90 %

Power supply

Voltage	90-230 VAC, 50-60 Hz
Power	35 W (during heating) 10 W (work)

PC interface

Type	Bluetooth, USB
Data rate	57 600 bps (RS 232)

Environment compensation

Wavelength compensation

Manual	Environments parameters entered from keyboard
Automatic	With the use of the Environmental Compensation Unit - (ECU) .

Parameters of the Environmental Compensation Unit - (ECU) compensation

Air temperature	Range 0 – 40 °C, accuracy 0,1 °C
Pressure	Range 940 – 1060 hPa, accuracy 1 hPa
Humidity	Range 10 – 90 %, accuracy 10 %
Time constants	Temperature 3 s, pressure 2s, humidity 30 s
Dimension	ϕ50x55 mm
Net weight	100 g

Material temperature compensation

Manual	Temperature of material entered from keyboard
Automatic	With the use of 1 to 3 temperature sensors .
Temperature sensor	Pt-1000 in oil resistant casing.
Time constant	5 s
Net weight	50 g

Our products are subject to continuous further development and improvement. Subject to technical changes without prior notice.

Status Pro®
maschinenmesstechnik