Instructions LASNIX Polarization Sensors
Models 601, 605, option H

1. HANDLING. LASNIX polarization sensors operate on the principle of a rotating linear polarizer. The polarizer element is a very thin structured metal membrane. Mod. 605 contains in addition an attenuating element also in form of such a membrane.

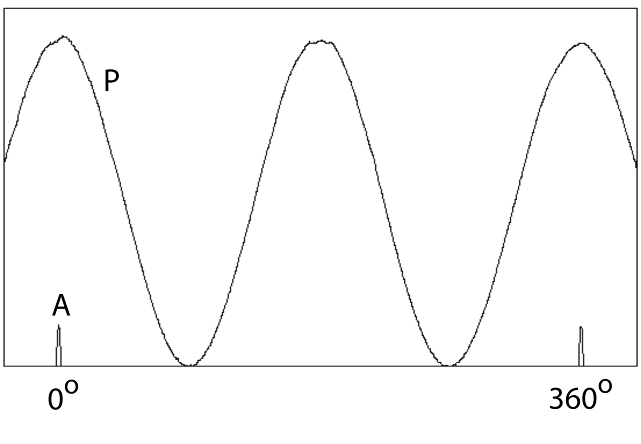
> WARNING:
> The metal membranes are mechanically fragile. Do not touch or blow air. Do not use cleaning liquids. Please read carefully parts 6 & 7 ("power limits") of these instructions before using the instrument.

2. INSPECTION. The polarization sensors are shipped with a battery case equipped with an OFF - ON switch. Two included AA Li batteries last for about 60 hours of continuous operation.

3. FUNCTION. The internal polarizer rotates when the supply voltage is switched on. The angle encoder signal gives one larger pulse each turn, when the polarizer is oriented to transmit vertically polarized radiation, and 35 smaller pulses at 10^o intervals. The pulses can also be seen as a brighness modulation of the green status LED which is situated next to the switch.

The incoming laser radiation is transmitted through the rotating polarizer and measured by the internal power sensor. Its output signal is a true d.c. voltage proportional to the power. When both signals are recorded vs. time the polarization state of the laser radiation can be simply determined by extracting (i) the ratio P_{min}/P_{max} of the sinusoidally modulated power signal, and (ii) the angular position of the power maximum. A detailed analysis is given in the Appendix.

Example:
Output signal P and encoder signal A vs. time showing the case of a linearly polarized laser beam with the electric field vertical.



4. INSTALLATION. The polarization sensors are to be mounted in the beam path on a user-supplied support. Mod. 601 has four M3 threads on a 28.8 mm dia. pitch circle on the input face for front mounting. Alternatively, there are four M4 threads for side-mounting, spaced 35 mm along the length of the Mod. 501, and 18 mm across. Tight mounting to a heat sink becomes necessary for input powers exceeding 10 W c.w..

Mod. 605 has a base plate for quick mounting e.g. by clamps. With the base plate removed four M5 threads become available for permanent mounting, separated by 34 mm along and 16 mm across the beam direction. This unit requires water cooling through plastic tubing with 8 mm o.d. and 6 mm i.d. We recommend a water flow rate of 1 liter/min. per kW of incident beam power.

5. ALIGNMENT. The laser beam must be aligned perpendicular to the input aperture, within a tolerance of ± 6° for Mod. 601, and even ± 1° for Mod. 605. We recommend for correct alignment to fix an auxiliary mirror on the entrance aperture and to observe the retroreflection of a visible pilot beam. Incorrect alignment of the input beam results in both a reduction of the power signal and, with large misalignment, a distortion of the polarization ellipse due to the possibility of depolarizing reflections within the sensor.

6. POWER LIMITS — Mod. 601:

The polarization sensor Mod. 601 handles a maximum power (c.w. oder quasi-c.w.) of 30 W (15 W for option H), and a maximum pulse energy density of 1 J/cm^2.

> WARNING: The specified power handling limit applies to a relatively wide smooth beam, for example, a near fundamental mode having a 1/e^2 diameter of 4 mm.

USING NARROW BEAMS:

For smaller beam diameters the power limit is reduced to :

20 W (15 for option H) at 3 mm,
12 W at 2 mm,
5 W at 1 mm.

USING SINGLE PULSES:

The specified limit of pulse energy density of 1 J/cm^2 applies to single short pulses, provided the intensity does not exceed the plasma breakdown threshold. The latter is near 500 MW/cm^2.

USING REPETITIVE PULSES;

The specified quasi-c.w. power limit applies to repetitively pulsed beams, with the added requirement that each pulse is within the specified pulse energy density limit. Thus for example, model 601 accomodates at a repetition rate of 300 pps pulse energies up to 0.1 J.

7. POWER LIMITS — Mod. 605:

The polarization sensor Mod. 605 handles a maximum power (c.w. or quasi-c.w.) of 3 kW, and a maximum power density of 2 kW/cm^2 (1 for option H). This means that a smooth beam of 272 W (136 for option H) max. may pass the sampling aperture of 4 mm diameter.

For near fundamental mode laser beams this means in practice the $1/e^2$ beam diameter has to be

≥ 20 mm for 3 kW (1.5 for option H)
≥ 16 mm for 2 kW (1 for option H)
≥ 12 mm for 1 kW (0.5 for option H).

USING NARROW BEAMS:

In the case that beams with small $1/e^2$ diameters are used the power limit reduces to

210 W (105 for option H) at 3 mm,
140 W (70 for option H) at 2 mm,
70 W (35 for option H) at 1 mm.

USING SINGLE PULSES:

A limit of pulse energy density of 12 J/cm^2 applies to single short pulses, provided the intensity does not exceed the plasma breakdown threshold. The latter is near 500 MW/cm^2.

USING REPETITIVE PULSES;

The power limits specified above apply also to repetitively pulsed beams, with the added requirement that each pulse is within the pulse energy density limit of 12 J/cm^2 . Thus for example, model 605 accomodates at a repetition rate of 300 pps pulse energies up to 10 J.

OPERATION

8. MEASUREMENT PROCEDURE. After mechanical installation connect a user-supplied scope to (i) the BNC outlet next to the LED to register the encoder signal, and to (ii) the other BNC outlet to register the power signal. Set the ranges to 1 V full scale, and the sweep time to 1 s/div.

Before applying the laser radiation please check:

- is the expected power/power density within the specified limits?
- is the water flowing? (Mod. 605 only)

When the battery switch is in the "OFF" position the internal polarizer stays at a fixed angular position and the encoder signal is zero. The power signal is however active without bias. Thus the power signal can be used in this situation to observe temporal variations of the laser power, e.g. during the switch-on phase of a high-power CO_2 laser.

With the battery switch "ON" the polarizer rotates, **in anti-clockwise direction as viewed from the laser**.
A full rotation period is 7 s. The encoder signal peaks once in this period. This occurs when the internal polarizer is oriented to transmit radiation with vertical electric field. The power signal oscillates sinusoidally, twice during a rotation period.

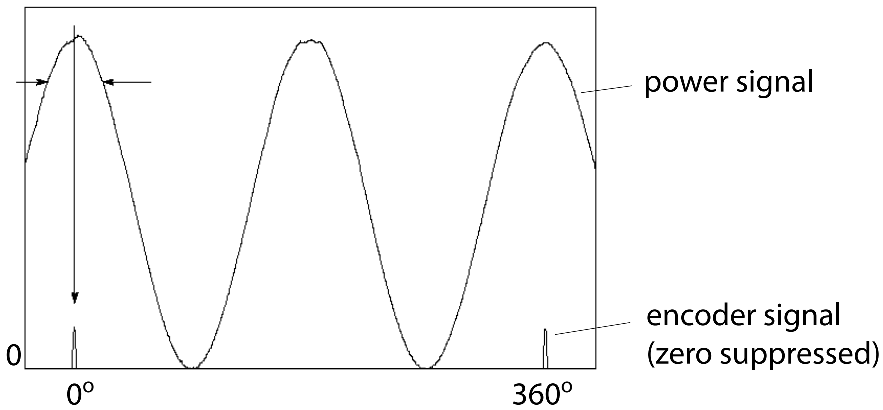
From the recorded signals it is easy to read two quantities of interest:

- the power ratio $r = P_{min}/P_{max}$
- the orientation angle α for maximum power signal.

9. POSSIBLE PROBLEMS. A common problem can be pickup and interference e.g. from a laser power supply disturbing the signal recording. Short cables, defined grounding and operation of the recording device from battery may help.
We recommend triggering the scope from the encoder signal and applying averaging to the power signal measurement in order to avoid influences from laser power fluctuations and ebvironmental disturbances. Also low-pass filtering on the scope can help to improve measurement accuracy.

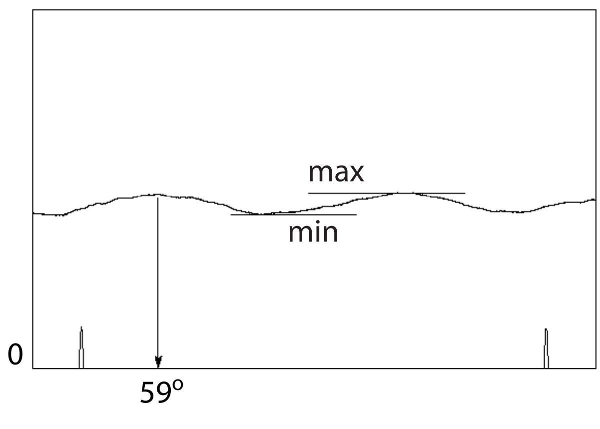
10. MEASUREMENT EXAMPLES. We illustrate the determination of the polarization ellipse by the following measured recordings.

A.



This is an example of a linearly polarized laser beam with vertical field orientation, since the power is modulated down to zero at the times of horizontal orientation of the polarizer (90°, 270°).

B.



This situation is typical for the machining application with a circularly polarized CO_2 laser beam. The polarization here is not perfectly circular because the power remains modulated, with a power ratio $r = P_{min}/P_{max} \approx 0.88$. The maximum power signal is seen to occur at an angular position of $\alpha \approx 59°$ from the encoder peak, i.e. from the vertical, in anticlockwise direction as viewed from the laser.
The results from the measurement, r and α, can be directly used to determine both sources of misalignment of the circular polarizer, i.e. azimuth and phase shift, as given below.

11. APPENDIX—THEORY. We follow the theory of polarization of a monochromatic plane wave as given in Born & Wolf, Principles of Optics. It is assumed that a laser beam has a horizontal and a vertical field component, E_h and E_v respectively, with relative phase difference δ, so that

$$E = E_h \cos(\omega t) + E_v \cos(\omega t+\delta). \quad (1)$$

The field E can be shown to describe an ellipse. With the definition of an azimuth angle $\alpha_0 = \arctan(E_v/E_h)$ the ellipse has an axial ratio ρ and its maior axis is oriented at an angle α where

$$\rho = \tan(0.5 \arcsin(\sin(2\alpha_0) \sin\delta)), \quad (2)$$
$$\alpha = 0.5 \arctan(\tan(2\alpha_0) \cos\delta). \quad (3)$$

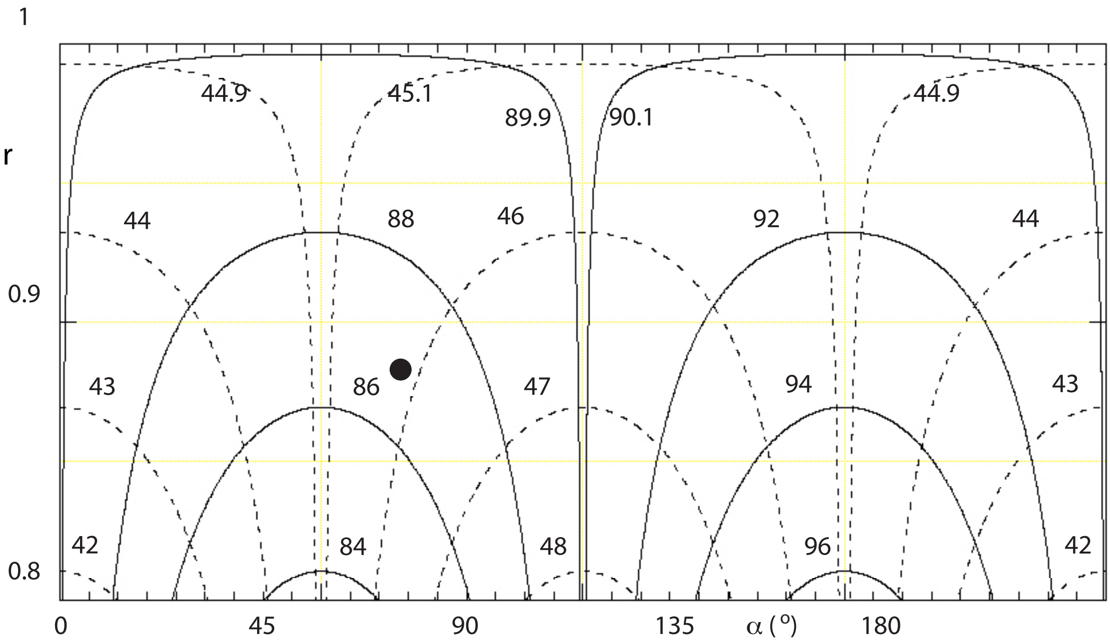
When this beam is transmitted through a linear polarizer as in the LASNIX polarization sensors the measured power ratio is $r = P_{min}/P_{max} = \rho^2$ and the power maximum occurs at a polarizer orientation α. It is therefore possible to determine both quantities $E_v/E_h = \tan\alpha_0$ and δ from a measurement of r and α.

Usually in CO_2 laser machining the beam is initially linearly polarized (i.e. $\delta = 0$) at azimuth angle $\alpha_0 = 45^o$ (i.e. $E_v/E_h = 1$), but then passes a phase retardation mirror to impose $\delta = 90^o$ which transforms the polarization into circular.

We consider first the beam before the retarder. Here the polarization is nearly linear ($\delta \approx 0^o$) and therefore, the polarization measurement can sensitively detect small deviations from the proper azimuth condition since from eq. (3) $\alpha \approx \alpha_0$.

Now we consider the beam after a phase retardation mirror. Here the polarization sensor not only allows to directly measure the power ratio r which is an essential beam quality factor for cutting—also referred to as "ellipticity" ratio in the literature. In addition, the separate determination of both r and α helps to find out which of the properties of the retarder may need adjustment, and moreover in which direction. To see this consider a retarder tuning chart in the following manner.

This retarder tuning chart is derived from eqs. 2 & 3: We plot r vs α, and obtain two families of curves, one with α_o = const. (broken), the other with δ = const (full). Any measurement with the polarization sensor results in a distinct pair of values r,α defining a single point in the tuning graph. This point in turn uniquely determines one pair of α_o,δ values characterizing the retarder alignment.



As an example we use the measured recording shown above in section 10.B. The result is represented as a black dot in the tuning graph. From this graph it becomes clear that $\alpha_o \approx 45.8^o$, $\delta \approx 86.8^o$; this uniquely determines how to adjust the phase retarder mirror in order to achieve perfect circularity (r=1).