VILNIUS UNIVERSITY
FACULTY OF PHYSICS
STUDIES OF LASERS LABORATORY

Laboratory work **No. KE – 1**

Research of He-Ne laser

Methodical instructions

Attention! Laser radiation sources are used during work – it is necessary to familiarize and strictly follow the respective rules of safety

Vilnius 2018

Purpose of the experiment

Investigate the He-Ne laser operation and the resonator properties.

Experiment tasks

1. Calculate the He-Ne laser stability conditions when radii of curvature of the resonator mirrors are 400 mm and 400 mm respectively.
2. Calculate the He-Ne laser stability conditions when radii of curvature of the resonator mirrors are 400 mm and 800 mm respectively.
3. Calculate the He-Ne laser stability conditions when one resonator mirror is flat and radius of curvature of the other one is 800 mm.
4. Adjust the alignment laser beam propagation direction (Performed if not already aligned).
5. Align the He-Ne laser system when mirrors radii of curvature are 400 mm and 400 mm.
6. While aligning the mirrors, generate higher order transverse modes.
7. Measure the laser output power dependence on distance between the mirrors. Determine stability limits.
8. Align the He-Ne laser system when mirrors radii of curvature are 400 mm and 800 mm.
9. Measure the laser output power dependence on distance between mirrors. Determine stability limits.
10. Align the He-Ne laser system when one resonator mirror is flat and radius of curvature of the other one is 800 mm.
11. Measure the laser output power dependence on distance between mirrors. Determine stability limits.
12. Measure the laser output power dependence on He-Ne laser tube position.
13. Measure the beam diameter dependence on position in the resonator.

Theoretical topics

1. Energy levels excitement in gas lasers.
2. How is the population inversion created in He-Ne laser?
3. The resonator stability condition.
4. Longitudinal resonator modes. Calculation of adjacent modes frequency difference.
5. Selection of the transverse and longitudinal modes.
6. How is polarized laser radiation obtained?
7. Formation of spectral characteristics of the laser radiation.

METHODICAL INSTRUCTIONS

Investigation for each task is performed by constructing the experimental setup according to provided setups.

Attention! Before beginning it is necessary to familiarize with descriptions of the used equipment and work safety features.

Equipment and materials

The experimental setup is depicted in Fig. 1. The He-Ne laser tube with output windows tilted at Brewster angle is used in the laser setup. The laser tube is mounted in the LVL optical holder. The laser resonator consists of an output coupler IŠV and a highly reflective mirror DAV. During experiments an output coupler IŠV400, a flat output coupler IŠVPLO and a highly reflective mirrors DAV400 and DAV800 are used.

Table 1. Parameters of laser mirrors.

A mirror	A radius of curvature, *r*	A reflection coefficient, *R*
IŠV400	400 mm	96%
IŠVPLO	∞	96%
DAV400	400 mm	>99,5%
DAV800	800 mm	>99,5%

The optical holder with the He-Ne laser tube LVL and mirrors are mounted on the optical rail with scale B.

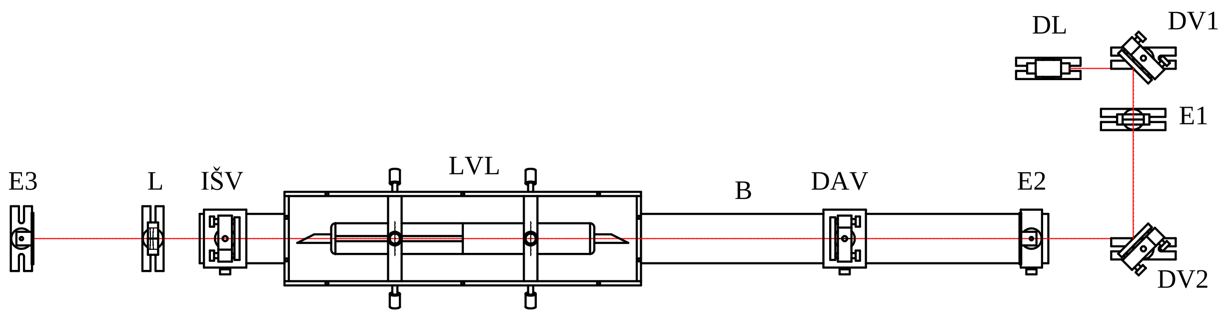


Fig. 1: Principal optical setup of the laser.

A laser diode module DL is used for alignment. Its beam is directed with mirrors DV1 and DV2 through the pinhole in the screen E1. The screen E2 is used for the laser DL beam adjustment along the optical rail B. The generated laser beam, when passed through the concave lens L, is observed on the screen E3.

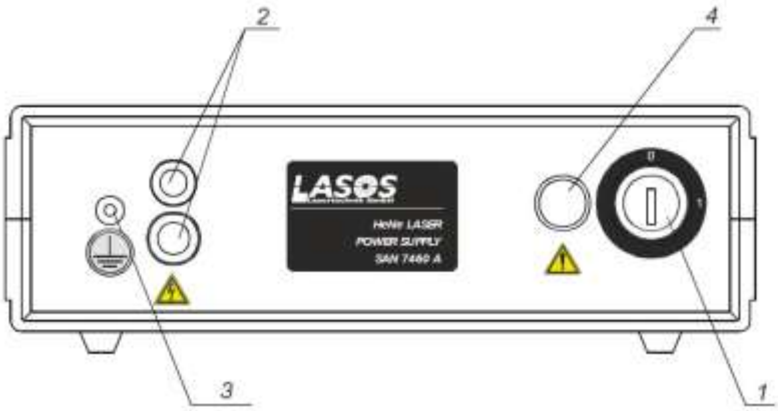


Fig. 2: He-Ne laser power supply.

A high voltage source LASOS SAN7640 A is used as a power supply for the He-Ne laser. It is turned on by rotating the key “1” clockwise. Before turning on the power supply, the He-Ne laser is connected to the supply via connection “2” and grounded via connection “3”. When the power supply is turned on, an indicator light “4” starts to shine.

The laser power meter PH100-Si is used for the laser output power measurement. Turn on the computer and connect the power meter through the USB port. Start the power meter software PC-Gentec-EO.

Fig. 3: PC-Gentec-EO icon.

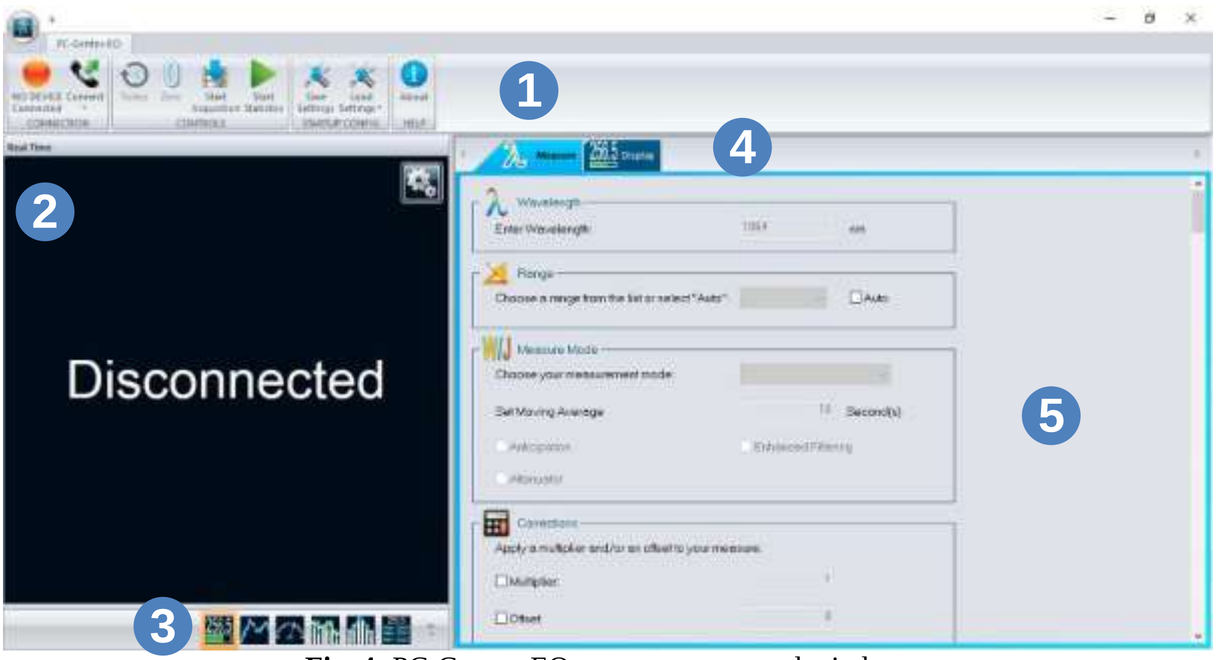


Fig. 4: PC-Gentec-EO programme control window.

1 – The Main controls menu with the Connection, Controls, Startup config and Help functions panels.

2 – The Display panel.

3 – The Change panel for changing the type of the Display panel.

4 – The Setup Panel – Selection tabs for choosing the desired set of controls.

5 – The Setup Panel – Controls for choosing and control of the different options of measurement, acquisition and display parameters.

An automatic connection of the power meter is performed by pressing the button **Connect** in the Main controls menu CONNECTION functions panel, while a disconnection is performed by pressing the button **Disconnect**.

Fig. 5: The CONNECTION functions panel when power meter is disconnected (left) and connected (right).

The display of the measured data statistics is enabled by pressing the **Statistics** button in the Change panel.

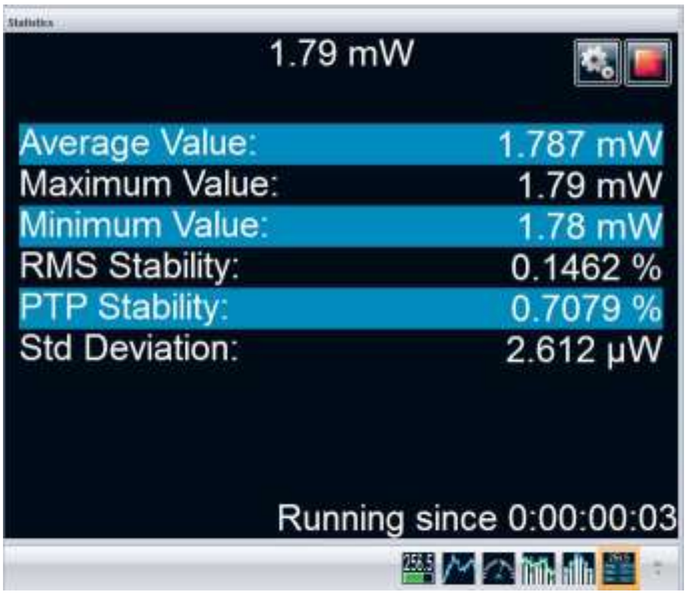


Fig. 6: The Display panel when the power measurement statistics is enabled.

Before the measurement it is necessary to set the zero power level in the power meter. To do it, when the laser and the alignment laser radiation are blocked, press the **Zero** button in the main control menu CONTROLS functions panel.

Fig. 7: The CONTROLS functions panel.

In the Setup panel Measure tab set the Wavelength to **633 nm**.

Fig. 8: The Setup panel Measure tab (left) and Display tab (right).

In the Setup panel Display tab Statistics Settings set the measurement **Duration** to **Continuous** and the power meter statistics calculation duration to 10 s.

The power meter statistics calculation is launched by pressing the main control menu CONTROLS functions panel button **Start Statistics** (Fig. 7). The statistics calculation is stopped by pressing button **Stop Statistics.**

Fig. 9: The CONTROLS functions panel when statistics calculation is launched.

<u>Experiment procedure</u>

1. Calculate the He-Ne laser stability conditions when radii of curvature of the resonator mirrors are 400 mm and 400 mm respectively.

For the investigation of two-mirror resonator stability conditions, a stability factor g is used:

$$g_i = 1 - \frac{d}{r_i} = 1 - \frac{d}{2f_i}\,, \tag{1}$$

where d is the distance between mirrors, r_i – a radius of curvature of the mirror, f_i – a focal length of the mirror. The resonator stability condition can be written as:

$$0 < g_1 g_2 < 1, \tag{2}$$

Here a mirror radius of curvature is positive for a concave mirror and negative for a convex mirror.

- Calculate $g_1 g_2$, when the distance d is varied from 0 to 1000 mm, for r_1 = 400 mm and r_2 = 400 mm. Graphically depict $g_1 g_2$ dependence on d.

- Determine laser stability limits.

2. Calculate the He-Ne laser stability conditions when radii of curvature of the resonator mirrors are 400 mm and 800 mm respectively.

- Calculate $g_1 g_2$, when the distance d is varied from 0 to 1000 mm, for r_1 = 400 mm and r_2 = 800 mm. Graphically depict $g_1 g_2$ dependence on d.
- Determine laser stability limits.

3. Calculate the He-Ne laser stability conditions when one resonator mirror is flat and a radius of curvature of the other one is 800 mm.

- Calculate $g_1 g_2$, when the distance d is varied from 0 to 1000 mm, for $r_1 = \infty$ and r_2 = 800 mm. Graphically depict $g_1 g_2$ dependence on d.
- Determine laser stability limits.

4. Adjust the alignment laser beam propagation. **(Performed if not already aligned)**

- Loosen mounting screws, carefully remove the optical mount with the He-Ne laser tube LVL from the rail B (perform with supervision of the lecturer).
- Turn on the alignment laser DL.
- Place the screen E2 on the rail closer to the alignment laser DL. Using the mirror DV1, align the laser beam to hit the center of the screen.

Fig. 10: Adjustment of alignment laser beam propagation.

- Place the screen E2 to the other end of the rail. Using the mirror DV2, align the laser beam to hit the center of the screen.

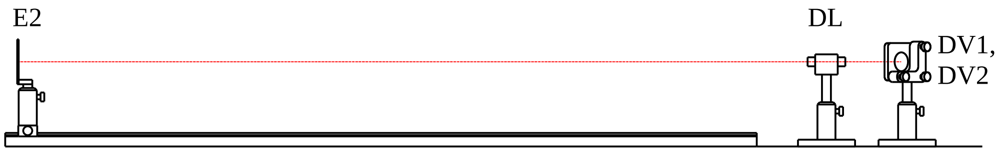
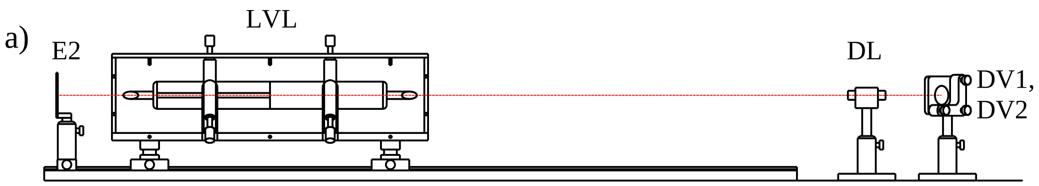


Fig. 11: Adjustment of alignment laser beam propagation.

- Place the screen E2 on the rail closer to the alignment laser. Repeat the mirror DV1 alignment.
- Repeat the alignment procedure until the beam propagates parallel to the rail.
- Place the screen to the further end of the rail.
- Place the optical mount with the He-Ne laser tube LVL on the further end of the rail leaving a few centimeters for mounting the output coupler and then tighten the screws

(perform with supervision of the lecturer). Make sure that the alignment laser beam passes through the He-Ne laser tube without touching the capillary. If the beam is obstructed by the tube, mirrors DV1 and DV2 need to be adjusted.



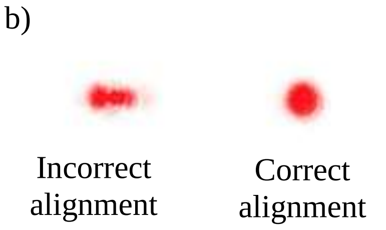


Fig. 12: a) Adjustment of the alignment laser beam propagation through the He-Ne laser tube. b) Image of the passing beam on the screen E2 when the beam propagation direction is aligned incorrectly (left) and correctly (right).

- When the alignment beam is correctly aligned, the screen E2 is removed from the rail. Then the screen E1 with a pinhole is positioned after the mirror DV1 closer to the alignment laser DL. The alignment beam must pass a pinhole in the screen E1.

5. Align the He-Ne laser system when radii of curvature of the mirrors are 400 mm and 400 mm.

- The output coupler IŠV400 is positioned within 10-20 mm distance from the He-Ne laser tube holder LVL (<u>the distance between the mirror surface and the edge of the mount on the rail is 8 mm (Fig. 13)</u>). The concave surface of the mirror must face the He-Ne laser tube. Using mirror adjustment screws, direct the alignment beam back through the He-Ne laser tube to the center of screen E1.

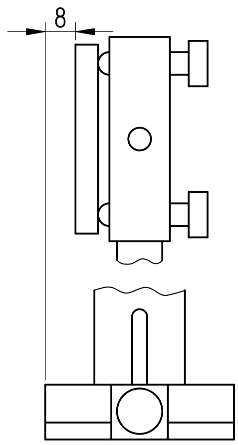
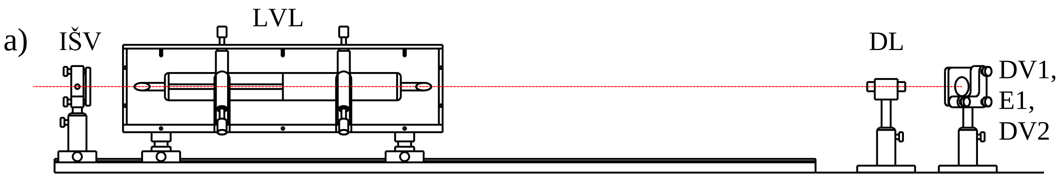


Fig. 13: The distance between the edge of the mount and the mirror surface is 8 mm.



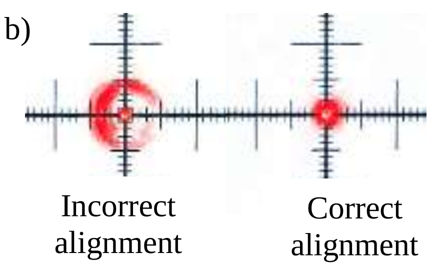


Fig. 14: a) Alignment of the reflected alignment beam. b) Image of the alignment beam on the screen E1 when the adjustment is incorrect (left) and correct (right).

- The highly reflective mirror DAV400 is positioned within 10-20 mm distance before the He-Ne laser tube LVL. The concave surface of the mirror must face the He-Ne laser tube. Using the mirror adjustment screws, direct the alignment beam to the center of screen E1.

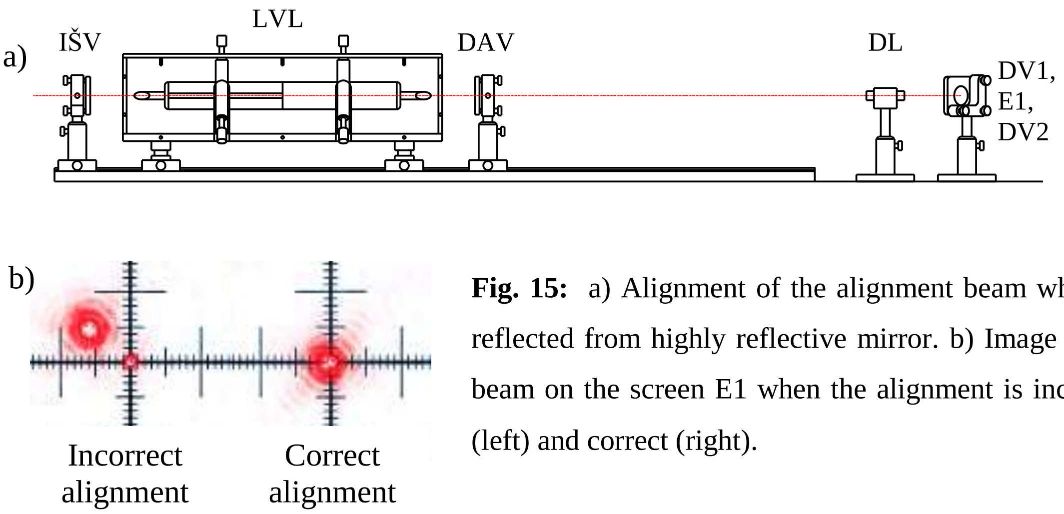


Fig. 15: a) Alignment of the alignment beam which is reflected from highly reflective mirror. b) Image of the beam on the screen E1 when the alignment is incorrect (left) and correct (right).

- Turn on the He-Ne laser tube power supply. The laser tube should start shining in a few seconds followed by laser generation. The laser radiation should be visible after the output coupler IŠV400. If the radiation is not present, resonator mirrors should be carefully adjusted until the laser generation starts.

6. While aligning the mirrors, generate higher order transverse modes.

- Place a concave lens L and the screen E3 after the output coupler IŠV400. A magnified image of the laser beam should be visible on the screen.

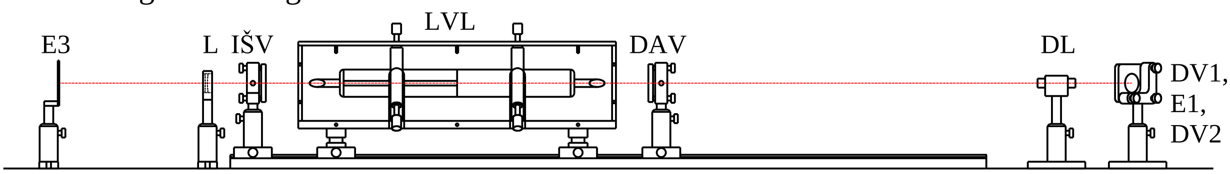


Fig. 16: Observation of generated transverse laser modes.

- While carefully adjusting resonator mirrors IŠV400 and DAV400, obtain the TEM00 transverse mode and record it.
- While carefully adjusting resonator mirrors IŠV400 and DAV400, additionally obtain three or more different laser beam transverse modes, record them and determine their order (Fig. 17).

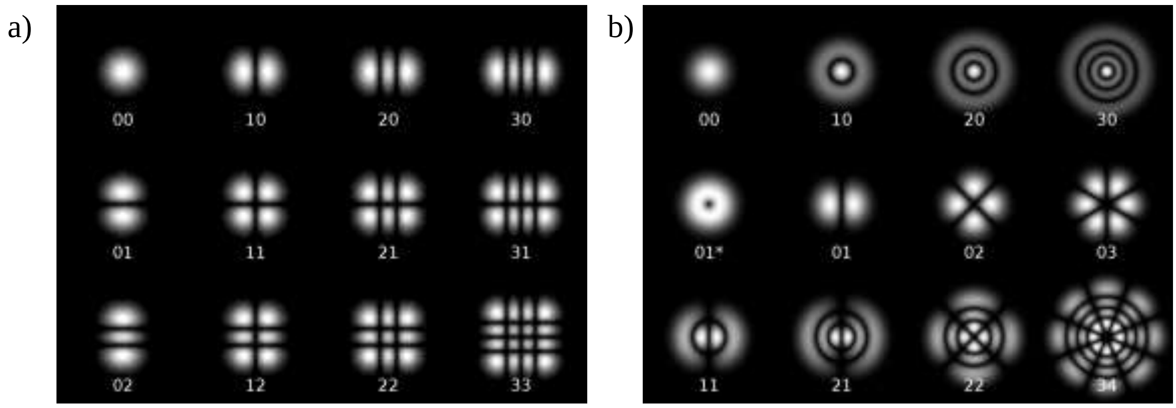


Fig. 17: a) Hermite-Gaussian beams, b) Laguerre-Gaussian beams.

7. Measure the laser output power dependence on the distance between mirrors. Determine stability limits.

- Place a power meter M after the output coupler IŠV400.

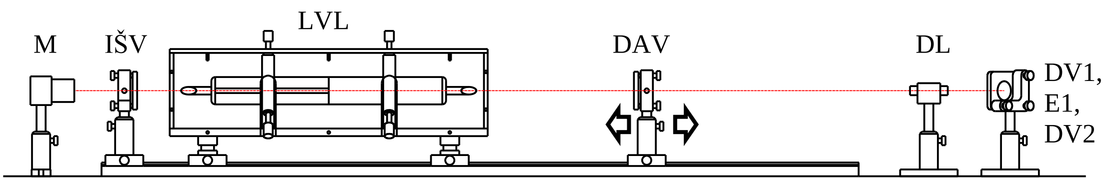


Fig. 18: Measurement of the output laser power dependence on the distance between mirrors.

- While carefully adjusting resonator mirrors IŠV400 and DAV400, achieve the maximum generated optical power and record it.
- Increase the distance between resonator mirrors by moving the highly reflective mirror DAV400 within 10-15 mm from the He-Ne laser tube LVL (be careful that the laser oscillation does not break off due to the shift, if the laser oscillation stops, the translation distance has to be decreased and mirror DAV400 has to be adjusted at intermediate positions). While carefully adjusting resonator mirrors IŠV400 and DAV400, achieve the maximum generated optical power and record it.
- Repeat measurements until laser generation is possible.
- Graphically depict results. Determine resonator stability limits and compare them with theoretically calculated values (task 1).

8. Align the He-Ne laser system when mirrors radii of curvature are 400 mm and 800 mm.

- Replace the highly reflective mirror DAV400 with the highly reflective mirror DAV800. The concave surface of the mirror must be facing the He-Ne laser tube. The distance between the mirrors should be ~850 mm. Using the mirror adjustment screws, direct the alignment beam back to the center of the screen E1 (Fig. 15).

- The laser beam should be visible after the output coupler IŠV400. If the laser oscillation is not present, resonator mirrors should be carefully adjusted until the laser generation starts.

9. Measure the output laser power dependence on distance between mirrors. Determine stability limits.

- Place a power meter M after the output coupler IŠV400 (Fig. 18).
- While carefully adjusting the resonator mirrors IŠV400 and DAV800, achieve maximum generated optical power.
- While moving (by few millimeter steps) highly reflective mirror DAV800 towards the He-Ne laser tube holder LVL and carefully adjusting resonator mirrors IŠV400 and DAV800 at intermediate positions, determine the minimum distance at which laser oscillation still occurs. While carefully adjusting resonator mirrors IŠV400 and DAV800, achieve maximum generated optical power and record it.
- Increase distance between resonator mirrors by moving the highly reflective mirror DAV800 within 10-15 mm from the He-Ne laser tube LVL (if the laser oscillation stops, the translation distance has to be decreased and the mirror DAV800 has to be adjusted at intermediate positions) While carefully adjusting resonator mirrors IŠV400 and DAV800, achieve the maximum generated optical power and record it.
- Repeat measurements until the laser oscillation is possible or until the optical rail end is reached.
- Graphically depict results. Determine resonator stability limits and compare them with theoretically calculated values (task 2).

10. Align the He-Ne laser system when one resonator mirror is flat and a radius of curvature of the other one is 800 mm.

- Remove the highly reflective mirror DAV800 from the rail. Replace the output coupler IŠV400 with the output coupler IŠVPLO. Using mirror adjustment screws, align the alignment beam back through the He-Ne laser tube to the center of the screen E1 (Fig. 15).
- The highly reflective mirror DAV800 is placed between the He-Ne laser tube holder LVL and the screen E1. It should be within 10-20 mm distance from the He-Ne laser tube holder LVL. The concave surface of the mirror must be facing the He-Ne laser tube. Using mirror adjustment screws, direct the alignment beam to the center of the screen E1 (Fig. 15).
- The laser beam should be visible after the output coupler IŠVPLO. If the laser oscillation is not present, resonator mirrors should be carefully adjusted until the laser

generation starts.

11. Measure the laser output power dependence on distance between mirrors. Determine stability limits.

- Place the power meter M after the output coupler IŠVPLO (Fig. 18).
- While carefully adjusting resonator mirrors IŠVPLO and DAV800, achieve the maximum generated optical power and record it.
- Increase the distance between resonator mirrors by moving the highly reflective mirror DAV800 within 10-15 mm from the He-Ne laser tube holder LVL (if the laser oscillation stops, the translation distance has to be decreased and the mirror DAV800 has to be adjusted at intermediate positions) While carefully adjusting resonator mirrors IŠVPLO and DAV800, achieve the maximum generated optical power and record it.
- Repeat measurements until the laser oscillation is possible.
- Graphically depict results. Determine resonator stability limits and compare them with theoretically calculated values (task 3).

12. Measure the laser output power dependence on the He-Ne laser tube position.

- Increase the distance between resonators mirrors to 700-750 mm by moving the highly reflective mirror DAV800. While carefully adjusting resonator mirrors IŠVPLO and DAV800, achieve the maximum optical power and record it (<u>the distance between center of He-Ne laser tube holder LVL and edges of the holder on the rail is 185 mm</u>).
- Move the He-Ne laser tube holder LVL towards the highly reflective mirror DAV800 by 10-15 mm. While carefully adjusting resonator mirrors IŠVPLO and DAV800, achieve the maximum optical power and record it.

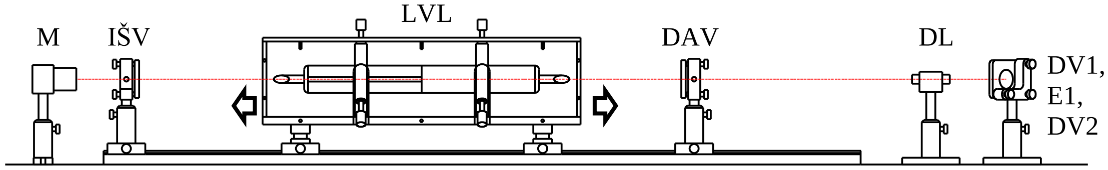


Fig. 19: Measurement of generated laser radiation power dependence on He-Ne laser tube position.

- Repeat measurements until the laser oscillation is possible or the He-Ne laser tube holder LVL reaches the highly reflective mirror DAV800.
- Graphically depict results.

13. Measure the beam diameter dependence on the position in the resonator.

- Return the He-Ne laser tube holder LVL to its initial position next to the output coupler IŠVPLO. While carefully adjusting resonator mirrors IŠVPLO and DAV800, achieve the maximum optical power.

- Place a mount with tunable width slit PL on the rail between the He-Ne laser tube holder LVL and the highly reflective mirror DAV800 within 10-15 mm distance from the He-Ne laser tube holder LVL. The width of the slit is adjusted with a micrometer on top of the mount.

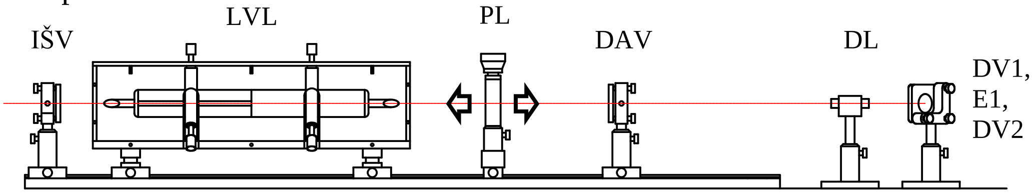


Fig. 20: Measurement of the beam diameter dependence on the position in the resonator.

- The center of the tunable width slit must match the center of the generated beam. If necessary, the position of the slit is adjusted with a translation stage.

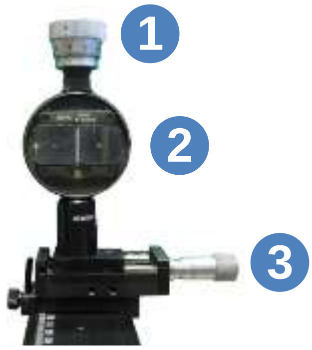


Fig. 21: A mount with a tunable width slit PL.

1 – A micrometer for adjustment of the slit width.

2 – A tunable width slit.

3 – A translation stage for adjustment of the transverse position of the slit.

- While adjusting the width of the slit and the position of its center, determine the minimum slit width at which laser oscillation occurs.
- Move the mount with the tunable width slit PL by 10-15 mm towards the highly reflective mirror DAV800. While adjusting the width of the slit and the position of its center, determine the minimum slit width at which laser oscillation occurs.
- Repeat measurements until the mount with the tunable width slit reaches the highly reflective mirror DAV800.

The Gaussian beam radius $\omega(z)$ dependence on a position z:

$$\omega(z) = \omega_0\sqrt{1 + \left(\frac{z}{z_R}\right)^2}, \tag{3}$$

where ω_0 – the Gaussian beam waist radius, z_R – the Rayleigh length. It is the distance from the waist at which the beam radius is increased by a factor of $\sqrt{2}$:

$$z_R = \frac{\pi\omega_0^2}{\lambda}. \tag{4}$$

The Gaussian beam wavefront (a plane at which the phase is constant) radius of curvature $R(z)$ is:

$$R(z) = z\left(1 + \left(\frac{z_R}{z}\right)^2\right). \quad (5)$$

In the ideal case, radii of curvature of the Gaussian beam wavefront in the resonator match mirror radii of curvature.

- Calculate the Rayleigh length of the Gaussian beam z_R when the first mirror is flat ($r_1 = \infty$) and the second mirror radius of curvature is $r_2 = 800$ mm. In such case the Gaussian beam waist can be matched with position of the first mirror. According to equation (5), the Gaussian beam wavefront radius of curvature at the second mirror position would be:

$$R(d) = r_2 = d\left(1 + \left(\frac{z_R}{d}\right)^2\right), \quad (6)$$

where d – the distance between mirrors.
- Using equations (3) and (4), calculate the Gaussian beam waist radius ω_0 and the beam radius $\omega(z)$dependence on the position z in the resonator.
- Graphically depict measured and calculated results. Compare them.

Literature

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