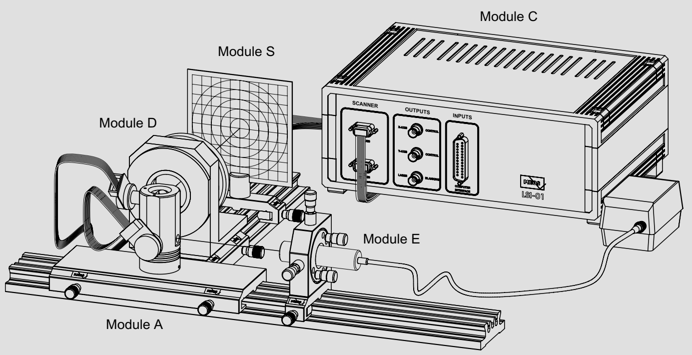
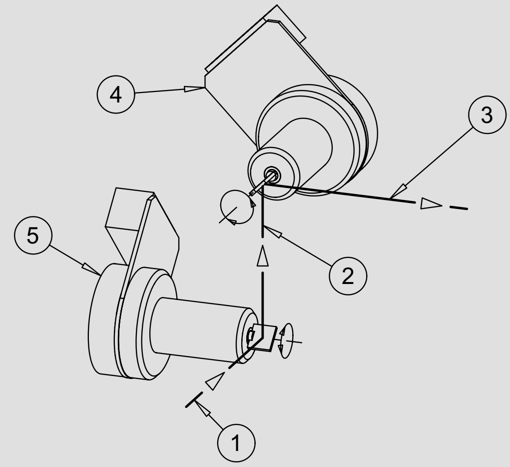
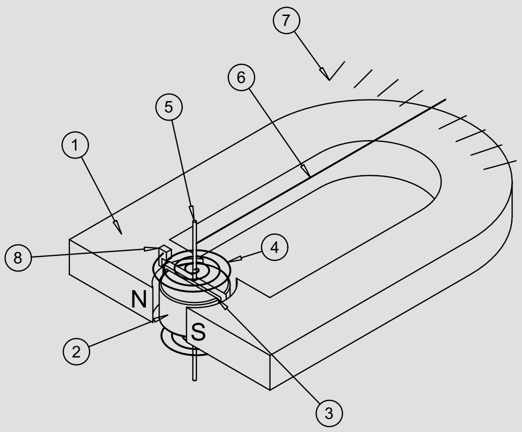
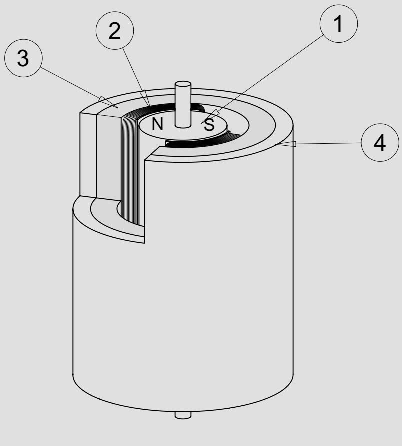


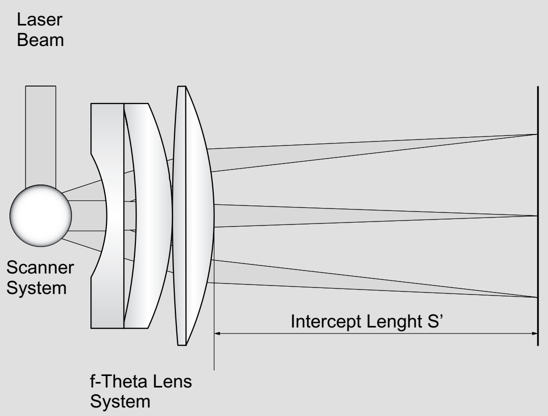




EXPERIMENT 28

LASER Scanner





1.0 Introduction

Fast and precise scribing or writing of information became a topic since the computer invaded the market. More and more so called Laser printers are replacing the existing printers technology. Another field of application in industry is the scribing on objects of mass production. In this case powerful Lasers are used to scribe permanent information into metal, plastic, paper etc. Last but not least Laser scanner will be used for the next generation of colour TV and large displays and they are even used for entertainment on festivals like the Olympic games and in modern discotheques. To generate arbitrary pattern the Laser beam must be deflected in two orthogonally directions as it is known from TV or oscilloscopes. Generally one has to distinguish two main fields of application, one is the fast material processing and the second is the entertainment. For the material processing it is necessary in almost all cases to focus the Laser beam onto the surface to be processed. With simple lens systems this cannot be achieved since the location of the foci lies in the plane of a sphere. A special optical system has been designed to image the focus always in a plane and is termed as fθ lens system. For entertainment like Laser light shows etc. a focusing of the beam is not required. However for both applications the same beam deflectors, so called Galvo scanner are used. This name stems from the historical Galvanometer, a moving coil instrument where a mirror was attached to the torsion band of the coil. Such instruments where used to demonstrate slow varying electric currents. The Galvo scanner use the same principle however, they are designed for rapid movement of the attached mirror. Instead of using a torsion band electromagnetic forces are applied. Commercial Galvo scanners are supplied with closed loop circuits to make sure that the desired position will be reached with high precision. Within this course an open frame Laser scanner system with two scanning mirrors, one for the X the other one for the Y direction including the necessary control electronics and personal computer are used to become well experienced in this exciting field.

Thomson Galvanometer 1870

2.0 Fundamentals

In principle the fundamentals to understand a Laser scanner system do not require a lot of basics, however the technical development of galvo scanner including the driver electronics as well as the software is a broad field which is still under investigation towards the way to Laser displays for large TV screens. It should be mentioned that for the time being, the mechanical scanner are still in use, especially for Laser engraving or marking as well as for professional Laser light shows. For this purpose the set-up is equipped with professional software to create and perform Laser light shows and templates for Laser marking.
For the understanding of the concept of the galvo scanner the next following chapter gives an introduction to the basics of this devices.

2.1 Galvo Scanner

Galvo scanner are seeming to be a remnant of the times where the electrical current has been measured by means of moving coil instruments. Although a high precision has been achieved with such instruments the availability of digital operating instruments immediately removed the fine mechanical instruments from the market because they where expensive and sensitive against mechanical stress. Nowadays digital voltmeter are available with extreme high precision at affordable prices. Nevertheless the mechanical galvo scanner survived and it seems that they are still best choice for the application discussed here.
To understand the concept of a galvo scanner we will start with the explanation of moving coil instruments.

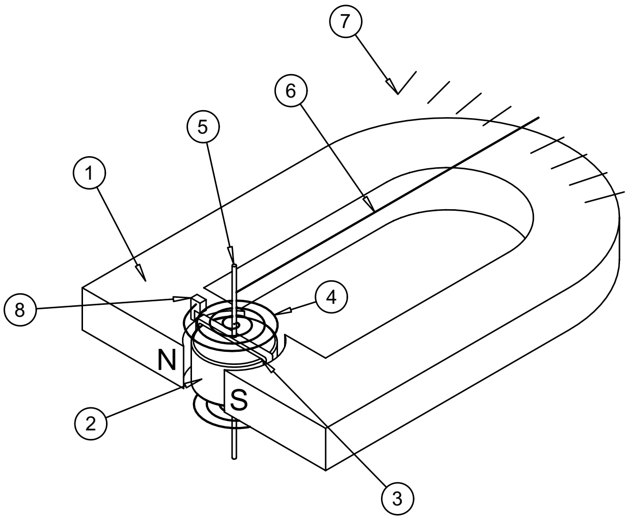


Fig. 1: Moving coil instrument

The basic idea is to exploit electromagnetically forces to generate an angular motion. For this purpose a moving coil (3) is placed inside a permanent magnet (1). By means of a spiral spring (4) which is fixed to the axis (5) the electrical current is supplied to the moving coil. The same arrangement is attached to the bottom side of the coil. Beside the transport of the electrical current to the coil the spiral springs are also used to balance the electromagnetically forces which appear when the current to be measured is flowing through the coil against its restoring force. A soft iron cylinder is mounted symmetrically between the curved pole pieces and generates a radial field distribution. The size of the gap between the cylinder and the pole pieces allows the coil to move freely inside the radial magnetic field. From the basics of electromagnetically phenomena we know that a current flux $\boldsymbol{j}$ always generates a magnetic field $\boldsymbol{H}$ like:

$$\nabla \times \vec{H} = \frac{\partial \vec{D}}{\partial t} + \vec{j}$$

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Since we consider here only conductors we can neglect the displacement field ***D***. From the equation above we conclude that a linear current ux density which is present in a straight conducting wire, generates a curled magnetic field as shown in Fig. 2. If however the current ows in a curled conductor as it is the case of a coil then the generated magnetic field becomes linear.

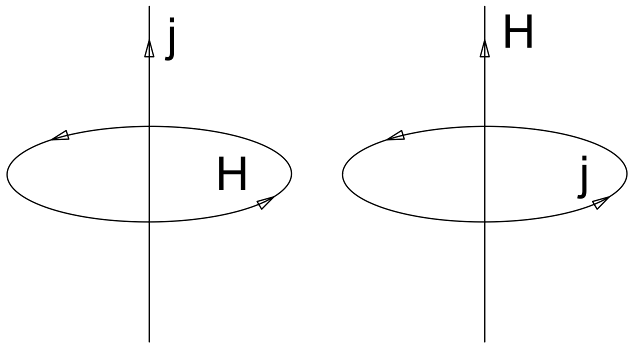

Fig. 2: A linear current ux generates a curled magnetic field and a curled ux generates a linear one

In the moving coil instrument the current ows in a curled manner thus generating a linear magnetic field H or magnetic ux density B. The superposition of the magnetic fields generated by the current ux and the permanent field results in a torque ***T*** of the moving coil:

$$T = N \cdot A \cdot I \cdot B$$

whereby **N** is the number of turns in the coil, **A** the area of the cross section of the coil, **I** the current owing through it and **B** the magnetic ux density inside the gap. The torque **T** tries to turns the coil in such a way that the overall magnetic ux density becomes a maximum. However the spiral springs are generating a restoring torque $\mathbf{T_r}$ which goes linear with the angular de ection α, i.e.

$$T_r = c \cdot \alpha$$

whereby c is the spring constant or the material property of it. The equilibrium is reached when both torques having the same value:

$$T = T_r \rightarrow \alpha = \frac{N \cdot A \cdot B}{c} \cdot I$$

From the equation above we can see that the de ection angle α is proportional to the current **I** owing through the coil. All other parameters are system constants of the particular instrument. The intentional use of such an instrument was the measurement of a steady owing current. But we want to exploit such an instrument for fast angular movements. Instead of attaching a pointer to the moving coil we try to attach a mirror to the spindle, which indeed has been done for the high precision mirror galvanometer and for so called light beam oscilloscopes. The basic idea of the mirror galvanometer was to increase the sensitivity. In Fig. 4 such a system is shown, where a light beam is de ected by means of an attached mirror. If the moving coil rotates by the angle β, then the de ected light beam is de ected by 2β due to the re ection laws. Up to now we assumed that the current **I** which ows through the coil is slow varying in time so that the pointer or beam could follow the changes.

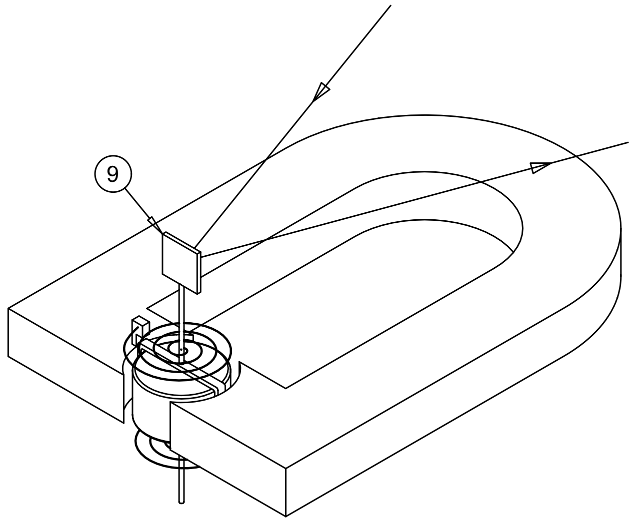

Fig. 3: Moving coil instrument with attached mirror

If we are now going to demand that the pointer or mirror has to follow also fast variations of the current we have to consider the dynamic of the system. In a first approximation the system consists of a mass and a spring which is driven by an external force.

$$\Theta \cdot \frac{d^2\alpha}{dt^2} + k \cdot \frac{d\alpha}{dt} + c \cdot \alpha = K_0 \cdot \cos(\omega \cdot t)$$

$$\text{inertial} + \text{friction} + \text{restoring} = \text{driving torque}$$

The equation above represents the differential equation for forced oscillation. Depending on the individual parameters as inertial moment, frictional (k) and restoring constants (spring constant c) such a system operates in four different modes:

1. Resonant mode
2. Damped oscillation
3. Maintained oscillation
3. Aperiodic mode

depending of the value of the relative damping factor γ :

$$\gamma = \frac{k}{\sqrt{\Theta \cdot c}}$$

We expect from a proper scanner, that it follows with highest possible speed the variation of the current **I**. This can only be achieved in the beginning of the aperiodic domain (critical damping), that means that a short and small over shooting of the desired mirror position occurs. For this case the following equation must be true:

$$k = 2 \cdot \sqrt{\Theta \cdot c} \text{ or } \gamma = 2$$

However, in this mode the amplitude decreases with

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increasing frequency. To extend the range within the amplitude does not drop to much for higher frequencies the resonance frequency ω_R of the system:

$$\omega_R = \sqrt{\frac{c}{\Theta} - \frac{k^2}{\Theta^2}}$$

should by designed as high as possible. This can be achieved by reducing the friction (k) or the inertia moment of the rotating coil. That means that actually the mass of the coil must be reduced. But here we are faced with the problem that reducing the mass finally means reducing the mass of the used conductor. For this reason aluminium instead of copper is used. In more advanced systems therefore moving magnets are used. This has the advantage that no electrical connections to the moving part are required and furthermore it lifts the limitation of the maximum power which can be introduced into a moving coil. We have to consider that the current which ows through the coil produces besides the magnetic field also heat of power $P=I^2/R$ where R is the resistance of the coil. The coil is moving inside an air gap. Next to total vacuum air is the worst thermal conductor. The only real heat sink for the coil is the pick-off structure. The heat therefore is mainly dissipated by convection to the pole pieces. Consequently the main failure of moving coil scanners is the coil burn out and degradation of the permanent magnet. It has been verified that two major problems are limiting the performance of such scanners:

1. The thermal limit defined by the heat transfer capabilities of coils and the Curie temperature of the magnet
2. The coil creep and deformation of the coil under centrifugal acceleration

A moving magnet system solves the problems of both burn out and magnet degradation. The principle of such a system is shown in Fig. 4 .

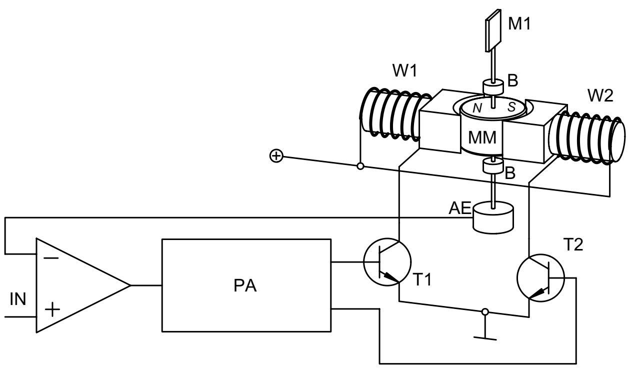

Fig. 4: Moving magnet arrangement

A permanent magnet (MM) is placed in the centre of two pole pieces which are supplied with two coils W1 and W2 which are thermally connected to the housing. High torque and high duty cycles, however, still require proper heat sinking to avoid thermal overload. A proper design of the magnet guarantees consistent properties beyond 135 °C. Compared to moving coil systems this arrangement can accommodate three times the power dissipation of equivalent inertia and torque constant.

A spindle is attached to the magnet which is fixed in position by means of two ball bearings (B). Instead of using a mechanical spring a servo loop with a position sensor (AE) and controller is used.

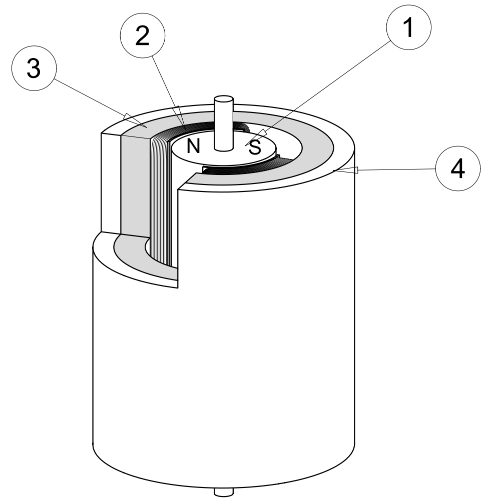

Fig. 5: Technical realisation of a moving magnet scanner

In the arrangement of Fig. 5 a cylindric permanent magnet (1) is used. Since the inertia of a solid cylinder is given by:

$$\Theta_{cyl} = \frac{1}{2} m \cdot r^2 = \frac{1}{2} \rho \cdot \pi \cdot L \cdot r^4$$

it is useful to use a cylinder which length is larger than the radius to obtain the smallest possible inertia.

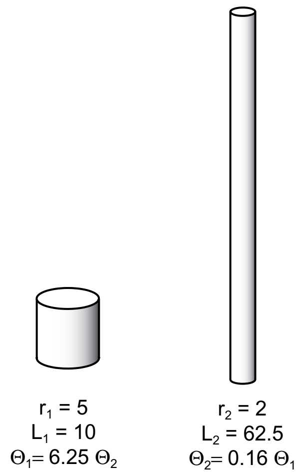

Fig. 6: Comparison of the inertia of two cylinders with equivalent volume

Permanent rotor magnets for scanners are manufactured from an alloy of Neodymium, Iron and Boron. This compound allows the strongest possible magnets for the time being. A small air gap is between the magnet and the coils (2) which are wound around the pole pieces of the ux return piece (3). The housing (4) is used as heat sink.

In this project are scanner used which has been manufactured from Cambridge Technologies, one of the leading manufacturer of optical scanners. The newest generation of the scanner are using optical instead of capacitive position decoder.

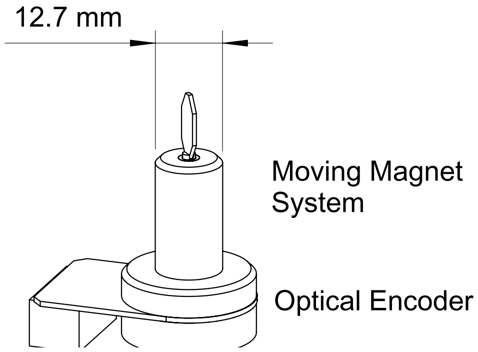

Fig. 6: Actual size of the scanner (Model 6800HP) used within this project

For more details about the scanner please see the attached instruction manuals for the scanner (Model 6800HP Galvanometer Optical Scanner) as well as the scanner drive electronics (6800/CB6588 Mirror Positioning System).

2.2 F-Theta Lens

A Laser beam which is de ected by a rotating or scanning mirror has an inherent circular plan

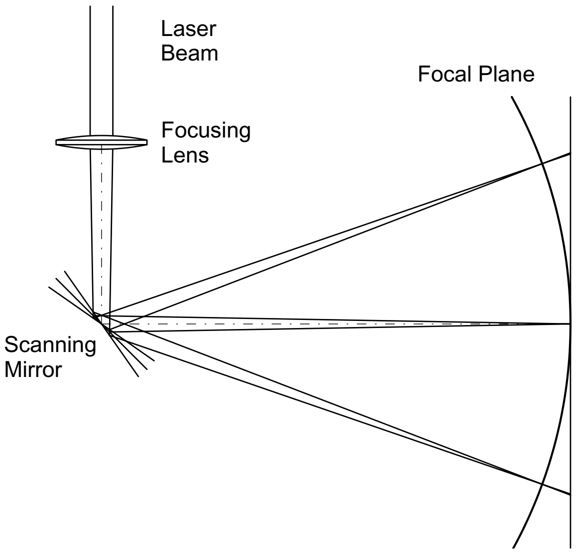

Fig. 7: Circular plan of de ected Laser beam

In Fig. 7 a laser beam is shown, which has been focused by means of a focusing lens. Due to the rotation symmetry of the scanner the foci of the de ected beams will be imaged in a circular or spherical plan. However, for engraving, labelling, phototype setting and material processing on plan work pieces such an arrangement will produce structures with different line width, especially for larger scan angle. To correct this behaviour so called f-theta lens systems (Fig. 8) are used. This lens system is a very special optical system which only a few in the optical community know how to design and fabricate. Commonly the f-theta lens is designed for a specific laser wavelength and focal distance. Within this project a f-theta lens manufactured by Rodenstock designed for 532 nm with a focal length of 100 mm is used.

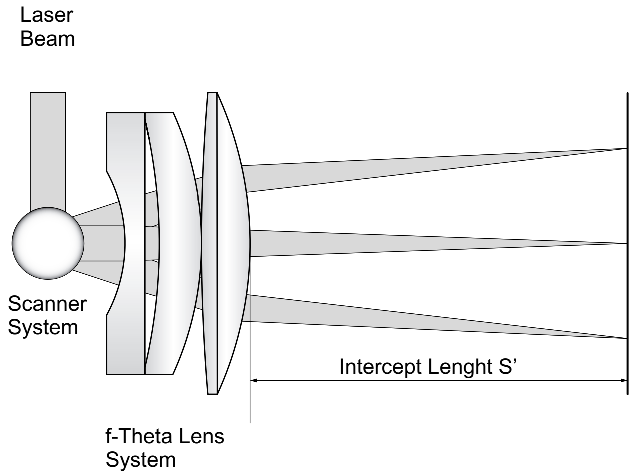

Fig. 8: Three Element f-Theta Lens system

The lens system is optimised in such a way, that for each scan angle θ the foci are located in a plan. The requirement for this is, that the so called f-θ condition must be fulfilled:

$$\text{Intercept Length } S' = F(f \cdot \theta) = \text{const.}$$

To design such a system Optics Engineers are using so called ray tracing software to optimise a basic layout. As free parameters the radii of curvature, the index of refraction and the spacing of the lenses are used for optimization. However, it should be mentioned, that the real art of the design is to find a solution which is not too sensitive against manufacturing tolerances. After creating the theoretical layout the Engineers are varying the variables within the production tolerances and study the tolerance of the final specification like the quality of the f-θ condition, minimum laser spot size and also the optical transmission. The f-θ lens system used in this project is optimised for the following specifications:

Wavelength	532 nm
Intercept Length S'	111.4 mm
f-θ condition accuracy	better than 0.1 %
Total scan angle θ	± 25°
Entrance beam diameter	8 mm
Spot diameter ($1/e^2$)	12 µm
Transmission	> 90%

If the requirement concerning the resolution are even higher, as it is the case for phototype setting machines, then so called telecentric f-θ lens systems are used. This optics are further optimised in such a way that the de ected beam is always perpendicular to the plan to avoid elliptical beam deformations which will still occur in "simple" f-θ lens systems.