The design of the Kolibri DVD-actuator.

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Introduction.
In any optical drive a laser beam is focused on to the disc trough an objective lens. As the disk is far from perfect the lens has to be actuated in two directions, the focus (vertical) direction and the tracking direction (horizontal). From the reflected laser beam both the data signal and servo signals are derived. A rough indication about the required accuracy's is 1 μm in focus direction and 100 nm in tracking direction. The servo loops used to position the lens have a typical bandwidth in the order of 1 to 5 KHz. The device to actuate the lens is the 2D lens actuator. In this article a number of main design decisions are described in the process of defining a new generation of lens actuators. It will be only a small part of the story, however most important, manufacturing and process aspects are not addressed here.

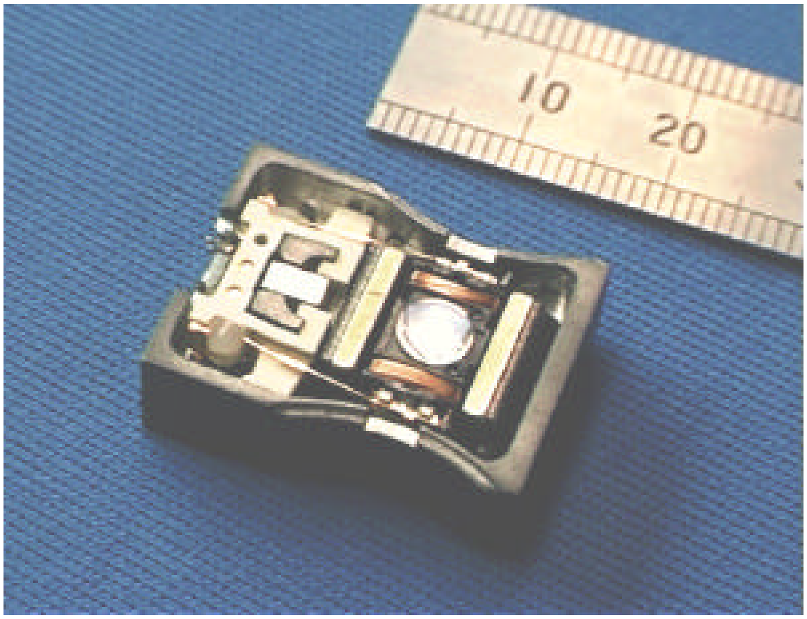

Fig. 1 The Kolibri actuator

The current design.

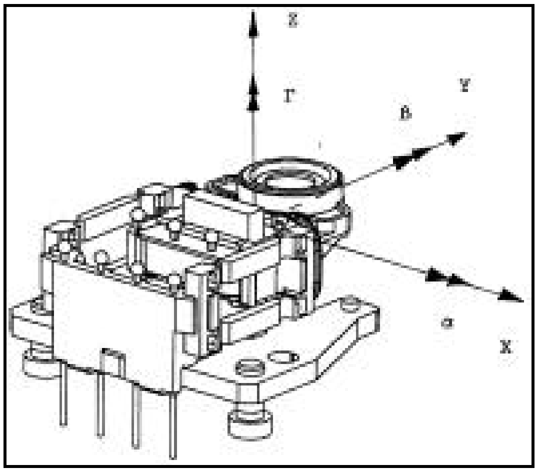

Fig.2 The CDM-12 actuator

The basis of our current actuators is the CDM-12 actuator. It's design is from about 1991. In that time it was meant to be a low cost, low spec actuator for cheap audio applications.
The actuator is based on a electro dynamic drive system with a single magnet and two coil sets for the two actuation directions. The coils are connected to the lens. This moving part is suspended with plastic hinges to the stationary world.
The CDM-12 has an asymmetric design: There is a single drive system and the lens is not near the center of gravity. This makes a cheap solution but also gives the optical designer great accessibility of the lens in various directions.
The electrical connections to the coils are made with four separate litze wires. Two adjustment screws are present to adjust the lens tilt angles with respect to the beam direction. A typical height of this actuator is 12 mm calculated from the bottom of the disk to the bottom of the base plate. From this design several ancestors are derived, notably for high speed CD-ROM and CD-Recordable/Rewritable applications. The current level of production is now about 20 million units a year.

Limitations of the current design.

Several limitations of the current design became apparent in the more demanding newer applications. These limitations should be addressed in a new design.

Size.
In the market is a clear trend towards flatter designs, mainly to accommodate for notebook ROM applications. This meant that for new designs a maximum building height of 7 mm.

Bandwidth.
The current actuator design is suitable up to a bandwidth of 3 KHz. The limitation of the bandwidth is found in modes of the lens holder in the frequency range of 10 KHz.
In the newest CD-ROM drives disk speeds are reached of 40 times the normal audio CD speed, approximately 7000 RPM. For DVD disk speeds are not as high but the track pitch on the disk is halved, requiring a much smaller servo error. For both cases the obtainable bandwidth should be increased above 5 KHz.

Tilt sensitivity.
A major problem in optical drive design is lens tilt An objective lens must be kept parallel with respect to the disk surface. If not so the light spot on the becomes 'blurred' and quality of the resulting signals from the optical system is detoriated. For normal CD the allowed angle error is in the order of ± 5 milliradians, for DVD ±1 mrad is required!
Power consumption
The requirement for a high bandwidth also leads to a high power dissipation in the actuator and the power driver. A level of 0.5 to 1 Watt is possible, leading to an undesirable temperature rise. Problems arise mainly in the focus loop.

Yaw sensitivity
A more obscure problem is the yaw sensitivity. Fig. 3 shows a top view of a part of the drive. The actuator is suspended elastically on a sledge. That sledge is guided on a shaft with sliding bearings with a certain amount of play.

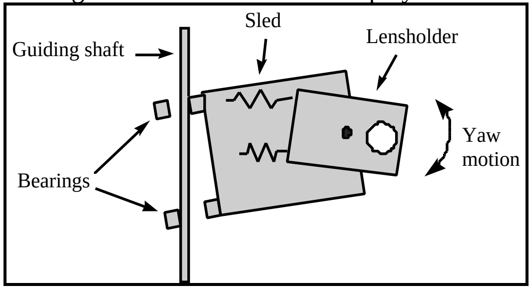

Fig 3. Yaw sensitivity.

If for some reason the sledge rotates instantaneously through the play the actuator *yaw* mode is excited. The lens holder starts to rate about a vertical axis through the center of gravity. If the play in the bearings is about 20 μm (a rather tight fit in our technology) and the distance between the bearings is 20 mm the rotation of the lens holder is excited with a step of 1 mrad. The lens holder starts to oscillate with the eigenfrequency of the yaw mode of about 1 KHz and an amplitude of 1 mrad. The distance of the center of gravity and the lens is 5 mm so the lens oscillates with an amplitude of 5 µm. This error is so large that the servo system loses track. In practice this phenomenon is seldom encountered. In a read-only system a recovery procedure is started and the user will never notice the problem. If one is writing a recordable disk, the disk is damaged and data may be lost.

Stability.
The CDM-12 actuator has plastic suspension hinges. This makes the actuator extremely robust. Also the designer has a lot of possibilities to influence the performance by changing the position of the films and the thickness of the films. However using plastic makes the design not inherently stable. For designs with small beam diameters and for DVD the stability must be improved.

Laws of scale applied to the current design.
As there is a trend in our world towards flatter designs (notebook CD-ROM) and higher specifications (DVD) the need for a new design became apparent. One of the ideas was just to make the current design smaller. By applying simple scale laws the performance of such a design can be easily calculated.
Four parameters are studied: Eigenfrequencies, efficiency, DC-power use and electrical time constant.

Eigenfrequencies are calculated with formulas like:

$$\omega_0 = \sqrt{\frac{c}{m}}$$

The mass m is proportional with the volume and scales with the third power of the scale factor x. The most simple equation for stiffness is the longitudinal stiffness of a bar.

$$c = \frac{E \quad A}{l}$$

The modulus of elasticity does not change, so the stiffness is proportional with length and scales with x.
Therefore the eigenfrequency is proportional to the inverse of the scale factor:

$$\omega_0 \approx \frac{1}{x}$$

This is favorable, by making the lens holder smaller one gets a stiffer coupling from driving coils to the lens.

The *efficiency* is a number indicating the amount of acceleration one gets for a certain electrical power level. It is expressed in g/√watt. The efficiency number is related to K^2/R of rotating DC-motors.

$$\eta = \frac{K}{m \quad g \quad \sqrt{R}}$$

K is the force constant in newton/ampère, m is the mass in kg, g is the gravitational acceleration and R the electrical resistance of the coil in. K can be written as:

$$K = B \quad n \quad l_{eff}$$

B is the magnetic flux density in tesla, n the number of windings l_{eff} de effective wire length in meter.
B is independent of the scale. With constant wire diameter the number of windings is proportional with the cross sectional area of the coil, so n is proportional with the square of x.
For K can be written:

$$K \approx x^2 \quad x = x^3$$

The electrical resistance is calculated with:

$$R = \rho \quad \frac{l \quad n}{A}$$

ρ is specific resistance in ohm/meter, A cross sectional area of a single wire, l the length of a single winding and the number of windings. A and ρ do not scale so:

$$R \approx x^3$$

Combining these formulas results in:

$$\eta \approx \frac{1}{\sqrt{x^3}}$$

Making the actuator smaller also improves the efficiency.

DC power is mainly dissipated to compensate for mechanical offsets an slowly varying disk errors.

the actuator displacement is given by:

$$z = U \quad \frac{K}{c \quad R}$$

U is the voltage over the actuator and c is the stiffness of the suspension.
The dissipated power is:

$$P = \frac{U^2}{R} = \frac{c^2 \quad z^2 \quad R^2}{K^2 \quad R} = \frac{c^2 \quad z^2 \quad R}{K^2}$$

The stiffness of the suspension is limited by practical considerations and cannot be made much lower so we keep it constant. Also z is determined by the drive and is kept constant.

$$P \approx \frac{1}{x^3}$$

DC-power is going in the wrong direction!

De *electrical time constant* is the quotient of inductance and resistance.

$$\tau = \frac{L}{R}$$

The inductance of a coil is given by:

$$L = \mu \quad \frac{n^2 \quad A}{l}$$

μ is the permeability, n the number of windings, A the enclosed area in the coil and l the length of the coil. Inductance is proportional with x^5. R was proportional with x^3.
So:

$$\tau \approx x^2$$

A small time constant gives less phase shift in the servo. Making the coil smaller is also an improvement.

Conclusion: Making the actuator smaller improves things, but you should take care for z-offsets because of the DC power.

Design decisions.
In a compact design as an actuator it is difficult to tackle a problem separated from other problems. A solution here will inevitably have drawbacks elsewhere.
Some of the design decisions are clarified next:

Bandwidth.
The current actuator design is suitable up to a bandwidth of 3 KHz. If one decreases the dimensions of the actuator with a factor of _√2 the mass reduces with a factor of 0.36. This is a quit drastic measure, the current mass of 600 mg becomes 220 mg. The obtainable bandwidth increases only with a factor of 1.41=4.2 KHz. This gain in bandwidth is clearly not enough. Just scaling down the design will not give the required bandwidth.

Actuator suspension
A solution for the stability problem is the use of a metal suspension. If one uses a rather standard configuration with four thin parallel beams torsion stiffness will not be enough. A tapered design will improve this.
Metal beams can also be used to connect the coils electrically.
The mechanical damping of a metal spring suspension will be very small, so a separate damping system must be provided.
Furthermore, metal springs are much more fragile than its plastic counterparts.

Symmetry
In fig 3. the solution for the yaw sensitivity problem is easily been seen, just move the lens to the center of gravity. The system is becoming very robust for errors in the sledge guidance. Of course there is a drawback. An actuator should be driven with a force through the center of gravity to avoid unwanted rotations. With the lens at the center of gravity one needs a double magnet system to accomplish this. In a flat design the optical system is built not below but alongside of the actuator. A symmetric drive configuration generally blocks the light path. In the Kolibri design this is solved with the so called light gate.
Also a symmetric design has the possibility of a very close mechanical coupling between coils and objective lens resulting in a high possible bandwidth.

Moving coil vs. moving magnet
A system with a stationary coil set and moving magnet(s) looks the most simple design. In this case there is no need for a dynamic electrical connection with the moving part.
The efficiency of moving coil system is generally better than a moving magnet system.

Yoke system
In an actuator acceleration is generated with electro dynamic forces on the moving lens

holder. Reaction forces however are exerted on the stationary part of the actuator and from there in the rest of the drive. This may lead to stability problems due to unwanted mechanical feedback.

In the CDM-24 actuator the yoke is suspended elastically to filter out the disturbances. In practice this solution has tolerance problems in the production line.

If one chooses a symmetric design with multiple magnet systems the design of such a suspension becomes quite difficult.

However, if the moving mass of the actuator is small with respect to the rest of the mechanics the acceleration forces are relatively small and a yoke suspension will be superfluous.

Description of the Kolibri design.

The final design of the prototype is shown in the last figure.

The *objective lens* and a *dichroic diaphragm* are mounted in the *lens holder*. On the lens holder the *focus coil* and a set of *tracking coils* are wound. The focus coil is lifted in the front surface of the lens holder. This is the *light gate* and makes it possible to mount the rest of the optics in the same plane as the actuator.

The *suspension block* contains the *wire springs* and is made with an insert molding technique. The suspension block is connected with the lens holder with four laser welds making both a mechanical and an electrical connection.

At the back of the suspension block are four positions where a droplet of *damping gel* must be applied.

The suspension block has a special interface with a mating part of the *sledge*. With two adjustment *screws* the tilt of the actuator can be adjusted. The position of the lens remains the same during that movement. This reduces the required actuator stroke. A *spring clip* holds suspension block together with the sledge before the angles are fixed with glue.

From the bottom of the sledge the *yoke* with its *magnets* is mounted. One should expect a double yoke system, but because of the light gate the front and back yoke part had to be split and four little magnets are mounted.

Conclusion.

In this moment the first prototypes are tested and the underlying models are verified. the results are promising and it is believed that this design will be the base of the new generation of Philips actuators.

Acknowledgments.

The design of an actuator is rally the work of a team, but at the risk of doing short to the other team members I have to mention Ben Stinesen who has done a extremely fine job in making the total mechanical design of the Kolibri.

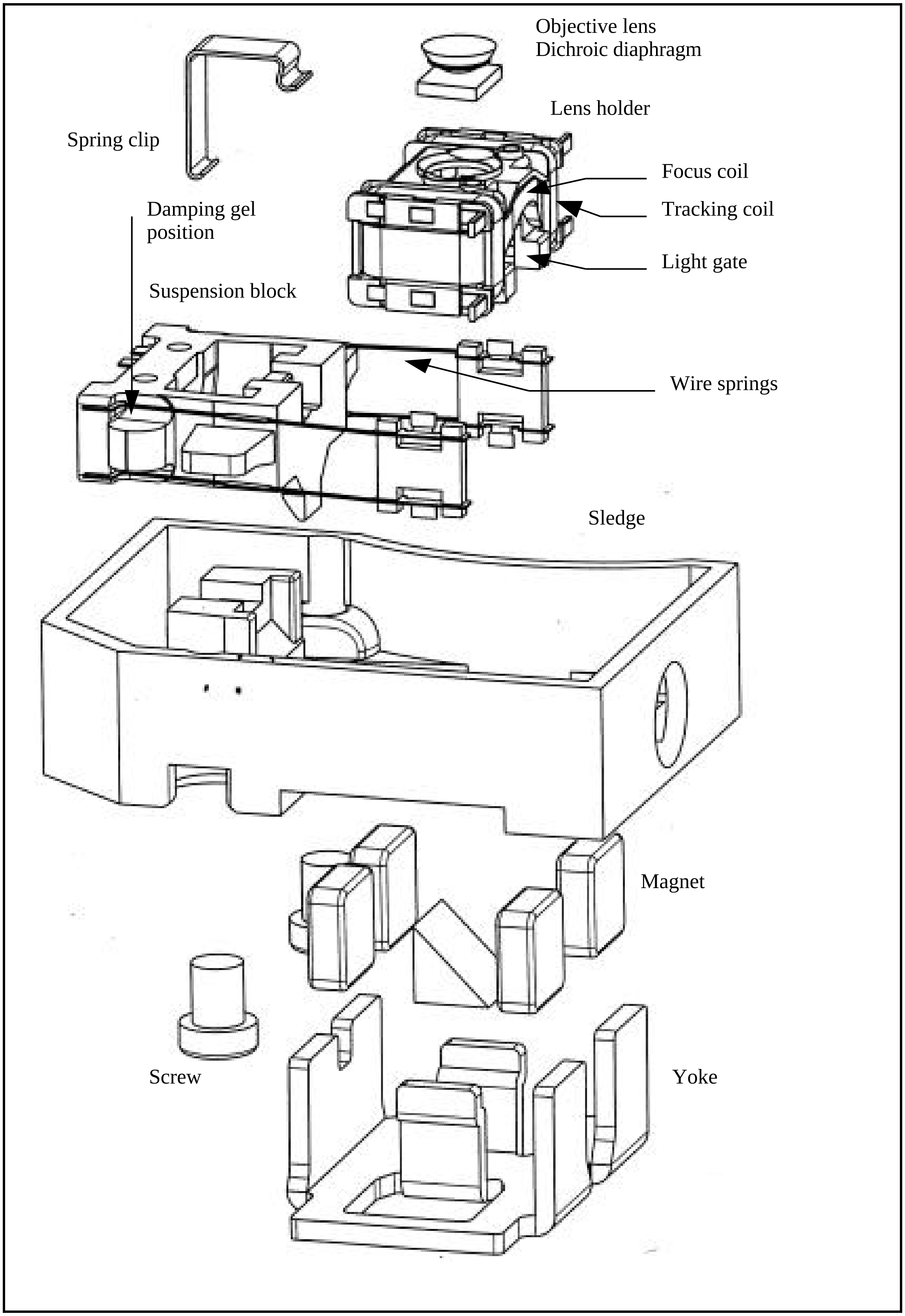

Fig. 5 Exploded view