The invention relates to an optical scanning device including an objective lens for a recording- and/or reproducing device in which a light beam is focused on a record carrier in accordance with the single beam method and is reflected from the record carrier onto a four quadrant photo-detector comprising four photodiodes of which one axis runs parallel to the track direction, in which the tracking error signal is obtained from the output signals of the photodiodes of the four quadrant photo-detector by forming the sums and differences, in which the light beam is guided onto the data track of the record carrier by means of a tracking control loop formed by a coarse adjustment means and a fine adjustment means mechanically connected to the coarse adjustment means, in which the objective lens is movable or tiltable relative to the four quadrant photo-detector by means of the fine adjustment means in a direction which forms a predetermined angle α to the normal to the track direction.

CD players, video disc players, DRAW-disc players or magneto-optical recording and reproducing devices are equipped for example with such types of optical scanning devices.

The construction and method of operation of an optical scanning device, a so-called optical pick-up, are described in "Electronic Components & Applications", Vol. 6, No 4, 1984 on pages 209 - 215..

The light beam emitted by a laser diode is focused by means of lenses on the compact disc and reflected from there onto a photodiode. The data stored on the compact disc and the current values for the focusing and for the tracking control loop are obtained from the output signal of the photo-detector. In the said document, the deviation of the current value from the reference value for the focusing control loop is referred to as "focusing error" while the expression "radial tracking error" is selected for the deviation of the current value from the reference value for the tracking control loop.

A coil, by means of whose magnetic field an objective lens can be moved along the optical axis, serves as control member for the focusing control loop. The focusing control loop now ensures that the light beam emitted by the laser diode is always focused on the compact disc by displacement of the objective lens. The optical scanning device is displaceable in a radial direction with reference to the compact disc by means of the tracking control loop which is often referred to as a radial drive. Thereby, the light beam can be guided onto the spirally shaped data track of the compact disc.

In some devices, the radial drive is constructed from a so-called coarse and a so-called fine adjustment means. The coarse adjustment means is implemented for example as a screw by means of which the whole optical scanning device consisting of the laser diode, the lenses, the prismatic beam splitter and the photo-detector is radially displaceable. The light beam is displaceable additionally in the radial direction or e.g. deflectable through a predetermined small angle by the fine adjustment means. Consequently, the light beam can be moved a small distance - about 1 mm - along the radius of the compact disc by means of the fine adjustment means.

In order to achieve a perfect reproduction of the data, be it now e.g. picture and sound in a video disc player or merely the sound from a CD player or the data on a magneto-optic disc, in addition to an exact focusing of the light beam on the disc, a precise guidance along the data track of the disc is required.

In the Fig. 1, the photo-detector PD of the optical scanning device of a CD player is shown, in which the three laser beams L1, L2 and L3 are focused on the compact disc. The laser beams L2 and L3 are the diffraction beams of +1 and -1 order. An optical scanning device of this type is referred to as a three-beam-pick-up in the aforementioned document because it works with three light beams.

Four square shaped photodiodes A, B, C and D are so arranged in the photo-detector that they themselves form a square. Two further rectangular photodiodes E and F are located diagonally opposite each other with reference to this square formed from the four photodiodes A, B, C and D. The central laser beam L1, which is focused on the four photodiodes A, B, C and D produces the data signal HF = AS + BS + CS + DS and the focusing error signal FE = (AS + CS) - (BS + DS). The two outer light beams L2 and L3, of which the front one L2 falls on the photodiode E and the rear one L3 on the photodiode F, produce the tracking error signal T = ES - FS. The photoelectric voltages of the diodes A, B, C and D are respectively referenced AS, BS, CS and DS.

In the Fig. 1, the central light beam L1 exactly follows a track S. The tracking error signal TE has the value zero.

TE = ES - FS = 0.

The case is illustrated in the Fig. 2 that the laser beams L1, L2 and L3 are displaced to the right of the track S. The tracking error signal adopts a negative value:

TE = ES - FS < 0.

The adjusting member of the tracking control loop now moves the optical scanning device to the left until such time as the tracking error signal TE is zero.

In the opposite case, when the laser beams are displaced to the left of the track, the tracking error signal is positive:
TE = ES - FS > 0. The adjusting member of the tracking control loop now moves the optical scanning device to the right until such time as the tracking error signal TE is zero. This case is shown in Figure 3.

Unfortunately, the three beam method cannot be used with record carriers that are writable once, so-called Write-Once-Discs, as will now be explained with the aid of the Fig. 4.

Because the data is recorded by means of the central laser beam L1, the front laser beam L2 always meets an already written location during the recording of the data while the rear laser beam L3 always shines on an unwritten location. The pits in the disc, whose direction of rotation is indicated by the arrow T, are referenced P. Because an already written location on the disc reflects more or less light than an unwritten location depending on the type of disc, the photodiode E, on which the front light beam L2 falls, receives more or less light than the photodiode F on which the rear light beam L3 falls. Although the central light beam L1 lies exactly in the middle of the data track S, because the tracking error signal TE is nevertheless not zero, the tracking control loop functions until the tracking error signal TE is zero. This is however, just the case of the central light beam L1 scanning the edge of a data track S.

This deviation from the centre of the track can of course be compensated by the addition of a compensating voltage, however the capture range of the regulator is reduced by this measure. Due to the smaller capture range, the sensitivity of the recording and reproducing device to external vibrations and shocks greatly increases.

Another solution presented by Sony at the Official Memory Symposium on the 18.12.1986 in Japan, which is shown in Figure 5, proposes that only the central light beam L1 fall on the middle of the data track S, while the front light beam L2 and

the rear light beam L3 fall exactly between the spirally shaped data tracks S. A photo-detector P1, P2 and P3, each consisting of two rectangular photodiodes G and H, is provided for each light beam L1, L2 and L3 instead of the photodiodes E and F, and of the photo-detector including the four square photodiodes A, B, C and D.

The difference of the output voltages of its two photodiodes G and H is developed in a differential amplifier for each of the three photo-detectors P1, P2 and P3. The difference voltages formed in this manner from the output voltages of the front photo-detector P2 and the rear photo-detector P3 are weighted, added and subtracted from the difference voltage formed from the output voltages of the central photo-detector P1 in order to obtain the tracking error signal TE.

As is apparent from the Figure 5, the same light energy irradiates the two photodiodes G and H of each photo-detector when the main beam L1 radiates onto the middle of the track and the beams of +1 and -1 order, the light beams L2 and L3, fall exactly between the tracks S onto the record carrier. During the recording of data, the front photo-detector P2 certainly receives more light than the rear photo-detector P3 but this difference is compensated by the weighting of the difference voltages which are formed from the output signals of the front photo-detector P2 and the rear photo-detector P3.

A first disadvantage of this modified three beam method shows itself in its great cost. A second disadvantage may be seen in that an optical grating has to be adjusted very exactly in the path of the beam in order that the light beams of +1 and -1 order, the front light beam L2 and the rear light beam L3, fall exactly in the middle between two tracks S.

The difficulties to be taken into account in the three beam method do not occur in the so-called push pull method which works with only one light beam. The light beam reflected from the disc contains both the data as well as the tracking error signal for the tracking control loop.

For the generation of the tracking error signal, one makes use of the diffracting properties of the pits or the embossed track on the disc. If the light beam leaves the middle of the track, the light intensity of the circular spot of light on the photo-detector, which is constructed from two photodiodes, becomes asymmetrical; in dependence upon which direction the light beam runs out from the track - radially inwardly or outwardly - the one half of the spot of light will be lighter while the other

half will be darker. The tracking error signal can be obtained from this difference in brightness which the photo-detector recognises. In order for the light beam to follow the data track to be scanned, which executes an untrue movement in the radial direction as a result of the eccentricity of the disc, the fine adjustment means moves the objective lens in the radial direction so that it follows the eccentric movement of the disc. Because the objective lens wanders from the optical axis due to this movement and because the spot of light follows the movement of the objective lens, it likewise wanders on the photo-detector. For this reason, an interference signal, that no longer guarantees an exact track following, is superimposed on the tracking error signal which is obtained by utilisation of the diffraction at the pits P or the embossed track of the disc. Because each disc has a larger or smaller eccentricity, the objective lens is therefore moved by the fine adjustment means at each rotation in order for the light beam to remain in the track. The said interference signal, which is also referred to as an offset, therefore appears more or less strongly with each rotation of the disc.

A fine adjustment means, which guides not only the relatively light objective lens but also the whole optical scanning device provides a remedy. However, because the movements controlled by the fine adjustment means must occur rapidly and exactly in order to retain the light beam constantly in the track, the least number of parts, whose mass moreover should be as small as possible, should be moved.

An optical scanning device having the following construction is described in the JP -A 58 146 034.

A laser beam shines through a collecting lens, a polarisation beam splitter, a $\lambda/4$ plate and an objective lens onto a record carrier which reflects the light beam back through the objective lens to the polarisation beam splitter from where it is deflected at right angles onto a photo-detector comprising two photodiodes. The objective lens is movable relative to the two part photo-detector. In order to be able to guide the laser beam along the data track of the record carrier, the objective lens is not movable as usual perpendicularly to the data track - i.e. in a radial direction with respect to the disc - but in a direction which forms an angle of 45° to the track direction.

An optical scanning device is known from the article "Bildplattensysteme im Vergleich" by Karl Tetzner appearing in Funkschau 22, 1981, pages 76 - 80 in which a light beam produced by a laser is focused on a picture disc by means of an objective

lens. The picture disc reflects the laser beam to a cylindrical lens which focuses it on a four quadrant photo-detector which is constructed from four photodiodes A, B, C and D.

The sum A + B + C + D of the output signals of the four photodiodes contains the video data. The focusing error signal, which is referred to in this document as a vertical signal, is formed in accordance with the formula (A + B) - (C + D). The photodiodes A and B or C and D are respectively located diagonally opposite in the four quadrant photo-detector.

It is now the object of the invention to develop an optical scanning device operating in accordance with the single beam method in which not the whole device but only the objective lens is moved by the fine adjustment means such that an exact track following is nevertheless achieved.

This object is achieved by the invention in that, the tracking error signal TE is calculated from the output signals of the four photodiodes of the four quadrant photo-detector by the following formula:

$$TE = k \cdot \{(AS + BS) - (CS + DS) - f \cdot [(AS + DS) - (BS + CS)]\},$$

wherein k and f are factor of proportionality.

There is shown in:

Figure 6 the movement of the light beam on the record carrier and the photo-detector in a known single beam method

Figure 7 the movement of the light beam on the record carrier and the photo-detector in the invention.

Figure 8 the movement of the light beam on the record carrier and the photo-detector in the astigmatic method

Figure 9 the intensity distribution of the spot of light for a record carrier written with pits

Figure 10 the direction of movement of the scanning device and of the objective lens in a first embodiment

Figure 11 the direction of movement of the scanning device and of the objective lens in a second embodiment

Figure 12 a further development of the optical scanning device in accordance with the invention.

The invention will now be described and explained with the aid of the Figures 6 and 7.

Three data tracks S are shown in the Figure 6, of which one is already written with pits P, one is being written by means of the light beam L and one is still unwritten. The direction of rotation of the disc is indicated by the arrow referenced with T while the double arrow referenced with R indicates the movement of the light beam L on the disc in the radial direction. The movements of the light beam L are imaged on the photo-detector which is constructed from two rectangular photodiodes E and F. The light spot L likewise moves in the direction of the double arrow R when the objective lens is moved in a radial direction.

The relationships for the invention are illustrated in Figure 7. Because the objective lens in the invention is not moved in the radial direction by the fine adjustment means but in a direction which forms an angle α to the radial direction, the light beam L likewise travels through this angle on the disc when the fine adjustment means moves the objective lens.

A four quadrant photo-detector comprising four photodiodes A, B, C, D is provided as photodetector of which one axis, which is subsequently referred to as the y- axis, runs in a tangential direction. The other axis running perpendicularly to the y- axis and parallel to the radial direction of the four quadrant photo-detector is referred to hereinafter as the x- axis.

If now, the fine adjustment means moves the objective lens in the given direction, which forms the angle α to the radial direction, in order that the light beam follows the track, the light spot L travels on the four quadrant photo-detector on a straight line which likewise forms an angle α with the x- axis.

It will now be explained how the tracking error signal TE is produced from the output voltages AS, BS, CS, DS of the photodiodes A, B, C, D.

The tracking error signal TE is derived from the signals

$$YS = (AS + DS) - (BS + CS)$$

and $$XS = (AS + BS) - (CS + DS).$$

Because the angle α is known, the following equations are valid for the signals XS and YS:

$$XS = \cos \alpha \cdot (TE + LX)$$

$$YS = LX \cdot \sin \alpha$$

The deviation of the light spot L in the x- direction from the centre of the detector is referenced with LX. The tracking error signal TE is given by

$$TE = XS / \cos \alpha - YS / \sin \alpha =$$

$$= [(AS + BS) - (CS + DS)] / \cos \alpha - [(AS + DS) - (BS + CS)] / \sin \alpha$$

$$TE = k \cdot \{(AS + BS) - (CS + DS) - \cot \alpha \cdot [(AS + DS) - (BS + CS)]\}$$

If the four quadrant photo-detector is so oriented that the dividing line, which separates the left photodiodes A and B from the right photodiodes C and D, the Y- axis, runs parallel to the track then the distribution of the intensity in the light spot with respect to the y- direction is symmetrical when the disc is homogeneous along the track, as is the case for example with a Write-Once-Disc or a magneto-optical disc.

For a compact disc however, the distribution of the intensity in the y- direction is unsymmetrical when scanning the beginning and the end of a pit. The time waveform of the signal YS is shown in Figure 9. Because this signal YS has no dc component, it can be easily eliminated by means of a low pass filter. Thus the invention is not only suitable for Write-Once-Discs but also for compact discs.

In some optical scanning devices, an element producing astigmatism, e.g. a cylindrical lens, is provided in the path of the beam. The astigmatism caused by the astigmatic element serves for the focusing of the light beam on the record carrier in the so-called astigmatic method.

If the optical scanning device is equipped with an element producing astigmatism, the four quadrant photo-detector has to be rotated through 90° as is shown in Figure 8.

In order to achieve the movement of the objective lens in a direction which forms the angle α to the radial direction, two solutions are possible. In the first solution, the optical scanning device is moved in a radial direction by the coarse adjustment means; in contrast, the objective lens is moved by

the fine adjustment means in a direction which forms the angle α to the radial direction. This first solution is illustrated in Figure 10.

However, it is also possible to provide the same direction of movement for the optical scanning device and the objective lens but to displace the movement axis parallel to the radial direction as is indicated in Figure 11.

Nevertheless, this second solution has the disadvantage that the angle α alters with the separation of the scanning device from the centre of the disc. The strength of the tracking error signal also alters thereby; it is dependent on the position of the scanning device. Moreover, the tangential components of the movement of the scanning device cause a phase jitter during read out of the data.

The deviation of the light spot in the x- direction is calculable by means of the measure of adding a movement in the y- direction to the movement of the light spot in the x-direction. For this, the deviation in the y- direction which is not dependent on the distribution of the intensity in the light spot is initially determined. However, because the angle α is known, the deviation of the light spot in the x- direction can be calculated. The sums and differences given in the formula for the tracking error signal TE are formed for example by means of differential and summing amplifiers. The weighting of the sums and differences takes place by means of an amplifier. The data signal and the focusing error signal for the focusing control loop can be obtained in a similar manner from the output signals AS, BS, CS, DS of the four quadrant photo-detector as in the three beam method.

In an optical scanning device that operates in accordance with the single beam method, the light beam of a laser is deflected e.g. by a semi-transparent mirror, at right angles to the disc, the so-called compact disc, and is focused by means of an objective lens on the disc. The light beam is reflected by the disc through the objective lens back to the semi-transparent mirror, through which it passes, in order to meet the four quadrant photo-detector PD through a convex lens e.g. a plano-convex lens. The four quadrant photo-detector is arranged at the focal point.

Because a circular light spot is required on the four quadrant photo-detector for the production of the data signal and of the focusing error signal, the convex lens K, which broadens the light beam, is located between the semi-transparent mirror HS

and the four quadrant photo-detector PD. Consequently, a circular light spot is formed on the four quadrant photo-detector PD instead of a point of light.

A substantial disadvantage of this optical scanning device is caused by the convex lens since the convex lens is an expensive optical component whose exact adjustment, which is absolutely essential, is relatively difficult.

A further disadvantage is that a misalignment of the beam is caused by the semi-transparent mirror HS.

In the further development of the optical scanning device shown in Figure 12, the light beam produced by a laser LA shines on a semi-transparent mirror HS which deflects the light beam at right angles onto the compact disc CD. The light beam is focused onto the disc CD, from where it is reflected back to the semi-transparent mirror HS, by means of an objective lens O located between the semi-transparent mirror HS and the disc CD. A glass plate P is attached e.g. by means of adhesive, at right angles to the semi-transparent mirror HS on a front face of the semi-transparent mirror. The light beam reflected by the disc CD passes through the objective lens O, through the semi-transparent mirror HS and through the glass plate P to the four quadrant photo-detector PD.

The glass plate P, which is arranged at right angles to the semi-transparent mirror HS, causes a broadening of the light beam like a convex lens. However, a simple glass plate is substantially cheaper than a convex lens.

A further advantage is achieved if either the glass plate P is attached to a front face of the semi-transparent mirror HS or the semi-transparent mirror HS is attached to a front face of the glass plate P. In this embodiment, only one part - the arrangement comprising the semi-transparent mirror HS and the glass plate P - needs to be adjusted. The adjustment of a convex lens is dispensed with.

Moreover, if the semi-transparent mirror HS and the glass plate P have similar optical properties, the troublesome misalignment of the beam is avoided. The plate P could also be manufactured from synthetic material instead of glass.

In the further development of the optical scanning device shown in Figure 12, the semi-transparent mirror HS is cemented to the front face of the glass plate P or the glass plate P is adhered to the front face of the semi-transparent mirror HS.

Claims

1. Optical scanning device including an objective lens for a recording- and/or reproducing device in which a light beam (L) is focused on a record carrier in accordance with the single beam method and is reflected from the record carrier onto a four quadrant photo-detector comprising four photodiodes (A, B, C, D) whose one axis runs parallel to the track direction, in which the tracking error signal TE is obtained from the output signals (AS, BS, CS, DS) of the photodiodes of the four quadrant photo-detector by forming the sums and differences, in which the light beam is guided onto the data track (S) of the record carrier by means of a tracking control loop formed by a coarse adjustment means and a fine adjustment means mechanically connected to the coarse adjustment means, in which the objective lens is movable or tiltable relative to the four quadrant photo-detector by means of the fine adjustment means in a direction (W) which forms a predetermined angle α to the normal (R) to the track direction, characterised in that, the tracking error signal TE is calculated from the output signals (AS, BS, CS, DS) of the four photodiodes (A, B, C, D) of the four quadrant photo-detector by the following formula:

$$TE = k \cdot \{(AS + BS) - (CS + DS) - f \cdot [(AS + DS) - (BS + CS)]\},$$

wherein k and f are factors of proportionality.

2. Optical scanning device in accordance with Claim 1, characterised in that, the factor of proportionality k is equal to $1 / \cos \alpha$ and the factor of proportionality f is equal to the $\cot \alpha$.

3. Optical scanning device in accordance with Claim 1 or 2, characterised in that, the angle α is selected to be smaller than or equal to 45°.

4. Optical scanning device in accordance with Claim 1, 2 or 3, characterised in that, the light beam emitted from a light source (LA) is guided onto the record carrier (CD) by means of a semi-transparent mirror (HS) and is reflected from the record carrier (CD) through the semi-transparent mirror (HS) onto the photodiode (PD) and that a transparent plate (P) is arranged in the path of the beam of the light beam reflected from the record carrier (CD) between the semi-transparent mirror (HS) and the photodiode (PD) at right angles to the semi-transparent mirror (HS).

* C L M S *

5. Optical scanning device in accordance with Claim 4, characterised in that, the semi-transparent mirror (HS) and the plate (P) are constructed of the same material

6. Optical scanning device in accordance with Claim 5, characterised in that, the semi-transparent mirror (HS) and the plate (P) are constructed in one piece.

7. Optical scanning device in accordance with Claim 4 or 5, characterised in that, the semi-transparent mirror (HS) and the plate (P) are attached to one another.

8. Optical scanning device in accordance with Claim 7, characterised in that, the semi-transparent mirror (HS) is attached to a front face of the plate (P) or the plate (P) is attached to a front face of the semi-transparent mirror (HS).

9. Optical scanning device in accordance with Claim 7 or 8, characterised in that, the semi-transparent mirror (HS) and the plate (P) are adhered to each other.

10. Optical scanning device in accordance with Claim 4, 5, 6, 7 8 or 9, characterised in that, the plate (P) is constructed out of glass or a synthetic material.

11. Optical scanning device in accordance with Claim 4, 5, 6, 7 8, 9 or 10, characterised in that, the semi-transparent mirror (HS) and the plate (P) are equally thick.

12. Optical scanning device in accordance with Claim 4, 5, 6, 7 8, 9, 10 or 11, characterised in that, the semi-transparent mirror (HS) and the plate (P) are constructed from material of similar optical properties.

* C L M S *