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(54) OPTICAL RECORD READ APPARATUS

(71) We, PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED, of Abacus House, 33 Gutter Lane, London, E.C.2., a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to apparatus for reading a record carrier which is provided with information, for example video and/or audio information, in an optically readable structure, which apparatus comprises a radiation source, an objective for focussing the radiation supplied by the radiation source onto the plane of the information structure, optical means for deriving a read beam and a focussing beam from the radiation supplied by the radiation source, a radiation-sensitive signal detection system for converting the read beam which is modulated by the information structure into an electrical signal, and a radiation-sensitive focus detection system for converting the focussing beam into an electrical signal.

A focussing beam is to be understood to mean an auxiliary beam which is employed to detect the occurrence of deviations between the desired and the actual plane of focussing.

An apparatus of the type mentioned in the preamble is described in Patent Specification No. 1,435,922 In the previously proposed apparatus a part of the radiation which is produced by a laser is passed through a narrow gap via mirrors, so that a narrow focussing beam is obtained. Said beam passes eccentrically through the objective and is subsequently reflected at the plane of the information structure of a record carrier. The reflected focussing beam traverses the objective for a second time and is then directed to a focus detection system which consists of two separate radiation-sensitive detectors. The

position of the plane of the information structure determines the height at which the reflected focussing beam passes through the objective and thus the position of the radiation spot which is formed on the focus detection system by said beam. By comparing the output signals of the individual detectors of said system an indication can be obtained about the position of the plane of the information structure relative to the objective.

The invention provides apparatus for reading a record carrier which is provided with information in an optically readable structure, which apparatus comprises a radiation source, an objective for focussing the radiation supplied by the radiation source onto the plane of the information structure, optical means for deriving a read beam and a focussing beam from the radiation supplied by the radiation source, a radiation-sensitive signal detection system for converting the read beam which is modulated by the information structure into an electrical signal, and a radiation-sensitive focus detection system comprising two radiation detectors in a plane transverse to the optical axis of said objective, said detectors being disposed to receive the focussing beam, via the objective and the information structure, and to produce a focus error signal characterized in that said optical means consist of a single optical element with is disposed between the radiation source and the objective system and which forms said read and focussing beams with different propagation directions, in that said detectors are separated by a dividing line transverse to the plan containing said read and focussing beams, and in that between the radiation source and said single optical element a radiation-absorbing element is disposed to intercept said focussing beam and to absorb different amounts of the two parts of said focussing beam incident one each on said detectors. The single optical

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element may be a Wollaston-prism but may also be, for example, a diffraction grating.

An embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 schematically shows a read apparatus.

Figure 2 shows the radiation paths in the apparatus of Figure 1.

Figure 3 shows the behaviour of the read spot and the focussing spot in the plane of the signal detection system and the focussing detection system respectively.

Figure 4 shows the variation of the control signal thus obtained as a function of the defocussing, and

Figure 5 shows the radiation path through a special Wollaston prism used in the present apparatus.

Figure 1 shows a cross-section of a record carrier 1, which by way of example is assumed to be disc-shaped and round. The information may be contained in said record carrier in a spiral track which consists of a multiple of quasi-concentric sub-tracks 3 which each extend along one revolution over the record carrier. Each subtrack may comprise a multitude of areas which alternate with intermediate areas, in the lengths of which areas and intermediate areas the information may be contained. The areas have a different effect on a read beam than the intermediate areas. The manner in which the information may be recorded in the tracks is irrelevant for the present invention and is therefore not discussed. The plane 2 of the sub-tracks may be disposed at the surface of the record carrier. However, it is also possible that, as is shown in Figure 1, a protective coating is provided on the information structure. The sort of information that is stored is of no significance for the present invention. This information may be a colour television programme, an audio programme or other information.

The record carrier is read by means of the radiation which is supplied by a radiation source 7, which may for example consist of a helium-neon laser or a light-emitting diode (LED). The radiation source 7 emits a beam of unpolarized radiation 20, of which for clarity only the chief ray is shown. The path of said beam includes a Wollaston prism 8. Said prism divides the unpolarized beam into two linearly polarized sub-beams 21 and 22 whose directions of polarization are mutually perpendicular. The sub-beams 21 and 22, of which only the chief rays are shown, emerge from the Wollaston prism at an angle β_1 and α_1 respectively to the direction of the original beam 20. The sub-beams 21 and 22 appear to originate from two virtual

radiation sources 24 and 25 respectively as is shown in Figure 2.

The angles α_1 and β_1 and also angles α_2 and β_2 to be described later are shown in Figures 1, 2 and 5 as being much larger than they are in practice for the sake of clarity.

In Figure 2 the radiation source is designated 7'. The boundaries of the cones of rays which are emitted by said source are represented by uninterrupted lines. The Wollaston prism is schematically represented as an interface 8' at which beam separation and beam refraction occurs. At the plane 8' two beams are produced whose marginal rays are represented by dashed lines and dash-dot lines. Said beams have the same aperture angle as the original beam and they fill the entrance pupil pp' of the objective completely, the effective aperture angle for each beam being defined by pupil pp' .

Of said beams one beam, the outgoing beam 21 in Figure 1, may be used as read beam. The direction of polarization of said beam is assumed to be normal to the plane of drawing. The read beam is focussed to a small radiation spot S_1 on the plane 2 of the information structure by an objective 13, which is schematically represented by a single lens. The read beam is reflected by the information structure, traverses the objective for a second time and emerges as incoming beam 22. When the record carrier is rotated by means of a shaft 5 which extends through a central opening 4 in the record carrier, the read beam is time-modulated in accordance with the sequence of the areas and the intermediate areas in a track to be read.

The incoming modulated read beam 22 then enters the Wollaston prism for a second time. In the radiation path between said prism and the objective a $\lambda/4$ -plate 12 is disposed in a diagonal position. "Diagonal position" means that the projection of the optic axis of the $\lambda/4$ -plate in the plane with is determined by the directions of polarization of the sub-beams 21 and 22 makes an angle of 45° with said directions of polarization. The $\lambda/4$ -plate is traversed once by the forward (unmodulated) beam and once by the returning (modulated) beam. As a result of this the direction of polarization of the read beam will be rotated through 90° , so that said direction of polarization is parallel to the plane of drawing in Figure 1. The Wollaston prism deflects the modulated read beam 22 in a direction at an angle β_2 to the direction of the beam which is emitted by the source 7.

The modulated read beam is finally intercepted by a signal detection system which takes the form of one radiation-sensitive detector 14. At the output of said

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detector an electrical signal I develops which is time modulated in accordance with the sequence of areas and intermediate areas in a track to be read. Said signal can be processed in known manner in an electronic device 15, to a signal which is adapted to be applied to a conventional apparatus for reproducing the information which is stored on the record carrier.

The outgoing radiation beam 22, whose direction of polarization is parallel to the plane of drawing in Figure 1, is employed as a focussing beam, i.e. as auxiliary beam for determining a deviation between the desired and the actual position of the plane of the information structure relative to the objective. The chief rays of the outgoing focus beam 22 and the incoming read beam 22 are shown as coincident in Figures 1 and 5 for convenience. In practice there is a small angular separation between these beams. Likewise, incoming focus beam 21 and outgoing read beam 21 are shown as coincident though they also are separated slightly in direction. The focussing beam first traverses the $\lambda/4$ -plate 12 and is subsequently focussed to a second radiation spot S_r at the plane of the information structure by the objective 13. The reflected focussing beam then passes through the objective and the $\lambda/4$ -plate for a second time, so that its direction of polarization will be perpendicular to the plane of drawing. The Wollaston prism then deflects the focussing beam to the focus detection system 16 at an angle α_2 . Said system consists of two separate radiation-sensitive detectors 17 and 18.

Since the principal rays of the outgoing beams 21 and 22 are separated by an angle $\alpha_1 + \beta_1$ and since the cones of rays for both of these beams are defined by the entrance pupil pp' of Figure 2, the corresponding cones of rays of the beams as they emerge from source 7 are not coincident. The pupil diameter can be selected so that, for example, only about half of each cone overlaps the other between source 7 and prism 8.

The right-hand part of Figure 3 shows a front view of said system. The radiation spot which is projected on the detectors 17 and 18 is designated S'_r . The left-hand part of Figure 3 shows the projection S'_i of the read beam on the signal detector 14.

If the plane of the information structure is in the desired position relative to the objective the radiation spots S_i and S_r are sharply re-imaged on the detectors. The radiation spots S'_i and S'_r then have minimum dimensions and the radiation spot S'_i is symmetrically incident on the radiation-insensitive area between the detectors 17 and 18. Said situation is

represented in Figure 3 under a. When the plane of the information structure moves to the left or to the right, the radiation spots S'_i and S'_r will expand.

When the plane of the information structure becomes defocussed, i.e. when deviations occur between the desired and the actual position of said plane, the focus detection system is asymmetrically illuminated by the focussing beam. This is achieved by interposing a knife-edged radiation-absorbing element 23, for example, between the radiation source 7 and the Wollaston prism 8, so that only that part of the cone of rays of the focus beam which is emitted by the source and does not overlap the emitted read beam cone is blocked on its way to the Wollaston prism. As can be seen in Figure 2 the element 23 only absorbs a part of the radiation which is emitted by the virtual source 25. By arranging the element 23 in this manner, the read beam is not substantially affected and the output signal of the signal detector 14 is not substantially attenuated. On the other hand, the element 23 blocks preferably half the focussing beam. The sub-beams 21 and 22 which are formed by the Wollaston prism and which are aimed at the entrance pupil of the objective are observed by said objective as originating from two separated light sources. As a result of this, the focus beam can be suppressed in part, whilst the read beam remains substantially unaffected.

When the plane of the information structure is in focus the presence of the element 23 only results in a reduction of the intensity in the spot S_r . The two detectors 17 and 18 then do not supply different signals. As the focussing beam does no longer fill the entire entrance pupil of the objective system the radiation spot S'_i in the situation a in Figure 3 is slightly larger than the radiation spot S'_r . The radiation spot S'_i is symmetrically incident on the detectors 17 and 18. When defocussing occurs the limitation of the focus beam which is introduced by the element 23 will become visible in the radiation spot S_r . When the defocussing increases one part of the radiation spot S_r will expand and the other part will shrink, so that one of the detectors will receive an increasingly larger amount of radiation than the other detector. Which of the two detectors receives more radiation depends on the direction of the defocussing. Figure 3b shows the situation in the case that the plane of the information structure is too close to the objective and Figure 3c the situation when said plane is too far from the objective.

By subtracting the output signals of the detector 17 and 18 from each other, for

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example in an electronic circuit 19, a signal C for focussing correction can be obtained. The manner in which the control signal is formed and the manner in which the focussing is corrected are not relevant to the present invention and will therefore not be discussed.

To obtain the required blocking of the focussing beam the Wollaston prism should not be disposed too far from the light source. The location of the Wollaston prism determines how far the read beam and the focussing beam can be spaced apart. When the Wollaston prism is made of quartz, the angle α_1 substantially equals the angle β_1 , while the angle α_2 substantially equals the angle β_2 . Furthermore, the angle α_2 is approximately $2\times$ the angle α_1 and the angle β_2 approximately $2\times$ the angle β_1 . In one embodiment of apparatus in accordance with the invention, in which the objective consisted of a lens with the numerical aperture of 0.4 and a magnification of $20\times$, and in which the angle $\alpha_1 \approx 2.10^{-2}$ rad, the quotient of the distance between the source and the Wollaston prism and the distance between the source and the entrance pupil of the objective the quotient $1/v$ in Fig. 2, had to be smaller than 0.5.

By means of the apparatus described a focus control signal of great steepness can be obtained. Figure 4 shows the variation of the amplitude of the signal S_v , which is the difference of the signals supplied by the detectors 17 and 18 as a function of the defocussing Δf . When the detectors 17 and 18 are photodiodes S_v can be plotted in nano-amperes. Owing to the greater slope of the signal S_v around the zero point ($\Delta f=0$) it is possible to accurately detect whether the plane of the information structure is in focus. Said slope is steeper as a greater part of the focussing beam is blocked by the knife 23. In practice the element 23 is arranged so that at least half the focussing beam is blocked. When the knife is disposed slightly higher it is still possible to obtain a suitable control signal, so that the location of the knife is not very critical.

The range within which focussing errors can be detected is determined by the size of the focussing diodes 17 and 18 and the amount of radiation which is emitted by the source 7. In a realized embodiment of an apparatus in accordance with the invention using an LED as radiation source, focussing errors of $-200 \mu\text{m}$ to $+290 \mu\text{m}$ could be detected.

The position of the Wollaston prism relative to the detectors 17 and 18 is rather critical. A deviation from said position will lead to incorrect focussing detection. For example, in the realized embodiment of a read apparatus according to the invention a

deviation of $20 \mu\text{m}$ in the position of the detectors 17 and 18 relative to the Wollaston prism resulted in a focussing error of $3 \mu\text{m}$ being detected, whilst in reality the plane of the information structure was in focus. When the detectors of the focus detection system are rigidly connected to those of the signal detection system, it is possible according to the invention to eliminate the effect of a deviation in the position of the focus detectors relative to the Wollaston prism. For this purpose, the signal detector 14 is divided into two halves $14'$ and $14''$, as is indicated by the dotted lines in the left-hand part of Figure 3, and the difference of the signals supplied by the detectors $14'$ and $14''$ is determined. In the case of a displacement of the Wollaston prism relative to the focussing detectors the difference signal of the detectors 17 and 18 and also that of the detectors $14'$ and $14''$ will vary independently of the focussing on the plane of the information structure. When the signals supplied by the detectors $14'$, $14''$, 17 and 18 are designated $S_{14'}$, $S_{14''}$, S_{17} and S_{18} , the information which is stored in the record carrier can be recovered from:

$$S_1 = S_{14'} + S_{14''};$$

the focus error can be derived from:

$$S_2 = S_{17} - S_{18};$$

whilst the signal

$$S_3 = \frac{S_{14'} - S_{14''}}{2} - (S_{17} - S_{18})$$

may be used for correcting the position of the detectors and the Wollaston prism relative to each other.

For apparatuses for optically reading a record carrier it has been proposed previously to separate the modulated read beam from the unmodulated read beam with the aid of a Wollaston prism and a $\lambda/4$ -plate. The source then emits linearly polarized light, so that only one beam emerges from the prism which is deflected at a certain angle. By simple means such an apparatus can be adapted for focus detection in accordance with the invention. The only additional elements to be employed are then a radiation-absorbing element between the Wollaston prism and the radiation source which should emit unpolarized radiation, and two focus detectors. In that case highly effective use is made of the Wollaston prism.

It is alternatively possible to employ the Wollaston prism only for forming two

beams at different solid angles. The modulated and the unmodulated beams can then be separated with a semitransparent mirror between the Wollaston prism and the objective system. It is then not necessary to include a $\lambda/4$ -plate in the radiation path.

If a semitransparent mirror is used for separating the modulated from the unmodulated beams, a diffraction grating can be employed instead of a Wollaston prism for forming two beams at different solid angles. In general, such a diffraction grating divides an incident beam in a zero order beam, two first order beams and a number of higher order beams. It is possible to prepare a diffraction grating such (for example by blazing of the grating) that practically all of the incident radiation is distributed over the +1 component beam and the -1 component beam. Then a situation, analogous to that of Figure 2 arises. The angle between the component beams and thus the positions of the imaginary radiation sources 24 and 25 is determined by the pitch of the diffraction grating.

The Wollaston prism in the apparatus of Figure 1 is of a special type. Said prism consists of three component prisms 9, 10 and 11 of a birefringent material (see Figure 5). The optic axes 9' and 11' of the component prism 9 and 11 are parallel to each other, whilst the optic axis 10' of the component prism 10 is normal to the optic axes 9' and 11'. Owing to the symmetrical construction of the composite prism 8 is non-astigmatic.

Figure 5 shows the radiation path through such a prism. The chief ray of the beam 20 passes through the component prism 9 without being refracted. For a sub-beam whose direction of polarization is parallel to the plane of drawing, the focussing beam in Figure 1, the chief ray traverses the component prism 10 as ordinary ray and the component prism 11 as extraordinary ray, and is refracted through a certain angle by each of the component prism, so that the chief ray 22 is deflected through a total angle α_1 relative to the direction of the incident ray, depending on the refractive indices of the material of the component prisms. After passing two times through a $\lambda/4$ -plate which is disposed in the diagonal position, the focussing beam has a direction of polarization which is perpendicular to the plane of drawing. The chief ray of the beam which is thus polarized passes through the component prism 11 as ordinary ray, through the component prism 10 as extraordinary ray and through the component prism 9 as ordinary ray. The chief ray of the incoming-focussing beam 21 emerges from the

composite prism at an angle α_2 relative to the chief ray of the incident beam.

The chief ray of the sub-beam whose direction of polarization is perpendicular to the plane of drawing (the read beam in Figure 1) traverses the component prism 10 as extraordinary ray and the component prism 11 as ordinary ray and is deflected through a total angle of β_1 . After having traversed the $\lambda/4$ -plate twice, the chief ray of the incoming read beam 22 passes through the component prism 11 as extraordinary ray, through the component prism 10 as ordinary ray and through the component prism 9 as extraordinary ray, so that the chief ray of the sub-beam 22 is deflected through an angle β_2 . When the prism material is quartz α_2 and β_2 are approximately equal and twice α_1 or β_1 .

Instead of a symmetrical Wollaston prism, it is also possible to employ a conventional Wollaston prism in the apparatus of Figure 1. The angles of refraction of such a prism, however, are only half those of the prism of Figure 5. Moreover, the conventional prism is astigmatic.

WHAT WE CLAIM IS:—

1. Apparatus for reading a record carrier which is provided with information in an optically readable structure, which apparatus comprises a radiation source, an objective for focussing the radiation supplied by the radiation source onto the plane of the information structure, optical means for deriving a read beam and a focussing beam from the radiation supplied by the radiation source, a radiation-sensitive signal detection system for converting the read beam which is modulated by the information structure into an electrical signal, and a radiation-sensitive focus detection system comprising two radiation detectors in a plane transverse to the optical axis of said objective, said detectors being disposed to receive the focussing beam, via the objective and the information structure, and to produce a focus error signal, characterized in that said optical means consist of a single optical element which is disposed between the radiation source and the objective system and which forms said read and focussing beams with different propagation directions, in that said detectors are separated by a dividing line transverse to the plane containing said read and focussing beams, and in that between the radiation source and said single optical element a radiation-absorbing element is disposed to intercept said focussing beam and to absorb different amounts of the two parts of said focussing beam incident one each on said detectors.



beams at different solid angles. The modulated and the unmodulated beams can then be separated with a semitransparent mirror between the Wollaston prism and the objective system. It is then not necessary to include a $\lambda/4$ -plate in the radiation path.

If a semitransparent mirror is used for separating the modulated from the unmodulated beams, a diffraction grating can be employed instead of a Wollaston prism for forming two beams at different solid angles. In general, such a diffraction grating divides an incident beam in a zero order beam, two first order beams and a number of higher order beams. It is possible to prepare a diffraction grating such (for example by blazing of the grating) that practically all of the incident radiation is distributed over the +1 component beam and the -1 component beam. Then a situation, analogous to that of Figure 2 arises. The angle between the component beams and thus the positions of the imaginary radiation sources 24 and 25 is determined by the pitch of the diffraction grating.

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Figure 5 shows the radiation path through such a prism. The chief ray of the beam 20 passes through the component prism 9 without being refracted. For a sub-beam whose direction of polarization is parallel to the plane of drawing, the focussing beam in Figure 1, the chief ray traverses the component prism 10 as ordinary ray and the component prism 11 as extraordinary ray, and is refracted through a certain angle by each of the component prism, so that the chief ray 22 is deflected through a total angle α_1 relative to the direction of the incident ray, depending on the refractive indices of the material of the component prisms. After passing two times through a $\lambda/4$ -plate which is disposed in the diagonal position, the focussing beam has a direction of polarization which is perpendicular to the plane of drawing. The chief ray of the beam which is thus polarized passes through the component prism 11 as ordinary ray, through the component prism 10 as extraordinary ray and through the component prism 9 as ordinary ray. The chief ray of the incoming-focussing beam 21 emerges from the

composite prism at an angle α_2 relative to the chief ray of the incident beam.

The chief ray of the sub-beam whose direction of polarization is perpendicular to the plane of drawing (the read beam in Figure 1) traverses the component prism 10 as extraordinary ray and the component prism 11 as ordinary ray and is deflected through a total angle of β_1 . After having traversed the $\lambda/4$ -plate twice, the chief ray of the incoming read beam 22 passes through the component prism 11 as extraordinary ray, through the component prism 10 as ordinary ray and through the component prism 9 as extraordinary ray, so that the chief ray of the sub-beam 22 is deflected through an angle β_2 . When the prism material is quartz α_2 and β_2 are approximately equal and twice α_1 or β_1 .

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WHAT WE CLAIM IS:—

1. Apparatus for reading a record carrier which is provided with information in an optically readable structure, which apparatus comprises a radiation source, an objective for focussing the radiation supplied by the radiation source onto the plane of the information structure, optical means for deriving a read beam and a focussing beam from the radiation supplied by the radiation source, a radiation-sensitive signal detection system for converting the read beam which is modulated by the information structure into an electrical signal, and a radiation-sensitive focus detection system comprising two radiation detectors in a plane transverse to the optical axis of said objective, said detectors being disposed to receive the focussing beam, via the objective and the information structure, and to produce a focus error signal, characterized in that said optical means consist of a single optical element which is disposed between the radiation source and the objective system and which forms said read and focussing beams with different propagation directions, in that said detectors are separated by a dividing line transverse to the plane containing said read and focussing beams, and in that between the radiation source and said single optical element a radiation-absorbing element is disposed to intercept said focussing beam and to absorb different amounts of the two parts of said focussing beam incident one each on said detectors.



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5 2. Apparatus as claimed in Claim 1 for reading a reflecting record carrier wherein the single optical element is a Wollaston-prism, characterized in that a $\lambda/4$ -plate in a diagonal position is disposed in the radiation path between the Wollaston prism and the objective and that the signal detection system and the focus detection system are disposed at the same side of the Wollaston prism as the radiation source.

10 3. Apparatus as claimed in Claims 1 or 2, the detectors of the focus detection system being rigidly connected to those of the signal detection system, characterized in that the signal detection system consists of two radiation-sensitive read signal detectors disposed in a plane transverse to the optical axis of said objective and separated by a dividing line substantially parallel to said focus detector dividing line, said apparatus comprising means for

generating a positioning signal indicating a deviation between the actual and desired position of the single optical element relative to the detectors, said focus error signal comprising the difference of the outputs of said focus detectors, and said positioning signal comprising the difference between said focus error signal and half the difference of the outputs of said read signal detectors. 25 30

4. Apparatus for reading an optical record carrier substantially as herein described with reference to the drawings.

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