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"APPARATUS FOR READING A DISK-SHAPED RECORD CARRIER".

The invention relates to apparatus for reading a disk-shaped record carrier having substantially concentric information tracks, which apparatus comprises an optical system for producing three radiation beams and projecting said radiation beams onto the record carrier as a first, a second and a third radiation spot, the second and third radiation spot being disposed on opposite sides of the first radiation spot in a direction transverse to the track direction and the distance between their respective centres and the axis which extends through the centre of the first radiation spot and parallel to the information tracks being at least substantially 1/4 of the track pitch of the information tracks, a first, a second and a third detector for detecting the amount of luminous energy in the radiation beams energing from the record carrier and corresponding to the first, the second and the third radiation spot respectively and for converting this luminous energy into corresponding electric output signals, a tracking system, which co-operates with the radiation beams, for centering the first radiation spot on an information track, and a control device coupled to the second and third detectors, for generating a tracking-system control signal which depends on the difference between the output signals of the second and third detectors.

Such apparatus is known from British Patent Specification 1,434,834. In the read apparatus for an optical record carrier described in this British Patent Specification the output signals of the second and third detectors are subtracted from each other in order to obtain a radial control signal which, when fed to the tracking system, centres the first radiation spot on the information track.

The generation of this radial control signal is based on the fact that the average luminous intensity of an emergent

radiation beam depends on the position of the corresponding radiation spot relative to an information track, specifically whether or not this radiation spot coincides with an information track. Since the second and third radiation spots, viewed in the radial direction, are situated at equal distances from the first radiation spot, the output signals of the second and third detectors will be equal if the first radiation spot is centred on an information track. However, if the spot is off-centre, the output signals of the second and third detectors will be unequal and the difference signal may be used for driving the tracking system so as to obtain the desired centring.

A disadvantage of the system described in said British Patent Specification is that the magnitude of the resulting control signal depends not only on the centring error of the first radiation spot relative to the information track but also on a large number of parameters both of the read apparatus itself and of the record carrier. In other words, the slope of the control signal around the desired control point is not well-defined but may vary depending on a number of system parameters which are subject to variations.

These parameters are mainly the following:

(a) the intensity of the radiation beams,

(b) the transmission coefficient of the record carrier material or, in the case of reflection mode reading, the reflection coefficient of the reflecting layer,

(c) the shape of the information areas in the information track,

(d) focussing errors of the radiation spots relative to the plane of the information track,

(e) the track pitch of the information tracks.

As all these parameters exhibit a substantial spread this means that the magnitude of the resulting control signal as a function of the tracking error may exhibit a substantial variation. This corresponds to a substantial variation of the gain factor in the radial servo-loop. However this impairs the operation of the servo-control loop. In a servo-control loop the transfer

characteristic for the relevant control function is optimized by means of frequency-dependent networks. However, if allowance has to be made for wide variations in the gain factor this imposes restraints on the overall transfer characteristic. If the overall transfer characteristic is laid down for one specific gain factor the control loop is likely to become unstable for markedly different gain factors.

It is an object of the invention to provide read apparatus for disk-shaped record carriers in which the generated radial control signal depends on the said parameters to a much reduced extent.

To this end the invention comprises apparatus for reading a disk-shaped record carrier having substantially concentric information tracks, which apparatus comprises an optical system for producing three radiation beams and projecting said radiation beams onto the record carrier as a first, a second and a third radiation spot, the second and third radiation spots being disposed on opposite sides of the first radiation spot in a direction transverse to the track direction and the distance between their respective centres and the axis which extends through the centre of the first radiation spot and parallel to the information tracks being at least substantially 1/4 of the track pitch of the information tracks, a first, a second and a third detector for detecting the amount of luminous energy in the radiation beams emerging from the record carrier and corresponding to the first, the second and the third radiation spot respectively and for converting this luminous energy into corresponding electric output signals, a tracking system, which co-operates with the radiation beams, for centring the first radiation spot on an information track, and a control device, coupled to the first, the second and the third detector, which in use generates a tracking-system control signal V_c given by the formula:

$$V_c = \frac{V_{R1} - V_{R2}}{V_{R1} + V_{R2} - \alpha V_s} \cdot V_{ref}$$

where V_s, V_{R1} and V_{R2} are the output signals of the first, the second and the third detector respectively, α is an adjustment factor, and V_{ref} is a reference signal.

As a result of this specified combination of the various output signals of the three detectors the control signal V_c thus obtained depends on said parameters to a much reduced extent. This means that the transfer function of the radial servo-control loop can be optimized with much reduced risk of instabilities.

In a first embodiment of apparatus in accordance with the invention the control device comprises a first difference-forming stage for determining the difference between the output signals of the second and the third detector, a second difference-forming stage for determining the difference between the sum of the output signals of the second and the third detector and the output signal of the first detector, and a divider stage for determining the quotient of the output signals of the first and the second difference forming stage and supplying a control signal which corresponds thereto. In another embodiment an amplifier is arranged between the second difference-forming stage and the divider stage for subjecting the output signal of said second difference-forming stage to a modulus operation. As a result of this modulus operation the divider stage may be simplified. Moreover, the control signal obtained in the case of movement transverse to the information tracks varies continuously, especially when the magnitude of the control signal is limited.

Embodiments of the invention will now be described in more detail, by way of example, with reference to the Figures of the accompanying drawings, in which:-

Figure 1 schematically represents an embodiment of read apparatus in accordance with the invention,

Figure 2 shows the position of the radiation spots on the record carrier,

Figure 3 represents the variation of the output signals of the detectors in the case of a displacement transverse to the track direction,

Figure 4 is an example of a frequency characteristic of a radial servo-system,

Figure 5 represents the variation of the control signal obtained by means of apparatus in accordance with the invention,

Figure 6 is the block diagram of a version of the control device used in apparatus in accordance with the invention,

Figure 7 shows a detailed circuit diagram of this control device, and

Figure 8 is a variant of the resulting control signal V_c.

In Figure 1 the reference numeral 1 denotes a disk-shaped record carrier comprising a multitude of concentric or quasi-concentric (spiral) information tracks. The information may be recorded in these information tracks in various known manners. As an example, reference is made to Patent Specification 1,391,541, where the information tracks comprise areas and intermediate areas whose different lengths represent the information. These areas and intermediate areas influence a radiation beam projected onto the information track in different manners, so that this radiation beam is modulated depending on the information stored. As an example, the transmission or reflection coefficient of the areas may differ from that of the intermediate areas, so that a read beam is amplitude-modulated. It is alternatively possible to arrange the areas and intermediate areas at different levels in the record carrier, so that the read beam is phase-modulated, which modulation may be converted into an amplitude modulation by suitable means. Since the method of modulation and the method of information-recording are of minor importance to the present invention they will not be described in more detail. In the present example it is assumed that the record carrier 1 has a reflecting information structure on the upper side.

This record carrier 1 is rotated by a motor 2 via a spindle 3 which engages with a central opening in said record carrier. For reading the record carrier 1 there is provided an optical system 4, which is accommodated in a housing 5. This optical system 4 comprises a radiation source 6 which emits three

radiation beams S, R_1 and R_2. These three radiation beams are together projected onto the record carrier 1 as radiation spots s, r_1 and r_2 via a semi-transparent mirror 7, a pivotal mirror 8 and a lens 9. The radiation beams S', R_1' and R_2' reflected from the record carrier are reflected to the detectors 10, 11 and 12 by the mirror 8 and the semi-transparent mirror 7. These detectors 10, 11 and 12 each supply an output signal on their outputs, which output signals represent the luminous intensities of the radiation beams S', R_1' and R_2' which have been modulated by the record carrier.

These output signals of the detectors 10, 11 and 12 are applied to a control device 13, which derives from these signals a radial control signal V_c for radially positioning the radiation spots s, r_1 and r_2 projected onto the record carrier by the radiation beams S, R_1 and R_2. In order to obtain this radial positioning said radial control signal V_c is applied to an actuating device 14 by means of which the mirror 8 can be pivoted about an axis 15. This actuating device 14 may, for example, be an electro-magnetic actuator driven by a control current. Furthermore, it is possible to derive an average control signal from the average position of the mirror 8, which average control signal is fed to a coarse control means 16 coupled to move the housing 5 in a radial direction.

Figure 2 shows how the radiation spots s, r_1 and r_2 are positioned relative to each other and relative to the information tracks on the record carrier. Viewed in the radial direction x, the radiation spots r_1 and r_2 are situated on opposite sides of the scanning spot s at a distance q/4 from this scanning spot s, q being the track pitch, i.e. the distance between the centres of adjacent information tracks (T_1,T_2).

This pattern of radiation spots has been chosen because the two radiation beams R_1' and R_2' corresponding to the radiation spots r_1 and r_2 have the same average luminous intensities when the radiation spot s is exactly centred at an information track. If the radiation spot s is not correctly centred the average luminous intensisties of the reflected radiation beams R_1' and R_2'

(18)

are different. Here the term "average" signifies that variations in luminous intensity caused by the high-frequency information structure in the information track are ignored. In fact, these high-frequency variations are removed by means of low-pass filters when deriving the radial control signal.

Figure 3 illustrates the variation of the average intensities A of the radiation beams R_1' and R_2' as a function of the radial position X of the radiation spot s relative to the information tracks. This shows that the difference between these luminous intensities, i.e. the difference between the output signals of the detectors 11 and 12, is representative of the direction and the magnitude of the radial tracking error. This difference signal may consequently be employed as a radial control signal for the radial actuating device 14 by which the radiation spot s is kept centred on the information track. Therefore, this radiation spot s may be used as a read spot and is modulated by the information stored in the information track. Consequently, the output of the detector 10 will supply the information signal and is connected to an information-processing unit. Since this information-processing unit is irrelevant to the present invention it is not represented in Figure 2.

When the radial control signal is generated in this way the problem arises that the control signal then depends on a number of parameters which are subject to variation. For example, the magnitude of the resulting control signal depends on the shape of the information areas in the information track. This shape, for example the depth and/or width of the pits in an information track formed as a high-low-structure, determines the average luminous intensity of the reflected radiation beam when the radiation spot coincides with the information track. As a result of this, the amplitude of the intensity variation V_{R1}, V_{R2} of the radiation beams during radial movement across the tracks depends on the shape of the information areas. As is indicated by the broken line in Figure 2, the magnitude of the control signal $V_{R1} - V_{R2}$ thus obtained depends on this amplitude and thus on the shape of the information areas.

A similar variation of the resulting radial control signal occurs if the focussing of the radiation spots at the information structure is not entirely correct. Normally, the focussing of the radiation beams at the information surface of the record carrier is optimized by means of a focussing control by which the lens 9 is positioned in the direction of the record carrier and by means of which a compensation is provided for out-of-flatness of the record carrier. Depending on the flatness of the record carrier, however, residual focussing errors persist, so that the diameters of the radiation spots s, r_1 and r_2 remain subject to certain variations. These variations of the diameters of the radiation spots, in turn, cause variations in the amplitudes of the luminous intensities V_{R1} and V_{R2} as is indicated in Figure 3 i.e. variations in the resulting radial control signal.

In the case of a variation of the track pitch the steepness of the control signal will vary inversely proportionally to said track pitch. The period of the control signal is directly proportional to the track pitch, so that the steepness is inversely proportional thereto.

Variations in the magnitude of the generated radial control signal restrain the the optimization of the radial servo-control loop, as will be demonstrated with reference to Figure 4. This Figure, by way of example, represents the frequency characteristic of the open-loop gain G of a radial servo-control loop. This characteristic is flat up to a frequency f1. For these low frequencies a very high gain is required because this determines the accuracy of the control system. From the frequency f1 to f2 the frequency characteristic rolls off comparatively steeply (for example 12dB/oct.), because in general the influence at high frequencies, for example caused by imperfections in the record carrier, on the control loop should be avoided. However, in order to ensure that the closed control loop remains stable, the roll-off of the characteristic at the point f3 where the gain factor G is 0dB should not exceed -6 dB/oct. Correction networks may be used to ensure a roll-off of 6 dB/oct. of the characteristic starting from the frequency f2.

However, if the magnitude of the control signal now varies as a result of a variation of the modulation depth or of focussing errors, which means a variation of the open-loop gain G, the frequency characteristic is shifted vertically. If this results in the characteristic represented by the broken line, the servo-control loop will become unstable because the slope will then be -12 dB/oct. at the point of intersection with the 0 dB-axis.

Therefore, the open-loop gain characteristic as a function of frequency should be selected so as to allow for a possible shift of this characteristic, so that optimization of the characteristic is more difficult.

In accordance with the present invention the generated radial control signal is rendered substantially independent of the said parameters, so that once a frequency characteristic has been selected it is well defined and is no longer subject to shifting. This means that this frequency characteristic can be optimized, which may provide a substantial improvement of the control behaviour of the radial servo-control loop.

In accordance with the invention the output signal V_s of the detector 11 is used, in addition to the two output signals V_{R1} and V_{R2} of the detectors 11 and 12, for deriving the control signal V_c. Specifically, a control signal V_c is generated which is given by the formula:

$$V_c = \frac{V_{R1} - V_{R2}}{V_{R1} + V_{R2} - \alpha V_s} \cdot V_{ref} \qquad (1)$$

where α is an adjustment factor and V_{ref} is a reference signal.

In order to demonstrate the effect of this step, the variation of the output signals V_{R1} and V_{R2} of the detectors 11 and 12 may be expressed by the following formulae:

$$V_{R1} = H\,(1 + m \sin 2\pi\tfrac{x}{q})$$
$$V_{R2} = H\,(1 - m \sin 2\pi\tfrac{x}{q}) \qquad (2)$$

Here, H is the luminous intensity of each of the radiation beams R_1 and R_2 projected onto at the record carrier, and m the modulation depth, which depends on the focussing and the shape of the information track.

The output signal V_s of the detector 10 is then given by the formula:

$$V_s = \beta H(1 - m \cos 2\pi\frac{x}{q}) \qquad (3)$$

where β H is the luminous intensity of the radiation beam S, which generally differs from that of the radiation beams R_1 and R_2.

Inserting formulas (2) and (3) in (1) yields:

$$V_c = \frac{2Hm \sin 2\pi\frac{x}{q}}{2H - \alpha (\beta H - Hm \cos 2\pi\frac{x}{q})} V_{ref} \qquad (4)$$

If, with the aid of an adjustment facility in the control device, it is ensured that $\alpha \beta = 2$, this formula reduces to:

$$V_c = \frac{\sin 2\pi\frac{x}{q}}{\cos 2\pi\frac{x}{q}} \cdot V_{ref} = \tan 2\pi\frac{x}{q} \cdot V_{ref} \qquad (5)$$

This shows that the undesired parameter m can be eliminated completely. Furthermore, it can be seen that the shape of the control signal V_c as a function of x (see Figure 5) is no longer sinusoidal as in the case of $V_{R1} - V_{R2}$ (see Figure 5), but tangential, as is represented by the broken line in Figure 5. It is obvious that the shape of the ultimate control signal may be adapted to specific requirements by further electronic processing.

By means of a hyperbolic-tangent operation the tangential shape may be converted into a straight line, so that a saw-tooth characteristic with a period of 1/2 q is obtained. Instead of this sawtooth characteristic it is also possible to generate a sawtooth characteristic having a period q by shifting the first-mentioned sawtooth within specific quadrants of the range $0 < x < q$. Alternatively, the sawtooth characteristic may be converted into a triangular characteristic. Of course, this is of minor importance

for the present invention, the non-ambiguity of the resulting control signal V_c in fact permitting the application of such operations without any risk.

Further, it has been found that the dependence of the control signal on track-pitch variations has been reduced substantially. This is because signal processing in accordance with formula 1 introduces an approximately directly proportional dependence on the track pitch, which at least partly compensates for the previously stated inversely proportional dependence.

Figure 6 schematically represents an example of the control device 13 for generating the desired control signal V_c. The control device 13 comprises three input terminals 21, 22 and 23 for receiving the output signals V_{R1}, V_{R2} and V_s respectively from the detectors 10, 11 and 12. The two signals V_{R1} and V_{R2} are subtracted from each other in a difference forming stage 24. Moreover, these two signals are added to each other in an adder stage 25. The signal V_s is applied to an adjustable amplifier 26 which serves to define the factor α in formula 4. The resulting sum signal $V_{R1} + V_{R2}$ and the output signal αV_s of the amplifier 26 are subsequently subtracted from each other in a difference-forming stage 27, after which the resulting difference signal is again amplified by means of an amplifier 28. This amplified signal from the amplifier 28 and the output signal of the difference-forming stage 24 are finally applied to a divider stage 29, which produces a control signal V_c on an output terminal 32. In the present example this divider stage comprises an amplifier 30 with a feedback circuit comprising a multiplier 31.

Hereinafter two further possibilities are given. If the multiplier is a four-quadrant multiplier a control signal V_c is obtained whose variation as a function of $\underline{x}$ is as represented by the broken line in Figure 5. However, it is alternatively possible to employ a two-quadrant multiplier. In that case the amplifier 28 should be designed so that its output signal corresponds to the modulus of its input signal. This version supplies a control signal V_c' whose variation as a function of x corresponds entirely

to the variation of V_c in the relevant quadrants $0 < x < 1/4q$ and $3/4 q < x < q$, but is inverted in the other two quadrants $1/4 q < x < 3/4q$ (see Figure 5 dash-dot line). By limiting the magnitude of the control signal V_c' in this version to a specific value Ao a continuous variation of control signal as a function of x is again obtained as shown in Figure 5, which only differs from the variation of the control signal $V_{R1} - V_{R2}$ as regards its shape.

Finally, Figure 7 represents the control device 13 shown in Figure 6 in detail. This control device also generates a control signal for focussing control, which is based on the so-called astigmatic focussing method as, for example, described in Netherlands Patent Application 7,703,076. In order to obtain a focussing-error signal by means of this method the detector 10 (Figure 1) for the radiation spot s is split into a plurality of sub-detectors. By a suitable combination of the output signals of these sub-detectors two signals F_1 and F_2 can be obtained whose difference represents the focussing error.

In the control device shown in Figure 7 these two signals F_1 and F_2, which are available as detector currents, are applied to the two inputs 31 and 32 respectively of a differential amplifier 30. The difference signal ΔF is then available on the output 33 of this differential amplifier 30 for further processing in the focussing servo-control loop.

The sum of the two signals F_1 and F_2, which sum corresponds to the signal V_s shown in Figure 6, is applied to the input 41 of the amplifier 26, which is arranged as a current-mirror circuit and on whose output 42 the amplified signal current is available. This current mirror circuit comprises a variable resistor 43 for adjusting the gain factor between the input and the output, which gain factor determines the factor α in formula (1).

The difference-forming stage 27 is also formed by a current-mirror circuit comprising an input 51 and an output 52. The sum of the output signals of the two detectors 11 and 12 is then applied to the input 51, so that first the sum of these two signals must be formed. However, a simpler solution is also possible. The detectors

10, 11 and 12 are generally integrated on one substrate and their respective detector currents are available on the relevant outputs. However, the substrate also carries a current which corresponds to the sum of all detector currents and thus corresponds to $V_{R1} + V_{R2} + V_s$. By feeding the substrate current to the input 51 of the current mirror 27 a separate adder circuit 25 (Figure 6) may be dispensed with, whilst the additional term V_s may be eliminated by adjusting the gain factor of the amplifier 26.

The output 52 of the current mirror 27 is connected to the output of the current mirror 26, so that the two output currents of the current mirrors are subtracted from each other and the difference signal $V_{R1} + V_{R2} - \alpha V_s$ is available on the output 52 as the difference current.

This difference current is applied to the input 61 of the amplifier 28. This amplifier 28 also performs a modulus operation. An input current of negative polarity on the input 61 is passed through two current mirrors, namely the mirrors 62 and 63 and hence is available on the output 64 as an output current of negative polarity. An input current of positive polarity on the input 61, however, is passed through one current mirror only, namely the current mirror 65, and is consequently also available on the output 64 as an output current of negative polarity.

This output current is applied to an input 71 of the divider stage 29. The second signal for this divider stage on input 72 is obtained from the difference-forming stage 24, which is formed by a current mirror, whose two inputs 81 and 82 receive the detector signals V_{R1} and V_{R2}. The quotient which is available on the outputs 73 and 74 of the divider stage as a difference signal is once more amplified in an amplifier stage 90 and is finally available on an output terminal 91 as the control signal V_c. This amplifier stage 90 comprises two further inputs 92 and 93 to which reference signals may be applied for correcting an offset in the circuit.

Finally, the circuit arrangement shown in Figure 7 comprises an output terminal 65 which is coupled to the modulus amplifier 28.

This output 65 supplies a squarewave output signal V_p, which has a first value for $0 < x < 1/4q$ and $3/4q < x < q$, and a second value for $1/4q < x < 3/4q$, as is shown in Figure 8. Figure 8 also represents the variation of the control signal V_c available on the output 91. The squarewave signal V_p may be used for modifying the control signal V_c in order to obtain an even more reliable centring. As is apparent from the shape of V_c, the control range is in fact limited to $-1/4q < x < 1/4q$. If the tracking error increases further, for example as a result of a fault condition, the control signal for $x > 1/4q$ suddenly decreases for increasing x. In that case, and also as a result of possible phase inversions upon exceeding the limit $x = 1/4q$, the control system may no longer be capable of returning the read spot to the desired track rapidly enough (x=0) but may move this spot to the next track (x = q).

Since it is at this very limit $x = 1/4q$ that the squarewave signal V_p becomes zero, this signal may be used for modifying the control signal in order to improve the stability. Specifically this signal V_p may actuate a hold circuit which upon the limit $x = 1/4q$ being exceeded holds the control signal V_c at the value Ao as long as this signal V_p is zero. In the same way the control signal V_c is held at the value -Ao upon the limit $x = -1/4q$ being exceeded. For centring on the track at x = 0 this yields a control signal V_o' which for $-1/4q < x < 1/4q$ corresponds to the control signal V_c. For $1/4q < x < 3/4q$ this control signal V_c' has the value Ao, for $-3/4q < x < -1/4q$ the value -Ao, whilst for $x < -3/4q$ and $x > 3/4q$ the signal V_o' is again equal to V_c. As is apparent from the Figure the hold range of the control system is substantially extended by this step, so that the read spot will remain centred at the desired track with a high degree of certainty.

It will be evident that the present invention is not limited to the embodiments shown in the Figures. Depending on the choice of the optical system modifications may be applied both as regards the system and the circuit design.

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CLAIMS:

1. Apparatus for reading a disk-shaped record carrier having substantially concentric information tracks, which apparatus comprises an optical system for producing three radiation beams and projecting said radiation beams onto the record carrier as a first, a second and a third radiation spot, the second and third radiation spots being disposed on opposite sides of the first radiation spot in a direction transverse to the track direction and the distance between their respective centres and the axis which extends through the centre of the first radiation spot and parallel to the information tracks being at least substantially 1/4 of the track pitch of the information tracks, a first, a second and a third detector for detecting the amount of luminous energy in the radiation beams emerging from the record carrier and corresponding to the first, the second and the third radiation spot respectively and for converting this luminous energy into corresponding electric output signals, a tracking system, which co-operates with the radiation beams, for centring the first radiation spot on an information track, and a control device, coupled to the first, the second and the third detector, which in use generates a tracking-system control signal V_c given by the formula:

$$V_c = \frac{V_{R1} - V_{R2}}{V_{R1} + V_{R2} - \alpha V_s} \cdot V_{ref}$$

where V_s, V_{R1} and V_{R2} are the output signals of the first, the second and the third detector respectively, α is an adjustment factor, and V_{ref} is a reference signal.

2. Apparatus as claimed in Claim 1, wherein the control device comprises a first difference-forming stage for determining the difference between the output signals of the second and the third detector, a second difference-forming stage for determining the

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difference between the sum of the output signals of the second and third detector and a proportion of the output signal of the first detector, and a divider stage for determining the quotient of the output signals of the first and the second difference-forming stage and supplying a control signal which corresponds thereto.

3. Apparatus as claimed in Claim 2, wherein between the second difference-forming stage and the divider stage there is arranged an amplifier for subjecting the output signal of said second difference-forming stage to a modulus operation.

4. Apparatus as claimed in Claim 2, wherein the second difference-forming stage receives a first input signal which is proportional to the sum of the output signals of the first, second and third detector.

5. Apparatus for reading a disc shaped record carrier substantially as described with reference to Figures 1,2,5 and 6 or to Figures 1,2,6 and 8 of the accompanying drawings.

6. Apparatus for reading a disc shaped record carrier substantially as described with reference to Figures 1,2,5 and 7 or to Figures 1,2,7 and 8 of the accompanying drawings.