

PATENT SPECIFICATION

(11) 1 490 726

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- (21) Application No. 48309/74 (22) Filed 7 Nov. 1974
 (31) Convention Application No. 7315419
 (32) Filed 10 Nov. 1973 in
 (33) Netherlands (NL)
 (44) Complete Specification published 2 Nov. 1977
 (51) INT CL³ G05D 3/02 G02F 1/29
 (52) Index at acceptance
 G3R 31F 69 9B 9E 9G



(54) READING OPTICALLY-RECORDED DISCS

(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 an apparatus for reading a disc-shaped record carrier in which signals are recorded in parallel tracks. The term "parallel tracks" is to be understood to mean a number of tracks constituting the successive turns of a spiral or a number of separate circular concentric tracks. The apparatus includes an optical read unit with a radiation source, a radiation directing system and a read detector, which radiation source emits a radiation beam, which is projected onto the record carrier as a read spot of radiation and which *via* the radiation directing system transfers the information contained in the scanning point of the record carrier to the read detector, a control system for controlling the radial position of the scanning point on the desired track, which control system includes a drive means for the radiation directing system and a first measuring system for measuring the radial position of the scanning point and supplying a corresponding first control signal to the drive means, which first measuring system employs a first pattern of radiation spots projected onto the record carrier, which first pattern is imaged onto a first measuring detector and which first measuring system supplies a first control signal, which during a radial movement of the scanning point over a number of adjacent tracks contains a periodic alternating component whose period corresponds to the track separation, the control system being stable for one half period of said alternating component and being unstable for the other half period. In this respect the terms stable and unstable denote a decrease and increase respectively of the kinetic energy in the system as the scanning point passes through the relevant periods.

Such an apparatus is known from Patent Specification No. 1,429,882. The radial control system used therein serves to ensure that when the information recorded on the record carrier is being read the scanning point always accurately follows the information track on said record carrier. The method of modulation of the recorded signal and the method by which said signal is recorded on the record carrier is not essential for the present invention, so that they will not be discussed in further detail. As an example of a method of recording reference is made to Patent Specification No. 1,391,541.

When the record carrier is provided with a spiral information track, the scanning point should be moved radially at approximately uniform speed. Said uniform movement is generally obtained by moving the read unit in a radial direction. In addition, it should be possible to effect relatively small but rapid radial movements of the scanning point because, for example as a result of an eccentricity of the pivot relative to the centre of the record carrier, there may be radial deviations in the position of the information track.

Said rapid radial movements of the scanning point are effected with the aid of said control system, which consists of the drive means for the radiation directing system and the first measuring system. The radiation directing system usually consists of a reflecting element, which under the influence of the drive means can be subjected to a rotation and can thus reflect an incident beam of radiation at a variable angle. Said radiation directing system, as in the said Patent Specification No. 1,429,882, can influence the direction of the radiation beam before said beam impinges on the record carrier or after said beam impinges on the record carrier and has already been

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modulated by the information contained therein. The record carrier itself may be either radiation-transmitting or radiation-reflecting.

The first measuring system for measuring the radial position of the scanning point may have different embodiments. For example, use can be made of a first pattern of radiation spots projected onto the record carrier by a radiation source, which pattern consists of two radiation spots which viewed in the radial direction are situated at either side of the scanning point, each of said radiation spots being imaged onto a separate part of the first measuring detector. The relative magnitude of the signals produced by the images of the two radiation spots on the separate parts of the measuring detector will change in accordance with the position of the scanning point relative to the information track. By subtraction of the signals supplied by the separate parts of the first measuring detector, a first control signal is obtained which is unambiguously representative of the position of the scanning point relative to the information track. Another possibility is to image a number of tracks with the aid of a relatively large radiation spot onto a grating-shaped measuring detector as described in Patent Specification No. 1,391,335.

In all said measuring systems a control signal is produced which, upon a radial displacement of the scanning point over a number of adjacent tracks comprises a periodic alternating component whose period corresponds to the track separation. In this respect track distance is to be understood to mean the distance measured in the radial direction between the centre lines of two adjacent tracks. The said alternating component is used as a control signal for the drive means of the directing system.

It has been found that in the case of a radial displacement of the scanning point over a number of adjacent tracks, the control system is in a stable state for half a period of the periodic alternating component, and in an unstable state during the other half period of said alternating component. This is because the alternating component, which is used as a control signal for the drive means of the directing system, has a positive slope during one half period and a negative slope during the other half period so that in the event of a change of the radial position of scanning point the variation of the control signal which is applied to the drive means is of opposite sign.

Normally, this property of the control system presents few problems because the system, once it is in the stable range, will always remain in the said stable range under normal conditions. However, if the control system leaves the stable range owing to a disturbance, for example owing to a shock or a flaw in the record carrier, said property may cause a relatively large, substantially undamped oscillation, so that the scanning point may effect an oscillation over a number of track distances in a radial direction and a correct reading of the information is not possible until after a certain, and sometimes comparatively long, time delay after the occurrence of the disturbance.

It is an object of the invention to provide an apparatus in which said time delay is limited. The invention provides apparatus for reading a disc-shaped record carrier on which signals are stored in parallel tracks as defined herein, which apparatus includes an optical read unit with a radiation source, a radiation directing system and a read detector, which radiation source is adapted to emit a radiation beam which is projected onto the record carrier as a scanning point of radiation and which, via the radiation directing system, transfers the information derived by the scanning point from the record carrier to the read detector, said apparatus further including a control system for controlling the radial position of the scanning point on the desired track, which control system includes drive means for the radiation directing system, a first measuring system for measuring the radial position of the scanning point and supplying a corresponding first control signal to the drive means, which first measuring system comprises means for projecting a first pattern of radiation spots onto the record carrier, and means for imaging said first pattern onto a first measuring detector, said first control signal, during radial movement of the scanning point over a number of adjacent tracks, including a first periodic a.c. component whose period corresponds to the track separation, the control system being stable for one half period of said first a.c. component and being unstable for the other half period of said first a.c. component said apparatus being characterized in that for assuring the stability of the control system a second measuring system is provided comprising means for projecting a second pattern of radiation spots onto the record carrier and means for imaging said second pattern onto a second measuring detector, which second measuring system supplies a second control signal, which during radial movement of the scanning point over a number of adjacent tracks contains a second periodic a.c. component whose period corresponds to the track separation, but which second a.c. component, as a result of a different radial position of the second pattern of radiation spots relative to that of the first pattern of radiation spots, exhibits a phase shift corresponding to

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substantially a quarter period of the track separation relative to the first periodic a.c. component of the first control signal, and in that the control system has a variable transfer function which is controlled by a control unit which receives a third control signal which is derived from the second control signal, and which control unit upon a movement of the scanning point over a number of adjacent tracks controls the transfer function.

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By means of the second measuring system a second control signal is obtained which provides an indication on whether or not the control system is in the stable range. Since the alternating component of said second control signal relative to the alternating component of the first control signal exhibits a phase shift of at least substantially a quarter period the half period of the one polarity of the alternating component of said second control signal corresponds to a half period of the alternating component of the first control signal with a slope of a first signal, and the other half period of the opposite polarity of said alternating component of the second control signal corresponds to the other half period of the alternating component of the first control signal with a slope of opposite sign.

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The third control signal may be derived as a square wave signal substantially in phase with the second control signal.

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Said third control signal may influence the transfer function of the control system when said system comes into its unstable range in such a way that as said control system passes through alternately stable and unstable ranges the kinetic energy exchanged during passage through an unstable range is smaller than the energy exchanged during passage through the stable range. For this purpose, various possibilities are available. First of all, the gain of the control system may be reduced as the control system passes through the unstable range. A second possibility is the reduction of the damping term in the control system, which gives rise to a negative damping in the unstable range. Finally, the sign of said damping term may be reversed in the unstable range, so that it provides a positive damping in said range.

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The third control signal may be derived in such a way as to provide an indication of the direction in which the scanning point is moved in a radial sense. Said control signal can be obtained by differentiation of the second control signal. Thus, a signal is obtained which is in phase or in phase opposition relative to the first control signal depending on the direction of movement of the scanning point. By controlling the transfer function with the aid of said signal an unambiguous stabilizing action results, because depending on the direction of movement the transfer function is varied either during the positive or during the negative period of the first control signal.

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It is also possible to multiply the differentiated second control signal by the first control signal, so that a signal is obtained whose polarity is a direct indication of the direction of movement of the scanning point. Said information may then be used for influencing the transfer function either during the positive or during the negative period of the first control signal.

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In addition to said two possibilities, a number of complementary steps may be taken, which will be further outlined in the description.

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The second measuring system may have different embodiments in accordance with the desired accuracy. The second pattern of radiation spots may consist of two radiation spots which are radially shifted relative to each other by a distance equal to half the track separation and which are each imaged onto a separate part of the second measuring detector, a second control signal being obtained by subtraction of the signals supplied by said separate parts of the second measuring detector. Said embodiment has the advantage that the second control signal thus obtained merely contains an alternating component, whilst the d.c. component normally present in the signal formed by imaging a radiation spot on a measuring detector is eliminated by the subtraction. Said d.c. component is both time-dependent as a result of noise in the radiation energy supplied by the radiation source and location-dependent as a result of differences in the radiation absorption and/or reflection as a function of the location on the record carrier and as a function of the location where the radiation beam in the read unit is transmitted, in particular of the lens systems used.

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The second measuring signal may be obtained by measuring the signal received by the read detector itself, specifically the low-frequency variations of said signal. This has the advantage that no additional measuring detector is required, but on the other hand it has the drawback that the supplied control signal contains a d.c. component which may give rise to less accurate operation.

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

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Fig. 1 shows a read apparatus embodying the invention, and
Figs. 2 and 3 show the associated control signals,
Figs. 4 and 5 show two methods of obtaining the desired control signal, and
Fig. 6 shows a number of signal characteristics in illustration of the method of
Fig. 5,

Figs. 7 and 8 show two methods of influencing the transfer characteristic of the servo-unit in accordance with the control signal,

Fig. 9 in conjunction with Fig. 10 shows an alternative method of obtaining the desired stabilization,

whilst Figs. 11 and 12 show two embodiments of the differentiation circuit employed for implementing the method described with reference to Figs. 9 and 10, in order to obtain a special effect.

In Fig. 1 the reference number 1 designates a disc-shaped record carrier, which at its underside is provided with a multiplicity of concentric or quasiconcentric tracks, not shown. In said tracks the information can be recorded in various known manners. As an example, reference is made to Patent Specification No. 1,391,541, in which the information track contains blocks and areas whose length represents the stored information. Said blocks and areas have a different effect on a radiation beam which is projected onto the information track, so that said radiation beam is modulated in accordance with the recorded information. For example, the transmission or reflection coefficient of the blocks may differ from that of the areas, so that a read beam of radiation is amplitude modulated. In a reflecting record carrier it is equally possible to dispose the blocks and areas at different levels, the difference in depth being one fourth of the wavelength of the radiation used for reading. The read beam of radiation is then phase modulated. As the method of modulation and the method of recording the signal which is recorded on the record carrier are only of secondary importance for the present invention, they will not be discussed in more detail.

The record carrier 1 is rotated by a motor M_1 via a shaft 2 which extends through a central opening in said record carrier. The information stored in said record carrier 1 is read with the aid of a beam of radiation, which after interaction with the record carrier is detected with the aid of an optical read device, which is accommodated in a housing 3. Said optical read apparatus, which substantially corresponds to that described in Patent Specification No. 1,429,882 includes a light source 6, which emits a read beam of radiation α . Via a semi-transparent mirror 7 said beam of radiation α reaches a plane mirror 8, so that the radiation beam is reflected in the direction of the record carrier 1. Said reflected beam of radiation α is shown schematically focussed to a scan spot S at the lower surface of the record carrier 1 by a lens 11. The radiation beam which is reflected by said record carrier is again reflected towards the semi-transparent mirror 7 by the plane mirror 8 and by the mirror 7 to a read detector 12, on which the scanning point S of the record carrier is thus imaged and which detects the information contained in the beam of radiation. Said detected information is available for further processing at an output terminal 14.

To guarantee a continuous reading of the information stored on the record carrier the scanning point S which is imaged on the read detector 12 should continually follow the information track of the record carrier. If said information track is spiral shaped, this means that the scanning point S must first of all be moved in a radial direction at a speed which corresponds to the pitch of said spiral information track. Furthermore, the scanning point S must be capable of following possible radial movements of the information track, for example those resulting from an eccentricity of the "central" opening of the record carrier.

This necessary control of the radial position of scanning point S is established by co-operation of two control systems, namely a coarse control which can only effect a slow radial displacement of the scanning point and a fine control which can only perform a relatively small but rapid radial displacement of the scanning point. In the embodiment shown the coarse control is obtained with the aid of a motor M_2 , which via a servo-amplifier 16 receives a control signal and which by means of a transmission, for example the worm 4 and the gear rack 5, can move the housing 3 in the radial direction. Fine control is effected with the aid of the plane mirror 8 which is rotatable about a spindle 9.

Rotation of the mirror 8 is effected by a drive element 10, for which various elements may be employed, a number of possibilities being given in the cited Patent Specification No. 1,429,882. Said drive element receives a control signal from a servo-unit 15.

The information concerning the radial position of the scanning point S relative to the desired track which is required for said control is obtained with the aid of a

radiation beam *b*, which is produced by the radiation source 6, and which also impinges on the lower surface of the record carrier 1 *via* the semi-transparent mirror 7, the mirror 8 and the lens 11. After reflection said radiation beam *b* *via* the mirror 8 and the semi-transparent mirror 7 reaches a control detector 13 whose output signal is fed to the servo-unit 15. As a control signal for coarse control, which is to be applied to the servo-amplifier 16, a signal is employed which is a measure of the average deviation of the mirror 8 relative to a central position. Such a signal can be obtained in various manners, which are obvious to those skilled in the art, for example with the aid of capacitive or inductive transducers, which is the reason why the figure only schematically indicates how the desired control signal is taken from the drive element 10.

Depending of the composition of the radiation beam *b* the control detector 13 may have different embodiments. As a first example reference is made to Patent Specification No. 1,391,335. The control detector described therein consists of a grating of radiation-transmitting and radiation-absorbing strips, onto which *via* the radiation beam *b* a number of tracks of the record carrier are imaged. The position of said grating shaped image of the track pattern relative to the grating-shaped detector by means of suitable transducer elements provides a control signal which is representative of the position of the scanning point *S* relative to the desired track. As a second example reference is made to Patent Specification No. 1,434,834. In this embodiment two radiation spots are projected at either side of the scanning point by the radiation beam *b* and the control detector consists of two separate sub-detectors, on each of which one of the radiation spots is imaged. The intensity of the two imaged radiation spots varies in accordance with the radial position of the scanning point and subtraction of the output signals of the two sub-detectors yields a suitable control signal.

Generally, a control signal is obtained with the aid of the control detector 13, which signal as a function of the radial position of the scanning point is substantially as shown in Fig. 2. Apart from a possible d.c. component said control signal contains an a.c. component whose period equals the track separation, *i.e.* the distance between the centre lines of two adjacent tracks. Fig. 2 shows a purely sinusoidal shape. However, it will be evident that depending on the detector system used said shape may depart from sinusoidal. For simplicity, only a sinusoidal control signal will be discussed hereinafter.

Fig. 2 represents the control signal which is obtained upon a displacement of the scanning point over 3 adjacent tracks. The control system is assumed to be in the stable state at the points where the control signal is zero and the slope is positive, *i.e.* points *s*₁, *s*₂ and *s*₃, which consequently correspond to the centres of said adjacent tracks. For example, if the scanning point moves from the track *s*₁ towards a higher value of the radius *r*, a positive control signal is produced, depending on which the control system is assumed to force the scanning point back to said position *s*₁. For a displacement of the scanning point towards a smaller value of *r* it is obvious that the reverse applies.

However, if the scanning point enters a range *Q*, which corresponds to a negative slope of the control signal, the control system suddenly becomes unstable. As it passes through the range *Q*, the system gains energy, which implies that if the scanning point traverses a full track distance owing to a disturbance, it will automatically traverse more track distances.

As a result of an extraneous disturbance the scanning point *S* may be moved over a number of track distances, which number is first of all determined by the deviation of the mirror at the instant of the disturbance. As the coarse control is also actuated for a rotation of the mirror *S* which corresponds to said displacement, a substantially undamped oscillation of the scanning point over a number of track distances may occur owing to interaction of the fine and the coarse control, so that at least for a certain time reading of the information stored on the record carrier becomes impossible.

In order to remedy this, the radiation source 6 in the read apparatus of Fig. 1 emits a third radiation beam *c*, which *via* the semi-transparent mirror 7, the mirror 8 and the lens 11 impinges on the record carrier. The portion of said radiation beam that is reflected by the record carrier is again reflected to an additional detector 17 *via* the mirror 8 and the semi-transparent mirror 7. Said additional detector 17 supplies an additional control signal, whose shape substantially corresponds to the shape of the control signal supplied by the control detector 13. As a result of a different radial position of the pattern of radiation spots which is projected onto the record carrier by the radiation beam *c* relative to the pattern of radiation spots which is projected onto the record carrier by the radiation beam *b*, the additional control sig-

nal exhibits a phase shift of $\frac{1}{2}$ period relative to the control signal supplied by the control detector 13.

For clarity the two control signals are shown in Fig. 3. The first control signal I_1 , which is supplied by the control detector 13 corresponds to the control signal shown in Fig. 2. The second control signal I_2 supplied by the additional detector 17 has the same shape as the control signal I_1 as a function of r , but is phase shifted by $\frac{1}{2}$ period. From said second control signal I_2 a third control signal I_2' can be derived in a simple manner, which has a first positive value when the second control signal I_2 is positive and a second negative value when said second control signal I_2 is negative. It is then evident from the Figure that the positive value of the third control signal I_2' corresponds to the stable ranges P of the first control signal I_1 and the negative value to the unstable ranges Q. For this, it is assumed that a positive value of the first control signal I_1 causes a displacement of the scanning point towards smaller values of r and a negative value a displacement towards higher values. The third control signal I_2' thus provides an indication whether the control system is in a stable range P or in an unstable range Q. Said information is used for influencing the control system during at least a part of the time that said control system is an unstable range.

The third control signal I_2' derived from the additional control signal of the detector 17 by a converter 18, in this case a squarewave generator, is fed to the servo-unit 15 which is included in the control system and which depending on the value of said third control signal I_2' may have two possible transfer functions. Obviously, the first transfer function, which is operative in the stable control range P, serves to obtain an optimum control behaviour within said stable range. The second transfer function, which is operative in the unstable range Q, has a different transfer function, such that whilst the scanning point passes through a number of stable and unstable ranges P and Q respectively, the energy exchanged by the servo-unit 15 during passage through the unstable range Q is smaller than the energy exchanged during passage through the stable ranges P. This ensures that upon the occurrence of an external disturbance a damped oscillation is always produced, so that the scanning point is restored to a stable setting. How fast this happens of course depends on the degree and the manner in which the transfer functions of the servo-unit 15 are varied. Naturally, if desired, the third control signal I_2' can be a continuously varying signal derived from the second control signal I_2 , at least during the unstable periods.

However first of all some possibilities of obtaining the desired control signals I_1 and I_2 will be described. A first possibility is represented in Fig. 4. A part of three adjacent tracks is designated by s_1 , s_2 and s_3 , which tracks are spaced at a track separation λ from each other. S is the scanning spot, i.e. the area of the record carrier which is eventually imaged onto the read detector 12. The pattern of radiation spots of the radial control system basically consists of two radiation spots R_1 and R_2 , which are situated at either side of the scanning spot S in the radial direction at a distance of $\frac{1}{2}\lambda$. The additional pattern of radiation spots obtained with the aid of the radiation beam c comprises the two radiation spots T_1 and T_2 . The radiation spot T_1 is radially shifted relative to the radiation spot R_1 by a distance of $\frac{1}{2}\lambda$, and the radiation spot T_2 is shifted by the same distance relative to the radiation spot R_2 . Each of the radiation spots is eventually imaged onto a separate detector or subdetector.

Generally, the signal I_{det} supplied by such a detector as a result of the radiation spot imaged thereon may be written in terms of:

$$I_{det} = I_0 \left(1 + m \sin \frac{r}{\lambda} \cdot 2\pi \right) \quad (1)$$

I_0 being the energy supplied by the radiation beam at the location of the radiation spot, m being the amplitude of the a.c. component upon a radial displacement of the radiation spot, r being the radial position of said radiation spot, and λ being the track separation.

Assuming that the image of the radiation spot R_2 actually results in such a signal, i.e.

$$I_R = I_0 \left(1 + m \sin \frac{r}{\lambda} \cdot 2\pi \right) \quad (2)$$

the image of the radiation spot R_1 will yield a signal

$$I_{B_1} = I_0 \left(1 + m \sin \frac{r + \frac{1}{2}\lambda}{\lambda} 2\pi\right) = I_0 \left(1 - m \sin \frac{r}{\lambda} 2\pi\right) \quad (3)$$

Subtracting the signal I_{B_1} from the signal I_{B_2} yields the following control signal

$$I_1 = 2 m I_0 \sin \frac{r}{\lambda} 2\pi \quad (4)$$

which is entirely in accordance with the waveform I_1 shown in Fig. 3 and in which I_0 appears as a multiplying factor only and not as an added d.c. component.

Similarly, the image of the radiation spot T_1 yields the signal

$$I_{T_1} = I_0 \left(1 + m \sin \frac{r + \frac{1}{2}\lambda}{\lambda} 2\pi\right) = I_0 \left(1 + m \cos \frac{r}{\lambda} 2\pi\right) \quad (5)$$

and the image of the radiation spot T_2 gives the signal

$$I_{T_2} = I_0 \left(1 + m \sin \frac{r - \frac{1}{2}\lambda}{\lambda} 2\pi\right) = I_0 \left(1 - m \cos \frac{r}{\lambda} 2\pi\right) \quad (6)$$

Subtracting the signal I_{T_2} from the signal I_{T_1} yields as additional control signal

$$I_2 = 2 m I_0 \cos \frac{r}{\lambda} 2\pi \quad (7)$$

which is fully in accordance with the signal waveform I_2 of Fig. 3.

If desired, the number of radiation spots for obtaining the desired control signal may be increased. Fig. 4 by way of example shows two additional radiation spots R_3 and R_4 , the radiation spot R_3 being located at a distance λ from the radiation spot R_1 and the radiation spot R_4 at a distance λ from the radiation spot R_2 . The signals I_{R_3} and I_{R_4} resulting from the radiation spot R_3 and R_4 respectively are therefore fully

in phase with the signals I_{R_1} and I_{R_2} resulting from the images of the radiation spots R_1 and R_2 respectively. When taking

$$(I_{R_2} + I_{R_4}) - (I_{R_1} + I_{R_3})$$

as a control signal, the resulting signal is entirely in phase with the control signal I_1 but has twice the amplitude.

The use of the additional radiation spots has some substantial advantages. First of all, as previously stated, the amplitude of the control signal thus obtained is doubled. Secondly, the effect of errors in the separation of the tracks is reduced, because the additional radiation spots result in a certain averaging. Furthermore, the influence on the control signal of the information which is contained in the tracks is reduced. Normally, said high-frequency information is removed with the aid of filters. Since the additional radiation spots also result in a certain averaging with respect to this parameter, the influence of this information component is automatically reduced. Naturally, it is also possible to use more than two additional radiation spots, so that the said effects become more marked. Further, the radiation spot R_3 may be situated at a track distance λ from the radiation spot R_2 , i.e. between the tracks s_2 and s_3 and the radiation spot R_4 at a track distance λ from the radiation spot R_1 , i.e. between the tracks s_1 and s_2 . The desired control signal is then represented by

$$(I_{R_2} + I_{R_4}) - (I_{R_1} + I_{R_3})$$

A second possibility of obtaining the desired control signals is represented in

Fig. 5, the associated waveforms being shown in Fig. 6. Fig. 5 shows a track s , on which a scanning spot S is projected. At either side of said scanning spot two radiation spots R_1 and R_2 are projected, which are radially shifted by a distance of $\frac{1}{2}\lambda$ relative to the scanning spot S . By means of the radiation spots R_1 and R_2 , the control signal I_1 is obtained in a manner identical to that described with reference to Fig. 4, which signal again complies with the formula (4) and which is shown in Fig. 6a.

However, in this case the additional control signal is not obtained with the aid of additional radiation spots, but is derived from the signal obtained by imaging the scanning spot S on the read detector. Generally, the information contained in the information track will have a higher frequency than the maximum control frequency. As a result, said low-frequency signal component can be extracted from the signal supplied by the read detector with the aid of filters. Said signal component, except for a phase shift, complies with the general formula (1) and may be written in terms of

$$I_T = I_0 \left(1 + m \sin \frac{r + \lambda/4}{\lambda} \cdot 2\pi \right) = I_0 \left(1 + m \cos \frac{r}{\lambda} \cdot 2\pi \right) \quad (8)$$

Said signal I_T , shown in Fig. 6b, contains an a.c. component which is suitable for deriving the desired control signal from it and also contains a d.c. component I_0 . With the aid of a separator stage the d.c. component I_0 can be extracted, after which the desired control signal I_T' (0), shown in Fig. 6c, can be derived from the remaining a.c. component, whose periods again accurately correspond to the stable and unstable ranges of the control system.

A problem associated with this embodiment is the presence of the d.c. component in the control signal I_T . Said d.c. component I_0 is not entirely constant, but is both time and location dependent. The time dependence is mainly caused by variations in the intensity of the radiation emitted by the radiation source. The location dependence is caused by a difference in absorption and/or reflection in accordance with the position of the record carrier and the location where the beam of radiation is transmitted through the optical system, in particular the lenses.

In order to obtain an insight into the consequences of these two variations of the d.c. component I_0 in the control signal I_T , the effect of variations of the d.c. level which is extracted from said control signal I_T will now be considered. Indeed, said extraction process itself may give rise to additional variations. Assuming that instead of the correct d.c. level I_0 , the D.C. level D.C. (1) is extracted, which is lower than I_0 , a control signal I_T' (1) is derived from the residual a.c. component, which control signal is shown in Fig. 6d. This reveals that only a part of the unstable ranges Q is acceptable because at any rate during a part of said unstable ranges the stabilizing steps can be taken, so that a possible oscillation is damped anyway. However, assuming that instead of the d.c. level I_0 , the higher d.c. level D.C. (2) is extracted, a control signal I_T' (2) as shown in Fig. 6e will be derived from the residual a.c. component. Said control signal I_T' (2) even identifies parts of the stable ranges P as unstable regions, so that during a part of the stable ranges the transfer function destined for the unstable ranges is rendered effective. Said transfer function may then cause an unstable behaviour in the relevant part of the "stable" range, which of course is highly undesirable. However, by a suitable choice of said transfer function, it can be achieved that even for this incorrect identification of parts of the stable and unstable ranges a stable system is retained under all conditions. This will be discussed in more detail when describing the embodiments of the servo-unit shown in Figs. 7 and 8.

A method of eliminating said undesired d.c. component of the control signal I_T is the formation of the sum of the signals produced by the radiation spots R_1 and R_2 , i.e. the sum of the signals which are represented by the formulas (2) and (3). Said sum signal equals $2I_0$ and therefore only contains the d.c. component. This allows said sum signal to be used for the compensation of the d.c. component I_0 contained in the control signal I_T , because said two components are always substantially subject to the same variations.

The embodiment of apparatus in accordance with the invention shown in Fig. 7 includes a servo unit 15, which receives its input signal from the control detector 13 and supplies a control signal for the drive means 10 of the mirror. The control signal supplied by the control detector 13 is applied both to an adder unit 21 and to a differentiator 19. Via an amplifier 20 the output signal of said differentiator 19 is inverted and applied to the adder unit 21. The output signal of the adder unit is finally amplified by the amplifier 22 and then serves as an output signal of the servo-unit.

The differentiator 19 together with the amplifier 20 provides the desired damping term in the transfer function of the servo-unit 15.

The transfer function of the servo-unit is influenced by a control signal which is derived by a squarewave shaper 18 fed with the second control signal I_2 supplied by the detector 17 and which control signal consequently corresponds to the third control signal I_2' shown in Fig. 3 except for the presence of the d.c. component I_0 . Said control signal may be applied to either or both amplifiers 20 and 22. If the control signal is fed to the amplifier 22, steps can be taken to reduce the gain factor of the transfer function of the servo amplifier in the unstable ranges of the control system. If the control signal is applied to the amplifier 20, the absolute value of the damping term in the unstable ranges of the control system can be reduced. In an unstable range, because of the opposite slope of the control signal which is supplied by the control detector 13 as a function of the radius r said damping term gives rise to a negative damping whose influence is diminished by said reduction of the gain factor of amplifier 20.

In the method of obtaining the control signal described with reference to Figs. 5 and 6 said method of influencing the transfer function of the servo-unit is preferred. The reduction of the gain factor of the amplifiers may then be selected so that the resulting reduced transfer function remains stable, even when switching over occurs in a stable range P of the servo system.

Fig. 8 shows a second embodiment of apparatus in accordance with the invention. The servo-unit 15 is of substantially the same design as that shown in Fig. 7. The output signal of the amplifier 20, however, is now applied to a switch 23, which in a first position directly supplies said output signal to the adder unit 21 and in a second position *via* an inverting amplifier stage 24. Said switch 23 is actuated by a control unit 25, which receives the third control signal I_2' supplied by the squarewave shaper 18. When the control system enters an unstable range, the switch 23 is set to the second position, so that the generated damping term is additionally inverted. As a consequence, said damping term also causes a positive damping in the unstable range.

Said method of influencing the transfer function of the servo-unit 15 by altering the sign of the damping term is not particularly suited to be employed in the method of obtaining the control signal described with reference to Figs. 5 and 6. This is because if, due to incorrect thresholding of I_2 , the control signal were changed over during a stable range, causing the sign of the damping term to be reversed, the control behaviour in said stable range would seriously be disturbed.

Fig. 9 shows a third embodiment of apparatus in accordance with the invention. The servo-amplifier 15 is identical to that of Fig. 7. However, in this case the control signal supplied by the detector 17 is not fed to a squarewave shaper, but to a differentiator 26. In the case of a first control signal I_1 (see Fig. 10a) which satisfies formula (4) and a second control signal I_2 (see Fig. 10b) which satisfies formula (7), said differentiator 26 supplies a signal

$$\frac{dI_2}{dt}$$

which satisfies the following formula:

$$\frac{dI_2}{dt} = -\frac{4m\pi}{\lambda} I_0 \cdot \left(\sin \frac{r}{\lambda} 2\pi \right) \cdot \frac{dr}{dt} \quad (9)$$

It follows from said formula that said differentiated signal

$$\frac{dI_2}{dt}$$

is in phase or in phase opposition with the first control signal I_1 , depending on the sign of

$$\frac{dr}{dt}$$

i.e. the direction of the radial movement. Said datum is used for stabilizing the control system.

If it is, for example, assumed that the differentiated signal

$$\frac{dI_1}{dt}$$

5 has the response

$$\frac{dI_1}{dt}(1)$$

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as shown in Fig. 10c, this signal is then exactly in phase opposition with the first control signal and thus denotes a positive value of

$$\frac{dr}{dt}$$

10 i.e. a movement of the scanning point towards a greater value of r. From this signal

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$$\frac{dI_1}{dt}(1)$$

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a squarewave signal $I_2(1)$ can be derived (see Fig. 10d) with the aid of a threshold value detector 27, which detects when said differentiated signal exceeds a positive threshold D. The gain factor of the amplifier 22 is controlled with said squarewave control signal $I_2(1)$ in such a way that said gain factor is reduced if the control signal is positive.

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This means that the gain is reduced during the first part of the negative half period of the first control signal I_1 . Assuming again that a positive value of said control signal I_1 tends to cause a movement of the scanning point towards a smaller value of r and a negative value a movement towards a greater value, this reduction of the gain during the negative half period will result in a stabilization of the control system. When passing through an even number of positive and negative half periods of the control signal I_1 , the energy which is exchanged during the positive half period which counteracts the movement towards a greater value of r and which energy still persists at that instant, is greater than the energy which is exchanged during the negative half periods, which tends to maintain the said movement. As a result, said prevailing movement is damped.

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If the movement of the scanning point is exactly the opposite, i.e.

$$\frac{dr}{dt} < 0$$

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the signal

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$$\frac{dI_1}{dt}(2)$$

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shown in Fig. 10c is produced as a differentiated second control signal, from which via the threshold detector 27 the squarewave signal $I_2(2)$ (Fig. 10d) is derived. The gain of the transfer function is then reduced during a part of the positive half periods of the first control signal I_1 , so that the desired stabilizing action is obtained again.

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If the threshold D (Fig. 10c) of the threshold detector 27 is selected to be zero, the gain factor will be reduced either during the entire positive or the entire negative half period of the first control signal I_1 , irrespective of the speed of the radial movement. This is less desirable, because in this case the gain factor would be switched if the scanning point moved a relatively small distance in the stable range around the desired stable settings (s_1, s_2, s_3 etc.) -

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This is prevented by selecting the threshold value D to differ from zero. The amplitude of the differentiated second control signal

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$$\frac{dI_2}{dt}$$

is proportional to the magnitude of the speed of movement of the scanning point. At a higher amplitude of the differentiated second control signal (see for example

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$$\frac{dI_2}{dt} \quad (3)$$

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in Fig. 10c) a squarewave signal (see $I_3(3)$ in Fig. 10e) is obtained with the aid of a threshold value D which is not zero, whose positive pulse width increases approximately proportionally to said amplitude. This means that the stabilizing action is proportional to the magnitude of the speed.

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If the speed decreases owing to said stabilizing action, the pulse width of the squarewave signal I_3 also decreases, which means that the switching points of the gain factor further recede from the desired settings (s_1, s_2, s_3 etc.), so that automatically the desired range with a fixed transfer function is obtained around said settings. In the extreme case the speed is so small, that the amplitude of the signal

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$$\frac{dI_2}{dt}$$

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is smaller than the threshold value D , so that no squarewave signal I_3 is produced. However, this situation is unlikely to occur because before such a situation can occur the control system is already locked in a stable range.

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In a modification of the embodiment described hereinbefore the differentiated second control signal

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$$\frac{dI_2}{dt}$$

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of formula (9) is again multiplied by the first control signal, which yields

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$$\frac{dI_2}{dt} \cdot I_1 = \frac{8m^2\pi}{\lambda} I_0^2 \left(\sin \frac{r}{\lambda} - 2\pi \right)^2 \cdot \frac{dr}{dt} \quad (10)$$

25

The polarity of this signal is a direct indication of the direction of the radial movement. By reducing the gain as a function of this polarity, either during the positive or during the negative half period of the first control signal I_1 , the desired stabilizing action is obtained again. Thus, in this case a threshold value detector is required to which the first control signal I_1 is applied and which in accordance with the polarity of signal expressed by the formula (10) either during the positive or the negative half period of said first control signal supplies a control pulse to the amplifier 22 in the servo-unit. By giving said threshold value detector a threshold which is not zero, a range which is situated around the desired settings (s_1, s_2, s_3 etc.) is excluded, so that a fixed transfer function is operative in this range under all conditions.

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In a second modification the differentiator 26 is designed in another manner, for example as shown in Fig. 11. This embodiment of the differentiator includes an operational amplifier V , whose inverting input is connected to earth via a capacitor C and via a resistor R to the output. The second control signal I_2 supplied by the detector 17 is fed to the non-inverting input of the operational amplifier V .

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If it is assumed that the signal I_2 satisfies the equation of formula (7), the output signal I_4 of the operational amplifier V will be:

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$$I_4 = I_2 + CR \frac{dI_2}{dt} = 2m I_0 \cos \frac{r}{\lambda} \cdot 2\pi - \frac{4m\pi}{\lambda} I_0 CR \left(\sin \frac{r}{\lambda} - 2\pi \right) \frac{dr}{dt} \quad (11)$$

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For a rapid radial movement of the scanning point the second term is predominant, so that in that case the system operates substantially in accordance with the stabilising

method described with reference to Figs. 9 and 10, because the signal I_1 then substantially corresponds to the signal

$$\frac{dI_1}{dt}$$

of formula (9). However, if the speed

$$\frac{dr}{dt}$$

of the radial movement decreases, the influence of the first term of formula (11) increases, until it finally becomes predominant. In this last extreme case the signal I_1 fully corresponds to the control signal I_2 , so that the system then operates in accordance with the stabilizing method given in Figs. 7 and 8 in combination with Fig. 3. Thus, depending on the speed one stabilizing method gradually merges into the other.

An additional advantage of said stabilizing method is the fact that for rapid movements the threshold value for the system may be zero without causing any problems, so that maximum stabilization is possible. This because at low speed the other stabilizing method is adopted.

A similar behaviour can also be obtained with the aid of a so called "poor" differentiator, for example as shown in Fig. 12. The differentiating network then consists of the parallel connection of a resistance R_1 and a capacitance C_1 in series with a resistance R_2 . The transfer function of said network is

$$\frac{R_2(1+pCR_1)}{(R_1+R_2)+pCR_1R_2} \quad (12)$$

where p is the imaginary angular frequency. If

$$\frac{1}{CR_1} < p < \frac{1}{CR_1} \frac{R_1+R_2}{R_2}$$

formula (12) may be approximated by

$$p \frac{CR_1 R_2}{R_1+R_2} \quad (13)$$

which implies a pure differentiation. For

$$p < \frac{1}{CR_1}$$

however, the transfer function may be reduced to

$$\frac{R_2}{R_1+R_2} \quad (14)$$

which is a normal voltage division. At relatively high frequencies, i.e. at high speed, the signal I_1 is differentiated, so that the stabilizing method of Fig. 9 is obtained, whilst at lower frequencies, i.e. at low radial speed, the stabilizing method of Figs. 7 and 8 is obtained with a continuous transition, between these two methods.

It is obvious, that the embodiment of the servo-unit is not limited to the embodiments shown in Figs. 7, 8 and 9. For example, it is also possible to realize a damping term with the aid of suitable transducers at the drive element 10 or the mirror 8. There are numerous forms of amplifier 20 and/or 22 and of methods by which this amplifier can be influenced by the control signal, because this type of amplifier is known in many versions. Consequently, selecting a suitable amplifier in

accordance with the requirements imposed and influencing the gain factor thereof in the correct manner will not present any problem to those skilled in the art.

WHAT WE CLAIM IS:—

1. Apparatus for reading a disc-shaped record carrier on which signals are stored in parallel tracks as defined herein, which apparatus includes an optical read unit with a radiation source, a radiation directing system and a read detector, which radiation source is adapted to emit a radiation beam which is projected onto the record carrier as a scanning point of radiation and which *via* the radiation directing system transfers the information derived by the scanning point from the record carrier to the read detector, said apparatus further including a control system for controlling the radial position of the scanning point on the desired track, which control system includes drive means for the radiation direction system, a first measuring system for measuring the radial position of the scanning point and supplying a corresponding first control signal to the drive means, which first measuring system comprises means for projecting a first pattern of radiation spots onto the record carrier, and means for imaging said first pattern onto a first measuring detector, said first control signal, during radial movement of the scanning point over a number of adjacent tracks, including a first periodic a.c. component whose period corresponds to the track separation, the control system being stable for one half period of said first a.c. component and being unstable for the other half period of said first a.c. component, said apparatus being characterized in that for assuring the stability of the control system a second measuring system is provided comprising means for projecting a second pattern of radiation spots onto the record carrier and means for imaging said second pattern onto a second measuring detector, which second measuring system supplies a second control signal, which during a radial movement of the scanning point over a number of adjacent tracks contains a second periodic a.c. component whose period corresponds to the track separation, but which second a.c. component, as a result of a different radial position of the second pattern of radiation spots relative to that of the first pattern of radiation spots, exhibits a phase shift corresponding to substantially a quarter period of the track separation relative to the first periodic a.c. component of the first control signal, and in that the control system has a variable transfer function which is controlled by a control unit which receives a third control signal which is derived from the second control signal, and which control unit upon a movement of the scanning point over a number of adjacent tracks controls the transfer function.

2. Apparatus as claimed in Claim 1, comprising means for deriving the third control signal as a squarewave signal substantially in phase with the second control signal.

3. Apparatus as claimed in Claim 1, comprising a differentiation circuit to which the second control signal is applied and from which the third control signal is derived.

4. Apparatus as claimed in Claim 3, comprising means for deriving the third control signal as a squarewave signal from the differentiated second control signal with the aid of a threshold value detector, which detects each period in which the differentiated second control signal exceeds a certain absolute threshold value and which during said period supplies a squarewave pulse of said squarewave signal, the polarity of which at each moment is related to the polarity of the differentiated second control signal.

5. Apparatus as claimed in Claim 1, comprising means for deriving the third control signal as a squarewave signal, which means comprises a threshold value detector, which detects the periods in which the first control signal has a specific polarity and at the same time exceeds a certain threshold value and which, during said periods, supplies a squarewave pulse of said squarewave signal, and means for selecting the specific polarity of the first control signal to be detected by said threshold value detector in dependence on the polarity of the product of the first control signal and the differentiated second control signal.

6. Apparatus as claimed in any one of Claims 1 to 5, characterized in that a gain factor of the transfer function is varied in accordance with the third control signal.

7. Apparatus as claimed in Claim 1 or 2, characterized in that a damping term contained in the transfer function is variable in dependence on the third control signal.

8. Apparatus as claimed in Claim 2, characterized in that the transfer function contains two damping terms of opposite sign, one of which is selected in dependence on the third control signal.

9. Apparatus as claimed in any one of Claims 1 to 8, characterized in that the second pattern of radiation spots consists of two radiation spots which are separated

accordance with the requirements imposed and influencing the gain factor thereof in the correct manner will not present any problem to those skilled in the art.

WHAT WE CLAIM IS:—

1. Apparatus for reading a disc-shaped record carrier on which signals are stored in parallel tracks as defined herein, which apparatus includes an optical read unit with a radiation source, a radiation directing system and a read detector, which radiation source is adapted to emit a radiation beam which is projected onto the record carrier as a scanning point of radiation and which *via* the radiation directing system transfers the information derived by the scanning point from the record carrier to the read detector, said apparatus further including a control system for controlling the radial position of the scanning point on the desired track, which control system includes drive means for the radiation direction system, a first measuring system for measuring the radial position of the scanning point and supplying a corresponding first control signal to the drive means, which first measuring system comprises means for projecting a first pattern of radiation spots onto the record carrier, and means for imaging said first pattern onto a first measuring detector, said first control signal, during radial movement of the scanning point over a number of adjacent tracks, including a first periodic a.c. component whose period corresponds to the track separation, the control system being stable for one half period of said first a.c. component and being unstable for the other half period of said first a.c. component, said apparatus being characterized in that for assuring the stability of the control system a second measuring system is provided comprising means for projecting a second pattern of radiation spots onto the record carrier and means for imaging said second pattern onto a second measuring detector, which second measuring system supplies a second control signal, which during a radial movement of the scanning point over a number of adjacent tracks contains a second periodic a.c. component whose period corresponds to the track separation, but which second a.c. component, as a result of a different radial position of the second pattern of radiation spots relative to that of the first pattern of radiation spots, exhibits a phase shift corresponding to substantially a quarter period of the track separation relative to the first periodic a.c. component of the first control signal, and in that the control system has a variable transfer function which is controlled by a control unit which receives a third control signal which is derived from the second control signal, and which control unit upon a movement of the scanning point over a number of adjacent tracks controls the transfer function.

2. Apparatus as claimed in Claim 1, comprising means for deriving the third control signal as a squarewave signal substantially in phase with the second control signal.

3. Apparatus as claimed in Claim 1, comprising a differentiation circuit to which the second control signal is applied and from which the third control signal is derived.

4. Apparatus as claimed in Claim 3, comprising means for deriving the third control signal as a squarewave signal from the differentiated second control signal with the aid of a threshold value detector, which detects each period in which the differentiated second control signal exceeds a certain absolute threshold value and which during said period supplies a squarewave pulse of said squarewave signal, the polarity of which at each moment is related to the polarity of the differentiated second control signal.

5. Apparatus as claimed in Claim 1, comprising means for deriving the third control signal as a squarewave signal, which means comprises a threshold value detector, which detects the periods in which the first control signal has a specific polarity and at the same time exceeds a certain threshold value and which, during said periods, supplies a squarewave pulse of said squarewave signal, and means for selecting the specific polarity of the first control signal to be detected by said threshold value detector in dependence on the polarity of the product of the first control signal and the differentiated second control signal.

6. Apparatus as claimed in any one of Claims 1 to 5, characterized in that a gain factor of the transfer function is varied in accordance with the third control signal.

7. Apparatus as claimed in Claim 1 or 2, characterized in that a damping term contained in the transfer function is variable in dependence on the third control signal.

8. Apparatus as claimed in Claim 2, characterized in that the transfer function contains two damping terms of opposite sign, one of which is selected in dependence on the third control signal.

9. Apparatus as claimed in any one of Claims 1 to 8, characterized in that the second pattern of radiation spots consists of two radiation spots which are separated



* C L M S *

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in the radial direction by a distance equal to half the track separation and which are each imaged onto a respective separate part of the second measuring detector, the second control signal being obtained by subtraction of the signals supplied by the separate parts of the second measuring detector.

5 10. Apparatus as claimed in any one of Claims 1 to 8, characterized in that the second measuring signal is derived from the low-frequency component of the signal which is supplied by the read detector. 5

10 11. Apparatus as claimed in Claim 3, characterized in that the differentiation circuit includes an operational amplifier, to the non-inverting input of which the second control signal is applied and whose inverting input is connected to a point of constant potential *via* a capacitance and to the output of the operational amplifier *via* a resistance. 10

15 12. Apparatus as claimed in Claim 3, characterized in that the differentiation circuit comprises a network which at comparatively low frequencies operates at least substantially as a proportional circuit and at comparatively high frequencies operates at least substantially as a differentiating circuit. 15

13. Apparatus substantially as described with reference to the accompanying drawings.

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Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1977
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from
which copies may be obtained.

