

PATENT SPECIFICATION

(11) 1 583 664

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- (21) Application No. 22070/77
- (22) Filed 25 May 1977
- (31) Convention Application No. 2623643
- (32) Filed 26 May 1976 in
- (33) Federal Republic of Germany (DE)
- (44) Complete Specification published 28 Jan. 1981
- (51) INT CL³ G01S 13/93
- (52) Index at acceptance
H4D 260 354 356 41X



(54) METHOD AND APPARATUS FOR THE CONTROL OF THE SAFETY DISTANCE BETWEEN A VEHICLE AND PRECEDING VEHICLES

(71) We, DAIMLER-BENZ AKTIENGESELLSCHAFT, of Stuttgart-Untertürkheim, Germany, a Company organised under the laws of the Federal Republic of Germany, 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 a method for the autarkic control of the safety distance between a vehicle equipped with distance and/or relative-speed measurement means and preceding vehicles, particularly but not exclusively for road or trackless vehicles. The invention also relates to apparatus for carrying out the method. By autarkic control is meant control by means self-contained upon the equipped vehicle and not dependent for its action upon the provision on a preceding vehicle of special complementary equipment such, for example as the harmonic generator and transmitting antenna disclosed in the Specification of United Kingdom Patent No. 1,416,504.

Known apparatus of this kind may measure the distance from a vehicle involving a possible collision risk and determine relative speed by differentiation (for example pulsed radar), or may measure distance and relative speed directly (for example pulsed Doppler radar). Apparatus determining simultaneously the distances and relative speeds for a plurality of targets (for example multi-target radar) has also been used. Taking into account the speed of the equipped vehicle, it is possible to provide an indication by warning means that the distance is less than a required safety distance or to determine the necessary braking deceleration of the vehicle and also, in some cases, to initiate automatically the braking of the vehicle, i.e. control of the distance.

If such apparatus has not hitherto been widely used in road traffic, despite its development being intensively studied, this is due primarily to fundamental difficulties.

A number of measuring processes have been shown to be suitable for determining distance and relative speed in relation to possible targets. In particular, radar measuring methods make it possible to recognise targets even in unfavourable weather conditions involving snow, rain or fog. In principle, it is possible to recognise not only vehicles, but also pedestrians and objects.

As such apparatus installed in motor vehicles can, at any time, scan only a certain region in front of the equipped vehicle, not only vehicles or obstacles on the traffic lane occupied by that vehicle, but also vehicles on adjoining traffic lanes or objects at the margin of the traffic lane will be detected. Particularly on bends, there is a danger of false alarms, that is to say erroneous warning to the driver or unjustified operation of the braking system.

Attempts have been made heretofore to avoid these difficulties, for example by employing narrow radar beam widths and/or presetting limited threshold values of signals which are allowed to produce control action in the equipped vehicle. Autarkic systems in this category are disclosed, for example in United Kingdom Patent Specifications Nos. 1,420,917, 1,404,634, 1,342,203, 1,330,879, 1,312,315 and 1,245,871. An autarkic system has also been proposed in United Kingdom Specification No. 1,346,685 for the different purpose of safeguarding passengers against injury in the event of a collision between an equipped vehicle and an object

in front of the said vehicle, whereby, when an object is detected in a region adjacent the vehicle, a signal is provided for activating a safety device such as an air-bag barrier for protecting occupants of the vehicle.

5 The present invention seeks to provide a method and apparatus by which it is possible to control the safety distance and avoid collision with a preceding vehicle, while substantially eliminating false alarms in a more positive and discriminating manner than heretofore. In particular, the range and area covered by the measurement can be adapted to road-bend conditions and spurious targets (particularly stationary targets having extent in the direction of travel) can be suppressed. 10

According to the invention, a method for the autarkic control of the safety distance between an equipped vehicle to be controlled and a preceding vehicle on a possibly obstructive course comprises determining a maximum safe disturbance-free range ahead of the equipped vehicle in dependence upon the course being followed by the equipped vehicle and monitoring ahead from the said vehicle to ascertain whether a possible obstructive target is present within the said range, measuring from the equipped vehicle the distance from the said vehicle of a target so ascertained, measuring from the equipped vehicle the relative speed of the said target with reference to the said vehicle, measuring the speed of the equipped vehicle, determining the angle of turning of the steering wheel of the equipped vehicle and/or the transverse acceleration of the equipped vehicle, and automatically combining data so ascertained and measured to suppress indication of a target other than a preceding vehicle within the said range and, in the case of indication of such a preceding vehicle, to produce a signal in the equipped vehicle. 15 20

To permit extended stationary obstructions to be distinguished and suppressed, variation of said measured distance may be compared with the variation of distance calculated by integration from said relative speed or said measured relative speed compared with the relative speed calculated by differentiation from said measured distance. 25

Using a swingable antenna for the monitoring, the angle of swing of the antenna may be varied in dependence upon the angle of turning of the steering wheel or upon the transverse acceleration of the equipped vehicle. 30

Using an antenna with a variable angle of transmission spread, the said angle of spread may be varied in dependence upon the angle of turning of the steering wheel or upon the transverse acceleration. 35

Of all targets detected, a target recognised as a "preceding vehicle" may be given preference.

The aforesaid signal may be utilised for controlling the equipped vehicle and/or to provide a warning signal for its driver. 40

By appropriate combination of the above specific forms of method, it is possible to obtain disturbance-free control under various traffic situations. 40

Control in dependence upon angle of turning of the steering wheel or transverse acceleration will be sufficient for travel on a bend of fixed radius.

Swinging of a swingable antenna is effective for an elongated bend but slight alignment while entering and running out of a bend is unavoidable for a short time. The aforesaid mode of suppression of extended targets is effective if the relative speed can be determined without reference of distance, but in practice, for any considerable curvature of the carriageway, it is effective in distinguishing stationary guard-rails and anti-dazzle barriers present. While the primary purpose of the invention is to eliminate sources of disturbance in a horizontal direction, that is disturbance targets to the left and right beside the actual traffic lane, elimination of disturbance in the vertical direction, that is to say for targets above the carriageway is also possible. 45 50

Apparatus in accordance with the invention for carrying out the aforesaid method may comprise radar apparatus on the equipped vehicle for monitoring ahead of the equipped vehicle to ascertain whether a possibly obstructive target is present within the said range and to measure the distance from the said vehicle of a target so ascertained and the relative speed of the said target with reference to the said vehicle, means for measuring the speed of the equipped vehicle, means for measuring the angle of turning of the steering wheel and/or the transverse acceleration of the equipped vehicle, and a computer unit to which the data ascertained by the said measuring means and the search time are fed and which calculates therefrom control values for the antenna and for a signal for control of the vehicle. 55 60

Further details of the invention will appear from the following description of an embodiment which is diagrammatically illustrated by way of example in the accompanying drawings,

5 Figure 1 is a diagram relating to a criterion a),

Figure 2 a diagram relating to a criterion b),

Figure 3 another diagram relating to criterion b),

Figure 4 a diagram relating to a criterion c),

Figure 5 a diagram relating to a criterion d), and

10 Figure 6 a circuit diagram of a form of apparatus in accordance with the invention.

Criteria a) to d) will first be explained individually by reference to Figures 1 to 5.

Criterion a):

15 On a bend (Figure 1), the maximum disturbance-free measurement range a is limited, that is targets at distances $a_m > a$ are suppressed. If the transverse acceleration and the speed or the angle of turn of the steering wheel are measured, it is possible to determine the curvature $1/R$ of the bend (R =radius of bend). Taking as starting point, a vehicle travelling in the middle of a traffic lane, the maximum disturbance-free measurement range a can be determined from the angle α of spread of the measuring beam from a radar transmitter on the vehicle and the mean width b of the lane.

If the transmitter antenna points in the direction of the longitudinal axis of the vehicle, the following is true:

$$a = -|R| \sin \alpha/2 + \sqrt{R^2 \sin^2 \alpha/2 + b \cdot |R|} \quad (1)$$

25 For the determination of R , use may conveniently be made of the transverse acceleration b_a in conjunction with the speed v of the vehicle, particularly for higher speeds, and for low speeds, the steering-wheel angle β_t .

If measurement of the transverse acceleration or steering-wheel angle and consequent determination of the curvature of the carriageway are dispensed with, the starting point may be the minimum radius of curvature of the roads which will be travelled over. Equation 1 will then permit calculation of the disturbance-free measurement range below which it is certain that no false alarms will occur. Thus, for example, minimum radii of about 600 metres can be expected on motorways. For $\alpha=2.4^\circ$ and $b=4.15$ m, a disturbance-free measurement range of 40 metres is then obtained.

Criterion b):

40 Arrangements are known in which headlamps or measuring devices are mounted pivotably on motor vehicles and, on a bend, turn into the bend in dependence on the steering-wheel angle or transverse acceleration. The angle of pivoting is, for example, so selected that, at a given speed, a stationary obstacle will still be recognised in good time, that is it will still be possible to brake with the deceleration theoretically possible for given road conditions. Although such pivoting improves visibility on bends, optimum conditions with respect to disturbance are not provided. If, for instance, a driver of a vehicle equipped with warning apparatus does not react by applying full braking when a stationary obstruction appears, then necessarily an accident will follow.

45 It is therefore advantageous for the angle γ of pivoting on bends to be so selected that adequate information is achieved and, at the same time, maximum disturbance-free measurement range. A minimum of false alarms will then occur on bends.

50 For this purpose, it will be necessary on tight bends (on fast roads) to pivot as far as the inner edge of the bend (Figure 2).

Precisely, the following apply to the angle of pivoting:

55 with $\gamma = \rho_T - \alpha/2$ for $R > 0$

$$\rho_T = \arccos \frac{|R| - b/2}{|R|} \quad (2)$$

$$\gamma = -\rho_T + \alpha/2 \text{ for } R < 0 \quad (3)$$

As a very good approximation, it is possible to take:

$$\varphi_T = \frac{180}{\pi} \cdot \sqrt{\frac{b}{R}} \quad (4)$$

On less tight bends (for example $|R| > 2500$ m for $\alpha = 2.4^\circ$), pivoting need not be as far as the inner edge of the bend, but only so far that the distances from the left-hand edge and the right-hand edge are equal (Figure 3).

From this condition the angle of pivoting can be calculated from:

$$\gamma = \frac{k}{R}$$

for $|R| > 2500$ m (5)

Thus, for example for $\alpha = 2.4^\circ$, we obtain $b = 4.15$ m, $k = 2978$ degrees/m.

For a pivotable antenna also, it is possible to apply criterion a). For the disturbance-free measurement range a , the following is valid for a pivotable measuring beam:

$$a = -|R| \sin(\alpha/2 - \gamma) + \sqrt{R^2 \sin^2(\alpha/2 - \gamma) + |R| b} \quad (6)$$

A possible simplification is:

$$\sin(\alpha/2 - \gamma) = \frac{\pi}{180} \cdot (\alpha/2 - \gamma) \quad (7)$$

False alarms can again be suppressed by comparison of the ascertained distance a_m to an obstacle with the disturbance-free measurement range a . Targets with $a_m < a$ are situated on the traffic lane in which the vehicle is travelling.

If the angle α of spread of the transmitter beam is also varied, for example in dependence on the angle of turn of the steering wheel or on transverse acceleration, the disturbance-free measurement range on bends can in a sense be "optimised".

Criterion c)

A large proportion of false alarms is due to fixed targets at the edge of the carriageways, particularly guard rails and anti-dazzle screens on bends as well as bridges and signboards. At least for "extended" targets which the vehicle passes, such as guard rails and anti-dazzle screens, and also tunnels, it is possible to distinguish these from stationary vehicles or obstacles towards which the equipped vehicle is travelling, if distance and relative speed are obtained separately (that is, the relative speeds are not obtained by differentiation of the distances).

A typical case of this kind is when the vehicle is passing a guard rail or anti-dazzle screen on a bend (Figure 4). Whether or not the "measuring beam" is pivoted into the bend, a measuring device (for example a pulsed double radar) will show one or more (with multi-target radar) relatively constant distances when travelling around a bend having a constant curvature. The relative speed is practically identical with the speed of travel (fixed target).

When the vehicle is travelling towards an obstacle standing on the same traffic lane, the distance continuously decreases in dependence on the speed of travel, in contrast with a guard rail for which the ascertained distances remain relatively constant.

If at a time t_1 , a distance a_1 and a relative speed v_{R1} are determined, and at a later time t_2 a distance a_2 and a relative speed v_{R2} , the following must apply in accordance with the fundamental relationship between variation of distance and (relative) speed:

$$\Delta a = a_1 - a_2 = - \int_{t_1}^{t_2} v_R dt \approx v_{R2} t_2 - v_{R1} \cdot t_1 \quad (8)$$

or

for $t_2 \rightarrow t_1$

$$\frac{\Delta a}{\Delta t} = \frac{a_1 - a_2}{t_2 - t_1} \approx v_R \quad (9)$$

The above formulae apply exactly in the case of analogue measurement of distance and relative speed. If distance and relative speed are measured digitally (to predetermined accuracies), a decision as to whether the target is one corresponding to a guard rail for example or possibly to an obstacle in the same traffic lane will be possible only when the variation of distance to be expected, calculated in accordance with equation (8), is greater than or equal to the smallest digitally measurable variation of distance. If at this time the variation of distance to be expected does not occur, it will certainly be a case of a false alarm.

Thus, if the distances are measured by a digital process, the times of expected changes of distance are predetermined. If no change of distance occurs at these times, the measured values are suppressed. With analogue measuring processes or processes which determine distance very accurately, the distances measured are appropriately differentiated and the speed thus obtained is compared with the measured speed.

It should be observed that the method can be used not only for fixed targets, that is to say for speeds of travel v = relative speed v_R , but also when v_R is not equal to v . This can be utilised particularly advantageously for suppressing false alarms occurring, for example, when overtaking slower vehicles on bends.

In particular, it is possible to suppress brief disturbances, since the measured distances are always followed up over a time determined by the relative speed and the accuracy of the measurements, before a measured value is taken up for the calculation, for example, of the safety distance.

Criterion d):

This criterion makes it possible, at least in cases in which a driver follows a preceding vehicle for a longer time, to achieve a drastic reduction of false alarms. As will be seen a prerequisite is that the measuring apparatus should not be solely able to measure the next target.

Previously known distance-measuring devices for road-traffic use have available a rigid search mode characterised by the feature that the distance and relative speed of the next target, or in some cases the next target but one, are determined. This search mode has the result that spurious targets, such as bridges for example, automatically trigger a false alarm if they are detected by the measuring beam at a shorter distance than the preceding vehicle (Figure 5).

With methods of tracking applied for military purposes, a flexible search mode can be evolved such that a target vehicle given priority is preferentially measured. This may, for example, be a preceding vehicle behind which the equipped vehicle travels for a predetermined time.

Such a method presupposes that the apparatus is able to recognise the same target again. This, however, can be easily achieved because, within a predetermined search time, there will usually be only predictable maximum changes of distance Δa_m and relative speed Δv_R between the vehicles. The maximum changes of distance and relative speed which occur within a certain time T are given primarily on the basis of the measured, or maximum possible, decelerations or accelerations b_{max} . Taking as basis a maximum deceleration of the preceding vehicle of -8 m/s^2 and a maximum acceleration of 5 m/s^2 of the following vehicle, the following will be obtained for the maximum relative speed variation occurring in the search time (if a collision is already to be excluded):

$$v_R(t) - v_R(t+T) = \Delta v_R = b_{max} \cdot T; \quad b_{max} = -8 \text{ m/s}^2 - 5 \text{ m/s}^2 \quad (10a)$$

This gives a maximum change of distance, within the search time, of:

$$a_m(t) - a_m(t+T) = \Delta a_m = -1/2 b_{max} T^2 \quad (10b)$$

If the preceding vehicle accelerates at 5 m/s² and the following vehicle decelerates at -8 m/s², we shall have:

$$v_r(t) - v_r(t+T) = \Delta v_r = -b_{max} \cdot T \quad (11a)$$

$$a_m(t) - a_m(t+T) = \Delta a_m = 1/2 b_{max} T^2 \quad (11b)$$

5 The same target is accordingly to be sought at the time $t+T$ in a region 5
predetermined by equations 10 and 11.

If no target is present in this region, then the target is no longer being detected, unless a collision has occurred. A target may then be sought with $v_r=v$ (v being the speed of travel) and with $a_m(t) - a_m(t+T) \leq v \cdot T$. If no target is present in this region 10
also, a new target is to be sought (in some circumstances only the next target). 10

The above criterion is particularly useful for suppressing spurious targets with a clearly different relative speed from that of the target being tracked.

Certain restrictive conditions are possible for the starting of tracking, for example adoption of target for tracking after a predetermined time of observation or after approximation to an absolutely disturbance-free distance (see criterion a). 15

Referring to Figure 6, a radar apparatus known *per se* comprises a transmitter with antenna 1. A signal-evaluating or strobing circuit 2 for determining the measured distance a_m and measured relative speed v_r is associated with a device 3 for swinging the antenna and varying the transmitter beam and with a computer unit 4. The unit 4 consists of five parts a to e , of which the parts a to d are associated with the criteria a to d , while part e constitutes a control unit which produces or determines control values and warning signals from the values measured and from decisions taken on the basis of the individual criteria. 20

The part a , a first decision unit, comprises a curvature computer 5 which calculates the curvature $1/R$ of the carriageway from the angle of turning β_L of the steering wheel or from the transverse acceleration b_q and speed v of the vehicle. The curvature value goes first to part b , which is provided with a computer 6 for angle of swing and a computer 7 for angle of spread, in which the angle of swing γ of the antenna 1 and angle α of spread of the transmitter beam are calculated. The two values γ and α are fed to the antenna for its adjustment, and then back to the first decision unit a , where they are fed together with the curvature to a measurement-range computer 8, which determines therefrom (equations 1 to 7) the maximum disturbance-free measurement range a . With this range, all targets detected by the antenna are compared in a following first comparison unit 9, in which a decision is taken whether or not they are within the measurement range determined by a , α and γ . All targets outside this range are suppressed as spurious targets. Part c includes a second decision unit comprising a differentiator 10 in which the relative speed v_r of a target is calculated from the measured distance a_m of that target in accordance with equations 8 and 9, that relative speed being compared with the measured relative speed v_r in a following, second comparison unit 11, which decides whether the two are different or not. Part d comprises a target-tracking unit 12 to which are fed the measurements of the distance a_m and relative speed v_r , as well as the speed v of the vehicle itself and the search time T , and which determines, in accordance with equations 10 and 11, whether the target is or is not a preceding vehicle. In this example, the tracking unit 12 is started when the target is within the measurement range and is not an extended, spurious, target. If it is determined that the target is a preceding vehicle, this is signalled to the signal-evaluation circuit 2 so that it can be tracked as a matter of priority. If the target is not a preceding vehicle, the tracking unit 12 is stopped and is restarted only for a new target. The decisions of the first and second comparison units 9 and 11 and of the tracking unit 12 are fed, together with the measurements a_m , v_r and v , to the control unit 13 in part e . 25
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In the unit 13, the safety distances necessary for individual actions are calculated from the measurements. For example action on the driving means, such as reduction of the fuel supplied, must take place before light application of the brakes which, in turn, must take place before emergency braking. The safety distances are compared with the measured distance a_m . Thereupon, taking into account the decisions of the comparison units and target-tracking unit, if the latter distance is less than the safety distance, warning signals at W or control values at R are released for achieving the required purpose. 50
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The method and/or apparatus may be so devised that the vehicle will run at a predetermined distance behind a preceding vehicle or that this distance will be 60

controlled. Also the speed of the equipped vehicle may be adjusted to suit the maximum disturbance-free measurement range, that is to say to effect automatic reduction of its speed on bends, and so forth.

WHAT WE CLAIM IS:—

- 5 1. A method, for the autarkic control of a safety distance between a vehicle equipped to be controlled and a vehicle preceding the equipped vehicle on a possible obstructive course, which comprises determining a maximum safe disturbance-free range ahead of the equipped vehicle in dependence upon the course being followed by the equipped vehicle and monitoring ahead from the said vehicle to ascertain whether a possibly obstructive target is present within the said range, measuring from the equipped vehicle the distance from the said vehicle of a target so ascertained, measuring from the equipped vehicle the relative speed of the said target with reference to the said vehicle, measuring the speed of the equipped vehicle, determining the angle of turning of the steering wheel of the equipped vehicle and/or the transverse acceleration of the equipped vehicle, and automatically combining data so ascertained and measured to suppress indication of a target other than a preceding vehicle within the said range and, in the case of indication of such a preceding vehicle, to produce a signal in the equipped vehicle. 5
- 10 2. A method according to the preceding claim, wherein, to permit extended stationary obstructions to be distinguished, variation of said measured distance is compared with the variation of distance calculated by integration from said relative speed or said measured relative speed compared with the relative speed calculated by differentiation from said measured distance. 10
- 15 3. A method according to Claim 1, wherein, using a swingable antenna for the monitoring, the angle of swing of the antenna is varied in dependence upon the angle of turning of the steering wheel or upon the transverse acceleration of the equipped vehicle. 15
- 20 4. A method according to Claim 1, 2 or 3, wherein, using an antenna with a variable angle of transmission spread, the said angle of spread is varied in dependence upon the angle of turning of the steering wheel or upon the transverse acceleration. 20
- 25 5. A method according to Claim 1, wherein a target recognised as a preceding vehicle is followed in preference to any other target detected. 25
- 30 6. A method for the autarkic control of a safety distance between a vehicle equipped to be controlled and a preceding vehicle substantially as hereinbefore described. 30
- 35 7. Apparatus for carrying out the method according to any one of Claims 1 to 6, comprising radar apparatus on the equipped vehicle for monitoring ahead of the equipped vehicle to ascertain whether a possibly obstructive target is present within the said range and to measure the distance from the said vehicle of a target so ascertained and the relative speed of the said target with reference to the said vehicle, means for measuring the speed of the equipped vehicle, means for measuring the angle of turning of the steering wheel and/or the transverse acceleration of the equipped vehicle and a computer unit to which the data ascertained by the said measuring means and the search time are fed and which calculates therefrom control values for the antenna and for a signal for control of the vehicle. 35
- 40 8. Apparatus according to Claim 7, wherein the computer unit comprises a first decision unit which includes a curvature computer which calculates the curvature of the carriageway from the steering-wheel angle or the transverse acceleration and the speed of the equipped vehicle, a measurement-range computer which calculates the maximum disturbance-free measurement range from the radius of the said curvature and the angle of swing and/or angle of spread of the antenna and a first comparison unit which decides whether a detected target is or is not within the said range. 40
- 45 9. Apparatus according to Claim 7 or 8, wherein the computer unit comprises an angle of swing computer which determines from the radius of curvature the optimum angle of swing of the antenna in relation to the longitudinal axis of the vehicle. 45
- 50 10. Apparatus according to Claim 7, 8 or 9, wherein the computer unit comprises an angle of antenna spread computer which determines the angle of spread of the transmission beam from the said radius of curvature and/or angle of swing. 50
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Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1981
 Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from
 which copies may be obtained.

Fig. 1

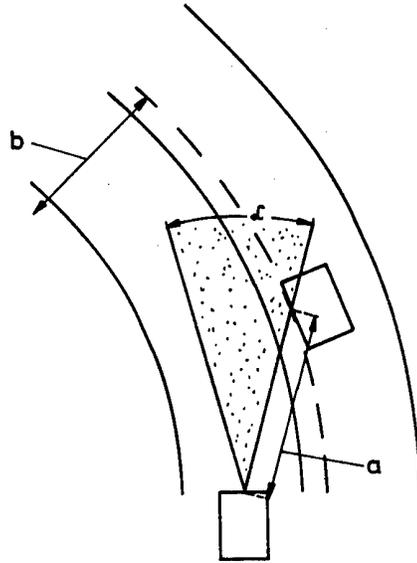


Fig. 2

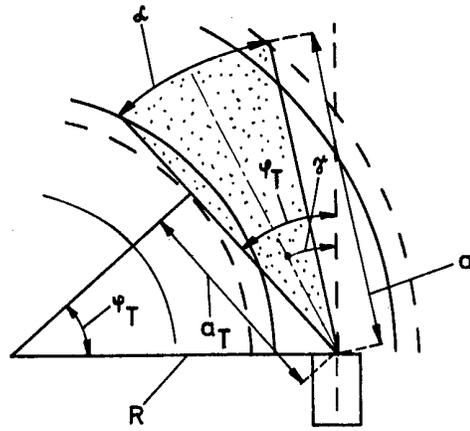


Fig. 3

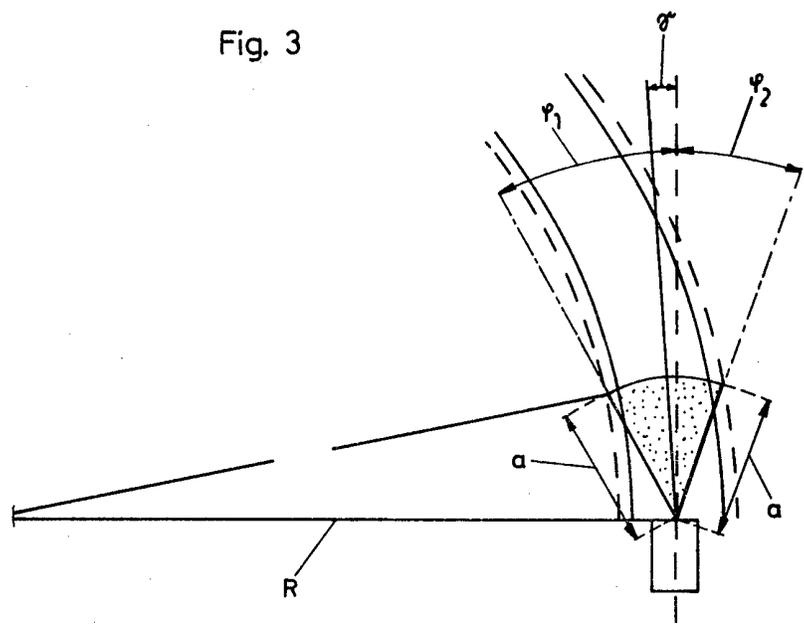


Fig. 4

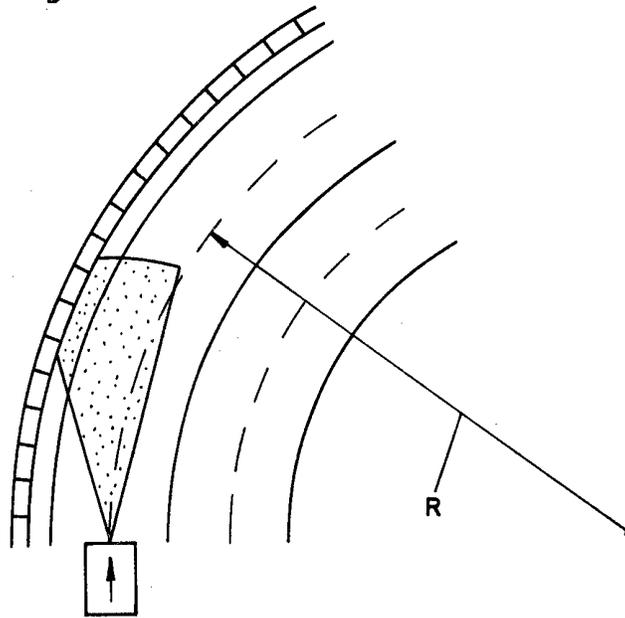


Fig. 5

