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03104060	13.02.1991	

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GB 2224126 A EP 0347042 A1 US 4783677 A

(58) Field of search
UK CL (Edition K) G2A ACW
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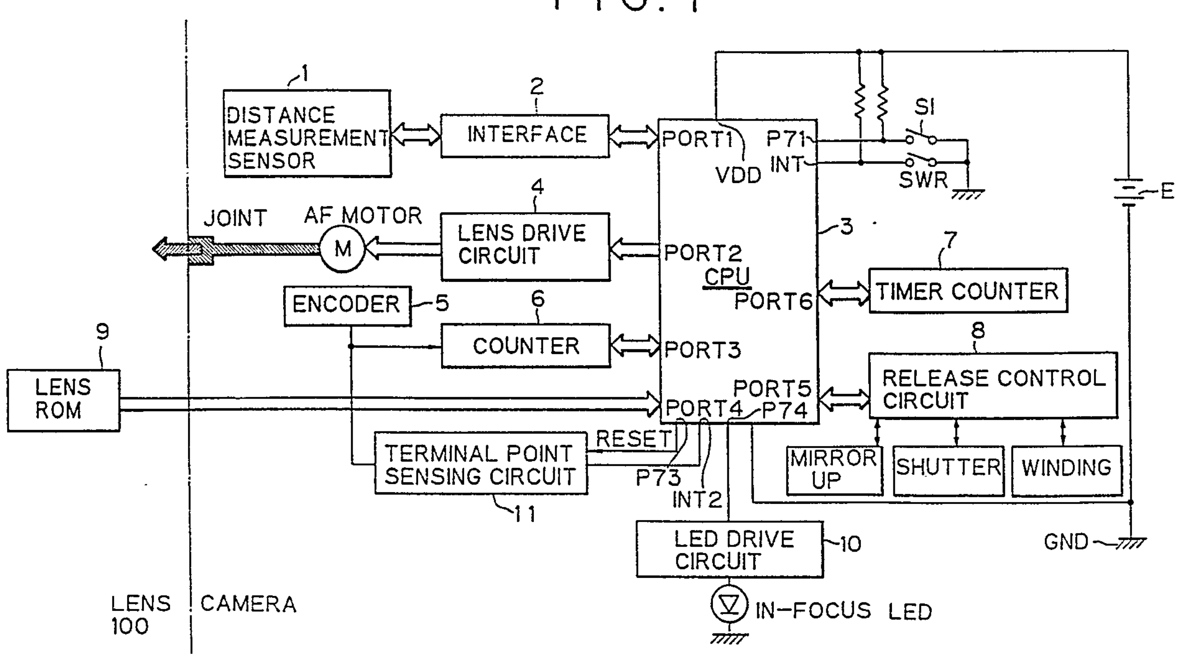
(54) Automatic focusing device

(57) An automatic focusing device is disclosed, in which a focus lens 100 is driven for tracking an object-in-motion to obtain an in-focus state, based upon a focus prediction executed from repeated distance measurements. A distance measurement for tracking is executed for continuous shots after elapse of a predetermined time from the start of a release operation and before completion thereof.

FIG. 1



GB 2 250 831 A

FIG. 1

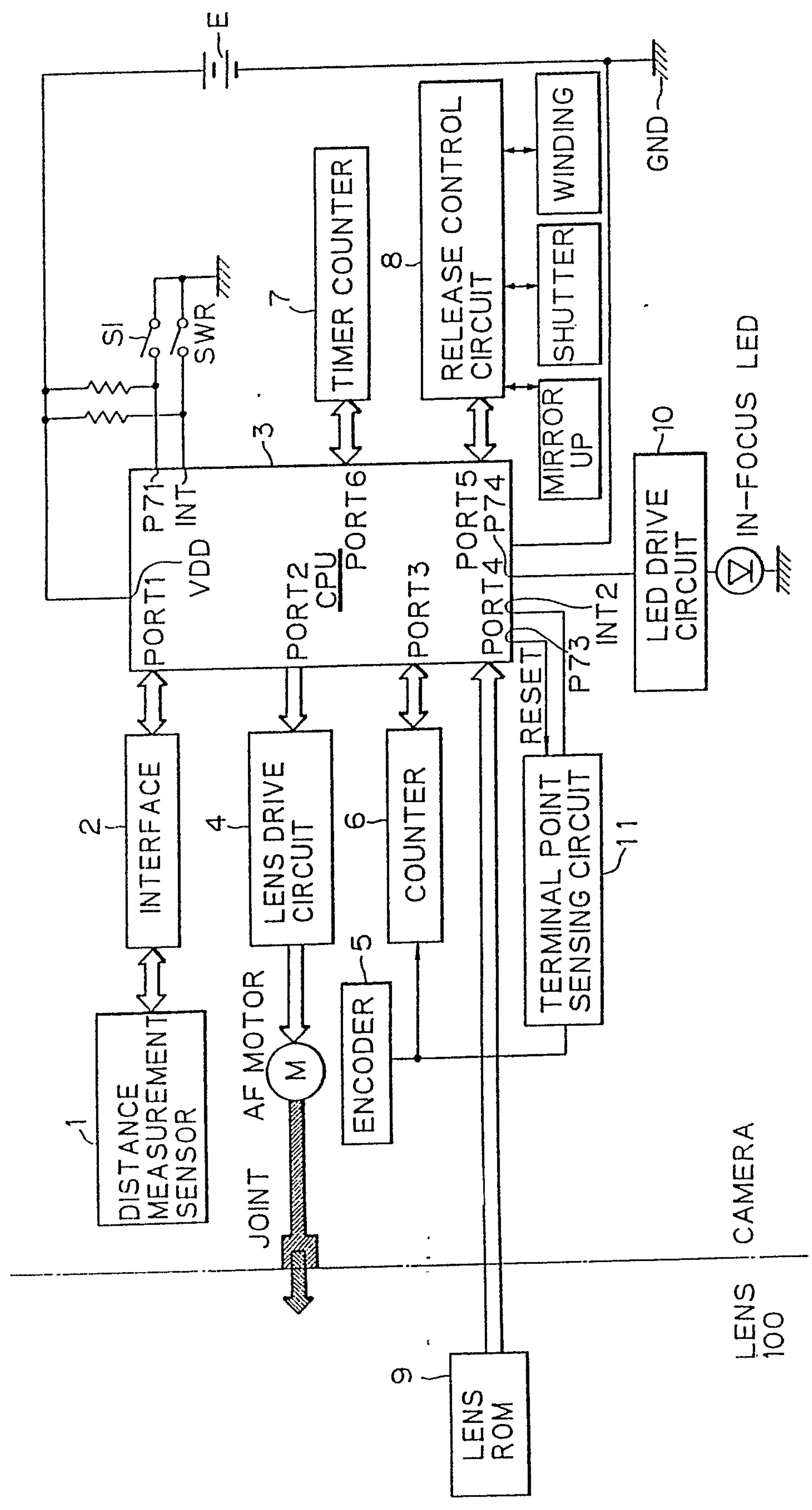

E
GND
SI
SWR
7
TIMER COUNTER
8
RELEASE CONTROL CIRCUIT
WINDING
SHUTTER
MIRROR UP
3
P71
INT
PORT6
PORT5
P74
VDD
PORT1
PORT2
CPU
PORT3
PORT4
PORT
INT2
P73
10
LED DRIVE CIRCUIT
IN-FOCUS LED
2
INTERFACE
4
LENS DRIVE CIRCUIT
6
COUNTER
RESET
TERMINAL POINT SENSING CIRCUIT
11
1
DISTANCE MEASUREMENT SENSOR
AF MOTOR
M
5
ENCODER
JOINT
CAMERA
LENS 100
9
LENS ROM

FIG.2

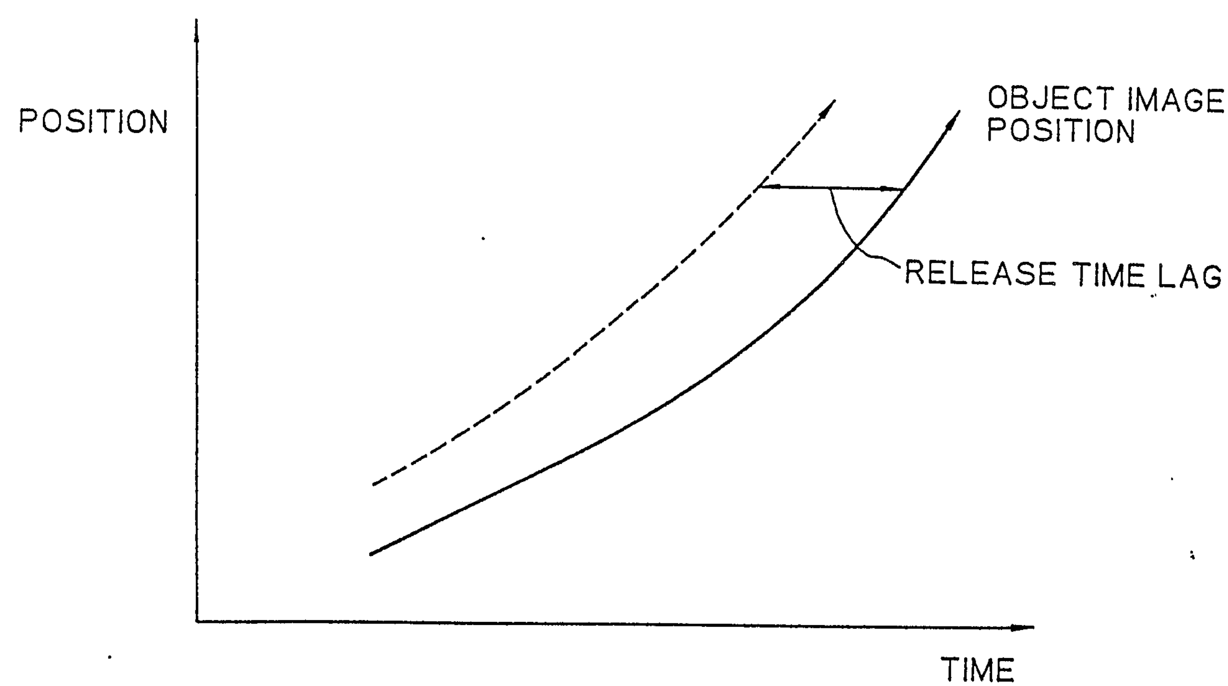
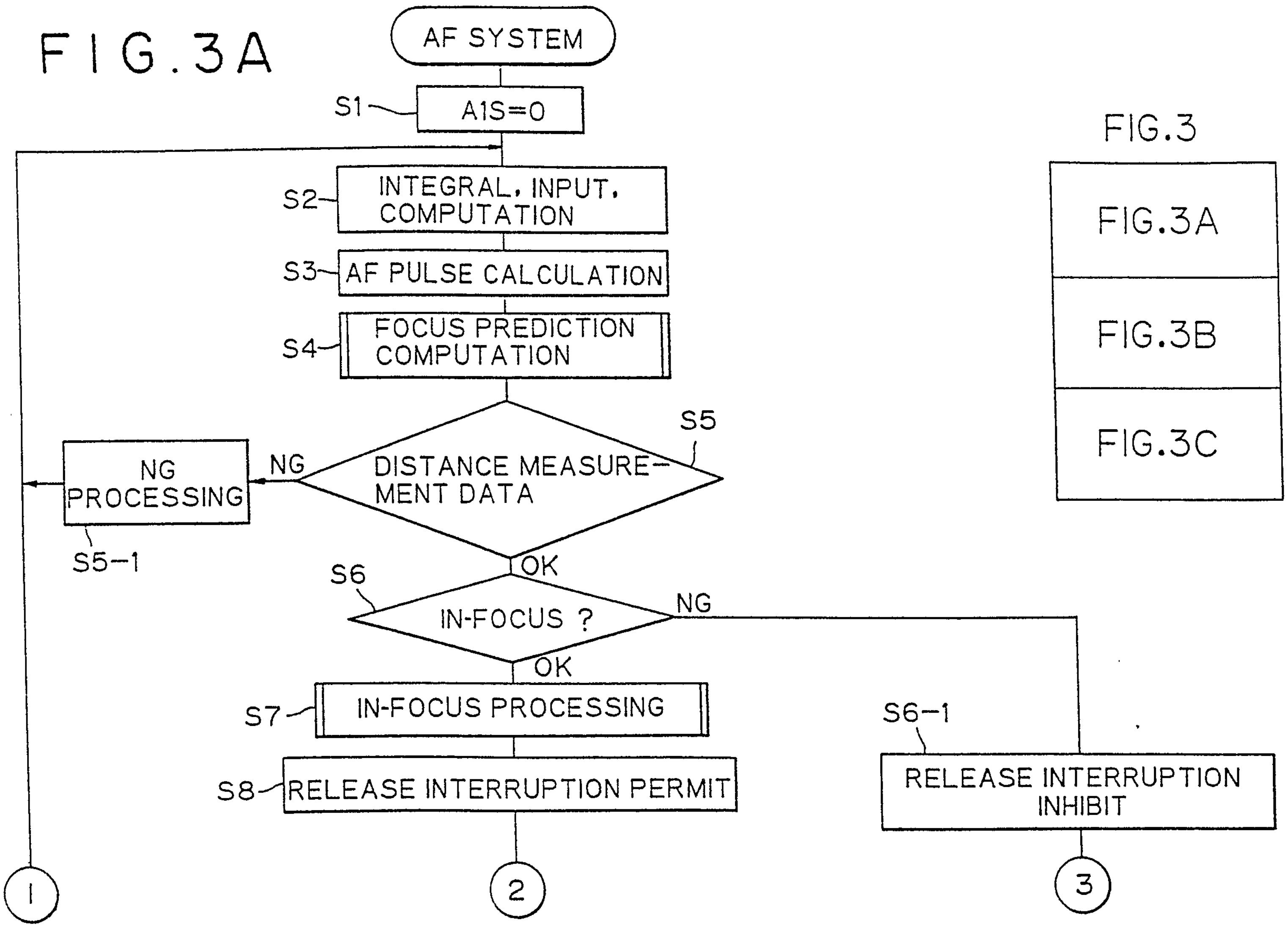


FIG.3A


AF SYSTEM
S1
A1S=0
S2
INTEGRAL, INPUT, COMPUTATION
S3
AF PULSE CALCULATION
S4
FOCUS PREDICTION COMPUTATION
S5
DISTANCE MEASUREMENT DATA
NG
NG PROCESSING
S5-1
OK
S6
IN-FOCUS ?
NG
OK
S7
IN-FOCUS PROCESSING
S8
RELEASE INTERRUPTION PERMIT
S6-1
RELEASE INTERRUPTION INHIBIT
1
2
3
FIG.3
FIG.3A
FIG.3B
FIG.3C

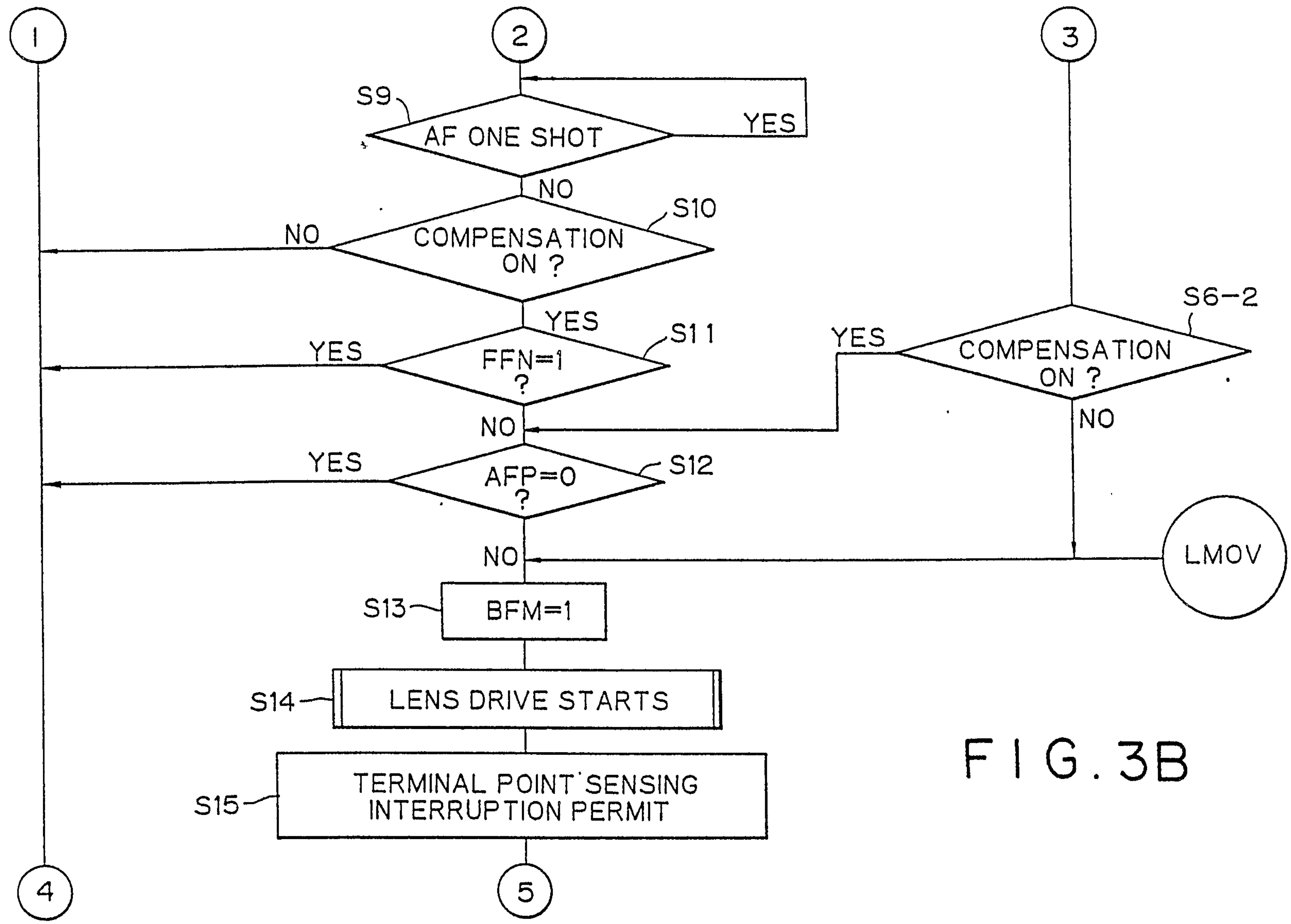
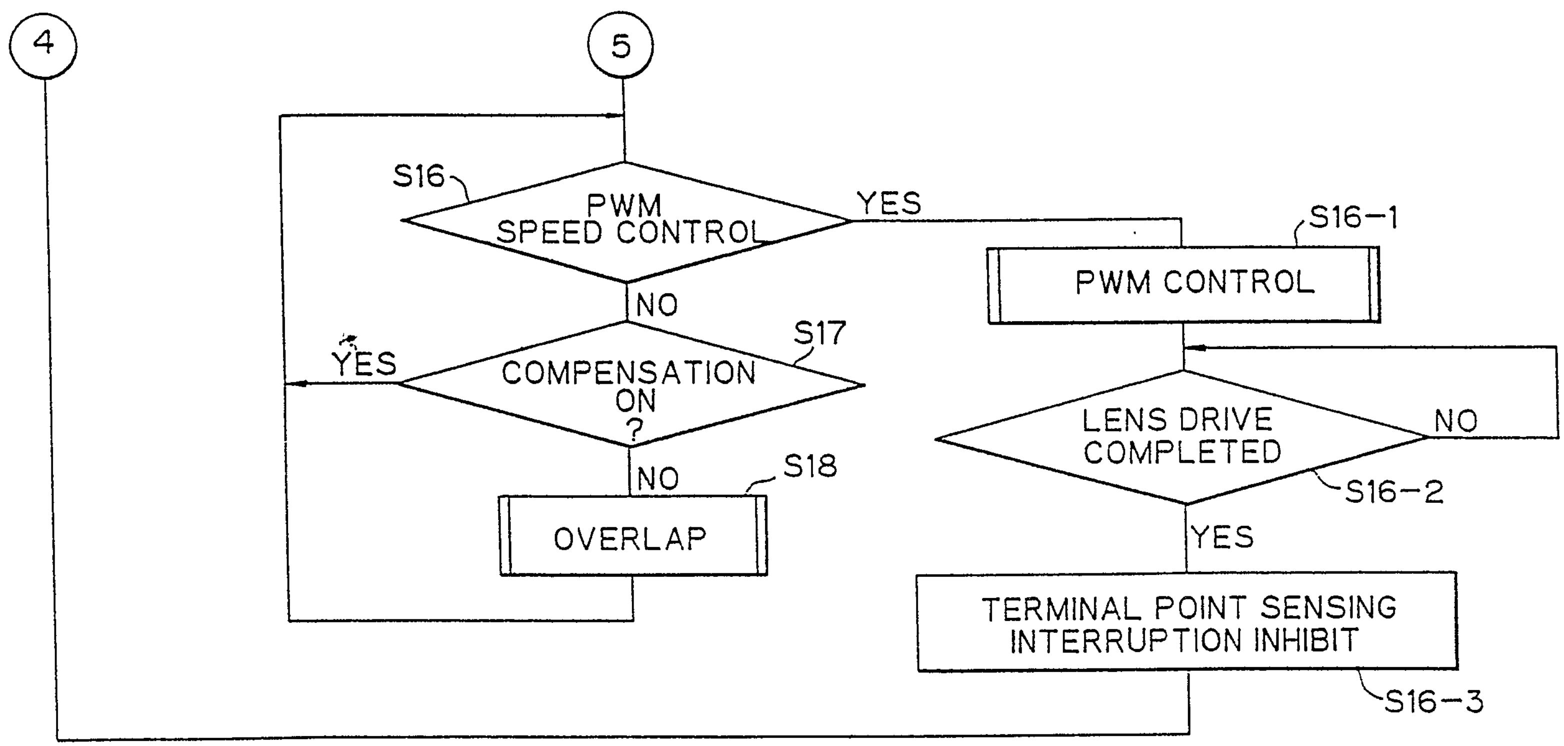

1
2
3
S9
AF ONE SHOT
YES
NO
S10
COMPENSATION ON ?
NO
YES
S11
FFN=1 ?
YES
NO
S12
AFP=0 ?
YES
NO
S6-2
COMPENSATION ON ?
YES
NO
LMOV
S13
BFM=1
S14
LENS DRIVE STARTS
S15
TERMINAL POINT SENSING INTERRUPTION PERMIT
4
5

FIG.3B

FIG.3C



4
5
S16
PWM SPEED CONTROL
YES
NO
S17
COMPENSATION ON ?
YES
NO
S18
OVERLAP
S16-1
PWM CONTROL
LENS DRIVE COMPLETED
NO
S16-2
YES
TERMINAL POINT SENSING INTERRUPTION INHIBIT
S16-3

FIG.4

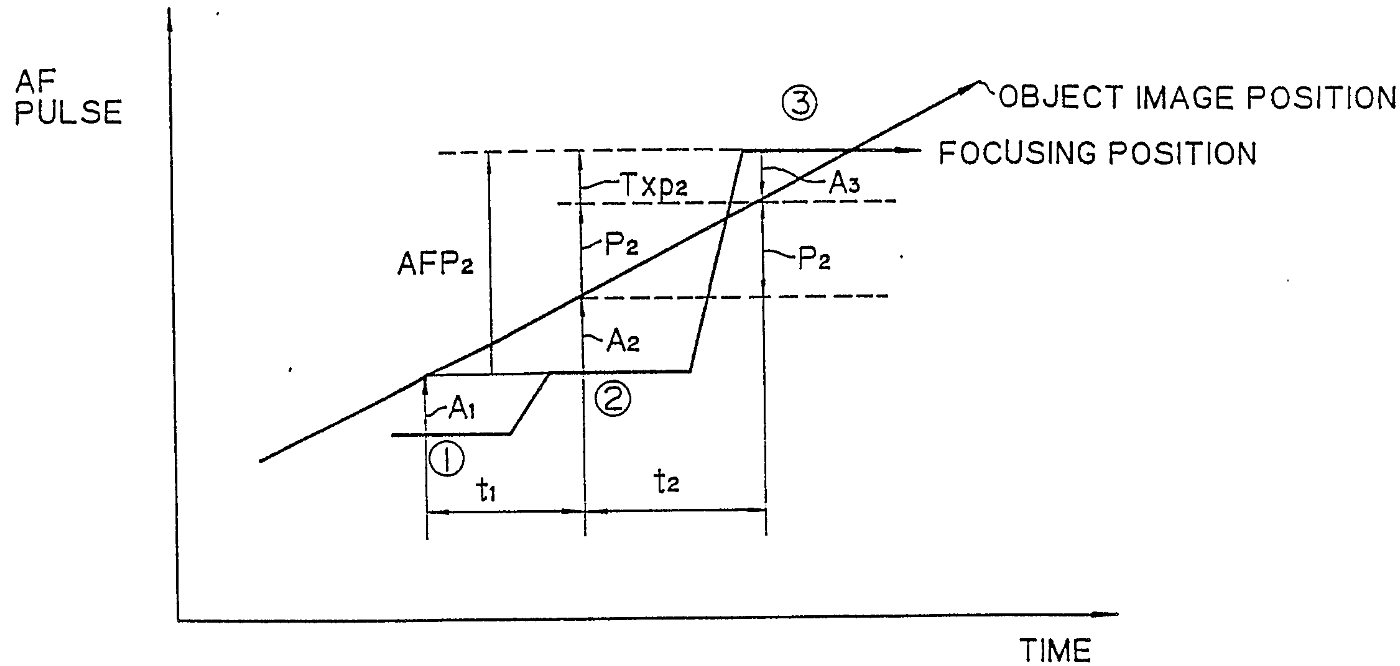

AF PULSE
③
OBJECT IMAGE POSITION
FOCUSING POSITION
Txp2
A3
P2
AFP2
P2
A2
A1
②
①
t1
t2
TIME

FIG.5

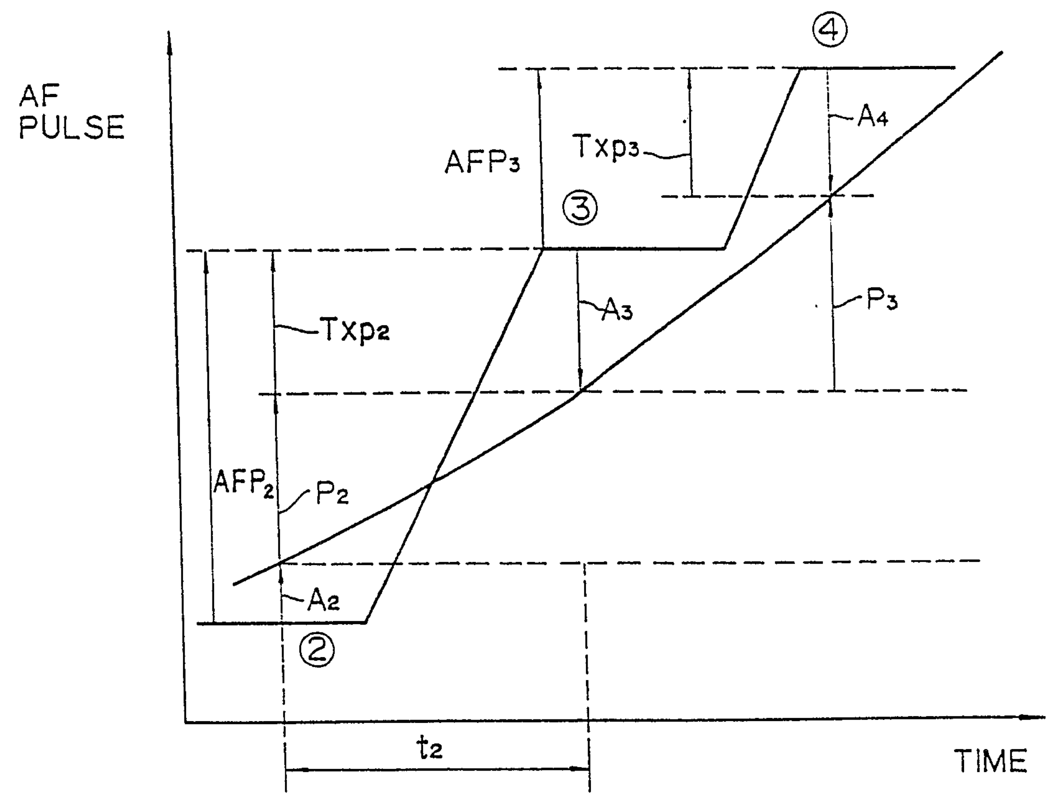
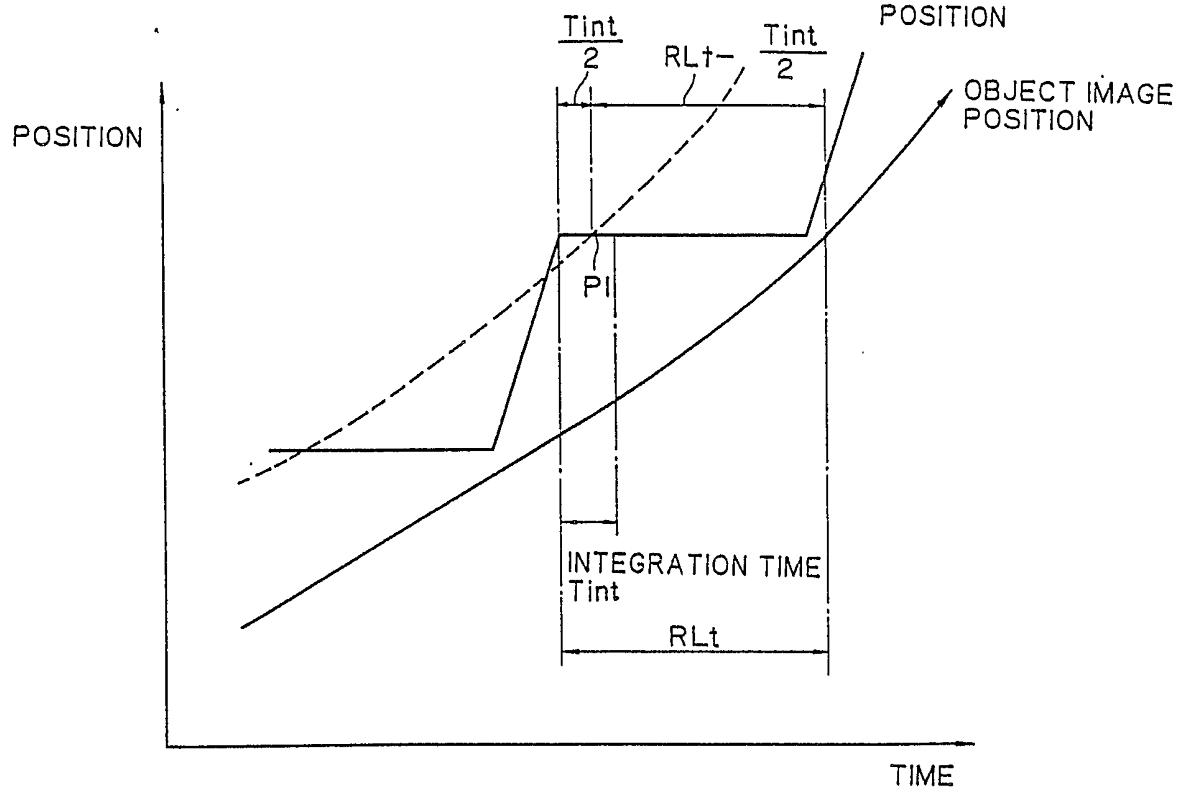


FIG. 6


POSITION
Tint/2
RLt−
Tint/2
FOCUSING POSITION
OBJECT IMAGE POSITION
PI
INTEGRATION TIME Tint
RLt
TIME

F I G. 7A

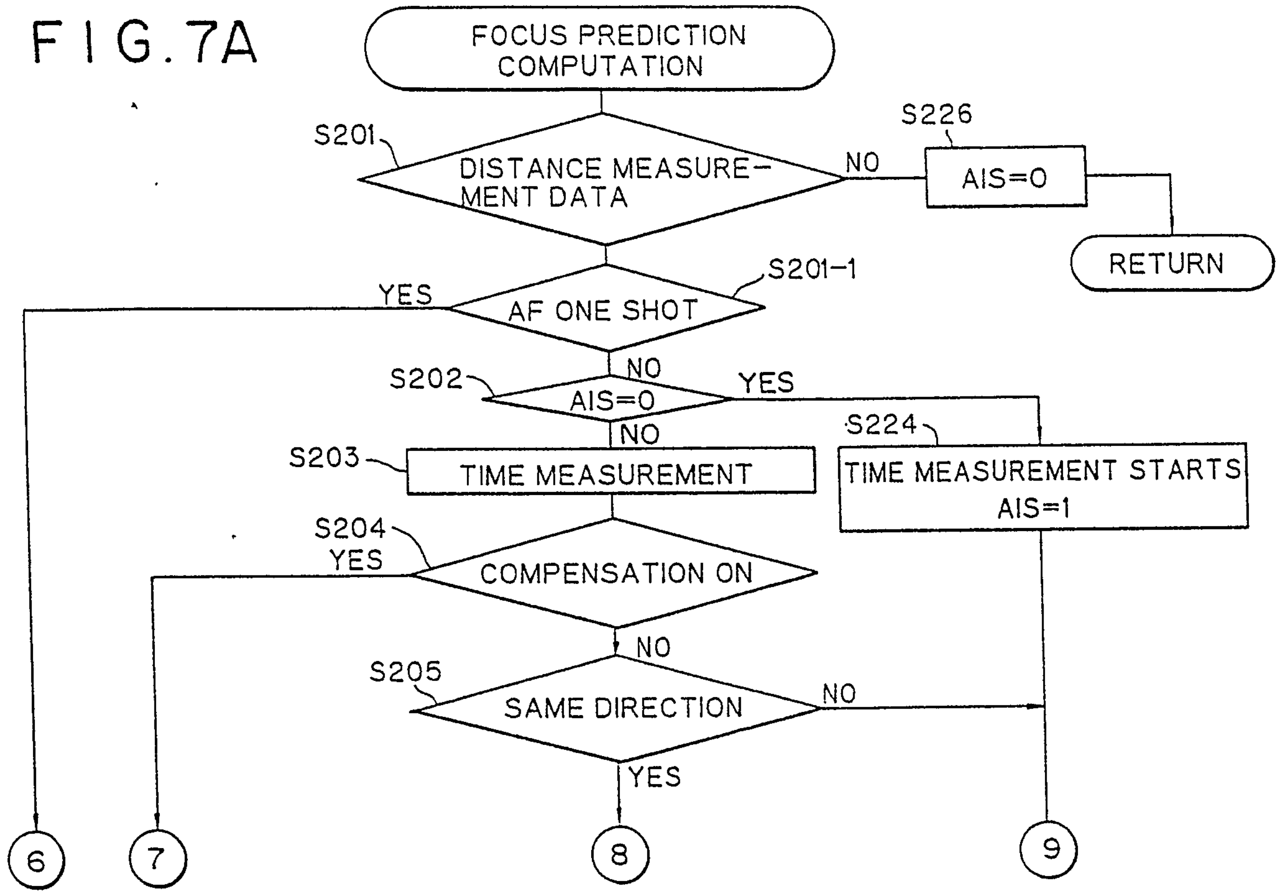
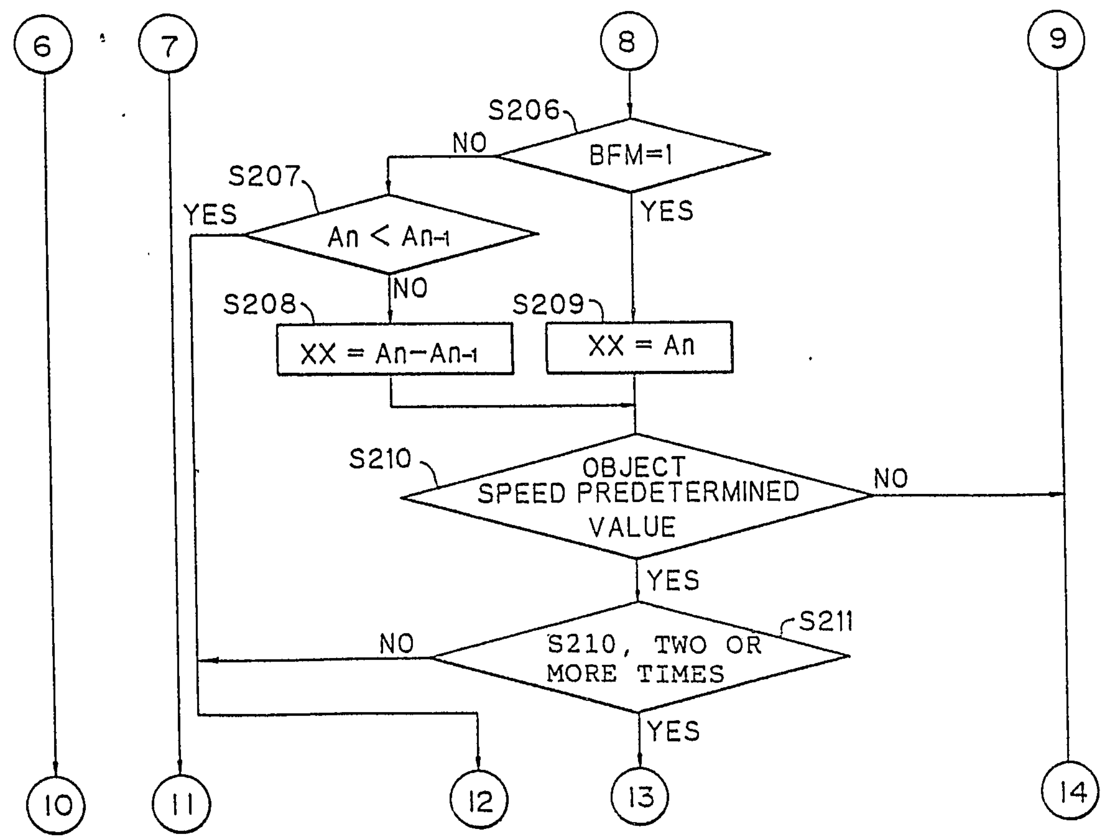

FOCUS PREDICTION COMPUTATION
S201
DISTANCE MEASURE-MENT DATA
NO
S226
AIS=0
RETURN
S201-1
AF ONE SHOT
YES
NO
S202
AIS=0
YES
NO
S203
TIME MEASUREMENT
S224
TIME MEASUREMENT STARTS AIS=1
S204
YES
COMPENSATION ON
NO
S205
SAME DIRECTION
NO
YES
6
7
8
9

FIG.7B



6
7
8
9
S206
BFM=1
NO
YES
S207
An < An-1
YES
NO
S208
XX = An−An-1
S209
XX = An
S210
OBJECT
SPEED PREDETERMINED
VALUE
NO
YES
S211
S210, TWO OR
MORE TIMES
NO
YES
10
11
12
13
14

- 10/34 -

FIG.7C

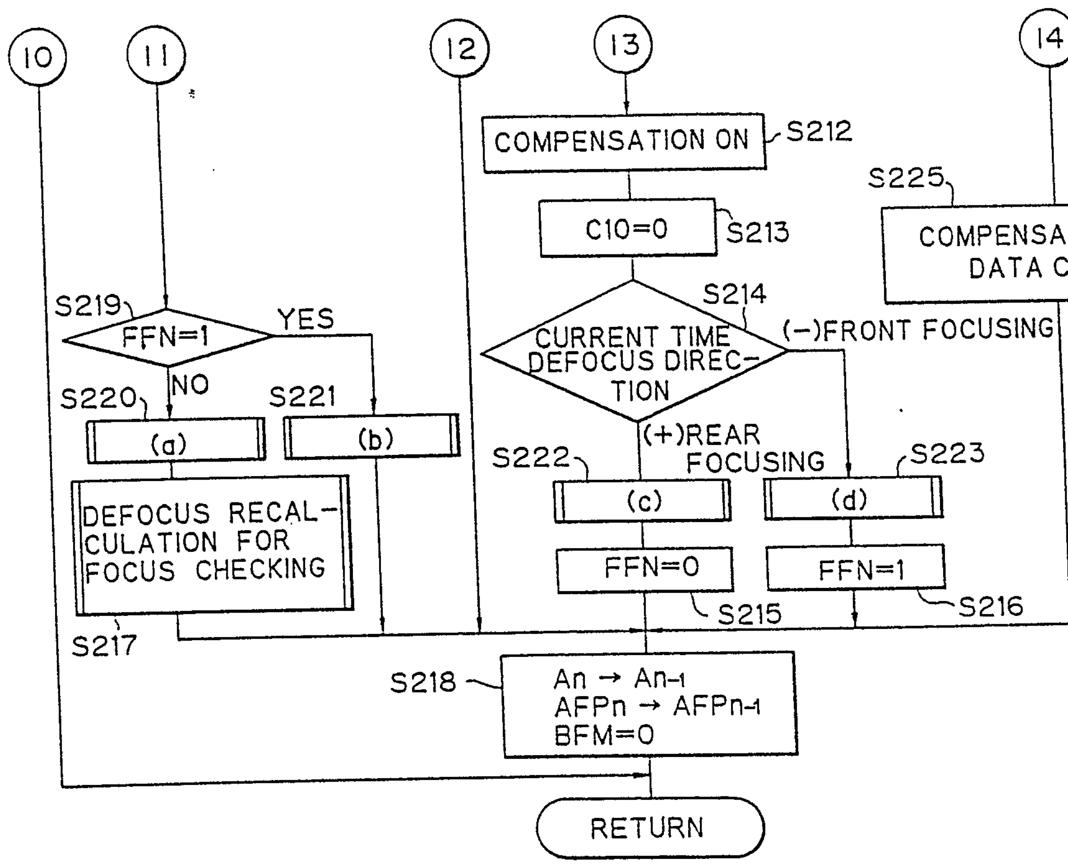

10
11
12
13
14
COMPENSATION ON
S212
C10=0
S213
S214
CURRENT TIME DEFOCUS DIRECTION
(−)FRONT FOCUSING
(+)REAR FOCUSING
S225
COMPENSATION OFF, DATA CLEAR
S219
FFN=1
YES
NO
S220
(a)
S221
(b)
DEFOCUS RECALCULATION FOR FOCUS CHECKING
S217
S222
(c)
S223
(d)
FFN=0
S215
FFN=1
S216
S218
An → An-1
AFPn → AFPn-1
BFM=0
RETURN

FIG.7

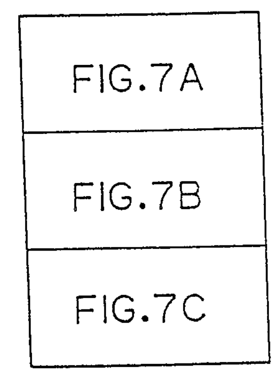


FIG.7A
FIG.7B
FIG.7C

FIG.8

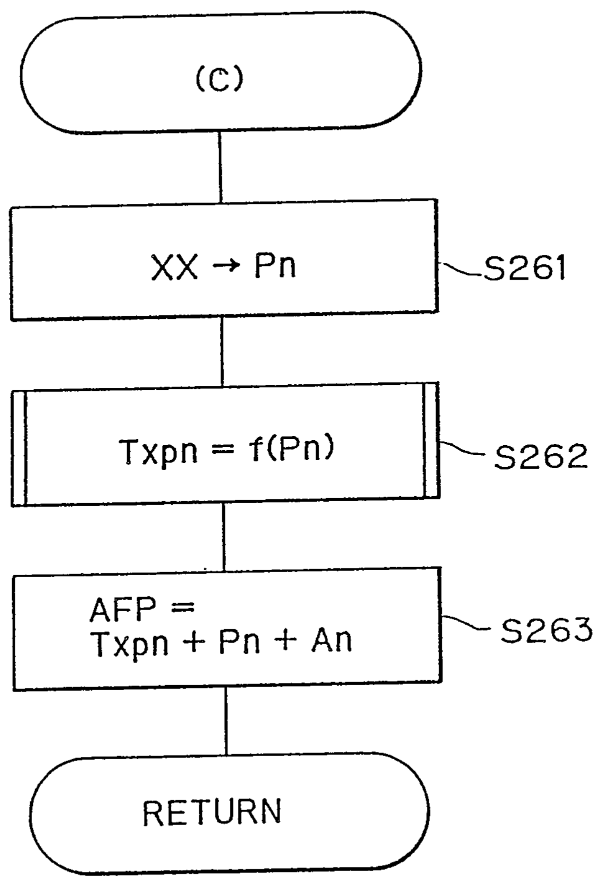


FIG. 9A

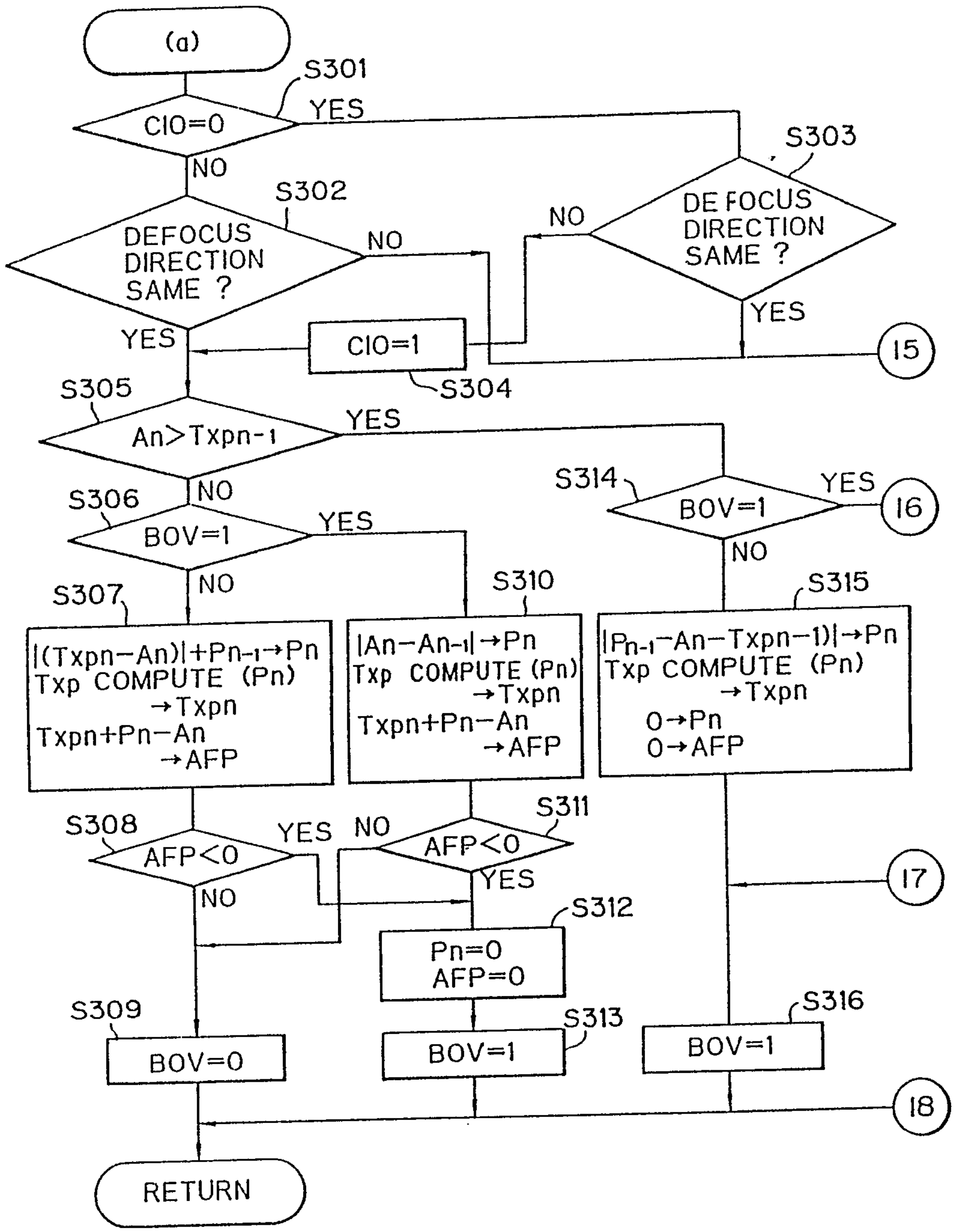

(a)
S301
CIO=0
YES
NO
S302
DEFOCUS DIRECTION SAME ?
NO
S303
DE FOCUS DIRECTION SAME ?
NO
YES
YES
CIO=1
S304
15
S305
An>Txpn-1
YES
NO
S314
BOV=1
YES
16
NO
S306
BOV=1
YES
NO
S307
|(Txpn−An)|+Pn-1→Pn
Txp COMPUTE (Pn) →Txpn
Txpn+Pn−An →AFP
S310
|An−An-1|→Pn
Txp COMPUTE (Pn) →Txpn
Txpn+Pn−An →AFP
S315
|Pn-1−An−Txpn−1)|→Pn
Txp COMPUTE (Pn) →Txpn
0→Pn
0→AFP
S308
AFP<0
YES
NO
S311
AFP<0
NO
YES
17
S312
Pn=0
AFP=0
S309
BOV=0
S313
BOV=1
S316
BOV=1
18
RETURN

FIG. 9B

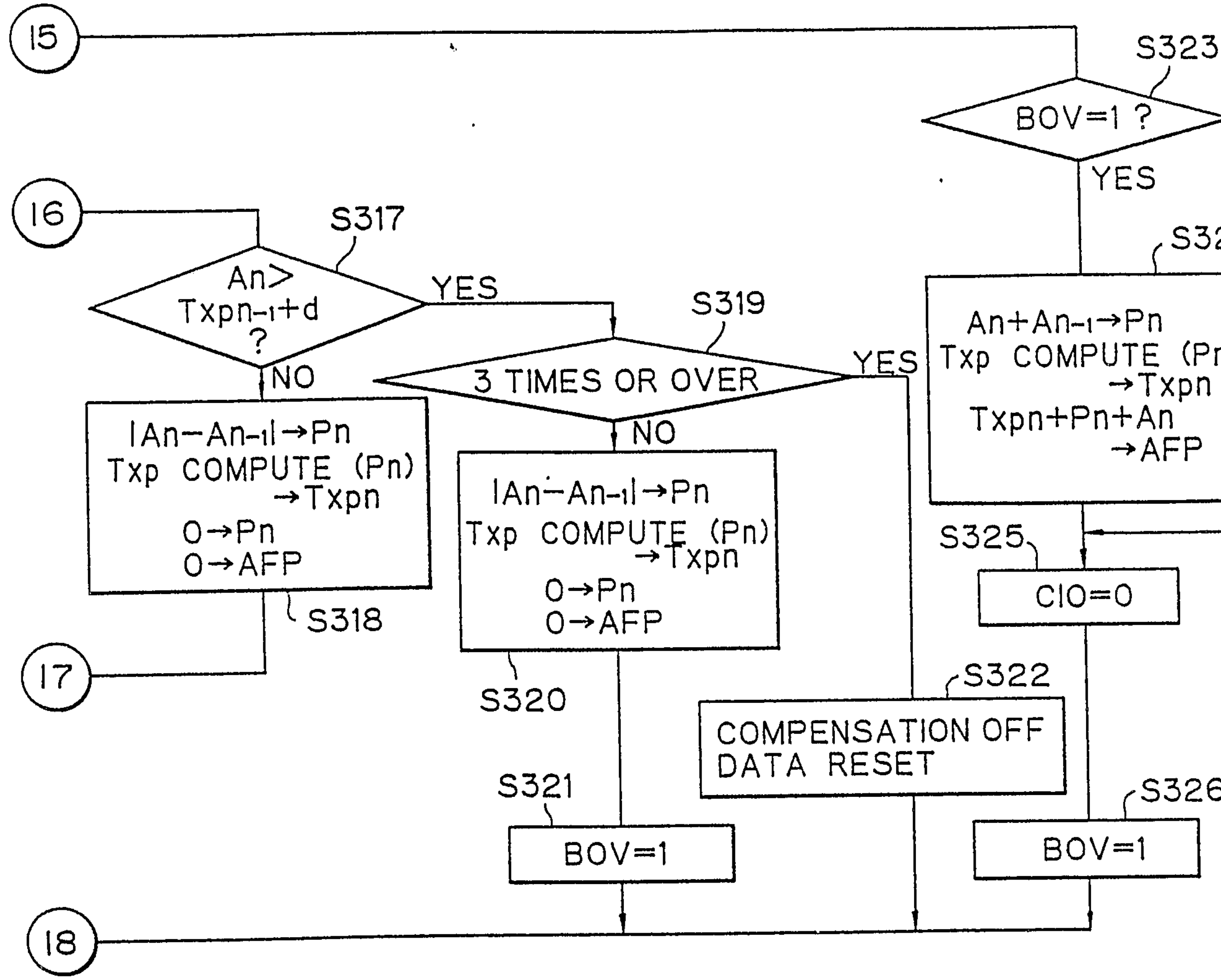

15
16
17
18
S317
An> Txpn-1+d ?
YES
NO
S318
|An−An-1|→Pn
Txp COMPUTE (Pn) →Txpn
0→Pn
0→AFP
S319
3 TIMES OR OVER
YES
NO
S320
|An−An-1|→Pn
Txp COMPUTE (Pn) →Txpn
0→Pn
0→AFP
S321
BOV=1
S322
COMPENSATION OFF
DATA RESET
S323
BOV=1 ?
YES
NO
S324
An+An-1→Pn
Txp COMPUTE (Pn) →Txpn
Txpn+Pn+An →AFP
S327
Txpn-1+Pn-1 +An→Pn
Txp COMPUTE (Pn) →Txpn
Txpn+Pn+An →AFP
S325
CIO=0
S326
BOV=1

FIG.9

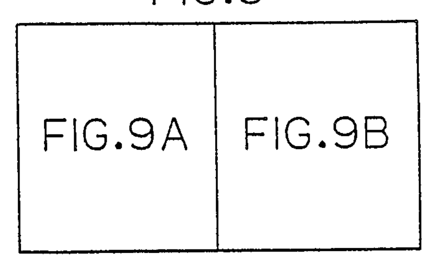


FIG.9A
FIG.9B

FIG.10

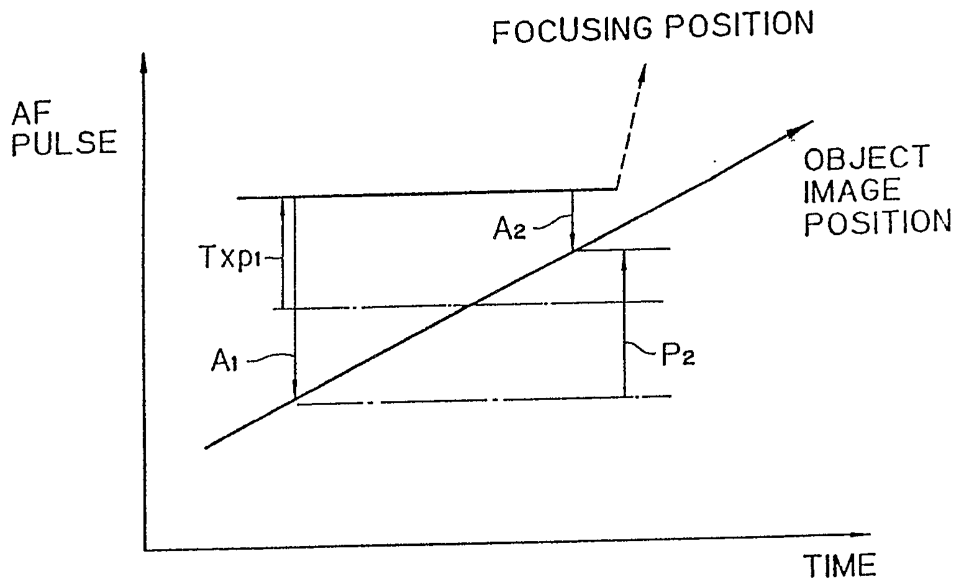

FOCUSING POSITION
AF PULSE
OBJECT IMAGE POSITION
A2
Txp1
A1
P2
TIME

FIG.11

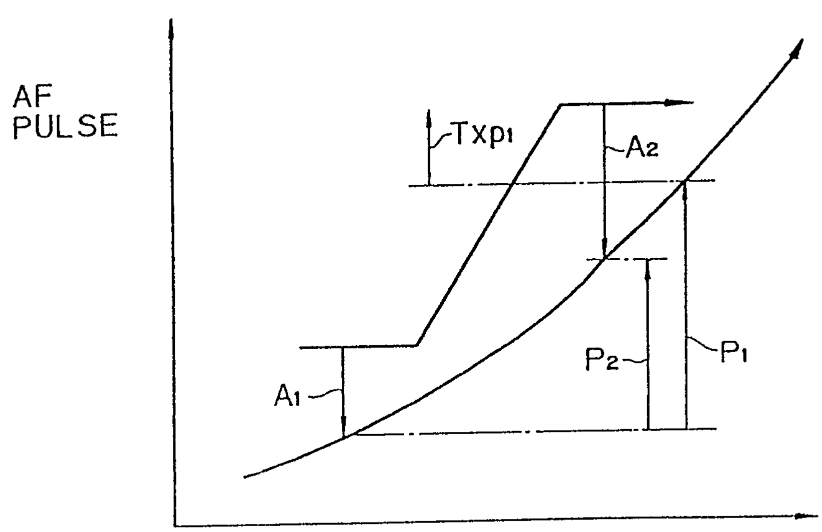
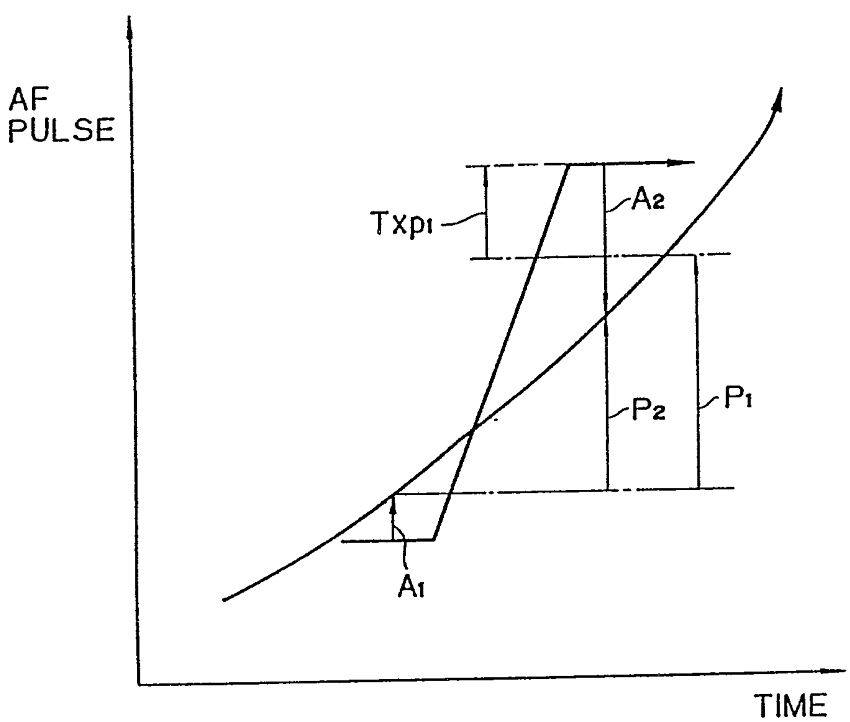
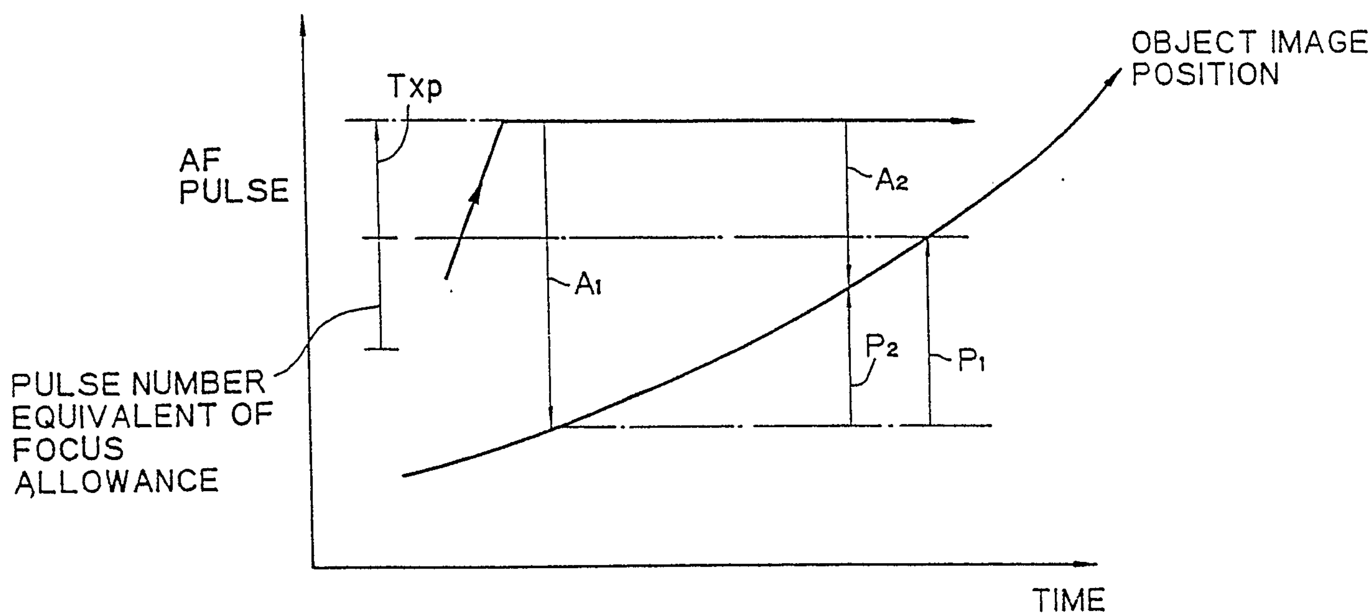

AF PULSE
Txp1
A2
A1
P2
P1

FIG.12



F I G. 13


AF
PULSE
Txp
PULSE NUMBER
EQUIVALENT OF
FOCUS
ALLOWANCE
A1
A2
P2
P1
OBJECT IMAGE
POSITION
TIME

-13/34-

F I G. 14

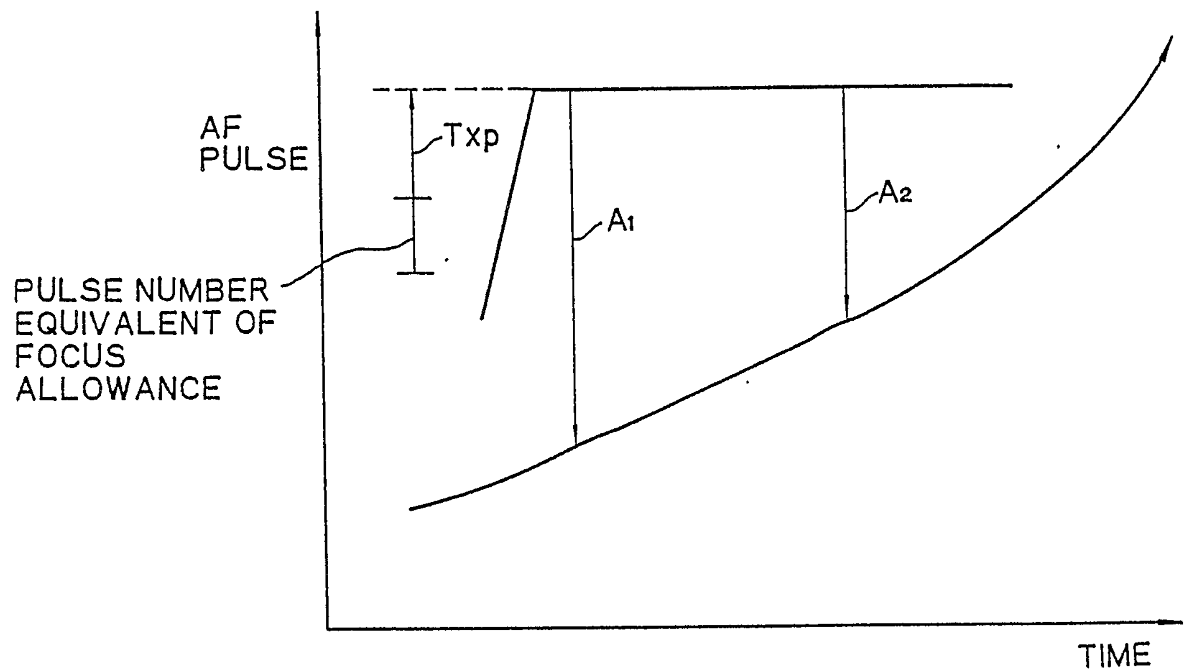

AF
PULSE
Txp
A1
A2
PULSE NUMBER
EQUIVALENT OF
FOCUS
ALLOWANCE
TIME

FIG.15

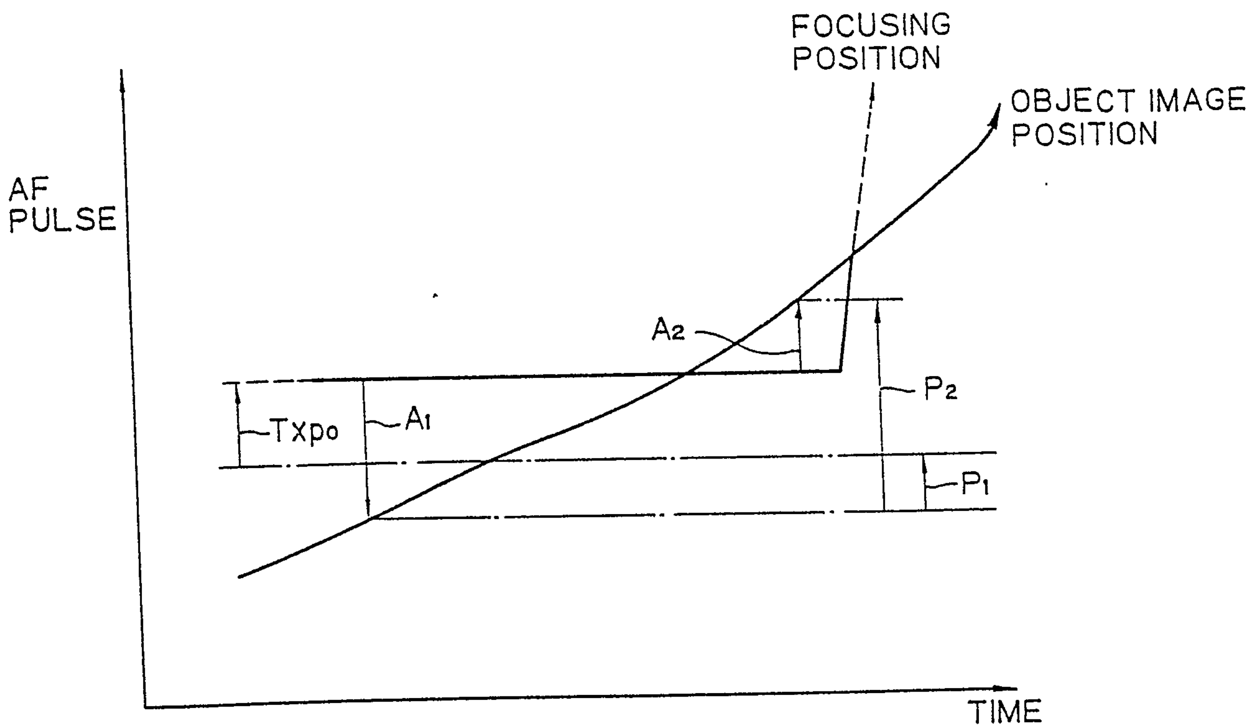

FOCUSING
POSITION
OBJECT IMAGE
POSITION
AF
PULSE
A2
Txpo
A1
P2
P1
TIME

FIG.16

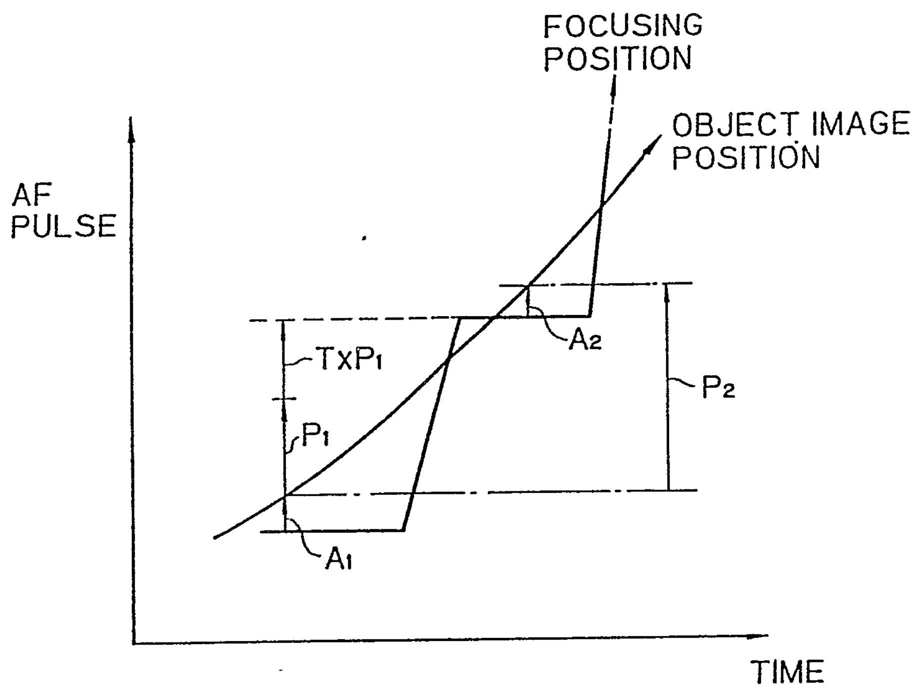

FOCUSING POSITION
OBJECT IMAGE POSITION
AF PULSE
TxP1
P1
A1
A2
P2
TIME

FIG.17

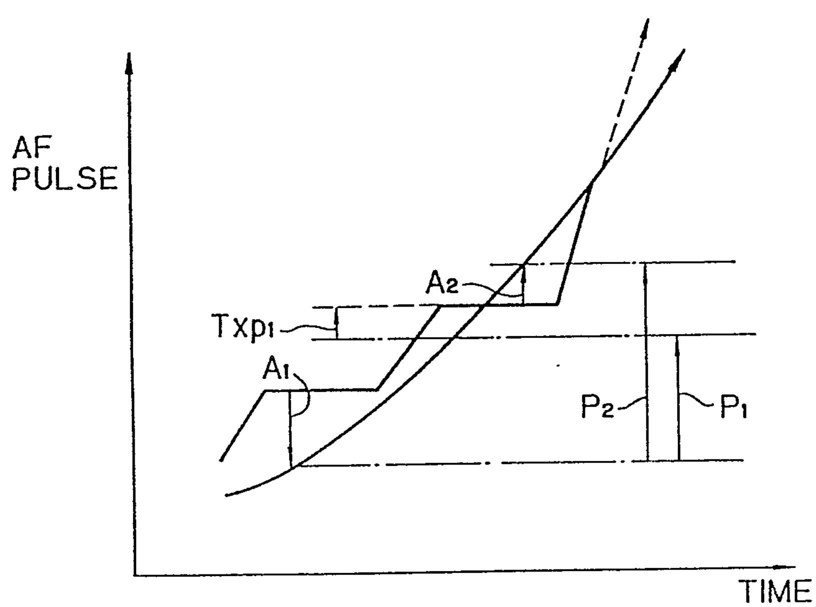
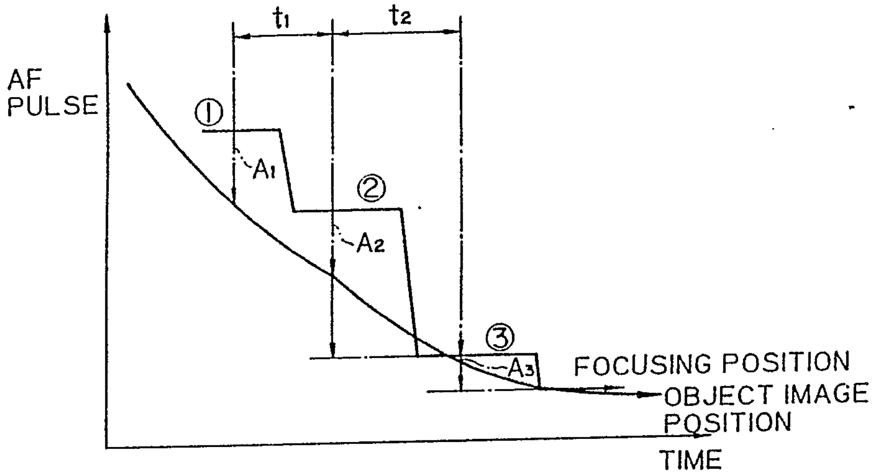
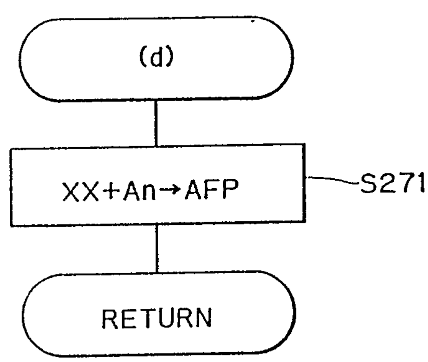

AF PULSE
A2
Txp1
A1
P2
P1
TIME

FIG.18



t1
t2
AF
PULSE
①
A1
②
A2
③
A3
FOCUSING POSITION
OBJECT IMAGE
POSITION
TIME

FIG.19



(d)
XX+An→AFP
S271
RETURN

FIG. 20

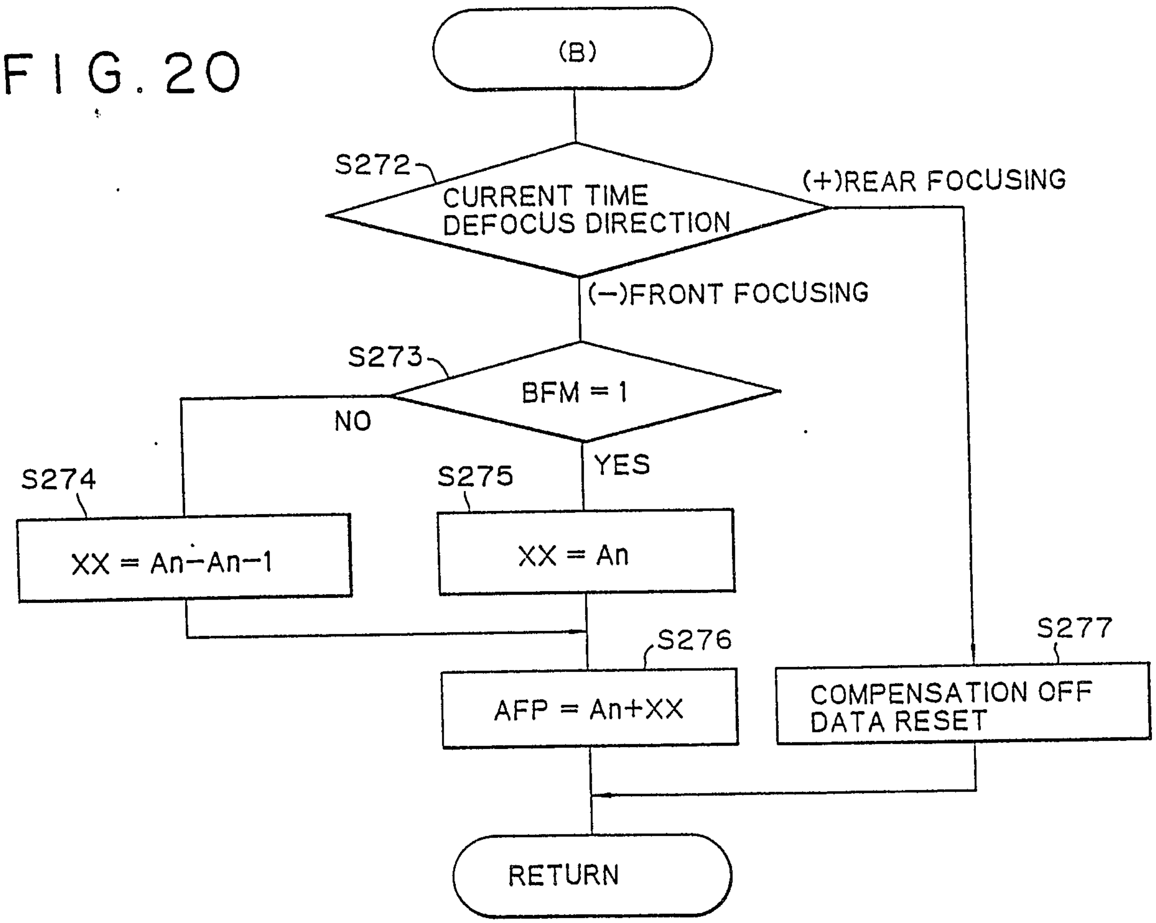

(B)
S272
CURRENT TIME DEFOCUS DIRECTION
(+)REAR FOCUSING
(−)FRONT FOCUSING
S273
BFM = 1
NO
YES
S274
XX = An−An−1
S275
XX = An
S276
AFP = An+XX
S277
COMPENSATION OFF DATA RESET
RETURN

FIG.21

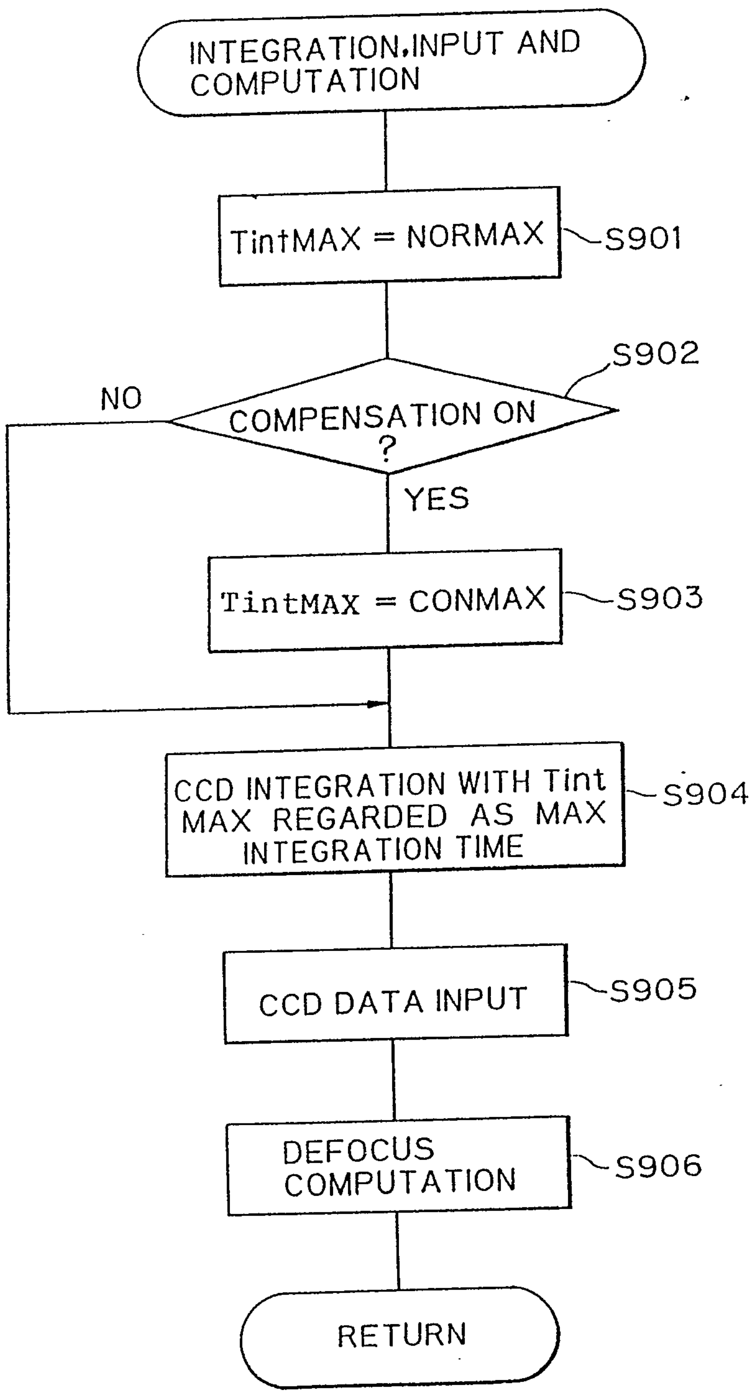

INTEGRATION,INPUT AND COMPUTATION
TintMAX = NORMAX
S901
COMPENSATION ON ?
S902
NO
YES
TintMAX = CONMAX
S903
CCD INTEGRATION WITH Tint MAX REGARDED AS MAX INTEGRATION TIME
S904
CCD DATA INPUT
S905
DEFOCUS COMPUTATION
S906
RETURN

FIG.22

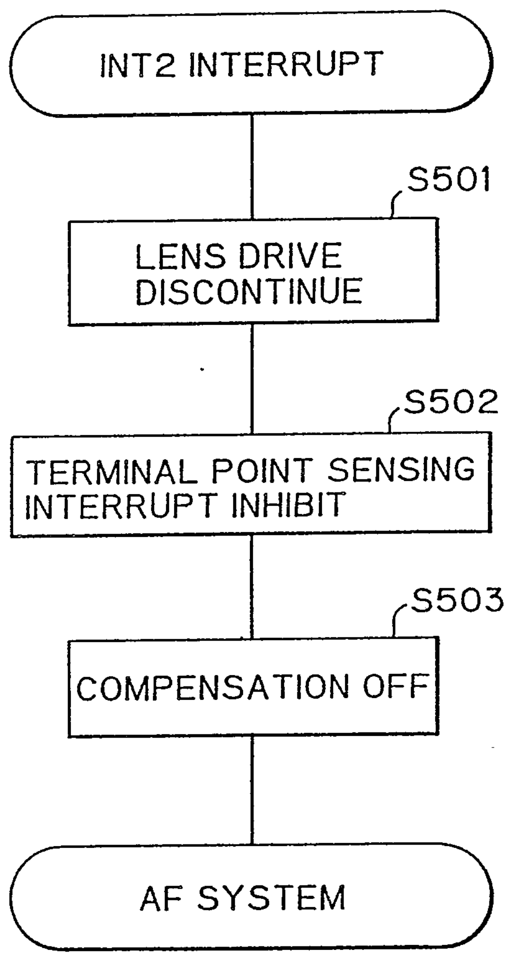

INT2 INTERRUPT
S501
LENS DRIVE DISCONTINUE
S502
TERMINAL POINT SENSING INTERRUPT INHIBIT
S503
COMPENSATION OFF
AF SYSTEM

FIG.23

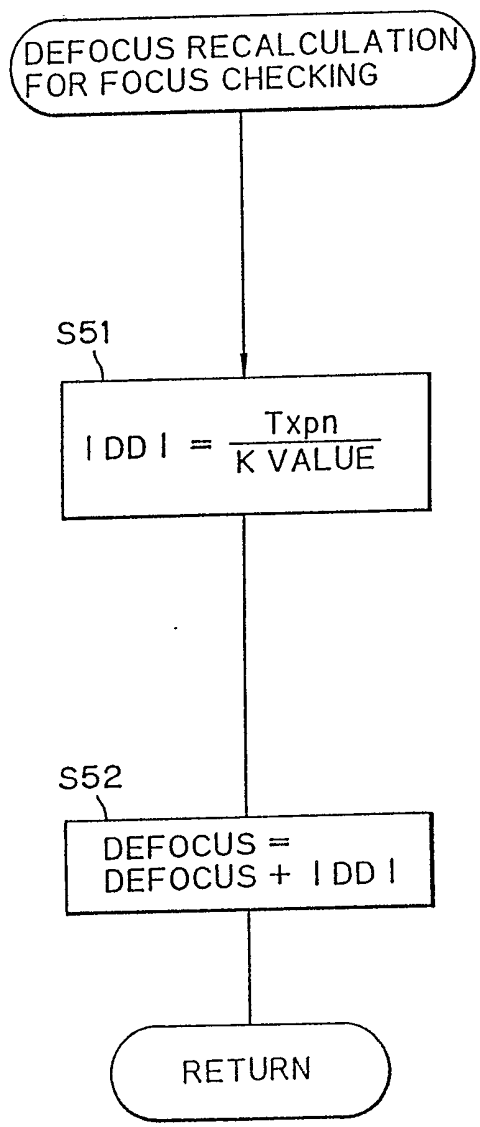

DEFOCUS RECALCULATION FOR FOCUS CHECKING
S51
| DD | = Txpn / K VALUE
S52
DEFOCUS = DEFOCUS + | DD |
RETURN

FIG. 24

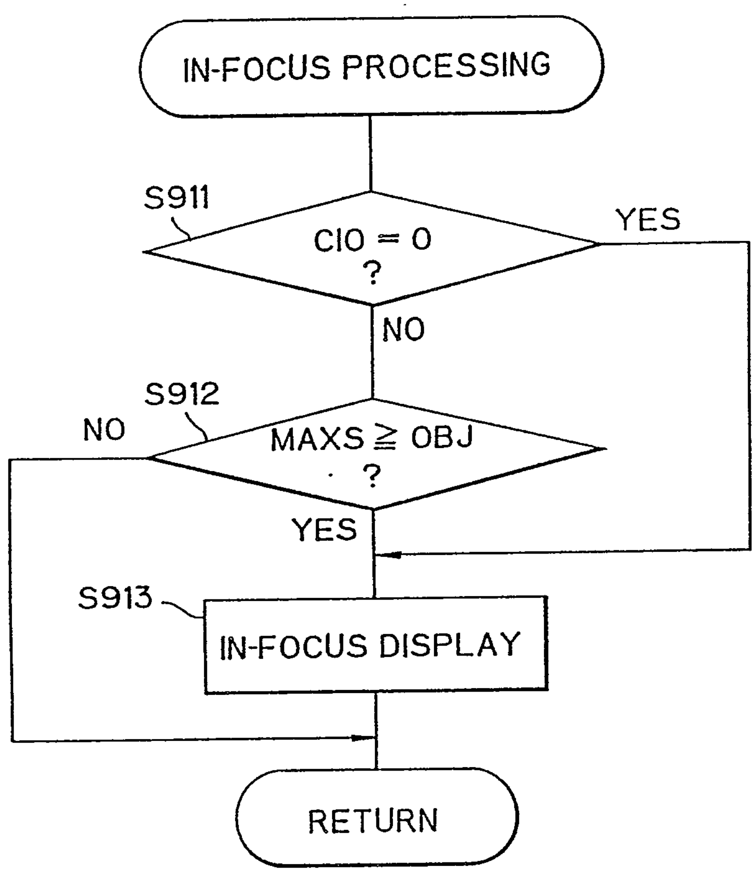

IN-FOCUS PROCESSING
S911
CIO = 0
?
YES
NO
S912
NO
MAXS ≧ OBJ
?
YES
S913
IN-FOCUS DISPLAY
RETURN

FIG.25A

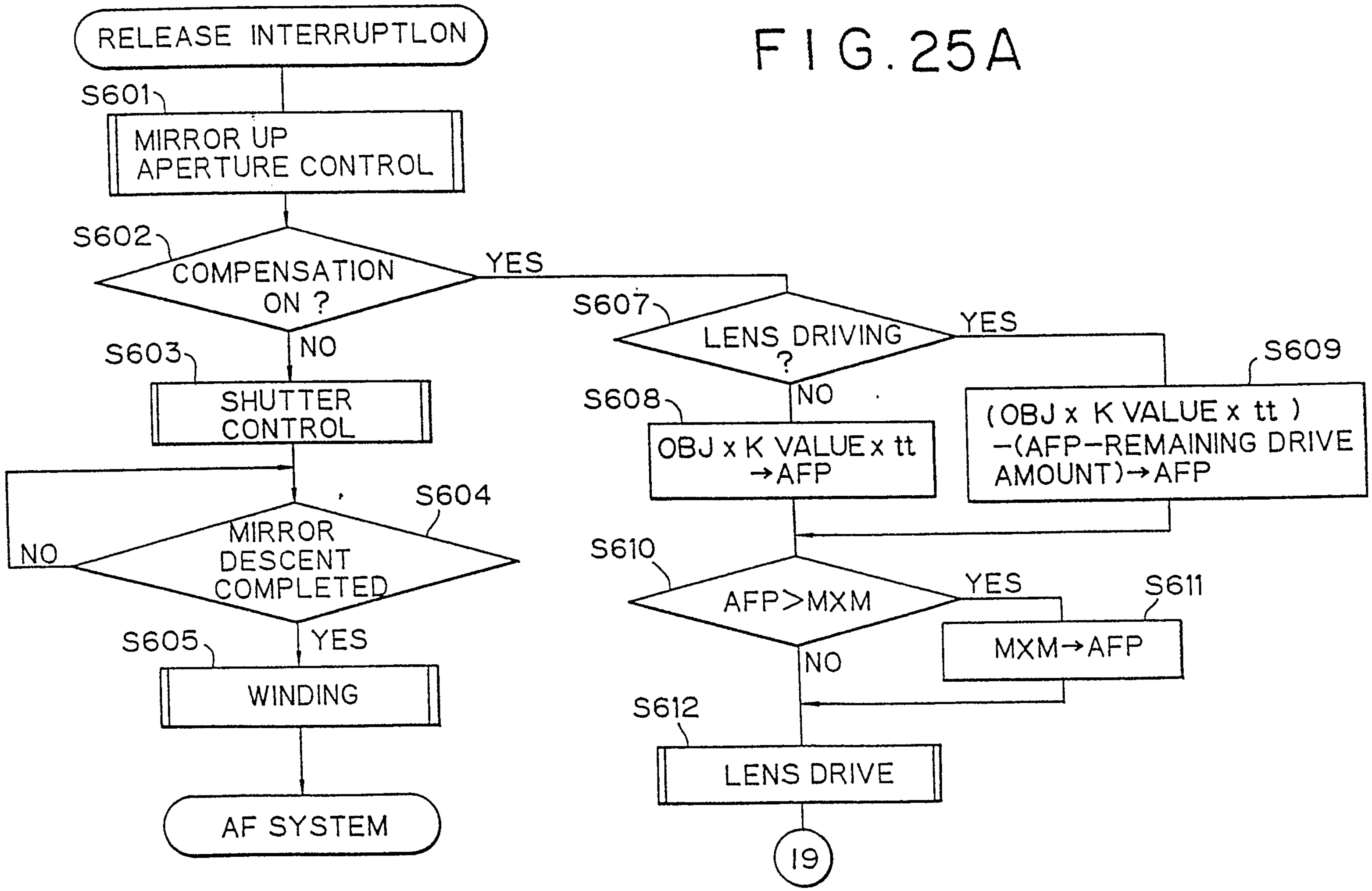

RELEASE INTERRUPTLON
S601
MIRROR UP APERTURE CONTROL
S602
COMPENSATION ON ?
YES
NO
S603
SHUTTER CONTROL
S604
MIRROR DESCENT COMPLETED
NO
YES
S605
WINDING
AF SYSTEM
S607
LENS DRIVING ?
YES
NO
S608
OBJ x K VALUE x tt →AFP
S609
(OBJ x K VALUE x tt) −(AFP−REMAINING DRIVE AMOUNT)→AFP
S610
AFP>MXM
YES
NO
S611
MXM→AFP
S612
LENS DRIVE
19

FIG. 25B

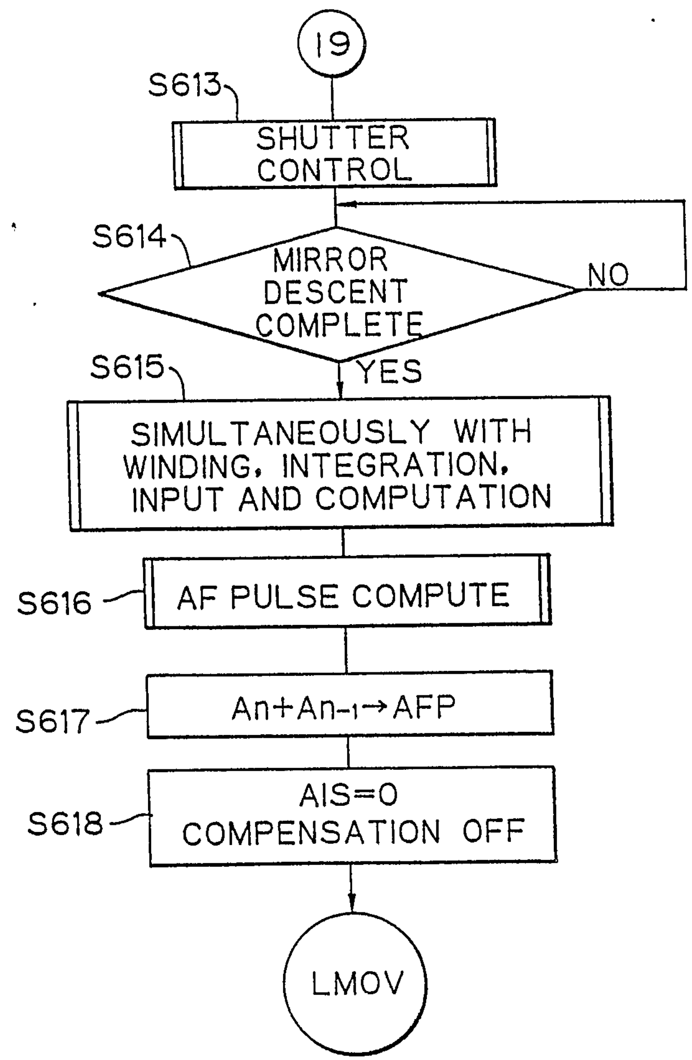


FIG.25

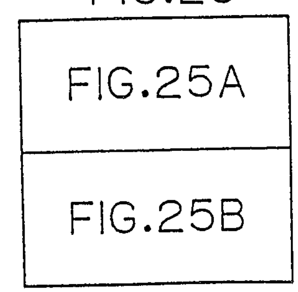


FIG. 26

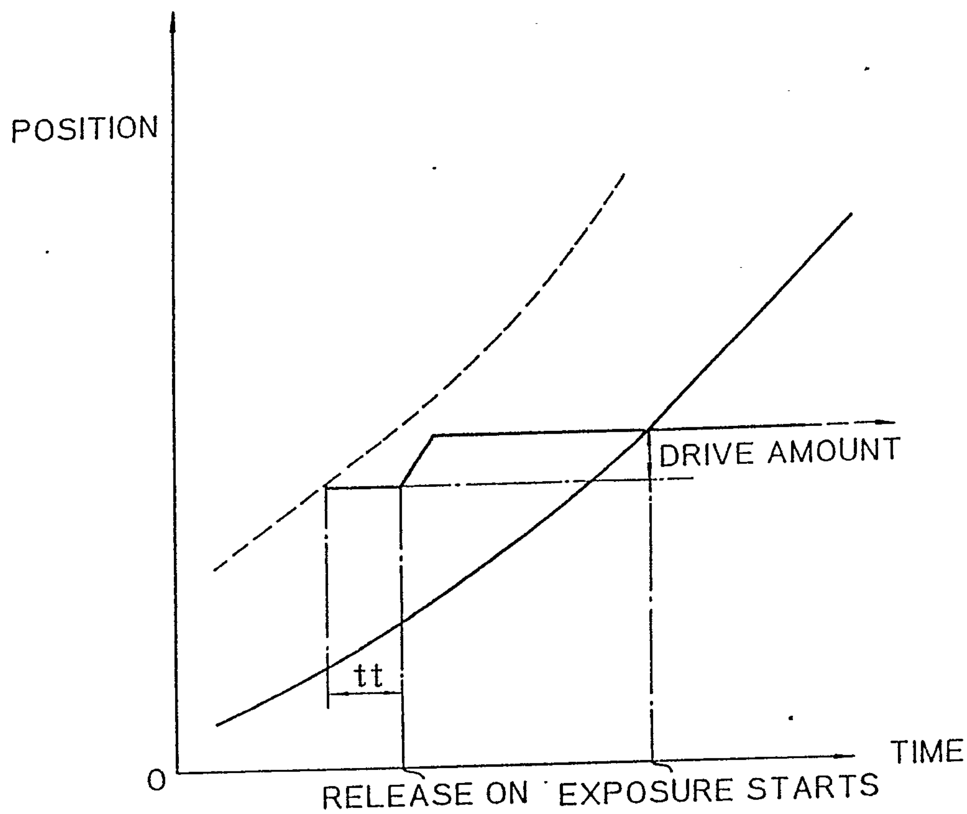


FIG. 27

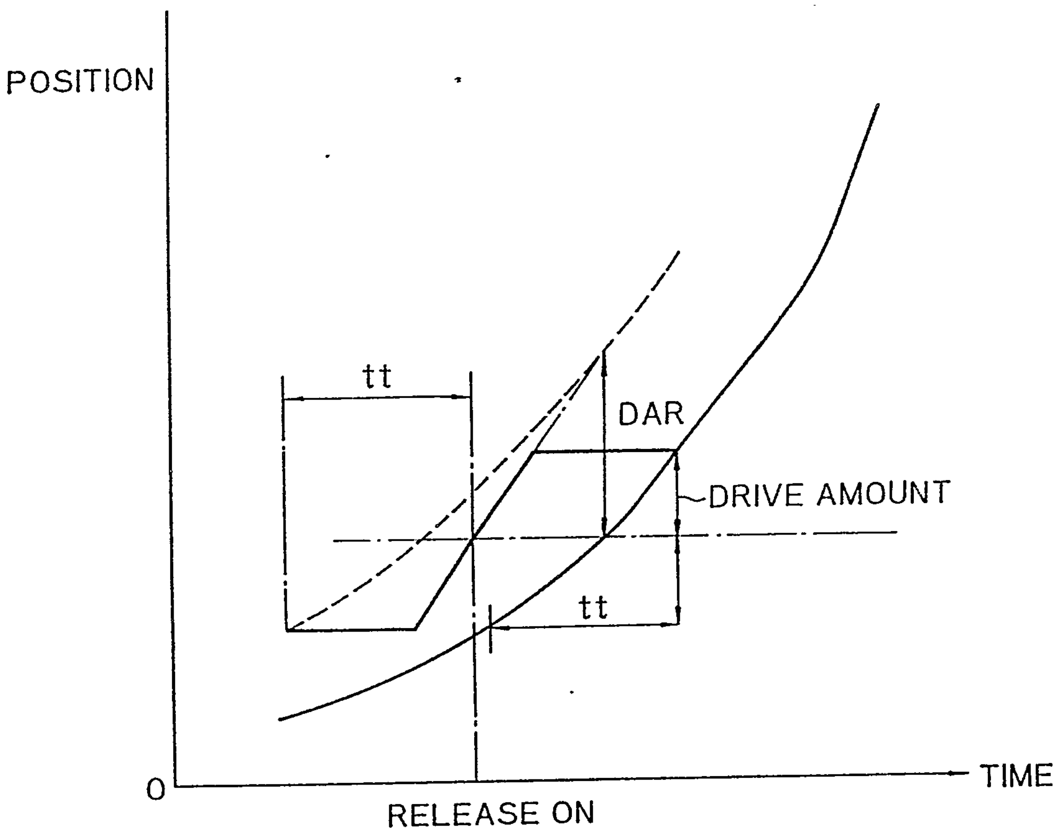


FIG.28

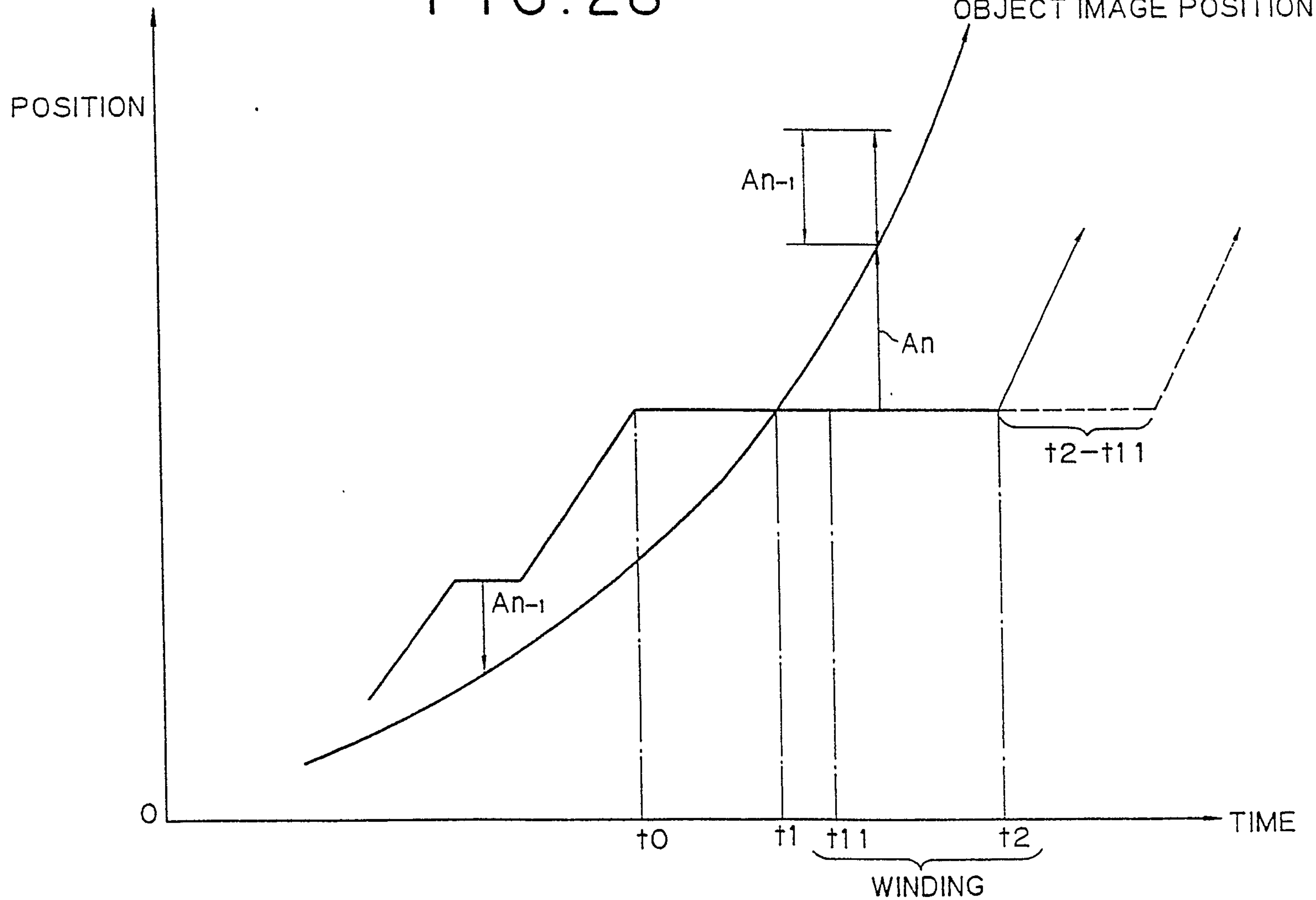

POSITION
OBJECT IMAGE POSITION
An-1
An
An-1
t2−t11
0
TIME
t0
t1
t11
t2
WINDING

FIG.29

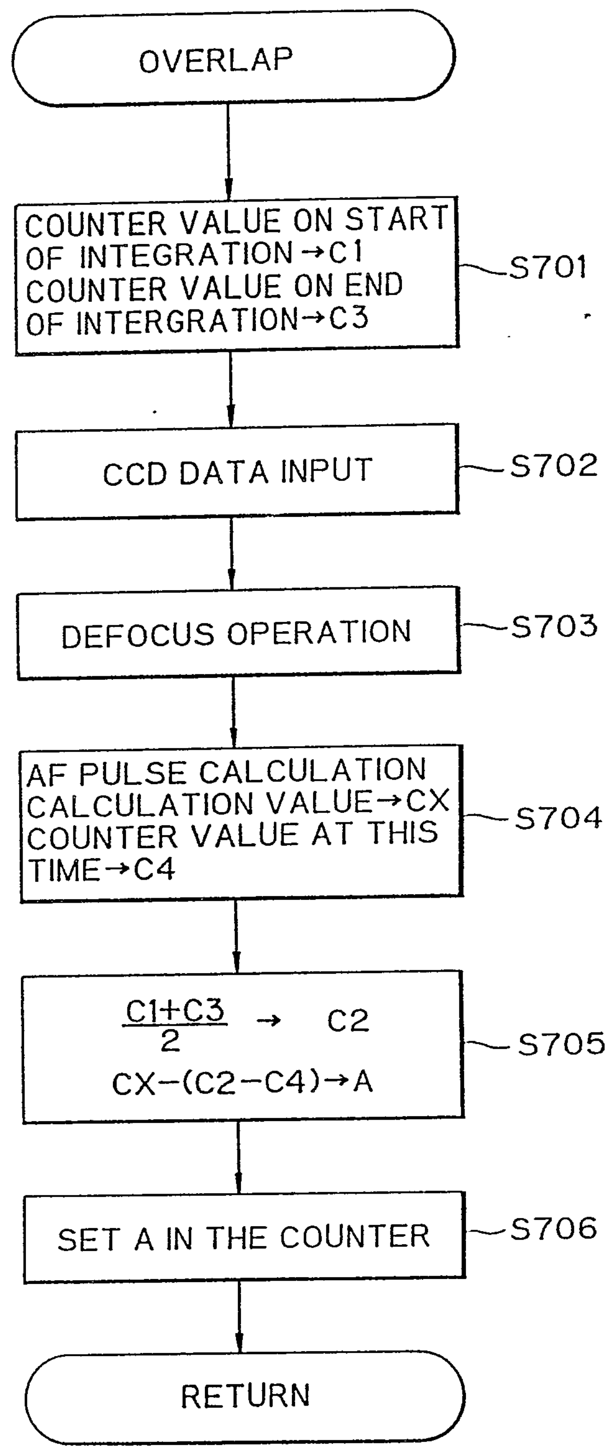

OVERLAP
COUNTER VALUE ON START OF INTEGRATION→C1
COUNTER VALUE ON END OF INTERGRATION→C3
S701
CCD DATA INPUT
S702
DEFOCUS OPERATION
S703
AF PULSE CALCULATION
CALCULATION VALUE→CX
COUNTER VALUE AT THIS TIME→C4
S704
$\frac{C1+C3}{2}$ → C2
CX−(C2−C4)→A
S705
SET A IN THE COUNTER
S706
RETURN

FIG. 30

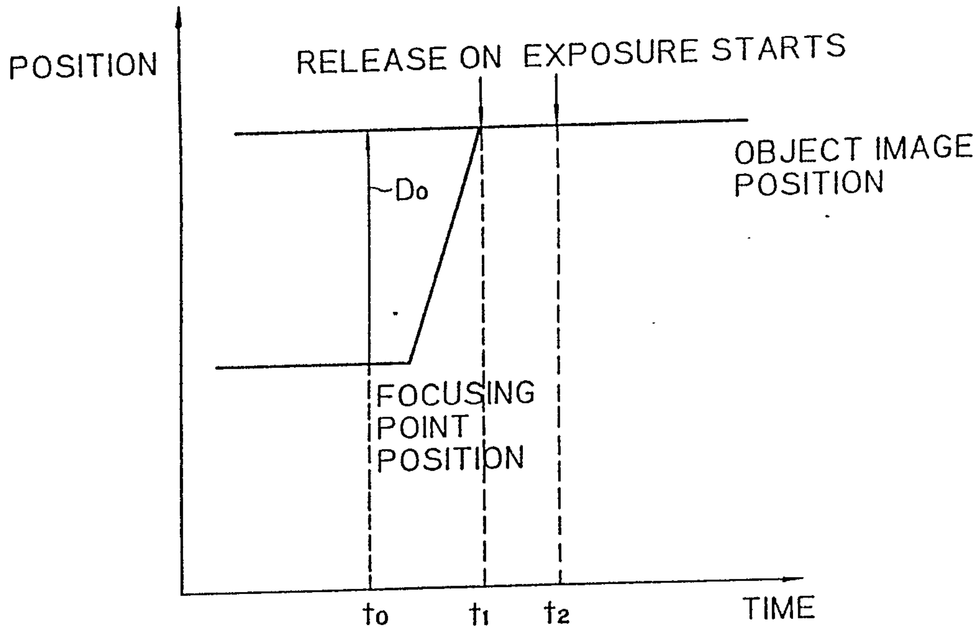

POSITION
RELEASE ON
EXPOSURE STARTS
OBJECT IMAGE POSITION
~Do
FOCUSING POINT POSITION
to
t1
t2
TIME

FIG. 31

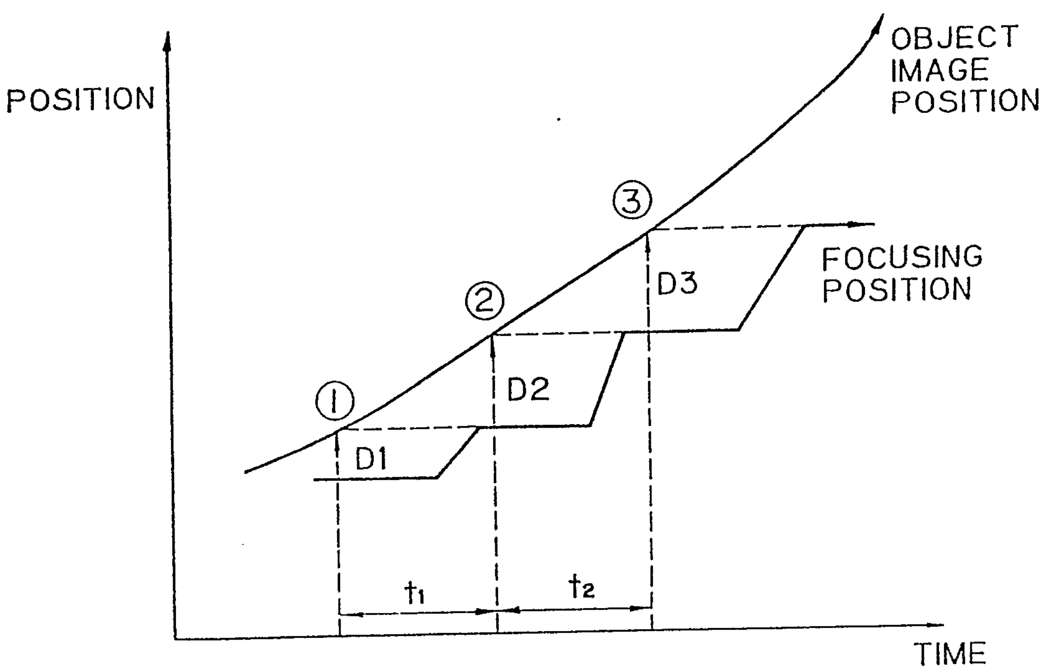
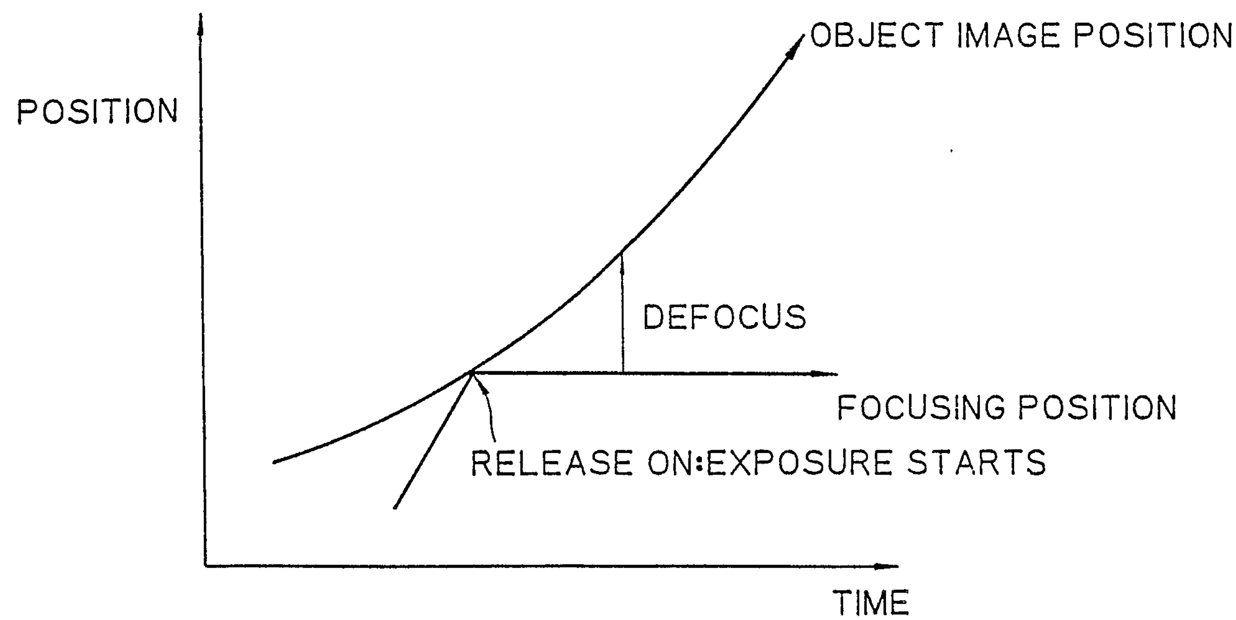

POSITION
OBJECT IMAGE POSITION
③
②
①
D3
D2
D1
FOCUSING POSITION
t1
t2
TIME

FIG. 32


POSITION
OBJECT IMAGE POSITION
DEFOCUS
FOCUSING POSITION
RELEASE ON:EXPOSURE STARTS
TIME

Automatic Focusing Device

The present invention relates to an automatic focusing device employed in, for example, a photographic camera.

In recent years, cameras equipped with an AF (automatic-focus) function are tremendously on the increase, and on single lens reflex cameras with interchangeable lens as well, AF function has become indispensable. In general, on single lens reflex cameras, a so-called phase difference detecting method is adopted for automatic focusing. The AF with the phase difference detecting method is executed with steps like the following.

Firstly, a pair of object images with spatial parallax are projected, respectively, onto a pair of photosensitive units such as CCD (charge coupled device) etc., and the light amount received by the respective photosensitive units is integrated in terms of time. Then, according to the phase differential of two object images on respective photosensitive units, the distance differential between the sensing element (film equivalent plane) and the imaging plane (focus position) of the photographing lens with respect to a photographing object, and the direction thereof (defocus amount/ defocus direction) are calculated.

From the calculated defocus amount and direction, a drive amount of a motor necessary to drive the photographing lens to make the imaging plane coincident with the film equivalent plane is obtained, based upon which the focus lens is driven along the optical axis thereof. The number of pulses applied to the motor in the above operation is obtained according to the following formula:

$$P = Kv \times D$$

Where, P is number of pulses applied to the motor,

D is the defocus amount, and

Kv is a so-called lens-movement-amount conversion coefficient (K value) which is a coefficient representing the relation between the defocus amount and the number of pulses to drive the motor as necessary to make the defocus amount zero, and is the value inherent to the respective lens.

Figs. 30 through 32 explain a conventional AF system as described above. In each drawing, "object image position" indicates the imaging plane of the photographing lens with respect to the photographing object with the position of the focus lens taken as a reference, and "focusing position" is the film equivalent plane also with the position of the focus lens taken as a reference.

In Fig. 30, as a result of distance measurement executed at time t0, it is assumed that the distance differential between the focusing position and the object image position, i.e., the defocus amount, is detected as D0. Then, to make the defocus amount D0 equal to zero (0), the lens is driven. When the photographing object is stationary or standing-still, the focusing position becomes consistent with the object image position by the results of lens driving. Under this state, the release ON interruption processing is executed, and exposure starts after elapse of a release-time-lag t2, that is, the time required for the mechanical operations for mirror ascent and stopping down of aperture. During exposure, as illustrated in Fig. 30, the focusing position and the object image position remain consistent with each other.

However, when the object is moving (more particularly, moving in the lens drive direction), even if integration and computation are once carried out during its movement, as the object keeps moving while the lens is being driven according to the results of such integration and computation, further integrations, computations and resulting lens drives must be repeatedly executed to keep the focusing position and the object image position consistent.

Fig. 31 shows the case wherein a photographing object is moving from a remote field to a near field at constant speed. The amount of movement of the object image position becomes larger as the object is the closer to the photographing lens.

It is assumed that the distance differential between the object image position and the focusing position, i.e., the defocus amount, at point (1) is D1. When the lens is driven by an amount corresponding to D1 and after elapse of time t1, the defocus amount D2 is obtained at point (2) . In the same manner, the lens is driven as for the amount corresponding to D2 and after elapse of time t2, the defocus amount D3 is obtained at point (3) . Here, the focusing position at point (2) corresponds to the object image position at point (1) , and since the object keeps moving while time t1 elapses, the defocus amounts would be,

$$D1 < D2 < D3.$$

Thus, the defocus amount increases gradually each time when the distance measurement is executed, while the object is moving toward the photographing lens at constant speed, and therefore the lens drive can not sufficiently follow the movement of the object image position.

In order to overcome the above problem, the above delay needs to be prevented by predicting the amount of the movement of the object image position from start of integration to completion of the computed lens drive, with which the lens is additionally driven. In this case, it is ideal that the focusing position is coincident with the object image position when the lens is completely driven by the total amount completed.

However, even though the ideal prediction is carried out and thereby the focusing position becomes coincident with the object image position at the time at which the exposure starts, it is necessary to execute the distance measurement for the next shot in the case of continuous shots.

In this case, conventionally, the distance measurement is not executed during the time required from release-ON to completion of winding. This means that the lens drive for tracking the movement of the photographing object based upon the focus prediction can not be executed during that time. However, the photographing object may well continue movement during the release operation. Accordingly, even if the distance measurement is re-executed and the lens is re-driven after completion of the release operation, the object image position deviates considerably from the focusing position at that time, thereby causing the time required to track the object to be longer. This defect due to delay of re-start of the distance measurement is serious, particularly in the case that the object is approaching the camera from a remote field, wherein the object image speed becomes gradually larger.

It is therefore an object of the present invention to provide an improved automatic focusing device to be employed in a camera, capable of executing an appropriate lens drive to follow the movement of a photographing object with prompt re-starting of the distance measurements for the next release operation.

According to the present invention, there is provided an automatic focusing device to be employed in a camera, comprising:

a focus lens movable along the optical axis thereof;

a drive means for driving said focus lens;

a distance measuring means for obtaining a defocus amount of said focus lens with respect to a photographing object;

a measurement control means for controlling said distance measuring means to repeat the distance measurements in a predetermined interval;

a computing means for computing the relative speed of movement of said photographing object with respect to said focus lens along said optical axis based upon the defocus amounts obtained by said distance measuring means;

a drive control means for controlling said drive means to drive said focus lens, based upon the results of computation by said computing means, to a position where an in-focus condition could be obtained with respect to said object after elapse of a predetermined time; and

a release means for executing exposure,

wherein said distance measuring means executes a next distance measurement after elapse of a predetermined time from the start of a release operation by said release means and before completion thereof.

An example of the invention will be described in detail below, by way of example, with reference to the accompanying drawings, in which:-

Fig. 1 is a block diagram showing principal parts of an automatic focusing device, embodying the invention, employed in a photographic camera;

Fig. 2 is a graph explaining a fundamental principle of a focus prediction system;

Fig. 3 is a flow chart showing the processing of an AF system with the focus prediction system;

Fig. 4 is a graph explaining the principles of a catch-up tracking mode and a preemptive tracking mode of the focus prediction system;

Fig. 5 is a graph explaining the computation under the preemptive tracking mode;

Fig. 6 is a graph explaining the principle of the focus prediction computation for an object-in-motion with integration time taken into consideration;

Fig. 7 is a main flow chart of a focus prediction computation;

Fig. 8 is a flow chart for a focus prediction computation, in the case that the object-in-motion is approaching the camera, executed immediately after the compensation is ON;

Fig. 9 is a flow chart for the computation, in the case that the object-in-motion is approaching the camera, for the second time and so on after the compensation is ON;

Figs. 10 through 17 are explanatory graphs for the focus prediction computation on the basis of moving state of the object-in-motion and results of lens drive;

Fig. 18 is a graph explaining the algorithm for the case of the object-in-motion moving away from the camera;

Fig. 19 is a flow chart explaining the computation for the case of the object-in-motion moving away from the camera after the compensation is ON;

Fig. 20 is a flow chart explaining the computation for the case of the object-in-motion moving away from the camera, for the second time and so on after the compensation is ON;

Fig. 21 is a flow chart showing the processing for the case that the integration time is limited;

Fig. 22 is a flow chart showing the processing for the case that a terminal point is detected during lens drive under the focus prediction;

Fig. 23 is a flow chart showing a defocus amount recomputation subroutine for checking whether the position where the lens has been driven based upon the focus prediction computation is the focusing position;

Fig. 24 is a flow chart for the focus indication under focus prediction;

Fig. 25 is a flow chart for the processing for the case that the distance measurement is executed immediately after mirror descent under the continuous-shot mode, and that further lens drive is executed after release processing;

Figs. 26 through 28 are graphs corresponding to the processing according to Fig. 25;

Fig. 29 is a flow chart showing the processing for overlap; and

Figs. 30 through 32 are graphs explaining the conventional AF systems.

Hereinafter, a preferred embodiment of the present invention is described with reference to the drawings.

Fig. 1 is a block diagram showing principal parts of a single lens reflex camera employing an automatic focus device embodying the invention.

In the illustrated camera, when an AF switch S1 is closed, the potential of a port P71 of a CPU (central processing unit) 3 is turned to LOW, with which operation of an AF system starts.

First, a distance measurement sensor 1, which comprises a CCD (charge coupled device) or the like, performs distance measurement. The obtained distance measurement data is transmitted to a port 1 of the CPU 3 via an interface 2, with which a defocus amount and direction thereof are computed by the CPU 3. Next, a lens drive amount required to bring a lens 100 to an in-focus condition is computed from a K-value stored in a lens ROM (read only memory) 9 and the computed defocus amount.

In the case that the defocus amount is not obtained, etc., it is checked whether the distance measurement data is effective, and if the data is found to be ineffective, such NG processing as to indicate that the distance measurement has not been appropriately done is executed. Then, the distance measurement is repeated.

Then, it is judged whether the defocus amount obtained falls within a predetermined focus allowance, and if it does, an LED (light emitting diode) drive circuit 10 is controlled through a port 74 of the CPU 3 to turn on an in-focus LED, and interruption for release-ON processing is permitted.

When the obtained defocus amount is out of the predetermined focus allowance, interruption for the release-ON processing is inhibited, the lens drive amount is set in a counter 6, and a lens drive circuit 4 is controlled to start lens driving. The number of revolutions of an AF motor driven by the lens drive circuit 4 is monitored by an encoder 5 to decrement the value of the counter 6 until it becomes zero (0), where the AF motor is stopped, and the lens drive is discontinued.

In the release-ON interruption processing, a series of release control processings such as mirror ascent, exposure, and mirror descent are executed by a release control circuit 8 via a port 5 of the CPU 3 when a release switch SWR is closed.

It is not at the moment when the release switch SWR is closed that a shutter is open. There is a time lag between closure of the release switch SWR and the start of exposure with opening of the shutter, which is known as "release-time-lag". That is, before opening the shutter, it takes time to stop down an aperture based upon an aperture value set in advance manually or by exposure control computation, and to ascend a reflecting mirror.

In the case that a photographing object is stationary or standing-still, the position of the object relative to the photographing lens does not change during the release-time-lag. Accordingly, once the photographing lens is driven to an in-focus position with respect to the object, further defocusing does not occur and therefore exposure can be done under the in-focus condition regardless of the length of the release-time-lag.

However, in the case that the photographing object is moving along the optical axis of the photographing lens (hereinafter called "object-in-motion"), as the position of the object relative to the photographing lens changes during the release-time-lag, even if the photographing lens is under the in-focus condition with respect to the object at the time when the release switch SWR is closed, the object may have moved to an out-of-focus position at the time when exposure starts.

In this embodiment, in order to make the object image position coincident with the focusing position at the time when exposure is performed (i.e., after the release-time-lag has elapsed), a focus prediction is executed, which will be hereinafter explained in detail.

In Fig. 2, a solid curved line shows movement of the object image position. If the lens drive is controlled such that the focusing position comes onto the solid line after elapse of the release-time-lag, exposure can be performed under the in-focus condition.

A dotted curved line in Fig. 2 represents changing of the object image position shifted to the left in parallel by an amount equivalent to the release-time-lag. If the lens is driven to make the focusing position follow this dotted curved line, exposure can always start with the focusing position being coincident with the object image position, i.e., under the in-focus condition, whenever the release switch SWR is closed.

Fig. 3 is a flow chart showing the main processing of the AF system employed in this embodiment. As in this flow chart the processing sequence is changed according to the number of times of AF distance measurement, a flag A1S that shows the number of times of AF distance measurement is initially cleared in the step S1.

In the step S2, the distance measurement data is obtained by the distance measurement sensor 1 and the defocus amount is computed therefrom. Then, in the step S3, the lens drive amount (i.e., AF pulse numbers) is computed and set in the counter 6, as previously mentioned.

In the step S4, a focus prediction computation, which will be described later in detail, is carried out.

Next, in the step S5, it is checked whether the distance measurement data is effective. If not effective, NG processing such as indicating that the distance measurement has not been properly executed is performed in the step S5-1, and the processing returns to the step S2, where the distance measurement is repeated.

It is judged in the step S6 whether the defocus amount falls within a predetermined focus allowance. If it does, in-focus processing such as lighting the in-focus LED is carried out at the step S7, and interruption for release-ON processing is permitted at step S8.

In the step S9, it is discriminated whether a so-called AF-one-shot mode is selected. If it is, the AF processing is effectively suspended, as the in-focus condition has been obtained at once, to await closure of the release switch SWR.

Next, it is discriminated in the step S10 whether compensation is ON, that is, whether the camera is in the focus prediction mode. If it is not, the processing returns to the step S2 to repeat the above explained steps. If it is, it is discriminated in the step S11 whether the photographing object is approaching the lens 100 or moving away from the lens 100 according to a flag FFN. When moving away from the lens 100 (in this case FFN=1), the processing also returns to the step S2.

When in the focus prediction mode and the object is approaching the lens 100, it is then discriminated in the step S12 whether the lens drive pulse number (AFP) of the current time is zero (0) or not. If it is, the processing returns to the step S2, while a lens drive flag BFM is set to 1 at step S13 if the lens drive pulse number is other than zero (0). This BFM flag is to indicate whether the lens has been driven or not.

In the case that it is found in the step S6 that the photographing object is not in a focusable area, (that is, the defocus amount does not fall within the predetermined focus allowance), interruption for release-ON processing is inhibited in the step S6-1, and it is discriminated whether the compensation is ON, i.e., whether the focus prediction mode is employed, in the step S6-2. If it is found to be ON, it is discriminated in the step S12 whether the lens drive pulse number AFP is zero (0). If it is found that AFP=0, the processing returns to the distance measurement processing of the step S2.

If AFP is other than 0 and therefore the lens should be driven, or if it is found in the step S6-2 that the focus prediction mode is not employed, the processing advances to the step S13 where the lens drive flag BFM is set to 1. Then, the series of instructions beginning with the step S14 for the lens drive processing is executed.

In the lens drive processing, firstly, in the step S14, the lens drive amount is set to the counter 6 and the lens drive circuit 4 is controlled to initiate the lens drive. The number of revolutions of the AF motor run by the lens drive circuit 4 is monitored by the encoder 5 to decrement the value in the counter 6. When the value in the counter 6 becomes zero (0), the AF motor is stopped and the lens drive is discontinued.

After the lens drive has thus started, interruption is permitted at the step S15 for the processing to be executed at a time should the lens reach the terminal point of the drive range thereof. Such interruption processing will be described later in detail.

In the step S16, it is judged whether PWM (pulse width modulation) control of the AF motor becomes necessary based upon the remaining pulse number in the counter 6. The PWM control is to control the AF motor so that the lens drive speed decreases step by step immediately before completion of the lens drive in order to accurately stop the lens at the position where the value of counter 6 becomes zero (0), i.e., at the in-focus position.

If the PWM control is unnecessary, that is, the lens is not about to complete driving, it is discriminated at the step S17 whether the compensation is ON. If the compensation is not ON, overlap processing for repeating the distance measurement and computation during the lens drive is executed at the step S18 for renewing the value in the counter 6. Then, the processing returns to the step S16 to repeat the judgment of whether the PWM control of the motor has become necessary. If the compensation is ON, however, the processing returns to the step S16 without executing the overlap processing. The relationship between the compensation ON and the overlap processing will be described later.

If it is judged at the step S16 that the PWM control has become necessary, that is, if it is immediately before the completion of the lens drive, the PWM control is executed in the step S16-1, and it is discriminated at the step S16-2 whether the lens drive is completed.

Upon completion of the lens drive, interruption for the processing to be executed when the lens reaches the terminal point, is inhibited at the step S16-3, and the processing returns to the step S2 for repeating the distance measurement and succeeding instructions.

Hereinafter, the focus prediction mode employed at the time of compensation ON is explained in detail.

In the focus prediction mode of this embodiment, the lens is driven according to two different algorithms, one of which is selectively adopted depending upon the case. One is a "catch-up tracking" mode and the other is a "preemptive tracking" mode. Under the preemptive tracking mode, the release-time-lag is taken into account, while it is not taken into account under the catch-up tracking mode.

First, referring to Fig. 4, the AF motor drive pulse number obtained at the point (1) is taken as A1. The defocus amount on the film equivalent plane can be converted, by multiplying it by the K-value, to the pulse number applied to the AF motor for driving the lens 100 to the in-focus position. Therefore, in the descriptions hereinafter, the pulse number applied to the AF motor to eliminate the defocus amount is called simply "pulse number" or "lens drive amount".

After the pulse number A1 is applied to the AF motor for lens driving, and after elapse of time t1, it is assumed that the pulse number A2 is obtained at the point (2) . The amount of movement of the object image position from the point (1) to the point (2) corresponds to the pulse number A2. Accordingly, between the points (1) and (2) , an object image speed OBJsp is obtained by:

$$OBJsp = A2 / t1.$$

Here, the object image position at the point (3) after elapse of time t2 from the point (2) can be expressed, if the object image speed is constant, by:

$$A2 + t2 \times OBJsp.$$

With the amount of movement of the object image position during time t2 being taken as P2, if the substitution is made with

$$P2 = t2 \times OBJsp,$$

then, the drive amount can be expressed as:

$$A2 + P2.$$

That is, the position to which the lens is driven by the AF motor by the drive amount of A2 + P2 is the object image position after elapse of time t2.

In the meantime, the above P2 must have been obtained before the lens drive amount is computed. Here, after the distance measurement data has been obtained, the time required for computation of the lens drive amount is constant and therefore the total time including the lens driving time can be considered to be not very different in respective cases. Hence, on the assumption that the computation time and driving time of the current time, that is, time t2, is the same as that of the previous time, i.e., time t1, time t2 can be obtained by actually measuring the time t1, with which P2 is computed.

The above explained computation is for the catch-up tracking.

However, as seen in Fig. 4, even if, at point (2), the AF motor is driven by the amount of A2 + P2 to make the focusing position and the object image position coincident and the release switch SWR is closed at point (3), it is after the release-time-lag has elapsed that exposure actually starts. Accordingly, further defocusing occurs at the time exposure starts and it is necessary to drive the lens in further preemption by an amount equivalent to the amount of movement of the object image position during the release-time-lag. This is the preemptive tracking which will be described in detail hereinafter.

If the release-time-lag is taken as RLt, a forestalled pulse number Txp2 required to additionally drive the lens to move the object image position to the position where it becomes coincident with the focusing position at the time of elapse of the release-time-lag is obtained by:

Txp2 = RLt x OBJsp.

Here, as shown in Fig. 6, the integration is carried out for the interval of time Tint in order to measure the defocus amount, and various data are obtained from the result of this integration. However, the point where the defocus amount is obtained is not the starting point of the integration, but is considered to be at the point Pi shifted by Tint/2 therefrom (i.e., the middle point of the integration time). So, if the lens drive amount is computed by taking this into account, i.e., if the release-time-lag used in the computation is calculated as

RLt - Tint/2,

more accurate focus prediction can be done.

Accordingly, in the computation formula of the above-mentioned Txp2, the compensation should be calculated according to,

Txp2 = (RLt - Tint/2) x OBJsp.

Then, by setting the lens movement amount AFP2 to:

AFP2 = A2 + P2 + Txp2,

the lens drive under the preemptive tracking mode will be executed.

Here, if a drive pulse number A3 actually obtained at point (3) coincides with the computed Txp2, it means the preemptive tracking has been successfully carried out. (In actual operation, since the object image speed is not always constant, A3 = Txp2 does not necessarily stand.)

Next, in Fig. 5, it is assumed that the drive pulse number A3 is obtained at the point (3) as the result of integration and computation. Then, as mentioned previously, the time in passing from point (3) to point (4) can be considered the same as the time t2, and the object image position moves between points (3) and (4) by the amount equivalent to that between points (2) and (3), in the case that the object image speed is constant.

Accordingly, P3, the amount of movement of the object image position between points (3) and (4) can be obtained by:

$$P3 = P2 + Txp2 - A3.$$

Therefore, AFP3, the lens drive amount from point (3) to point (4) is:

$$AFP3 = P3 + Txp3 - A3.$$

The above relations can be applied to the movement of the object image position between the points n-1 and n, and thus the following general formulae are obtained:

$$Pn = Pn-1 + (Txpn-1 - An)$$

$$Txpn = f(Pn)$$

AFPn = Txpn + Pn - An

Thus, Txpn can be obtained as a function of the object image movement amount Pn, i.e., f(Pn). Txpn in principle can be obtained according to:

Txpn = (Pn / t) x RLt.

However, as explained above, the release-time-lag used in the computation should be calculated as:

RLt - Tint/2,

in order to execute more accurate focus prediction.

Accordingly, a general computation formula of the above-mentioned Txpn should be:

Txpn = (Pn / t) x (RLt - Tint/2).

Txpn is obtained from the distance measurement data and is affected greatly by dispersion of the distance measurement data, so that in this embodiment, the data obtained in four past time intervals immediately before executing the computation is averaged according to the following formula and used:

Txpn = (Txpn + Txpn-1 + Txpn-2 + Txpn-3) / 4

In the case that there is an item for which no past data is available, zero (0) is substituted into the computation in order to keep the Txpn value small.

Fig. 7 is a flow chart of a subroutine for "focus prediction" carried out in the step S4 of Fig. 3.

In the step S201, the distance measurement data is checked. If the data is found ineffective, the distance measurement times counter flag A1S is reset to 0 at the step S226 and the processing returns to the main routine. The cases where such situations occur are, for instance, when an object is extremely weak in contrast, or defocusing is so large that no distance measurement data is obtained.

Even if the distance measurement data is effective, if the AF one-shot mode is selected, that is, in the case that the focus processing is inhibited once the in-focus condition is obtained, as it is unnecessary to enter into the focus prediction mode, the processing returns to the main routine (step S201-1).

Further, even if the AF one-shot mode is not selected, when the processing comes to this routine for the first time (i.e., A1S = 0), the processing returns to the main routine through the steps S224, S225 and S218. At the step S224, the counting flag A1S is set to 1 to indicate that the processing has come to this routine at least once, and the timer 7 starts for measuring the time interval between successive distance measurements. Then, data employed in computation is cleared at the step S225.

When the number of distance measurements is more than one (1), i.e., the second time and on, the processing advances from the step S202 to the step S203, and in the step S203 the time interval t from the previous distance measurement is obtained by the timer 7. Then, at step S204, it is discriminated whether the compensation is ON, i.e., the focus prediction mode is employed. As the compensation is not ON under the initial state, i.e., the focus prediction mode is not employed, the processing advances to step S205. In the steps S205 through S211, it is determined whether the photographing object is to be treated as the object-in-motion.

At step S205, the defocus directions of the previous time and the current time are compared. If found different, it is considered that the photographing object has changed direction of movement, and therefore the processing returns, without judging whether the object is to be treated as the object-in-motion, to the main routine through steps S225 and S218. If the defocus directions are the same, it can be regarded as the photographing object continuing movement in the same direction and the processing advances to step S206.

At step S206, it is discriminated according to the flag BFM whether the lens drive has previously been carried out. In the case that the lens drive was carried out in the previous distance measurement cycle, that is in the case that BFM = 1, the processing advances to step S209, where the object image movement amount XX of the current cycle is set to An. In the case that the lens drive was not carried out in the previous cycle, that is, in the case that BFM = 0, the processing goes to step S207, where the previous time defocus amount An-1 and the current time defocus amount An are compared to discriminate whether the object image position is approaching the focusing position.

In the case that the object image position is approaching the focusing position (in case of An < An-1), the in-focus state will be obtained without employing the focus prediction mode, so that the processing returns to the main routine through step S218.

On the other hand, at step S207, in the case that the object image position is found to be moving away from the focusing position or in the case that it is found to be at an equal distance (no distance change, in the case other than An < An-1), the previous time defocus amount An-1 is subtracted from the current defocus amount An in step S208, and the current object image movement amount is defined as XX = An - An-1.

Then, at step S210, the object image speed OBJsp during one distance measurement cycle from time t, that is, XX / (Kvalue x t)

is judged whether the object image speed OBJsp is larger than a predetermined value. Here, the predetermined value corresponds, for example, to the speed at which the amount of movement of the object image position, during the period of the sum of the interval between the successive distance measurements plus the release-time-lag RLT, coincides with the predetermined focus allowance, which is expressed by the formula:

Focus Allowance / (t + RLt).

In other words, in the case that the object image speed OBJsp is smaller than the predetermined value, if the interruption for the release-ON processing is executed after the lens is driven based on the distance measurement of the current time, the object image position will remain within the focus allowance at the time of exposure start after elapse of the release-time-lag. Thus the focus prediction is not required.

Meanwhile, the above-mentioned predetermined value may be set to a smaller value, in order to make definite identification of the object-in-motion. Further, although the judgment may become more or less approximate, the predetermined value may be set to correspond to the speed at which the amount of movement of the object image position during the release-time-lag coincides with the focus allowance.

As above, when the object image speed OBJsp is smaller than the predetermined value, the processing returns to the main routine through steps S225 and S218.

On the other hand, in the case that the object image speed OBJsp is larger than the predetermined value, it is then discriminated at step S211 whether the above-mentioned speed judgment has been executed for the first time, and if so, the processing returns to the main routine through step S218.

If the object image speed OBJsp is discriminated as being larger than the predetermined value, in the second or succeeding computation cycle, the compensation is set to ON for the first time, and the lens drive according to the focus prediction mode is employed.

In the steps S212 and S213, respectively, compensation ON and flag C10 = 0 (this means that this is the first cycle after compensation ON starts, and for the second cycle and so on, C10 = 1) are set. In the step S214, the defocus direction of the current time is discriminated, based on which direction of movement of the object image position is judged. In other words, in the case of rear-focusing (+), it is judged that the photographing object is approaching the camera, and in the step S222, the preemptive tracking starts. On the other hand, in the case of front-focusing (-), the object is moving away from the camera, and in the step S223, the catch-up tracking starts.

In step S215, a flag FFN representing the relative positional relationship between the object-in-motion and the camera is set to 0 to indicate that the object is approaching the camera. On the other hand, in S216, the flag FNN is set to 1 to indicate that the object is moving away from the camera. Subsequently, the processing returns to the main routine through the step S218.

When the routine comes to the present routine after the compensation ON has come to start, the processing diverges to the step S219 from the step S204, and in the case that the object is approaching the camera, the processing of the step S220 is executed, and the defocus amount is recomputed in the step S217 according to the routine of Fig. 23. In the case that the object is moving away from the camera, the processing of the step S221 is carried out and the processing returns to the main routine via step S218.

In the step S218, to facilitate the next computation, AN, AFPn are set as An-1 and AFPn-1, respectively and saved, and the flag BFM is reset to

0.

Fig. 8 shows the subroutine executed at step S222 for the case wherein the processing is shifted from the catch-up tracking mode to the preemptive tracking mode.

XX is the object movement amount (pulse number) which is set to Pn to be used for the computation this time (Step S261). As described previously, as a function of the object movement amount Pn, the drive amount equivalent of the release-time-lag Txpn is calculated (Step S262), then the lens drive amount AFP this time (the drive amount to shift from the catch-up tracking mode to the preemptive tracking mode) is calculated at the step S263, as already described in the explanation for the fundamental calculations.

In the focus prediction computation, in the second time after the compensation ON starts and afterwards, on the basis of the value of FFN set during the steps of S215 and S216 of Fig. 7, the processing executed is differentiated according to the movement direction of the photographing object.

Fig. 9 shows the processing of the step S220, one of the alternatives, where the photographing object is approaching the camera.

If the processing comes to this routine for the first time after the compensation is ON, the flag

C10 is 0 (step S301) and it is discriminated at step S303 whether the processing has entered into the preemptive tracking mode with the focusing position overstepping the movement of the object image position. If the defocus direction is different between the previous time and the current time, which means that the processing has entered into the preemptive tracking mode, the flag C10 is set to 1 at step S304, and the processing advances to step S305. If the defocus directions are the same, it is judged that the catch-up tracking mode remains and the processing goes to step S323.

If the processing comes to the routine for the second time and subsequently after the compensation is ON and the preemptive tracking mode has been employed, as the flag C10 is 1 (step S301), it is judged at step S302 whether the defocus direction is the same between the previous time and the current time. Since the processing has already entered into the preemptive tracking mode in the previous cycle, if the defocus directions are different, it means that the situation has changed to the catch-up tracking state from the preemptive tracking state, and the processing goes to the step S323. If the defocus directions are found to be the same, it means the preemptive tracking state continues and the processing goes to the step S305.

In the step S305, the defocus amount An according to the distance measurement this time is compared with the lens drive amount Txpn-1 corresponding to the release-time-lag of the previous time. This is the processing to compensate errors occurring when executing the computation of Pn with the object image speed assumed to be constant as stated above.

If An > Txpn-1, it means the actual object image movement amount is smaller than Pn, and the lens drive amount of the previous time is judged too large and the processing enters into the processing for the case of the preemptive tracking amount being too large (Step S314 and afterward). If NO is judged in the step S305, it means the actual object image movement amount is either equal to or smaller than Pn and the next processing will be for the case of the lens drive amount of the previous time being either insufficient or adequate.

The flag of BOV in the following steps S306 and S314 is the flag to represent the result of the judgment of the previous step (S305) in the previous cycle. In the case of BOV = 1, it represents excessive advance movement, and in the case of BOV = 0, it represents either insufficient or adequate advance movement. If the processing comes to this routine for the first time, the processing is carried out under BOV = 0.

The step S307 shows the calculation of the case where An > Txpn-1 is not effected for both this time and the previous time as illustrated in Fig. 5, and the computation as already explained above with respect to Fig. 5 is executed.

The step S310 shows the calculation formula for the case where An > Txpn-1 in the previous time but not so in this time as illustrated in Fig. 10.

In Fig. 10, the compensation amount (object image movement amount) P2 is,

$$P2 = |A2 - A1|,$$

and

$$Txp2 = f(P2),$$

the drive amount AFP is

$$AFP = Txp2 + (P2 - A2.)$$

When the above relations are generalized, the following formulae stand,

$$Pn = |An - An-1|$$

$$Txpn = f(Pn)$$

$$AFP = Txpn + (Pn - An).$$

In either case of the above-mentioned steps S307 and S310 being executed, it is examined, in the subsequent step S308 or S311, whether AFP < 0. Then, in the case of AFP < 0, the processing goes to the step S312 where Pn = 0, and AFP = 0 are set, respectively, and no lens drive is carried out (i.e., no lens drive is carried out in reverse direction). In either of these cases, BOV is set again on the basis of the computation value of the current time in the subsequent steps S309 or S313.

In the case that An > Txpn-1 this time, the processing goes to the loops of the steps S314 and subsequent. In this case, as An is larger than Txpn-1, the focusing position has been advanced by an amount more than that corresponding to the release-time-lag, and it is unnecessary to drive the lens. Thus, both the compensation amount Pn and the lens drive amount AFP are set to 0 in either of these cases, and only the computation of Txp is carried out for the next time. In the step S314, case judgment which is the same as that done in the step S306 is carried out.

The step S315 constitutes the calculations of the case where An > Txpn-1 was not established in the previous time but An > Txpn-1 in the current time as illustrated in Figs. 11 and 12, wherein the compensation amount P2 is represented by:

$$P2 = P1 - (A2 - Txp1).$$

Accordingly,

$$Txp2 = f(P2).$$

When generalized, the following formulae stand:

$$Pn = Pn-1 - (An - Txpn-1)$$

$$Txpn = f(Pn),$$

After computation of Txpn;

Pn = 0, AFP = 0.

The steps S317 and subsequent show the processings for the case where An > Txpn-1 is established in both the previous time and the current time.

In the step S317, in order for the purpose of making the judgment of whether the amount of An exceeding Txpn-1 falls within the predetermined focus allowance used for the in-focus judgment in the step S6 of Fig. 3, i.e., whether the object image position after the elapse of the release-time-lag is within the focus allowance from the focusing position, the pulse number d equivalent to the focus allowance plus Txpn-1 is compared with An.

The next step S318 is the case where the amount of An exceeding Txpn-1 is smaller, i.e., the case where the object image position falls within the focus allowance after elapse of the release-time-lag, and shows the calculation for the case shown in Fig. 13.

From that figure, P2 = A2 - A1 and accordingly,

Txp2 = f(P2).

When generalized,

Pn = An - An-1

Txpn = f(Pn).

After computation of Txpn;

Pn=0, AFP=0

In the case that, in the step S317, it is judged that the amount of An exceeding Txpn-1 is not within the focus allowance, then, the processing goes to the step S319.

It is judged in the step S319 whether the judgement of the amount of An exceeding Txpn-1 is out of the focus allowance occurred three or more times consecutively. If so, it is the case where the object image position deviates greatly from the focusing position or the case where the object image movement direction or speed of movement is greatly changed. This means that the possibility of the object image position entering within the focus allowance is less, and in order to discontinue the focus prediction mode, the compensation is set to OFF in the step S322 and all calculated data are cleared. Then, with the data of this time taken as the first time data of AF, the focus prediction computation is carried out again.

The step S320 is for the calculation of the case shown in Fig. 14 and the contents thereof is the same as for the step S318.

In the step S302 or S303, if it is discriminated that it is not the preemptive tracking state this time, it is judged in the step S323 whether it was An > Txpn-1 in the previous time from the flag BOV. When it was An > Txpn-1 in the previous time, the processing goes to the step S324. That is the case shown in Fig. 15 where the preemptive tracking was carried out in the previous time but the focusing position is behind the object image position this time.

In this case, the compensation amount P2 is expressed by:

$$P2 = A2 + A1.$$

Accordingly,

$$Txp2 = f(P2).$$

The drive amount AFP is,

$$AFP = Txp2 + P2 + A2.$$

When the above relations are generalized,

$$Pn = An + An-1$$

$$Txpn = f(Pn)$$

$$AFP = Txpn + Pn + An.$$

If it is judged in the step S323 that it was not An > Txpn-1 in the previous time, the processing goes to the step S327. Fig. 16 is the case where the processing for shifting from the catch-up tracking state to the preemptive tracking state was tried but failed. Fig. 17 shows the case where the preemptive tracking has failed whilst the preemptive tracking is under way. In these cases, the compensation amount P2 will be,

$$P2 = Txp1 + P1 + A2.$$

Accordingly,

Txp2 = f(P2).

The drive amount AFP will be,

AFP = Txp2 + P2 + A2.

When the above relations are generalized:

Pn = Txpn-1 + Pn-1 + An

Txpn = f(Pn)

AFP = Txpn + Pn + An.

After the calculation of the step S324 or the step S327 is carried out, the flag C10 is set to 0 in the step S325, and in the next distance measurement, the computation of this time will be taken as the first computation after compensation. The flag BOV = 0 is set in the step S326.

In Fig. 7, both the steps S221 and S223 are the cases that the photographing object is moving from the near field to the remote field. In the case that the object is moving away from the camera at constant speed, the object image speed slows down gradually, so that the lens drive amount is decreased accordingly. If, in the above case, the compensation is made in preemption of the equivalent of the release-time-lag in a manner similar to the case of the object approaching the camera, there is a high possibility of over compensation resulting therefrom. In the case that over compensation occurs, rear-focusing results therefrom, which is not desirable in view of the photographic conditions. Accordingly, in the case that the photographing object is moving away from the camera, the focus prediction without preemption of the equivalent of the release-time-lag, i.e. the catch-up tracking, is simply executed.

Fig. 18 is a graph showing the relationship of the object image position and the lens drive pulses for the object moving away from the camera.

In Fig. 18, the motor drive pulse number obtained at point ① is taken as A1. Subsequently, the pulse A1 is applied to the motor to drive the lens, and after the time t1 has elapsed, the pulse number A2 is assumed to have been obtained at point ② . The amount of movement of the object image position between points ① and ② is A2 when converted to the pulse number. Therefore, the object image speed OBJsp between points ① and ② is,

OBJsp = A2 / t1.

Here, the object image position at the point ③ where time t2 has elapsed from point ② with the object image position at the point ① taken as reference, is, assuming that the object image speed is constant, expressed by:

A2 + t2 x OBJsp.

As mentioned in the explanation for the

preemptive tracking, t2 is considered to be equal to t1, and the amount of the object image movement during t2 is considered to be equal to A2. Hence, the drive amount is calculated by 2 x A2. That is, the focusing position obtained with driving the AF motor by 2 x A2 from point (2) coincides with the object image position after the time t2 has elapsed. In this case, even if interruption processing for release-ON is executed after the lens drive has been completed and exposure started after elapse of the release-time-lag, the focusing position is placed in front of the object image position at the time of exposure start, i.e., not in the rear-focusing state. Accordingly, Txp calculation is not carried out and the catch-up tracking is performed.

As above, if it is assumed that, on the basis of the defocus amount A2 obtained at the point (2), the lens drive of 2 x A2 has been carried out, and that the defocusing amount A3 has been obtained at the point (3), such compensation as for the preemptive tracking is not carried out for the next drive amount, but, as in the previous time drive, simply A3 x 2 is used.

That is, as a general formula to obtain the lens drive amount during the catch-up tracking for the case of the object moving away, the following formula stands:

Lens drive amount AFP = 2 x An
(Where, t1 = t2, and the lens drive is assumed to have been carried out in the previous time).

Figs. 19 and 20 indicate the subroutines of the steps S223 and S221 of Fig. 7, respectively.

In Fig. 19, the sum of the object image movement amount (pulse number) XX and the defocus amount An (pulse number) is used as the lens drive amount in the step S271. The object image movement amount XX has been calculated in the steps S206 through S209 on the basis of whether the lens has been driven in the previous time. In the case that the lens has been driven in the previous time, XX = An, otherwise, XX = An - An-1. The lens drive amount AFP calculated in the step S271 of Fig. 19 never exceeds 2 x An.

In Fig, 20, the defocus direction of the current time is checked in the step S272. This is the check for avoiding over-compensation which is recognized when the defocus direction after completion of the lens drive is positive, i.e., the rear-focusing state, despite that the object is moving away. In the case of over compensation, the compensation is set to OFF in the step S277, and the calculation data are cleared, and the recalculation will be carried out with the data of this time used as the first AF data. After checking for over-compensation is executed, the object image movement amount is calculated according to whether the lens has been driven in the previous time in the subsequent steps S273 through S275 as well as in the steps S206 through S209 of Fig. 7, and the lens drive amount AFP is set in the step S276. The above are the same as in the case of Fig. 19.

Here, the in-focus judgment of the step S6 of Fig. 3 is explained. The judgment is made according to whether the defocus amount obtained at the step S2 is within the predetermined focus allowance as described previously. However, in the preemptive tracking mode, the lens drive is always carried out to have the preemption equivalent of the release-time-lag, so that the defocus amount is not necessarily within the focus allowance even though the in-focus condition will be obtained after elapse of the release-time-lag.

Also, even though the defocus amount is within the focus allowance at the time of the distance measurement, it does not mean that it is within the focus allowance after elapse of the release-time-lag. Thereupon, the in-focus judgment can not be made from the defocus amount.

Hence, in the step S217 of Fig. 7, the defocus amount for the in-focus judgment is calculated, which will be described in association with Fig. 23.

Firstly, in the step S51, the lens drive amount Txpn-1 equivalent of the release-time-lag obtained by the AF processing in the previous time is converted from the number of pulses to an image plane defocus amount DD by dividing Txpn with K-value.

Next, in the step S52, regardless of the sign (+ or -) of the defocus amount DEFOCUS obtained by the distance measurement of this time, the image plane defocus amount DD is added thereto to be taken as a focus-check defocus amount. Meanwhile, in the case of catch-up tracking, as the lens is not driven additionally by an amount equivalent to the release-time-lag, such a calculation of the focus-check defocus amount as above is not executed.

According to the above, the lens is driven in advance by the equivalent of the release-time-lag in the case that the photographing object is approaching the camera, so that considerable rear-focusing does not occur whenever the shutter release is turned ON and photography in the in-focus state is always possible.

On the other hand, in the case that the photographing object is moving away from the camera, the algorithm to carry out the catch-up tracking is used, so that over-compensation which results in rear-focusing does not occur and well-focused photography will be possible.

Meanwhile, in the distance measurement operation, intervals for sampling the distance measurement data can be made shorter if the integration time is taken to be shorter, and tracking of the photographing subject becomes easier. So, the integration may be controlled within the time limit.

Fig. 21 is a flow chart for the case that a time limit is set to the integration. That is, usually, the maximum value of the integration time Tint MAX is set as the normal maximum integration time NORMAX (step S901). However, if it is discriminated that the compensation is ON, at step S902, the maximum integration time CONMAX for the compensation, which is smaller than the normal maximum integration time NORMAX, is used as the maximum value for the integration time Tint MAX (step S903). Thus, the distance measurement with the integration time shorter than normal is executed during the compensation ON. That is, the CCD integration with Tint MAX regardless of the maximum integration time is executed at step S904, and the obtained CCD data is input at step S905 to execute the computation of the defocus amount (step S906).

Further, as previously mentioned, it is

conceivable that the lens may be driven to the terminal point during the tracking drive. So, during the lens drive, in the step S15 of Fig. 3, the terminal point sensing circuit 11 (Fig. 1) is reset, and an INT2 interruption is permitted. In the case that no pulse is entered from the encoder 5 during a certain period of time to the terminal point sensing circuit 11, INT2 interruption of INT2 of the CPU 3 occurs. That is, in the case that the lens has been driven to the terminal point during the lens drive, no pulse is generated by the encoder 5 so that the terminal point sensing circuit 11 is turned ON and the interruption of INT2 occurs. Fig. 22 is the flow chart of this interruption processing. When interruption occurs, the lens drive is discontinued, terminal point sensing interruption is inhibited, and then, the compensation is made OFF (steps S501 through S503). In the case that no interruption occurs and the lens drive has been completed, in the step S16-3 of Fig. 3, the INT2 interruption is inhibited.

Fig. 24 is a subroutine showing an example of in- focus processing of the step S7 in Fig. 3, wherein the in-focus LED is lit by the LED drive circuit 10 (Fig. 1) to inform an operator that the camera is in an in-focus state. It is desirable that the in-focus LED is provided in the viewfinder of the camera. Here, in cases other than C10 = 1, only in-focus indication is executed and the processing returns.

When C10 = 1, i.e., the preemptive tracking is being executed, and when

MAX AFP speed / Kvalue $\gg$ OBJsp (mm/s)

where, MAX AFP speed: Maximum drivable speed (Pulse/s)

OBJsp: object image speed (mm/s),

the in-focus indication is always carried out. Thus, even during the preemptive tracking, in-focus photographs can always be ensured as long as the in-focus indication is on (In the flow chart, MAXS = MAX AFP speed / Kvalue, OBJ = OBJsp).

In the case that the object image speed exceeds a tracking speed limit, i.e., when

MAX AFP speed / Kvalue < OBJsp (mm/s)

applies, the preemptive lens drive of the release-time-lag equivalent is impossible and therefore a well-focused photograph can not be obtained if the shutter is released, so that in this case the in-focus indication is not given.

In the preemptive tracking mode, as the preemptive lens movement equivalent of the release-time-lag is carried out, when the AF switch S1 is first closed to drive the lens to the in-focus position, and the release switch SWR is closed upon completion of the lens drive, the object image position and the focusing position coincide at the time when exposure starts.

However, if the release switch SWR is closed at a time other than the above, or if the release switch SWR is closed simultaneously with closure of the AF switch SW1 and the shutter release ON interruption is permitted after elapse of the predetermined time subsequent to the lens drive, the start point of the release-time-lag presumed in advance and the actual timing of the shutter release ON interruption do not coincide. Further, in the case of catch-up tracking, the release-time-lag is not taken into consideration. Accordingly, in such cases, the object image position and the focusing position do not always coincide at the time when exposure starts. For this reason, if the camera is designed such that the lens is also driven for a further possible amount even during the release-time-lag, still more accurate focusing can be achieved.

Moreover, when photographs are to be taken several times consecutively in the preemptive tracking mode, high tracking ability can not be obtained if the AF operation is restarted after the exposure, mirror descent and film winding are completed. Since the distance measurement becomes possible again after mirror descent, it should be started immediately after the mirror descent regardless of whether film winding is completed. Then, the lens drive should be carried out for the sum of the drive pulse number obtained by the distance measurement of this time and that of the previous time before the shutter release, whereby the tracking ability can be improved.

Fig. 25 is a flow chart of the release-ON interruption processing prepared by taking the above into consideration. Figs. 26 and 27 show the states of lens drive controlled with this flow chart.

Fig. 26 shows the case where the release-ON interruption occurs during the lens stoppage, while Fig. 27 shows the case where the release-ON interruption occurs during the lens drive.

In the step S8 of Fig. 3, the interruption for the release-ON processing is permitted, and the above processing starts by the interruption caused by a shutter release ON signal from the release switch SWR.

Firstly, the mirror ascent and lens stopdown control are executed at the step S601, and it is discriminated in the step S602 whether the compensation is ON. If the compensation is OFF, normal shutter release control and film winding upon mirror descent are executed at steps S603 through

S605 to complete the interruption processing. If the compensation is ON, it is discriminated at the step S607 whether the lens is being driven. Based upon this discrimination, the lens drive amount AFP is set over again in either step S608 or S609.

In the case that the lens is not being driven, in the step S608, the object image movement amount from completion of the previous time lens drive is calculated based upon the elapsed time tt from completion of the previous time lens drive, as shown in Fig. 26, according to the formula:

OBJsp x K value x tt,

and the obtained value is newly set to AFP.

On the other hand, in the case that the lens is being driven, at the step S609, the equivalent of the amount already driven,

(AFP - Dar)

where, Dar: Remaining lens drive amount, and
AFP: Current lens drive set value,

is subtracted from the lens drive amount (the same as for the above-mentioned step S608),

OBJsp x Kvalue x tt,

to be executed during time tt as from the previous time lens drive completion, as shown in Fig. 27, and the result is set as a new lens drive amount AFP.

In the case that the AFP newly set in step S608 or S609 exceeds the maximum pulse number M x M capable of being driven during the release-time-lag, then, in the step S611,

$$AFP = M \times M$$

is set. According to the AFP set as above, the lens is driven and exposure is performed (steps S612 and S613).

When the mirror descent is completed (step S614), the next distance measurement, i.e., integration, data input and computation are carried out at step S615 simultaneously with the film winding, and the defocus pulse number An is computed in step S616.

Here, with reference to Fig. 28, the function for increasing tracking ability by means of starting the next tracking action immediately when the distance measurement becomes possible after the shutter release has been completed is explained. That is, tracking ability can not be improved if the next time distance measurement computation, and so on, is started after the film winding is completed subsequent to completion of the shutter release under the tracking mode. Since the distance measurement is possible after the mirror descent, after the mirror ascended at t0, the shutter release is started at t1, and at t11 when the mirror descent is completed, the distance measurement is started and the defocus pulse An is obtained. Then, the defocus pulse number An-1 obtained by the distance measurement of the previous time is added to the defocus pulse number An and the result thereof is used as the new drive pulse number AFP.

With this arragnement, the tracking action can be taken faster by t2 - t11, as illustrated by a solid line in Fig. 28, than the case illustrated by the dotted line in Fig. 28 where the next distance measurement is started after t2 when the film winding is completed subsequent to the mirror descent. Then, AFP is taken as the sum of the previous time defocus amount An-1 and this time defocus amount An (step S617), and the flag A1S is cleared, the compensation is made OFF, and the release-ON interruption processing is terminated (step S618). After termination of the interruption, the processing shifts to LMOV of Fig. 3, and the lens is driven by the above-mentioned drive amount AFP.

Fig. 29 is a flow chart showing a series of instructions for the so-called overlap processing wherein the further distance measurement is repeated, while the lens is being driven, to obtain a still more accurate lens drive amount.

If, in the first distance measurement, an object which stands far away from the in-focus position at that time is measured, the obtained defocus amount itself includes extensive error, so that the lens drive amount obtained is also not accurate, and accordingly, the focusing action will not be carried out satisfactorily. Hence, by renewing the lens drive amount even when the lens is being driven to execute accurate focusing action, the overlap processing is employed.

As usual, is set to the counter 6, the originally computed lens drive pulse member which is continuously discriminated with driving of the lens. While the lens is being driven, the CCD integration starts. In step S701, the lens drive pulse number remaining in the counter 6 at the time the integration started is taken as C1 and the lens drive pulse number remaining in the counter 6 at the time of completion of integration is set to C3. In step S702, the CCD integration data is inputted, and the defocus amount is obtained by computation of the CCD integration data in the step S703. In step S704, the AF pulse number is calculated based upon the defocus amount thus obtained, in a manner the same as the step S3 of Fig. 3, and the calculated value is taken as Cx. The lens drive pulse number in the counter 6 at the time of the calculation of Cx is taken as C4. In step S705, the lens drive pulse number for renewal of the lens drive pulse number in the counter 6 is obtained by the following formula:

$$C2 = (C1 + C3) / 2$$

$$A = Cx - (C2 - C4).$$

The above-mentioned A is the renewed lens drive pulse number which is set to the counter 6 in the step S706 and the processing is terminated. Meanwhile, as is apparent from the steps S17 and S18 of Fig. 3, if the compensation is ON, i.e., when under the tracking mode, the overlap processing is not carried out. That is because, as mentioned previously, the overlap processing is the processing necessary in the case that the defocus amount is large, but, if the compensation is ON, the focusing lens is tracking the object image position and so the defocus amount is not so extensive. Furthermore, such a problem would occur as the AFP value obtained for tracking is renewed by the AFP calculation executed for the overlap processing carried out in the routine other than the main routine so that the tracking action itself may become impossible.

With the automatic focusing device mounted on the camera as described above, the focus lens is controlled in such a manner as if the object image position is moving at a speed exceeding the predetermined one, i.e., the photographing object is the object-in-motion, tracking with two different algorithms is executed. That is, if the object is approaching the camera, the preemptive tracking is selected, wherein the focus lens is moved in preemption of the equivalent of the release-time-lag. On the other hand, if the object is moving away from the camera, the catch-up tracking wherein no preemptive lens drive is executed is selected. Hence, even if the photographing object is the object-in-motion, an adequately focused photograph can be taken.

When entering into the tracking mode, it is carefully confirmed that the photographing object is the object-in-motion by repeating the measurements of the object image speed more than the stipulated number of times.

Further, even in the case where the focus lens is already positioned within the focus allowance and the in-focus indication is made, if the processing is under the tracking mode, the focus lens is further driven for tracking the object-in-motion so as to obtain the complete in-focus state.

The release-time-lag used for the tracking computation is that obtained by taking the integration time for the distance measurement into consideration, whereby smoother tracking action becomes possible.

In the case that the release-ON interruption does not occur immediately upon termination of the lens drive, the focus lens may be further driven by the maximum possible amount within the release-time-lag, whereby the defocus amount can be made still less.

Further, in case of continuous shots and so on, by starting the distance measurement for the next shot at a certain time while the shutter release operation for the current shot is being executed, for instance, at the time of completion of the mirror descent, consecutive and adequate tracking can be executed.

The in-focus indication during the tracking operation is to be carried out when the in-focus state is obtained and tracking is possible. It is desirable to make lighting of the LED for the in-focus indication recognizable in the viewfinder of the camera.

Although, in the above explained embodiment, the processing enters into the tracking with the focus prediction when it is twice discriminated that the object image speed exceeds the predetermined value, it can be set in excess of a predetermined number of times other than two. Further, although tracking is terminated as tracking is not properly performed if it is discriminated three times that the lens drive amount during the tracking operation exceeds the predetermined value, it can be set in excess of a predetermined number of times other than three.

There is the possibility that the integration/computation time is so long that the subsequently executed lens drive cannot follow the object image movement. Accordingly, the integration time is limited during the tracking operation to curtail the total distance measurement time, whereby the tracking is effectively executed.

Further, in the case that the object image speed is high and accordingly the lens drive amount becomes relatively large, the overlap processing is considered necessary. During the tracking operation, however, the required lens drive amount is normally small, or if the required lens drive amount is considerable, it can be the case that the object image speed is so high that the tracking can not be performed. Accordingly, the overlap processing is not performed under the tracking mode for ensuring the tracking lens drive ability.

Meanwhile, in the above embodiment, description is given to the case where the shutter release is executed upon achievement of the in-focus condition, i.e., the focus-priority case. The present invention can, of course, be applied to the shutter-release priority case where the shutter release can be executed regardless of focus state. In the latter case, steps S6-1 and S8 of Fig. 3 should be skipped to make the release-ON interruption always possible.

CLAIMS

1. An automatic focusing device comprising:

a focus lens movable along the optical axis thereof;

a drive means for driving said focus lens;

a distance measuring means for obtaining a defocus amount of said focus lens with respect to a photographing object;

a measurement control means for controlling said distance measuring means to repeat the distance measurements in a predetermined interval;

a computing means for computing the relative speed of movement of said photographing object with respect to said focus lens along said optical axis based upon the defocus amounts obtained by said distance measuring means;

a drive control means for controlling said drive means to drive said focus lens, based upon the results of computation by said computing means, to a position where an in-focus condition could be obtained with respect to said object after elapse of a certain time; and

a release means for executing exposure, wherein said distance measuring means executes a next distance measurement after elapse of a predetermined time from the start of a release operation by said release means and before completion thereof.

2. An automatic focusing device according to claim 1, wherein said release means includes a movable mirror which is ascended for exposure; and wherein said predetermined time is the time required between ascent and descent of said movable mirror.

3. An automatic focusing device according to claim 1 or 2, wherein said drive control means controls said drive means, when said next distance measurement is executed, to drive said focus lens based upon the sum of the drive amount computed from the defocus amount obtained by said next distance measurement and that obtained before the start of said release operation.

4. An automatic focusing device according to any one of the preceding claims, wherein said certain time is the sum of the time required for obtaining said defocus amount by said distance measuring means and the time required for executing said lens drive by said drive control means, in the case that the object is moving away from the focus lens.

5. An automatic focusing device according to any one of claims 1 to 3, wherein said certain time is

the total sum of the time required for obtaining said defocus amount by said distance measuring means, the time required for executing said lens drive by said drive control means, and a release-time-lag between a shutter operation and the start of exposure, in the case that the object is approaching the focus lens.

6. An automatic focusing device according to any one of the preceding claims, wherein said object speed is detected as the speed of movement of the image of said object formed by said focus lens.

7. An automatic focusing device substantially as hereinbefore described with reference to the accompanying drawings.

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Documents considered relevant following a search in respect of claims 1-7

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
A	GB 2224126 A Asahi	1
X	EP 0347042 A1 Nikon (see page 40, line 9 onwards)	1
A	US 4783677 A Hamada (see claim 8)	1

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Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family, corresponding document.

Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).

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